Team Joseph: Adaptive Aquatic Device

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Statement of Disclaimer

Statement of Acknowledgement

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Executive Summary

The scope of this project included designing and fabricating an adaptive aquatic device for Joseph, a 20 year old student in the Special Education Program at San Luis Obispo High School with a subset of cerebral palsy known as spastic quadriplegia. The project was presented at the beginning of the Fall 2013 quarter to the mechanical engineering students at Cal Poly with the aspiration that a team of engineers would construct a device that would allow Joseph, his friends and family to compete in their first triathlon on July 27, 2014. The project was humbly accepted by mechanical engineering students Lilly Hoff and Paul Sands, as well as kinesiology student Andrea Voigt.

The team designed a device for Joseph that emphasizes the least restrictive environment by orienting him in a prone position that immerses the majority of his body in the water, yet provides the necessary features to satisfy all safety concerns. A PVC frame is incorporated to provide stability in the water, attached to which are floats that provide buoyancy as well as a mesh material body support for him to lay on. Buoyancy and hydrodynamics are factored into the design by attaching a fiberglassed bow that extends forward from the front of the frame. Joseph will be pulled through the water by a swimmer wearing a swimming belt attached to the device.

In conclusion, all of the customer requirements were satisfied by the design, and all testing performed validated the performance of the device. This report details the project specifications, design decisions, background research on both Joseph's disability as well as similar existing products, the manufacturing process used to construct it, a full detailed description of the final design, and the testing procedures performed to ensure that the device is fully functional and safe.

Figure 1.1 - Team Joseph with the completed device at the Senior Project Expo

1 - Introduction

The goal of this project is to improve the quality of Joseph Cornelius's life through sports, specifically by participating in the SLO triathlon on July 27th 2014. Joseph lives with a form of cerebral palsy called spastic quadriplegia. Due to his disability, Joseph is non-ambulatory and is unable to participate in sports on his own. Over the past few years he has been able to complete many half and full marathons with the assistance of his father and friends who make up the running team popularly known as Team Joseph. This event will be the first that Joseph and members of the running team will ever take part in.

With the support and sponsorship of Special Olympics of Southern California, we as Cal Poly students will significantly change his life by designing and manufacturing an adaptive aquatic flotation device that utilizes the least restrictive environment for the half mile swim of Joseph's first triathlon. This device will allow him to be in his comfort zone and experience the thrill and enjoyment of sports activity that he craves so much as his father and team members tow him through the water. As additional safety, encouragement and support for Joseph during the swim, the device will be surrounded by a couple members of the team. This device will be crucial in unifying the variety of activities that he enjoys so much (running, biking, and swimming). He has been restricted to experiencing only one of these activities at a time, but through the completion of this project he will have the pleasure of completing all three events at once. Not only will this device be beneficial for Joseph in increasing his range of abilities and love for the water, but it will also be a great tool for his father John, as he can personally use this with his son for therapeutic activity as well as competing in future triathlons.

The project is well structured over a nine month period. The first quarter is spent defining the problem statement as well as selecting a final design concept. The Winter Quarter is then spent working on the detailed design and beginning project fabrication. Lastly, the spring is spent continuing to construct and perfect the device so that it may be complete for the Senior Project Expo on May 31, 2014, as well as be fully functional in time for the SLO Triathlon on Sunday July 27, 2014.

Mission Statement

Team Joseph: I’m on a Float is dedicated to constructing a safe, adaptive flotation device that will enhance Joseph Cornelius’s physical activity by allowing him the opportunity to experience the SLO Triathlon with as least of a restrictive environment as possible. In addition, the design team is committed to maintaining open communication, collaboration, and positivity throughout the design process, not only with each other but with Joseph’s father John Cornelius, his teacher William Walters, and the team’s project sponsor Michael Lara.

Customer Requirements

The following requirements outline what the customer has either required or asked to be integrated into the design of the device:

- Provide Joseph with trunk and head support laterally and longitudinally
- Provide the least restrictive environment for Joseph
- Allow Joseph visibility so that he can see the race as it progresses
- Protect Joseph from inhaling water
- Have the device be confined to 1 swimmer towing it
- Allow the largest amount of Joseph’s body to be submerged in the water
- Allow Joseph’s legs from the knee down to be free of support
- Distribute pressure to reduce excess pressure on his hip
- Preferred that the device have a reclined seating arrangement, but possible for an inclined position if he were to safely be leaning forward in the water on his stomach
- Preferred that Joseph be facing forward in the water
- The device must float
- Have one person attached to the device in order to tow Joseph in the water
- It must be capable for an average swimmer, particularly John, to pull the device
- The device shall fit in the bed of John’s truck
- The device must be completed in time for the triathlon in July 2014
- The device shall strap Joseph in with a harness
- The device shall incorporate the colors of Team Joseph (red and yellow) along with a Cal Poly and Team Joseph decal/sticker

Engineering Requirements

Table 1.1 lists the preliminary requirements outlined by the team's engineers. These requirements are focused on physical properties of the flotation device (i.e. weight and dimensions) as well as logistical concerns such as budget, project deadlines and life span of the device. Dimensions of the device and the customer are essential in performing a buoyancy analysis in order to ensure that the device floats. Additionally, properties of the materials selected for the flotation device will be crucial in its ability to float, as well as its capability to be used for a long term. Ultimately, the success of the final solution will be judged on how well it meets and complies with the outlined specifications and regulations. These specifications will serve as a basis for the testing plan.

In order to verify that the formal engineering specifications are maintained throughout the design and fabrication process, a "compliance" method is employed to verify each requirement. These requirements are as follows, and are shown in Table 1.1for how they will be used with respect to the requirements.

1. Analysis/Calculation (A)
2. Test (Physical testing the device) (T)
3. Similarity to Existing Designs (S)
4. Inspection (Visually) (I)

Additionally, a risk level is provided for each specification based on the team members' confidence in the accomplishment of these specifications. Figure 1.2 below depicts the three dimensional orientation for referencing directional classification (i.e. height, length and width) of a possible seat/device.

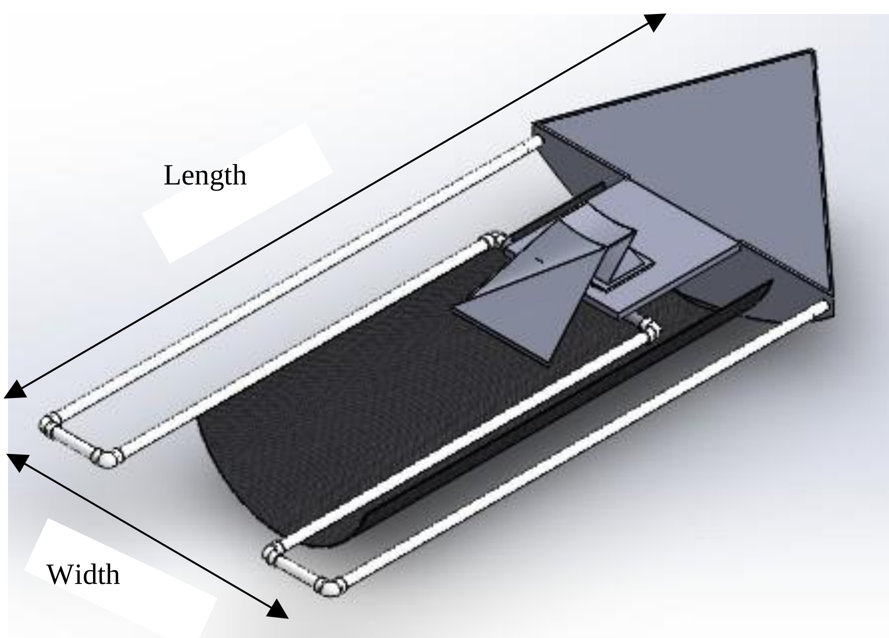


Figure 1.2 - Reference for seat/device dimensions

It is important to note that after the approval of these engineering requirements and the final design selection, changes to the requirements made by the customer will no longer be accepted without the approval of each team member. This prevents gridlock and stalling of the project's continuation so that the device shall be completed in time for Joseph's race. Any changes requested by the customer will have to be presented to and approved by each member of the team.

Table 1.1 - Formal Engineering Requirements

Specification No.	Parameter Description	Requirement or Target (w/Units)	Tolerance	Risk	Compliance
1	Joseph's Orientation	Forward Facing	-	L	I
2	Production Cost	$1500	Max	L	A
3	Device Width	36 in	±3 in	L	I, T
4	Total Device Weight	25 lbs	±5 lbs	M-H	T
5	Cable Restriction for the Swimmer	None		L	I, A
6	Selection of Material Exposed to Water	Non-Corrosive		M	I, A
8	Materials Function at Pool Temperatures	60-90˚F		L	I, A, T
9	Device Length	6 ft.	±0.5 ft	L	I, T
10	Production Time	May 29, 2014	Latest	M	A, T
11	Amount of Joseph's Body Above Water Level	20" (Lower chest and above)	Max	L	T
12	Device Assembly	May be assembled/ disassembled in < 5 min	Max	M-H	I, A, T
13	Height (Depth) of the Device	18 in.	Max	L	T
14	Safety (MIL-SPEC 1629A)	18-20 Acceptable without review	Max	M	I

Quality Function Deployment

A formal specification and compliance matrix is developed and documented through what is known as Quality Function Deployment (QFD), seen in Appendix B. The QFD allows one to identify and weigh out all customer requirements and preferences, integrate them into a list of engineering requirements that can eventually be tested, as well as benchmark the target design to market or relatable products. Due to the shape of the matrix, it is also referred to as the *House of Quality*.

- **Area 1,** on the left side is used to list customer wants and needs as WHAT's. This may be divided into categories and specific needs for better understanding of these needs.
- **Area 2** is used to quantify each WHAT with a weight factor that specifies the importance of each customer desire or need. In our case, each requirement is assigned a weight from a scale of 1-5.
- **Area 3** is used to list product specifications (or engineering specifications) and features as HOW's. Through these features and specifications, it is hoped that the customer needs and wants (WHAT's) will be satisfied.
- **Area 4** is used for benchmarking the present product (if there is one) as well as competitor's products (if any). Since there are no current devices for this customer need, we selected a regular inflatable raft – which is used by Team Hoyt – as well as a patented flotation device that has characteristics applicable to the adaptive aquatic flotation device we desire.
- **Area 5** is the relationship matrix which details the relationships between the WHAT's and the HOW's. In each cell the strength of the relationship is indicated with the following weight factors:

  ● = 9 Strong correlation
  ○ = 3 Medium correlation
  Δ = 1 Weak correlation

Cells left blank infer that there is no correlation between the respective customer and engineering requirements

- **Area 6** is used to denote interactions, correlations, trade-offs or compromises between different product specifications and features. For our purposes, this section is not of great importance and is left out.
- **Area 7** is used for engineering targets and benchmarks. This area is used for a technical evaluation and deciding on target values that will be used in the design of the product, the final result of this QFD exercise.

From the QFD analysis, the team has gained an understanding of the correlation between the various engineering and customer requirements, in addition to possible tradeoffs that may need to be made. For example, a device that ensures support and safety may meet that requirement well; however, it may not meet the least restrictive environment requirement to its fullest extent.

These tradeoffs will have to be addressed once the conceptual designs have been produced and presented. Additionally, the QFD table shows that all the benchmark designs aside from the inflatable raft like the desired support. On the other hand, the inflatable raft does not allow the user to be immersed in the water and thus rates very poorly.

Management Plan

It is essential that the responsibilities of the three team members be properly outlined and communicated in order for the team to work effectively and productively. As the project expands and becomes more in depth, new positions may take shape that will be presented again. All team members will collaborate in the design process in order to combine the most successful ideas.

Communications – Lilly Hoff
Lilly is responsible for setting up times and locations for all meetings held with John, Joseph, William and Michael. Additionally, her responsibilities include sending out update emails in order to keep everyone informed on the status of the project, as well as being the source of contact for the team. All phone calls and emails should be sent/made to Lilly in order for things to run smoothly and efficiently with the one source of contact.

Treasury & Budgeting – Paul Sands
Paul's position designations include applying cash-management skills and investment acumen to ensure that project spending remains within the $1500 budget allocated. Paul will be required to file all quotes, purchase requisitions and package invoices in addition to maintaining a project expense report. Paul will place all part orders with the consent of the team, and he will be in charge of tracking and following up on all orders made.

Physical Activity & Disability Awareness – Andrea Voigt
Physical activity and disability awareness chair acts as a liaison between the project and the kinesiology department at Cal Poly, specifically with Dr. Taylor. Due to her background in adapted physical activity, Andrea will ensure that the project remains as least restrictive as possible while providing the necessary support for Joseph. Since she does not have an engineering background, she will not be as involved with specifically designing the device but her approval and advice is still needed wherever possible. Dr. Taylor and the other members of the Activity 4 All program in the Kinesiology Department have much experience working with people with disabilities. Andrea is expected to communicate with them regarding the status of the project, and relay information back to Lilly, Paul, and team supervisor Dr. Widmann.

2-Background

Joseph's Background

As a young child, Joseph would have 75-100 seizures per day as a result to everyday occurrences such as the ringing of a doorbell or a gust of wind. He has aged and grown out of these frequent seizures with the help of daily medication, but is diagnosed with cerebral palsy; specifically, spastic quadriplegia. This is defined by spasticity of the limbs due to hypertonia of the muscles that causes very jerky and uncontrolled movements. Joseph is also non-verbal. He has limited trunk stability, balance and head control. Over an extended period he can hold his head up for around 75% of the time. Joseph has hip dysplasia in his right leg, so his femur is positioned incorrectly in the acetabular socket of his hip joint. This results in his right leg being significantly shorter than his left.

Spastic quadriplegia causes Joseph to have high body tone in all of his limbs, especially his legs. He has unpredictable movements that cause him to extend or arch his back and press down with his legs, especially in his wheelchair. Joseph now enjoys motion and is in his most relaxed state (least spastic contractions) while moving, whether on a long run in his runner or in his wheelchair.

A large concern with the design of the flotation device will revolve around his inability to swallow. While he can sometimes swallow foods with a consistent texture, he cannot swallow water. If water gets in his mouth he will aspirate it directly to his lungs. Joseph must take medication and nutrients through his gastric feeding tube; however, the tube is safe to be submerged in the water.

Joseph's Current Devices

Throughout a typical day at school and at home, Joseph uses an adaptive tricycle, swing, wheelchair, and runner. The devices are shown below with further description.

The tricycle requires Joseph to be in a sitting position. Sometimes he uses a mechanism that supports his trunk along with his hips so that it is easier to maintain a sitting position. There is a large strap that helps secure him in the chair. His feet are also strapped into the tricycle so that he is able to experience the motion of pedaling. The tricycle is different from most of the other devices that he uses in that it does not give him much head support. This requires him to work on lifting his head.

Figure 2.1 - Joseph's adaptive tricycle at SLO High School

A less mobile activity that Joseph participates in while at school is swinging in his support. The swing is not personalized for Joseph's body structure; however, its positioning and motion are still comfortable for him. It is in a reclined position and has a seatbelt that prevents him from falling out. Due to his lack of controlled motion, the reclined seating has enough support to keep him from falling laterally and forward.

Figure 2.2 - Joseph's swing that he has access to at SLO High School

Figure 2.3 - Joseph's personalized wheelchair used for everyday mobility

Everyday Joseph uses the wheelchair shown above. This is his most supportive device; it fully supports his trunk with two side supports as well as shoulder braces. The combination of all of the braces supports Joseph from falling forward or to the side, as he has a tendency to lean to the left. There is also an abductor pad between his legs which helps in breaking up his tight body tone. His feet are also strapped in so that his muscle contractions do not cause him to fall out of the chair. Limited head support is present on the wheelchair; however, the additional support elsewhere makes it easier for his head to be held upright.

Not pictured is the report is the runner that Joseph uses weekly and has used in many running competitions. The device was built specifically for Joseph. It has no head support, which is not ideal for Joseph to visually experience the race as his head tends to fall forward; however, the sling-like design is very relaxing and comforting for Joseph. It distributes his weight so as to not concentrate pressure on his right hip joint where the hip dysplasia is present. A combination of the most successful aspects of each of these device will be considered when constructing the design for his adaptive aquatic device.

SLO Triathlon

The 35th Annual SLO Triathlon will take place on the morning of Sunday July 27, 2014 at Sinsheimer Park/SLO Swim Center in San Luis Obispo. This short course (or sprint) triathlon consists of a half-mile swim, 15 mile bike and 3.1 mile run. Participants are sent on the course in waves throughout the day.

The swim takes place at the SLO Swim Center. Each participant swims 36 laps (900 yards) in the Olympic-sized pool. An Olympic-size pool swimming pool has a total width of 25 yards (82 feet) and a lane width of 2.5m (8 ft. 2 in.) for 10 lanes. Team Joseph will be assigned the two shallowest lanes to use on the day of the event. The temperature of the pool will be set to 80˚F. Each participant is required to bring his or her own lap counter. Only the participant and their lap counter will be allowed on the pool deck according to the rules of the triathlon. Supporters will be allowed in the water along the lane to provide safety measures and be an encouragement for Joseph. San Luis Obispo weather is usually mild in the summer, ranging from the mid to high 70's. Mornings may be foggy and cool and the offshore breeze usually picks up in the early afternoon.

Patent Research

The first step in the team’s background research was to perform a patent search in order to discover if anything similar to this device has been designed before. As of this date, there are no patented devices that exactly fit Joseph’s needs, although the following three patents found are of particular interest.

First, is patent publication number US5667416 A, published on September 16, 1997. The abstract for this flotation device and swimming aid states the following:

> “A floatation device for safely supporting a person, including paralyzed, disabled, or mobility impaired persons, upon a body of water for exercise or relaxation. This device encloses the person within concentric outer flotation members and a seat assembly from which position the person may float, walk or wade in the water as desired while either being continuously supported or providing only the support required. The outer flotation members are spaced from the user to also enclose him and these outer members provide the buoyancy and stability required for use. If desired, a hand rest can be positioned intermediate the outer flotation members and seat assembly of the floatation device for further ease of use and for grasping purposes.”

Another object of this invention is to provide a buoyant vessel that is capable of safely supporting a person with a disability while also allowing this person to swim and kick in order to steer and guide the vessel. This invention can also be used who have less range of motion for any number of reasons, including age or illness. This design excels in providing the least restrictive environment that we desire, but lacks the structural support that is needed for Joseph. It would be constructed of PVC tubing. Figure 2.4 below depicts the patent design.

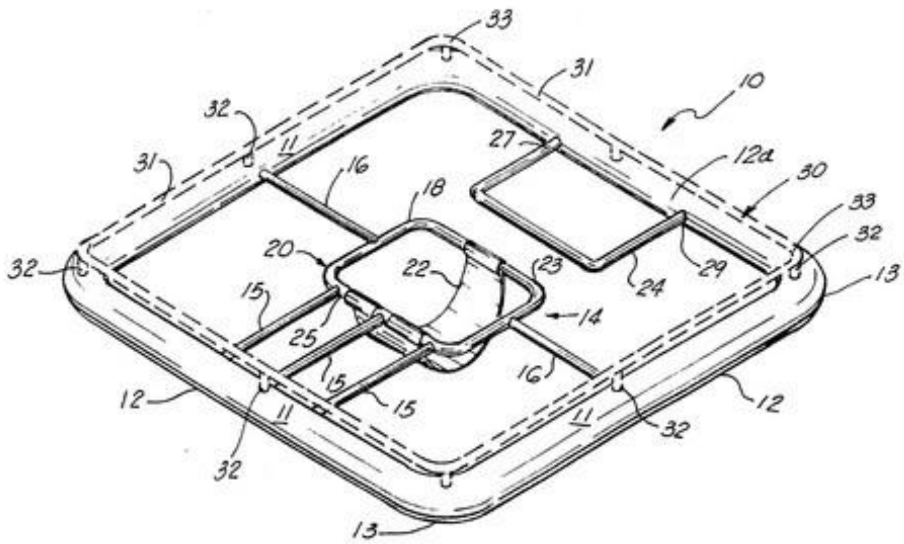


Figure 2.4 - Perspective view of the apparatus embodiment

The second patent, patent publication number US2994095 A published on August 1, 1961, relates to a water skiff model. It is supported by a plurality of pontoons for transporting a person across water. The description for this patent design states the following:

> "It is manifest to anyone familiar with aquatic sports such as surf-board riding, water skiing, or the like, that it is desirable that the participant in these water sports derive the benefit of the water by submerging therein. The prime object of my invention is to provide a skiff consisting of a skeleton like and relatively open frame, supported by pontoons, and equipped with a seat to permit the occupant to manually propel the device along the surface of the water, while permitting the occupant to be partially or substantially entirely submerged in the water during manipulation of the skid. A further object is to provide such a device that may be propelled easily by means of oars, paddles, or with the hands or legs of the occupant."

From Figure 2.5 it is clear that the device has the structural rigidity and ensured buoyancy that is essential to keep Joseph safe in the pool. However, like the previous design, there is absolutely no support on and around the seat that would be able to keep Joseph up and supported in the device.

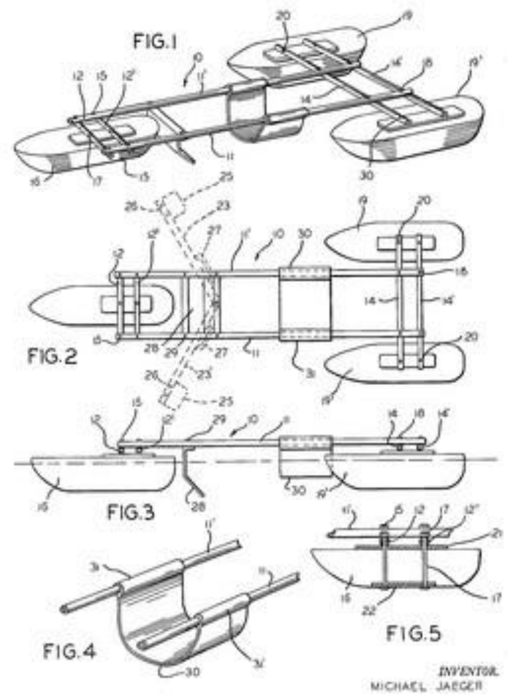


Figure 2.5 - Perspective view of the assembled water skiff device

The final patent relatable to our problem statement is patent number US2946068 A, published on July 26, 1960. The design provides a combination of a frame and buoyant elements similar to the designs previously discussed. In addition, a seat is mounted in or on the frame. The description from the patent reads as follows:

> “A principal object of the invention is to provide a float for supporting an occupant, such as a child or a physically incapacitated person, in upright floating position on the surface of a body of water. Structures contemplated by the invention are thus adapted to be used as recreational devices by which very young children may be supported, safely and with a minimum tendency to become frightened, in upright position in the water of a swimming pool or the like; and in substantially the same construction, made in larger proportions, the device may be used by adult invalids for recreational floating at bathing resorts or as a physiotherapy adjunct, e.g., for sitz bath use, for floating the patient in curative spring waters, etc.
>
> One object is to provide a float of the class indicated which will allow the hands and arms of the occupant to have ready access to the water on each side of the float while the body is partly submerged in the water, and allowing the legs free motion in the water, and in a preferred embodiment fore and aft of the seat also, in order to paddle or propel himself about.
>
> A further object is to provide a float of the class indicated which will be remarkably stable when in operative position in the water so as to be entirely safe for use with very young children, physically handicapped persons, and others whose safety might be jeopardized, or who might tend to become frightened, by such prior art devices as water wings, buoyant jackets, annular shaped floats, etc.”

The device is intended for a baby or child, so it would not suitable for Joseph. It appears that this design has the proper stability that is crucial for our requirements. The seating allows the user to have their legs completely free of restriction in the water, although only just above their hips and below would be submersed. Figure 2.6 illustrates this design.

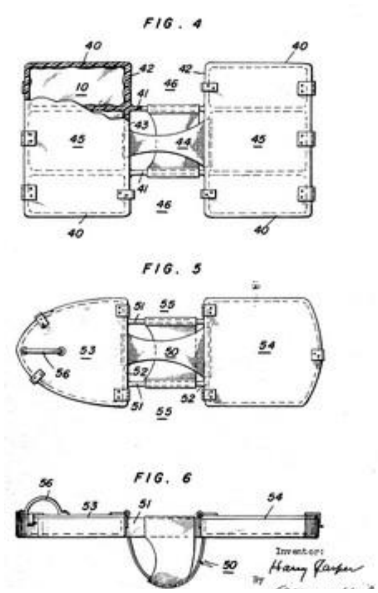


Figure 2.6 - Sketches of the personal use flotation device for young children

It is important to note that a common theme throughout these patent designs is the lack of back, side and head support for the user. None of these have been designed specifically for Joseph. Therefore, the device that we build will be unique. Additionally, this device may have the potential to be used by many others with similar disabilities who are in need of a full range of support, yet seek the freedom of enjoying the swimming experience.

Current Adaptive Flotation Devices & Equipment

It is very important to note that there are no current devices related to this project that are being used in Special Olympics events and triathlons. Team Hoyt is a famous team consisting of father and son Dick and Rick Hoyt from Massachusetts who have competed together in various athletic endeavors, including marathons and triathlons. Rick has cerebral palsy and during competitions his father pulls Rick in an inflatable raft as they swim, carries him in a special seat in the front of a bicycle, and pushes him in a special wheelchair as they run. Dick merely pulls his son on an inflatable boat during the swimming portion of their races. It’s exciting to learn that such a famous duo with incredible support and funding do not have a customized device of their own. This project can be a gateway to many other opportunities and applications in which not only Joseph, but many others with disabilities can enjoy the therapeutic experience of swimming.

Figure 2.7 - Rick Hoyt with his son Dick after swimming

A possible design for this device may comprise of an orientation in which Joseph lays forward on his stomach. The Aquatic Therapy Float (see below) allows for a more realistic swimming position and contributes to the least restrictive environment that is sought in this project. It is designed for use by children or adults with lower or upper extremity disabilities. It supports the user in a prone or supine position during aquatic therapy for lower and upper extremity strengthening and range of motion. The device's contour lines allow free movement of arms and legs while the individual is securely strapped to the float. The small model supports up to 50 pounds; the medium model supports 50-100 pounds; and the large supports more than 100 pounds. The price for this device ranges from $195 to $255, depending on size.

Figure 2.8 - Aquatic therapy float

The team continued to find adaptive equipment that is relatable to the application and saw various features from the following equipment to continue inspiring thoughts and ideas for the design of Joseph's flotation device. The device below is used for people with paraplegia and allows the user's chest and below to lay underneath the water line. The team liked the simple structure and use of a buoyant foam wrapped around PVC pipe for this piece of equipment.

Figure 2.9 - Water walking assistant

Information from the following adaptive bath seats is crucial in the design of Joseph's adaptive device in order to reference what is successful or what can be adapted into Joseph's float. Below, in Figure 2.10, are two adaptive bath seats. The one on the left incorporates an abductor cup and overhead harness. This design is similar to a seat that may be used in a reclined seating design. The image on the right is more restrictive than is desired for Joseph's device, but it does use mesh. This would allow Joseph to be surrounded by water without having any accumulate near his face, as well as providing a supportive alternative to a seat or platform.

Figure 2.10 - Adaptive bath chairs

Another piece of adaptive equipment is a Kaye harness, pictured below. They vary in size and support levels but overall are a great option for safely keeping Joseph in the final design. Each harness is made of material that has a high compression element so that the vest fits snuggly around the client and fastens with buckles. As stated above, the harnesses come in different support levels and styles depending on the size and weight of the client. Models 9820- Small and 9821-Medium Slim, have three components: a body vest, four compression straps and four strap pads. These harnesses fit between the legs like pants and buckle up each side. The full harness would be supportive, comfortable, and safe to use in the final design.

Figure 2.11 - Kaye harnesses

The final piece of adaptive equipment that was researched is another bath chair; however, this design can be easily adapted to be a flotation device with little alteration in the basic design. There is a concern that it may be too narrow and therefore is prone to easily tip. The seat uses an overhead seatbelt that attaches to the back of the seat. This eliminates the need to have an abductor cup or full body harness because it would adequately keep Joseph strapped to the back of the seat. The bottom of the seat is a mesh material, which, as stated above, would provide ample support for his hips while still allowing him to be comfortably submerged in the water.

Figure 2.12 - Hi-back, wrap-around bath support

Aside from flotation devices, there are many ADA compliant pool lifts that allow a person with a disability to be placed in and out of the pool. There will be a lift available on the race day if additional aid is needed to place Joseph in his flotation device.

Figure 2.13 - Pool lift

Standards and Codes

The safety of Joseph throughout the race and with other operations of the flotation device are of the utmost importance to our team. There are a few standards that we will be regulating the design with. The first code to be followed is the regulation of flotation devices by the Coast Guard. The second is the other military safety code, MIL-STD-1629A. The first standard will be used to assess the buoyancy of the flotation device to ensure that Joseph will neither sink nor aspirate water into his lungs. The latter evaluates the overall safety of the device and the effect of its failure. Both of these methods of safety regulation are described in further detail below.

Personal Flotation Device Regulation from Coast Guard

The Coast Guard regulates life jackets and other flotation devices in the United States. The Coast Guard has approved five different categories for personal flotation devices (PFDs):

Type I - Off-shore life jacket
Type II - Near-shore buoyancy vest
Type III - Flotation aid
Type IV - Throwable devices, such as cushions or rings
Type V - Special use devices, such as float coats and deck suits

Types I, II and III are the flotation aids most commonly worn by recreational boaters. Generally, PFDs with lower numbers provide more buoyancy.

MIL-STD-1629A Standards

This regulation creates a correlation between the failure modes, the severity of the consequences of those failures, and the frequency of failure. Listed in Appendix B are tables that detail the analysis done to determine the acceptability of failures. In this project, failures that are classified as negligible, occasional, remote or improbable will be accepted. In the chart provided, these cases are described with a value between 18 and 20. All other failure modes will be considered unacceptable and will require revaluation and redesign.

Materials

Research was done on the different types of material that are both buoyant as well as non-corrosive so that Joseph will be able to use this device for many years. It was found that there are a variety of different foams that are often used in flotation devices, as well as common materials that are detrimental to the project's end goal. Most of the buoyant, non-corrosive materials are the foams such as polyurethane. This particular foam has a flotation range from 100-120 lbs/qt. Polyurethane is normally poured into a cavity where it can expand to become a buoyant material. This type of foam is very resistant to absorbing water, being that it is 95-98% closed cell. The term closed cell refers to the structure of the foam; a closed cell structure means that the pores are not interconnected. This increases the buoyancy as well as the absorptivity of the foam. Using foam of this standard could be beneficial to the flotation device for Joseph because it can withstand long-term use; however, if it is submerged for extended periods of time the foam will lose some ability to float.

Research shows that the structure of the device could potentially be made using rigid PVC piping. While it is non-corrosive, it is dense (~1.4g/cm) and will likely add a substantial amount of weight to the device as well as decrease its buoyancy. Although this material is not ideal, it is non-corrosive, and potentially a better option than metals that will rust or deteriorate over time after exposure to water.

Nylon fabric can be used to protect the structure. It is found to be the used as the exterior of many life jackets. Vinyl is a slightly more protective covering that may be utilized in the design. The materials that are used in surf boards were also researched. It was found that most surf boards use polyurethane foam that is fiberglassed. Both of these are viable options to build the structure of his flotation device, as stated above.

Neoprene is another water resistant fabric that should be considered. It is often used in wet suits. The material is made of closed-cell foam that encases small gas bubbles within a plastic. In most cases the gas is nitrogen. The main purpose of the gas is to create a higher thermal resistance, although it also aids in the buoyancy of the material. This is a good choice to use in addition to other flotation devices or materials. Additional flotation materials may be required because although neoprene is buoyant, it does not support enough weight to keep Joseph above the water. Possibly this material can be used to help with Joseph's trunk support because it withstands varied water conditions including salt water.

For the main source of flotation, variations in the type of foams discussed above can be used as well as plastics such as nylon to trap air, similar to a blow up raft or tube. The benefit to foam over a blow-up device is the consistency in buoyancy. Air contracts and expands with temperature change, which alters the device’s ability to remain float. However, a blow-up flotation device would make it more transportable and compact when it is not in use.

3 - Design Development

Concept Generation

Creative Conceptual Modeling

In the early stages of the design process, the team worked on building small models in order to better understand solutions to this engineering problem. Many viable designs were developed in this process and were then further developed into large models and final designs. The goal of this activity was to spark creativity and to begin thinking outside of the box, while having visual models to communicate ideas.

One of the models can be seen below in Figure 3.1. This design was focused on leg and hip support for Joseph. The seating extended to the ends of Joseph's legs so as to reduce drag on both the swimmer, yet still have a portion of his body submerged in the water. Further analysis of this design displayed faults in the least restrictive environment requirement because of the lack of mobility he would have.

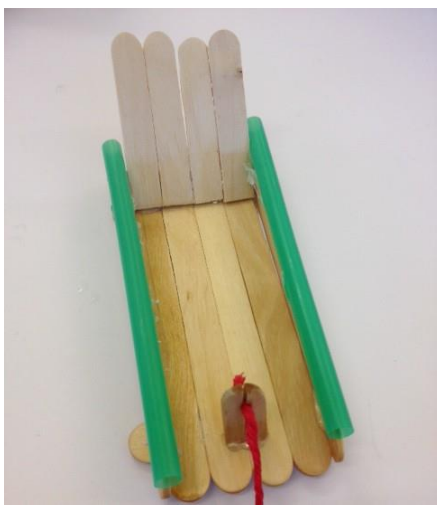


Figure 3.1 - Reclined mattress design

Another design incorporated a bucket seat, similar to a child's swing seat, which is suspended by bungee cords to increase the amount of movement for Joseph. The wide base and centered seat was developed further in other models because of the increased safety due to the centrally located center of mass. The main focus of this design was creating a non-restrictive environment for Joseph that keeps him in a seated position.

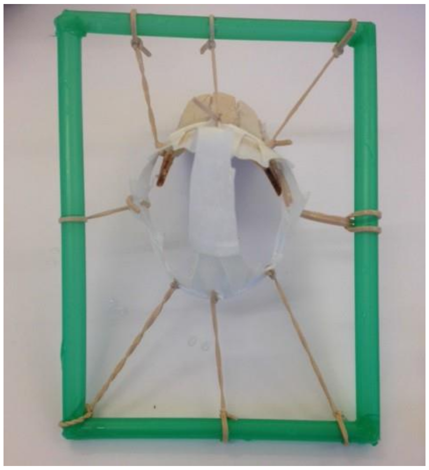


Figure 3.2 - Bungee cord and bucket seat design

Figure 3.3 illustrates a model that combined the previous two concepts, and expanded on the flotation ability. However, it was discovered that the seat placement disrupted the center of balance, thus causing the device to tip when weight was placed in the seat. However, developments were made from this model in regards to creative and innovative flotation methods, most notably the use of foam pool noodles attached to the frames of the large-scale mock ups.

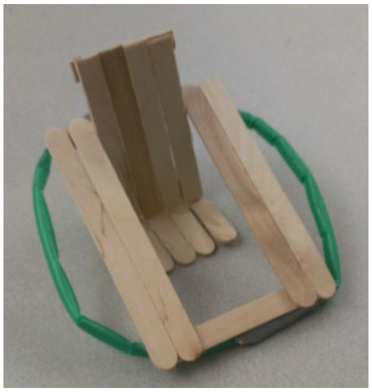
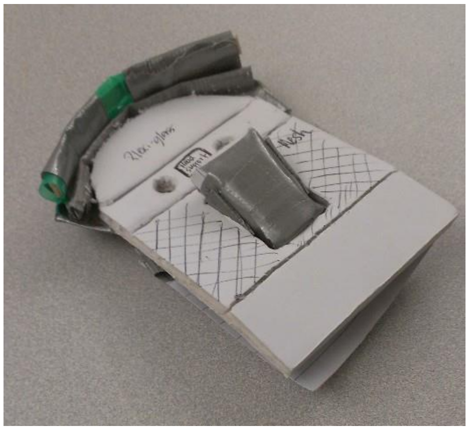


Figure 3.3 - Reclined flotation ring

This image in Figure 3.4 demonstrates the forward facing design that would compile safety, stability, and a realistic swimming experience into one device for Joseph. The jacket that would be used in this design was further developed to accommodate multiple other designs, including the larger scale mock up that was tested on Joseph in the water. This design allowed the group to thoroughly understand mechanisms that would be required on a forward facing design such as the head support and adaptive trunk support. Many aspects of this design were considered when developing a more complex and complete forward facing design.



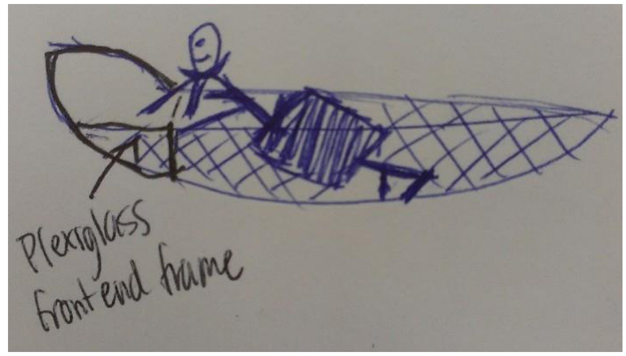


Figure 3.4 - Prone position mini-boat model and sketch

Mock-Up Building & Testing

Once the small models were constructed, the design phase shifted to building larger and more applicable mock-ups that were tested in the pool with Joseph. The first mock-up was created from a rectangular frame of PVC piping and a small lawn chair attached to the interior supports of the frame. This was mainly built to see how Joseph would react to the water in a seated position. His position in the mockup can be seen in Figure 3.5. The frame was roughly 4 feet long by 4 feet wide. The seat was positioned towards the center of the frame in order to place the center of gravity in a location that would eliminate the chance of it tipping. The chair was placed at a slightly reclined angle to accommodate a comfortable seated environment for Joseph. A development on this design included a life vest with clips that acted as a supportive harness to better attach Joseph to the device. This adaptation seemed to be very successful and a modification of the life vest will be implemented in the final design. Another feature of this design was the pool noodles that were added to the exterior to increase the buoyancy. The floats were wrapped around the PVC pipe. The harness that attaches the swimmer towing Joseph to the device was connected by a long rope that distributed the pulling force to two separate points along the front of the frame and towards the edge. The choice to attach the rope in two different points will increase the control the swimmer has on the device. This was the only apparatus that was pulled by the swimmers and the drag seemed very minimal for the lack of hydrodynamic design. Even with the life vest strapped to the back of the seat, Joseph seemed to slide forward. This observation clarified the need for a more supportive harness that goes between his legs or an abductor cup. Because he was in such an upright position, he had greater ability to see his surroundings while being towed.

Figure 3.5 - Joseph in lawn chair with PVC frame

The second full size mock-up that was constructed placed Joseph in a prone position. The harness from the previous concept was used again in this design to secure Joseph to the frame. This device was made from a PVC frame; this time the frame was 2 feet wide and 5 feet long with 4 cross bars to create the surface Joseph would lie on. A thick foam mat was placed on top of the PVC pipe cross beams to create a comfortable platform for Joseph. While testing this device, a flotation mat was added to the top of the frame in order to keep Joseph's face farther from the water line and provide extra comfort. The device held Joseph entirely out of the water except for his hands, which wrapped underneath the head rest; however, safety was much more of a concern with this design so we wanted to make sure his face was far enough from the water. In that sense the design could be improved to make the prototype more realistic to the final design. Joseph was extremely relaxed and comfortable while lying on top of it, which was anticipated because of his comfort in this position outside of the water. An important observation of this test was the accumulation of his saliva near his mouth. The final design will have to factor this into consideration in order to increase his safety. Another key observation was his natural body curvature. This is important to design for the center of gravity to ensure the raft will not tip to the side. It is crucial to notice the placement of Joseph's arms in the photograph. This arm placement is key for Joseph's comfort level, as well as for continuing to create the most natural swimming experience for him.

Figure 3.6 - Prone orientation mock-up

The final design that was tested in the Rec Center pool was a combination of two separate inflatable tubes. The first tube was a C shape tube with a sling style seat and the second was a ring shaped tube with a mesh bottom. The tube with the mesh bottom was placed below the larger tube. Joseph then rested on the sling seat in a cradled position. This design placed his body in a more horizontally reclined position that decreased the drag on his legs. The air filled tube created a comfortable environment for Joseph to rest his head on and allowed him to slouch to either side while still remaining at ease in the device. Joseph seemed to relax in this design more so than the previous seated design. His hips were well supported by the mesh and raising his feet to the surface of the water eliminated stress on his knees from his dragging legs. Once again, Joseph would easily slip down into the seat, so the team noted that an abductor pad would be essential for any reclined seat that it tests.

Figure 3.7 - Reclined position testing with two inflatable pieces

Pugh Matrix

After completing concept generation and testing with Joseph in the pool, the team compiled a Pugh matrix (See Appendix C). A Pugh matrix is a quantitative technique used to rank the multi- dimensional options of a design. Team Joseph gained many valuable takeaways from this evaluation technique, including the top design considerations. The Pugh matrix is a formatted chart that compares all of the possible designs to a baseline design, or datum. For this application, the team selected the design of the reclined adaptive chair locked into an external tubing frame because they built and worked most with this in the testing process. The designs are ranked against this datum as either +, -, or the same adequacy (S) as the baseline design. After ranking the ten designs on all of the customer requirements, it became apparent that four designs were much more successful than the rest. The top four designs were improvements upon the original design that was modeled and tested in the pool. One of the designs that was most attractive was the prone swimming position design. It excels in protecting Joseph from aspirating water, as well as providing the least restrictive environment for him. Another design that stood out above the others was the basket style design. After further analysis of this design it seems too unsupportive; however, if this design were to be combined with another appealing design concept it has more potential to be successful. For example, the design can be combined with a life vest/harness that clips Joseph into place. The final design that stood out from this table was design 10. Although there are some portions of this design that cause it to not be extremely successful in the original stages of design, it has potential to improve and exceed the customer requirements that it currently lacks, such as trunk support.

After compiling the results of the Pugh matrix, it became apparent that a mesh bottom design would decrease the drag on Joseph's legs as well as on the swimmer pulling him in the race, thus improving the design's viability. Another conclusion regarding a portion of the concept is that the designs with an abductor cup or some restraint between Joseph's legs were ranked higher and more successful than those that lacked this extra support, which is known to break up Joseph's body tone. It is apparent that multiple designs met the customer requirements equally well as the mock-up design that combined the PVC piping and a lawn chair; however, combining concepts from multiple designs would create a more successful design. For example, design 10 can be improved by combining it with a harness and mesh under the seat to make it more comfortable and safe for Joseph. On the other hand, some designs, such as design 4, appeared to be very unsuccessful and not worth pursuing. This design is similar to a few of the other designs; however, the weight distribution, lack of trunk support, and the unrealistic body positioning does not make it an ideal design for Joseph. The Pugh matrix brought to light to one of the customer requirements that needs improvement: the amount of Joseph's body in the water. Most of the designs were similar in ability to submerge his body in comparison to the datum that Team Joseph created and tested, or were inadequate. This allows room for improvement in all of the designs, and in particular the top four designs that were selected from this process. While the Pugh matrix does not compare designs to one another, it is an important step in the selection process to understand the positive aspects of each design, as well as the improvements that can be made for a final design that combines the most successful aspects of each concept. These final takeaways from the Pugh matrix were the support and freedom that the mesh design will offer Joseph, the importance of Joseph's safety in regards to aspiration of water, securement to the device, and stability of the device to stay upright. Lastly, the Pugh matrix reiterated the importance of an abductor cup or harness to help control Joseph's high body tone and his tendency to slide out of the adaptive flotation device without the necessary restraints or support. From group discussion and break down of the Pugh Matrix, the team decided on following main designs to evaluate with serious consideration for the final design solution.

Design A

This design uses the combination of two individual pieces: an inflatable upper body frame to act as a backrest and a mesh flotation seat to support his lower body, yet keep him under the water. The device would require the use of an abductor cup to prevent Joseph from sliding down within the seat, as well as upper body braces or a separate harness that Joseph wears and that straps and locks him into the device. This device ensures that his chest and below can be immersed in the water, yet provides the necessary safety to prevent Joseph from taking water into his mouth. This design cradles his legs up near the water surface and would thus be less resistive for the swimmer towing him.

Figure 3.8 - Design A

Design B

Design B is the only design to position Joseph in a realistic swimming position in which he lays down on his stomach. The design was inspired when the team visited Joseph at school and found him lying very comfortably on his stomach. Once the team learned that he is most relaxed in this position and even sleeps on his stomach, they became encouraged to pursue a design that incorporated this prone position of Joseph in the water. This design meets and even exceeds the customer requirements. It is the most hydrodynamic of the four designs because of its streamlined shape. This device is great at implementing the least restrictive environment that the team strives for. The front end, or bow of the device would either be made of Plexiglas or clear plastic so that Joseph can see through it. The device also requires that Joseph wears a safety harness that straps into rings located around the internal cavity that he would lay within. This is possibly the most supportive of the designs because it provides near full body support, especially on his head and trunk. His legs are supported by mesh that would hang under the device below the water level.

Figure 3.9 - Design B

Design C

This design consists of two separate pieces: an adaptive seat and an external tubing frame that the seat locks onto. The plastic frame would most likely be made of polyethylene, which is a low density plastic. The seat has an abductor pad and shoulder braces similar to that on his wheelchair. The device requires a safety harness to lock him into the seat. The seat is reclined to keep his head up and provide visibility. Also, the reclined seat brings his center of mass more towards the center of the overall device and prevents any tipping forward. The wide tubing prevents Joseph from rocking and tipping to the sides. It is anticipated that the water line would be around his lower chest area with this device.

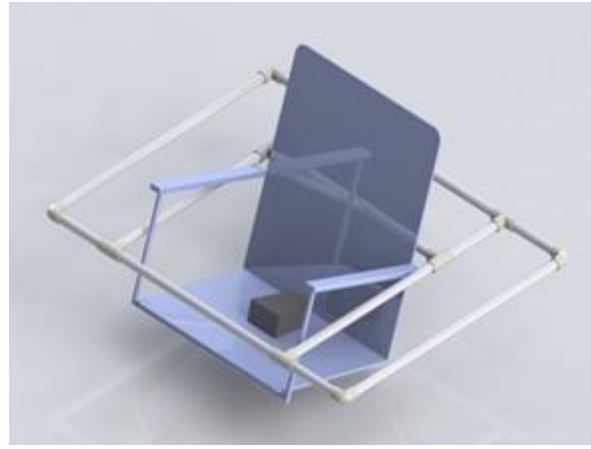


Figure 3.10 - Design C

Design D

The last of the four designs is very similar to Design C in that the structure is comprised of lightweight plastic tubing that surrounds a reclined seat. Rather than using an external safety harness, the seat has an integrated strap to fix Joseph to the device. The concave lower section of the seat allows Joseph's stomach and below to be immersed in the water. The lower section of the seat also extends out far enough so that the majority of Joseph's legs are supported and held out straight. This results in decreased resistance on the swimmer. Although it cannot be seen from the picture, the frame would extend out wider than the seat so as to prevent tipping from side to side.

Figure 3.11 - Design D

Idea Selection

The idea selection process for selecting the final design is carried out through a tool known as an Analytical Hierarchy Process. This is a structured technique for organizing and analyzing decisions, with a particular application in group decision making. First, the decision problem is decomposed into a hierarchy of more easily comprehended sub-problems or objectives, each of which can be independently analyzed. Once the hierarchy is built, the team members systematically evaluate its various elements by comparing them to one another two at a time, with respect to their impact on an element above them in the hierarchy. The Analytical Hierarchy process then converts the evaluations to numerical values which can be processed and compared over the entire range of the problem. The numerical weights are calculated for each of the decision alternatives; in this case, each of the four designs being considered. These numbers represent the designs' ability to achieve the decision goal.

In order to build the hierarchy, the major objectives/criteria that are to be implemented in the final design need to be outlined. Many requirements were presented by the customer, but there are a few of significant importance that are mainly evaluated when analyzing the presented designs. The following six requirements were selected by the team to be most important in the final design application:

Safety – Safety includes the device's protection from splashing water into Joseph's face, prevention of tipping, prevention from collection of water near Joseph's face, as well as flotation capability

Maneuverability – Maneuverability pertains to the ease of pulling the device through the water, and is focused on making the swimmer's job as easy as possible. A device that is hydrodynamically poor and creates a lot of resistance for the swimmer would be weak in this aspect

Ergonomics – This objective relates to Joseph's comfort level in the device. This includes minimal pressure on his hips and his comfort in the position he sits in

Maintains Least Restrictive Environment (LRE) – Least Restrictive Environment relates to the device's ability to provide a realistic swimming experience for Joseph

Provides Support – This includes upper body support, upper leg support, head support and the implementation of harnesses/straps in the design

Provides Enjoyment – Enjoyment relates to the device's ability to allow Joseph vision so that he sees the race unfold and can fully enjoy the experience. Additionally, this includes the device's ability to increase his activity level in the orientation that it positions him in.

To begin the selection process for the final design solution, a pairwise comparison table is created. This table allows the team to rate the importance of each criterion over the others. The left hand column is compared to the top row and a ratio is assigned according to the relative importance of the column objective to the row objective. For example, if safety is valued moderately more important than maneuverability, then a ratio of 3/1 would be assigned. Reciprocally, maneuverability vs. safety would receive a ratio of 1/3 because maneuverability is deemed less important. Each of the three team members completed this individually, in order to prevent any bias. The table below lists the averages of the numerical values assigned by the team, and thus is listed as a number rather than a ratio. The following lists the weighting of the number system used:

1 = equal; 3 = moderate; 5 = strong;   7 = strong;   9 = extreme

Table 3.1 - Pairwise comparison table of the overall design objectives and requirements

Objective	Safety	Maneuverability	Ergonomics	LRE	Provides Support	Provides Enjoyment
Safety	1.000	4.000	2.667	5.000	1.667	5.667
Maneuverability	0.250	1.000	0.389	0.400	0.244	3.000
Ergonomics	0.389	2.667	1.000	1.417	1.056	3.000
LRE	0.225	3.000	1.778	1.000	0.583	2.067
Provides Support	0.778	4.333	2.500	3.000	1.000	4.667
Provides Enjoyment	0.181	0.714	0.333	2.111	0.222	1.000

The process is then repeated, but now each design is evaluated against the others within the analysis of each of the six objectives listed. Once again, these tables list the average numerical weight values assigned by the three team members on a scale of 0-10.

- Safety

Table 3.2 - Comparison of the designs' measurement of safety

Design	A	B	C	D
A	1.000	1.778	1.194	4.000
B	1.278	1.000	2.778	4.667
C	1.556	1.178	1.000	2.000
D	0.250	0.233	0.500	1.000

- Maneuverability

Table 3.3 - Comparison of the designs' measurement of maneuverability

Design	A	B	C	D
A	1.000	0.344	2.833	2.833
B	3.333	1.000	4.500	3.111
C	0.844	0.770	1.000	1.667
D	0.833	1.167	0.667	1.000

- Ergonomics

Table 3.4 - Comparison of the designs' measurement of ergonomics

Design	A	B	C	D
A	1.000	0.244	3.333	3.333
B	4.333	1.000	6.333	6.333
C	0.333	0.170	1.000	2.333
D	0.306	0.170	0.944	1.000

- Least Restrictive Environment

Table 3.5 - Comparison of the least restrictive environment of the top designs

Design	A	B	C	D
A	1.000	0.181	1.556	1.583
B	5.667	1.000	6.667	5.067
C	2.083	0.159	1.000	0.833
D	2.083	1.759	1.333	1.000

- Provides Support

Table 3.6 - Comparison of the support provided by the designs

Design	A	B	C	D
A	1.000	0.289	0.583	1.917
B	3.667	1.000	3.833	2.733
C	2.333	0.819	1.000	1.667
D	2.067	0.261	0.778	1.000

- Provides Enjoyment

Table 3.7 - Evaluation of how well the designs provide enjoyment with respect to each other

Design	A	B	C	D
A	1.000	0.214	0.317	0.483
B	5.000	1.000	2.067	2.167
C	3.667	1.889	1.000	1.333
D	3.333	0.889	0.833	1.000

These tables are turned into square matrices and an iteration process is used to calculate the normalized eigenvector for each. The eigenvector represents a normalized criteria ranking of the objectives and design features.

For example, the first table weighed out the design objectives against each other. The calculated eigenvector for this matrix is as follows:

$$\begin{bmatrix} Safety \\ Maneuverability \\ Ergonomics \\ LRE \\ \Pr ovides Support \\ \Pr ovides Enjoyment \end{bmatrix} = \begin{bmatrix} 0.326 \\ 0.071 \\ 0.149 \\ 0.129 \\ 0.251 \\ 0.074 \end{bmatrix}$$

$$\sum = 1$$

Thus, this eigenvector concludes that safety is the most important of the design objectives, followed by the criteria that the device be supportive. The eigenvectors for the other tables that weigh out the various designs against each other are then calculated as well. Finally, the design criteria rankings are multiplied by the objective criteria rankings in order to calculate the overall scores for each design. The raw score for each is listed between 0 and 1, with a score of 1 being highest.

$$
\begin{array}{l}
 \\
\textit{Design A} \\
\textit{Design B} \\
\textit{Design C} \\
\textit{Design D}
\end{array}
\begin{array}{cccccc}
\textit{Safety} & \textit{Maneuverability} & \textit{Ergonomics} & \textit{LRE} & \textit{Provides Support} & \textit{Provides Enjoyment} \\
0.307 & 0.231 & 0.217 & 0.126 & 0.142 & 0.074 \\
0.360 & 0.431 & 0.603 & 0.517 & 0.466 & 0.383 \\
0.260 & 0.169 & 0.103 & 0.106 & 0.242 & 0.326 \\
0.250 & 0.169 & 0.077 & 0.252 & 0.151 & 0.217
\end{array}
\times
\begin{bmatrix} 0.326 \\ 0.071 \\ 0.149 \\ 0.129 \\ 0.251 \\ 0.074 \end{bmatrix}
=
\begin{bmatrix} 0.206 \\ 0.450 \\ 0.211 \\ 0.133 \end{bmatrix}
$$

$$
\begin{array}{l}
\textit{Design A} \\
\textit{Design B} \\
\textit{Design C} \\
\textit{Design D}
\end{array}
=
\begin{bmatrix} 0.206 \\ 0.450 \\ 0.211 \\ 0.133 \end{bmatrix}
$$

This reduced matrix concludes that Design B is the best solution for this project, and thus justifies the team's consensus to pursue it as a final concept decision. In summary, the Analytical Hierarchy Process provides a logical framework to determine the benefits of each design.

4 - Final Design

Design Description

The final design selected by Team Joseph is shown below, in which Joseph lays in a prone orientation within the device. His upper body is supported by a head rest to elevate his head from the water, and his torso and legs are supported by a polyester sheet of mesh underneath the water line. The team recognizes that this design is the most comfortable for Joseph, is the most hydrodynamic of the designs considered, and is best at satisfying the least restrictive environment. It is also the best at situating Joseph in the most active and enjoyable position that would help relax his tense muscle tone. The design can be broken down into four main parts or sub-systems. These include a frame, an upper chest/head rest, a front end bow and a splashguard. The overall size of the device is 70 inches long and 44 inches wide.

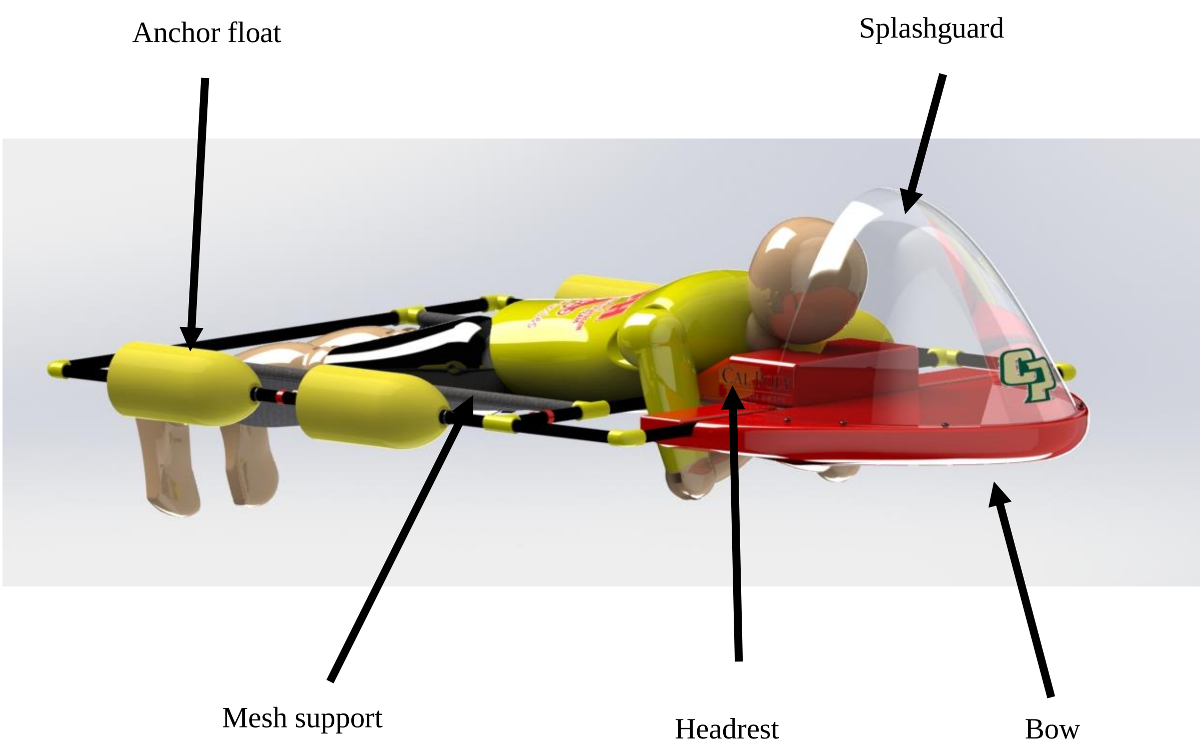


Figure 4.1 - Annotated final design layout

Joseph will wear the full body rock climbing harness seen below, which attaches to four buckle straps located on the side and front bars of the device. This will ensure that he is secure in the device and guarantees no possibility of him slipping backwards into the water. These straps will be sewed in place over the tubing. Thus, they will be unable to slide and the tightness of them can be adjusted. Additionally, the swimmer will wear a swimming belt that is tethered to the two outermost points on the front of the frame. This swimming belt is shown in Figure 4.3.

Figure 4.2 - Full body harness

Figure 4.3 - Swimming belt

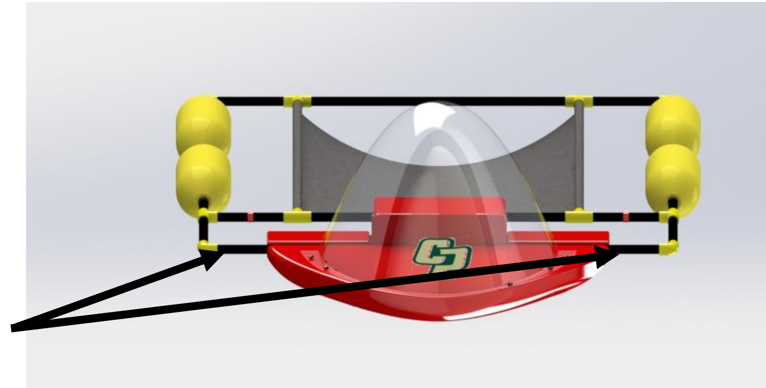


Figure 4.4 - Front view of the final design

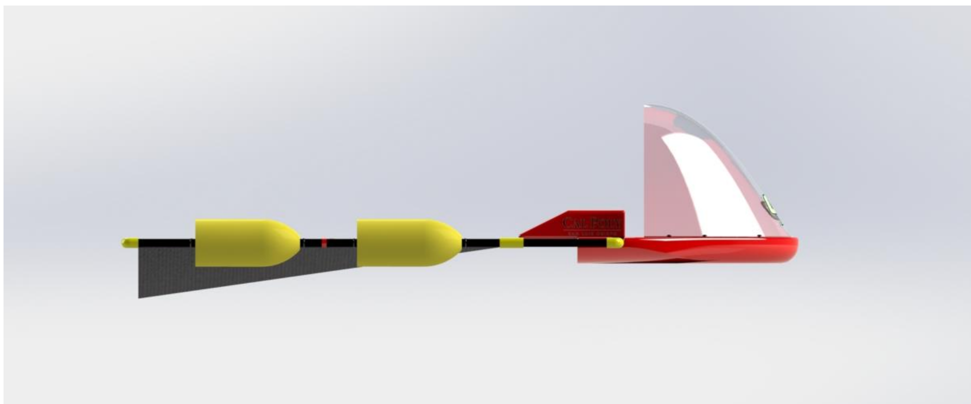


Figure 4.5 - Side view of the final design

Figure 4.6 - Isometric view of the device and Joseph in the pool

Frame

This outer frame is very similar to what was used to build the team's mock-ups. For this final product we will be using ½" black furniture grade PVC pipe. Not only does the furniture grade piping have a glossy appearance, it is also UV resistant. As a result, it won't deteriorate and crack due to UV exposure like standard PVC does. The black tubing gives the device a sleek appearance and yellow components contrast well, in addition to incorporating the Team Joseph color. The shape of the frame prevents Joseph from tipping because the width displaces enough water to provide a large amount of stability. The width of the frame also assists in breaking waves that the device may encounter from other swimmers and reduces any rocking from side to side. Less movement against Joseph's body causes less jarring forces that may create discomfort on his back and hips. PVC cement is used to seal all the fittings and thus keep the structure rigid and prevent it from filling with water. A complete dimensioned layout of the frame can be found in Appendix G. Table 4.1 lists the pipe lengths used to assemble the frame.

Table 4.1 - PVC pipe lengths needed for assembly

Length (in)	Quantity
39	4
7	4
24	2
9.75	2
41	1

Attached to the frame are foam PVC anchor floats, with two being placed on each side. These are commercial-off-the-shelf products. They are 11" long, with a 5" outer diameter and a 1" hole through the center. The overall purpose of these floats is to add buoyancy to the non-buoyant PVC frame. They are traditionally used to get kayak and fishing gear afloat. Consisting of solid PVC foam, the Promar PVC foam floats will not crack or get waterlogged when damaged. The placement of the external floats aides in the distribution of buoyancy so that the middle and rear of the device are equally buoyant as the front end where the significantly buoyant bow is located. Since the outer diameter of the ½" PVC pipe is 0.840", O-rings will be placed on either end of the floats so that they can remain in place. This ensures that the floats don't slide along the bars and affect the buoyancy stability in any way.

Figure 4.7 - PVC foam float to provide buoyancy

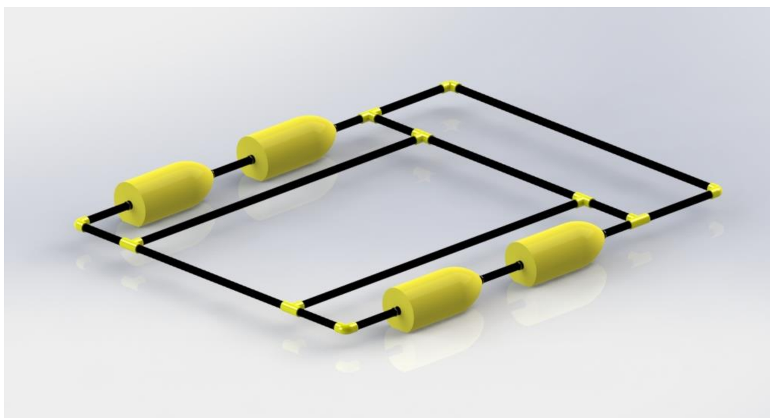


Figure 4.8 - Frame with PVC floats attached

The design cleverly uses polyester mesh to support Joseph, yet allow the majority of his body to be immersed in the water. The utilization of mesh also assists in creating a fluid and relaxing environment for Joseph. With this application, no rigid material will be applying any uncomfortable pressure on his hips and stomach. The angled shape of the mesh orients Joseph's body at a consistent incline with the headrest so that any strain on his back is negated. The mesh gives Joseph a realistic swimming experience in the water. It will be sewed around the inner side and front bars of the laying space of the device, as seen in Figure 4.9. The tautness for it has been determined from the team's final prototype testing during the winter quarter.

The mesh has a 1.5mm gage, thus giving it a full appearance and ensures that its holes are not large enough for Joseph to get caught in. This gage size alleviates the risk of his feeding tube catching in the netting as well. In addition to the mesh, four polypropylene buckle straps will be sewed around the frame, with one on each side and two in the front. These will keep Joseph securely fixed in place and prevents him from slipping backwards and into the water. Figure 4.9 shows all the sewing locations for these buckle strap attachments.

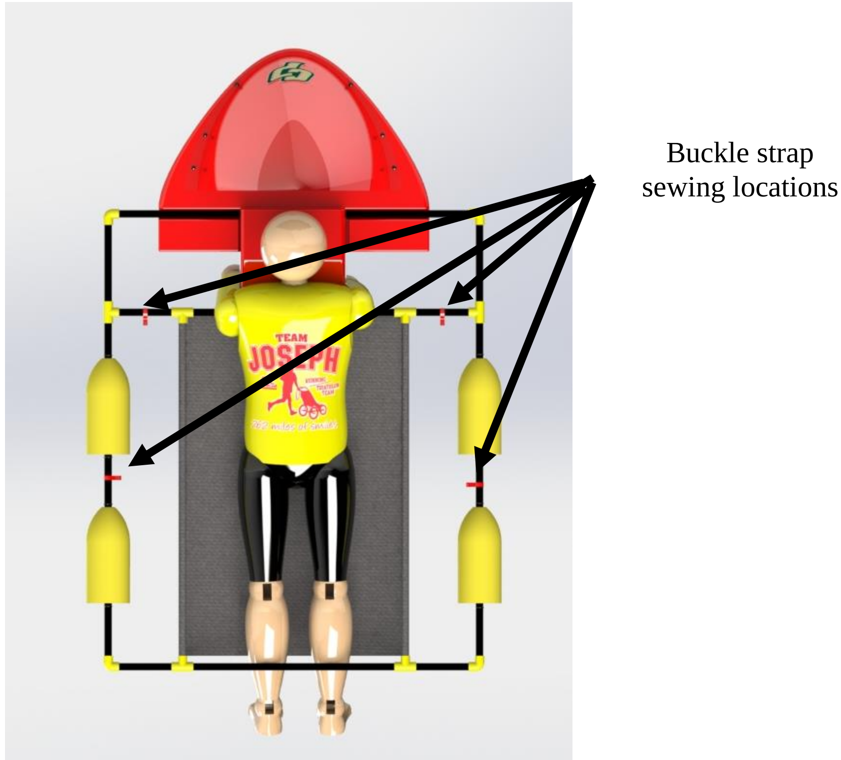


Figure 4.9 - Straps sewn around the tubing frame

Figure 4.10 - Polyester hex mesh – zoomed in image displaying 1.5mm gage

Chest & Head Support

The chest and head support is a single, fluid piece that is shaped at an appropriate angle for Joseph's body. The very natural and organic design of this piece settles Joseph's upper body comfortably into the device and increases his relaxation level. This piece will be cut and shaped from medium density, 6 lbs/in^3 polyurethane foam. This closed-cell foam has been donated to Cal Poly for student use from Precision Board. The general dimensions of the support can be found in the detailed drawing in Appendix G. The foam will then be fiberglassed in order to strengthen it and keep it from incurring any indentations or deterioration.

Figure 4.11 - Chest & head support rendering

During testing, the team observed the importance of locking his arms underneath the headrest and the effect of this on his body tone. The detailed design of the head support takes this into consideration as the dimensions of the device are sized properly for him to fold his arms and keep them at rest under the water. This also helps maintain his position and ensures that he can quickly enter a comfortable position as soon as his arms fold together. Figure 4.12 shows a visualization of this description.

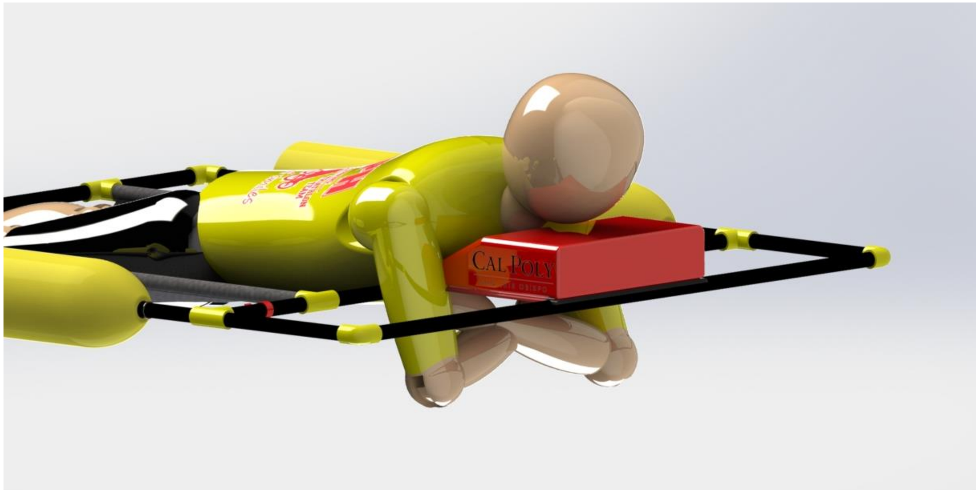


Figure 4.12 - Joseph's arms crossed underneath the headrest

It is crucial to create and maintain a comfortable, protective, and supportive platform for Joseph to rest upon while in a prone position in the device. A 12" x 20" Versa Form pillow will be attached to the head rest with Velcro. These Versa foam pillows are full of small, styrene beads that mold to the body's shape once a pump is used to extract air from it. Joseph can rest his head on top of this pillow and his dad can use the vacuum pump that comes along with it to remove air so that it conforms to his shape. This will provide extra comfort so that he can be as relaxed as possible for the 20-30 minute portion of the swimming event. The exterior of the pillow is made from polyvinyl and is water resistant. Overall, the pillow allows the freedom for John's dad to regulate the density of it and evaluate Joseph's comfort level.

Figure 4.13 - Versa Form pillow

Plastic Plate

The headrest is supported by this ¼" thick clear polycarbonate sheet. The plate is an off the shelf part with dimensions of 12"x12". The edges of the plate will be rounded and it will then be epoxied to the PVC pipes as shown in Figure 4.14 to secure it in place.

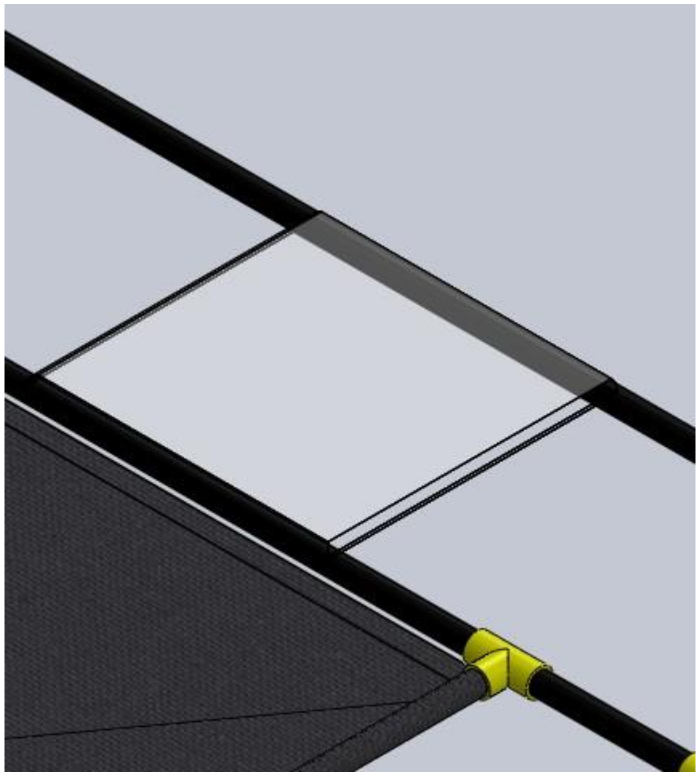


Figure 4.14 - Plastic support plate mounted to PVC bars

Bow

The bow is a critical component of the device. The purpose of this piece is to make the device more hydrodynamic, increase the overall buoyancy and provide a platform for the front splashguard to be mounted to so that no water may splash into Joseph's face due to the kicking of the swimmer in front of him. This part is made from 8lbs/in^3, high density urethane foam, also donated by Precision Board. It will be received as a 20"x60"x6" sized sheet and will then be cut and sanded into its final shape. This is closed cell foam, but it will be coated with a couple layers of fiberglass to strengthen it and prevent it from chipping or indentations.

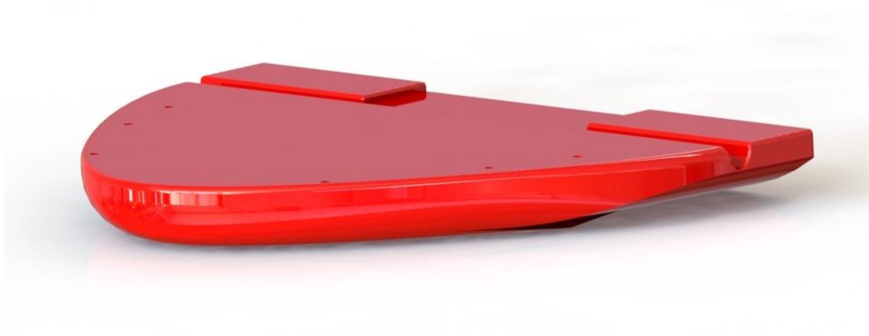


Figure 4.15 - Front isometric view of the bow

A 1” wide, 1” deep slot will be cut across the top of the bow for the front bar of the PVC frame to fit into. A 12” wide slot will also be shaped for the plate to sit within. Epoxy will be used to mount these parts into these respective slots.

Figure 4.16 - Rear isometric view of the bow

Holes will be drilled into the top of the bow in order for seven composite inserts to be put sealed into with resin. These composite inserts are necessary since the screws being used to assemble the splashguard to the bow cannot be threaded into the foam. Instead, they will be threaded into the inserts. The inserts will be donated by the team’s assistant George Leone. They match a screw size of ¼”-28 x ½”.

Splashguard

A huge safety concern with placing Joseph in a prone position is the danger of water splashing in his face, mostly from the kicking of the swimmer in front of him. In order to prevent this, the design uses a clear, plastic splashguard to ensure that Joseph does not take any water into his mouth. This splashguard will be fabricated by blow molding a 1/8” thick sheet of PETG through a mold made of the shape required. PETG is the best material for this application because it has a low melting temperature, is easy to work with and provides a very clear finished product, which is important to the design in providing Joseph full visibility. Once the splashguard is formed, a 1.5” wide lip will be cut around it. This lip, or flange, allows the splashguard to be screwed onto the foam bow underneath it with seven 1/4”-28 x ½” machine screws. Figure 4.17 clearly displays this feature of the part. This assembly method has its advantage because PETG is known to begin deteriorating after a couple of years due to UV exposure. Thus, it would be beneficial to make more than one splashguard so that it can be replaced in the future if any deterioration occurs.

Figure 4.17 - Splash Guard

Technical Analysis

Buoyancy

The most important analysis of this device is to verify that it will float in the water, even when carrying Joseph's weight of 70lbs. The figures below show the various forces on the device, as well as the nodal mesh used to calculate the hydrostatic forces. The two external loads are the distributed load from Joseph's body on top of the mesh support as well as a small distributed load applied on top of the head rest. External forces are demonstrated with purple arrows and all the hydrostatic forces surrounding the frame and bow are shown with red arrows.

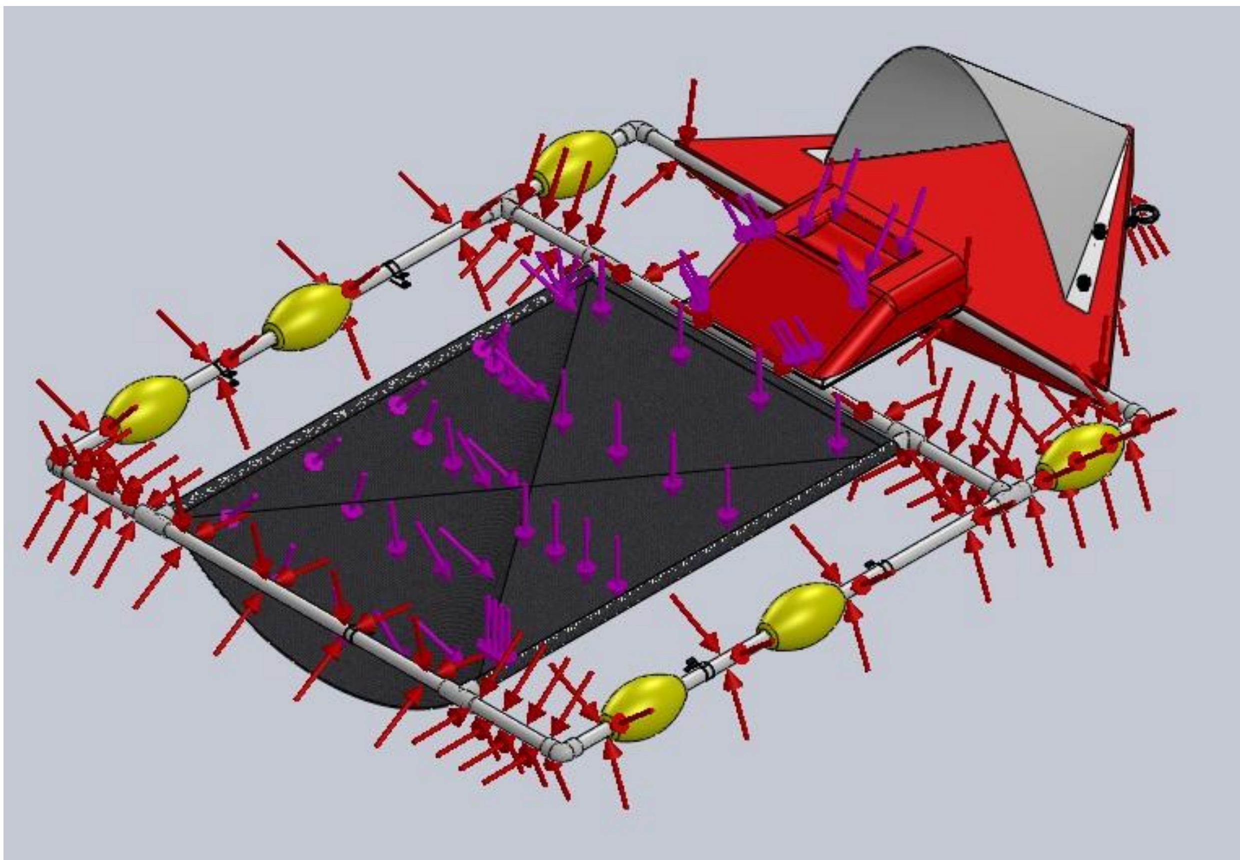


Figure 4.18 - Free body diagram showing loads and hydrostatic forces on the device.

The buoyancy of the device is verified by calculating its overall weight as well as its total volume in order to calculate the amount of water it displaces. The weight is determined given the density of each respective part in the overall assembly. The table below lists the densities of the main materials being used for the device. Appendix E lists the expanded table of densities, volumes and weights of each part of the device used in calculating the net buoyancy force. Small or lightweight parts including the mesh, straps, inserts and screws are negligible to the buoyancy and are thus left out of the analysis. Joseph's weight and data on the average human density were used in order to calculate his approximate total volume, which is factored into the buoyancy force.

Table 4.2 - Densities of the material considerations of the device

Section	**Density (lb/in^3)**
Medium Density Urethane Foam Bow	0.00347
PVC Tubing	~0.05
PVC Foam Float	0.02
Fabric Mesh	~0.001
Water	0.036

Archimedes' Principle and static equilibrium are then used to calculate the net buoyancy force as follows, where F_{Bnet} represents the net buoyancy force on the device and Joseph:

$$F_{Bnet} = F_B - W_{Joseph} - W_{Device}$$
$$F_B = \rho_{H20} g V_{displaced}$$
$$F_B = \rho_{H20} g (V_{Device} + V_{Joseph}$$

From the calculated weight and volume of both Joseph and the device, the net buoyancy force is calculated to be 35.2 lbs. According to the U.S. Coast Guard regulations, a life-jacket must provide a minimum 22-lb net upward force on its user. Thus, it is safe to say that this device meets the necessary buoyancy safety precautions.

Plate Deflection

It is also important to consider the deflection of the plate supporting Joseph's headrest. This deflection must be minimized because it is undesired for Joseph's head to move any closer to the water line as safety concerns are then increased. In order to perform this analysis, the plate is treated as a beam supported on both ends since it both are mounted on top of the PVC frame. The loading was approximated to be 20% of Joseph's body weight (18lbs). This body weight percentage is based off anthropometric data for the average percentage of body weight above the chests since this is the portion of his body that is loading the headrest and plate. The analysis was performed for both polypropylene and polycarbonate plates of 3/8" and 1/2" thickness. All plates tested are 12"x12" square dimensions. The results in Appendix E show the lowest deflection of -0.103" occurs for the 1/2" polycarbonate sheet, and thus this thickness is selected for use on the device.

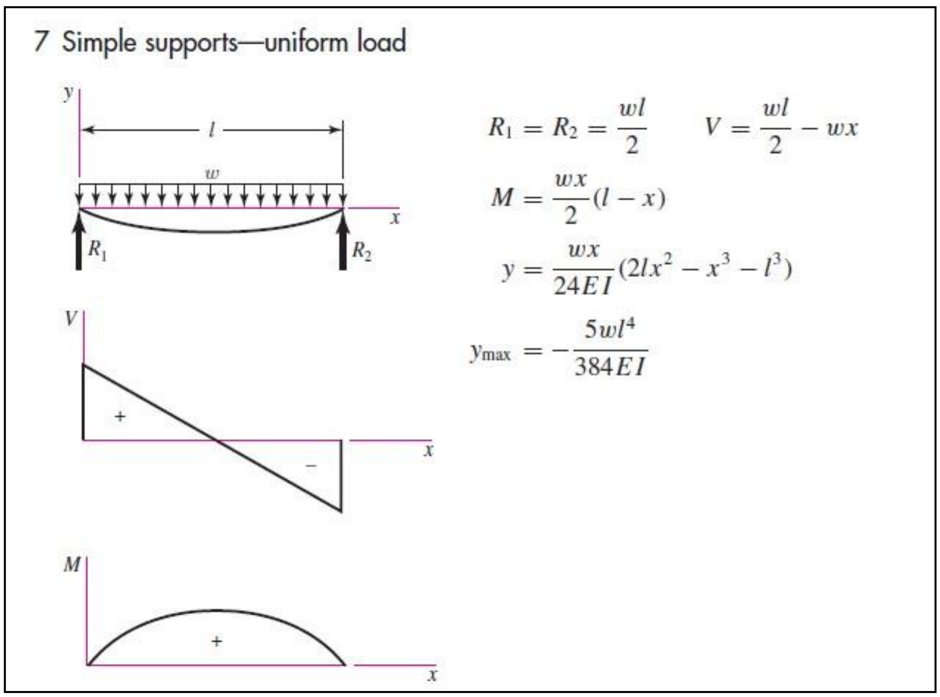


Figure 4.19 - Simplified model of the plate deflection

Drag Force

The drag force causing resistance on the swimmer must be kept relatively low in order to create a successful experience for all participants. The drag is calculated using the rough dimensions of the surface area of the device perpendicular to the flow of water past it, along with the density of the water. An appropriate drag coefficient was found through combining different research publications to develop a reasonable estimate for the shape of the team's design. The drag coefficient resembles an average between the drag coefficient of a cone and an average swimmer. The final value of the coefficient used was 0.4. A graph of the drag force versus velocity is provided in Appendix E along with a more detailed table of the drag forces. The velocities used are the range of swimming speeds an average swimmer may encounter during the triathlon. Below is the equation that was used to generate the different drag coefficients. The drag forces does not exceed 20 lbs with the swimmer's expected speed. While this may seem large, the overall drag has been reduced to allow an efficient swimming experience.

F_D = Drag Force
C_D = Drag Coefficient
A = Cross-sectional Area Perpendicular to Flow
ρ= Density of the Pool Water
V = Velocity of the body

$$F_D = C_D \rho A \frac{v^2}{2}$$

Table 4.3 - Drag Force on Device

Velocity	Coefficient of Friction	Drag Force
(ft/s)	-	lbf
0.23	0.4	0.4
0.46	0.4	1.5
0.68	0.4	3.3
0.91	0.4	5.9
1.14	0.4	9.2
1.37	0.4	13.3
1.59	0.4	18.1
1.82	0.4	23.6
2.05	0.4	29.9
2.28	0.4	36.9

Cost Analysis

The team was presented with an initial budget of $1,500. Table 4.4 below lists the total bill of materials for the hardware and accessories of the device. The total device alone costs $590.78. Much of the team's expenses went towards the cost of building mock-ups and manufacturing expenses. $372.94 was spent on creating mock-ups to test with Joseph during the fall and winter quarters, as well as procuring materials in preparation for the final device. A total of $324.26 was spent on manufacturing costs. These costs included the following: sandpaper, paint, fiberglassing materials, polishing compounds, a variable speed buffer, PVC cement, silicone sealant, wood for the blow molding tooling fixture, and more. Overall, a total of $1,772.80 was spent this year on designing and building the adaptive aquatic device for Joseph.

Table 4.4 - Bill of materials for the adaptive aquatic device

Part	Part #	Supplier	Description	Quantity	Cost	Total Cost
Mesh	F03A-POSP-HEXM-MX15--ZS	ahh.biz	1.5mm Polyester Hex-Mesh (1 Yard)	1	15.95	15.95
Straps	SRBS1L	StrapWorks	Polypropylene Buckle Straps	4	2.90	11.60
Anchor Floats	4913	AustinKayak	5x11" Promar PVC Foam Float	6	6.99	41.94
Splashguard			4'x8' PETG Sheet	1	80.00	80.00
PVC	P012FGP-BK-1	FORMUFIT	1/2" Black PVC Tubing 0.84"OD (~30ft)	30	0.88	26.40
Tees	F012TEE-YE	FORMUFIT	1/2" PVC Tee (0.848" ID)	6	1.30	7.80
Elbows	F01290E-YE	FORMUFIT	1/2" PVC Elbow (0.848" ID)	4	1.17	4.68
Harness	824916	Moosejaw	Rock Climbing Harness	1	64.95	64.95
Plate	8574K28	McMaster Carr	Plastic Sheet (Under Headrest) (12"x12"x1/4")	1	16.03	16.03
Rubber Trim	8507K52	McMaster Carr	Rubber Edge Trim 1/16", 1/4" Height, 10 ft. Length	1	8.80	8.80
Headrest		Precision Board	Medium Density Polyurethane Foam	1	Donated	-
Bow		Precision Board	High Density Polyurethane Foam	1	Donated	-
Composite Inserts			Stainless Steel Composite Inserts	7	Donated	-
		McMaster Carr	Flat Washer, Stainless Steel, 1/4" Screw Size (Pack of 50)	1	5.88	5.88
Screws	91772A557	McMaster Carr	1/4"-28 x 1/2" Stainless Steel Machine Screw (Pack of 50)	1	9.03	9.03
Swimming Belt	622	Sprint Aquatics	Swimming Belt	1	59.95	59.95
Versa Form	2825	Adaptive Specialties	Versa Foam Pillow (16"x20")	1	132	132.00
Pump	2823	Adaptive Specialties	Vacuum Pump	1	98	98.00
O-Ring	58282	Home Depot	1" O.D x 3/4" I.D. x 1/8" Thick O-Rings	1	2.78	2.78
Velcro		Home Depot	Velcro	1	4.99	4.99
					Total	$590.78

Safety Considerations

This project requires great attention to safety because of the severity that can ensue if these precautions are not met. Joseph's disability is to be kept in mind throughout the entirety of the design and manufacturing process. While the team is designing for other considerations such as a realistic environment for Joseph, the most important consideration is his protection. Built into the device are some key features that we feel will alleviate concern for his security. Most importantly, Joseph's inability to swallow or aspirate water must be constantly considered in the design. The splashguard must reflect this concern by being formed tall enough to cover well above his head. The design is also configured to secure Joseph to the device so that he does not fall off of it and into the water. However, along with this portion of the design, the process to secure him must also be fast releasing. This is crucial in case there is an emergency such as an unexpected seizure, or a mishap with the device. The team must be able to quickly remove Joseph from the device in order to prevent further injury in any of these cases. In order to complete this consideration, buckle straps are used to clip Joseph into the device. Each buckle will remain unobstructed throughout the entire race and use of the device because they are located on the exterior of the frame. Finally, in addition to these important design considerations, additional swimmers will accompany Joseph on either side of the device during the race in order to make sure that no injuries occur. The goal of this device is to assist Joseph in the completion of his first triathlon, and should not add additional safety risks to the situation.

Maintenance and Repair

The final product should withstand the conditions it is subjected to for many years and be adjustable to accommodate Joseph's growth. Therefore maintenance may be required throughout the lifetime of this device. This might include replacing the splashguard due to discoloring or deterioration of the plastic from the exposure to the sun. Multiple splashguards will be produced so that the team can simply unscrew the existing bolts and remove the old splashguard replacing it with a newer one. It is not expected that this will need to be a frequent process, rather one that occurs roughly every 3-5 years. The only other repair that may need to be evaluated is deterioration in the mesh. This should not be a concern because the material selected is meant to withstand water and wear without ripping or fraying.

To adjust for any growth Joseph undergoes the versa form pillow will need to be reshaped. This is a simple process that involves opening the valve to release the vacuum seal on the styrene pellets. Then Joseph can lie on the pillows while they are reformed to his chest size. If the chest piece becomes uncomfortable for Joseph this process can be done more frequently for individual uses.

5 - Manufacturing

The manufacturing process for this device was divided into four parts or sub-assemblies: the frame, the headrest, the bow, and the splashguard. Below is an in depth description of the manufacturing process of each of part. Once the individual parts were fabricated, the entire device was assembled by slipping the mesh over the interior PVC bars and then placing the frame into the slot on the bow. The splash guard was assembled to the bow by screwing to the composite inserts. Finally, the headrest was epoxied onto the frame.

Frame

The frame was built using furniture grade PVC fittings and ½” PVC pipes. The stock ½” PVC pipe was cut to the correct dimensions as seen in Appendix G. The layout of the final frame is similar to earlier prototypes with the mesh sewn around the interior bars. The correct length and depth of the mesh was measured with Joseph in the pool. Once these measurements were made, the mesh was sewn to fit over the outer diameter of the PVC pipes. Webbing was used along the seams so as to create a stronger stich that would not fail underneath Joseph’s weight. The same webbing was sewn along the edges of the mesh to finish the ends so that tears or fraying would not occur after continued use. Finally, the mesh was cut so that the T’s were exposed as well as the section underneath the headrest plate. The mesh was cut around the T’s otherwise the bars would be difficult to slip into the mesh sleeves and there would be a greater possibility for rips to occur in the mesh. The exposed section underneath the headrest allows the epoxy to bond directly to the bar. The red buckle straps that attach to Joseph’s harness were sewn around the bars as well. The clips were located on the bars near the outside of the device so that in case of an emergency, Joseph would be able to be removed quickly due to the easy access to the clips. A single seam was used to create the loop that the bars slide through.

The next step in constructing the frame was attaching the large PVC floats and O-rings to the long outermost side-bars. The PVC floats are 11” long and have an inner diameter of 1”. The inner diameter of the floats is slightly larger than the outer diameter of the PVC pipe frame causing a clearance of roughly 0.15”. To ensure that the floats stay in place while operating the aquatic device, O-rings were placed on either side of the floats. Once the rest of the device was constructed and no other dimensions of the frame needed to be altered, the pipes were glued together using clear PVC cement. The frame was then set aside to ensure the joints had sealed entirely before the device was used in the water for further testing.

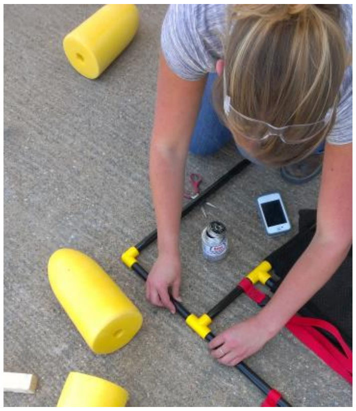


Figure 5.1 - Assembly of the frame

Chest & Head Support

This piece was cut from a large block of medium density foam that was then sanded and shaped to meet the design requirements. Red acrylic paint was used to cover the entire headrest. Once the paint dried, the headrest was then prepared to be fiberglassed. Fiber-glassing was an extensive process that used a UV cure laminating resin to apply the fiberglass cloth to the foam headrest. The fiberglass sheet was laid over the headrest and cut to the correct size. Next, generous amounts of resin were spread on top of the fiberglass by beginning in the center of the cloth and then working outward to remove all the excess air underneath it. Each side of the headrest was done separately and hardened before moving on to the next side. This ensured that there were no large wrinkles or overlaps in the fiberglass.

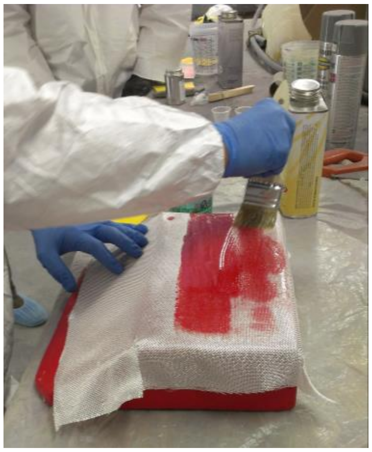


Figure 5.2 - Fiberglassing the headrest

All the rough fiberglass edges were filed down and a final hard coat was then painted over it. This coat, referred to as the hot coat, is a mixture of surfacing agent and laminating resin. The mixture develops into a waxy substance. A thick coat of this was applied to cover the entire headrest. Prior to exposing it to the sun, the coat had to sit on the part for 5 minutes in order for all the wax in it to rise to the surface so that it can later be sanded. The part was then carried outside and exposed to the sunlight for a couple of minutes until it set.

Next, the head rest was sanded using a hand-held orbit sander. The grit of the sandpaper was gradually increased starting at 220 and ending with 600 grit to create a smooth surface that then could then be polished. The polishing process consisted of applying a series of three different compounds. Each step was applied the same, but included different polishing coats to gradually improve the shine and appearance. After the third polishing compound was spun on with a variable speed buffer, JB water weld putty was applied to the bottom of the headrest and the top of the clear plastic plate to assemble the two together. The plate had been cut to fit the rounded corners of the headrest. All of the edges and the corners of this part were filed down to create a smooth features to make sure that when Joseph reaches around the sides of it, his arms are not scraped, nor will he experience any uncomfortable rubbing against it.

Figure 5.3 - Initial headrest before second hot coat was applied

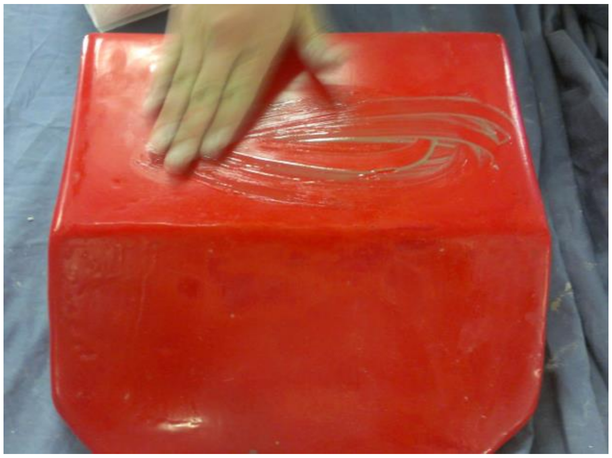


Figure 5.4 - Applying the final polishing compound to the headrest

Because this procedure was new to the team, multiple errors were encountered that needed to be remedied before moving forward. One of these included applying the Cal Poly stickers underneath the resin which deteriorated and bubbled to the surface causing visual flaws. In order to fix this, the stickers were painted over and another hot coat was applied applied. The headrest was the first part that the team attempted to fiberglass. Due to our lack of experience, some air bubbles formed underneath the fiberglass and needed to be covered. This was done by repainting the headrest and applying another coat of resin. The last difficulty that was encountered during the process that the team first sanded the part aggressively with sanding blocks. This left deep scratches across the part. This was resolved when the entire part was repainted.

Fortunately, all of these situations were resolvable and the only expense was the additional time spent during the manufacturing process.

Figure 5.5 - One of the errors that was encountered was applying the sticker underneath the hot coat.

<u>Bow</u>

The bow was made by following the same process as the headrest. First, a solid sheet of high density foam (8lbs/ft^3) was cut down to a rough shape. Files were then used in order to create the hydro-dynamically curved features, as well as for creating the slot for the front bar of the frame to fit into. A slot was also created in order for the headrest plate to rest into.

Figure 5.6 - Sanded foam bow

Just as was done with the headrest, the bow was then painted with red acrylic paint prior to fiberglassing it. A series of steps were taken to fiberglass the different sides of the bow by cutting sections of 4 oz fiberglass cloth and coating it with UV cure laminating resin. The part was then taken outside and would set within two minutes.

A week later the team discovered that the fiberglass on the bow filled up with large pockets of air. It was later learned that this was due to the fact that the fiberglass did not adhere well to the painted foam surface. The bow was left out in the sun for a week, and the heat caused the moisture in the paint to expand and push the glass away from the surface, thus creating the large air pockets that were discovered. We then had to strip the bow bare of all glass and paint in order to start from scratch. Figure 5.7 below shows the bow after the first run of fiberglassing and during the removal of the glass and paint.

Figure 5.7 - Before and after pictures of the bow

We were able to learn from these mistakes and approach the fiberglassing process with better understanding. This second time we fiberglassed the plain foam first. After filing down all the rough edges, we applied a couple layers of the paint, and once dried we put on the Team Joseph decal. A thick layer of hot coat consisting of the mixed laminating resin and surfacing agent was then applied to all surfaces in order to give it a glossy appearance, yet allow for the part to be sanded smooth. Figure 5.8 shows a layer of fiberglass being applied to the slot and the bow covered in the hot coat.

Figure 5.8 - The bow during fiberglassing and after final hot coat was applied

Once the hot coat was set, the part was then ready to be sanded to a smooth surface finish. The orbit sander was used to accomplish this by working through the following series of sandpaper: 220, 320, 400 and then 600 grit. Some sections of the bow had only a thin layer of the final hot coat applied to it and so the sander sanded through this and begin removing some paint. These spots had to be repainted and had a thin layer of hot coat applied over them to seal the paint.

Figure 5.9 - Sanding the bow

With the bow sanded down to a smooth surface finish, it was then ready to have the composite inserts mounted into it. An 11/16" spade bit was used to carefully drill out each of the holes just deep enough so that the inserts may lay flush with the top surface. A few small holes were punctured into the side walls of these holes so that the catalyzed resin used to fix the inserts in place would have places to seep into. The composite insert (shown below) was filled with Kleen Klay, an oil-less clay that protects the threads from getting hardened resin on them.

Figure 5.10 - Composite insert used to screw the splashguard to the bow

The catalyzed resin was created by mixing a 1/8 quart of the laminating resin with three drops of MEKP (methyl ethyl ketone peroxide) liquid hardener. A small amount of the resin was poured into each hole and was coated around the outside of each insert. The inserts were then put into the hole and topped with a cap with two holes on it that lined up with the holes on the top of the insert. A syringe was used to inject the catalyzed resin down into the insert. One hole acted as a sprue and the other as a riser. Once the resin came up through this riser the process was complete. The inserts were then left for a set and cure time of eight hours, after which these caps were peeled off and any hardened resin on the inserts was chipped off.

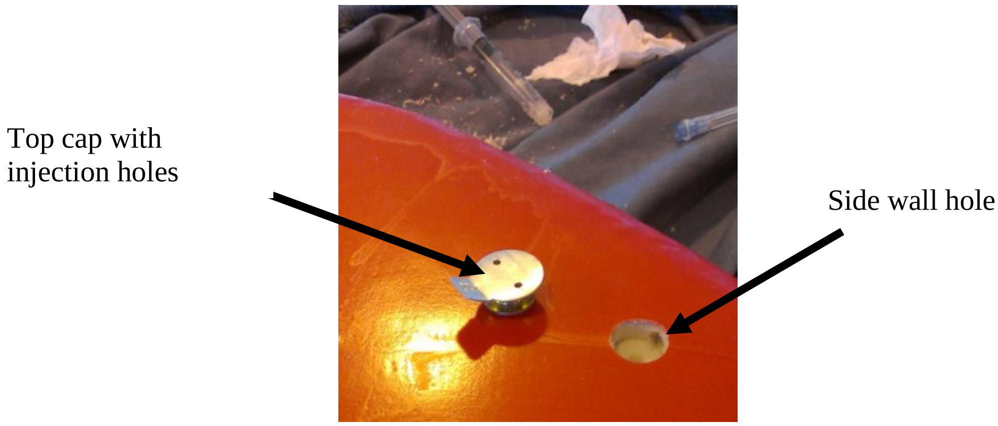


Figure 5.11 - Annotated process image of putting in the inserts

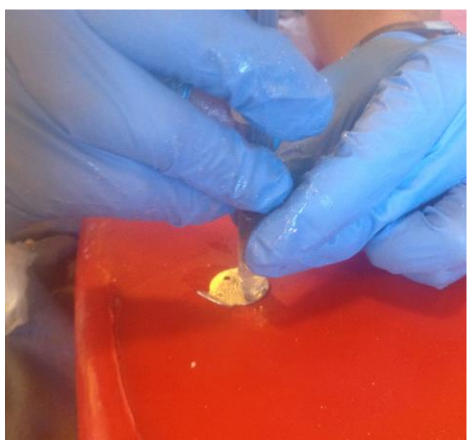


Figure 5.12 - Injecting resin to seal the composite insert in place

The last step in manufacturing the bow was to apply a series of polishing compounds and spin them on with a variable speed buffer, first at a low speed to work them in and then gradually working up to a high speed of around 3500 rpm to bring out the color and shine.

Figure 5.13 - Polishing the top of the bow

<u>Splash Guard</u>

The team's plan for manufacturing the splashguard was originally to create a mold and vacuum form a sheet of PETG plastic over it to accomplish a thin, clear appearance. In order to do this, a mold, or plug had to first be made. Figure 5.14 shows the general series of steps for this process.

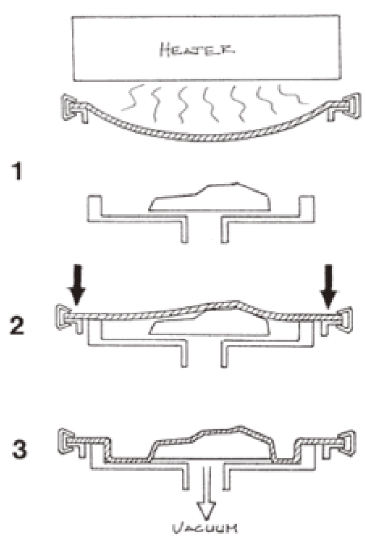


Figure 5.14 - Vacuum forming process steps
(Source: Workshop Publishing)

A block of medium density (6lb/ft^3) polyurethane foam was used to shape the desired mold. After cutting down a rough shape, we used sanding files to smoothen out the rough cut part. A series of cardboard templates were then placed over the mold at every 2 inches from the front face in order to achieve the proper curvature. These templates corresponded to the dimensions of the various cross sectional front views of the mold, and are attached in Appendix G. Figure 5.15 below shows the rough outline created in the foam in order to make the first series of cuts, and then the placement of a template at 4 inches from the front face to create the desired curvature.

Figure 5.15 **-** *Shaping the splashguard mold*

Once the shape was obtained, 100 grit sand paper was used to remove flaws and make the surface as smooth as possible. The mold was then ready to be fiberglassed in order to give it the necessary strength for it to be subjected to such high pressure during the vacuum forming process. However, prior to fiberglassing, the team learned that the vacuum former they were going to use didn’t have the capabilities of manufacturing this part because it required the sheet of plastic to be drawn into a mold rather than over a mold. Having to create an internal mold required a significant amount of work, but the team was referred by shop technician George Leone, a project assistant, to seek out the help of Rifle in Atascadero. Rifle manufactures custom made motor cycle windshields and they had the ability for us to blow mold this part. Extrusion blow molding is a very similar process to vacuum forming. A sheet of plastic is placed underneath high temperature heaters. Once the sheet begins to melt, it is rolled over and clamped down on top of a 2D mold pattern. High pressure air is then blown through a nozzle above the sheet in order to press the liquefying plastic down through the mold.

After a series of meetings with the company's owner, it was agreed upon that they would assist the team in manufacturing the splashguard. In order to fabricate it, a tooling fixture needed to be built in order to create an airtight mold. This fixture consisted of two pieces: an upper and lower shell half as shown below.

Figure 5.16 - Blow molding tooling fixture parts

Both of these structures were built from ½" thick plywood, 2x4's and ½" thick decking board. All pieces were cut on a table saw and were assembled with 2" and 3" long wood screws. Three inch wide flanges were attached to each in order for them to be clamped and locked in place within the blow molding fixture. Appendix G can be referenced for the dimensioned manufacturing drawings for these two parts. The bottom half was built to be 17" tall in order to allow enough depth for the thermoplastic to be blown up through. The hole on the top was cut using a sabre saw and is sized accordingly to the dimensions of the footprint of the part. This design requires two parts to be made at once since the shape of the part is mirrored about the center line so that a complete dome, or arc, can be blown. The completed dome is then cut in half after being formed. The top shell half, as shown on the right, was built to the same width and length as the bottom, since the two need to come together in order to form an enclosure. A hole was cut into the top of the upper half in order for a ¼" male air nozzle fitting to be pressed into. This fitting was used to blow pressurized air against the melted plastic. The fitting was epoxied into the hole using JB Weld. Figure 5.17 shows it in the described location.

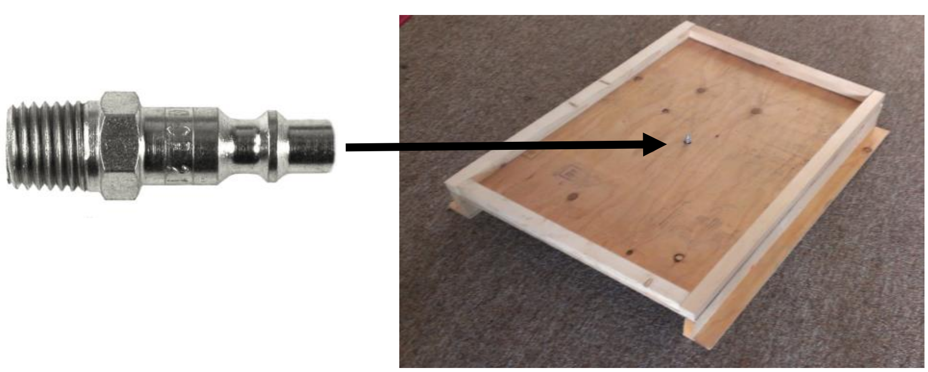


Figure 5.17. ¼" - Industrial air nozzle fitting epoxied to the upper shell half

The strength of the lower shell half then had to be significantly increased so that it would not fail underneath the large pressure of the air. Two cross braces were attached across the bottom of it using 2"x4"s.

Figure 5.18 - Completed bottom shell half

The blow molding of the splashguard was performed in two nights on site at Rifle's facilities in Atascadero. The first night was spent setting up the system by clamping down both shell halves in the machine and making minor adjustments. Black vinyl foam tape was applied around the edges of each half where they come together in order to prevent air leaks and seal the fixture, thus improving the blow molding ability for such a tall part. Figure 5.19 shows the bottom half locked into place and the mounting of the upper half on top of it.

Figure 5.19 - Setup for the tooling fixture

After setup was complete, the team returned the following night to complete the job. The 4’x8’ sheet of 1/8” thick PETG was cut to the correct length on a circular saw stand, as seen below.

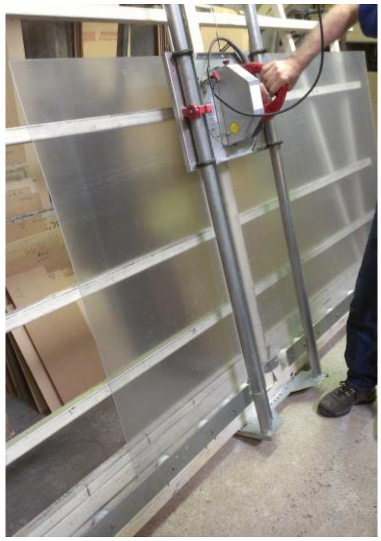


Figure 5.20 - Cutting the 4’x8’ PETG sheet

The sheet was then clamped into the fixture in between the lower and upper shelf halves. Figure 5.21 is annotated to show the location of these parts as well as the location of the heaters used to melt the thermoplastic.

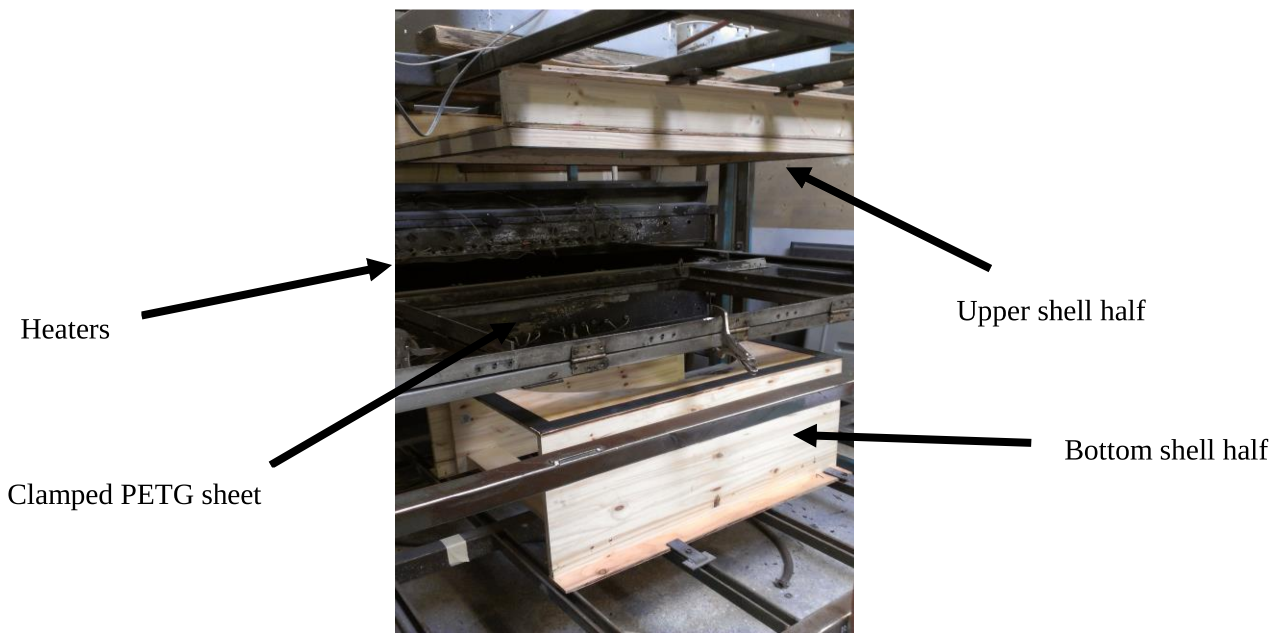


Figure 5.21 - Final setup of the tooling fixture and thermoplastic in the machine

The sheet was rolled back into the heaters for approximately 30 seconds and we then watched the plastic drape in order to visually judge the appropriate time to pull it out. Once the plastic was liquefied enough, it was rolled out and clamped back into its starting position. The lower and upper shell halves were quickly brought together with the plastic in between and the 100 psi pressurized air line was opened. Within seconds the pressurized air forced the plastic down through the mold hole. A piece of string was tied across the bottom shell half as a visual marker to know when the required part height was reached and that the air could be shut off. Figure 5.22 shows the clear plastic expanding with the fixture.

Figure 5.22 - Expansion of the PETG plastic within the fixture

The dome was then cut in half to create two identical parts using a band saw, as shown in Figure 5.23. A small, pneumatic circular cutter was then used to cut the 1.5” lip around the part in order for it to be mounted to the bow. Seven clearance holes were then drilled into this flange in order for the screws to fit through. Lastly, all edges were filed down and a black rubber trim was fit over these edges. The completed splashguard was then mounted to the bow, as shown in Figure 5.24.

Figure 5.23 - Cutting the blow molded part

Future Manufacturing Recommendations

After fabricating the device, the team acknowledges that there are improvements in the manufacturing process that can be made for a second generation device. First, it is important that the fiberglassing of both the bow and head rest should be done prior to any painting. The team discovered that the fiberglass does not adhere well to the foam if it has been painted. This also reduces to the concern of having to worry about small air pockets and visual flaws in the fiberglass since it will then be painted over. A lot of time was lost on the project in dealing with delaminating and repainting the fiberglassed parts.

We also recommend that careful time be taken with the sanding process. First, it is important to use a variable speed sander that can start at a low speed. Having control of the speed will prevent the possibility of sanding completely through the final hot coat, as the team experienced. Using a single, high-speed sander created flaws that had to be then painted over and didn't completely match the color of the rest of the part.

Lastly, we recommend that a better design be made for the assembly of the frame to the bow. The current method has design this interface to be a hinge, and since all the weight of the device is on the front, a large amount of torque is placed on the bar when moving it around. The epoxy used to assemble these two together did not work well. In the future, a mending plate should be placed over the bar on each side so as to hold it in place. This also would allow the device to be assembled and fit more easily into John's car.

Figure 5.24 - Completed device on display at the Senior Project Expo

6 - Design Verification

<u>Test Procedures</u>

Test: **Depth of mesh Test**

1. Attach mesh to the flotation device at an estimated depth
2. Place Joseph in device
3. Measure and analyze body positioning
4. Readjust depth of the mesh and re-evaluate until appropriate

Test: **Buoyancy Test**

1. Place the flotation device in water
2. Add twice Joseph's equivalent weight to device, creating a safety factor of 2 for buoyancy
3. Analyze flotation ability with the added weight

    Pass = Plate below headrest is at water level and evenly buoyant

    Fail = sinks, or device is submerged past the plate underneath the head rest

Test: **Enjoyment Test**

1. Place Joseph in the device while it is in the water and lock him into place with the harness
2. Attach swimmer to swimming tether or belt
3. Pull Joseph 2 laps/lengths of the pool
4. Have Michael, William, and John rate Joseph's comfort level
5. Scale:

    1- Unacceptable discomfort level

    2- Slight discomfort or irritation

    3- Not uncomfortable

    4- Relaxed but could be improved

    5- Very relaxed and comfortable & enjoying experience

Note: Acceptable range must be within a 4-5 approval rating

Test: **Drag Test**

1. Place Joseph in the flotation device
2. Connect a spring scale to swimmer's end of the towing rope
3. Pull the device an entire pool length
4. Record both the average and the maximum drag incurred during the test
5. Drag must be less than 15 pounds force

Test: **Entry Time Test**

1. Place flotation device in the water
2. Begin timing the process of connecting Joseph and the swimmer to the flotation device
3. Stop timing when both Joseph and swimmer are attached and secured in the device
4. The time to load the device must be less than 5 minutes

Purpose of Test Procedures

Test: **Depth of Mesh Test**
The purpose of this test is to adequately attach the mesh to the device in order to create the most supportive and comfortable environment for Joseph. Another key aspect of this test is to accommodate for some of the safety concerns including hip and back support as well as keeping Joseph's head far enough away from the water.

Test: **Buoyancy Test**
The buoyancy test will be very important in the success of the project. There will be a no fail requirement, meaning the device must adequately support Joseph's body weight while remaining afloat. There will be a safety factor placed on this test of 2. This safety factor will keep the device afloat with at least double Joseph's actual body weight. This worst-case scenario will likely not happen; however, it is important to design for it to make sure that the risk reduction is met to protect Joseph from injury or harm.

Test: **Enjoyment Test**
This procedure requires more qualitative reporting. There is a numerical value attached to the qualitative requirements to make it better defined regarding what is expected. Those that know Joseph's needs and personality will be reporting their most accurate grade on a scale of 1-5 for his enjoyment and comfort in the device. This is important to meet the customer's goals of creating a new experience for Joseph that he can enjoy, relax, and progress in. Without the input from John, Michael, and William, the device may not reach its full potential of success.

Test: **Drag Test**
In order to create an accurate assessment of the drag force, the swimmer will experience a test that measures the drag force experienced by pulling Joseph. Because of the non-uniform shape of the device, simply using background knowledge of drag calculations may not be adequate for realistic data. If the forces exceed the design requirement, the device will need to be adjusted before it can be complete. Pulling the device while swimming is what completes the experience for Joseph and without that ability the design is not successful.

Test: **Entry Time Test**
The purpose of this test is for the race day as well as future uses of the device. On the day of the triathlon, a significant portion of time cannot be spent getting Joseph into the device, otherwise the start time may be delayed. In regards to future uses, Joseph will be more comfortable if the entry process does not take an extended period of time. During previous testing, this portion of time is less comfortable for him and often causes him to not regain his comfort level.

Materials Necessary to Complete Testing:

1. Spring scale
2. Stop watch
3. Tape measure
4. Final model of design

DVP & R

All of the necessary tests have been completed aside from the comfort level of the swimmer pulling Joseph. However, we believe that the device will not provide a significant amount of resistance on the swimmer due to observations made from the testing of mock-ups. Since the team will be taking turns in pulling the device during the triathlon, the endurance of the swimmer with the device is not a huge concern. Below is the DVP&R report of the completed tests. Each of the tests is given a stage and type. Their specifications are listed as follows:

Test stage:
CV-Concept Validation
DV- Design Validation
PV-Product or Process Validation

Sample type:
A- Concept Verification
B- Design Verification
C- Product Validation

Table 7.1 - DVP&R test plan and report

Team Joseph: I'm on a Float DVP&R													
Report Date		1/28/14	Sponsor	Michael Lara			Component/Assembly				REPORTING ENGINEER:		Lilly Hoff
TEST PLAN										TEST REPORT			
Item No	Specification	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Depth of Mesh	Prototype testing in pool	fully supported body positioning	Lilly	DV	1	B	1/30/14	2/28/14	Pass	N/A	N/A	N/A
2	Minimal Drag on swimmer	Drag test	≤15 lbs	Lilly	DV	3	B	5/2/14	5/9/14	pass	15 lbs	N/A	N/A
3	Buoyancy	Buoyancy test	no fail	Paul	DV	1	B	5/2/14	5/9/14	pass	N/A	N/A	N/A
4	Comfort level	Enjoyment rating	≥4	Paul, Lilly, Andrea	PV	5	C	1/30/14	5/2/14	pass	4.5	N/A	N/A
5	Assembly timing	Entry time for device	≤5 mins	Andrea	PV	5	C	2/28/14	2/28/14	pass	3 minutes	N/A	N/A
6	Aspiration of water	splash test	no fail	Paul, Lilly, Andrea	DV	5	B	4/4/14	5/2/14	pass	N/A	N/A	N/A

Results of Test Procedures

Testing was completed with and without Joseph present at the Cal Poly Rec Center pool. Some of the tests needed to be altered due to time constraints that occurred because of delays in the manufacturing process. However, all requirements were met with the device. Testing occurred over two days in the pool.

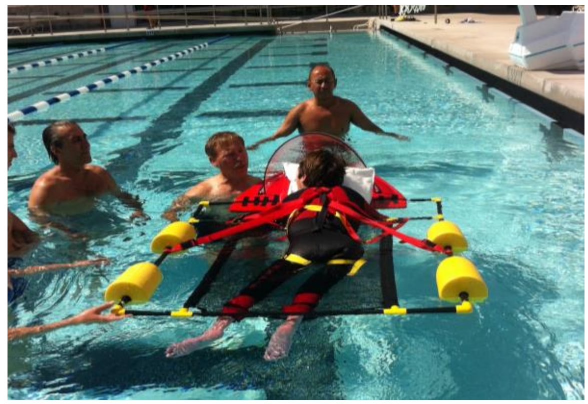



Figure 6.1 - The two rounds of testing - the bow was attached and the final frame was used instead of the prototype frame for the second day

Buoyancy testing was done over the two days. For the first day, the original smaller floats were used on the prototype. While Joseph was still at the water level, the device did not seem buoyant enough. With this design the device did not pass the buoyancy test. Therefore, the design was slightly altered and four larger floats were added to the device, with two placed on each side. For the second day of testing, the final frame was used with the larger floats and the device easily passed the buoyancy test, while keeping Joseph's body mostly in the water to provide the most realistic swimming experience.

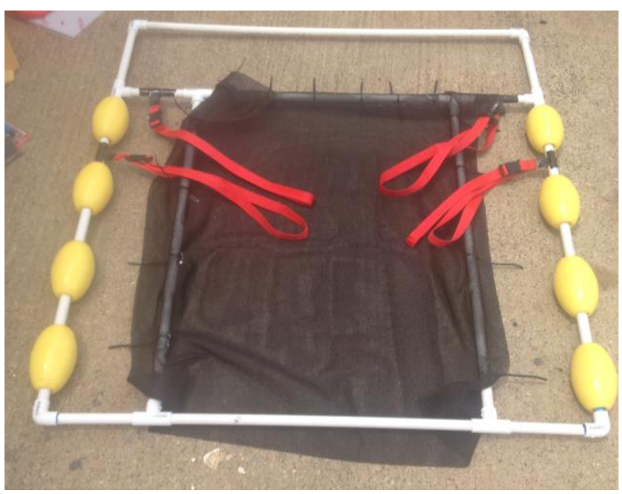


Figure 6.2 - Frame for day one of buoyancy testing

The entry time for the device was fairly quick at just under 3 minutes. A video of the process was taken so that the results would be repeatable. By keeping the procedure consistent, the time it takes to get Joseph in the device will continue to decrease. It is important to note that the entry time does not include getting Joseph into his wet suit, nor putting his harness on, which will be done prior to the start of the race. The time began to be recorded once Joseph was at the edge of the pool and was stopped once his harness was clipped into the straps on the bars.

Joseph's comfort level has increased each time that he has used the device. Once he starts to be pulled in the water he becomes relaxed and his body tone loosens up. It is interesting to note that the more roughly he is pulled through the water, the more relaxed and comfortable he is. Even when the water is near Joseph's face or there is any splashing coming from the swimmer, the height and width of the splashguard is able to protect him from this.

Testing was completed in a shorter time span than previously expected because of manufacturing delays. However, testing on a previous prototype was effective and helped to make many of the crucial design decisions.

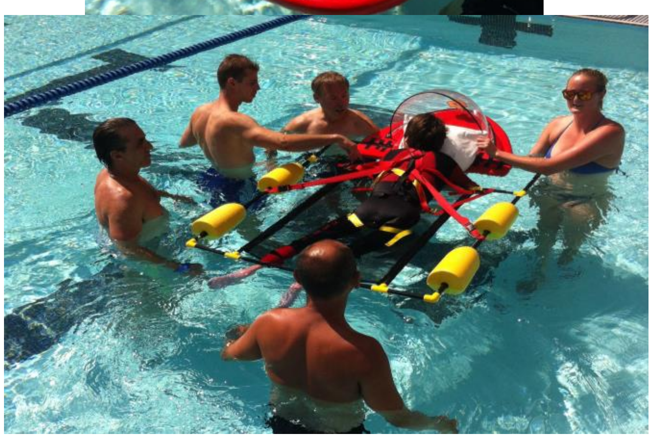


Figure 6.3 - Front View of the head positioning in relation to the splashguard

Figure 6.4 - Rear view of Joseph in the final stages of testing

7 – Conclusions

This project has been more than simply a senior project for credit, it has also been a chance to get to know an inspiring group and expand the opportunities of a young man. Knowing the impact we had in making Joseph's life has been very rewarding. The team feels confident that this device will be a great benefit for Joseph long after the SLO triathlon. We hope that it becomes a tool that Joseph can use to be more active in the pool and in future triathlons.

Overall, the project was a success and the device passed all of the requirements while remaining very safe for Joseph to use. The concept of the device was one that initially did not stand out as the best option for Joseph's comfort, however early on in the design process it became very apparent that this was indeed the best position for Joseph to be. The aquatic device gives Joseph the realistic experience of swimming in a least restrictive environment. The device is most importantly designed for the safety and comfort for Joseph. Team Joseph wants to create a memorable experience for Joseph and his family and friends, and this aquatic device exceed those expectations

There is certainly room for improvement on the current prototype. Some of the advancements that can be made include adding a cross bar that lies perpendicular to the front bar of the frame that is placed in the slot on the bow. This alteration would create a mechanical block that would eliminate the torque on the front bar created when carrying the device. Currently, the bow and frame connect as a hinge with no stop other than the epoxy that it was sealed with. Over an extended period of time the epoxy may break down and not create a solid connection; however, the current addition of plate brackets will secure the frame in place. Another alteration that can be done to improve the current design is to make a pillowcase for the versa form-positioning pillow out of neoprene. This would make it waterproof as well as more comfortable for Joseph. The pillow currently is just the polypropylene exterior of the Versa Form pillow. This addition can help absorb Joseph's and thus eliminate the possibility of saliva build up near his mouth during the race. Currently, these are the only foreseen improvements besides creating more professional fiberglassed parts. The team is satisfied in their fabrication of these parts given their lack of fiberglassing experience. In conclusion, Team Joseph is pleased with the turnout of the device and it has been received extremely positively by Joseph's father, teacher and the project sponsor Michael Lara.

References:

Safety Standards & Codes

http://www.fmeainfocentre.com/handbooks/milstd1629.pdf

http://www.uscg.mil/hq/cg5/cg5214/pfdselection.asp

Life Jackets & Materials

http://www.outdoors.net/Outdoors/Article/524

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Patents

https://www.google.com/patents/US5667416?dq=US5667416+A&hl=en&sa=X&ei=upZp UoulEIb9iQL4yoHQBg&ved=0CDkQ6AEwAA

https://www.google.com/patents/US2994095?dq=US2994095+A&hl=en&sa=X&ei=_pZp UrvGKoWdiAKXrYGgCw&ved=0CDsQ6AEwAA

https://www.google.com/patents/US2946068?dq=US2946068+A&hl=en&sa=X&ei=IZdp UqbYDYuUigKH2YHQDw&ved=0CDkQ6AEwAA

Current Flotation Devices

http://www.abledata.com/abledata.cfm?pageid=113583&top=0&productid=126139&trail= 0

Appendices

Appendix A

Description	Category	Mishap Definition
Catastrophic	I	Death or system loss
Critical	II	Severe injury, minor occupational illness, or major system damage
Marginal	III	Minor injury, minor occupational illness, or system damage
Negligible/Minor	IV	less than minor injury, occupational illness, or system damage

	Hazard Category			
Frequency of Occurrence	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible
A. Frequent	1	3	7	13
B. Probable	2	5	9	16
C. Occasional	4	6	11	**18**
D. Remote	8	10	14	**19**
E. Improbable	12	15	17	**20**

Hazard-risk Index	Criterion
1-5	Unacceptable
6-9	Undesirable
10-17	Acceptable with review
18-20	Acceptable without review

Appendix B

QFD

Team Joseph: I'm On a Float

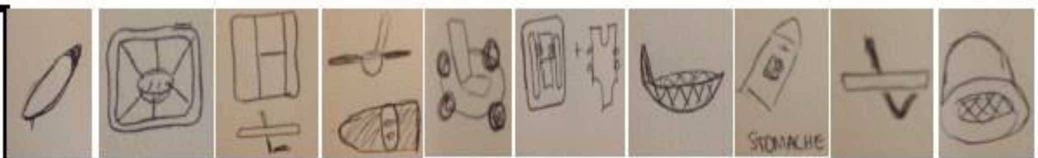
Engineering Requirements (HOWS)

Customer (Step #1) Requirements (Whats) / Customer Requirements (Step #2)	Weighting (1-5 Scale)	Forward Facing	Budget	Width	Device Weight	No cable restriction for swimmer	Non corrosive material in the water	Long term use	Functions at pool temperatures	Length	Production time	Amount of body out of water	Can be disassembled	Comfort in device	Overall device height	MIL-SPEC 1629A	Inflatable Raft	Flotation Device (Patent)	Water Skiff Model (Patent)	Child's Flotation (Patent)	Forward facing device
Device supports Joseph's trunk	5	Δ	○	Δ	[illegible]					Δ		○	Δ	●	○	●	1	1	1	1	4
Least Restrictive Environment (LRE)	3	●		Δ	Δ					Δ		●		Δ	Δ	○	2	3	3	3	3
Allow Joseph visibility in the race	4	●										○				Δ	1	2	3	3	2
Protect Joseph from inhaling water	5	Δ										●				●	5	4	4	4	2
Allow 1 person to tow him	4		Δ	Δ	○	●				Δ		○					4	4	4	4	4
Have most of his body in the pool	5	Δ					●		●			●	Δ	Δ		Δ	1	3	3	3	2
Have knee and below fall free in the pool	5						○		Δ					●			1	5	5	5	2
Distribute pressure on his hips	5													●		Δ	5	3	3	3	5
Reclined/Inclined seating	4	Δ										○		●	○		2	1	1	1	4
Must float	5		○		●		●	○			○	●	Δ			●	5	5	5	5	5
Must be easily pulled by average swimmer	5	○	Δ		●	○		○			Δ	Δ					3	4	2	3	4
Trasportation capability	5			●	Δ					●			●		●		5	5	1	4	4
Ready to use in time for the race	5		Δ								●						5	5	5	5	5
Straps Joseph in	4	Δ	Δ		Δ						Δ	○		●		●	1	2	1	2	5
Incorporates Team Joseph colors (red and yellow)	4										Δ						4	4	4	4	4
Units		-	$	4	lbs	-	-	yr	-	ft.	-	in	-	-	in.	-					
Targets		Yes	1500	3	20	Yes	Yes	20	Yes	5	5/29/14	18	Yes	Relaxed	44	18-20					
Raft		No	40	4	10	Yes	Yes	20	Yes	6	Complete	58	No	Relaxed	6	18-20					
Flotation Device (Patent)		Yes	40-50	3	<5	Yes	Yes	12	Yes	2.5	Complete	28	No	Low-Medium	6	1-3					
Water Skiff Model (Patent)		Yes	100	5	20-30	Yes	Yes	10	Yes	6	Complete	28	No	Low	8	1-3					
Child's Flotation (Patent)		Yes	40-50	2	15	Yes	Yes	10	Yes	3	Complete	28	No	Medium	6	10-17					
Forward Facing, Inclined Device		Yes	30	2	<10	Yes	Yes	8	Yes	3	Complete	12	No	Medium-High	4	10-17					

● = 9	Strong Correlation
○ = 3	Medium Correlation
Δ = 1	Small Correlation
Blank	No Correlation

Appendix C

Pugh Matrix



Criteria \ Concept	1	2	3	4	5	6	7	8	9	10
Floats	S	S	D	S	-	S	S	+	S	S
Trunk Support	-	+	D	+	S	+	S	+	+	S
Visibility	S	S	D	S	S	+	-	-	S	-
Towable	+	S	D	-	S	S	+	+	S	+
Body in water	-	S	D	S	S	+	+	S	S	+
Knee and below in water	-	-	D	-	S	S	+	-	+	-
LRE	+	+	D	S	S	S	S	+	S	S
No aspiration	-	S	D	S	S	S	-	+	S	S
1 Swimmer	+	S	D	-	S	S	+	S	S	-
Support Hips	-	-	D	-	S	+	+	-	+	+
Σ+	3	2	D	1	0	4	5	5	3	3
Σ-	5	2	D	4	1	0	2	3	0	3
ΣS	2	6	D	5	9	6	3	2	7	4

Appendix D

Bill of Materials

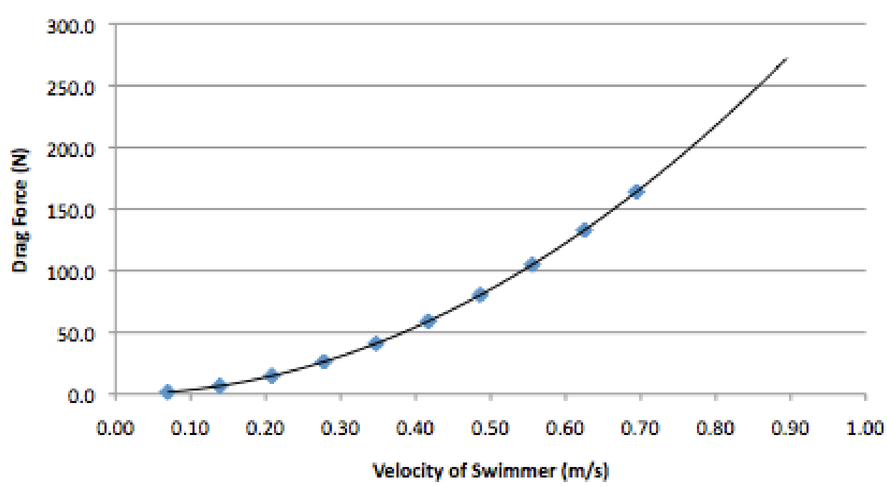
Part	Part #	Supplier	Description	Quantity	Cost	Total Cost
Mesh	F03A-POSP-HEXM-MX15--ZS	ahh.biz	1.5mm Polyester Hex-Mesh (1 Yard)	1	15.95	15.95
Straps	SRBS1L	StrapWorks	Polypropylene Buckle Straps	4	2.90	11.60
Anchor Floats	4913	AustinKayak	5x11" Promar PVC Foam Float	6	6.99	41.94
Splashguard			4'x8' PETG Sheet	1	80.00	80.00
PVC	P012FGP-BK-1	FORMUFIT	1/2" Black PVC Tubing 0.84"OD (~30ft)	30	0.88	26.40
Tees	F012TEE-YE	FORMUFIT	1/2" PVC Tee (0.848" ID)	6	1.30	7.80
Elbows	F01290E-YE	FORMUFIT	1/2" PVC Elbow (0.848" ID)	4	1.17	4.68
Harness	824916	Moosejaw	Rock Climbing Harness	1	64.95	64.95
Plate	8574K28	McMaster Carr	Plastic Sheet (Under Headrest) (12"x12"x1/4")	1	16.03	16.03
Rubber Trim	8507K52	McMaster Carr	Rubber Edge Trim 1/16", 1/4" Height, 10 ft. Length	1	8.80	8.80
Headrest		Precision Board	Medium Density Polyurethane Foam	1	Donated	-
Bow		Precision Board	High Density Polyurethane Foam	1	Donated	-
Composite Inserts			Stainless Steel Composite Inserts	7	Donated	-
		McMaster Carr	Flat Washer, Stainless Steel, 1/4" Screw Size (Pack of 50)	1	5.88	5.88
Screws	91772A557	McMaster Carr	1/4"-28 x 1/2" Stainless Steel Machine Screw (Pack of 50)	1	9.03	9.03
Swimming Belt	622	Sprint Aquatics	Swimming Belt	1	59.95	59.95
Versa Form	2825	Adaptive Specialties	Versa Foam Pillow (16"x20")	1	132	132.00
Pump	2823	Adaptive Specialties	Vacuum Pump	1	98	98.00
O-Ring	58282	Home Depot	1" O.D x 3/4" I.D. x 1/8" Thick O-Rings	1	2.78	2.78
Velcro		Home Depot	Velcro	1	4.99	4.99
					Total	**$590.78**

Appendix E

Drag calculations

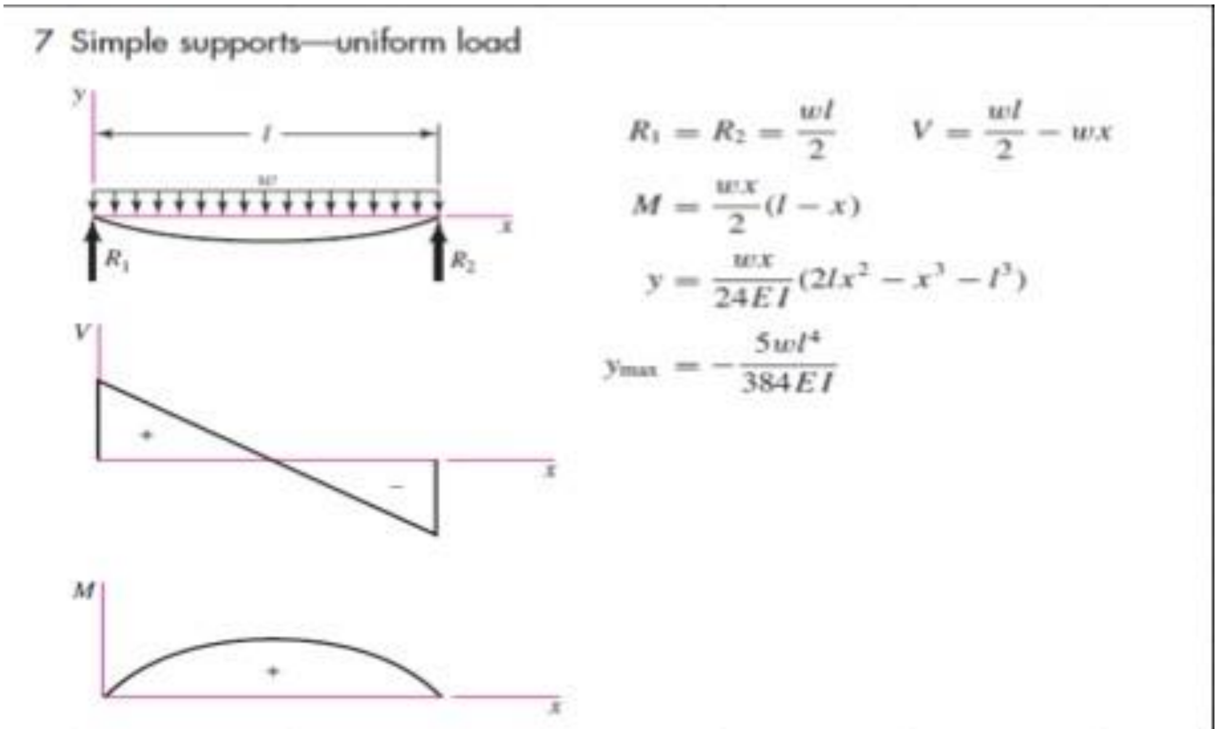
Constants		
Density of pool water	1000	kg/m^3
Waterline length	1.4	m
Surface Area of bow	1.7	m
nu (kinematic viscosity)	0.000000801	m^2/s

Velocity	Velocity	Reynolds Number	Coefficient of Friction	Drag Force	Drag Force
(ft/s)	(m/s)	-	-	N	lbf
0.23	0.07	121376	0.4	1.6	0.4
0.46	0.14	242752	0.4	6.6	1.5
0.68	0.21	364128	0.4	14.8	3.3
0.91	0.28	485504	0.4	26.2	5.9
1.14	0.35	606880	0.4	41.0	9.2
1.37	0.42	728256	0.4	59.0	13.3
1.59	0.49	849632	0.4	80.3	18.1
1.82	0.56	971008	0.4	104.9	23.6
2.05	0.63	1092385	0.4	132.8	29.9
2.28	0.69	1213761	0.4	164.0	36.9



Plastic Plate Deflection

Note: Assuming 15% of his body mass is above his chest (based of anthropometric data)



Material	Part #	width (in)	thickness (in)	F (lbs)	length (in)	E (Gpa)	E (psi)	I (in^4)	ymax (in)
Polycarbonate	8574K45	12	0.375	18	12	2.6	377098	5.273E-02	**-0.2444**
	8574K32	12	0.5	18	12	2.6	377098	1.250E-01	**-0.1031**
Polypropylene	8742K136	12	0.375	18	12	1.75	253816	5.273E-02	**-0.3631**
	8742K137	12	0.5	18	12	1.75	253816	1.250E-01	**-0.1532**

Buoyancy Analysis:

Coast Guard life vest standard Buoyancy force = 25 lbf

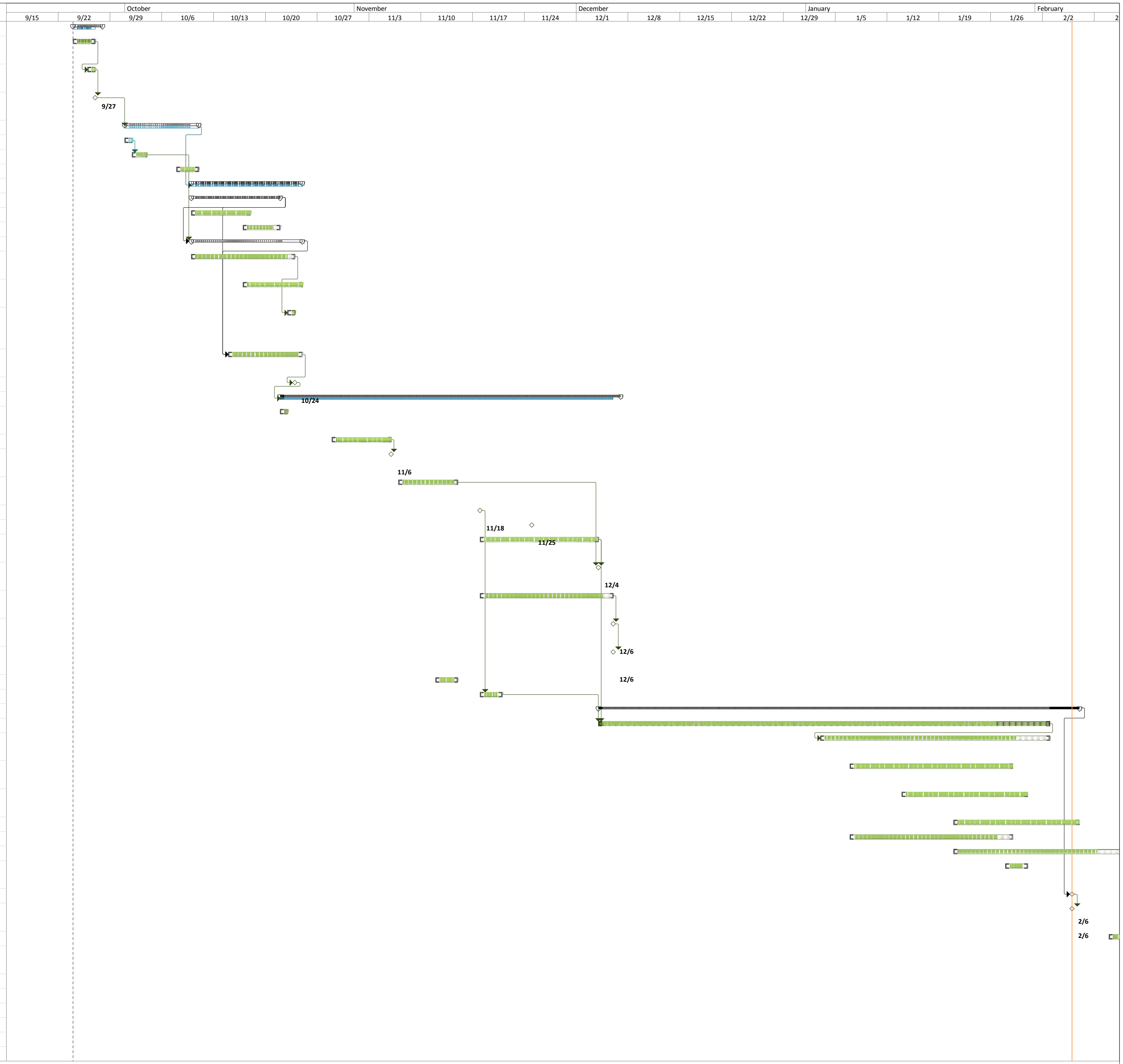
Part	Material	Density (lbs/in^3)	Volume (in^3)	Weight (lbs)	Quantity	Total Volume (in^3)	Total Weight (lbs)
Displaced Water	Water	0.0361					
Float	PVC Foam	0.02	35.564	0.71128	6	213.38	4.27
Foam Bow	Medium Density Urethane Foam	0.003472222	1116.39	3.876354142	1	1116.39	3.88
Splashguard	PETG	0.046	56.94	2.61924	1	56.94	2.62
Plate	Polycarbonate	0.048	71.521	3.433008	1	71.52	3.43
Foam Headrest	Medium Density Urethane Foam	0.003472222	191.413	0.664628468	1	191.41	0.66
Tubing	PVC	0.053					
36"	PVC	0.053	12.882	0.682746	4	51.53	2.73
24"	PVC	0.053	8.588	0.455164	2	17.18	0.91
42"	PVC	0.053	14.671	0.777563	1	14.67	0.78
9.75"	PVC	0.053	3.489	0.184917	2	6.98	0.37
7"	PVC	0.053	2.505	0.132765	4	10.02	0.53
Elbow	PVC	0.053	1.04	0.05512	4	4.16	0.22
Tee	PVC	0.053	1.41	0.07473	6	8.46	0.45
						Total Volume	Total Weight
						1573.05	20.85

Average human density (kg/m^3)	1010
Average human density (lb/in^3)	0.0365
Joseph's Volume (in^3)	1917.808219

Buoyancy Force (lbs)	Device Weight (lbs)	Joseph's Weight (lbs)	Net Buoyancy (lbs)
126.0199456	20.85	70	35.170

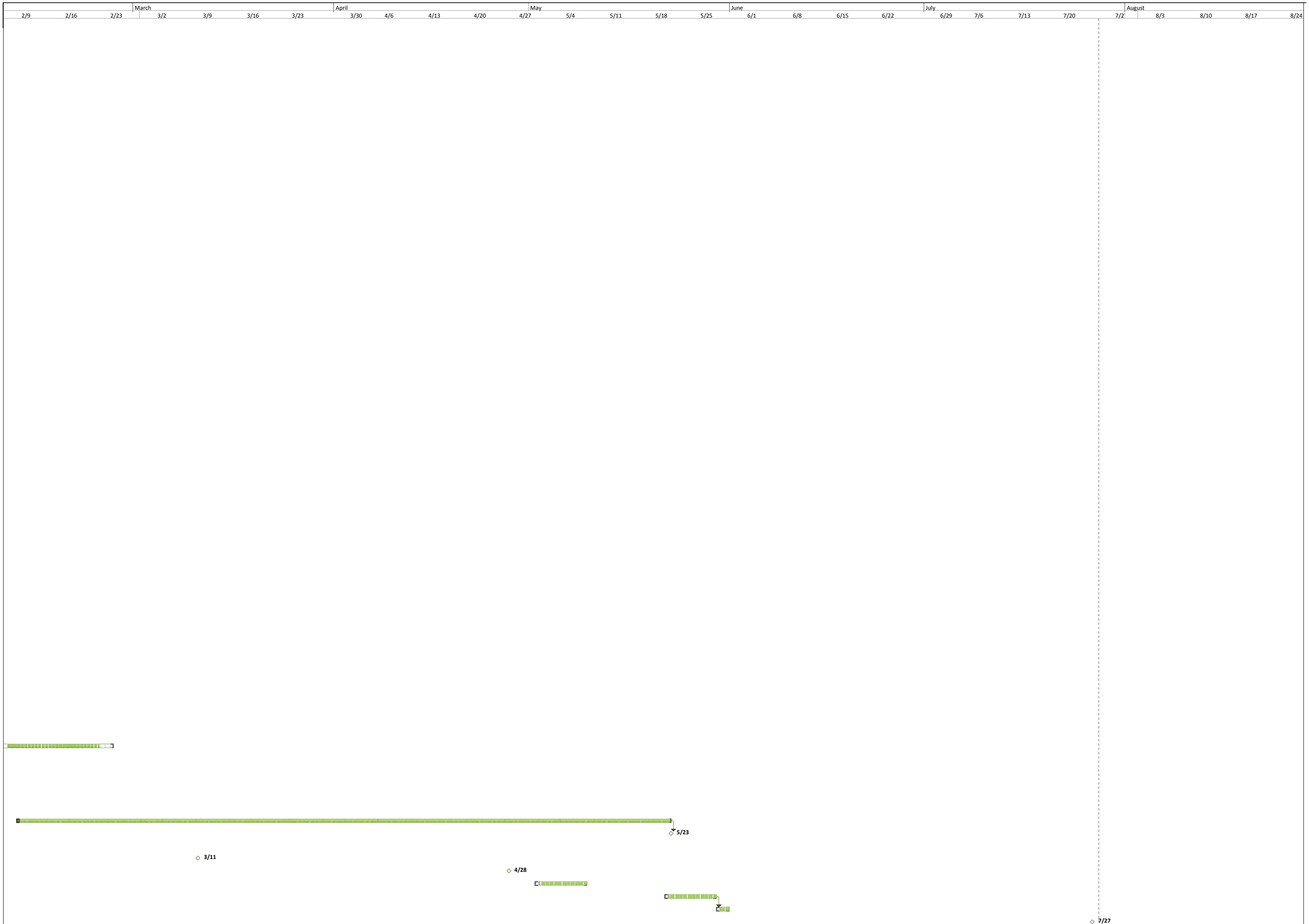
*Note because Net Buoyancy force is greater than standard for life vest it is within an acceptable range

ID	Task Mode	WBS	Task Name	Duration	Start	Finish	Predecessors
1		**1**	**Project Selection**	**4 days**	**Tue 9/24/13**	**Fri 9/27/13**	
2		1.1	Watch Project Presentations	3 days	Tue 9/24/13	Thu 9/26/13	
3		1.2	Fill Out Project Preference Form	1 day	Thu 9/26/13	Thu 9/26/13	2
4		1.3	Turn in Project Preference Form	0 days	Fri 9/27/13	Fri 9/27/13	3
5		**2**	**Project Introduction**	**8 days**	**Tue 10/1/13**	**Thu 10/10/13**	**4**
6		2.1	Introductory Letter	1 day	Tue 10/1/13	Tue 10/1/13	
7		2.2	Sponsor Visit	2 days	Wed 10/2/13	Thu 10/3/13	6
8		2.3	Team Contract	3 days	Tue 10/8/13	Thu 10/10/13	
9		**3**	**Project Definition**	**11 days**	**Thu 10/10/13**	**Thu 10/24/13**	**5**
10		**3.1**	Background Research	8 days	Thu 10/10/13	Mon 10/21/13	
11		3.1.1	Patent Search	6 days	Thu 10/10/13	Thu 10/17/13	
12		3.1.2	Material Research	3 days	Thu 10/17/13	Mon 10/21/13	
13		**3.2**	QFD	11 days	Thu 10/10/13	Thu 10/24/13	7,10
14		3.2.1	Customer Requirements	10 days	Thu 10/10/13	Wed 10/23/13	
15		3.2.2	Engineering Requirements	6 days	Thu 10/17/13	Thu 10/24/13	
16		2.3	Requirements Review with Sponsor	1 day	Wed 10/23/13	Wed 10/23/13	14
17		3.4	Writing Project Proposal	8 days	Tue 10/15/13	Thu 10/24/13	10,13
18		3.5	Project Proposal	0 days	Thu 10/24/13	Thu 10/24/13	17
19		**4**	**Concept Development**	**34 days**	**Tue 10/22/13**	**Fri 12/6/13**	18
20		4.1	Morphological Matrix Development	1 day	Tue 10/22/13	Tue 10/22/13	
21		4.2	Conceptual Modeling	6 days	Tue 10/29/13	Tue 11/5/13	
22		4.3	Conceptual Model Presentation	0 days	Wed 11/6/13	Wed 11/6/13	21
23		4.4	Prototype Development	6 days	Thu 11/7/13	Thu 11/14/13	
24		4.5	Pugh Matrix	0 days	Mon 11/18/13	Mon 11/18/13	
25		4.6	Yellow Tag	0 days	Mon 11/25/13	Mon 11/25/13	
26		4.7	CAD/SolidWorks Modeling	12 days	Mon 11/18/13	Tue 12/3/13	
27		4.8	Conceptual Design Review Presentation	0 days	Wed 12/4/13	Wed 12/4/13	23,26
28		4.9	Writing Conceptual Design Report	14 days	Mon 11/18/13	Thu 12/5/13	
29		4.10	Conceptual Design Report	0 days	Fri 12/6/13	Fri 12/6/13	28
30		4.11	Conceptual Design Review with Sponsor	0 days	Fri 12/6/13	Fri 12/6/13	29
31		5	Gantt Chart	3 days	Tue 11/12/13	Thu 11/14/13	
32		6	Pick a Solution	3 days	Mon 11/18/13	Wed 11/20/13	24
33		**7**	**Detail Design**	**47 days**	**Wed 12/4/13**	**Thu 2/6/14**	
34		7.1	Detail Drawings	44 days	Wed 12/4/13	Sun 2/2/14	26,32
35		7.2	BOM (Bill of Materials)	22 days	Fri 1/3/14	Sun 2/2/14	34
36		7.3	Design Verification Plan and Report	16 days	Tue 1/7/14	Tue 1/28/14	
37		7.4	Test Plan Development	13 days	Tue 1/14/14	Thu 1/30/14	
38		7.5	Prepare CDR	13 days	Tue 1/21/14	Thu 2/6/14	
39		7.6	Engineering Analysis	16 days	Tue 1/7/14	Tue 1/28/14	
40		8	Order Supplies	26 days	Tue 1/21/14	Tue 2/25/14	
41		9	CDR Practice Presentations	3 days	Tue 1/28/14	Thu 1/30/14	
42		10	Submit Design Report	0 days	Thu 2/6/14	Thu 2/6/14	33
43		11	Critical Design Review with Sponsor	0 days	Thu 2/6/14	Thu 2/6/14	42
44		12	Manufacturing	73 days	Tue 2/11/14	Thu 5/22/14	
45		13	Manufacturing test review	0 days	Fri 5/23/14	Fri 5/23/14	44
46		14	Project Update Memo	0 days	Tue 3/11/14	Tue 3/11/14	
47		15	Assembly Demo	0 days	Mon 4/28/14	Mon 4/28/14	
48		16	Test	6 days	Fri 5/2/14	Fri 5/9/14	
49		17	Prepare for Expo	6 days	Thu 5/22/14	Thu 5/29/14	
50		18	Senior Expo	2 days	Fri 5/30/14	Sat 5/31/14	49
51		19	SLO Triathlon	0 days	Sun 7/27/14	Sun 7/27/14	

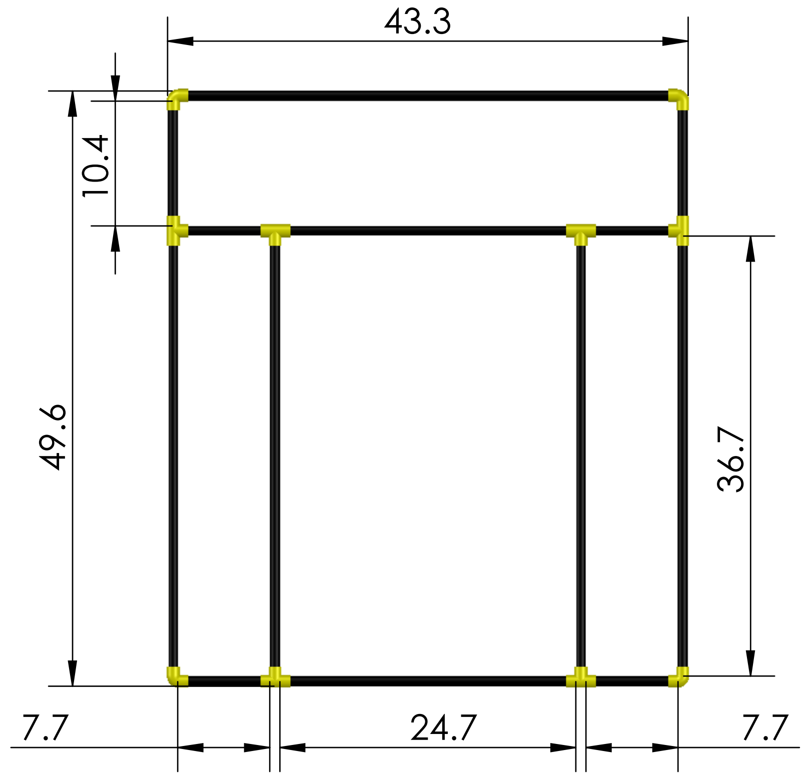


Project: Gantt Chart Senior Projec
Date: Thu 2/6/14

Task	Milestone	Project Summary	External Milestone	Inactive Milestone	Manual Task	Manual Summary Rollup	Start-only	Deadline
Split	Summary	External Tasks	Inactive Task	Inactive Summary	Duration-only	Manual Summary	Finish-only	Progress



Project: Gantt Chart Senior Projec Date: Thu 2/6/14	Task	Milestone	Project Summary	External Milestone	Inactive Milestone	Manual Task	Manual Summary Rollup	Start-only	Deadline	
	Split	Summary	External Tasks	Inactive Task	Inactive Summary	Duration-only	Manual Summary	Finish-only	Progress	



NOTE: TUBING AND FITTINGS ARE STANDARD 1/2" PIPE SIZE, (0.84" OD)

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± ONE PLACE DECIMAL ±0.1	DRAWN		
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL PVC	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

NEXT ASSY	USED ON
APPLICATION	

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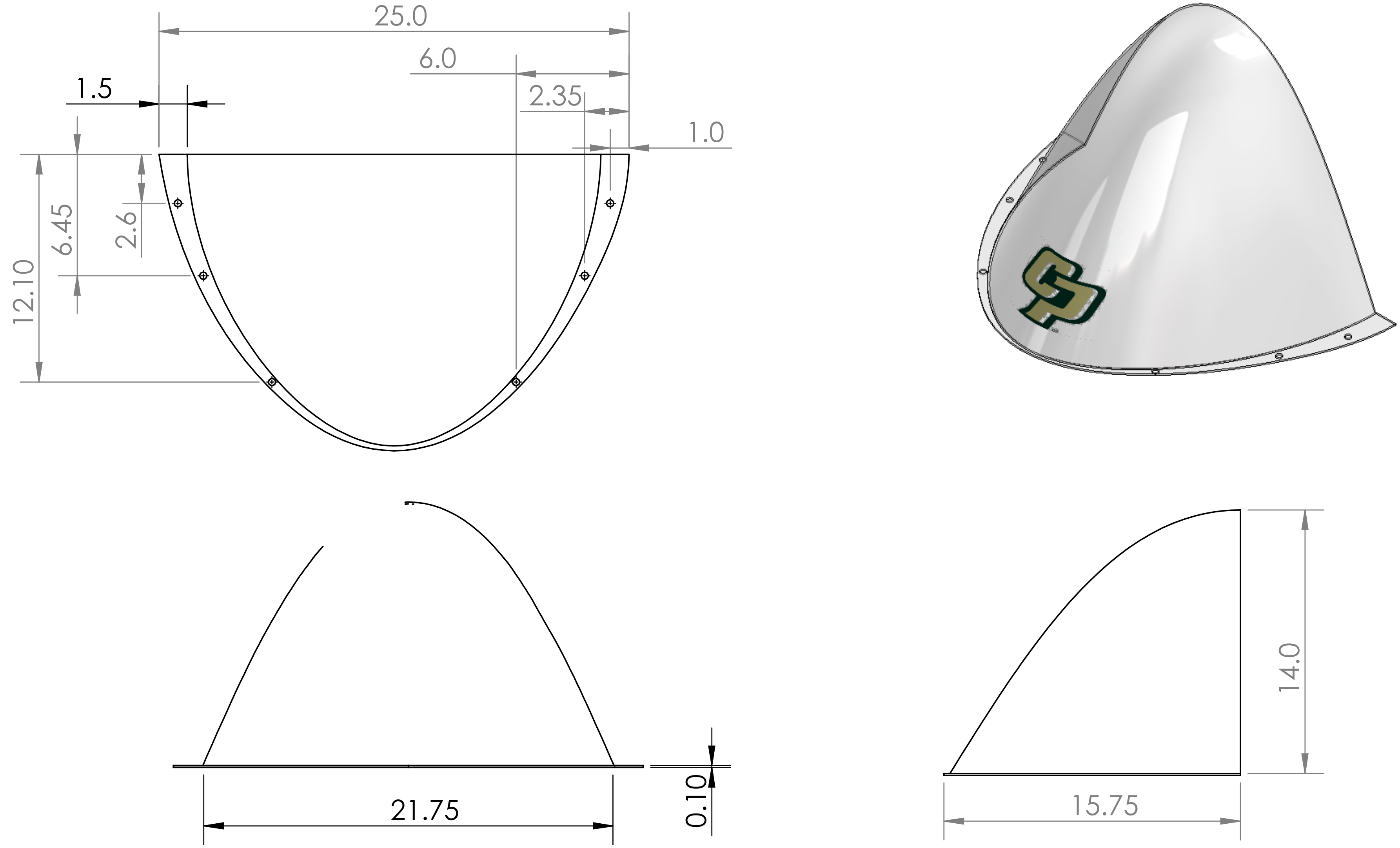
TITLE:

FRAME LAYOUT

SIZE	DWG. NO.	REV
A	12121	

SCALE: 1:16 WEIGHT: 3.977 lbs SHEET 1 OF 1

5 4 3 2 1



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APPLICATION	

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
ONE PLACE DECIMAL ±0.1
TWO PLACE DECIMAL ±0.01

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
PETG

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

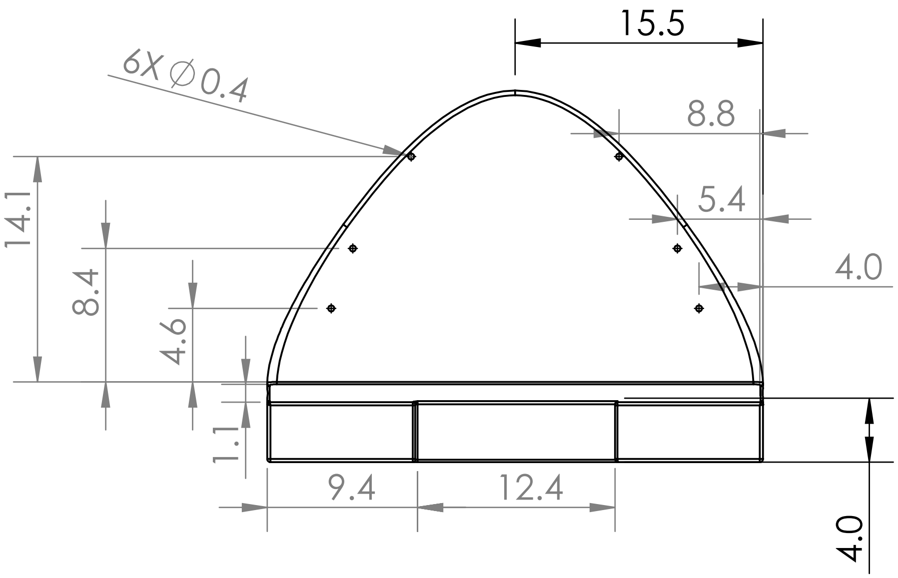
TITLE:

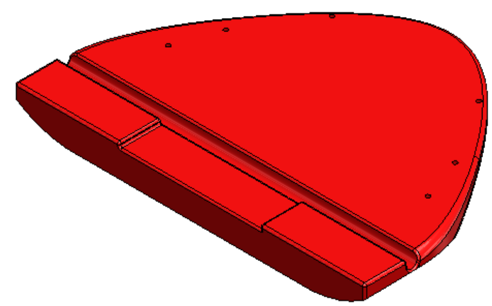
SPLASHGUARD

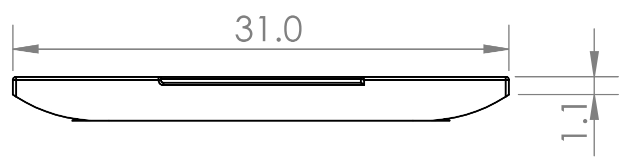
SIZE	DWG. NO.	REV
A	12122	

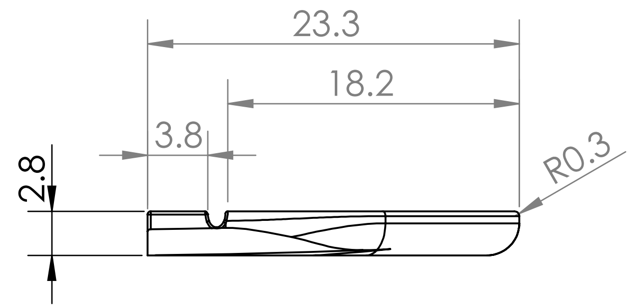
SCALE: 1:8 WEIGHT: 1.6 LBS SHEET 1 OF 1

5 4 3 2 1









FIBERGLASS PART AFTER SHAPING
ROUNDS ARE UP TO DESIGNER'S DISCRETION

PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
ONE PLACE DECIMAL ±0.125
TWO PLACE DECIMAL ±0.01

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
POLYURETHANE FOAM

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

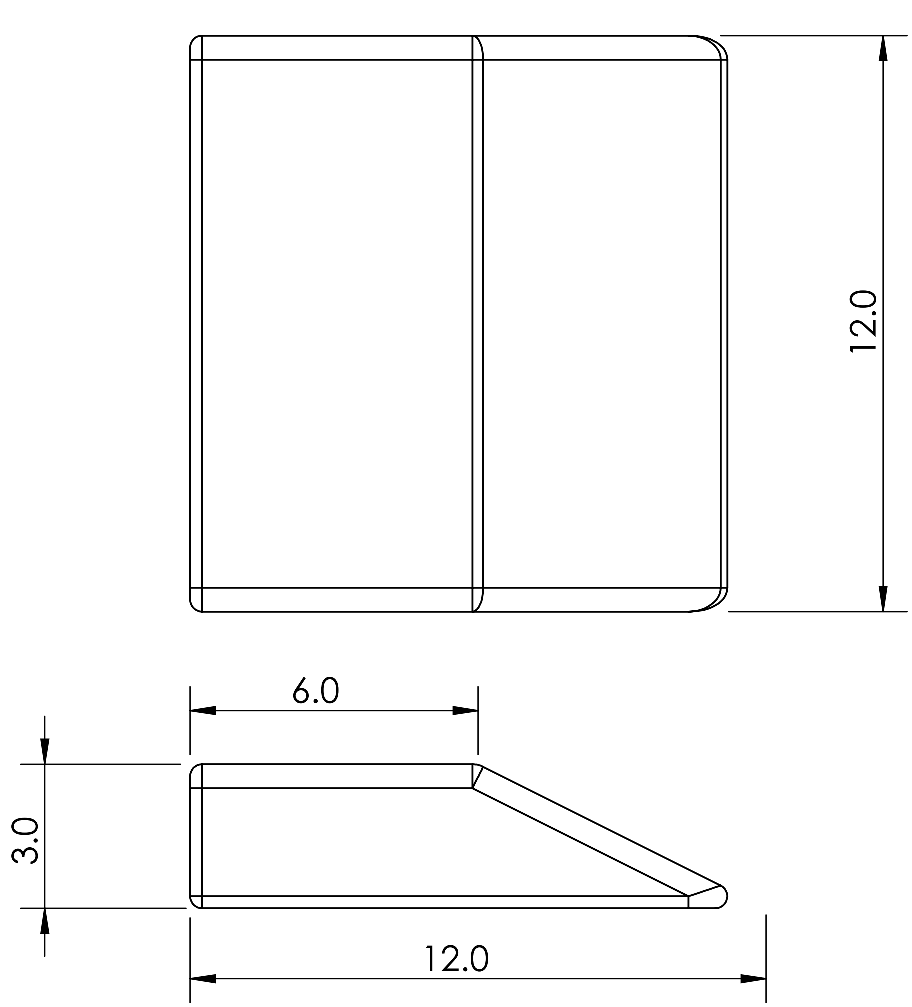
TITLE:

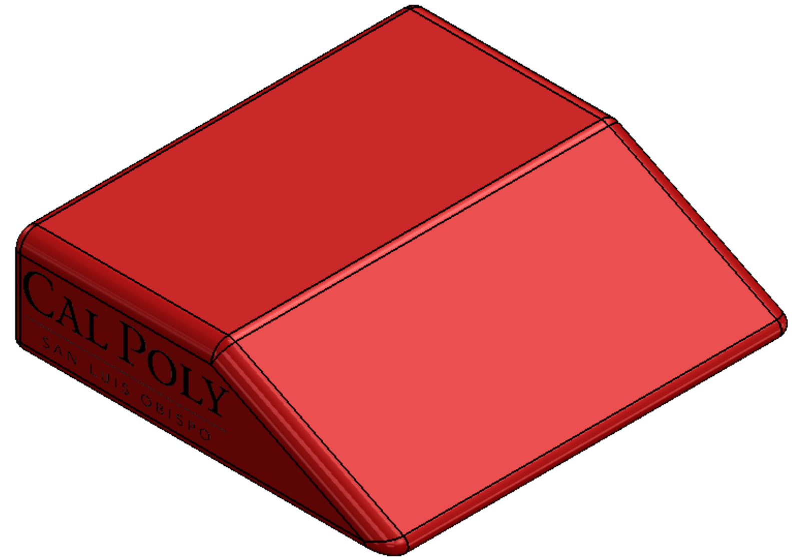
BOW

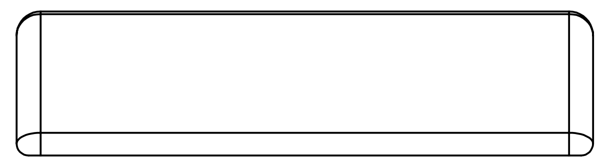
SIZE **A** DWG. NO. 12123 REV

SCALE: 1:12 WEIGHT: 3.87 LBS SHEET 1 OF 1

5 4 3 2 1







NOTE: ALL ROUNDS 0.25"
PART IS FIBERGLASSED AFTER SHAPING

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
ONE PLACE DECIMAL ±0.125
TWO PLACE DECIMAL ±0.01

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
POLYURETHANE FOAM

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

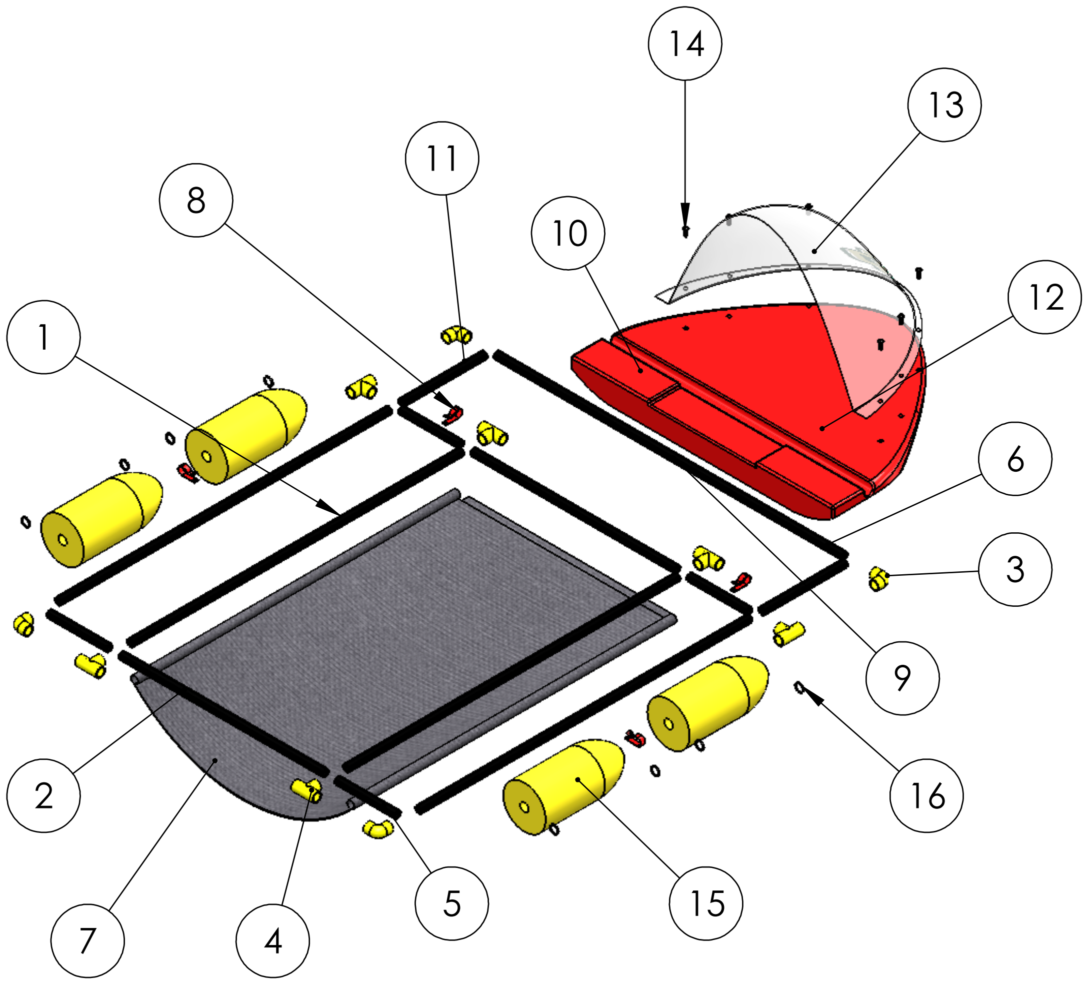
TITLE:

HEAD REST

SIZE	DWG. NO.	REV
A	12124	

SCALE: 1:4 | WEIGHT: 0.66 LBS | SHEET 1 OF 1

5 4 3 2 1



ITEM NO.	PART	QTY.
1	42" PVC PIPE	4
2	24" PVC PIPE	2
3	PVC ELBOW	4
4	PVC TEE	6
5	7" PVC PIPE	4
6	41" PVC PIPE	1
7	POLYESTER MESH	1
8	BUCKLE STRAP	4
9	SUPPORT PLATE	1
10	HEAD REST	1
11	9.75" PVC PIPE	2
12	BOW	1
13	SPLASHGUARD	1
14	1.4"-28x1/2" SCREW	7
15	PVC FOAM FLOAT	4
16	O-RING	8

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

DEVICE ASSEMBLY

SIZE A | DWG. NO. | REV

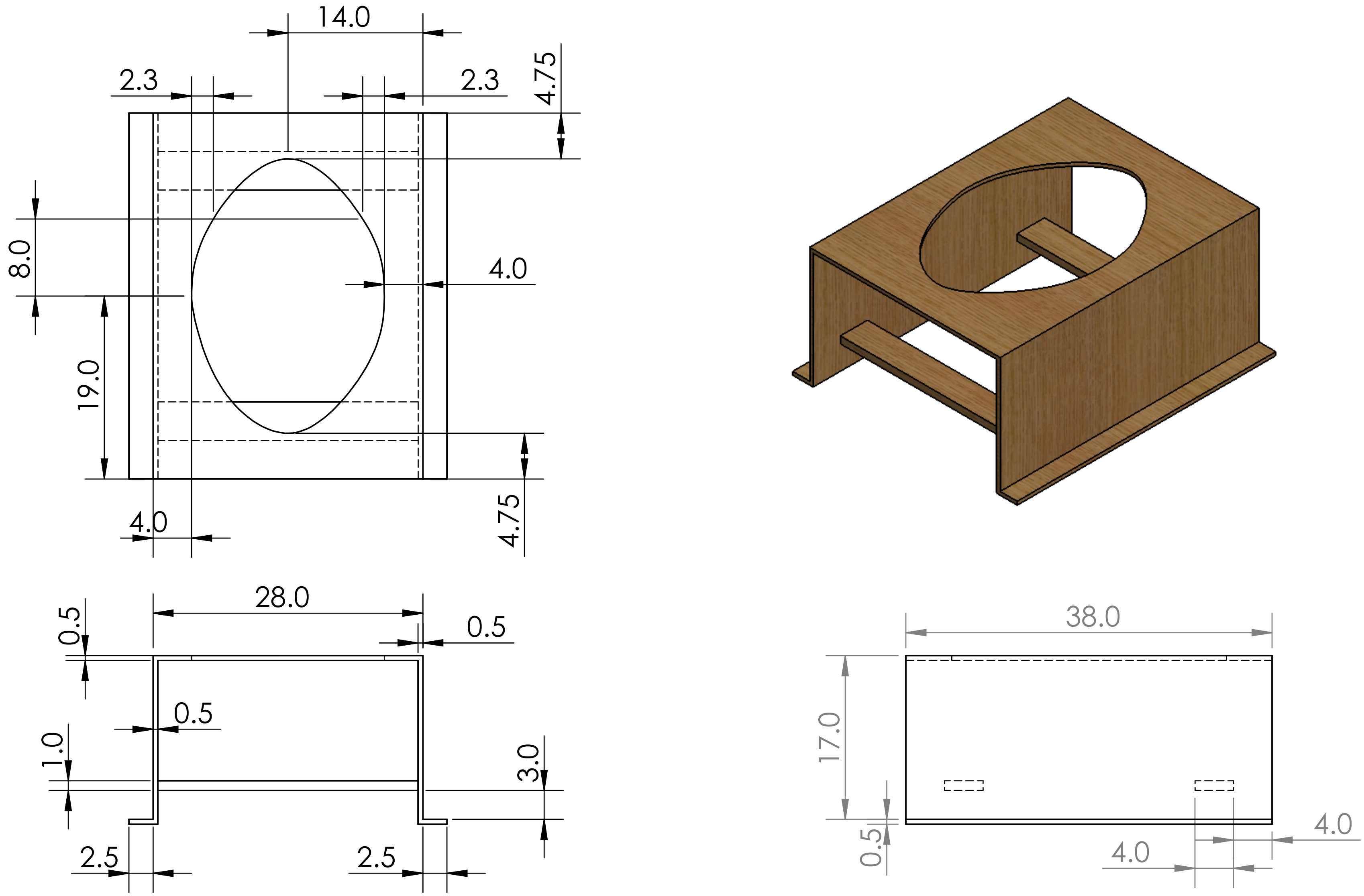
SCALE:1:16 | WEIGHT: 17.7LBS | SHEET 1 OF 1

NEXT ASSY | USED ON

APPLICATION

DO NOT SCALE DRAWING

5 4 3 2 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
ONE PLACE DECIMAL ±0.125
TWO PLACE DECIMAL ±0.01

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
WOOD

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

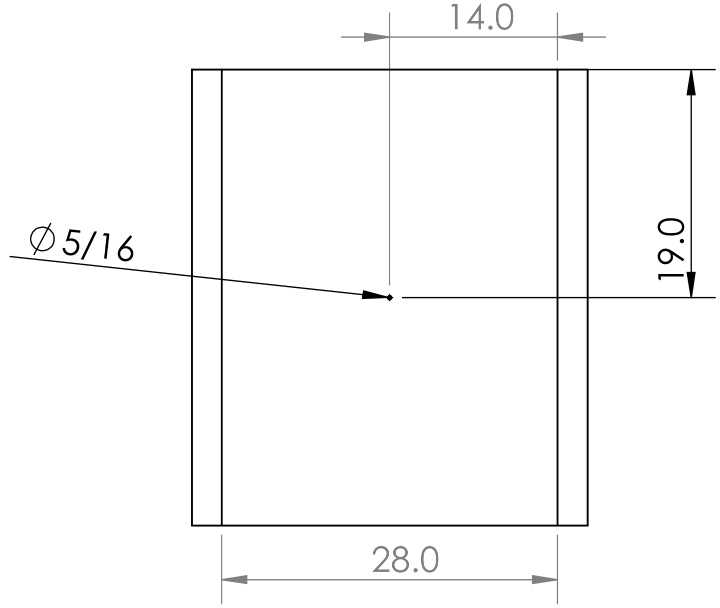
TITLE:

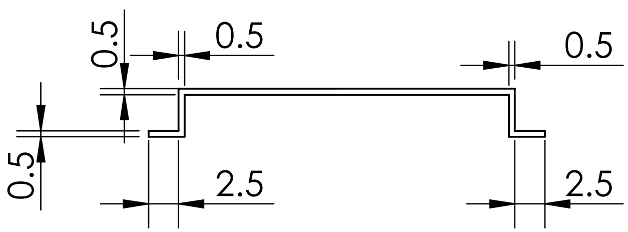
BOTTOM SHELL HALF

SIZE	DWG. NO.	REV
A	0582	

SCALE: 1:16 WEIGHT: SHEET 1 OF 1

5 4 3 2 1





NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
ONE PLACE DECIMAL ±0.125
TWO PLACE DECIMAL ±0.01

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
WOOD

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

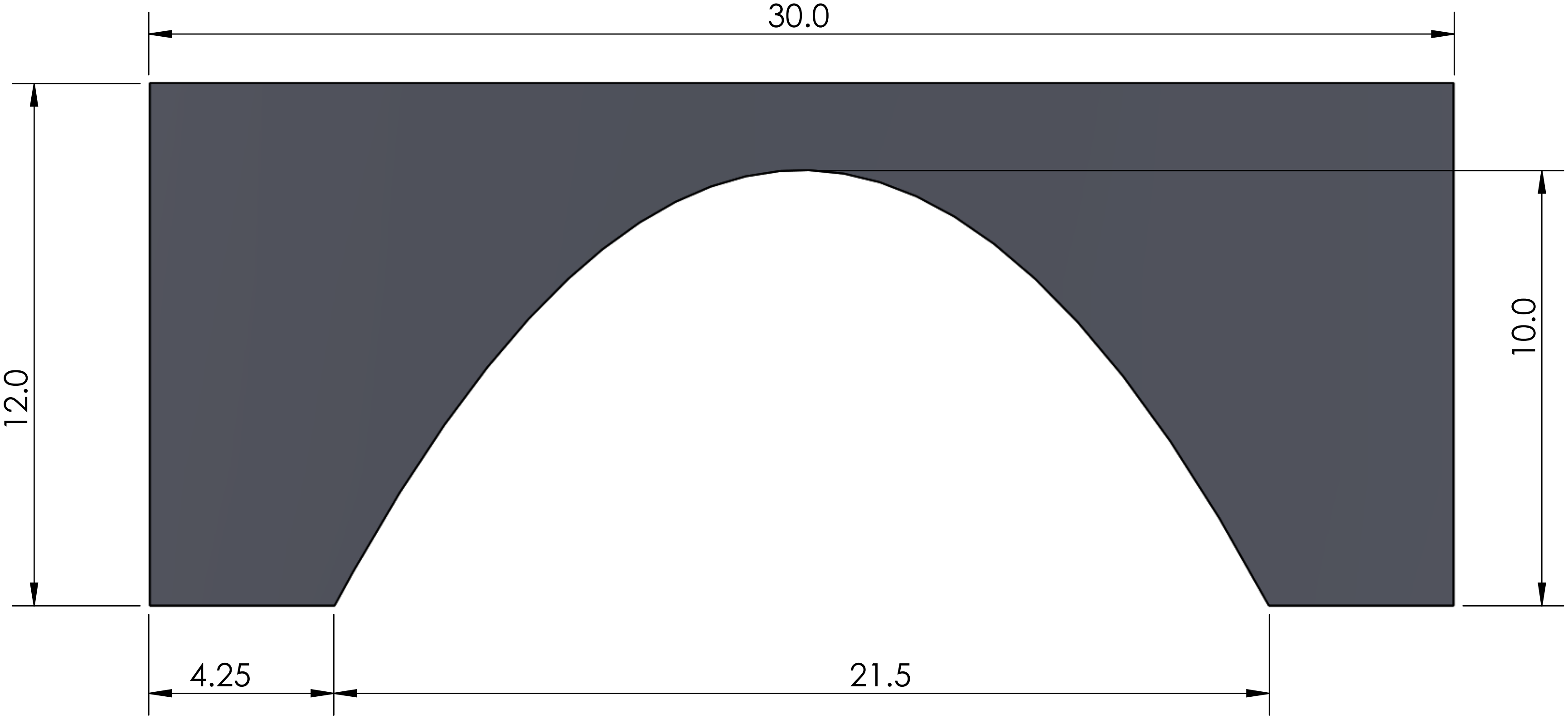
TITLE:

UPPER SHELL HALF

SIZE **A** DWG. NO. 0583 REV

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

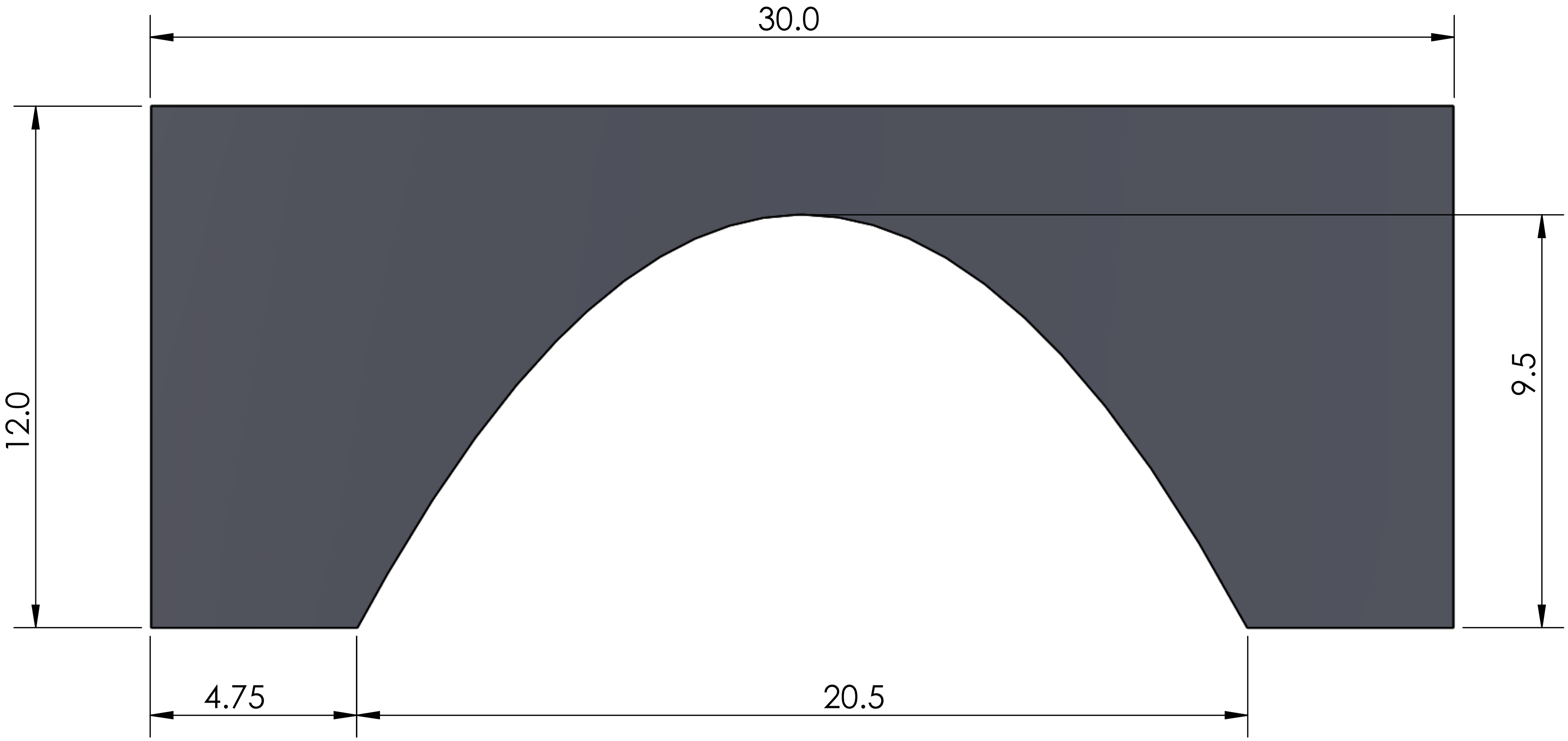
5 4 3 2 1



NOTE: TEMPLATE PLACED 2'' FROM FRONT FACE

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± ONE PLACE DECIMAL ±0.125 TWO PLACE DECIMAL ±0.05	DRAWN			
			CHECKED			TITLE:
			ENG APPR.			SPLASHGUARD TEMPLATE #1
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL CARDBOARD	COMMENTS:			SIZE A / DWG. NO. 151 / REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4 / WEIGHT: / SHEET 1 OF 1

5 4 3 2 1



NOTE: TEMPLATE PLACED 4" FROM FRONT FACE

UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± ONE PLACE DECIMAL ±0.125 TWO PLACE DECIMAL ±0.05	DRAWN			TITLE:	
	CHECKED			SPLASHGUARD TEMPLATE #2	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL CARDBOARD	COMMENTS:			SIZE A	DWG. NO. 152
FINISH				REV	
DO NOT SCALE DRAWING				SCALE: 1:4	WEIGHT:
				SHEET 1 OF 1	

NEXT ASSY	USED ON
APPLICATION	

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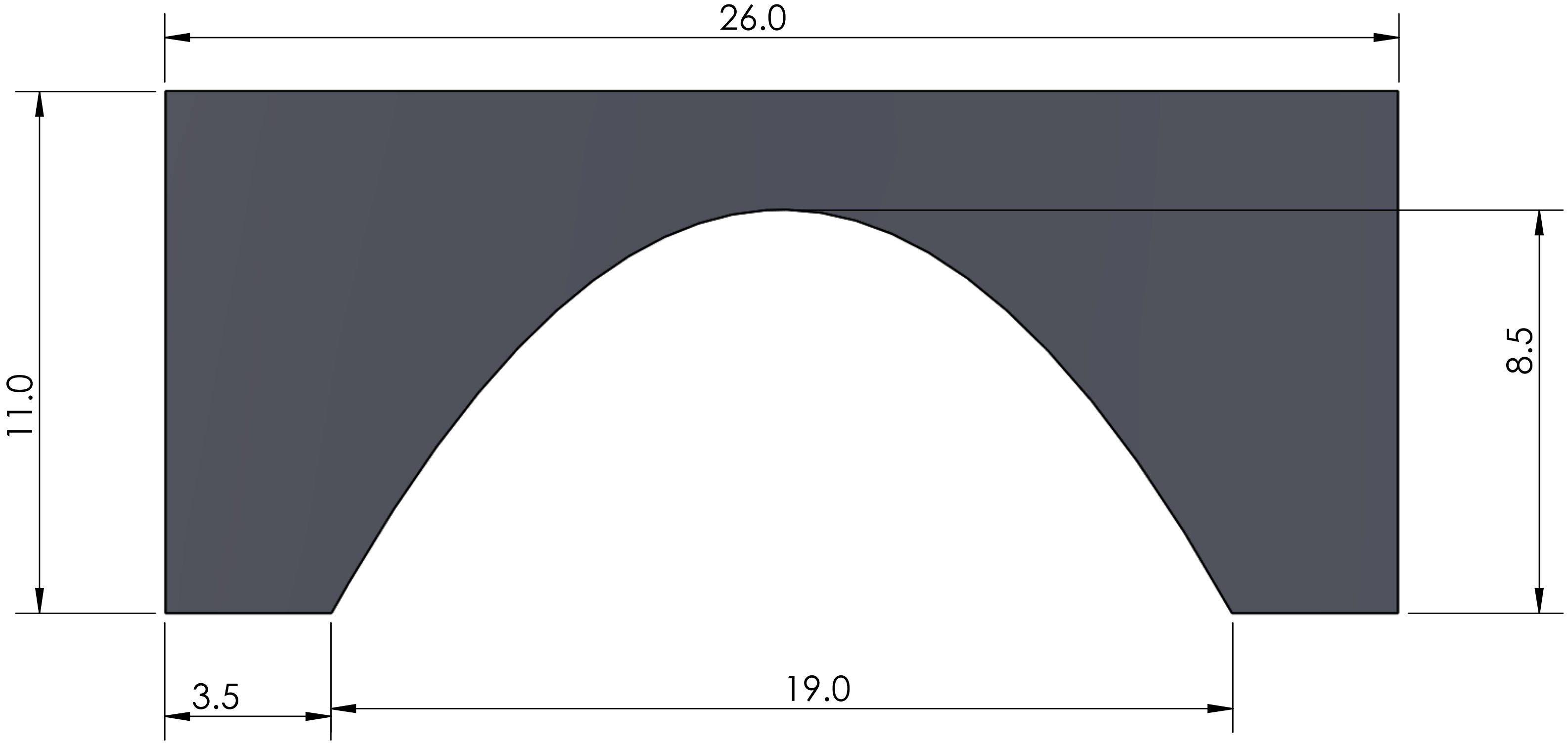
5 4 3 2 1



NOTE: TEMPLATE PLACED 6" FROM FRONT FACE

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
ONE PLACE DECIMAL ±0.125
TWO PLACE DECIMAL ±0.05

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL CARDBOARD

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY | USED ON

APPLICATION

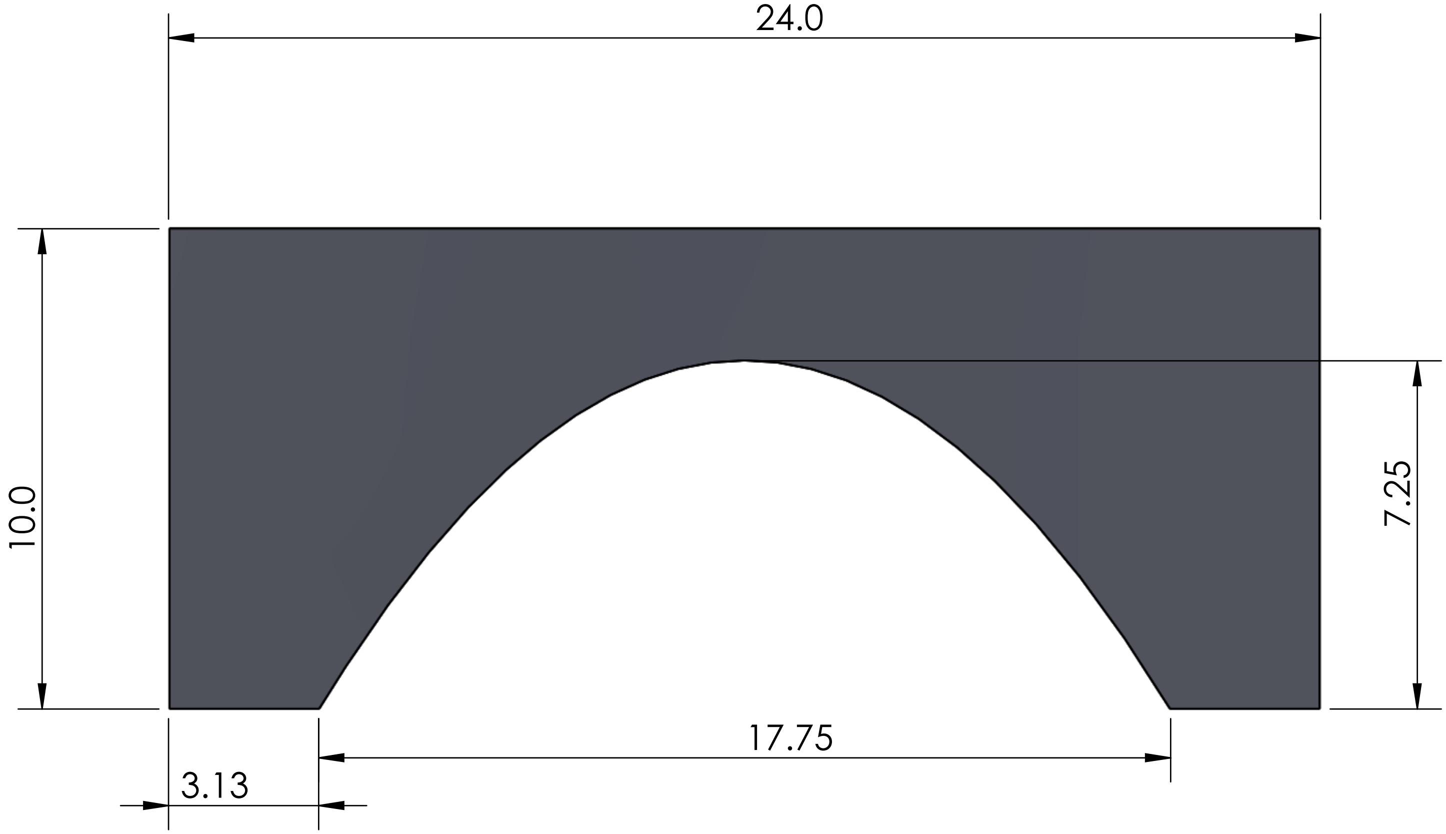
TITLE:

SPLASHGUARD TEMPLATE #3

SIZE A | DWG. NO. 153 | REV

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

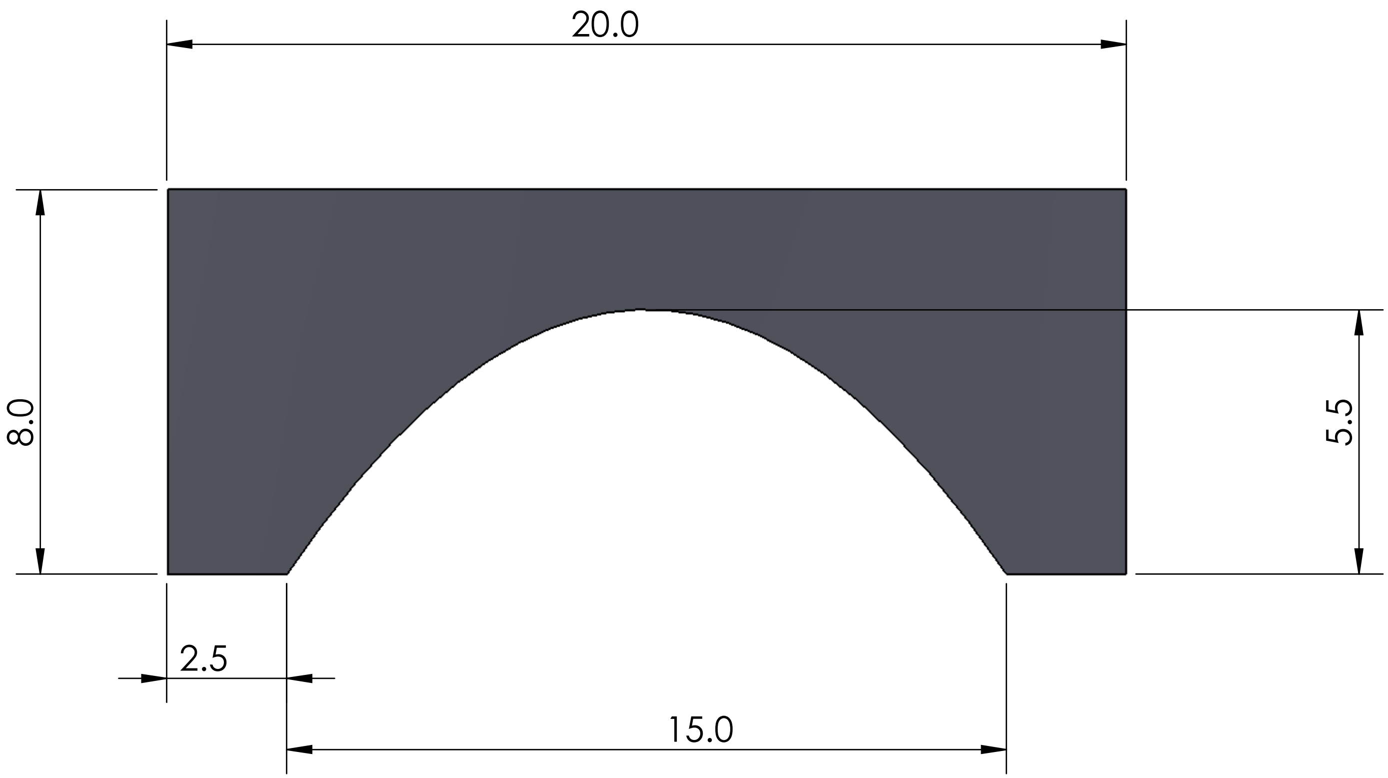
5 4 3 2 1



NOTE: TEMPLATE PLACED 8" FROM FRONT FACE

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± ONE PLACE DECIMAL ±0.125 TWO PLACE DECIMAL ±0.05	DRAWN			TITLE:
			CHECKED			SPLASHGUARD TEMPLATE #4
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL CARDBOARD	COMMENTS:			SIZE A DWG. NO. 154 REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



NOTE: PLACE TEMPLATE 10" FRONT FRONT FACE

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
ONE PLACE DECIMAL ±0.125
TWO PLACE DECIMAL ±0.05

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
CARDBOARD

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

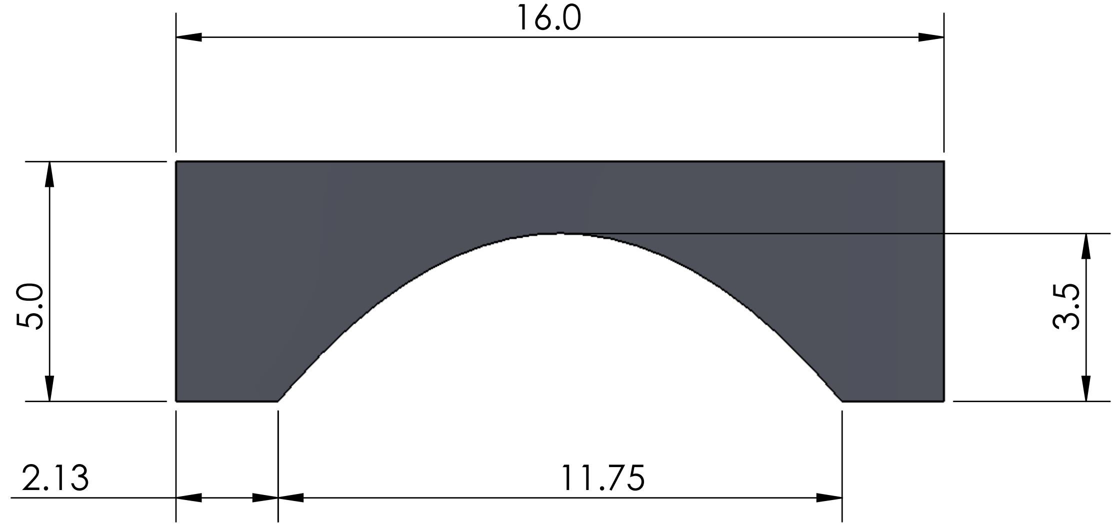
COMMENTS:

TITLE:
SPLASHGUARD TEMPLATE #5

SIZE	DWG. NO.	REV
A	155	

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



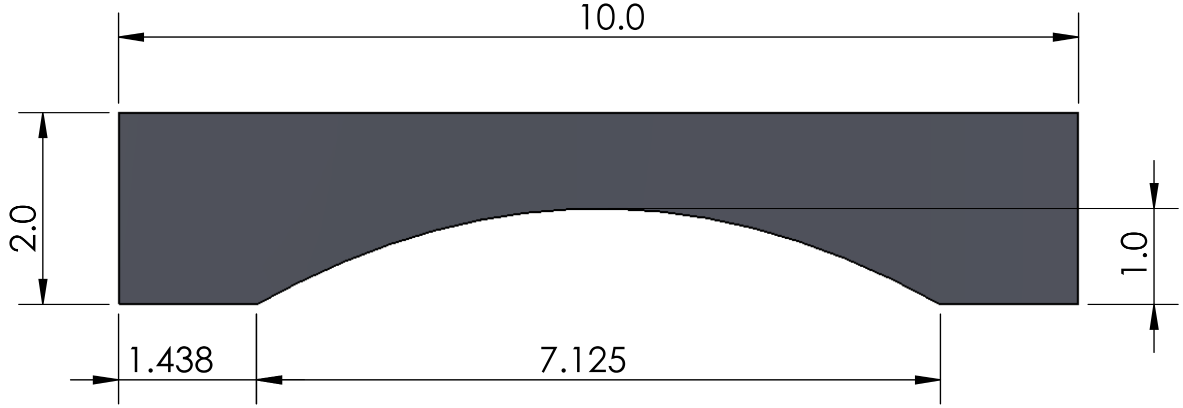
NOTE: TEMPLATE PLACED 12" FROM FRONT FACE

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± ONE PLACE DECIMAL ±0.125 TWO PLACE DECIMAL ±0.05	DRAWN			TITLE:
			CHECKED			SPLASHGUARD TEMPLATE #6
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL CARDBOARD	COMMENTS:			SIZE A · DWG. NO. 157 · REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4 · WEIGHT: · SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

5 4 3 2 1



NOTE: TEMPLATE PLACED 14'' FROM FRONT FACE

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± ONE PLACE DECIMAL ±.125 THREE PLACE DECIMAL ±0.05	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL CARDBOARD	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SPLASHGUARD TEMPLATE #7

SIZE	DWG. NO.	REV
A	157	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1