Adaptive Paddle Board: Final Design Review

PREPARED FOR THE CENTRAL CALIFORNIA ADAPTIVE SPORTS CENTER

Presented by:

The Adaptive Paddle Team
adaptivepaddle@gmail.com

Sean Yueh
syueh@calpoly.edu

Alexander Holthaus
aeholtha@calpoly.edu

Garrett Holmes
ggholmes@calpoly.edu

Garett Jones
gjones04@calpoly.edu

MECHANICAL ENGINEERING DEPARTMENT
CALIFORNIA POLYTECHNIC STATE UNIVERSITY
SAN LUIS OBISPO

FALL 2018 – SPRING 2019

Statement of Disclaimer

Abstract

This Final Design Review (FDR) document outlines the Adaptive Paddle Board senior project, done by four Mechanical Engineering Students at California Polytechnic State University and provides detail on the project and what the team has accomplished. The goal was to create a universally adaptive paddle board that can be used by the Central California Adaptive Sports Center for a wide range of persons with disabilities. This document highlights current research from patents and existing products, details regarding customer specifications, results from concept generation, the manufacturing and testing that went into the final design, and the process taken to get there. Testing has proven the final design to crucial specifications such as cost, reproducibility, and tipability.

Contents

List of Figures

List of Tables

1 Introduction

Our team of four mechanical engineering seniors, sponsored by Randy Coffman of the Central California Adaptive Sports Center, aims to develop an affordable adaptive paddle board for persons with mobility-affecting disabilities to overcome such obstacles. Mr. Coffman works with Adaptive Sports USA to help individuals with disabilities develop independence, confidence, and fitness through community sports such as paddle boarding. Current adaptive paddle boards on the market are prohibitively expensive and tend to focus on a single disability. Such products are ill suited for adaptive sports centers, which accommodate users with a wide range of mobility limitations. Our goal was to produce a paddle board that is not only affordable but can be easily configured for a wide variety of users. If possible, we wanted it to be reproducible by individual organizations with readily available consumer-grade tools and products, not limited to large-scale manufacturing firms. Our team has worked through June 2019 to produce a fully functional adaptive paddle board.

Our Final Design Review (FDR) contains updates regarding the developments that we have made following our Critical Design Review. The background highlights research on existing products, research articles, and patents we used to formulate ideas for possible designs. With those ideas, we narrowed down the engineering specifications to measurable parameters using the Quality Function Design process. In the concept design, we introduce the process that our team took to generate ideas and rank designs with Pugh matrices and a weighted decision matrix. Analyses and results from tests of our prototypes provide validation for our chosen design.

Our final design highlighted in this report is accompanied with the results of the manufacturing and testing that was completed, SolidWorks models, and safety considerations. A Gantt chart reveals our project timing and the individuals responsible for each task and deliverable. The project began in September of 2018 and was completed in June of 2019. This project is overseen by Sarah Harding, a professor in the Mechanical Engineering Department at Cal Poly.

2 Background

To prepare for the design process ahead our team has undertaken a background research regimen spanning several different areas pertinent to the project. We have directed our research to several different products currently on the market to help generate ideas for components of our paddle board.

2.1 Customer Needs

Early in the project, we met with Mr. Coffman and he informed us of the current alternatives to an adaptive paddle board used by the adaptive sports center at Shaver Lake. The sports center uses straps to keep the participants' wheelchairs down onto a standard paddle board. This method not only provides insecure attachment, but it also brings a risk for the user to fall over and possibly injure themselves. Since existing adaptive paddle boards an extremely expensive, costing over $5000, the adaptive sports centers around the US cannot afford them. Our mission is to modify a less expensive, high volume paddle board to accommodate a variety of mobility limiting conditions so that adaptive sports centers have an affordable method to get clients to enjoy the water atop a paddle board.

Based on Mr. Coffman's experiences with his users, he has developed a list of requirements for the paddle board as well as stretch goals, as presented in Table 2.1.

Table 2.1 Customer Requirements and Specifications

Customer Requirements	
Requirements	Loading mechanism from dock and shore Adjustable outriggers System for securing user's own wheelchair (fits a range of wheelchair sizes) Detachable seats Rub-point elimination to prevent friction burns Different configurations Support for two people
Stretch Goals	Swivel seat Lean-bar for kneeling users

2.2 Existing Designs

There is currently only one existing product on the market for adaptive paddle boards – the Onit Ability Board - which is priced at $5000. (Spinal, 2016) (Revolution) As shown in Figure 2.1 Onit Paddle Boards, the Onit board design has a lot of components similar to what the adaptive sports center is looking to use, including a loading ramp, and stabilizing outriggers. The cost of this board comes from the fact that it incorporates a specialized wheelchair, and ramp as well as a paddle board. These components are vital to the function of Onit's design, while we are attempting to allow users to paddle board from the comfort of their own daily use chair.

Figure 2.1 Onit Paddle Boards

Table 2.2. Onit Ability Board Specifications

Onit Ability Specifications	
Length	11'6
Weight Rating	320 lb.
Board Material	Fiberglass and bamboo
Outriggers	Carbon fiber
Ramp	9' Aluminum ramp

From research conducted on videos, pictures, and product descriptions provided on the Onit website, we were able to determine a few design components of their board, as presented in Table 2.2.. Onit uses a fiberglass, Expanded Polystyrene (EPS) foam, bamboo paddle board with carbon fiber outriggers, which can be attributed to the high price. According to their website, a combination of the EPS foam, fiberglass, and bamboo allows for a lightweight and strong board. Also, the stabilizing outriggers are removable, allowing users with different levels of experience to enjoy paddle boarding. Though Onit chose to have their outriggers made with carbon fiber, we determined that to be too costly. The board’s weight rating allows two persons to be on the board at once, which is a capability we want our board to have.

An “all-terrain surf chair”, which appears to be specific to that paddle board only, is provided with the board and there is no mention of alternate wheelchair compatibility. However, our goal is to design a paddle board that can accommodate a broad range of wheelchairs and other forms of seating such as a swivel seat or kneeling bar.

The Onit Ability Board also has an aluminum loading ramp that can be used from a dock or beach. As seen in Figure 2.1 Onit Paddle Boards, the ramp system allows the user to directly wheel the chair onto the board and into the channels where the wheels are locked down. Our goal is to build a similar ramp mechanism that attaches seamlessly to the paddle board from a beach or dock of any height, while providing quick and safe loading.

Being the only manufacturer of adaptive paddle boards currently on the market, Onit has a board that is not only costly but low in adaptability. Our group wants to develop a board that is affordable, has potential reproducibility, and can be easily used by all. Though, Onit has several components we can from which we can draw inspiration to help improve the design of our board.

Our research also discovered a company called Expandacraft which makes outrigger pontoon systems for small watercraft. These pontoons could be adapted well for use with a paddleboard. The pontoons are made of plastic and come in interlocking sections which can be broken apart and reattached for transport. The company also offers aluminum crossbeam for attaching the outriggers to the customer’s vessel, complete with bolts and pins. A disassembled kit can be seen in Figure 2.2

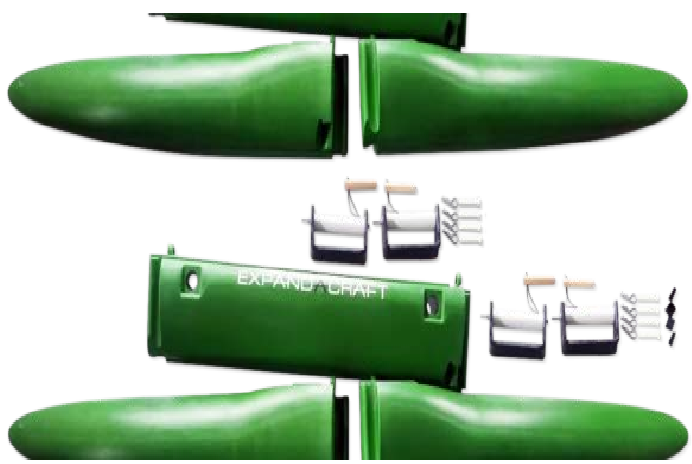


Figure 2.2 Expandacraft Outrigger Kit

An eight to twelve-foot-long outrigger kit, like what would be used for a paddleboard, can cost between $500 and $1000. With a kit costing almost as much as a standard paddleboard, this price could be prohibitively expensive for a person looking to manufacture their own adaptive paddleboard.

2.3 Patent Search

Our patent searches did not reveal any existing designs for an adaptive paddle board specific to our customer specifications. There are, however, several patent results related to individual components that may prove useful in the design of our paddle board.

2.3.1 Paddleboard with Removable Seat (US8752492B1)

This patent is for a twin hull paddle board with a detachable seat. Though our group is using an existing single-hull paddle board, the removable seat is related to a component we will be designing. Our paddle board needs a versatile mounting system that works for wheelchairs, stands, and any other components used to fix the user. Components 206 and 120 form a possible solution in creating a secure and quick mounting system as shown in Figure 2.3. (Harris, 2014)

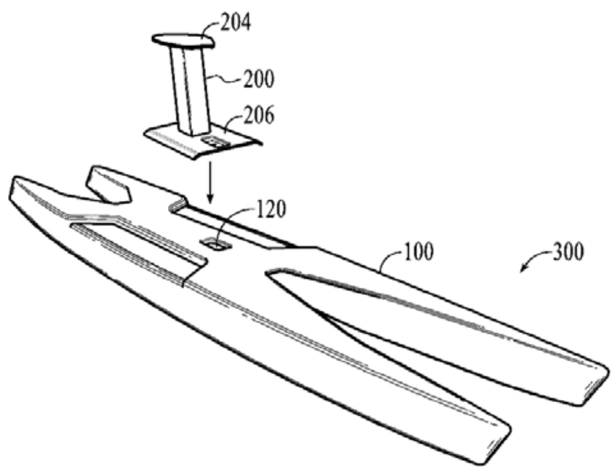


Figure 2.3 Removable Seat Paddle Board Drawing

2.3.2 Vertical Bicycle Storage Rack (US20130270201A1)

The vertical bicycle rack storage provides a solution to mounting and securing a wheelchair onto our paddleboard. Both existing products have the wheelchair mounted in the center, which creates a need for a support in the center of the underside of the chair. This may provide us with more versatility with the range of wheelchairs we can use. With the bicycle mount, we provide another alternative on how we can secure our wheelchair, as seen in Figure 2.4. (Vineyard, 2015)

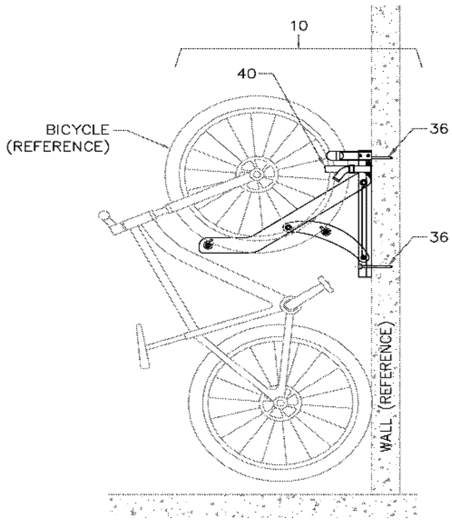


Figure 2.4 Vertical Bicycle Rack Sketch

2.3.3 Longitudinally Adjustable Mount for a Snowboard Binding (US20010038182A1)

The snowboard rail system is a great analog to look at for an adjustable rail mounting system used in recreational sports. This design is particularly relevant because it must maintain a water tight seal so that as snow melts on the board's surface, the core stays dry and does not become heavier, or sustain damage from rot. As shown in Figure 2.5**,** the mounting system relies on a set of teeth on the mounting rail as locations to lock into. (Carlson, 2004)

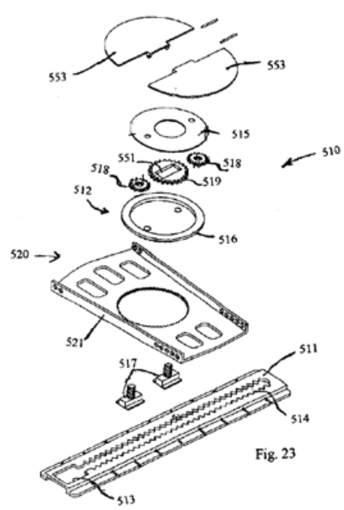


Figure 2.5 Longitudinally adjustable snowboard binding mounting system exploded view

2.3.4 Binding Mounting System for Recreational Board (US20050248129A1)

This is another patent used in mounting bindings onto a recreational board. This patent is more focused on how the rail system is mounted onto the board while maintaining the watertight seal, ensuring the durability of the system. Figure 2.5 is a cross section of the mounting device installed in a board. (Pelchat, 2007)

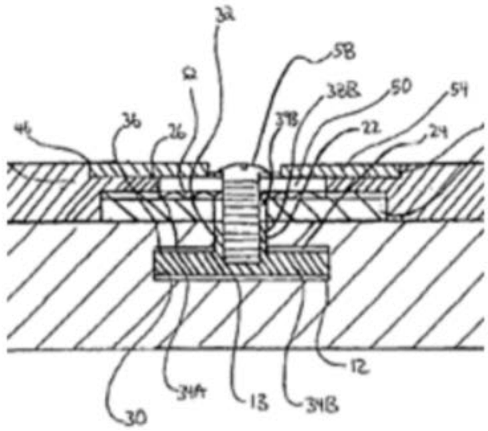


Figure 2.6 Cross section of a binding mounting system installed into a recreational board

2.3.5 Adjustable Scope Mounting System (US7543405B1)

The dovetail rail mounting system used to attach scopes to rifle barrels is also applicable to the design of a wheelchair attachment system for the adaptive paddle board. Figure 2-g shows an exploded view of how a dovetail attachment system is feasible for applications that need to be longitudinally adjustable. Additionally, the system shown here may be compatible with quick-release mechanisms to reduce setup and teardown time. The important component in Figure 2.7 is the angular rail capturing mechanism and the tightening system. (Ivey, 2009)

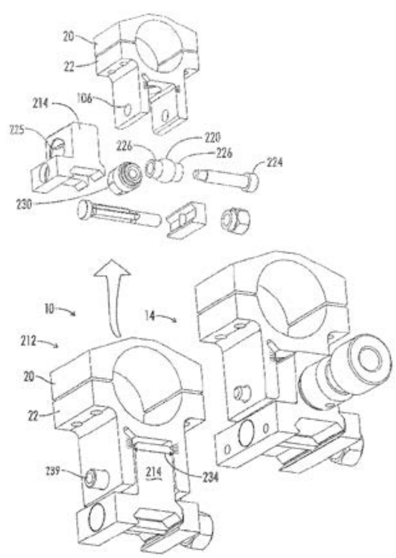


Figure 2.7 Dovetail rail mounting system for scopes on rifles

2.4 Technical Literature

The team conducted research of technical literature from various published research articles and websites that included information regarding wheelchair usage, manufacturing, and paddle board design and material. It is very important to have a broad perspective of wheelchairs and paddleboards in order to generate the best ideas.

2.4.1 Wheelchair Manufacturers' Reporting

Wheelchair manufacturers Karman and Quickie/Sunrise Medical both measure chairs by their seat width, measured from edge-to-edge on the seat padding between the frame supports. Karman reports that while sizes ranging from 8" to 28" are available, the standard adult sizes are 16" (small), 18" (medium), and 20" (large). Karman further reports that 90% of their users found a 20" seat acceptable (Karman Healthcare, Inc., 2017).

A spec sheet from Quickie/Sunrise Medical additionally introduced the aspect of wheel camber, or angle from vertical. Several of the lighter wheelchairs examined at from Quickie/Sunrise Medical had a slight pitch to the wheels of up to 6°. With 24" wheels this camber would widen the stance of the treads on the ground by 2.5" (1.25" per wheel) without affecting the axel width of the chair frame (Sunrise Medical Holdings, Inc., 2018).

2.4.2 Wheelchair Buyer's Guide

In their digital guide to choosing a wheelchair correctly sized to fit the customer and their environment, the medical equipment wholesaler ADT Medequip, Inc (DBA Preferred Health Choice) says the following:

> *…use these formulas to determine the* ***overall width of a wheelchair:***
> - *Transport Wheelchair: Seat Width + 3"*
> - *Standard Folding Wheelchair: Seat Width + 8"*
>
> (Preferred Health Choice, 2018)

The team compared this information to the actual measurements of a folding Sunrise Medical wheelchair donated by a local businessman to the Adaptive Paddle project. When fully extended, the test wheelchair had a seat width of 16" and an overall width of 24", matching the Preferred Health Choice formula. Note: that the overall width included the push rims, which protruded two inches past the actual treaded wheel. The overall tread width was only 20".

2.4.3 Medical Case Study

A Bond University case study published in 2017, found that the benefits of stand-up paddle boarding include weight loss and improvement of quality of life. The main purpose of our project is to create a paddle board that helps provide an opportunity to be active and help those with disabilities improve their quality of life. The case study provides insight on how much of an affect paddle boarding has on people by providing several statistics of body fat and psychological health of participants over a 52-week period. This study helps define and validate the premise of the project. (Schram, Hing, & Climstein, 2017)

2.4.4 Previous Senior Projects

A previous senior project, found on the Cal Poly Digital Commons, where all available previous senior projects completed at Cal Poly San Luis Obispo are recorded and displayed online, also worked on an adaptive paddle board for people who have limited mobility below the waist. Although they have a different design in which their person stays standing against a support, their project provides insight on how to cut into the board and attach components to it. The methods the group used to test their board

as well as additional design considerations can be applied to the new adaptive paddle board project. The team used this report as a set of guidelines and learned from their mistakes and experiences (Group 36, 2016). The report from the hydrofoil bike senior project also provided a lot of insight on how to manufacture pontoons. This team laid out the entire process they took from shaping the foam to curing the resin which is extremely similar to the process used in this project.

2.4.5 Surfboard Foam Discussion

The paddle board Mr. Coffman provided us is a Surftech Universal Fleet Coretech board with an expanded polystyrene (EPS) foam core and layers of polymer resin and fiber glass, as shown in Figure 2.8, obtained from the Surftech website.

Figure 2.8 Detailed Material Composition of the TekEfx Paddle Board

A combination of resin and Polystyrene decrease the weight of our paddle board while maintaining the structural strength necessary for use. One main concern of this board material the propensity of foams for absorbing water. Unless the board remains completely watertight at the end of this project the water absorption and retention of the core will drastically limit its useable lifespan. This issue requires deep research at later stages of the project to ensure we thoroughly seal the board after cutting through the outer layer to make our final modifications. (Surftech)

2.5 Disability Regulations

In its 1991 publication of the Title III regulation the American Disabilities Act (ADA) provides guidelines on typical wheelchair dimensions for a large adult male (Figure 2.9).

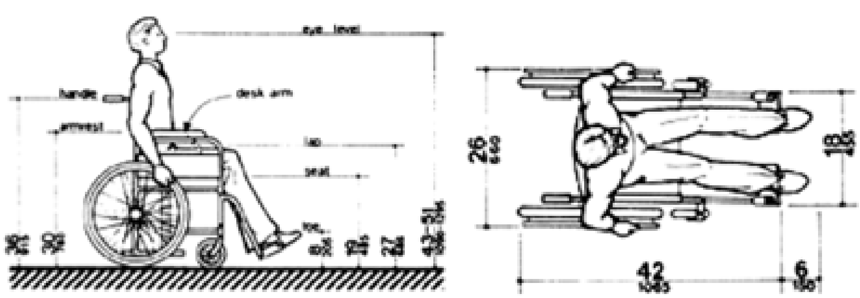


Figure 2.9 Typical Wheelchair Dimensions for Large Male, ADA Title III

While these guidelines are a bit dated, they show that the general sizing and proportions of wheelchair technology has remained relatively unchanged for the last three decades. The only notable change is that the average American width preference has gone up a size from 18” to 20” (Karman Healthcare, Inc., 2017) since the ADA research of the late 80’s and early 90’s. The final design should be able to accommodate wheelchairs for decades to come.

3 Objectives

3.1 Formal Problem Statement

Surprisingly, the adaptive paddle boards for individuals with limited mobility are prohibitively expensive. Therefore, adaptive sport centers need an affordable option for paddles boards that properly accommodate clients with various limited mobility conditions, but in particular attaches to wheelchairs. This solution is important to these centers because it offers an adventurous activity that provides a sense of achievement to the individuals.

3.2 Boundary Diagram

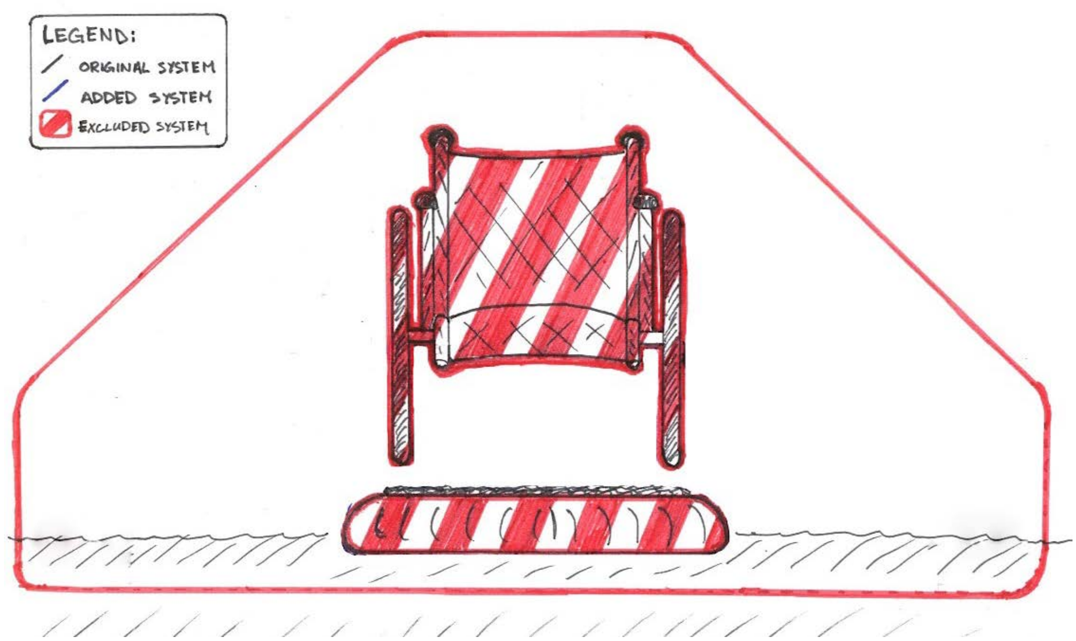


Figure 3.1 Boundary Diagram Sketch

The boundary diagram, shown in Figure 3.1, indicates retrofitting an existing board, not building a new one. Consequently, no part of the wheelchair or paddleboard is within the scope of the project. The primary goals of the project are to create an attachment point for a wheelchair and include removable outriggers that can be loaded and unloaded within a reasonable amount of time. In addition, if time permits, our stretch goal is to create a swivel seat that attaches to the board allowing users to lower their center of balance on the board while still maintaining a sturdy connection to the board. It is important that this chair is easy to get into and out of for amputees.

3.3 Scope

To clearly address our problem statement, and find viable solutions, our group analyzed the current products on the market, and rated their ability to meet the demands of the user and theorizes testing methods to quantify how well each criterion is met. This process is called Quality Function Deployment (QFD).

The first step of developing a QFD chart is to define the main users. In our case these are adaptive sports centers, along with amputees, paraplegics, and individuals with motor neuron damage. Each of these users has slightly different needs and wants, and to take this into consideration, the QFD ranks each desired function for each user, allowing for weighted analysis which gives more importance to the higher importance functions.

After defining the users and their desired attributes, the next step is market research into existing products and defining tests that quantify how well each desired function is achieved. These tests are given minimum acceptable “pass” criteria. Ideally each of the existing products would be tested, but due to time and money constraints, we decided to forego this step. However, each competing product was ranked on how well they meet the functions based on user reviews, and research into the products online.

The most current version of the QFD can be seen in Appendix A. Some areas are left blank because we have not yet built a product to compare with the existing market. However, the relative weights for desired functions can be seen. These values help determine and is used as a reference of our design direction.

Table 3.1. contains a list of measurable engineering specifications to ensure that we are meeting the requirements of our sponsor and ensuring that the paddle board will be fully functional. We have established specific standards to meet and methods with which we will measure them. In the risk column, we ranked each specification with a risk to determine how difficult it would be to meet the specification. Under the compliance column, we listed the methods with which we will ensure that our design meets each specification: Testing (T), Analysis (A), and Inspection (I).

Table 3.1. Engineering Specification Table

Spec.	Parameter Description	Requirement [Units]	Tolerance	Risk	Compliance
1	Tipability	200 lb/pontoon	Max	High	T, A
2	Production Cost	$1000	Max	Low	A
3	Time to Load	5 minutes	Max	Moderate	T
4	Weight of Equipment	75lb	Max	High	T
5	Outrigger Width (end to end)	10 ft	-1/+2	Moderate	A, I
6	Center of Gravity (longitudinally)	Unchanged	-/+ 7 in	Moderate	T, A
7	Secure wheelchair	250lb/strap	Max	Moderate	T

The torque test ensures that our wheelchair mount will be able to support any torque applied from the swaying motion of the user. It will be conducted by hanging fixed weights from the wheelchair with the board at different angles. Analysis will be done beforehand to calculate the weights to be used.

Production cost will be estimated during the design phase to ensure that we will not go over the budget. The $1000 is our maximum budget that we will use for the retrofit.

One of the main goals is to develop a system that allows for quick loading of the user and switching of components. Ideally, we want the entire process to be under five minutes and we will measure that through continuous testing and data recording.

Our supplied paddle board has a maximum weight it can support. In order to consider a range of weights for our users, we need to keep the weight of our equipment under 75lbs. To ensure that we meet these criteria, we will perform analysis with SolidWorks and make estimated weight calculations.

The tolerance column is a reference to what the acceptable range for the specified test result is. If noted with “Max” this refers to the degree with which we can measure and be certain of the result. For example, the cost can be derived from receipts, and labor calculations which will give an extremely accurate cost.

The risk column refers to the consequences of failing to meet the requirement. For obvious reasons, the torque test is high risk because if the board fails with a torque applied while in use, the wheelchair can become detached and sink into the body of water, essentially rendering our product useless. If the added equipment is too heavy, the board again will not float, and is therefore a high risk. Similar reasoning can be applied to the other tests to acquire the level of risk for each.

The reach of paddle strokes will affect how far our outriggers will be placed. Paddle strokes differ in length specific to the user, so we need to accommodate for a wider range, hence the adjustable length of rails for outriggers. We plan to design for roughly 7-10 feet of width for the stabilizers. The initial design will be easily modifiable in the event that our analysis does not match up with common body sizes during testing. A conceptual sketch can be seen in Figure 3.2 showing how the adjustable outriggers function. This adjustment allows for not only the user to utilize less stabilization to step closer removing them altogether, but to reduce water and air resistance on the paddleboard to travel faster on the surface of the water.

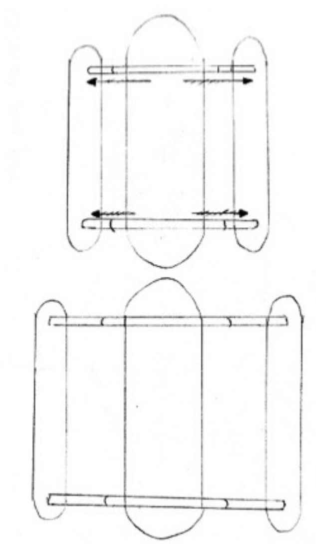


Figure 3.2 Telescoping outrigger diagram

The QFD in Appendix A is organized such that the needs and wants our project aims to satisfy are listed along with their relative importance to each end user. Additionally, the QFD shows testing methods for each criterion and how we define success.

4 Concept Design Development

Our team began with the base functions and customer requirements to eventually develop a chosen concept model for our paddle board. We ran several ideation sessions, took those ideas and evaluated them through Pugh matrices, developed a morphological table to combine top concepts, and ranked those top concepts to choose our final concept design.

4.1 Ideation Generation and Development Process

Our team initially held a series of four ideation sessions to brainstorm potential designs as a group, with one session led by each team member. We utilized a ‘brain-sketching’ technique in which the team members spend five minutes drawing up their initial ideas for a solution to the problem at hand. Once complete, the members each explain their ideas to the group. The process is then repeated as desired. The goal of these sessions is to generate a plethora of concepts, however absurd they are, not necessarily just good ideas. This broad approach helps stimulate new and innovative solutions which will be audited for feasibility at a later stage. The first session focused on the broad scope of the project and served as a jumping off point for potential designs. The second session concentrated on methods of latching to the wheelchair, while the third session looked at ways of embedding an anchor into the board. The fourth session focused on both the means of stabilizing the board in the water and loading the user and chair onto the board. After discussion with our sponsor led to a change in design direction, we later held a fifth ideation session. This last session was to brainstorm ways to attach the chair to the board without cutting into the board. At this point in time previous ideas that involved modifying the board itself were abandoned. We chose to focus on designs that involved no modifications to the board but would allow for parts above the surface of the board. Therefore, we conducted a new ideation brain sketching session on this topic. The main benefits of this new design direction were not having to cut into our existing board and the versatility of being able to attach the system to different boards. The new design direction had less risk of damaging the board and would offer a greater weight capacity for the board.

After ideation, we took the concepts we deemed most feasible and put them into Pugh matrices, found in Appendix B. These matrices rate the proposed designs as superior, inferior, or the same at fulfilling the customer requirements compared to the existing product in the market. The list of requirements was taken from the QFD. Our team made Pugh matrices for four design functions: attaching our anchor base to the board, attaching the chair to the base, stabilizing the board, and loading the wheelchair. From these Pugh matrices, we selected our top designs for each function, which would later be evaluated with a morphological table and a weighted decision matrix. The Pugh matrices compared our various ideas to the existing Onit Ability Board found on the market.

4.1.1 Attachment Frame

From our ideation on attaching the anchor base, we produced two designs that we considered practical. One was a harness system with a solid frame attached to it. The frame would likely be made of metal or

carbon fiber and used as the attachment point for the wheelchair. The other involved a pair of semicircular solid attachments, one on each side of the board, which would be connected by horizontal cross straps. The wheelchair would be anchored to the side attachments, which we referred to as side cups. The side cups would likely be made of plastic or PVC pipe and potentially lined inside with a soft foam material. These two harness systems are pictured in Figure 4.1 Frame with harness and Figure 4.2.

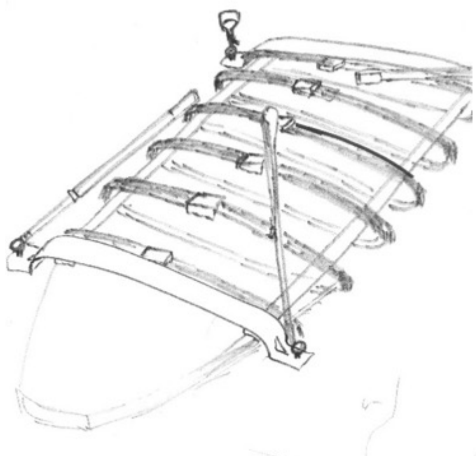


Figure 4.1 Frame with harness

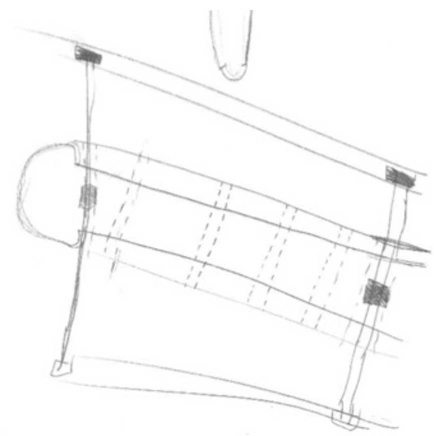


Figure 4.2 Side cups with harness

4.1.2 Anchor Straps

The Pugh matrices for wheelchair attachment led us to move forward with one concept of using a clamp that would go over the rim of the wheel and lock it in place. Another idea to progress with was to use ratchet straps that would hook onto the frame of the chair and anchor it in place. There would be four straps attaching to four points around the chair, as shown in Figure 4.3 . The third idea continued to consider was a similar concept the second system chosen but used Velcro straps instead of ratchet straps. These Velcro straps are seen in 4.4. We eliminated the idea of using a bungee cord system with a rubber torsion rod because we felt it would be more difficult to manufacture. We also eliminated the idea of attaching the chair from a single point under the chair as we felt this would limit our ability to change chair position on the board.

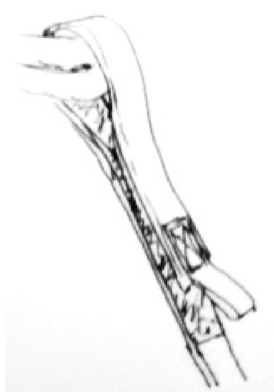


Figure 4.3 Velcro strap

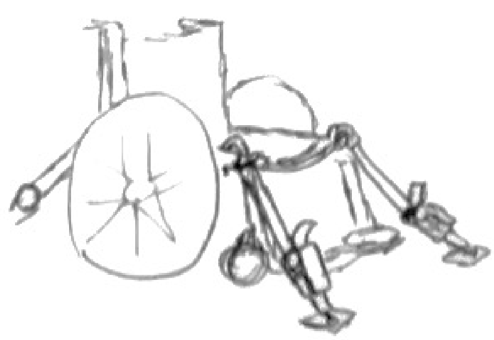


Figure 4.4 Four-point strap attachment

4.1.3 Stabilizing Outriggers

The matrices on stabilization led us to view outriggers as a strong design, which are pictured in Figure 4.5 Outrigger. They would consist of pontoons attached to outrigger poles which would be extendable and removable. We also chose to move forward with the idea of pontoons attached directly to the side of the board with Velcro and canvas, which we called side riggers. The side riggers can be seen in Figure 4.6. The last concept considered was using deep fins underneath the board to provide stability in the water, but this idea scored much lower due to concerns about the ability to launch from a beach.

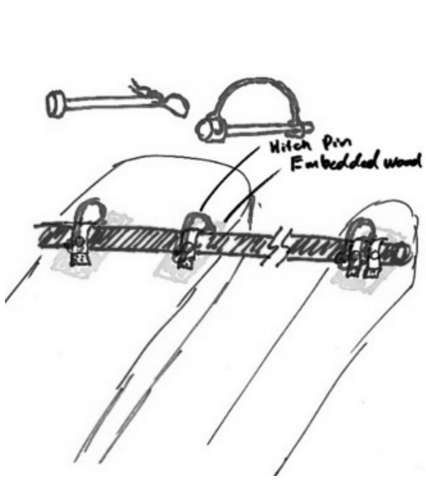


Figure 4.5 Outrigger

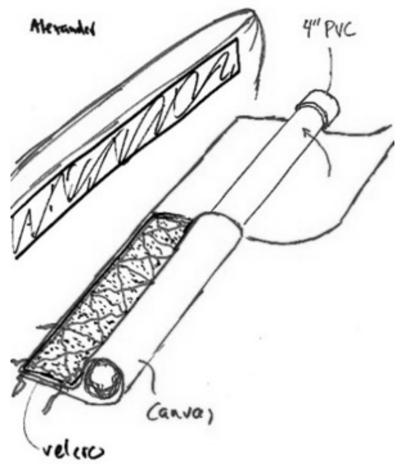


Figure 4.6 Siderigger pontoon

4.1.4 Loading Ramp

The fourth of the Pugh matrices was for the loading mechanism. One idea that scored well was a ramp with two parallel sections, one for each wheel, with hinges at two points to allow flexibility, and hooks at the end to attach to the frame. Another strong concept was again, a two-section ramp with hinges. However, this concept used a pair of arms on either side of the board and a center peg which would slot into the notch in the center of the board to hold it in place. This peg and arm design, or 3-point ramp is illustrated in Figure 4.7 Peg and arm ramp. The third design with which we would proceed was a simpler ramp that would be one section as wide as the board and easier to make.

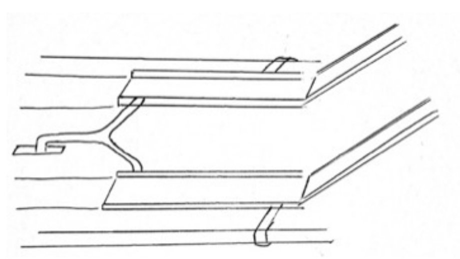


Figure 4.7 Peg and arm ramp

4.2 Design Selection Process

After comparing the proposed design solutions for each component of the adaptive paddle board to the existing solution in the market, a morphological table was generated to combine component designs

into several overall designs, as shown in Table 4.1. In order to evaluate these designs to choose the best solution, a weighted decision matrix was used to compare the overall design outputs from the weighted decision matrix. The results of the weighted decision matrix, which can be found in Appendix B, are numerical values that represent the performance of the proposed solution based on various customer needs and their relative importance.

The morphological table included component ideas formulated in the ideation sessions that were found to be favorable to the Onit paddle board, or at least comparable. Table 4.1. shows the morphological table that produced two overall designs designated Concept 1 and Concept 2. These concepts were then put into a weighted design matrix.

Table 4.1. Morphological Table

Subsystem	Concept 1	Concept 2
Attachment Frame	Frame	Side Cups
Anchor Straps	Velcro	Ratchet
Loading Ramp	Full Width Ramp	
Stabilizing Outriggers	Outrigger	

This weighted decision matrix uses each customer requirement and assigns a weight 1-5 depending on how vital the requirement is to the function of the adaptive paddle board. For example, having a positive buoyancy is weighted a 5 because it is the primary function of a paddle board; to support a person above water to enable them to paddle around. On the other hand, ease of dock loading was weighted a 2 because our primary customers will load from the shore. After weighting each requirement, a score 1-5 was given to each overall concept based on how well the design would meet the customer need or design requirement. The final result of the weighted decision matrix was that Concept 1 met the requirements better than Concept 2, and therefore the chosen design to move forward with is an Aluminum Frame that attaches to the wheelchair with Velcro straps, and utilizes outriggers for stabilization. The chair will be loaded with a full width ramp that sits on top of the frame.

4.3 Selected Concept Design

Many deciding factors went into selecting our concept design in order to meet our customer specifications. Figure 4.8 shows a model of what we expect our overall system will look like and where each subsystem will be located. There are still details regarding specific dimensions and materials that have not yet been decided, which further analysis and prototype testing will allow us to determine.

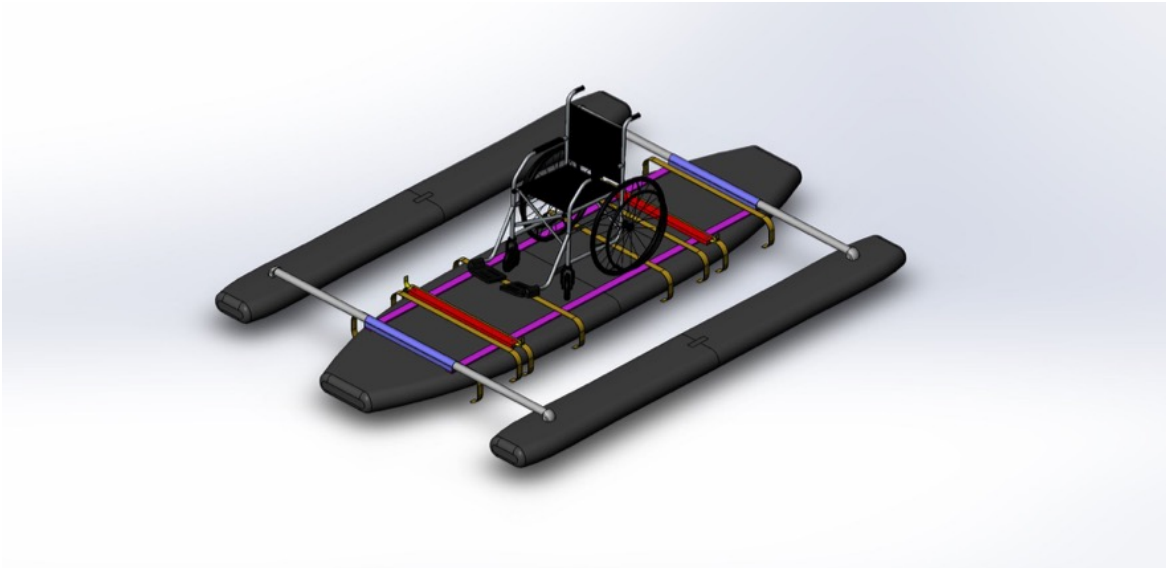


Figure 4.8 Complete Paddleboard Assembly

4.3.1 Attachment Frame

The attachment frame, which will serve as an attachment to the board, will be constructed out of three main components: a longitudinal rail, a transverse box beam, and an outrigger strut housing. A full assembly of the subsystem is shown in Figure 4.9. The longitudinal rails will run 8' down the length of the board, the transverse box beam will be 32'', and the outrigger strut housings will be 20''. The purpose of the transverse box beam is to provide a strap attachment point as well as another element of rigidity to the frame. The outrigger strut housings will have a top end of a box beam cut out with a round tubing sitting into it, welded on three contact points. The struts will provide a tube for the outriggers poles to fix into and prevent significant sliding or deflection.

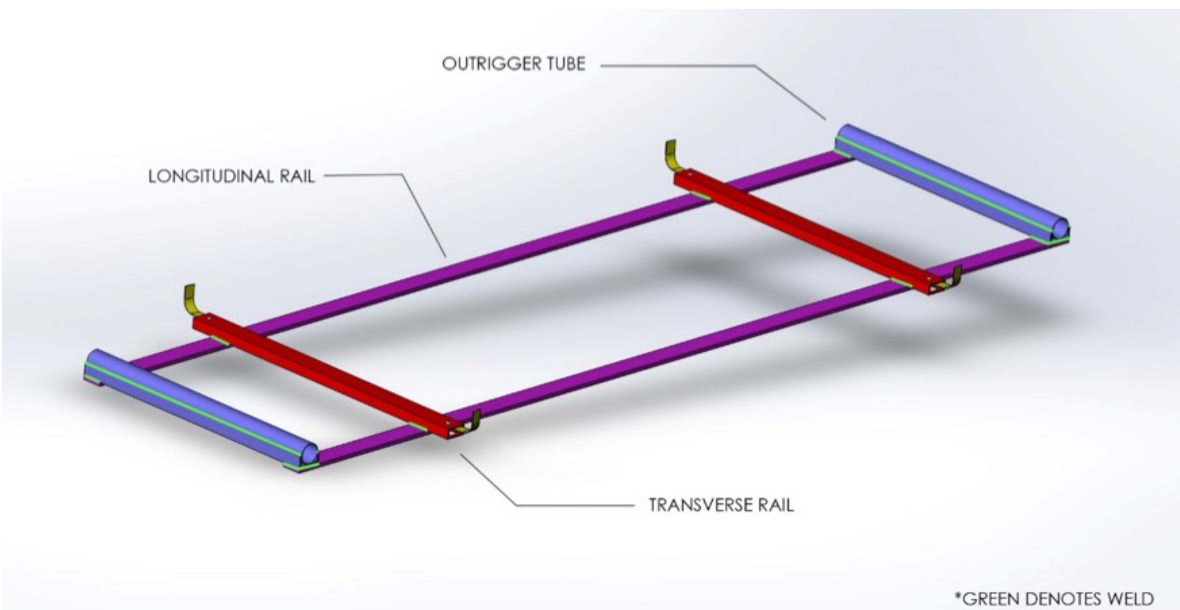


Figure 4.9 Anchor Base Subsystem

One of our concerns is the strength of the weld between each component. Though a quality weld should be more than enough to support any load that the frame will be seeing, we will be conducting precautionary measure to ensure that the weld does not fail. In the later stages of our project when we will be manufacturing our frame, we will conduct a test to see what load our weld will fail at.

4.3.2 Anchor Straps

The anchor strap system sits on the end of the transverse box beam and connects to points along the frame of the user's wheelchair. The function of the chair attachment system is to keep the wheelchair firmly secured to the board, even in the presence of loads due to tipping. The configuration of securing the strap to the frame is shown in Figure 4.10.

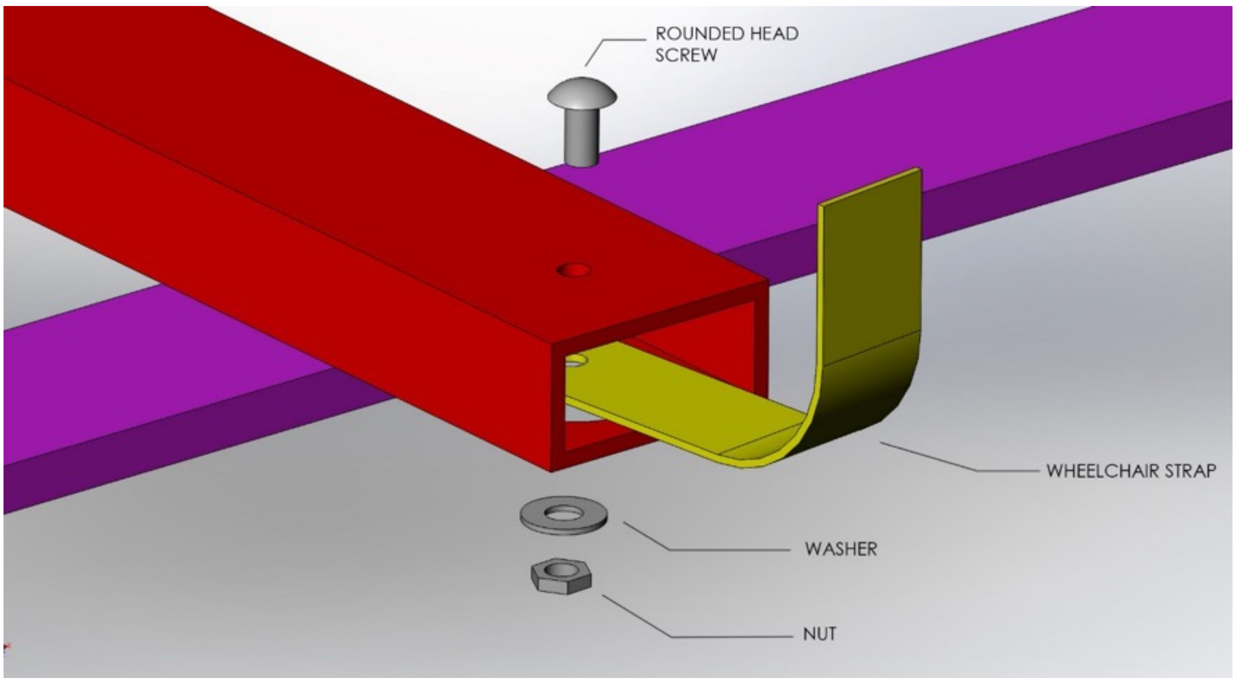


Figure 4.10 Strap Connection Configuration

The strap will sit on the underside of the inside of the transverse box beam and will be secured using a combination of nuts, bolts, and washers. The purpose of the washer will be to distribute the load from the nut and bolt over a wider area of the strap to prevent quicker strap wear and guarantee a more secure connection.

On the wheelchair side of the connection, we plan to use Velcro straps to attach to the frame of the wheelchair. Compared to ratchet straps, we felt that the Velcro straps would provide more flexibility in terms of where it can attach.

One potential problem we see arising is the failure of the strap. We plan to perform calculations to estimate the load that the strap will be seeing and load testing a sample model strap configuration to see when and where the strap will fail.

4.3.3 Stabilizing Outriggers

The main source of stabilization on our paddleboard will be from outriggers. Our sponsor requested an outrigger system that would be adjustable in length and detachable from the paddleboard. Figure 4.11 shows how our pontoons will connect to long poles which will run through the outrigger strut housing.

For the pontoons, we are planning to purchase a set of outriggers online from a manufacturer. We are still unsure as to what exactly we will be purchasing, as more research is still required. Based on a rough search, we have determined many of the outriggers to be either expensive or not within dimensions to fit our design.

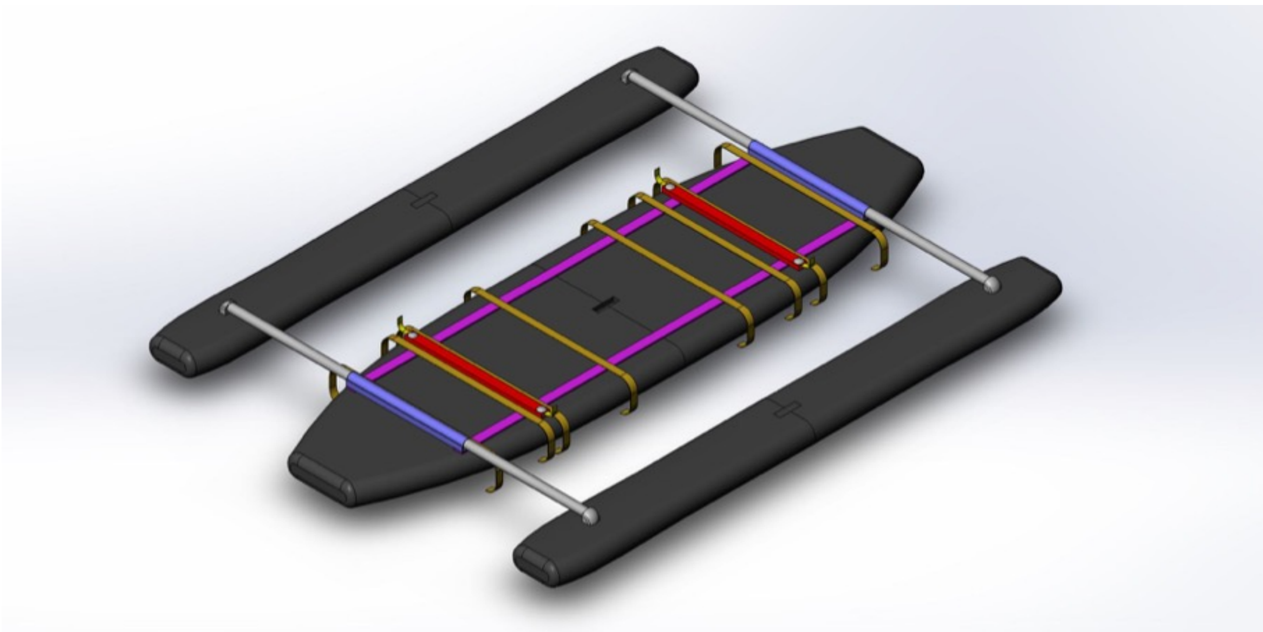


Figure 4.11 Outrigger Subsystem

Calculations are also still needed for the buoyancy force that will be required from each of the outriggers in order to support any amount of tipping. We anticipate running into more issues with our design when we select exactly what outriggers we will be purchasing to use.

4.3.4 Loading Ramp

Our loading mechanism is designed to allow quick transporting of the user onto the board from both a desk and shore. It is shown in Figure 4.12 that the ramp sits above the frame where the outrigger struts are. The paddleboard side of the ramp will remain fixed while the other side is free to rotate.

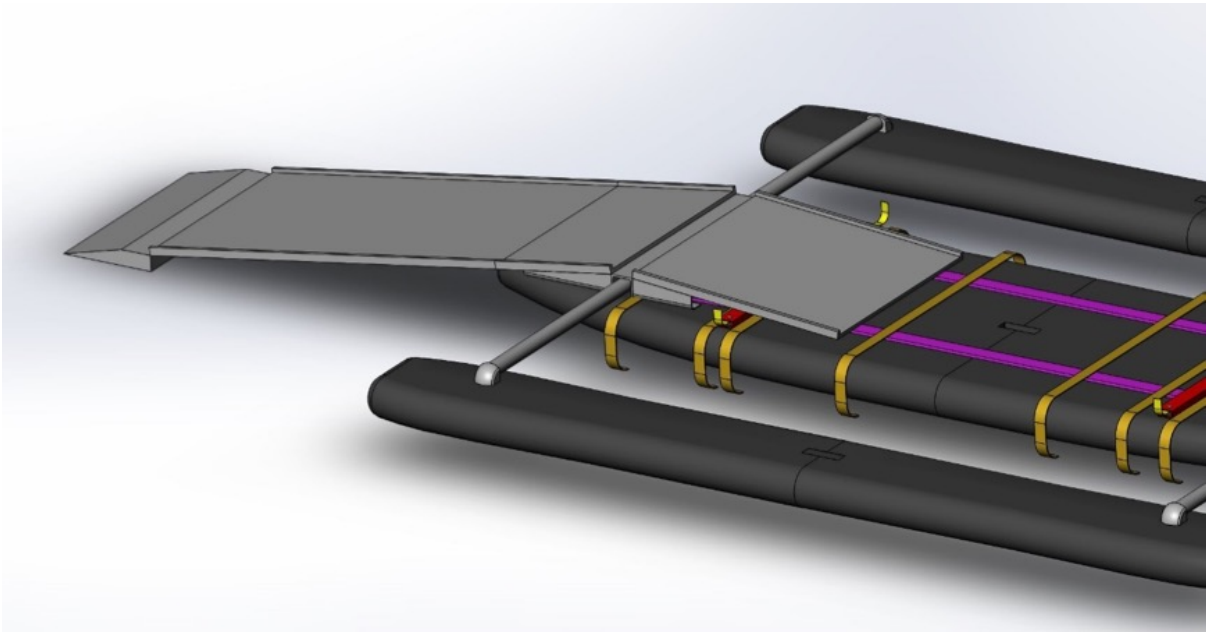


Figure 4.12 Loading Mechanism Subsystem

We plan on constructing the loading mechanism with sheet metal, as that would provide the greatest amount of support against loading from the user. The portion that rests near the outrigger strut and raises the ramp will be made from angled pieces of metal. The ramps will be connected with several hinges which will allow free rotation. The top surfaces will also be coated in a layer of truck bedliner to provide grip and additional corrosion resistance to the ramp.

One large concern for this ramp is the weight of the design. With the entire ramp constructed from metal, there will be no doubt that it will be heavy. This could potentially make it difficult for the people helping load the user to set up the ramp quickly. Further calculations and tests will be necessary to determine how much material can be removed to reduce weight while maintaining the same strength.

4.4 Preliminary Analyses

One of the concerning critical failure locations is at the junction of the transverse and longitudinal beams, as shown in Figure 4.13. This joint is where the full load of the user will be transferred from the anchor straps into the frame in the event of a roll over or tipping situation.

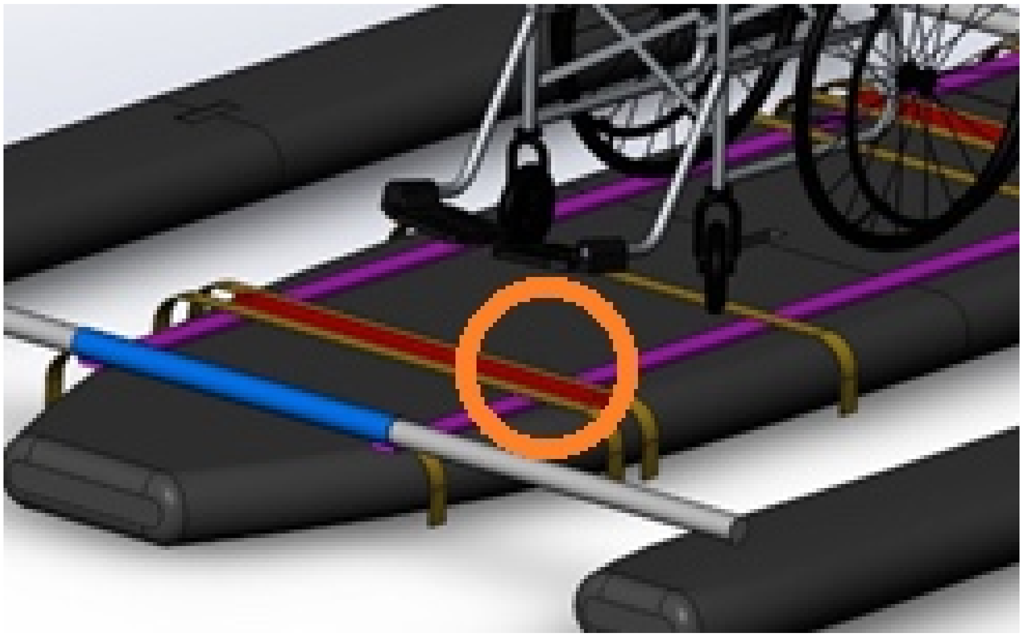


Figure 4.13 Transverse beam critical failure location (in orange)

An initial structural stress calculation for a worst-case bending scenario (found in Appendix C) indicates that a $15 2"x1" aluminum box beam would require over 1200 lbs. of force from the user to compromise its integrity. This analysis reassures us that we can build a suitable robust frame of this design at a reasonable cost.

4.5 Risks and Challenges

Our Design Hazard Checklist (found in Appendix D) shows that our design has very few safety concerns. The main potential hazard is that parts of the design could pinch or chafe against the user. The straps attaching to the chair are the chief concern. To avoid any risk of pinching we will make sure that all the strap attachments are secured well away from the user, preferably on the underside of the chair. The risk of chafing against their seat can be kept relatively low because our design will keep the user in their own personal wheelchair, which should be well suited to their comfort. By not transferring the user between chairs we can minimize the risk of chafing due to a poor chair fit. We are also concerned about the danger of hard attachments to the board that could cause injury to the user. If the user did fall from their chair, we would not want them to hit their head or any other body part against the hard frame on top of the board. We intend to cover the hard parts of the frame with a foam mat in order to alleviate this concern. Drowning is a natural concern with any aquatic activity, but the risk is low for in our case. The occupant will be wearing a life vest and will in no way be strapped into the chair or otherwise constrained. Using our design is not significantly more dangerous than an able-bodied person using a standard paddleboard.

A concern that we had about unknowns for our design is that we do not have experience working with the foam core and other materials the board is made from. We would have needed more experience before actually attempting to modify the board our sponsor has provided us as it is quite valuable, and we could not afford mistakes. We also would have needed to learn more about exact methods of sealing any incision we made into the board so as to keep it waterproof. These concerns about cutting into the

board are a major reason why we elected to go with a harness system that does not cut into the board. A harness system eliminates a major challenge that could have caused our design to fail. That being said, we must still take great care that any bolts or other parts of the frame do not damage our board accidentally. If the frame scratches or cracks the board surface the issue of waterproofing will become a problem once again.

We are also concerned about the potential issues of rust or corrosion. The board will experience frequent contact with water during its normal usage, and so all components must be able to withstand submersion in water without being compromised. The materials for parts must be carefully selected so that they will not be heavily damaged by rust or corrosion from exposure to water. If parts rust or corrode they could fail during use and potentially lead to harm to the user.

Our team also must determine how the outriggers for our board will be manufactured. There are options available to purchase but they tend to be expensive. If we decide the market options are not worth the money, we will need to build our own outriggers. We will have more clarity on this issue after discussing it with our sponsor. Our sponsor can decide if they are willing to budget for high quality, professionally manufactured outrigger pontoons or not. If we must build our own, we need to do more research on how to do so. Research topics for this would include materials selection, potential adhesives, and methods of waterproofing.

5 Final Design

This section includes detailed design descriptions of the attachment frame, anchor straps, outrigger stabilization, and ramp loading subsystems updated from the Critical Design Review (CDR). Detailed parts, Bill of Materials (BOM), dimensioned drawings, and costs are included.

5.1 Final Design: Subsystems and Components

From the CDR, modifications and improvements were made with regards to safety, weight, and manufacturability. While the frame remained unchanged, the ramp and stabilizing outriggers underwent considerable redesigns. Our final design allows any user to easily load themselves onto the board and stay securely attached and balanced while performing an activity. An exploded view highlighting each subsystem along with the fully assembled system is shown in Figure 5.1. Detailed parts, Bill of Materials, and dimensioned drawings can be found in Appendix E.

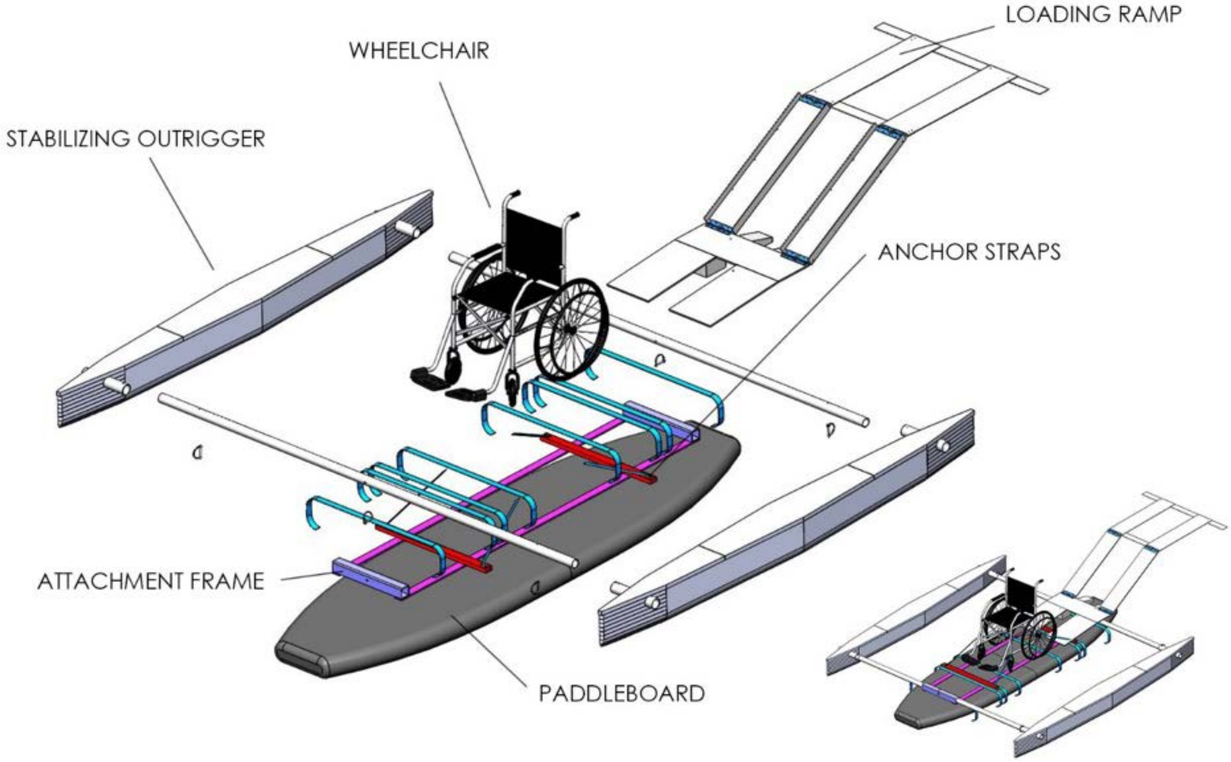


Figure 5.1 Exploded view of overall design assembly

The material of the loading ramp, which was initially metal sheets, was replaced with High Density Polyethylene (HDPE) sheets. The middle section was also shortened as our ramp test (Appendix H) revealed that there was too much deflection. The pontoons are now manufactured by our team, as there were not any products on the market that met our specifications. Lastly, D-ring pins were chosen as a quick way to secure the stabilizing outrigger system.

5.1.1 Attachment Frame

Sitting above our paddleboard is the attachment frame, which serves as a method to secure the user's wheelchair and outriggers onto the paddleboard. Much of the design has remained the same, consisting of three components as shown in Figure 5.2: the longitudinal rail, transverse box beam, and outrigger strut housing.

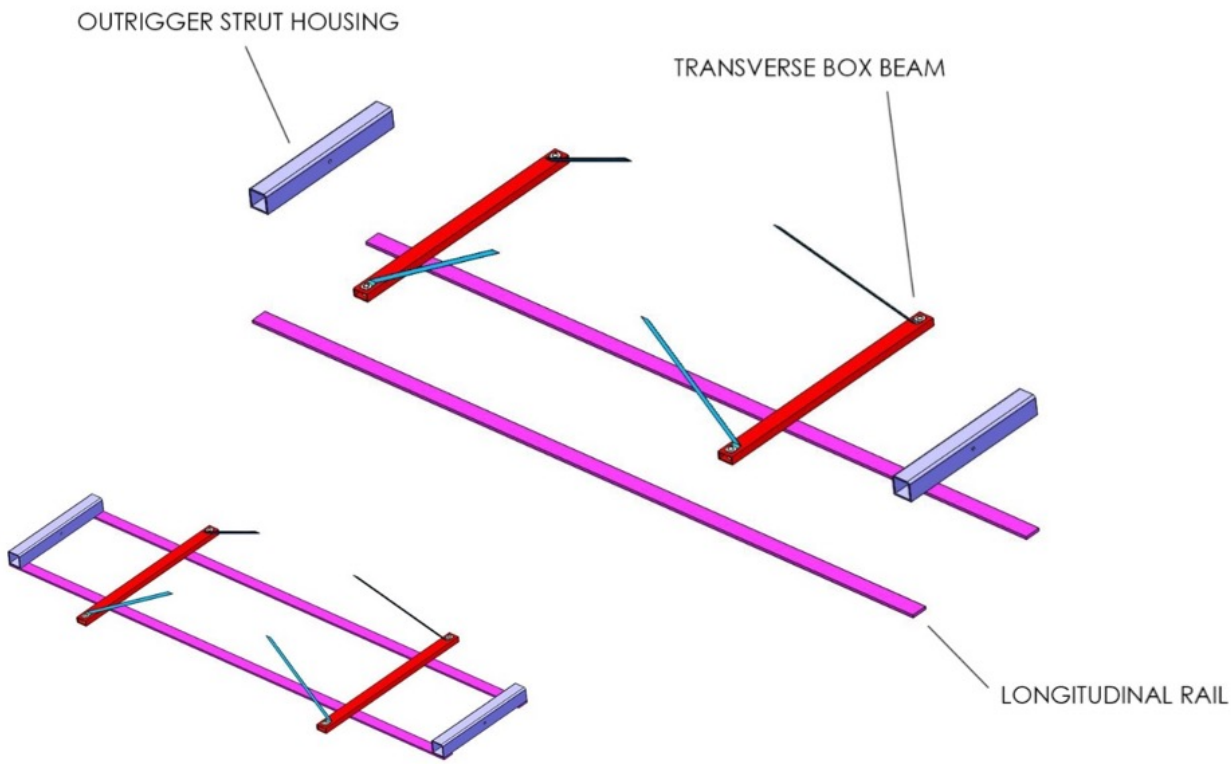


Figure 5.2 Exploded model of frame subsystem

The longitudinal rail is an 8′ x 2′′ x 3/8′′ extrusion, the transverse box beam is 32′′ x 1′′ x 2′′ with a 1/8′′ thickness, and the outrigger strut housing is a 1.8′′ box beam with a 3/16′′ thickness. All components will be 6061 T6 Aluminum, which we have found to be the best grade in terms of water and corrosion resistance. The components will be joined with a lap weld where the edges of each part meet (details of the manufacturing plan can be found in section 6). The rigid, rectangular frame design will minimize any possibility of the frame slipping over any edge of the paddleboard.

We decided on altering the outrigger strut housing design to a box beam for ease of manufacturing. Our initial design was composed of a round tubing welded into a three-faced box beam. The new design will eliminate an additional concern for failure at a weld as well improve ease of reproducibility. We also drilled a ¼′′ hole on each front and back face of the housing to fit a D-ring. The round poles extending to the pontoons will have a minimal clearance fit into the square strut housing to ensure that there is no "wobbling" of the poles. The design for the transverse box beam has remained unchanged as it would provide the most structural rigidity.

In addition to the frame are eight straps from Northwest River Supplies (NRS) responsible for securing the frame onto the paddleboard, shown in an exploded view in Figure 5.3. The straps will wrap around the underside of the paddleboard and over the top of the frame. One of the main concerns was that having eight straps on the underside of the board would produce significant fluid drag in the water. To test the feasibility of our design, we conducted a hydrodynamic test by loading eight straps onto a paddleboard and testing the time it takes to travel a fixed distance under a constant force. The straps ended up having a small but negligible effect on the dynamics of the paddleboard and we concluded that they would not be an issue. More details regarding the test can be found in Appendix F.

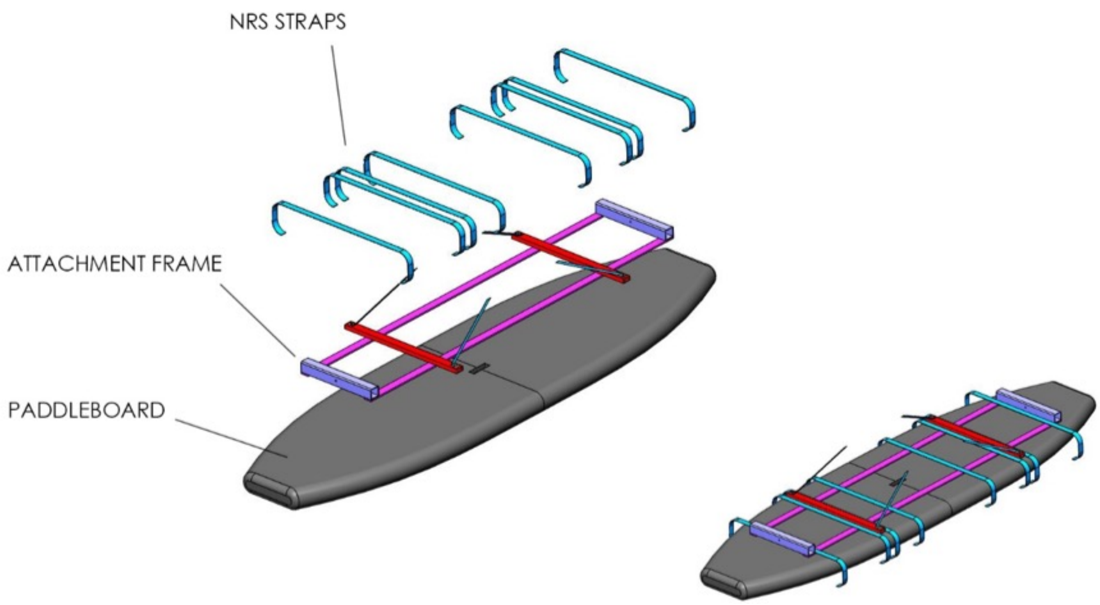


Figure 5.3 Exploded view of frame and paddleboard

With a combination of the NRS straps and the rigidity of the frame, the user and its wheelchair will be able to remain fixed on top of the paddleboard without concern of the frame slipping off.

5.1.2 Anchor Straps

On top of the transverse box beam sits the anchor straps that will be responsible for connecting the frame to the wheelchair. Since CDR, we have kept the location of the strap to the top of the transverse beam to eliminate potential wear from the edge of the beam.

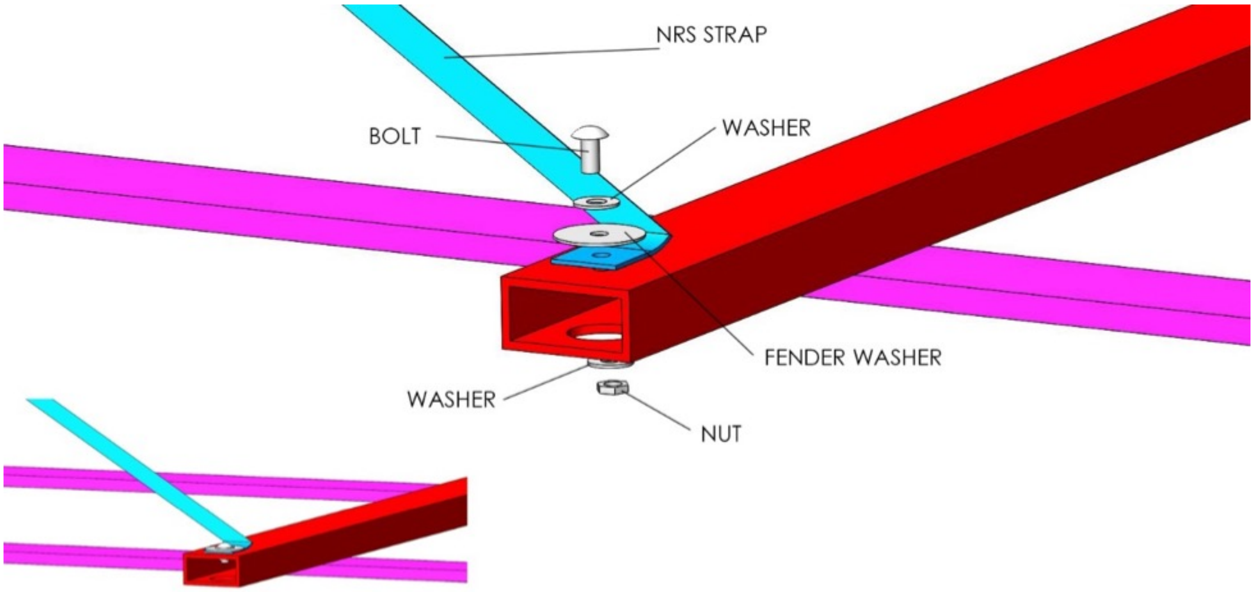


Figure 5.4 Bolted strap attachment to frame

To meet the requirement of accommodating a variety of wheelchair sizes and designs, a Velcro strap system is utilized to allow continuous adjustability of the loop length that attaches though the frame of a wheelchair. We were able to manufacture our own Velcro straps and are confident based on the quality of sewing that we produced a quality strap.

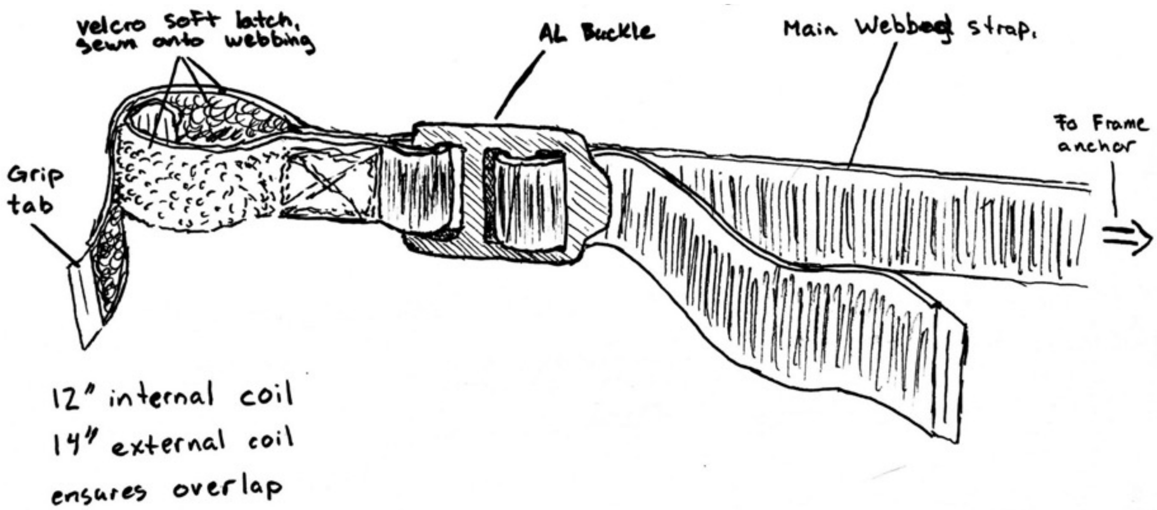


Figure 5.5 Velcro strap attachment to chair

As displayed in Figure 5.5, Velcro is sewn on to one side of the nylon webbing to allow a secure temporary loop to be formed around a member of the user's wheelchair. The Velcro is secured through a buckle that will connect to the nylon strap portion that is mounted to the frame. The Velcro also has a fair amount of surface area of contact to ensure the method of securing the straps in place will not fail under proper use.

A tensioning buckle is included on each strap to allow for pre-tensioning. This eliminates the possibility of slack in the attachment straps and ensures a tight clamping force between the board and the wheelchair.

On the side of the strap that attaches to the aluminum frame, the webbing is captured between a fender washer and the rectangular aluminum tube. The fender washer helps evenly distribute the clamping force over a wider area of the strap. An exploded view of the sub assembly can be seen in Figure 5.4. Each of the four attachment points will have a 3/8'' bolt, two 3/8'' washers, a 3/8'' fender washer, and a nut.

A main concern for the strap connection design was strap failure under a tensile load. We ran the strap configuration through a tensile tester and in each test case, the strength of the low-budget test webbing exceeded our predicted calculations for worst case scenario load. This test eliminated any concern for strap failure due to the strap and connection withstanding more force than the worst-case loading scenario. More details of the test and predicted load can be found in Appendix J.

An important consideration for this design is to minimize sharp points and edges on the tips of the bolts and ends of the transverse beams. To address any potential dangers to the users or instructors that interact with the paddleboard, a protective rubber adhesive is placed on protruding corners.

5.1.3 Stabilizing Outriggers

Our stabilization outriggers will consist of two pontoons mounted at either end of the aluminum struts that extend from the frame. These struts will pass completely though the pontoons, allowing for the adjustment of the pontoons along their length. The location of the pontoons will be fixed with D-ring pins.

To ensure adequate room for the end user's paddle stroke and sufficient buoyancy, the pontoons will be 10' x 8" x 8".As shown in Figure 5.6, they will follow a hydrodynamic curve reminiscent of a sculling boat.

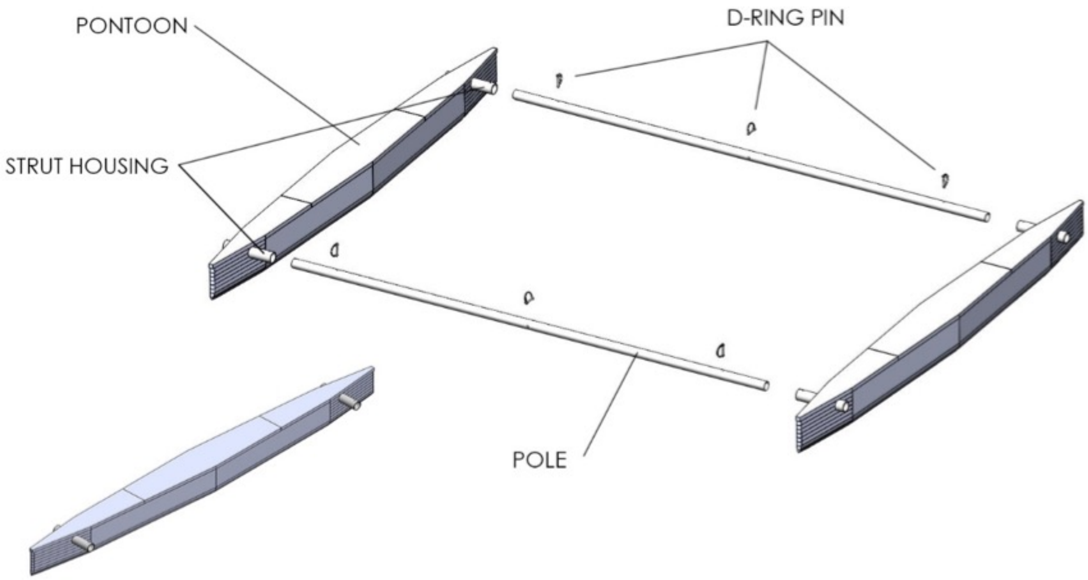


Figure 5.6 CAD model of outrigger pontoon

After discussing manufacturing options with local fiberglass expert and former Cal Poly shop director George Leone, we selected a polyurethane (PU) foam and UV-cure polyester resign design. The pontoons consist of a 1 ½" wall of PU foam and three layers of glass cloth saturated with resin and topped in a wax 'hot-coat' layer to provide a complete cure.

From George Leone's advice and the process documentation of the 2013 Cal Poly senior project 'Human Powered Hydrofoil' we concluded that it would be feasible to assemble a layered foam design using the more readily available 1" sheets of PU foam instead of a solid 10' block. We cut individual layers out of PU foam and adhered them together with a water-activated foaming glue – Gorilla Glue – before sanding to shape and glassing.

The aluminum strut housing inserts are placed into holes drilled through the bow and stern of the pontoon and epoxied in place. The location of the holes was determined by conducting a simple test of placing the board and pontoons into the water and seeing where they floated relative to each other. Because the holes sit so high on the pontoons, additional reinforcement was needed ensure that the pontoon would not fail at a given load. After the inserts were secured, we used carbon fiber and several additional layers of fiberglass to reinforce that area. The tubes are offset from the outer face of the pontoon on one side and have a through-hole perpendicular to the tube to allow for the wire snap pin to lock to the struts.

To validate our process and develop a familiarity with fiberglass George Leone invited us to his workshop in Atascadero and walked us through the process of developing four test samples of fiberglass on a scrap surfboard core. Additionally, the results of our tipability test in Appendix G show that the outrigger system holds up extremely well to large loads and cannot flip the paddleboard.

5.1.4 Loading Ramp

After considerations of our previous ramp, we decided to switch to an HDPE double ramp which cuts down on weight and provides more strength (calculations of HDPE strength can be found in Appendix K). We modified the lengths of the middle section of the ramp to reduce deflection and added corners to both sides of each ramp to ensure a safe loading for the user.

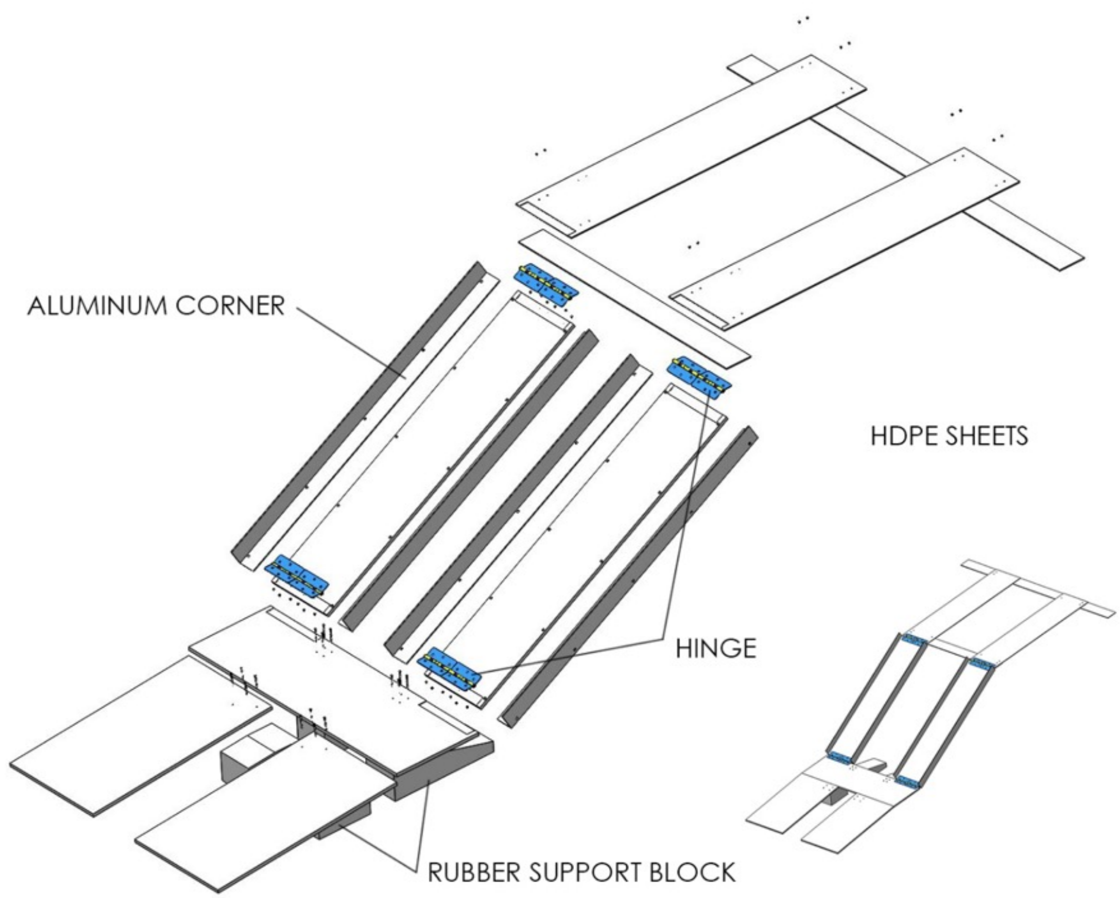


Figure 5.7 CAD Model of Ramp

The loading ramp, seen in Figure 5-g, is constructed of two parallel longitudinal rails, which are hinged and broken into three sections. The first sections, onto which the user will initially begin loading, are 8" x 36" x 1". The second middle sections, going between the loading surface and the board, are also 8" x 36" x 1". This was the section we shortened to reduce deflection. The third sections, which go over the struts on the board, are 12" x 25" x 1". Three horizontal crossmembers connect the parallel rails. The crossmember sitting at the very beginning of the ramp is 3" x 48" x 1". Another crossmember sitting at the hinges between the first and second rails is 3" x 30" x 1". The third crossmember sits between the

second and third rail sections measures 10” x 30” x 1”. This crossmember is supported by two support blocks which raise it off the board surface. These blocks are angled and cut from sections of rubber blocks. One block rest under each side of the crossmember. A pair of smaller angled support blocks sits under the third ramp sections. The support blocks are connected to the boards with #8 x 2” construction screws.

Steel hinges are used to connect the ramp sections. Two 3-1/2” wide hinges are placed side by side on a single rail section at each connection. The hinges are screwed into the ramp with #8 x 1-1/4” construction screws, and eight hinges are used in total. Layers have been removed from the boards to allow the hinges to sit flush with the rest of the ramp surface. The ramp will be coated with a sealant to protect against water damage and a layer on the upper faces to provide additional traction.

The purpose of the three-section hinged ramp is to provide versatility and portability. The middle section can pivot to slope upward and downward, allowing for loading from a shore or from a dock. The sections at the beginning and end will sit firmly on the initial loading surface and the board itself, respectively. These sections provide stability during loading and a smooth transition on and off the ramp. The crossmember at the beginning of the ramp extends wide to either side of the parallel rails. A person who is assisting in loading the user onto the board places their feet on either end of this crossmember. The weight of them standing on the member helps keep the ramp in place during loading. Once on the ramp, the user must be able to get over the protruding parts of the board frame. For this reason, the last sections of the ramp are supported by blocks which sit on either of the housing tube for the outrigger struts. The support blocks keep the ramp raised above the frame so the user can roll easily over the housing tubes. The ramp then angles the user smoothly down onto the board surface. The L-shaped brackets running along the edge of the ramp function as a wall that prevents the user from rolling sideways off the ramp during loading.

Our ramp design was tested by building a full-scale prototype out of plywood and loading a person in a wheelchair onto the paddleboard. The test, which is discussed in greater detail in Appendix G, proved that the design could effectively and comfortably allow a user to load themselves onto the paddleboard with minimal assistance. The entire process was simple and expedient.

Our loading ramp provides a versatile way in which users can load themselves onto the board. Our design is lighter, more compact, and more rigid than previous revisions.

5.2 Safety, Maintenance, and Repair Considerations

From our Design Hazard Checklist (found in Appendix D) we can determine that our planned final design has few major safety concerns. Our worst-case scenario would be a situation in which the user falls from the wheelchair and injures themselves by hitting a body part against one of the hard metal components of our design. In order to prevent this a layer of soft foam matting will be used to cover hard raised surfaces and sharp edges wherever possible. Additionally, the board will be used on deep water, so the risk of drowning must always be considered. However, we deem the risk of drowning with our design to be low. The user will not be strapped into their chair, so they would not be trapped underwater in the event of capsizing. The user will also be wearing a life jacket and will generally be supervised.

Some parts of our design may need to be checked regularly for signs of wear and tear, as determined by our Failure Modes and Effects Analysis (FMEA). A more detailed breakdown of the FMEA we performed

can be found in Appendix D. The straps connecting the wheelchair to the frame should be inspected frequently to ensure that the strap is not tearing at the point where it is bolted to the frame. The bolt should also be examined. If it proves necessary to replace either part, the strap can be easily unbolted, and the system then reassembled with whatever new or repaired parts are required. The ramp is at risk of suffering damage from water or from scraping or bumping against rocks and beaches. The wood of the ramp may need to periodically be resealed against water damage. Components or even the entire ramp may need to be replaced from time to time. If individual components need replacing, they can be easily unscrewed from the rest of the assembly and new components can be simply installed. If the entire ramp needs to be replaced, a new one would be cheap and relatively easy to manufacture. Because the entire system will be frequently exposed to water, all metal components should be checked for rust or corrosion. Small components such as the hinges and screws of the ramp, the bolts, nuts and washers attaching the chair straps to the frame, and the pins for the outrigger struts, can all be easily and affordably replaced. Replacing or repairing any part of the welded frame itself would prove far costlier and more difficult. As such, great care is taken to select frame materials that will be as resistant to water damage as possible.

5.3 Cost Analysis

A cost estimate of all the components of our design was compiled to ensure that our product would not exceed the budget of our sponsor. Table 5.1 shows the cost summary and a subtotal cost of each subsystem. A comprehensive table of components, costs, part numbers, and vendors can be found in Appendix E.

Table 5.1 Materials cost summary

Subsystem	Cost	
Stabilizing Outrigger	$2680.11 (foam purchased)	$1180.11 (foam donated)
Loading Ramp	$450.57	
Attachment Frame	$148.82	
Anchor Straps	$57.80	
Total	$3337.3 (foam purchased)	$1837.3 (foam donated)

At a total cost of $3337.3, our project will have a low budget relative to that of the Onit Ability Board. The polyurethane foam will be the most expensive component of our design, priced at roughly $1600 for the construction of both pontoons. We have looked into the possibility of having foam donated to our team and there are currently two potential suppliers.

George Leone, the advisor of Cal Poly's Human Powered Vehicle Team, has offered to donate some foam that he regularly picks up from a manufacturer in Southern California. However, the date at which he is going is still undetermined. Jim Cullins, one of Cal Poly's Machine Shop advisors, also mentioned the possibility of donating some of the foam that the shop currently has in inventory.

6 Manufacturing Plan

This section highlights the detailed steps we will be taking to manufacture each subsystem. The general work flowchart for the project's manufacturing can be seen in Figure 6.1 Manufacturing system

flowchart. Most notably, the frame must be completed before the pontoon's metal inserts can be installed.

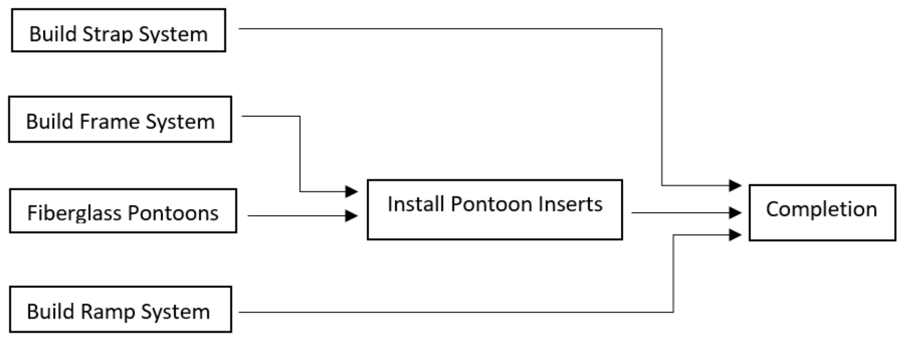


Figure 6.1 Manufacturing system flowchart

6.1 Aluminum Frame System

The frame is constructed from 6 main aluminum pieces which are described in Table 6.1.

Table 6.1 Aluminum Frame Components

Name	Length (in)	Width (in)	Height (in)	Wall Thickness (in)	Quantity
Longitudinal Rails	96"	2"	3/8"	N/A	2
Transverse Box Beam	32'	2"	1"	1/8"	2
Strut Housing	20'	2 ½"	2 ½"	3/16"	2
Strut	120"	2 ¼"	N/A		2

The first step in manufacturing the frame was to cut the metal stock to size. The longitudinal rails were purchased at the correct length, while the remaining aluminum pieces were cut to length in Mustang 60 using a chop saw. All aluminum pieces were also deburred to remove sharp edges. Next, the holes that the frame attachment straps are bolted to the transverse box beams were drilled. On the top on the box beams, a 3/8" holes were drilled centered on the centerline of the box and 2" from each end. On the bottom, 2" diameter holes were drilled in the same locations. These holes were then deburred to break sharp edges. This process of preparing the aluminum pieces took about 6 hours of work over two days.

Once all the aluminum pieces had been sized, they were ready to be welded. The components were brought to Kevin Williams who runs the Industrial Manufacturing department's welding lab. Using the fixturing table along with stop pins to ensure perfectly square corners, the frame was arranged to be welded. The fixturing of the strut housings was paramount because there is a critical geometric tolerance of parallelism between the strut housings on opposite sides of the frame within the strut housing. This ensures the pontoons are interchangeable on either side and can be adjusted to different lengths on the struts by sliding along the length of the strut.

Once the frame was properly fixtured, the weld locations were pre-heated with an oxygen-Acetylene torch set with a neutral flame to ensure heat was not conducted away from the weld too fast, while welding. These welds were performed with a Tungsten-Inert Gas (TIG) welding system set to 130 Amps AC using a green tipped tungsten electrode. There are four welds at each intersection of components. Welds between the transverse box beam and the longitudinal rails are represented in blue in Figure 6.2 where two welds are on the top of the frame, and two welds are on the bottom.

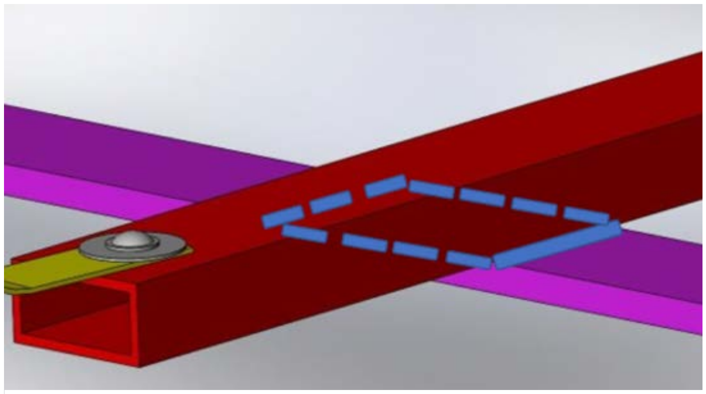


Figure 6.2 Box Beam Welded to Longitudinal Rail

At the ends of each longitudinal beam, the square tube strut housing was welded in a similar fashion, however for the front and back ends of the frame create slightly different weld geometries due to the end of each component at the intersection. To ensure the parallelism target was achieved, the two top strut housing welds at each corner of the frame were completed to guarantee that the transverse box beam welds do not distort the frame before the strut housings are fixed in place. Then the remaining transverse box beam welds located on the top of the frame were completed. Next, the frame was flipped over, and the remaining welds were completed. Finally, the strut housings had a though hole drilled through their centers on the vertical walls. These are used to attach the struts to the frame with D-pins.

The final step on the frame was to create the struts. These were cut from one 20’ long aluminum tube. Then, two through holes were cut 2” from the ends through the center using a hand drill. These are for attaching the struts to the pontoons. Another hole was drilled in the center of the strut at 90 degrees from the end holes to attach to the frame. The process of creating the frame took 35 hours spanning over two months due to scheduling difficulties.

6.2 Loading Ramp System

Table 6.2 Purchased Ramp Materials

Purchased Material	Size	Material	Quantity
Plywood sheet	4 ’x 4’ x 1”	HDPE-UV	1
Small Screw	#8 x 1-¼"	Stainless Steel	36
Long Screw	#8 x 2"	Stainless Steel	20
Hinge	3-½”	Stainless Steel	8
Angle Support Beam	2” x 2” X 6’	Aluminum	2
Support Block	N/A	Plastic	2

Table 6.2 is a condensed list of the purchased materials used in the design of the ramp system. The surface that the user's wheelchair will roll on is made out of UV resistant high-density polyethylene (HDPE). This sheet will have the appropriate size of rolling surfaces for the ramp cut out of it. These sizes are listed in Table 6.3. These sheets are to be cut out using a table saw in Mustang 60. The aluminum angle support beams are cut in half to create four sections that are 36" long on a chop saw.

Table 6.3 HDPE surface components and sizes

HDPE Component	Size	Quantity
Foot Pad Cross Struts	3" x 48"	1
Unconstrained Surfaces	8" x 36"	4
Transverse Middle Surface	3" x 30"	1
Elevated Transverse Surface	10" x 30"	1
Boardside Surface	12" x 22"	2

Once the four unconstrained ramp surfaces have been made, aluminum angle support beams are screwed onto the length of both sides of two of them to form channels that reinforce the ramp section against bending. This is achieved by predrilling the aluminum and screwing the L bracket straight onto the bottom of the board.

To ensure that the ramp components are squared to 90 degrees, a large construction square is used to align parts before they are attached. All holes for the screws are pre-drilled with a 3/32" drill bit before being screwed in with battery powered hand drill. The 90 degrees Overall, the construction of the ramp prototype made from plywood took 25 hours to build, including material sourcing. Therefore, the estimated time for the manufacture of the HDPE ramp is 20 hours to account for gained knowledge and experience in building the same structure out of a different material.

6.3 Stabilizing Outrigger System

This section explains the detailed steps taken to manufacture the stabilizing outrigger system. This includes CNC machining for the foam, adhesion of the cuts, and the entire fiberglassing process to strut housing reinforcement.

6.3.1 CNC Machining

To cut the layers of the pontoons that are to be glued together, a CAD model of the pontoon was created on Fusion360. This model represented the shape of the pontoon prior to 3D contouring or rounding of edges; it was essentially an extruded shape of the top view. This model was then sliced into 1" thick layers. These layers were then adjusted to allow for a hollow center of the pontoon, while keeping the nose and tail solid to retain the strength needed to transfer load to the struts. Since the hollowed geometry created thin wall made of strips in every layer, the strips were replaced by vertical sheets to simplify the process. Once the layers had been appropriately modified, the required foam pieces for each section were arranged onto a 4' x 8' x 1" sheet in Fusion360. The required pieces for both pontoons required three sheets. Using Fusion360 for its useful function of adding tabs around 2D contours in the generation of G-Code, a toolpath was created for each of the three sheets.

This code was run on the ShopBot in the Hangar, and each sheet took about two hours to complete. A picture of this setup can be seen in Figure 6.3. Upon completion of the CNC toolpath, the pieces were

cut out of the sheet by slicing through the tabs with a box cutter. The pieces were then sprayed off with compressed air and had the remnants of the tabs removed in preparation for the adhesion step. The CNC phase of the pontoon creation took 32 hours of work over two weeks due to scheduling conflicts and machine availability in the hangar.

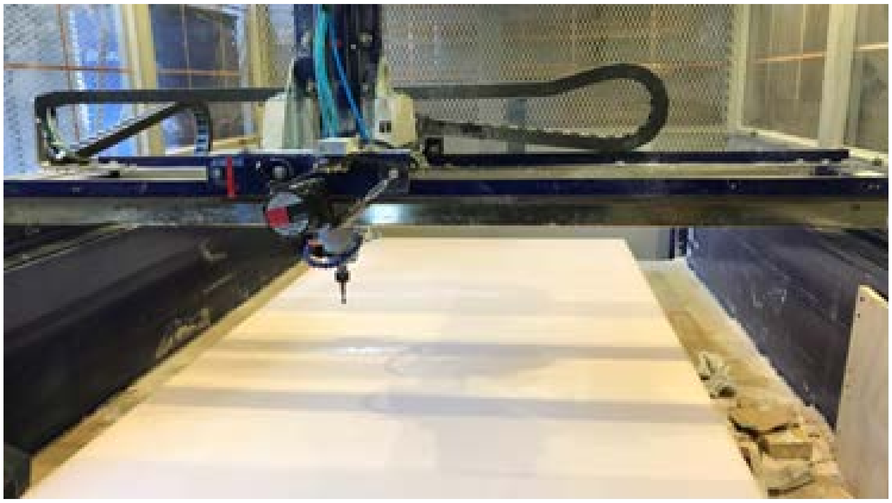


Figure 6.3 ShopBot prior to cutting a sheet of foam

6.3.2 Adhesion

This phase covers the process of joining all 2D components of the pontoons into a basic 3D shape with hard 90-degree angles. This process was completed in the senior project room in the Bonderson Project Center. On a flat surface, the layer components of foam were aligned, and a THIN layer of Gorilla Glue was applied onto one sheet, spread until the glue color was almost undetectable. Then, using a spray bottle the face of the next layer was moistened and evenly distribute moisture across sheet. At each layer, the sheets of foam were aligned, and checked to ensure the adhesive was in contact with both surfaces to be joined. After all layers are aligned and in contact, a flat plank was placed across top of foam stacks and 5-gallon buckets filled with water were placed on top to ensure adequate pressure on expanding glue. Since the hollow inside of the pontoon needs to be reinforced later with fiberglass composite, the top layer was left off to allow access. The top layer pieces were glued together and held together using screws. The excess foaming glue was scraped from seam faces as it emerged to ensure a quality surface finish. Allow 24 hours to cure. The adhesion phase took 60 hours including the curing time.

6.3.3 Model Shaping

The shaping phase consisted of the processes required to generate a final 3D shape for the foam parts of the pontoon and prepare it for fiber glassing. The cross-sectional profile of the exterior of the pontoon is U-shaped profile, ensuring minimum corner radius of 1” to provide a good surface to fiberglass over and provide hydrodynamic properties. This profile was achieved through sanding by hand using a range of sandpaper grit. A pneumatic disk sander and a 36 grit 3” diameter sand disk was used to shape the interior corners of the pontoon’s hollow center into 1 ½” radii. This process can be seen in Figure 6.4. The top layer’s edges were sanded to 1” radii by hand using a range of sandpaper grit. When needed, UV curing polyester resign combined with quartz spherical cells (Q-Cell) to add volume was used to fill any scars in the surface. The process of shaping the pontoon took 120 hours over two weeks. This phase was completed at a well-ventilated paint booth with opaque walls.

Figure 6.4 Sanding interior radii with a disk sander

6.3.4 Fiber Glass Reinforcing

This phase includes the processes used to complete three layers of fiber glass on the exterior and three layers of fiberglass on the interior, as well as on the top layer. The overall process path for one pontoon is outlined in the flowchart in Figure 6.5 Pontoon Fiber Glassing Flowchart. This phase was also completed at an off campus composite workshop. Since the polyester resin used in the lay-up was UV curing, a workspace that is completely blocked from sunlight while still well ventilated is required.

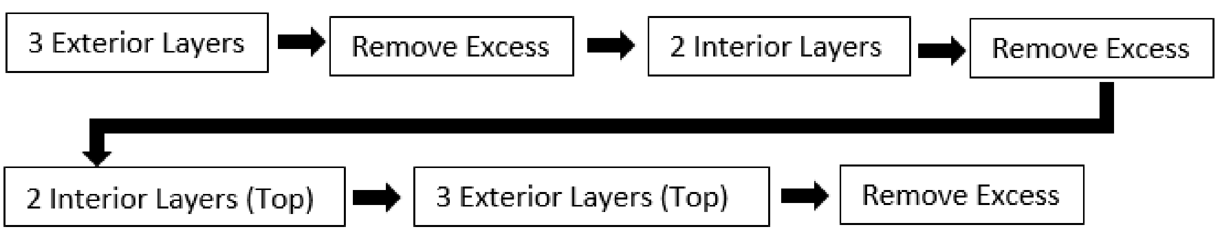


Figure 6.5 Pontoon Fiber Glassing Flowchart

The first step is the three external fiberglass layers for the bottom. The fiberglass cloth was cut to fit model shape. At tips and corners angles were cut to remove wrinkles and overlap wings, similar to knuckle adhesive bandages. After completing the mock layup of cloth, the cut section of cloth was checked for errors and properly adjusted. This cutting process was repeated for each layer needed and can be seen in Figure 6.6. After the preparation was completed for the first three exterior layers, a single layer of the cut cloth was draped over the pontoon.

Figure 6.6 Mock lay-up of an external layer of the bottom

Once the cloth is draped over the foam in the correct location, the wet lay-up process begins. The UV curing polyester resin was applied to the cloth and spread from the center at 90 degrees to ensure minimal cloth shifting and wrinkles. If a wrinkle developed, the nearby cloth was pulled at 90 degrees to the wrinkle to remove it. Continue adding and spreading the resin until the cloth is saturated (when the cloth appears transparent). An example of a saturated layer can be seen in Figure 6.7. Once the first layer is saturated, expose the lay-up to sunlight for five minutes per side, or until the resin tacks. Then repeat the wet lay-up process for the remaining layers on the section of the pontoon being fiber glassed. After the final layer on the exterior surfaces, an extra layer of polyester resin mixed with a hot-coat wax was added to allow the polyester resin to fully cure and allows the surface to be sanded.

Figure 6.7 Exterior layer wet lay-up with excess hanging down

Upon completion of the three exterior layers of the bottom section the pontoon, an excess of fiber glass composite was hanging down off the edge. This excess was in the way of accessing the interior of the pontoon to fiber glass that surface. The excess material here was removed by a pneumatic reciprocating saw and sanded flush to the wall of the pontoon using the pneumatic disk sanders previously used in the shaping phase as shown in Figure 6.8.

Figure 6.8 Removing Excess material with the reciprocating saw and disk sander

The interior of the pontoon was then fiber glassed using the same techniques for two layers. The excess material was again removed to create a flat surface on the top of the bottom section of the pontoon to glue the top layer onto. These surfaces did not require a hot coat. The process of coating the interior is shown in Figure 6.9.

Figure 6.9 Mock lay-up of the second interior layer

The bottom of the top layer (facing the interior of the pontoon) was then fiber glassed using these same techniques for two layers, and once the excess material was removed, the top layer was placed onto the bottom section, and aligned. Then the top layer was glued into place as shown in Figure 6.10.

Figure 6.10 Un-glassed top layer glued on the bottom section

The cloth sections used to cover the top of the pontoon draped over the side walls for a minimum of 3" in all places to ensure a strong connection. Once top had been reinforced by three layers of fiberglass and fully cured using hot coat, the final step of removing excess material began. This step included removing all sections of fiber glass composite that were not flush with the pontoon. This phase of manufacturing the pontoons took an estimated 350 hours of work over seven weeks between five people.

6.3.5 Strut Insert Installation

This phase includes all process used to attach the aluminum inserts onto the pontoon. Then, once the pontoon was fully cured, the next step is to drill holes through the pontoons 8' apart and 3 ½" from the top of the board. This is where the metal inserts are installed. This was done by using a drill press and a 2 ½" arbor drill. Two levels were used to assure that the pontoon was positioned such that the holes were square and parallel. This step was completed at the Mustang 60 machine shop.

The remaining steps were completed at a composites workshop. The holes were adjusted for using a file to ensure the metal inserts fit in place. Then, each of the metal inserts were sanded to rough up the surface, allowing superior adhesion. After sanding the metal inserts, they were cleaned using denatured ethyl alcohol to remove any debris from the surface and then etched using and phosphoric acid. This created micro-pitting to improve the adhesion between the epoxy and the metal. It is important to wear a respirator and chemical shield when handling these chemicals for personal protection.

At this point, the aluminum inserts are ready to be fixed in place. To ensure they are located in the correct place, the frame was assembled with the struts through the strut housing and attached with a D-pin to fix the inserts in place while the epoxy used to adhere them cured. Prior to mixing the two-part epoxy, tongue depressors were sanded into wedges to use as shims on a belt sander. These shims were placed in between the strut housing on the frame and the strut to ensure the struts remained centered within the strut housing. Then, the two parts of the epoxy were mixed and Q-Cell was added to increase volume. The epoxy was used to coat the aluminum inserts and they were slid into the holes in the pontoons to the correct depth. Once both of the inserts were in place on the pontoon, the pontoon was slid onto the struts. Then, the shims were placed in between the struts and the inserts to ensure they

were concentric as the epoxy cured and fixed the inserts in place on the pontoons. The epoxy was then allowed to cure overnight in this setup position.

After aluminum inserts were fixed in place, the area surrounding the inserts was sanded to allow the reinforcement layers of fiberglass and carbon fiber to adhere properly. At this point, epoxy was used to wet the strip of carbon fiber which was then wrapped around the two sides of the insert in a figure-eight pattern for three layers and rectilinear for two layers as shown in Figure 6.11.

Figure 6.11 Carbon fiber reinforcement pattern

The reinforcement pattern for the fiberglass layers accounted for six to seven layers in the surrounding area and was laid up in a variety of patterns as shown in Figure 6.12. The phase of installing the inserts took 150 hours between five people and four weeks.

Figure 6.12 Fiberglass reinforcement patterns

6.3.6 Gel Coating

This phase consists of the processes involving preparation and coating the pontoon with a protective gelcoat. Upon completion of the strut installation, the pontoon was sanded using a pneumatic long-board sander and by hand in tight spaces with 80 grit sandpaper. This process allowed areas the reinforcement jutted out of the pontoon's surface to be sanded flush with the surrounding area. In this sanding process, it was vital to avoid sanding through the layers of fiberglass, so if the checkered pattern emerged, the area was not sanded further. This process was located outside of the Bonderson project

center and took 25 hours between three people over four days. Once the pontoon's surface was adequately rough, it is ready to be taken to the paint booth in the Hanger 4 to be coated with the protective gelcoat. The coating process is estimated to take 20 hours over one week.

6.4 Wheelchair Tie-down Strap System

6.4.1 Frame Attachment Strap

This phase includes the processes used to make a strap the attaches to the frame using a bolt assembly. To prepare the strap, a ¼" hole was created by continuously forcing increasing sizes of metal files through the center of the strap 1 ½" away from the end until the hole is ¼" in diameter. To assemble the bolt sub assembly, smaller washer was placed on the bolt first followed by the carriage washer. Then the bolt was put through the hole in the strap by spinning through the strap as if the strap were threaded. Next, the bolt was placed down through the top of the drilled hole and put the plastic washer in between the steel washer and the transverse box beam on the underside. Then, the nut was tightened down with at least 20 ft-lb of torque ensuring the strap on the topside is angled appropriately towards the location a wheelchair would be when the system is in use (this can be checked and adjusted later). Repeat four times, once on each end of the transverse box beams. This phase took six hours in one day, including the time to purchase materials and was assembled in the Bonderson Project Center.

6.4.2 Buckle Attachment Strap

To manufacture the Buckle subassembly, four sections of 36" of the NRS straps were cut to become the soft attachment loops and the ends were fused to avoid fraying. Then, the strap was doubled back 1" on one side and the tabs were double stitched into place which can be seen on the bottom left of Figure 6.13 and on the center right of Figure 6.14. These became the pull tabs for the Velcro. Then, 10" of the prickly Velcro side was sewn onto the end of the strap with the pull tab and 14 inches of the soft Velcro side was sewn on the other end, on the opposite side. This was completed using a double stitch around the outside rectangle of the Velcro. Then, the soft attachment strap was slid through the singular side of the buckle, shown on the left side of Figure 6.13, to the remaining 12" of strap in the middle of the two Velcro sections. Then it was folded in half to form the permanent loop. The loop was secured loop with two of the 2 inch "X" sewn patterns.

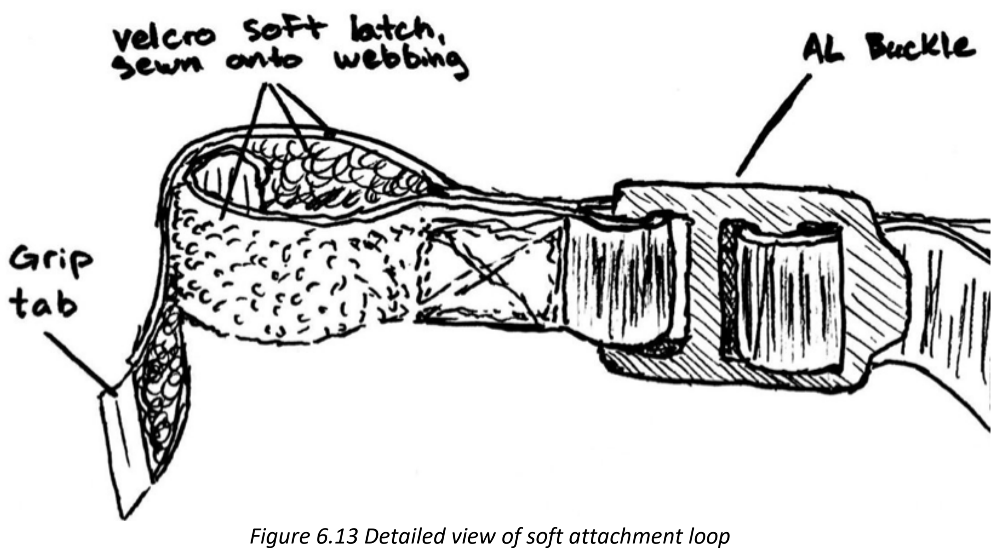


Figure 6.13 Detailed view of soft attachment loop

Figure 6.14 shows the components of the strap attachment system prior to the Velcro side being permanently attached to the buckle with the reinforced X pattern. This process was repeated four times to make four buckle strap assemblies and took nine hours over three days.

Figure 6.14 Components of the strap attachment system

6.5 Strap System Assembly

This phase includes the processes involved assembling the two different straps within the wheelchair attachment strap system. To attach this buckle sub assembly to the strap attached to the transverse box beam, the strap from the transverse box beam was placed through the middle slot on the buckle. Then, it was doubled back through the end slot, shown on the right side of the buckle in Figure 6.13 so that the strap has a one-way tightening mechanism when positioned in line with the two straps. This is the same buckle used on the straps that hold the frame on the board. This installation process took one hour and was completed in the Bonderson project center.

7 Design Verification Plan

Throughout the build process we performed tests to assess our design validity and construction integrity. These tests will provide a solid base of evidence to ensure high product quality and/or suggest improvements not previously conceived. The following section describes the conclusions we drew from each test. More information regarding the set-up, materials, and methods of testing can be found in Appendix G. The Design Verification Plan and Report can be found in Appendix J, showing how the tests align with each specification.

7.1 Pre-Build Tests

These tests were completed before constructing/assembling the relevant components.

7.1.1 Strap Rip Strength

To verify that nylon straps would perform to our specifications in our anchor strap system, we performed tensile tests. Small sections were cut from longer straps, attached to testing plates, and loaded into the tensile tester in the Cal Poly IME welding lab. These sections were tested to ensure they can sustain 500lb loads. The straps were tested under various loading torques for the bolt. The straps

did not fail until the load was over 500lb in all cases. The NRS straps with sewn Velcro used in our final product are even more robust. We do not consider strap failure to be a concern because of this.

7.1.2 Hydrodynamic Drag Test

Our sponsor was concerned that the straps attaching the frame to the board would cause an undue amount of drag on the board. In order to verify that this was not the case, we performed a series of drag tests. We used a fishing rod with a force gauge attached to it to pull the board across a pool at a constant force. The speed of the board with and without the straps under this constant force differed by 0.2% which passed our criterion of a less than 5% difference. Two other tests were conducted, one testing how far the board would be traveling when given a push and a second timing how long it takes to paddle the board a set distance. However, we realized later that the straps were improperly attached for these two tests and therefore they returned faulty data.

7.2 Mid-Build Tests

These tests were carried out throughout the build phase.

7.2.1 Balance

To address balance concerns from our sponsor and maintain a consistent center of gravity for our paddleboard we conducted balance tests throughout the build phase. We used the 'pencil test' to check for center of gravity in each component. This test entails rolling the component around over a dowel on a flat surface to find the balance point. The paddleboard, frame, and both pontoons were all tested. Each component had a center of gravity precisely aligned with its geometric center. When the entire system is assembled, all the components are positioned so they are centered on the center of the board. Because of this the center of gravity of the entire system is at the center of the board.

7.3 Post-Build Tests

These tests were carried out after the construction/assembly of the relevant component(s) was complete.

7.3.1 Setup and Teardown

To ensure ease of setup and loading for the end users we will perform practice tests on our completed ramp and frame using the paddleboard provided by our sponsor and the wheelchair donated to our project. We began with the entire system dissembled. Then, using a team of two people, we had the two people set up the system. After that was done, the process was performed in reverse and the system disassembled. Both setup and teardown were timed. The tests showed that assembly took 3:57, while disassembly took 1:10. Both these times are within our goal of setup and teardown times under five minutes.

7.3.2 Tipabiliby

Once the pontoons and frame systems were completed, we performed counterbalance load tests on the stabilization system. We attached both the frame and outrigger systems to the board and then took it out into the water. One team member stood on each pontoon and rocked the system back and forth.

The goal was to determine if a pontoon would submerge under this loading of greater than 150 lb. The results of the test showed that pontoons did not submerge.

7.3.3 Loaded Paddle Test

We additionally performed a high-load test to assess the stability and performance of our systems above the rated capacity of the paddle board. We loaded three persons totaling 465lbs onto the board, one sitting in the attached wheelchair, one sitting at their feet, and one standing behind the chair paddling. While the published capacity of the board used for testing was merely 240lbs and the board sat noticeably lower in the water than usual it did not submerge, noticeably pull off from the frame, or exhibit any signs of increased instability. While it was difficult to pin down a hard value for speed performance compared to the paddle board alone the system did not feel very sluggish. It was more difficult to accelerate two additional passengers than just the paddler alone, but still very manageable and timely for one paddler to move the passengers across the water.

8 Project Management

Our team began the project by discussing with our sponsor the scope of our project and the requirements that would need to be met. Through extensive brainstorming and ideation sessions, our team came up with several designs that we eventually narrowed down after our Preliminary Design Review. We then proceeded with a design and constructed a prototype to test the feasibility of the concepts. After careful reconsiderations, we moved into the Critical Design Review to confirm our final design before purchasing parts and manufacturing. Our final prototype was then tested and presented at the Senior Project. The entire process was met with challenges and several unanticipated setbacks.

8.1 Gantt Chart

To organize the tasks of each individual member and make sure all the deadlines were met, out team used a Gantt chart on TeamGantt. With a Gantt chart, we were able to assign tasks to each member and monitor our percent progress. Having four different subsystems to keep track of, the dependencies on TeamGantt helped us better prioritize our tasks and organize what needed to be completed first. Our team's Gantt chart highlighting the entire project from start to finish is shown in Appendix L.

8.2 Redesign

One major setback we faced during our Preliminary design review was a total redesign of our project. After brainstorming and ideating off of what we believed to be our scope, we had to modify our scope and change directions. Though this was an unanticipated setback, it helped redirect our team in a better direction.

8.3 Challenges

Having four subsystems to focus on, our team took the approach of collectively working on one at a time instead of splitting up the responsibilities. All the subsystems of our paddleboard had to come together flawlessly and so we decided that this strategy would eliminate the possibility of any misaligned parts. However, with this strategy, we faced the challenge of project timing. Our team did not anticipate the

amount of time required to manufacture our own pontoons and so other systems such as the ramp were very rushed. For a future design project, we would either start the manufacturing process earlier or try to more thoroughly research the details of it and plan accordingly.

9 Conclusion & Recommendations

This concludes the Final Design Review (FDR) for our adaptive paddle board project. Our FDR shows that we have conducted detailed research through patents and existing products, designed and prototyped to meet customer specifications, and manufactured and tested our final product. This section explains what we achieved

9.1 Achievements

When we began this project, we had a completely different scope and several stretch goals that we wanted to meet. The initial considerations for our design involved an invasive procedure to the board provided by our sponsor. Our chosen design at CDR, which was inspired by a previous adaptive paddleboard senior project, involved cutting into the board and placing blocks that would allow attachment points to the wheelchair. However, after presenting our design to our sponsor Randy and meeting with Eric Pulse, who had experience with adaptive paddleboards, we quickly realized that our design would not be a viable solution. It was not a design that allowed universal use of any paddleboard and required an expensive and high-risk manufacturing procedure. After going back to the drawing board, we came up with our current attachment frame design which better fits the needs of our sponsor. During our ideation and design process, our team overlooked the importance of utilizing our on-campus resources early and getting in contact with those who already had prior experience with similar projects. Although a redesign is not always avoidable, this is something we would do differently if we had to do it over again. After our reiteration, our final design was able to meet all of the requirements of the user, which we centered all of our decisions around. In the end, we were able to produce a product that was affordable, adaptable to any paddleboard and wheelchair, and easy to use.

Three of our biggest achievements with the adaptive paddleboard was our results with the time to load, the minimization of the cost, and the tipability of the board. One of our sponsor's concerns was being able to load all the components of the paddleboard and swap users in a timely manner. When they use the paddleboard up at Shaver Lake, they will have several users swapping in and out of the paddleboard and so it was important to keep the loading time under five minutes. With all that in consideration, we designed simple geometries and components that would easily fasten together and come apart. After running several tests, we concluded our setup time to be about three minutes and tear down time to be a minute. This will make running the activity at the lake very efficient.

One of the main reasons this project was presented was due to the high cost of the current boards on the market. Our board came out to a little over $3000 (not including the paddleboard) which is significantly cheaper than the current products on the market. The most expensive component of the project was the Expanded Polyurethane Foam (XPU) which we estimated to have received $1600 worth of. If this project were to be redone, we would recommend finding a cheaper alternative to the XPU in order to significantly save on costs. We were informed by one of the composites professors that there is a blue foam that is not only cheap but becomes stronger in the presence of water. This is a material that can be considered in a future project.

Another concern we developed when we did research on the general weight capacity of paddleboards was the tipability of our system. In extreme cases, wheelchair users can weigh up to 300 pounds, and so it was important for us to design a stabilizing outrigger system that would not only accommodate the weight of two individuals but be able to prevent tipping. We designed our pontoons to provide a lot of buoyancy and a test run in Morro Bay revealed that our system can hold up to three individuals. With that, we eliminated any concerns for overloading the paddleboard.

Although reproducibility was one of our lower priority objectives, we decided to place a greater emphasis on the quality of the design. The frame is composed of relatively simple parts and the welding process can be easily outsourced to welding shop. However, with the pontoons, we decided to pursue a fairly complicated fiberglassing process over buying premade pontoons. It was a compromise we agreed on with our sponsor to prioritize durability and customizability over the convenience of being able to buy a new one. Even though the fiberglass of our pontoon came out flawlessly, we should have conducted more research on any manufacturing processes that we were unfamiliar with. Having never fiberglassed before, our team did not expect the pontoons to take several hundred man-hours. And so, that took away from a good amount of focus on other subsystems such as the ramp.

One of the stretch goals we failed to meet with our sponsor was the swivel seating. In addition to being able to accommodate a wheelchair, our sponsor also wanted a swivel seat on the paddleboard. This is potentially something our team can create designs for and send to our sponsor.

After receiving the results of our testing and feedback from our peers at the Senior Expo shown in Figure 9.1, we concluded that we successfully designed and manufactured a paddleboard that surpasses the ones currently on the market. Our board trumps the Onit board in versatility, cost, and reproducibility and would probably be received with popularity if placed on the market. We have provided persons with disabilities the opportunity to once again pursue an active lifestyle and enjoy outdoor sports. We hope our project will be able to impact the lives of many at Shaver Lake for years to come.

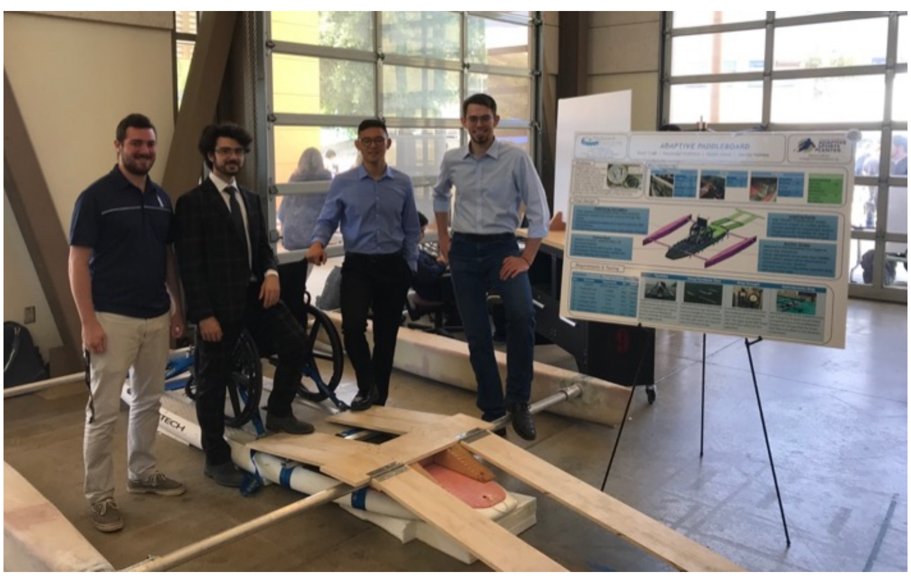


Figure 9.1 Completed Project at Senior Project Exposition

9.2 Next Steps for Sponsor

Since the manufacturing and testing have been completed and the adaptive paddleboard has been confirmed by our team to be fully functional and ready for use, the next step is to assure the longevity of the adaptive paddle board. The board will be used during the summer at Shaver Lake and we anticipate it lasting for several summers to come. It will be crucial to follow the operator manual in Appendix I and to read the instructions before anything to ensure proper use and maintenance of the board.

10 References

Carlson, S. R. (2004). *Patent No. US6786502B2.*

Group 36. (2016). *Adaptive Stand Up Paddle Board.* San Luis Obispo: California Polytechnic State University.

Harris, D. R. (2014). *Patent No. US8752492B1.*

Ivey, S. (2009). *Patent No. US7543405B1.*

Karman Healthcare, Inc. (2017). *Determining the Seat Width for a Wheelchair.* Retrieved 10 17, 2018, from Karman Healthcare: www.karmanhealthcare.com/determining-the-seat-width-for-a-wheelchair/

Pelchat, J.-F. (2007). *Patent No. US7300070B2.*

Preferred Health Choice. (2018). *How to Measure For Wheelchair.* Retrieved 10 17, 2018, from PHC-Online: https://www.phc-online.com/Measure-for-wheelchair_a/6.htm

Revolution, A. (n.d.). *Onit Ability Board*. Retrieved from Access Revolution.

Schram, B., Hing, W. F., & Climstein, M. (2017). The long-term effects of Stand-up Paddle Boarding. 7.

Spinal, L. (2016). *Bias Ability Paddle Board Stand up Paddle board*. Retrieved from Living Spinal.

Sunrise Medical Holdings, Inc. (2018, 03). *Quickie-7R-Order-Form.* Retrieved 10 17, 2018, from Sunrise Medical: http://www.sunrisemedical.com/getattachment/ba5e5005-15bd-4903-bc0d-a6316f43009a/Quickie-7R-Order-Form.aspx

Surftech. (n.d.). *TEKefx Graphics* . Retrieved from Surftech .

Vineyard, D. A. (2015). *Patent No. US20130270201A1.*

"Epoxy - Primers - Automotive Finishes - Auto Paints & Equip." *Auto Body Repair Tools Shop - Auto Body Supplies - Classic Car Restoration*, www.eastwood.com/paints/automotive-finishes/primers/epoxy.html.

Appendix A: QFD House of Quality

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: ____________________

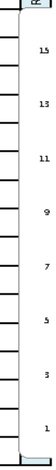
Revision Date: ______________

−

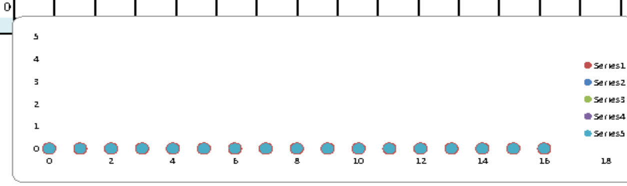
\+

Row #	Weight Chart	Relative Weight	Adaptive Water Sports Centers	Double Amputees	Parapalegic/Single Amputee	Limited Mobility Individuals	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants)
1		14%	10	10	10	8	9	Wheel Chair Securely Attached
2		10%	10	6	6	6	9	Waterproof
3		7%	10	3	3	5	3	Different Configurations Possible
4		10%	7	7	7	7	3	Loading mechanism from shore
5		7%	5	5	5	5	3	Loading mechanism from dock
6		5%	8	3	3	1	3	Multiple chair sizes
7		6%	7	4	4	2	3	Removable outriggers
8		5%	7	7	1	1	3	Swivel seating
9		7%	5	5	1	7	3	Lean rail
10		5%	5	1	8	1		Avoid chafing
11		14%	10	10	10	10	9	Positive Bouyancy
12		10%	7	7	7	7	9	Affordability
13		0%					9	Lightweight
14		0%						
15		0%						
16		0%						

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	NOW: Curr. Products					
Direction of Improvement	▲	▼	◇																			
HOW: Engineering Specifications (Tests)	Torque test: twist-off	Submersion test	Time to load/remove chair	Weight requirement	Cost analysis	Bouyancy Test	Time to change configuration										Our Current Product	Competitor #1: Onit Ability	Competitor #2: Living Spinal			Row #
Wheel Chair Securely Attached	●																	5	3			
Waterproof		●		▽		▽												5	5			
Different Configurations Possible	▽		○															2	4			
Loading mechanism from shore			○				▽											1	5			
Loading mechanism from dock			○				▽											1	2			
Multiple chair sizes			▽				○											1	1			
Removable outriggers							○											5	5			
Swivel seating							○											1	1			
Lean rail							○											1	1			
Avoid chafing																		4	4			
Positive Bouyancy				○		●												5	5			
Affordability					●													2	1			
Lightweight				●		○																

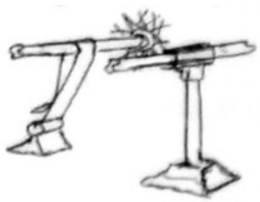
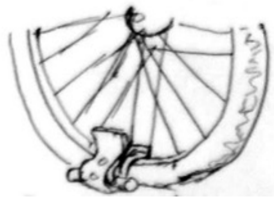
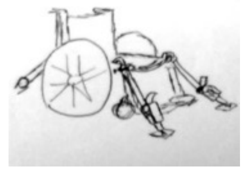
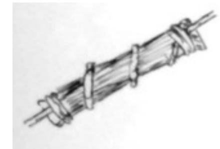


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target Values	100 ft-lb	no bubbles	5 min	75 lb of additional equipment	retrofit for less than $1000	floats with 200lb plus wheelchair										
Max Relationship	9	9	3	9	9	9	3									
Technical Importance Rating	129.5	87.8	78.1	53.1	91.0	139.7	84.7									
Relative Weight	20%	13%	12%	8%	14%	21%	13%									
Curr. Products: Our Current Product																
Competitor #1: Onit Ability																
Competitor #2: Living Spinal																
0																
0																
Column #																16

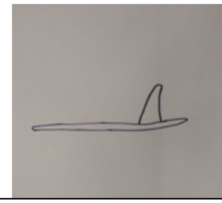
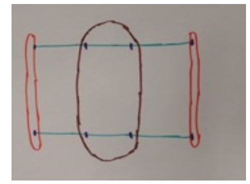
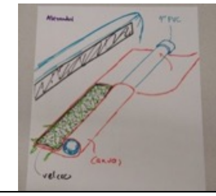


Appendix B: Pugh Matrices and Weighted Decision Matrices

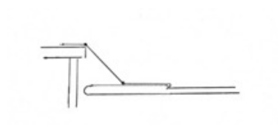
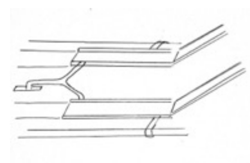
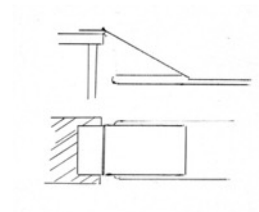
Pugh Matrix (Wheelchair Connection):

Concept / Criterion	 Onit Post & Strap	 Rim Lock	 Frame Hook w/ Ratchet	 Frame Hook w/ Bungee	 Frame Hook w/ Velcro
Secure/Stable	S	S	S	-	-
Waterproof	S	S	-	S	-
Diff. Configs Poss. (W/C, Deck, etc)	n/a	n/a	n/a	n/a	n/a
Loading from Shore	S	S	S	S	+
Loading from Dock	S	-	-	-	-
Multi Chair Sizes	-	S	+	+	++
Removable Stabilizers	n/a	n/a	n/a	n/a	n/a
Avoid Chafing	S	+	+	+	+
Positive Buoyancy	S	+	S	S	+
Affordability	-	S	S	S	+
Light Weight	S	+	S	S	+
Reproducibility	-	S	+	S	+
Adjustability	S	+	+	+	+
Total +	0	4	4	3	9
Total -	3	1	2	2	3
Total Same	8	6	5	6	0

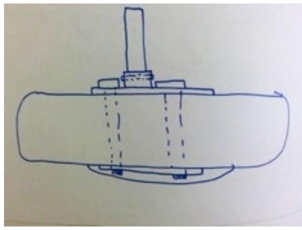
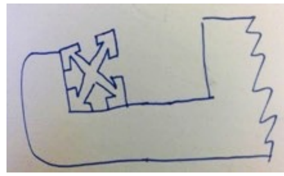
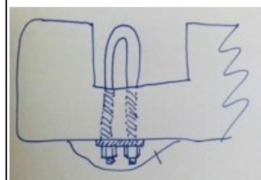
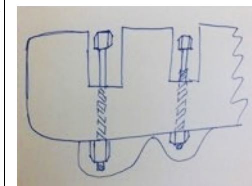
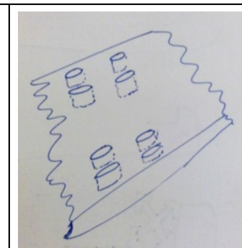
Pugh Matrix (Stabilization):

Concept / Criterion				
	Onit Ability Board	Deep Fins	Outriggers	Sideriggers
Secure/Stable	S	-	S	-
Waterproof	S	S	S	+
Diff. Configs Poss. (W/C, Deck, etc)	N/A	N/A	N/A	N/A
Loading from Shore	S	-	S	S
Loading from Dock	S	S	S	S
Multi Chair Sizes	S	N/a	N/A	N/A
Removable Stabilizers	S	-	S	S
Avoid Chafing	S	N/A	N/A	N/A
Positive Buoyancy	S	-	S	S
Affordability	S	S	S	+
Light Weight	S	+	S	+
Reproducibility	S	-	S	+
Adjustability	S	-	S	-
Total +	0	1	0	4
Total -	0	6	0	2
Total Same	10	3	10	4

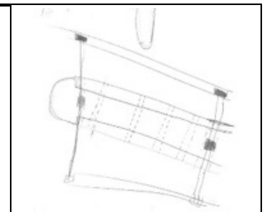
Pugh Matrix (Ramp):

Concept / Criterion	Onit Ability Board	Hook Attach Ramp 	Peg and Arm Ramp 	Full Width Ramp 
Secure/Stable	S	S	+	S
Waterproof	N/A	N/A	N/A	N/A
Diff. Configs Poss. (W/C, Deck, etc)	N/A	N/A	N/A	N/A
Loading from Shore	S	S	+	S
Loading from Dock	S	S	+	S
Multi Chair Sizes	S	S	S	+
Removable Stabilizers	N/A	N/A	N/A	N/A
Avoid Chafing	N/A	N/A	N/A	N/A
Positive Buoyancy	N/A	N/A	N/A	N/A
Affordability	S	S	-	+
Light Weight	S	S	-	-
Reproducibility	S	S	-	+
Adjustability	N/A	N/A	N/A	N/A
Total +	0	0	3	2
Total -	0	0	3	1
Total Same	7	7	1	3

Pugh Matrix (Wheelchair Connection):

Concept / Criterion					
	Onit - Single Embedded Block	Dual Channel	Embedded U-Bolt	Embedded Hex Bolts	Thru Holes
Secure/Stable	S	S	-	-	-
Waterproof	S	-	S	S	-
Diff. Configs Poss. (W/C, Deck, etc)	-	+	S	S	S
Loading from Shore	S	+	S	S	-
Loading from Dock	S	+	S	S	S
Multi Chair Sizes	S	S	+	+	+
Removable Stabilizers	S	+	S	S	S
Avoid Chafing					
Positive Buoyancy	S	-	S	S	-
Affordability	S	S	+	+	+
Light Weight	S	-	+	+	+
Reproducibility	-	S	+	+	S
Adjustability	-	+	S	S	S
Total +	0	5	4	4	3
Total -	3	3	1	1	4
Total Same	9	4	7	7	5

Pugh Matrix (Frame to Board):

Concept							
Criterion	Onit Post & Strap	Top-Deck Frame, Made of:			Strap Web	Rail Sleeve	Side Cups
		Fe	Aluminum	Carbon Fiber			
Secure	S	-	-	-	- -	-	-
Stable	S	-	-	-	- -	-	-
Waterproof	S	-	-	-	+	S	+
Diff. Configs Poss. (W/C, Deck, etc)	S	S	S	S	+	+	+
Loading from Shore	S	-	-	-	-	-	-
Loading from Dock	S	+	+	+	S	S	S
Multi Chair Sizes	S	S	S	S	+	+	+
Removable Stabilizers	S	+	+	+	S	S	S
Avoid Chafing	S	+	+	+	+	+	+
Positive Buoyancy	S	-	+	+	+ +	+ +	+ +
Affordability	S	+	+	-	+ +	+ +	+ +
Light Weight	S	S	S	S	+	+	+
Reproducibility	S	+	+	S	+	+	+
Adjustability	S	+	+	+	+	+	+
Total +		6	7	5	11	6	11
Total -		4	3	4	5	4	3
Total Same		4	4	5	2	4	2

Finalized Weighted Decision Matrix (Strap-on frames only):

Criteria	Weight	Designs			
		1 Frame, Velcro, Full Ramp, Outriggers		2 Side cup, Ratchet, Full Ramp, Outriggers	
		Score	Total	Score	Total
Longitudinal Adjustability	4	5	20	4	16
Secure	5	5	25	5	25
Waterproof	5	5	25	4	20
Different Configs. Poss.	4	5	20	5	20
Stable	4	5	20	5	20
Shore Loading	3	5	15	5	15
Deck Loading	2	5	10	5	10
Multiple Chair Sizes	5	5	25	4	20
Reproducibility	3	5	15	4	12
Affordability	4	4	16	4	16
Positive Buoyancy	5	4	20	4	20
Transferability	3	4	12	4	12
Total			223		206

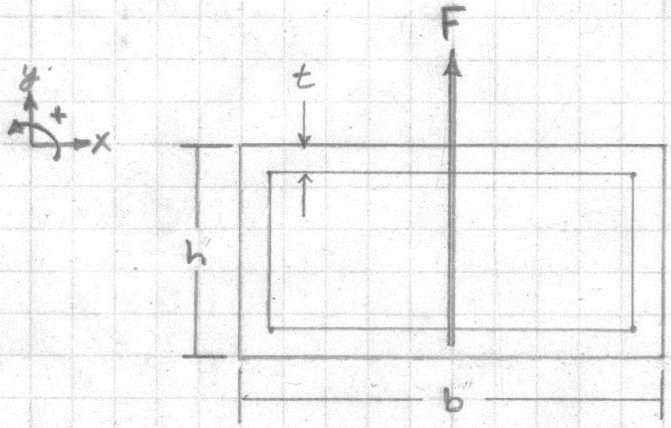
Original Weighted Decision Matrix (without strap-on frame):

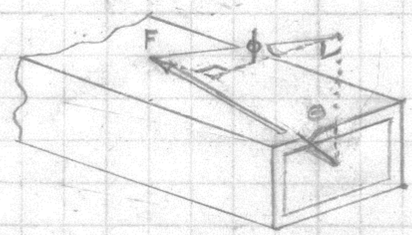
Criteria	Weight	Designs													
		1 Chnls & Rails, Velcro, 3-Point Ramp, Outriggers		1a Rails Only, Velcro, 3-Point Ramp, Outriggers		2 Deck Bolts, Ratchets, 3-Point Ramp, Outriggers		2a Deck Bolts, Velcro, 3-Point Ramp, Outriggers		3 Chnls & Rails, Rim Locks, Full Ramp, Sideriggers		4 Aluminum Frame, Velcro, 3-Point Ramp, Outriggers		5 Side Cups, Velcro, 3-Point Ramp, Outriggers	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Longitudinal Adjustability	4	5	20	5	20	4	16	5	20	4	16	5	20	5	20
Secure	5	4	20	4	20	5	25	4	20	3	15	3	15	2	10
Waterproof	5	4	20	5	25	5	25	5	25	4	20	5	25	5	25
Different Configs. Poss.	4	5	20	5	20	3	12	4	16	5	20	5	20	0	0
Stable	4	5	20	5	20	5	20	5	20	3	12	4	16	3	12
Shore Loading	3	5	15	4	12	4	12	4	12	4	12	4	12	5	15
Deck Loading	2	5	10	4	8	4	8	4	8	4	8	4	8	5	10
Multiple Chair Sizes	5	4	20	5	25	5	25	5	25	2	10	5	25	5	25
Reproducibility	3	3	9	4	12	4	12	4	12	3	9	5	15	4	12
Affordability	4	3	12	5	20	5	20	5	20	3	12	5	20	5	20
Positive Buoyancy	5	2	10	4	20	5	25	5	25	2	10	3	15	5	25
Transferability	3	0	0	0	0	0	0	0	0	0	0	5	15	5	15
Total			176		202		200		203		144		206		189

Appendix C: Preliminary Analysis

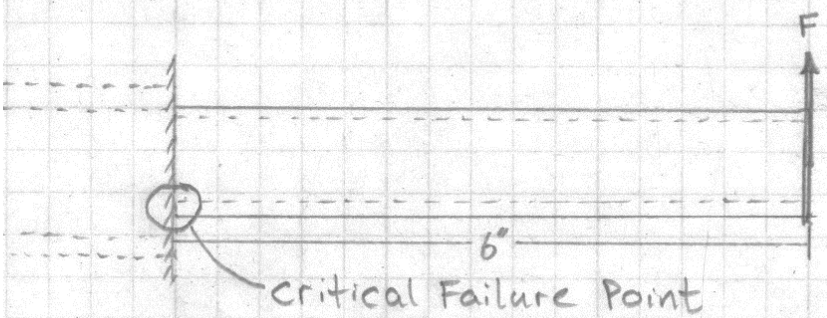
Stress Analysis of Transverse Cross-Member

→ Analyze under worst-case loading, full transverse across narrowest dimension of beam





↑ Actual Orientation



→ Model clamped member as cantilever beam

Yield Strength

$$\sigma_m = -\frac{Mc}{I} = -\frac{F\ell c}{I}$$

$$|F| = \frac{\sigma_m I}{\ell c}$$

Moments

$$I = \frac{1}{12} bh^3 - \frac{1}{12} b_i h_i^3$$

$$= \frac{1}{12}\left(bh^3 - (b-2t)(h-2t)^3\right)$$

2" x 1" x 1/8" 6061 T6 → $\sigma_y = 35$ ksi

$$I = \frac{1}{12}\left((2)(1)^3 - (1.75)(.75)^3\right) = .1051 \text{ in}^4$$

$$F_{max} = \frac{(35{,}000 \frac{lb}{in^2})(.1051 \text{ in}^4)}{(6 \text{ in})(.5 \text{ in})} = \boxed{1226 \text{ lb}}$$ → maximum load per strap

Appendix D: Design Hazard Checklist, Risk Assessment, & FMEA

Team: __Adaptive Paddle___________________________ Advisor: __Sarah Harding______Date: 11/25/18

YN
☐× ☐ 1. Will the system include hazardous revolving, running, rolling, or mixing actions?
☐ ☐× 2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions?
☐ ☐× 3. Will any part of the design undergo high accelerations/decelerations?
☐ ☐× 4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces?
☐ ☐× 5. Could the system produce a projectile?
☐ ☐× 6. Could the system fall (due to gravity), creating injury?
☐ ☐× 7. Will a user be exposed to overhanging weights as part of the design?
☐ ☐× 8. Will the system have any burrs, sharp edges, shear points, or pinch points?
☐ ☐× 9. Will any part of the electrical systems not be grounded?
☐ ☐× 10. Will there be any large batteries (over 30 V)?
☐ ☐× 11. Will there be any exposed electrical connections in the system (over 40 V)?
☐ ☐× 12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases?
☐ ☐× 13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system?
☐ ☐× 14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design?
☐ ☐× 15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing?
☐ ☐× 16. Could the system generate high levels (>90 dBA) of noise?
☐× ☐ 17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use?
☐× ☐ 18. Is it possible for the system to be used in an unsafe manner?
☐ ☐× 19. For powered systems, is there an emergency stop button?
☐ ☐× 20. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

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

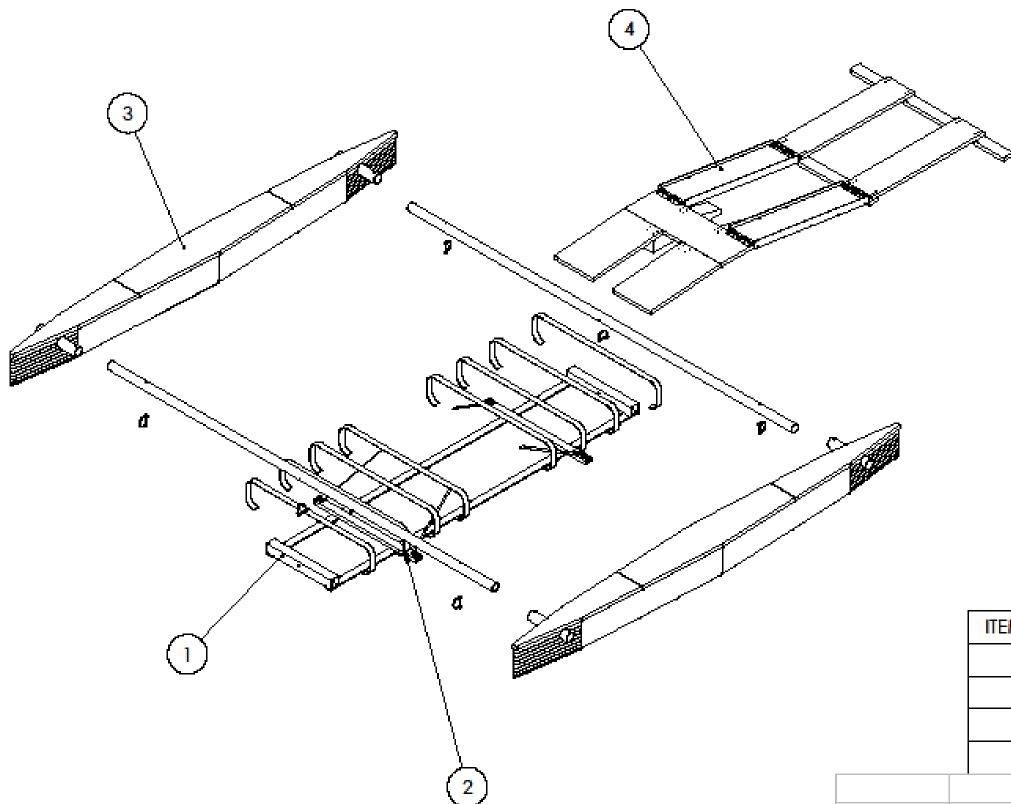
Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Potential Pinching where straps attach to chair	Design the attachment system so that the straps attach to parts of the chair that are well away from the user. Make sure users are aware of this potential risk and how to avoid it.	12/6	12/8
Frequent exposure to water could lead to rust, corrosion or leaking.	Avoid using metal in the design, and when metal is necessary use metals that would be more resistant to corrosion or rust. Research methods of properly sealing the board. pontoons and ramp against water damage.	1/10	1/26
If the user is not properly attached to the chair, they could be injured	Provide clear instructions on proper usage of the board. Educate adaptive centers about proper mounting techniques.	3/17	5/25
Hard pieces of the above-board frame that the user could hit themselves against	Cover hard points of the frame with a soft foam mat cut to fit protruding geometries using a waterproof silicone adhesive	3/1	6/3

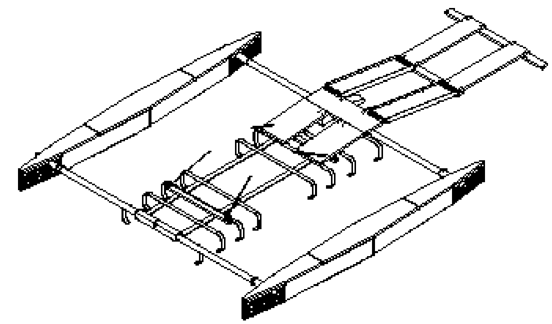
												Action Results				
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**RPN**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Criticality**	**RPN**
Frame to Board Attachment	Frame is loose	a) User falls into water b) wheelchair gets wet c) risk of injury from hitting board or frame d) trouble paddling around	6	1)Straps fail/slip 2)Buckles fail/corrode 3)Loose Straps 4)Not enough friction between rails and board	1) Purchase higher grade straps with higher friction 2) Apply water resistsnt coating to buckles	3	Torque Test Accelerated Corrosion Test	1	18							
	Frame comes unattached	a) user falls off board b) frame and wheelchair sink and are lost	8	1)Straps fail/slip 2)Buckles fail/corrode	1) weigh users 2) impact factor 3) stress analysis 4) fatigue strength	1	Strap stress test	1	8							
	Attachment system pinches user	a) user suffers injury	9	1) Buckles corrode/are difficult to use	1) deflection analysis 2) fastener shear analysis	2	Accelerated Corrosion Test	3	54							
Wheelchair attachemnt system	Wheelchair comes unattached to frame	a) user falls off board b) wheelchair sinks and is lost	8	1)Straps break 2)Velcro Fails 3)Transverse bars become unattached to frame 4)Strap tears 5)Trasverse bars break	1) High quality straps 2) Weld the transverse boards 3)Climbing grade carabiners 4)Large safety factor on stress analysis for tranverse bars	2	Load test	2	32							
	Wheelchair shifts position but is still secure	a) user is in wrong position b) user cannot paddle effectively	4	1) Velcro slips 2) frame slips 3)loosened straps	1)High quality straps	7	Strap stress test Velcro shear test	2	56							
	Wheelchair can move easily	a) user falls b) user is out of position on board	4	1) Straps break 2) Velcro Fails 3) Transverse bars become unattached to frame	1) High quality straps 2) Weld the transverse boards	6	Strap stress test Velcro shear test Weld inspection	4	96	1)Practice welding the joints and perform a study on the weld strength 2)Increase velcro strap width	GJ-practice welds by Feb 1st and contact Kevin Williams					
	Frame loses structural integrity	a) chair comes off b) pontoons come off	7	1)frame components become unattached 2)frame components bend/break	1) large safety factors on stress analysis	1	NA	10	70	1) Test frame by loading with more weight than that of a typical user	Sean - testing after frame protoype is built (4/30)					
Outrigger system-provide buoyancy	Paddleboard sinks	a) user is not supported	9	1) Pins break 2) Struts break	1) pins and struts with high yield strength	1	Stress test on pin	3	27							
	Paddleboard submerged underwater	a) user in the water b) user is injured	6	1)pontoons lose buoyancy	1) waterproof sealing of pontoons	2	Leak test	5	60							
	Pontoons become unattached	a) board feels unstable	3	1) Hardwear fails 2)Struts break 3)Attachment brackets fail	1)Stress analysis on hardwear loading and struts	2	NA	10	60							

												Action Results				
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality	RPN
Outrigger System-Prevents Tipping	Fail to transfer balancing reactions from outrigger buoyancy	a) board rocks b) board capsizes	6	1)pontoons lose buoyancy 2)frame breaks 3)attachment brackets fail 4)struts break	1)Stress analysis on hardwear loading and struts 2) weld frame well	3	visual weld inspection	4	72	1)Practice welding the joints and perform a study on the weld strength 2)Increase size of carbon fiber struts	GJ-practice welds by Feb 1st and contact Kevin Williams					
	Paddle board Tilts (imbalanced)	a) user is uncomfortable b) user falls	4	1) Outrigger tubes asymmetrical 2) Pins break	1) Align pin in center of rail 2) Higher grade material pin with low stress cofiguration	3	Visual Inspection	2	24							
Ramp System-Supports Load	Ramp loses structural integrity	a) ramp breaks b) user cannot be loaded onto board	7	1) Hinge breaks 2) Hinge corrodes	1) Coat ramp metal 2) Higher grade attachments	2	Load test	1	14							
Ramp System-Secures loading surface	Shifting during loading	a) user ends up out of position b) user rolls off board	4	1) Ramp not securely attached	1) Proper selection of components for appropriate strength	6	Attempted wheelchair load test w/ Poly student subjects	4	96	If willing, run Sponsor's central coast contact or group membersthrough a series of loading tests.	AH - Contact sponsor and request contact's availability 12/5 Schedule tests 3/15					
Ramp System-Secures loading surface	Ramp tips up during loading	a) user falls out of chair during loading	4	1) ramp not weighted down sufficently	1) design feature to prevent occurances	4	Attempted wheelchair load test w/ Poly student subjects	4	64							

Appendix E: BOM & Assembly Drawings

Part Number	Lvl0	Lvl1	Lvl2	Lvl3	Details
	Final Assy				
100000		1) Attachment Frame			
101000			1.1) Frame Straps		
				Nylon Lashing Straps	NRS 1.5" x 6'
102000			1.2) Aluminum Frame		
102001				Longitudinal Rail (8')	6061 T6 Al Beam .375" x 2" x 8'
102002				Transverse Box Beam (32")	6061 T6 Al Sq Tube 1" x 2" x 0.125" x 32"
102003				Strut Housing (20")	6061 T6 Al Rd Tube 2.5" OD x 0.1875" x 20"
200000		2) Anchor Straps			
200001				Nylon Strap	NRS 1.5" x 6'
200002				Velcro Straps	
200003				SS Hex Nut	
200004				SS Hex Bolt (3/8")	
200005				SS Cut Washer (3/8")	
200006				SS Fender Washer (3/8")	
200007				SS Lock Washer (3/8")	
200008				SS Nylock Nut (3/8")	
200009				Nylon Washer (3/8")	
300000		3) Stabilizing Outriggers			
301000			3.1) Struts		
301001				Strut Poles	
301002				Strut Pins	
301003				Inserts	
302000			3.2) Pontoons		
302001				Polyeurethane Foam	Sheets, 4'x10'
302002				~~7.2~~ 6oz cloth (30" width)	per yard
302003				UV-Cure Polyester Resin	5 Gal (George wants to purchase remainder)
302004				Wax Hot Coat	Quart
302005				Q-Cell Filler Material	Pint
302006				F/G Tape	per yard
302007				Stir Sticks	Bundle
302008				Squeegee	6"
302009				Brushes (2")	Box, 2 dozen per
302011				Masking Tape	Roll, 2"
302016					Roll, 1"
302012				Sandpaper	36 grit, 3" disc
302017					60 grit, Sheet
302018					80 grit, box
302019					100 grit, sheet
302020					220 grit, sheet
302021				Adhesive	Bottle, aerosol
302013				Acetone	5 Gal (George wants to purchase remainder)
302010				Gloves	Box, size L
302014				Resirator Kits	
302022					Respirator Frame
302023					OV Cartridge Pack
302024					Dust Cartridge Pack
302025				Dust mask	
302015				Inserts	Al 6061 T6 Tube 2.5" OD x 0.125" x 12"
302026				Gel Coat	White
302027				Duratek	
302028				HVLP Paint Gun	
400000		4) Loading Ramp			
401000			4.1) Deck		
401100				HDPE Sheet Stock	
401101				10" x 30" x 1" HDPE	
401102				12" x 22" x 1" HDPE	
401103				8" x 36" x 1" HDPE	
401104				8" x 36" x 1" HDPE	
401105				3" x 30" x 1" HDPE	
401106				3" x 48" x 1" HDPE	
402000			4.2) Support Legs		
402100				4x4 Stock	4" x 4" x 8'
402101				Support Block (large)	
402102				Support Block (small)	
402200				Tire Chocks	
403000				Hinges	
404001				#8 x 2" Construction Screws	
404002				#8 x 1-1/4" Construction Screws	
405001				Angle Stock	
405002				Angle Supports	2" x 2" x 3'





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	100000	ATTACHMENT FRAME	1
2	200000	ANCHOR STRAP	1
3	300000	STABILIZING OUTRIGGER	1
4	400000	LOADING RAMP	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

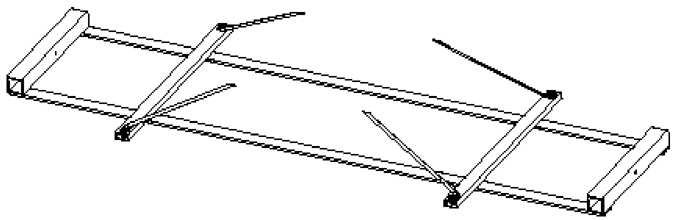
NEXT ASSY | USED ON
APPLICATION

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

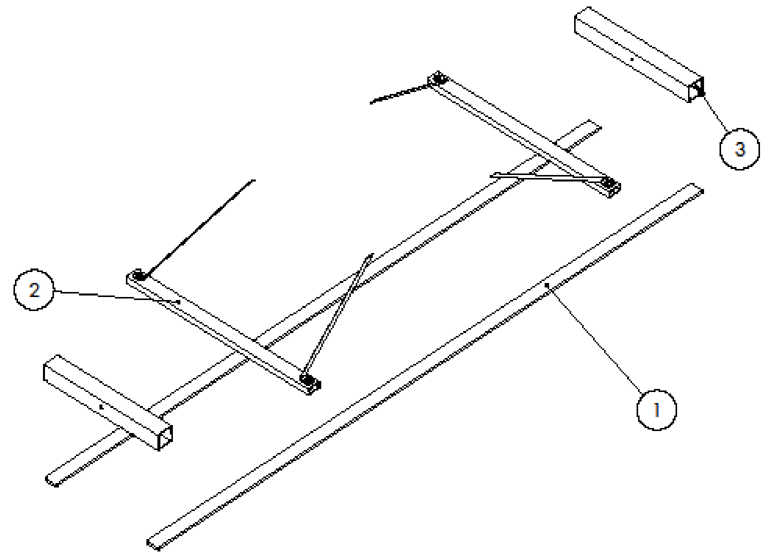
TITLE:
ADAPTIVE PADDLE BOARD

SIZE B | DWG. NO. | REV

SCALE: 1:48 WEIGHT: 140 LBS SHEET 1 OF 1



NOTE: PERPENDICULARITY TOLERANCE ±1°



ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	102001	8' LONGITUDINAL RAIL	6161 T6 ALUMINUM	2
2	102002	32" TRANSVERSE BOX BEAM	6161 T6 ALUMINUM	2
3	102003	OUTRIGGER STRUT HOUSING	6161 T6 ALUMINUM	2

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.

NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.0625
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

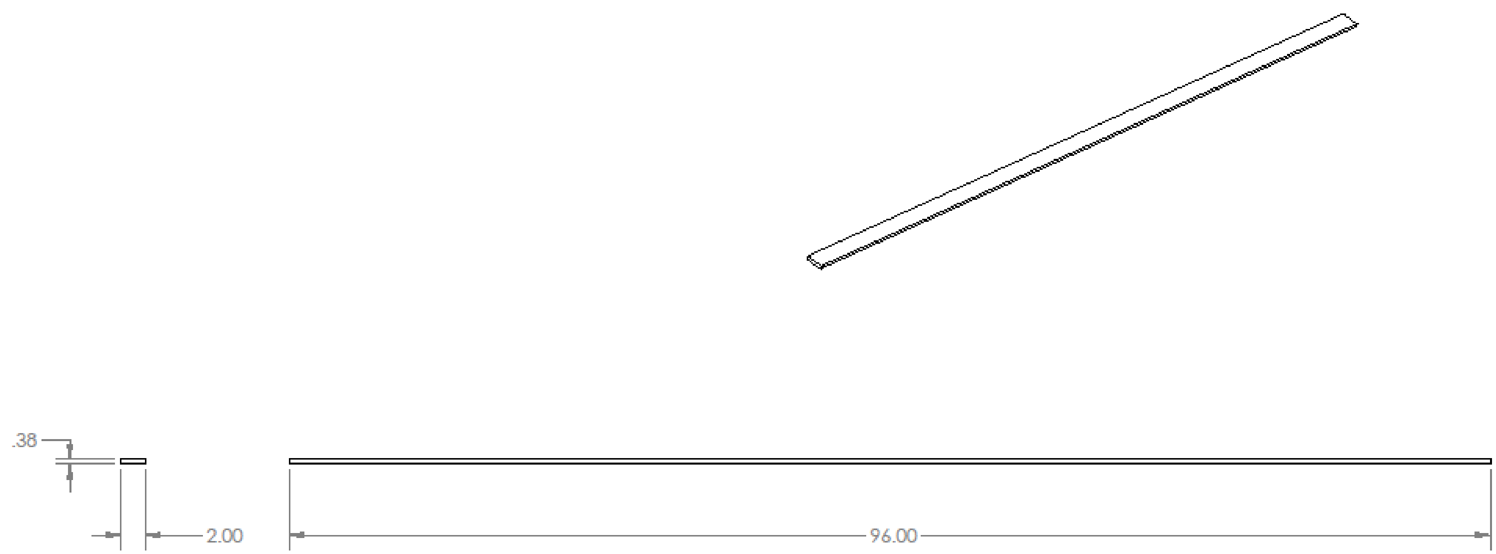
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
ALL ALUMINUM COMPONENTS ARE WELDED WHERE EDGES MEET.

TITLE:
ATTACHMENT FRAME

SIZE **B** | DWG. NO. 100000 | REV

SCALE: 1:20 | 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.

NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.0625
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

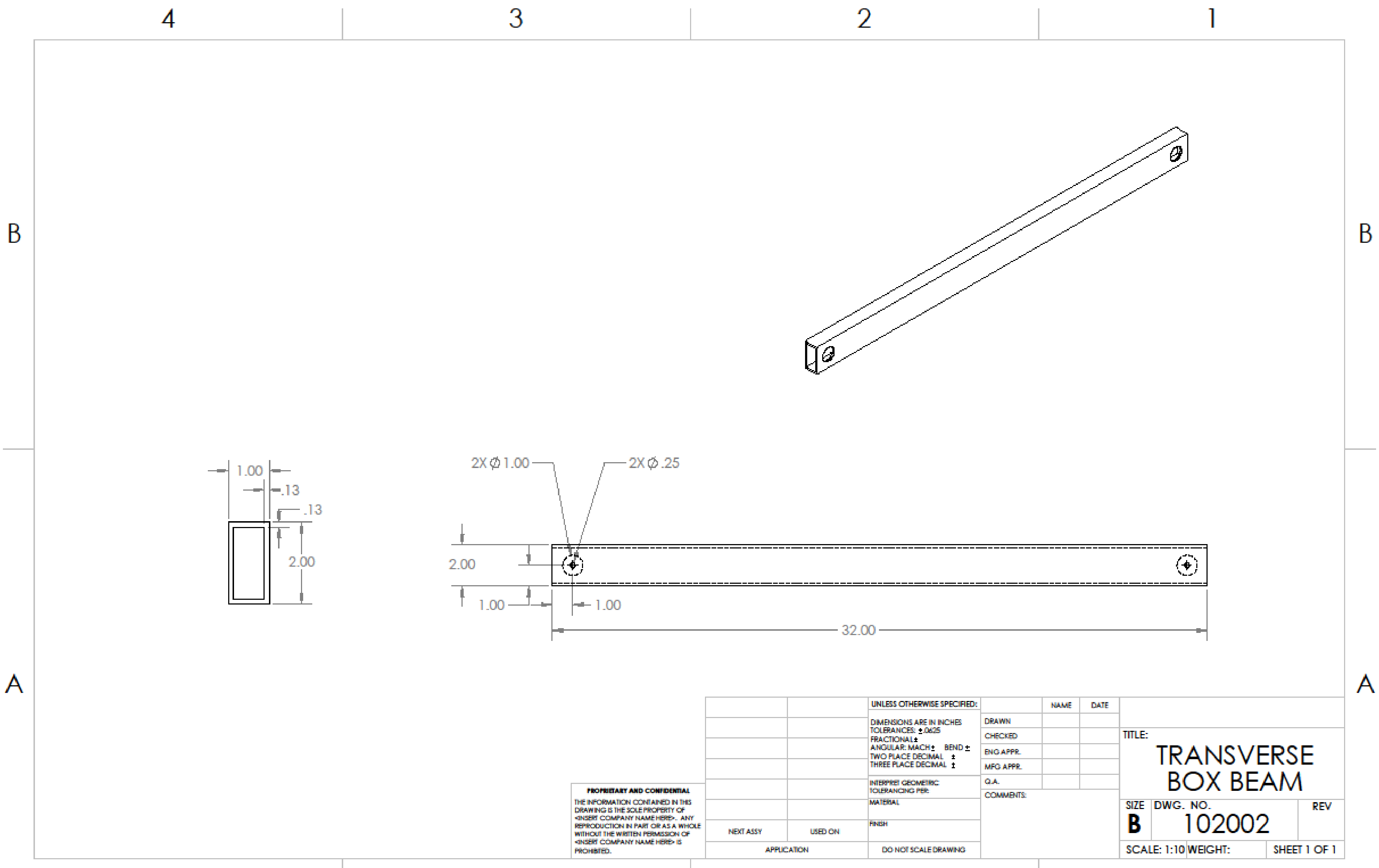
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

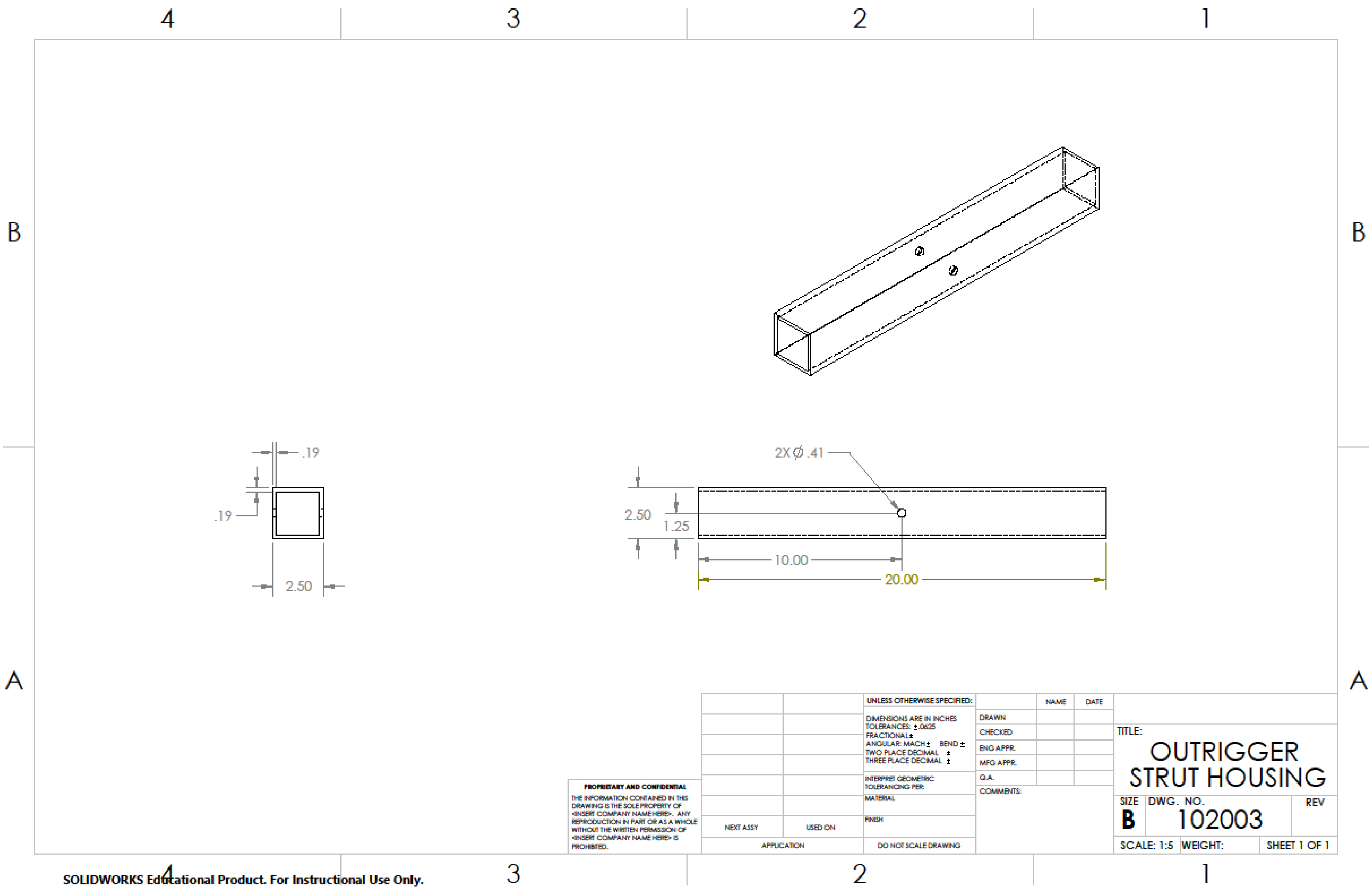
COMMENTS:

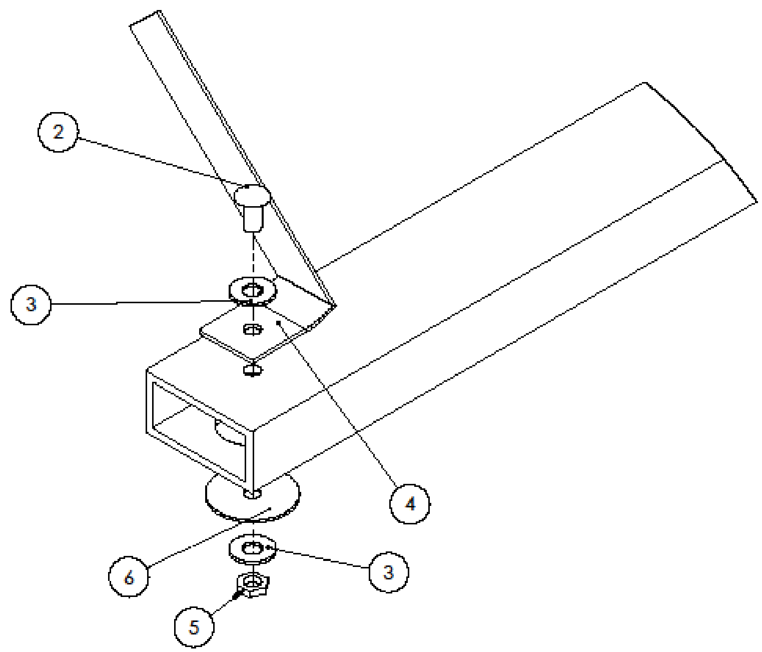
TITLE:
LONGITUDINAL RAIL

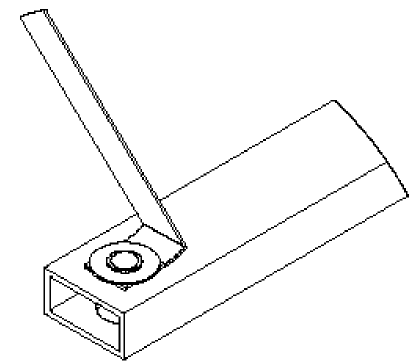
SIZE B | DWG. NO. 102001 | REV

SCALE: 1:50 | WEIGHT: | SHEET 1 OF 1


2X Ø1.00
2X Ø.25
1.00
.13
.13
2.00
2.00
1.00
1.00
32.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.0625
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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.
TITLE:
TRANSVERSE BOX BEAM
SIZE
B
DWG. NO.
102002
REV
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1


.19
.19
2.50
2X Ø .41
2.50
1.25
10.00
20.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.0625
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NEXT ASSY
USED ON
APPLICATION
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.
TITLE:
OUTRIGGER STRUT HOUSING
SIZE
B
DWG. NO.
102003
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1





ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	102002	32" TRANSVERSE BOX BEAM	6161 T6 ALUMINUM	1
2	200004	3/8" HEX BOLT	ZINC	2
3	200005	3/8" CUT WASHER	ZINC	2
4	200001	NRS STRAP	NYLON	2
5	200003	3/8" HEX NUT	ZINC	2
6	200006	3/8" FENDER WASHER	ZINC	2

NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

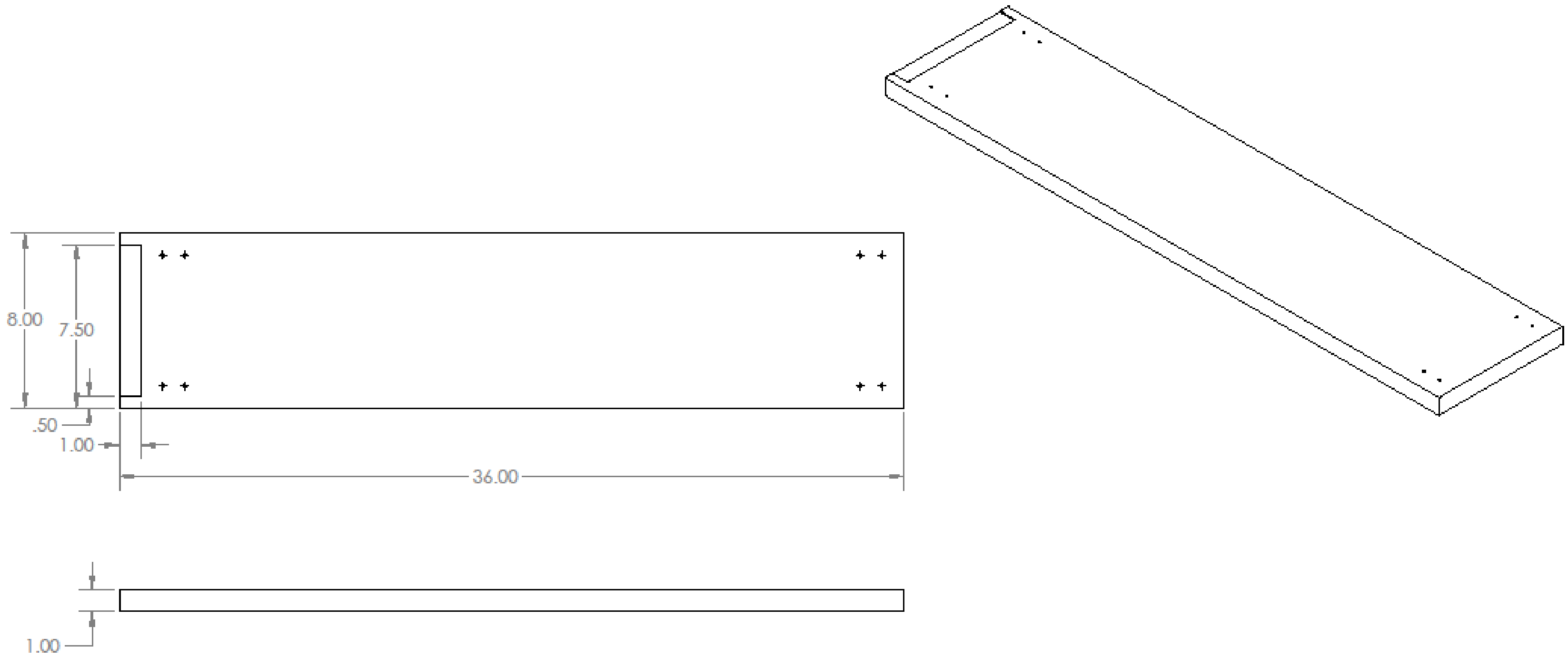
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
ANCHOR STRAPS

SIZE **B** | DWG. NO. 20000 | REV

SCALE: 1:10 | 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.

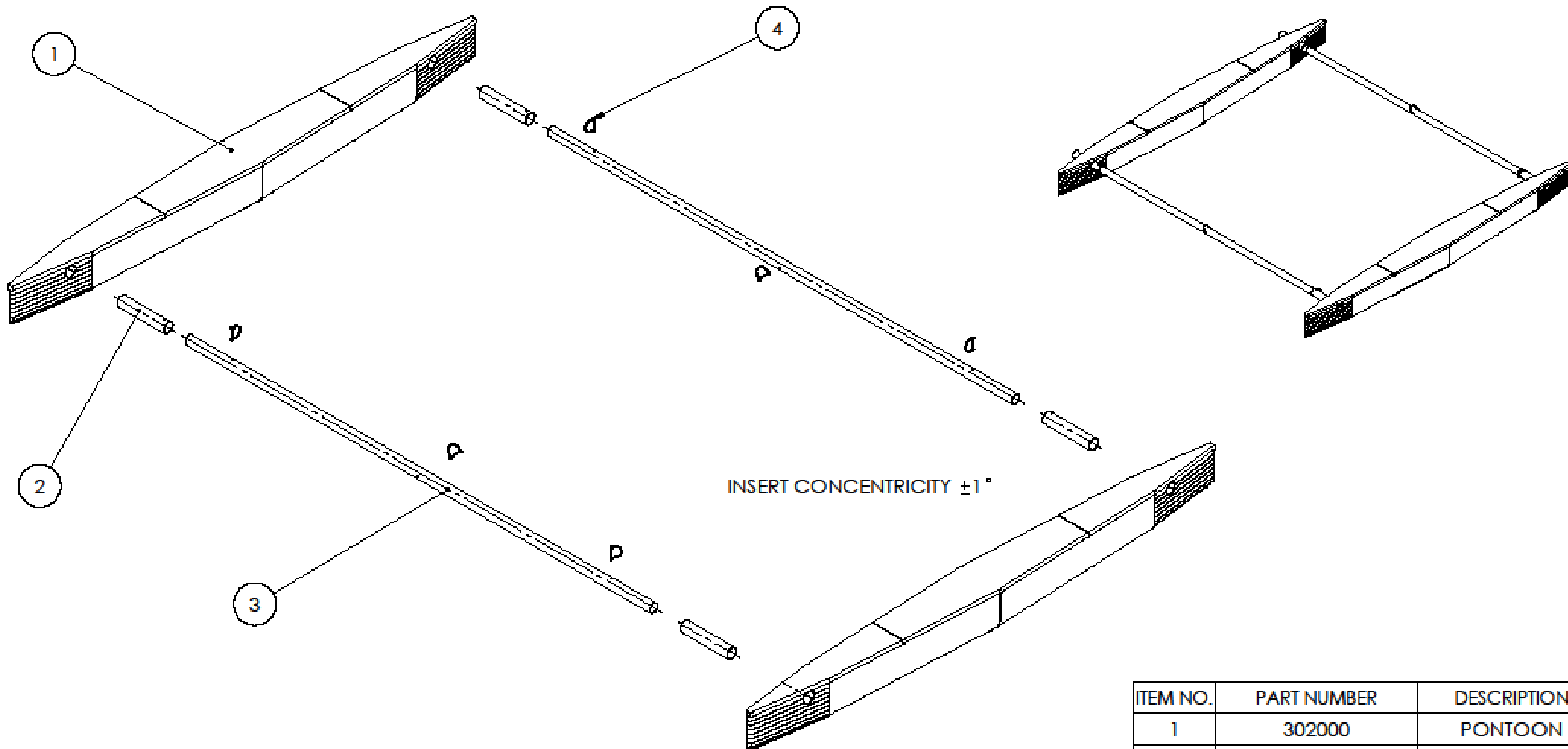
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: ±.125 FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH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

TITLE:

8" X 36" X 1" HDPE

SIZE	DWG. NO.	REV
B	401104	
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	302000	PONTOON	2
2	301003	INSERTS	4
3	301001	STRUT POLES	2
4	301002	STRUT PINS	6

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.

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

COMMENTS:

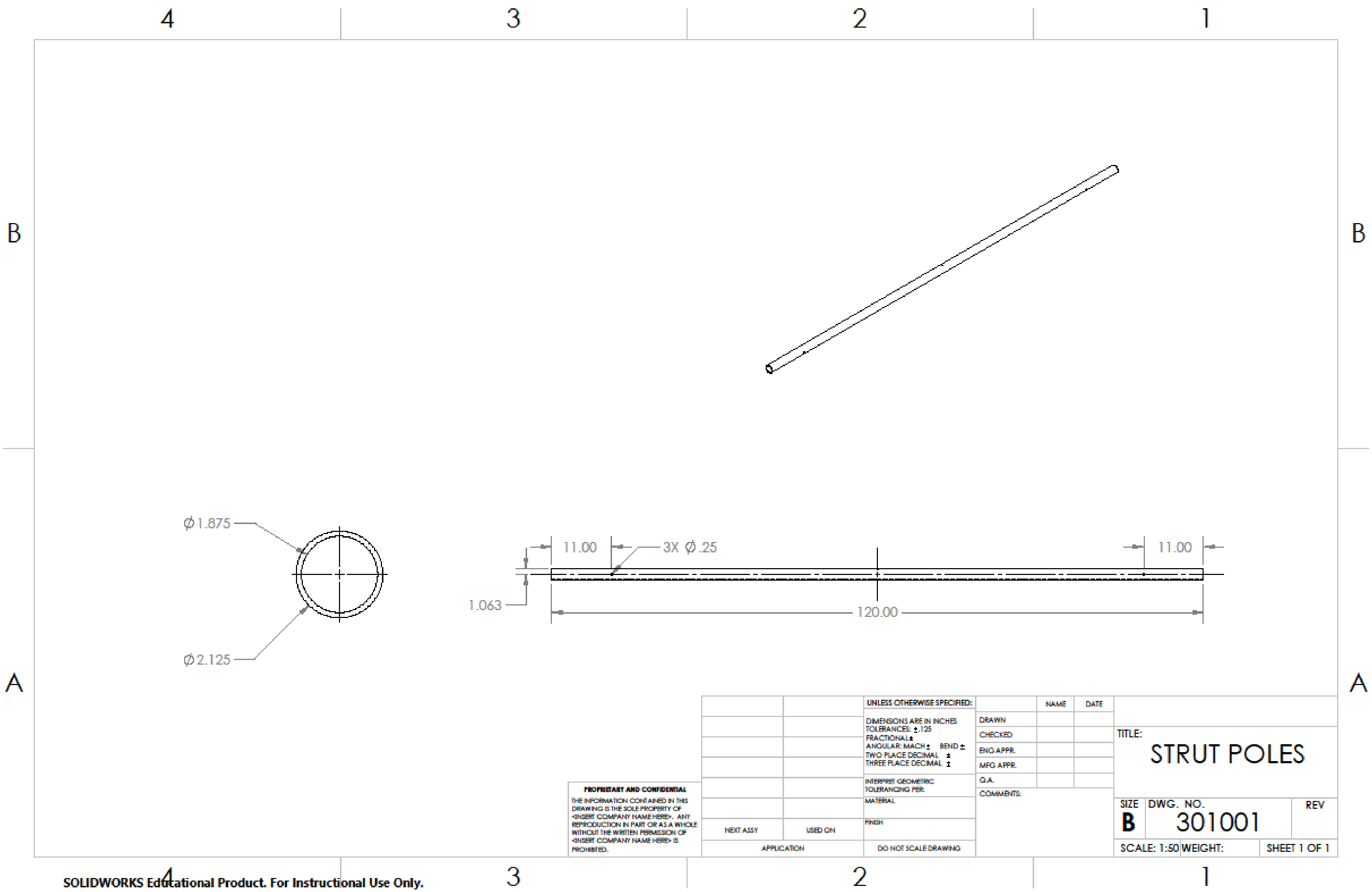
TITLE:

STABILIZING OUTRIGGER

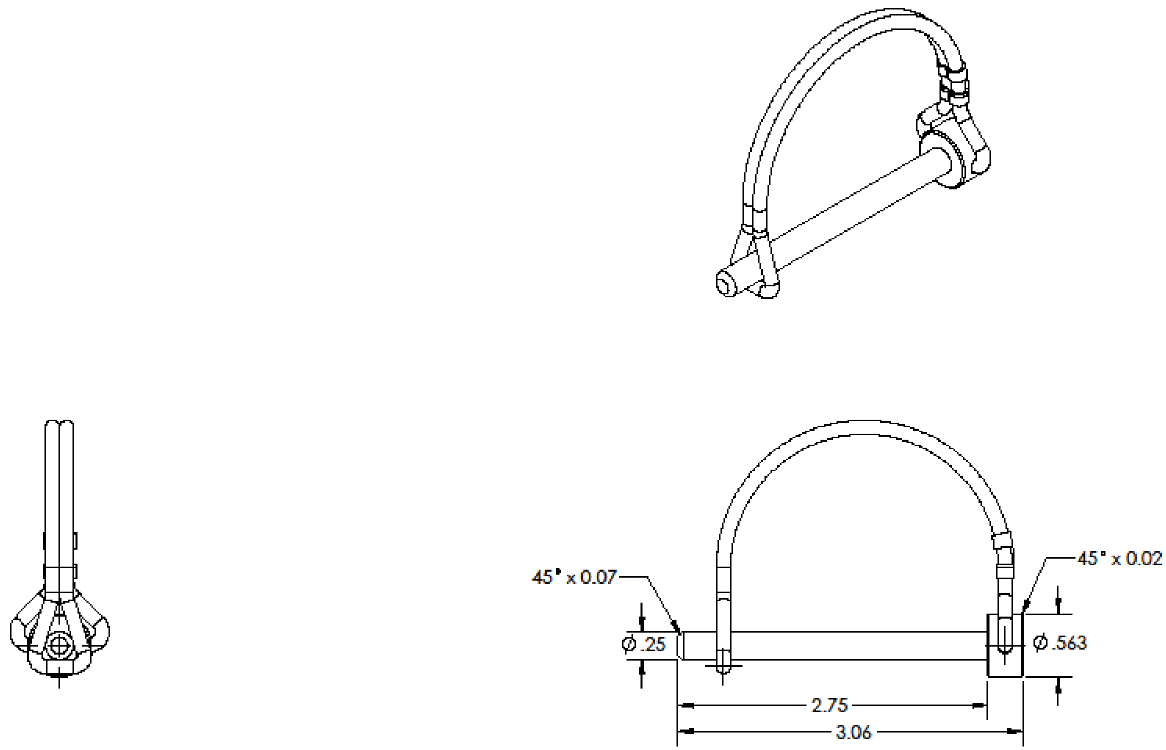
SIZE **B** | DWG. NO. 300000 | REV

SCALE: 1:50 | WEIGHT: | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



Ø1.875
Ø2.125
1.063
11.00
3X Ø.25
11.00
120.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
STRUT POLES
SIZE
B
DWG. NO.
301001
REV
SCALE: 1:50
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
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.
SOLIDWORKS Educational Product. For Instructional Use Only.

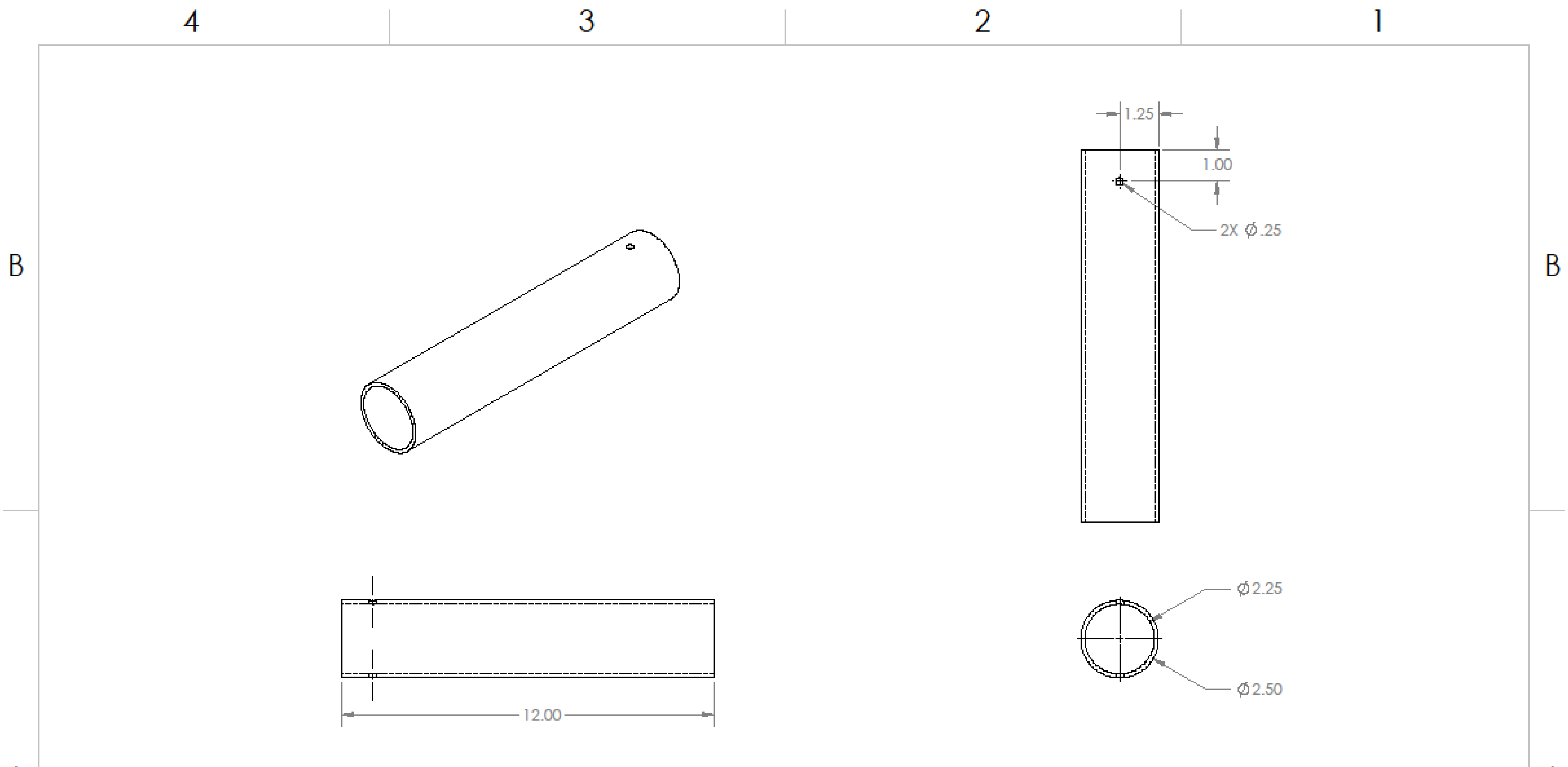


UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
DIMENSIONS ARE IN INCHES TOLERANCES: ±.0625 FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE:	STRUT PIN
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL	COMMENTS:			SIZE B	DWG. NO. 301002 REV
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT:	SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

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.



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.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

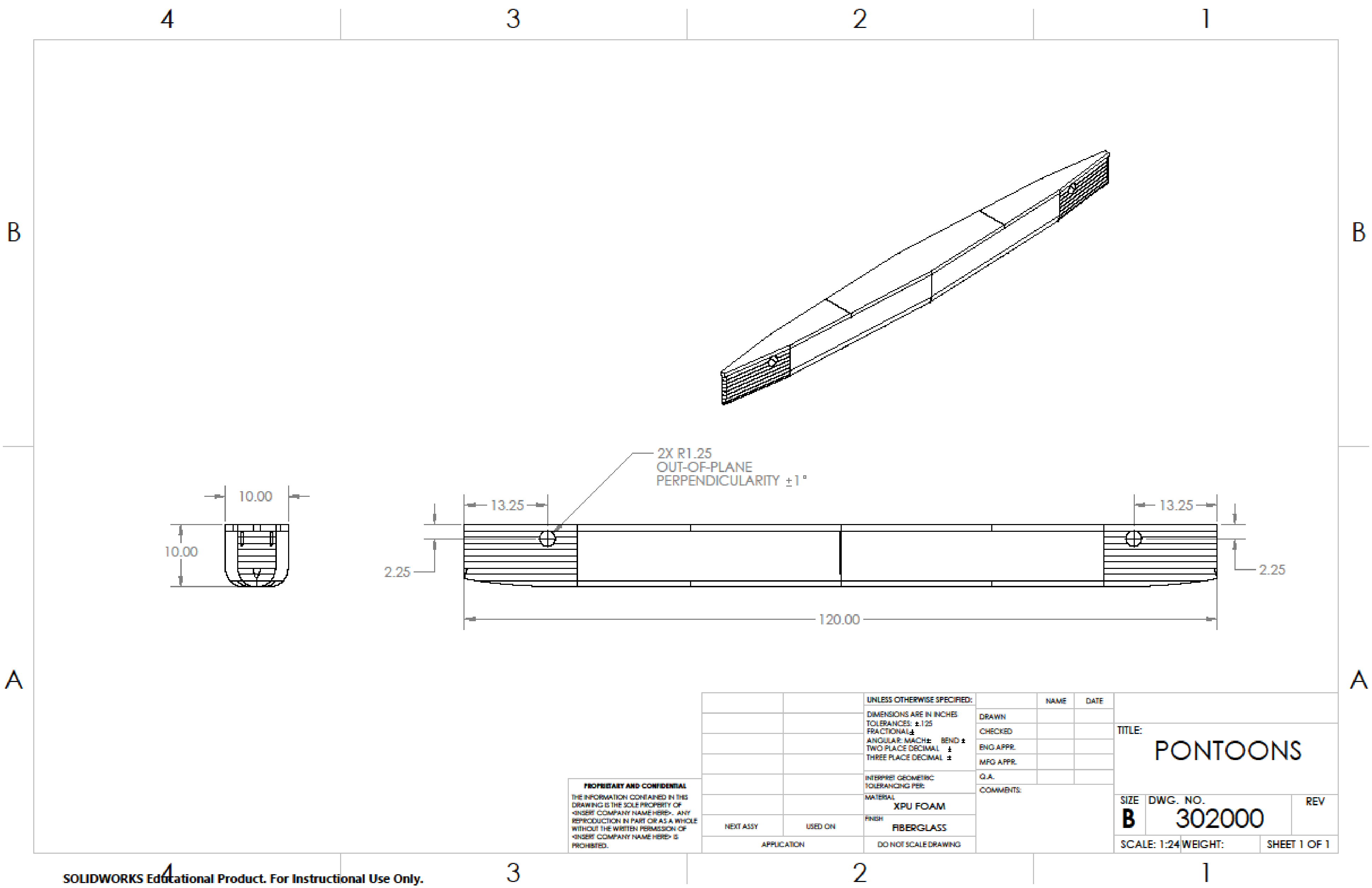
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

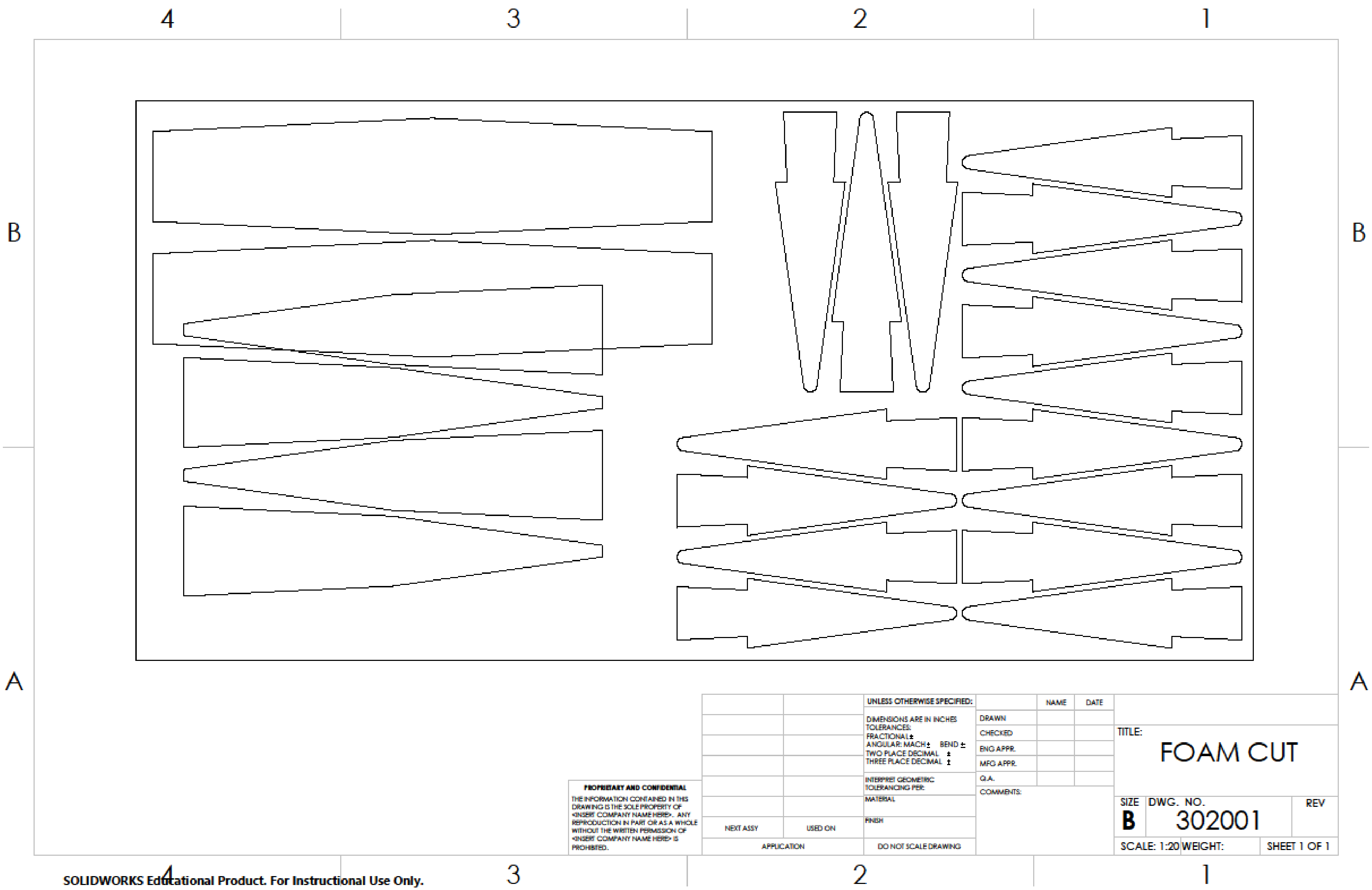
COMMENTS:

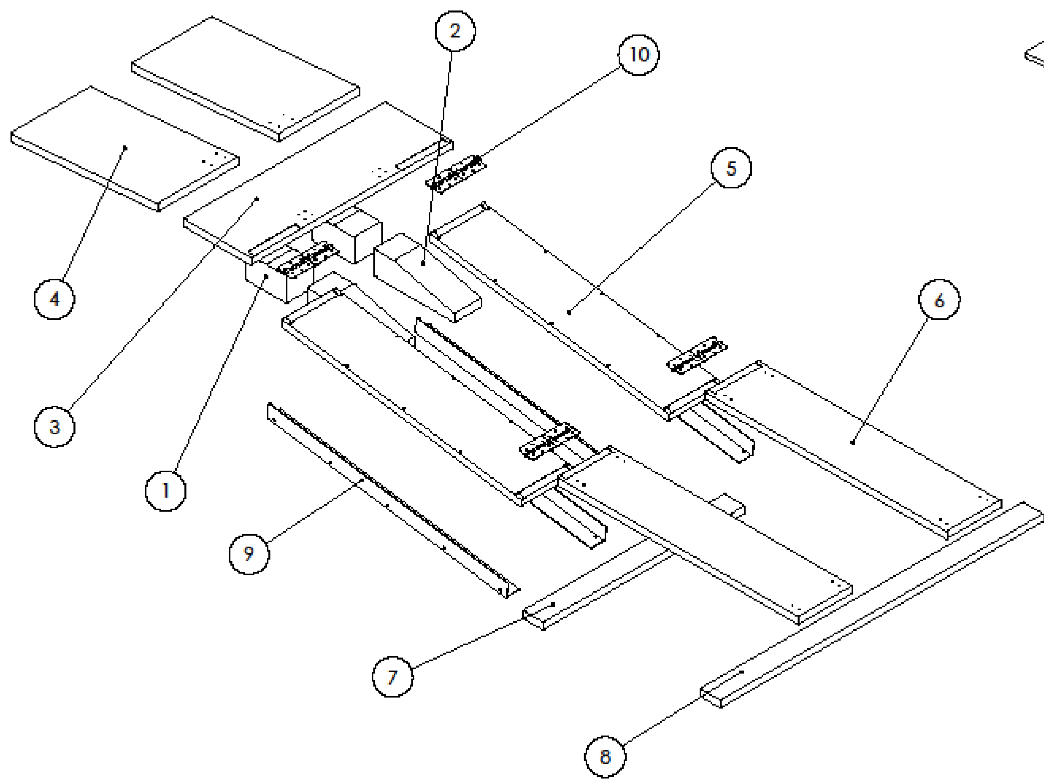
TITLE: INSERT

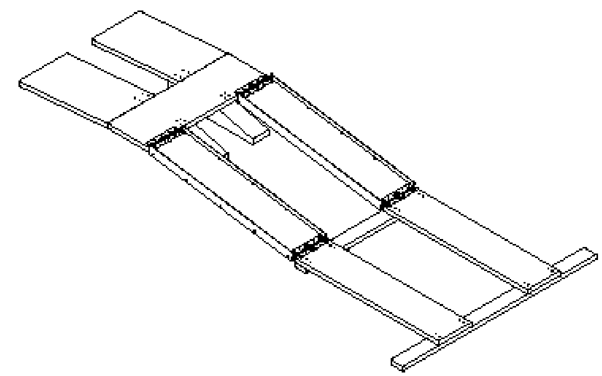
SIZE	DWG. NO.	REV
B	301003	
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.


2X R1.25
OUT-OF-PLANE
PERPENDICULARITY ±1°
10.00
10.00
13.25
13.25
2.25
2.25
120.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
XPU FOAM
FINISH
FIBERGLASS
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
PONTOONS
SIZE
B
DWG. NO.
302000
REV
SCALE: 1:24
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.
SOLIDWORKS Educational Product. For Instructional Use Only.


4
3
2
1
B
B
A
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
FOAM CUT
SIZE
B
DWG. NO.
302001
REV
SCALE: 1:20
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.
NEXT ASSY
USED ON
APPLICATION





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	402101	SUPPORT BLOCK, SHORT	2
2	402102	SUPPORT BLOCK, LARGE	2
3	401101	10" X 30" X 1" HDPE	1
4	401102	12" X 22" X 1" HDPE	2
5	401103	8" X 36" X 1" HDPE	2
6	401103	8" X 36" X 1" HDPE	2
7	401105	3" X 30" X 1" HDPE	1
8	401106	3" X 48" X 1" HDPE	1
9	405001	ALUMINUM ANGLE	4
10	403000	HINGE	8

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.

NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .125
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

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

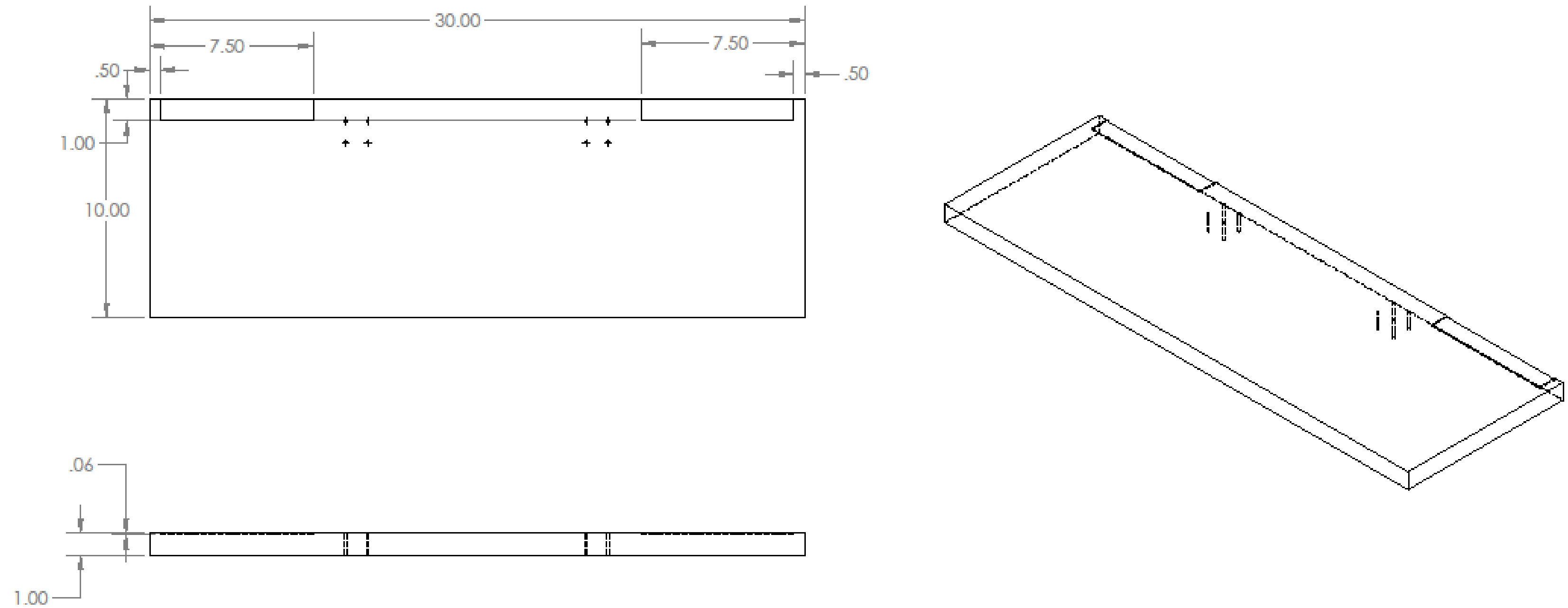
COMMENTS:

TITLE:

LOADING RAMP

SIZE B | DWG. NO. 400000 | REV

SCALE: 1:24 | 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.

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

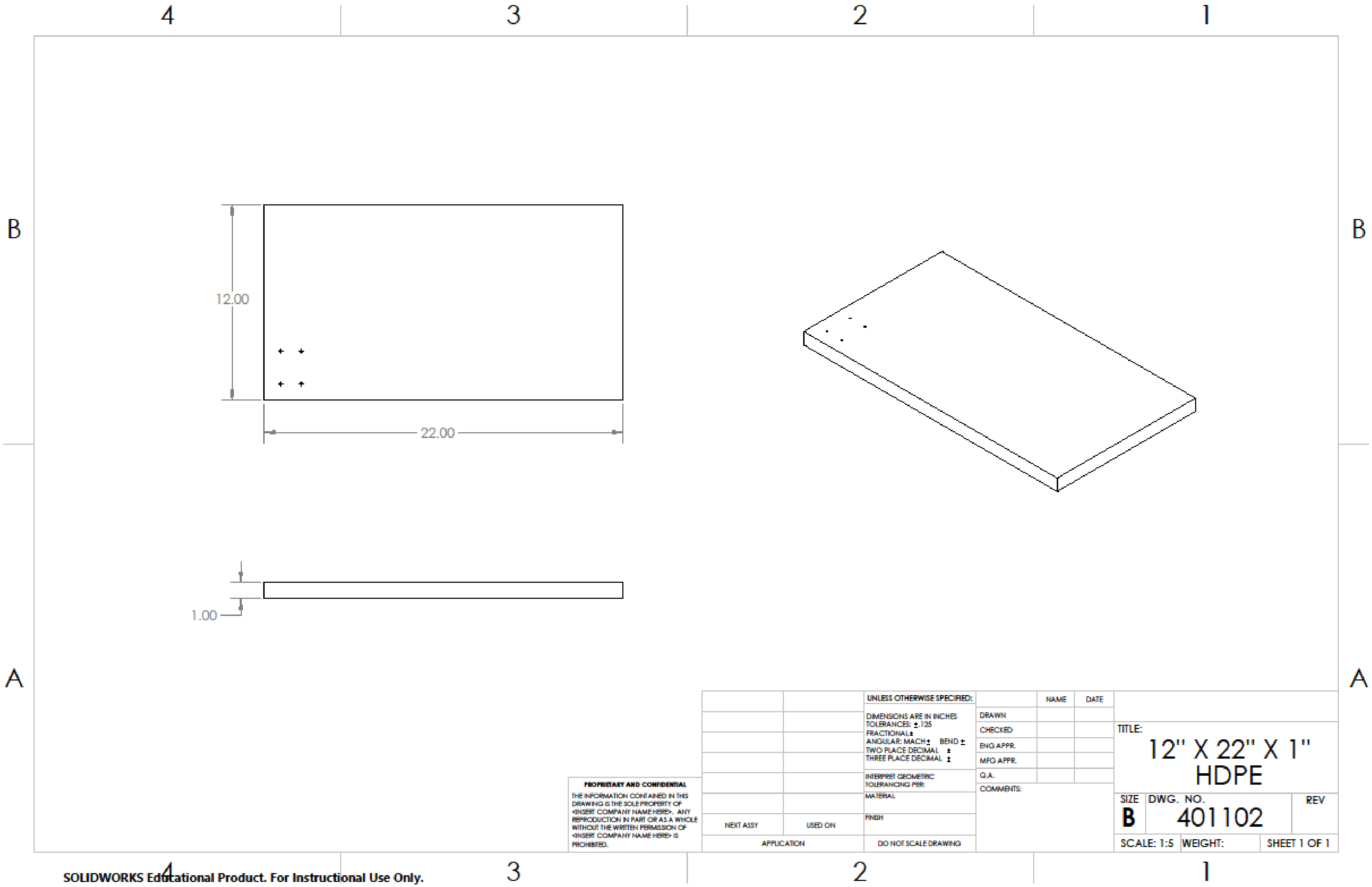
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

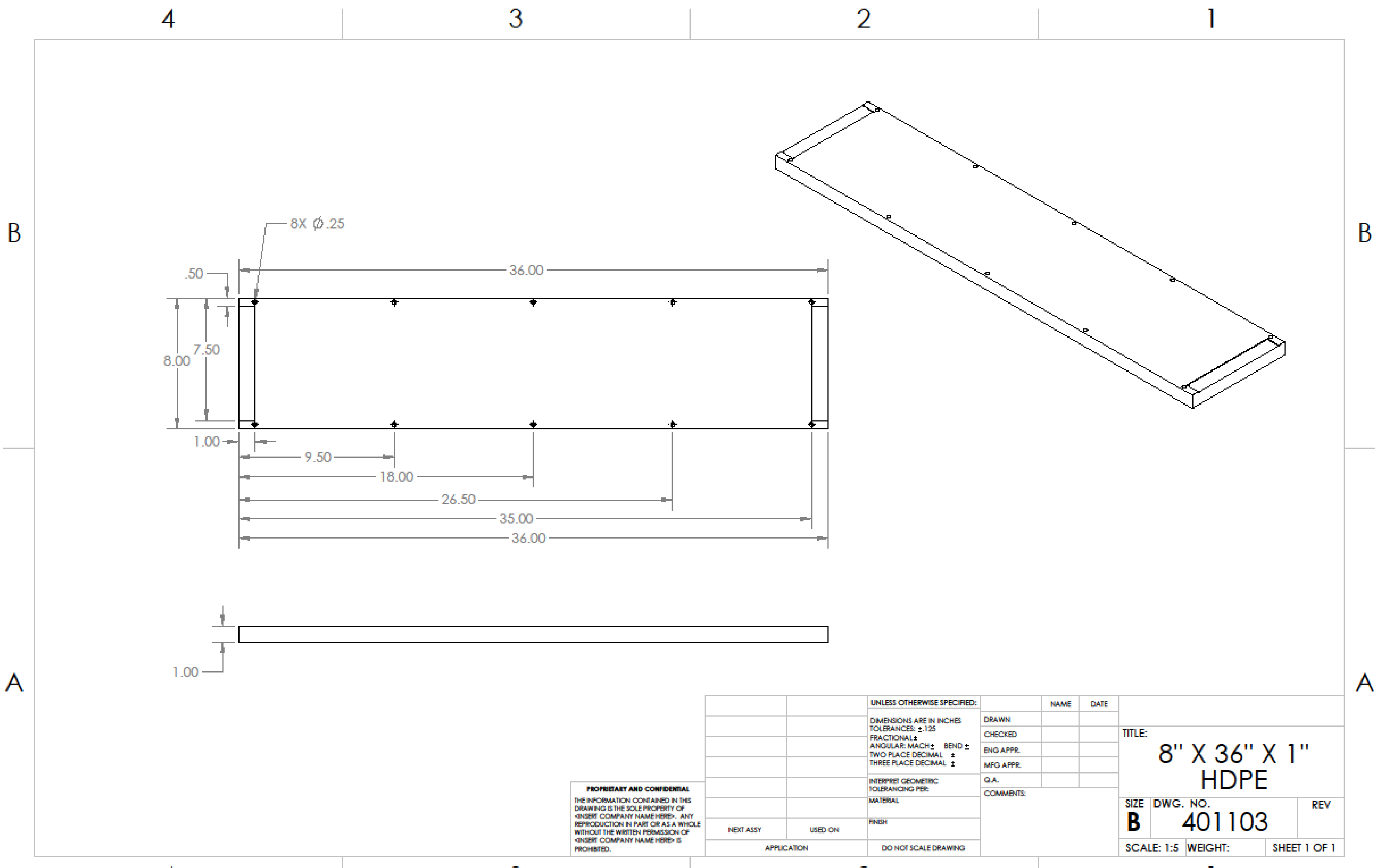
TITLE:
10" X 30" X 1" HDPE

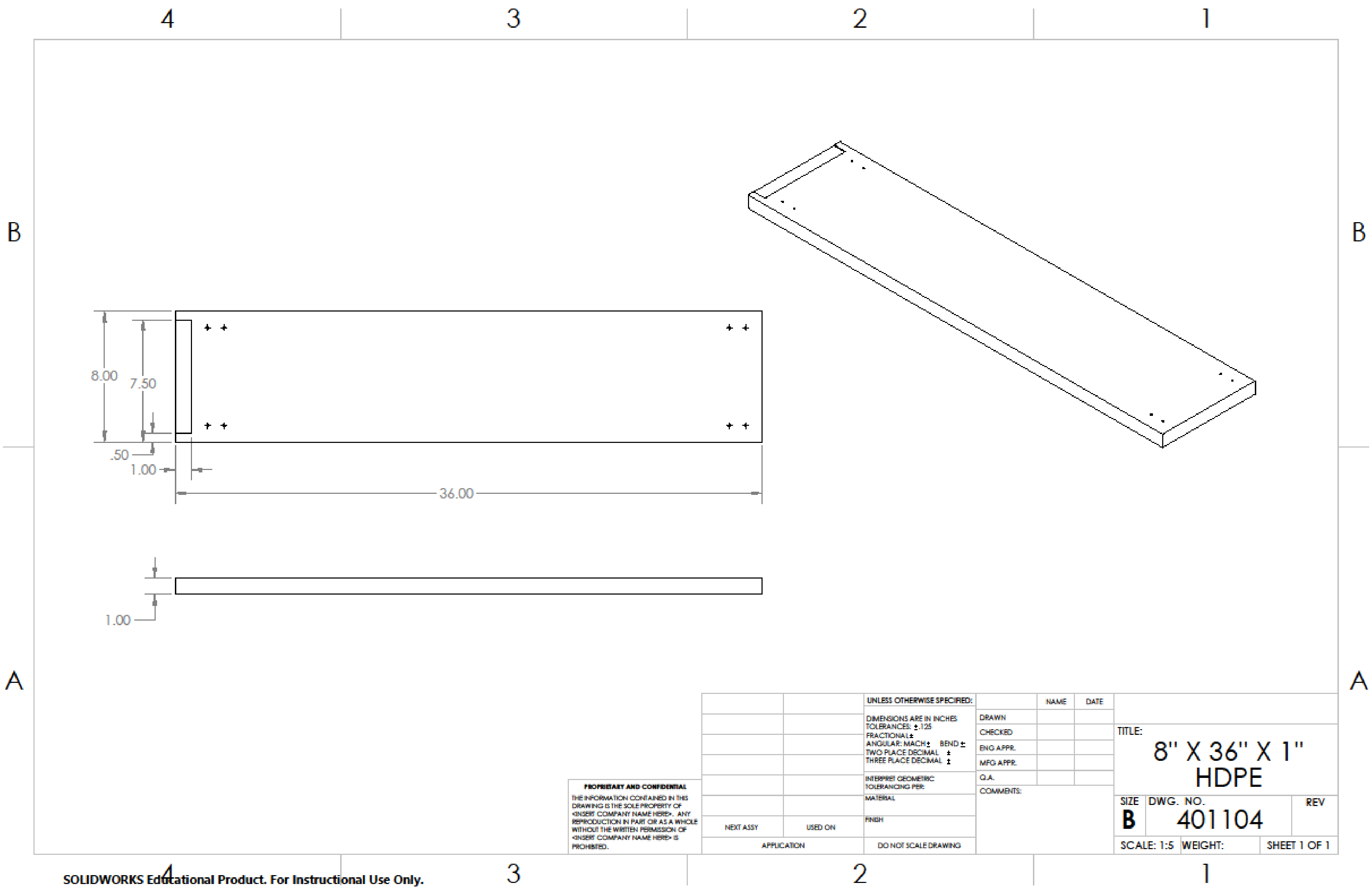
SIZE B | DWG. NO. 401101 | REV

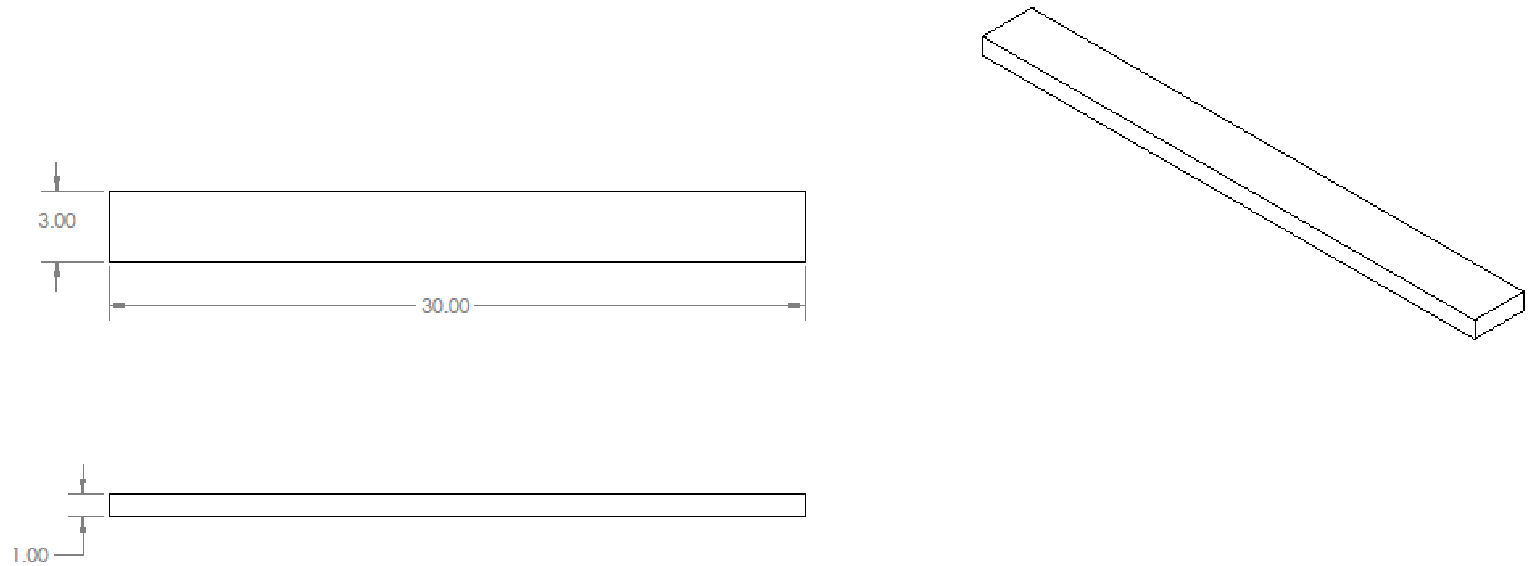
SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.


4
3
2
1
B
A
12.00
22.00
1.00
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.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
12" X 22" X 1"
HDPE
SIZE
B
DWG. NO.
401102
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.


8X Ø.25
36.00
.50
8.00
7.50
1.00
9.50
18.00
26.50
35.00
36.00
1.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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.
TITLE:
8" X 36" X 1"
HDPE
SIZE
B
DWG. NO.
401103
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1


4
3
2
1
B
A
8.00
7.50
.50
1.00
36.00
1.00
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.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
8" X 36" X 1"
HDPE
SIZE
B
DWG. NO.
401104
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.



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.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

COMMENTS:

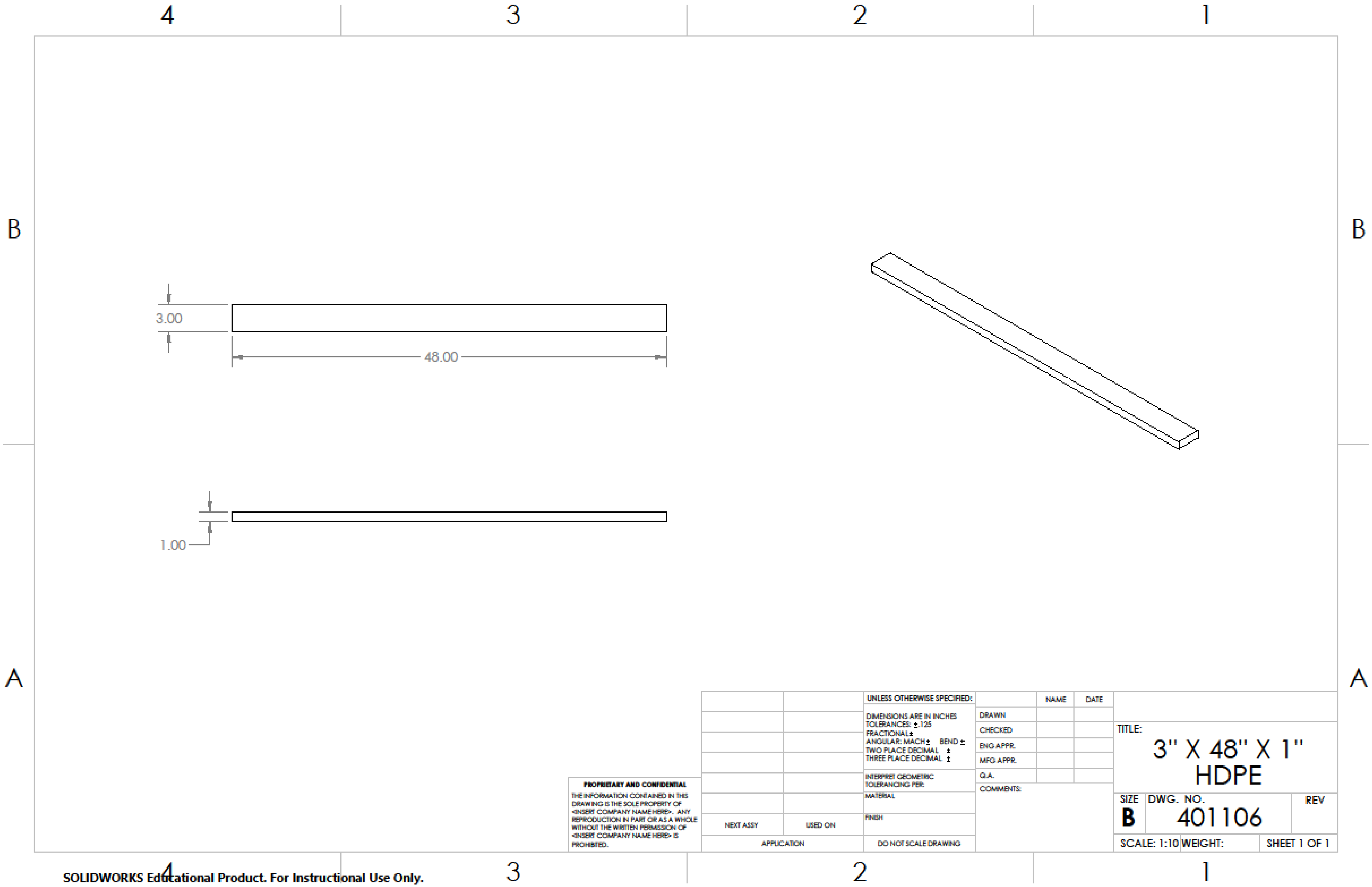
TITLE:

3" X 30" X 1"
HDPE

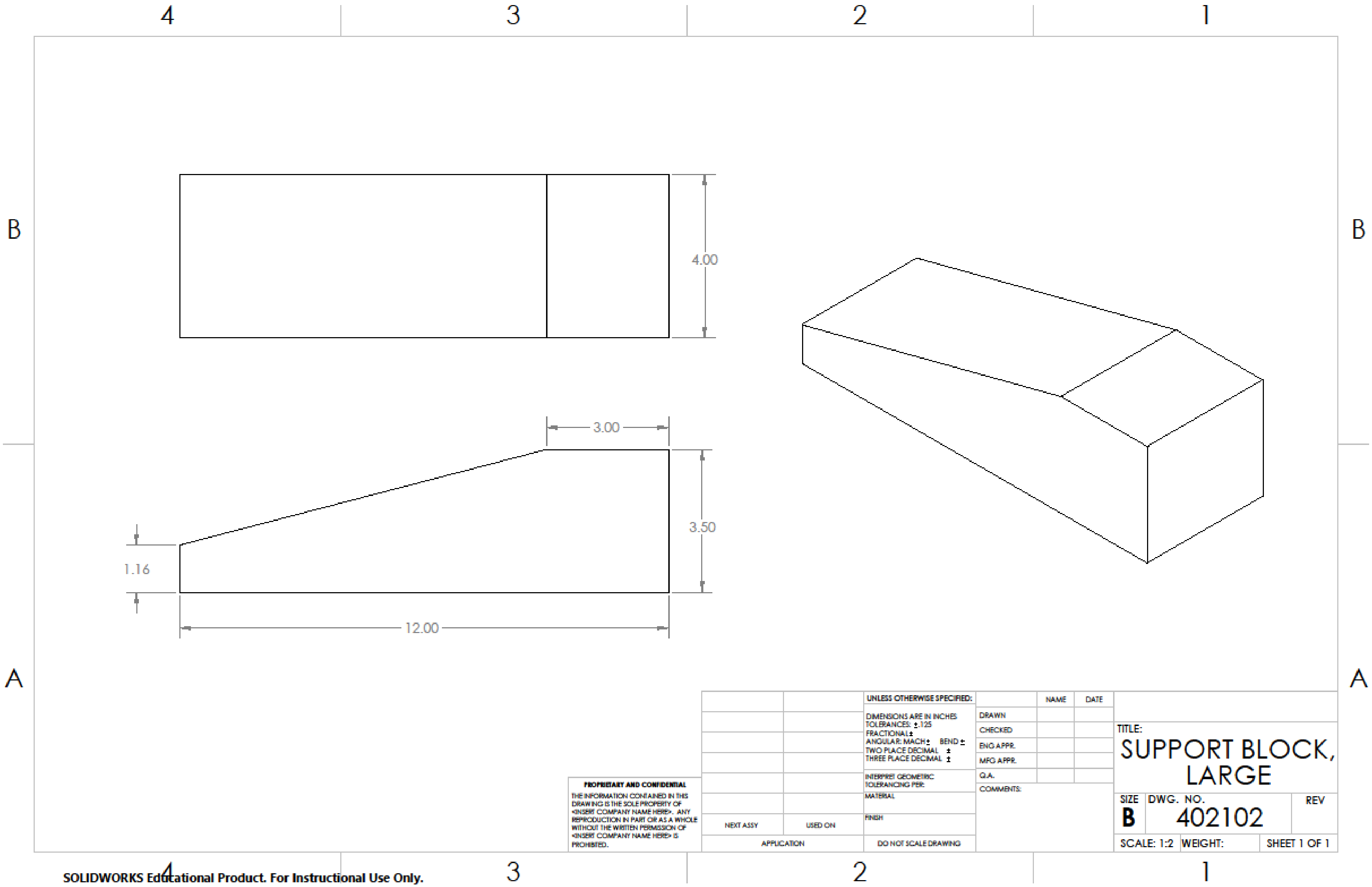
SIZE	DWG. NO.	REV
B	401105	

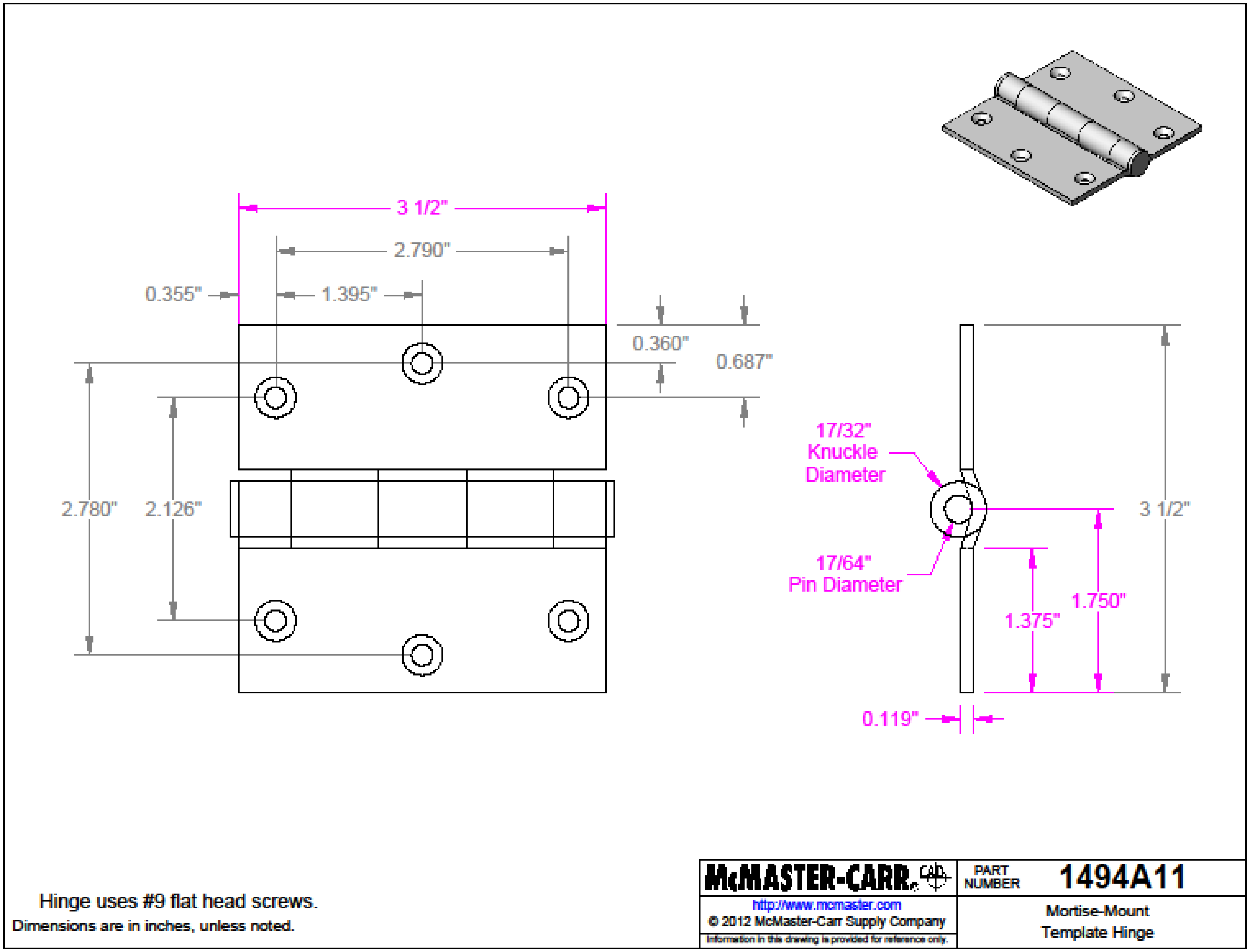
SCALE: 1:5 WEIGHT: SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

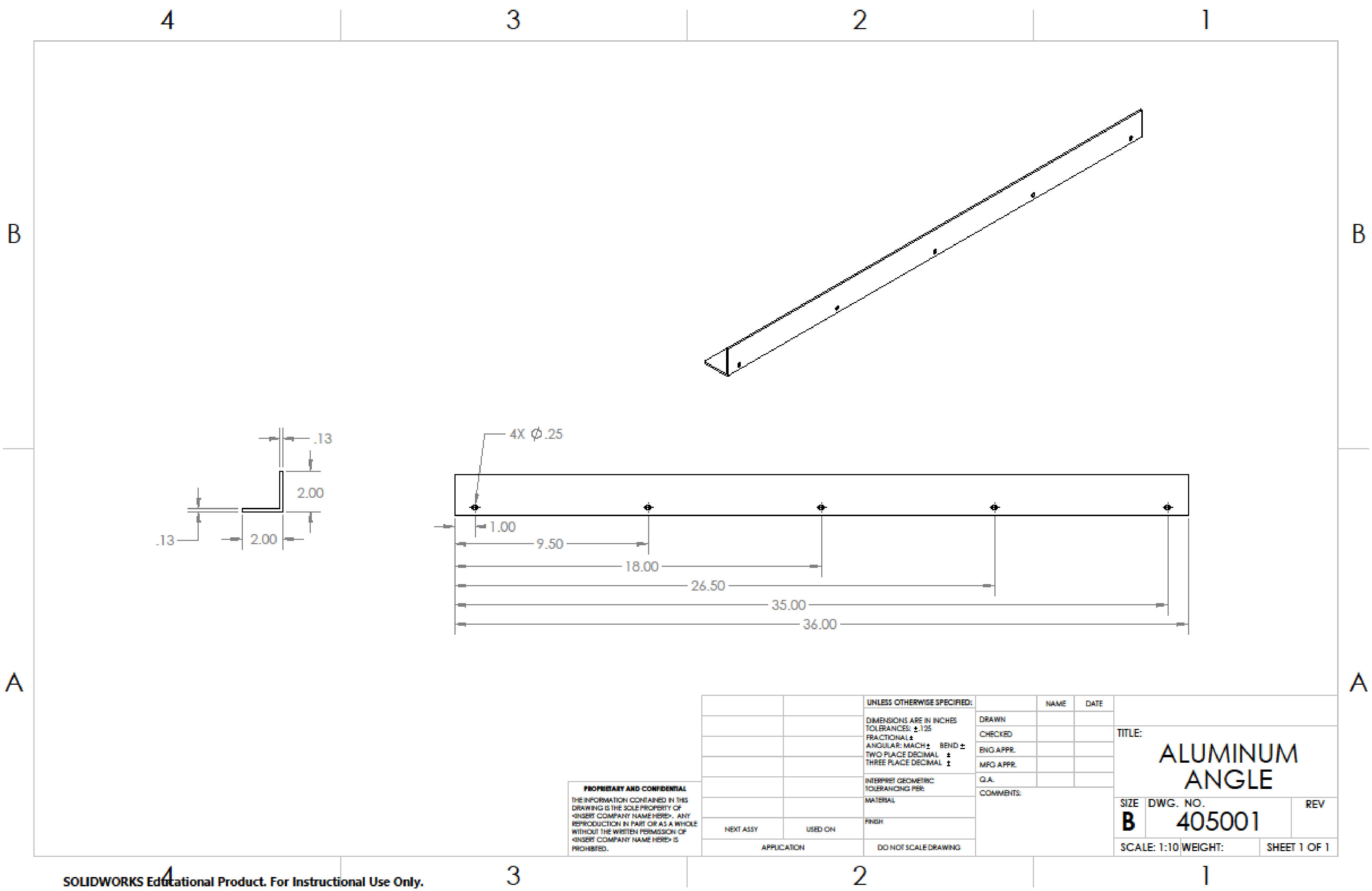


4
3
2
1
B
A
3.00
48.00
1.00
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
3" X 48" X 1"
HDPE
SIZE
B
DWG. NO.
401106
REV
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1


4.00
3.00
3.50
1.16
12.00
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.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SUPPORT BLOCK, LARGE
SIZE
B
DWG. NO.
402102
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.



SOLIDWORKS Educational Product. For Instructional Use Only.



.13
2.00
.13
2.00
4X ϕ.25
1.00
9.50
18.00
26.50
35.00
36.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±.125
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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.
TITLE:
ALUMINUM ANGLE
SIZE
B
DWG. NO.
405001
REV
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1

Appendix F: Project Budget

				Estimated			Purchased		
Part	Details	Vendor	Mfg Part #	Qty	Unit Cost	Total Cost	Qty	Unit Cost	Total Cost
Nylon Lashing Straps	NRS 1.5" x 6'	NRS	-	8	5.50	44.00	8	5.50	44.00
Longitudinal Rail (8')	6061 T6 Al Beam .375" x 2" x 8'	Onlinemetals	1157	2	24.82	49.64	2	24.82	49.64
Transverse Box Beam (32")	6061 T6 Al Sq Tube 1" x 2" x 0.125" x 32"	Onlinemetals	18003	2	11.22	22.44	2	11.22	22.44
Strut Housing (20")	6061 T6 Al Rd Tube 2.5" OD x 0.1875" x 20"	Onlinemetals	14496	2	16.37	32.74	2	16.37	32.74
				Sys Subtotal		148.82	**Sys Subtotal**		148.82
Nylon Strap	NRS 1.5" x 6'	NRS	-	4	5.5	22.00	4	5.5	22.00
Velcro Straps	-	Beverleys	-	4	6.5	26.00	4	6.5	26.00
SS Hex Nut	-	Ace Hardware	-	4	0.13	0.52			
SS Hex Bolt (3/8")	-	Ace Hardware	-	4	0.22	0.88	4	0.22	0.88
SS Cut Washer (3/8")	-	Ace Hardware	-	8	0.15	1.20	8	0.15	1.20
SS Fender Washer (3/8")	-	Ace Hardware	-	8	0.28	2.24	8	0.28	2.24
SS Lock Washer (3/8")	-	Ace Hardware	-	-	-	-	4	0.25	1.00
SS Nylock Nut (3/8")	-	Ace Hardware	-	-	-	-	4	0.37	1.48
Nylon Washer (3/8")	-	Ace Hardware	-	-	-	-	4	0.75	3.00
				Sys Subtotal		52.84	**Sys Subtotal**		57.80
Strut Poles	-	Onlinemetals	-	4	33.55	134.20	4	33.55	134.20
Strut Pins	-	Home Depot	-	8	3.20	25.60	8	3.20	25.60
Inserts	-	-	-	-	-	-	-	-	-
Polyurethane Foam	Sheets, 4'x10'	Donation	-	8	200.00	0.00	3	200.00	0.00
7.2 6oz cloth (30" width)	per yard	The Craft	-	37	5.99	221.63	45	3.25	157.58
UV-Cure Polyester Resin	5 Gal (George wants to purchase remainder)	The Craft	-	2	170.00	340.00	1	159.00	171.32
Wax Hot Coat	Quart	The Craft	-	1	18.00	18.00	1	15.00	16.16
Q-Cell Filler Material	Pint	The Craft	-	1	7.00	7.00	1	7.50	8.08

F/G Tape	per yard	The Craft	-	12	1.50	18.00	1	42.00	45.26
Stir Sticks	Bundle	The Craft	-	1	3.00	3.00	1	3.00	3.23
Squeegee	6"	The Craft	-	5	1.50	7.50	5	1.50	8.08
Brushes (2'')	Box, 2 dozen per	The Craft	-	1	12.00	12.00	1	12.00	12.93
Masking Tape	Roll, 2"	The Craft	-	2	4.50	9.00	1	5.00	5.39
	Roll, 1"	The Craft	-	-	-	-	1	3.50	3.77
Sandpaper	36 grit, 3" disc	The Craft	-	-	-	-	3	1.50	4.85
	60 grit, Sheet	The Craft	-	30	1.00	30.00	10	0.57	6.14
	80 grit, box	The Craft	-	-	-	-	1	22.50	24.24
	100 grit, sheet	The Craft	-	-	-	-	15	0.45	7.27
	220 grit, sheet	The Craft	-	-	-	-	20	0.40	8.62
Adhesive	Bottle, aerosol	The Craft	-	-	-	-	1	12.99	14.00
Acetone	5 Gal (George wants to purchase remainder)	The Craft	-	1	65.00	65.00	1	59.99	64.64
Gloves	Box, size L	The Craft	-	1	9.00	9.00	2	8.99	19.37
Respirator	-	Home Depot	-	3	40.00	120.00	-	-	-
	Respirator Frame	The Craft	-	-	-	-	3	14.99	48.46
	OV Cartridge Pack	The Craft	-	-	-	-	3	12.99	41.99
	Dust Cartridge Pack	The Craft	-	-	-	-	4	7.50	32.33
Dust mask	-	The Craft	-	-	-	-	3	3.99	12.90
Inserts	Al 6061 T6 Tube 2.5" OD x 0.125" x 12"	Onlinemetals	7047	1	103.70	103.70	1	103.70	103.70
Gel Coat	White	The Craft	-		-	-	2	60.00	120.00
Duratek	-	The Craft	-		-	-	1	40.00	40.00
HVLP Paint Gun	-	Harbor Freight	-		-	-	1	40.00	40.00
				Sys Subtotal		1123.63	**Sys Subtotal**		1180.11
HDPE Sheet Stock	-	McMaster	-	1	35.98	35.98	1	360.46	360.46
10'' x 30'' x 1'' HDPE	-	-	-	1	-	-	1	-	
12'' x 22'' x 1'' HDPE	-	-	-	2	-	-	2	-	
8'' x 36'' x 1'' HDPE	-	-	-	2	-	-	2	-	
8'' x 36'' x 1'' HDPE	-	-	-	2	-	-	2	-	

3'' x 30'' x 1'' HDPE	-	-	-	1	-	-	1	-	
3'' x 48'' x 1'' HDPE	-	-	-	1	-	-	1	-	-
4x4 Stock	4" x 4" x 8'	Home Depot	-	1	9.09	9.09	-	-	-
Support Block (large)	-	-	-	1	-	-	-	-	-
Support Block (small)	-	-	-	1	-	-	-	-	-
Tire Chocks	-	Walmart	-	-	-	-	3	9.68	29.03
Hinges	-	Home Depot	-	8	2.97	23.76	8	2.97	23.76
#8 x 2'' Construction Screws	-	Home Depot	-	16	0.04	0.64	16	0.04	0.64
#8 x 1-1/4'' Construction Screws	-	Home Depot	-	64	0.04	2.56	64	0.04	2.56
Angle Stock	-	Onlinemetals	-	2	17.06	34.12	2	17.06	34.12
Angle Supports	2" x 2" x 3'	-	-	-	-	-	-	-	-
				Sys Subtotal		106.15	**Sys Subtotal**		450.57
				Total		**1431.44**	**Total**		**1837.30**

Vendor	Contact Information
NRS	877.677.4327
McMaster	562.692.5911
The Craft	805.782.9802
Harbor Freight	805.549.0483
OnlineMetals	+1.800.704.2157
Ace Hardware	805.543.2191
Beverly's	805.543.6433
Walmart	805.474.0800

Appendix G: Test Results

Test #1: Setup and Teardown Time Test

Description: To ensure that all components of the paddleboard are fully functional and can be assembled quickly by undergoing a simulation run of the setup and teardown procedure.

Required: Paddleboard

Frame, Attachment and Outrigger subsystems.

Timer

Location: Beach Shore (Morro Bay)

Procedure: 1. Have the frame, straps, pontoons, outrigger struts and paddle board placed apart from each other.

2. Time the process of setting up the complete board including the outrigger system including attaching the frame and outrigger struts and adjusting each.

3. After complete assembly of the system, preform a teardown test by recording the time it takes to disassemble the system.

Data:

Trial	Time [min:sec]
Setup	3:57
Teardown	1:10

To pass, the time to setup up the paddle board should be less than 15minutes.

Time requirement (Pass/Fail)
Pass

Comments:

The results of this test show that the assembly and disassembly times for our system are well under the goal of a setup time less than fifteen minutes. The system passes the test.

Test #2: Tipability Test

Description: To ensure that the paddleboard with outriggers attached is not susceptible to tipping given a load on either outrigger

Required: Paddleboard

Frame prototype

Outrigger prototype

Life-vests

Location: Ocean (Morro Bay)

Procedure: 1. Strap the frame to the paddleboard.

2. Attach the outriggers to the frame.

3. Place the paddleboard in the water at Morro Bay.

4. Once the board is out in the water, have a team member stand on one of the outrigger pontoons.

5. Have a second team member stand on the other outrigger pontoon.

6. Have team members take turns jumping on the pontoons and moving their bodyweight around in such a manner as to place a large load on a single pontoon. The team is attempting to submerge a pontoon and tip the system over.

7. Attempt to submerge the second pontoon.

8. Remove board from water and disassemble prototype into subsystems.

Data:

Submersion/Tipping Left Outrigger	Submersion/Tipping Right Outrigger
No submersion	No submersion

Figure 0.1. Team members attempting to capsize system

The load to induce tipping should be greater than 150 lbs on a pontoon.

Left Pontoon Pass/Fail	Right Pontoon Pass/Fail
Pass	Pass

Comments:

The team was not able to submerge either of the pontoons, and therefore unable to tip the system over. We conclude from the test that a pontoon will not submerge during normal use conditions, so the system succeeds in preventing the board from tipping over. The user will be safe from the danger of tipping.

Test #3: Strap Strength Test

Description: To ensure that the sewn Velcro straps attaching from the frame to the wheelchair will not easily fail when subjected to a tensile force. This test will determine that if the sewing onto the strap or getting it wet alters its strength.

Required: Nylon straps

Tensile Tester

Torque wrench

Location: IME welding lab

Procedure: 1. Take the extra nylon straps into the IME welding lab.

2. Place the straps under the tensile tester machine and record the load at which the straps break (total failure).

3. Repeat under three different loads using the torque wrench.

4. Record the data.

Figure 0.2. Strap and bolt test assembly

Data:

Torque (Ft-Lb)	Force Reading (Lb)	Results
10	600	Ripped down the center of the hole
15	600	Ripped down the center of the hole
20	600	Ripped through the side of the hole

Figure 0.3. Strap tearing after testing

The passing criterion for this test is the average breaking strength of all the tests is over 250 lbs.

Strap Strength Test Pass/Fail
Pass

Comments:

Based on the results, each strap failed at the same load. Though, the highest torque resulted in the hole tearing from the side unlike the lower two that failed straight down the middle. We concluded that torqueing the nut and bolt more would not improve the performance of the strap. We purchased low quality nylon straps for the purpose of testing, and the straps exceeded our predicted maximum load of 500 pounds. For our final product, we are utilizing higher quality NRS straps which should eliminate any concern for strap failure.

Test #4: Balance Test

Description: To ensure that the center of gravity of the paddleboard has not changed given the attached frame.

Required: Paddleboard (completed prototype with frame and straps attached)
4-foot-long, 1.5 in diameter rod (wood)

Location: Hard, flat surface (most likely a dock in Morro Bay)

Procedure:

1. Perform a baseline by placing the paddleboard alone across the top of a 4 foot long, 1.5 inch diameter rod at about the location of the handle. Mark the location that the board balances. Record the distance from the center of the board.

Repeat this same test procedure for the frame.

Repeat test for each pontoon.

Data:

Component	Distance from center (in)
Paddleboard	0
Frame	0
Pontoon 1	0
Pontoon 2	0

The pass/fail criterion is that the center of gravity for each part with not differ from the geometric center of the part by more than 1 inch.

Component	Center of Gravity Requirement (Pass/Fail)
Paddleboard	Yes
Frame	Yes
Pontoon 1	Yes
Pontoon 2	Yes

Comments:

All four tested components proved to have their center of gravity precisely at their geometric center. When the system is assembled, each separate part is geometrically centered on the same point at the center of the board, therefore this point will be the center of gravity for the entire system.

Test #5: Hydrodynamic Drag Test

Description: To ensure that the paddleboard with the NRS straps does not have significantly increased drag compared to a normal paddleboard.

Required: Paddleboard

NRS straps

Location: Cal Poly pool

Procedure: 1. Place the paddleboard in the pool.

2. Have one person sit on the board.

3. Use a fishing rod with a force scale to have another person pull the board across the pool at a constant 1lb of force

4. Record the time taken to cross the pool for three runs.

5. Have someone push and release the unladen board and record the distance it travels.

6. Repeat for five runs.

7. Have someone paddle the board across the pool and record the time taken.

8. Repeat for four runs.

9. Attach the NRS straps to the paddleboard.

10. Repeat steps 1-9 with the straps attached.

11. Disassemble.

Figure 0.4. Fishing rod and force gauge drag test

Data:

Hydrodynamic Strap Drag Test					
Test 1		Test 2		Test 3	
Powered Drag		Unladen Push		Powered Paddle	
Travel time [s]		Glide distance [in]		Travel time [s]	
free	straps	free	straps	free	straps
40.25	37.18	594.5	377.5	16.53	22.59
38.28	37.78	605.5	396.5	16	24.06
34.53	37.91	616.5	390.5	17.69	21.28
		557.5	426.5	17.81	22.75
		609.5	395.5		
37.69	37.62	596.70	397.30	17.01	22.67
-0.2%		-33.4%		33.3%	
		Suspected Strap Installation Error			

The passing criterion for these tests is a difference of less than 10%.

Test No.	Pass/Fail (Yes/No)
Test 1	Yes
Test 2	No
Test 3	No

Comments:

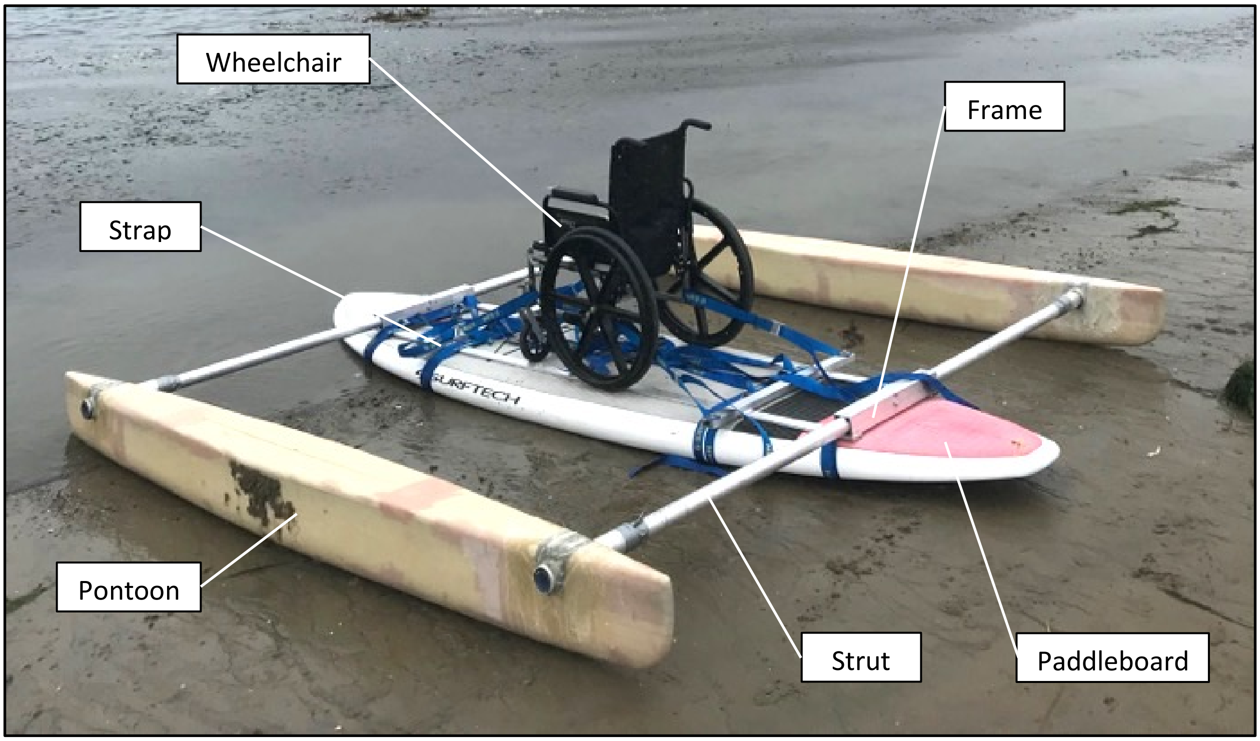
The negative impact of the straps on the drag of the board is negligible with proper strap installation. For tests 2 and 3 the straps were attached incorrectly and were twisted and created more drag. The straps pass the test when properly installed.

Appendix I: Operator's Manual

The adaptive paddleboard has four systems – frame, outrigger, ramp, and attachment – and each requires its own set up. The following are detailed instructions on how each system should be assembled for use. Please read the instructions before proceeding with assembly and use of product. The figure below shows the overall layout of the system and its individual parts.

Warning:

Do not burn or expose the pontoons to flame. Burning polyurethane will generate toxic cyanide fumes.
Do not store pontoons with pins in. Metal-on-metal wear will cause corrosion.



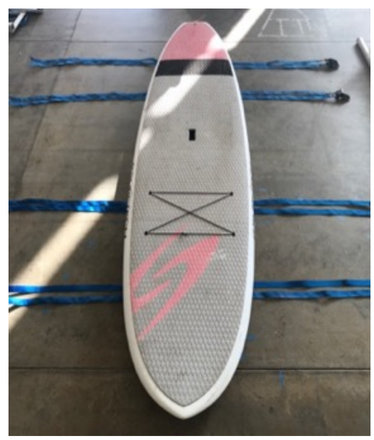
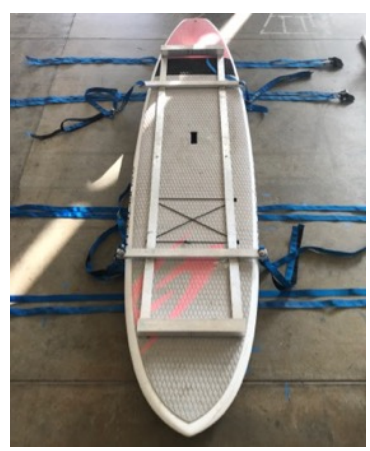
The following is a list of components required for complete assembly of the system:

- 1.5'' NRS Strap (8x)
- 10' Aluminum Strut (2x)
- D-Ring Pin (4x)
- Square Pin (2x)
- Wheelchair (1x)
- Pontoon (2x)
- Paddleboard (1x)
- Attachment Frame (1x)

Attachment Frame Assembly

Warning:

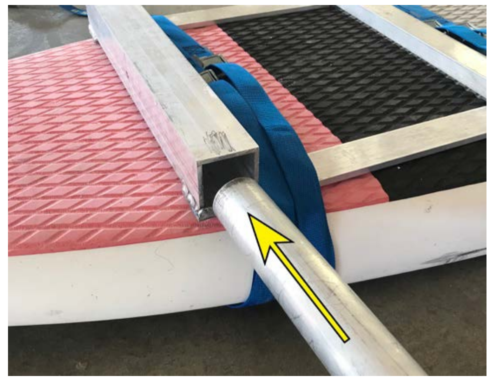
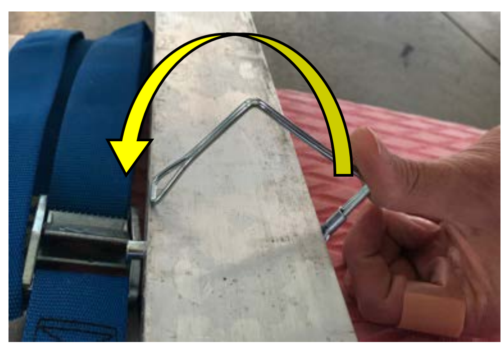
•The frame may contain sharp edges on corners or ends.
•Be careful of pinch points on straps.
•The NRS straps contain moving parts that create pinch points. Exercise caution when tightening the straps and operating the buckles.

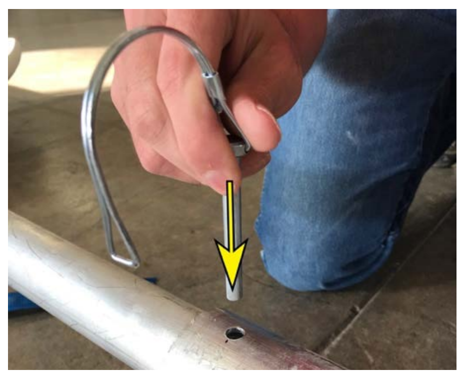
Step	Instruction	Visuals
1	Place all 8 of the 1 ½” blue NRS straps parallel on a large flat area about 8” apart.	
2	Carefully place the paddle board across all straps.	
3	Place the frame on top of the paddleboard. Align it such that the frame is equidistant from all sides.	

4	Align the straps such that there are two straps on the inside face of each of the transverse box beam and strut housing.	
5	Tighten all 8 the straps by sliding it through the buckle. Ensure that the frame is fixed.	

Stabilizing Outrigger Assembly

Warning: •The outrigger system contains pinch points on the pin connection and where the strut and its housing meet. Exercise caution when sliding the outrigger to its desired length.

Step	Instruction	Visuals
1	Match the frame square beam strut housing with the strut and slide the pole to the appropriate location. Beware of possible pinching between the strut and its housing.	
2	Lock the strut into the beam with a snap-lock pin.	 

		
3	Align pontoon inserts with the strut and slide in.	
4	Measure the stroke distance by having the user perform a practice stroke. Align the holes on the inserts with one of the holes on the strut poles.	
5	Insert and lock pins for the 4 locations.	 
6	Repeat for the other pontoon.	

Ramp Assembly

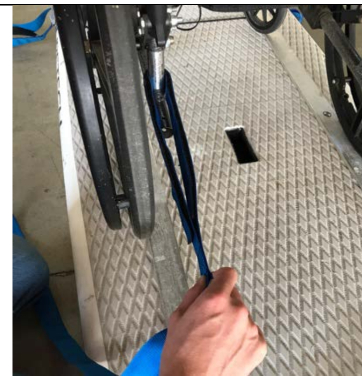
Warning: ⚠	•The ramp folds into 3 separate sections, with pinch points at each connecting section. •The ramp is considerably heavy and should be operated with two people to ensure safe mounting.

Step	Instruction	Visuals
1	Unfold the ramp and place it onto the paddleboard. Ensure that the ramp is centered across the paddleboard and that the strut housing on the frame sits in the gap. Set up should be performed with two people.	

Loading from Shore

Warning:	•Loading of the user should be performed with a minimum of two people to reduce risk of injury to both the user and loaders. •The surface of the ramp may be wet and slippery. Exercise caution when wheeling the user in place. •Ramp contains several pinch points. •Ensure that the user is wearing a life vest. Do not secure user to wheelchair in the event of tipping.

Step	Instruction	Visuals
1	Ensure that the assembly has been completed and that all systems are ready (note: the ramp is also designed for loading from a dock. The configuration will be similar.)	
2	Wheel the user and their wheelchair onto the board.	
3	Have another person in position to grab the wheelchair once it is on the board to ensure that the user does not roll too far.	
4	Fasten the Velcro straps around the wheelchair.	

		
5	Once the chair is firmly strapped to the board, remove the ramp from the board.	
6	Equip the user with a paddle and secure a strap on their wrist.	
7	Push the paddleboard all the way into the water.	

Unloading to Shore

Warning:

- Unloading of the user should be performed with a minimum of two people to reduce risk of injury to both the user and loaders.
- The surface of the ramp may be wet and slippery. Exercise caution when wheeling the user off the ramp.
- Ramp contains several pinch points.

Step	Instruction	Visuals
1	Pull the paddleboard from the water onto the shore. If unloading from a dock, bring the paddleboard close to the dock.	
2	Place the ramp onto the board.	
3	Unfasten the Velcro straps from the wheelchair.	
4	With one person on each side of the board, take hold of the wheelchair and guide it backwards onto the ramp and assist the user in rolling onto the beach. If unloading from a dock, have the user wheel themselves up the ramp.	

Loading Ramp Disassembly

Warning:	•The ramp folds into 3 separate sections, with pinch points at each connecting section. The ramp is considerably heavy and should be operated with two people to ensure safe mounting.

Step	Instruction	Visuals
1	Lift the ramp off the paddle board. Place it onto the shore or dock. Fold the three sections up then move to storage.	

Stabilizing Outrigger Disassembly

Warning:	The outrigger system contains pinch points on the pin connection and where the strut and its housing meet. Exercise caution when sliding out the pontoon.

Step	Instruction	Visuals
1	Remove the pins holding the pontoons in place.	
2	Slide the pontoons off of the struts.	
3	Slide the struts out from the strut housings.	

Attachment Frame Disassembly

Warning:	•The frame may contain sharp edges on corners or ends. •Be careful of pinch points on straps. •The NRS straps contain moving parts that create pinch points. Exercise caution when tightening the straps and operating the buckles.

Step	Instruction	Visuals
1	Ensure outriggers have already been disassembled.	
2	Loosen and unbuckle all straps along the paddle board. Lay the ends of the straps off to the side.	
3	Carefully lift frame off the board.	
4	Lift paddle board off the straps.	

Maintenance & Troubleshooting

The following instructions explain how to troubleshoot problems that may arise and recommended maintenance to ensure full functionality of the paddleboard. Failure to perform regular maintenance may result in injury of the user from part failure.

System	Issue	Solution	Maintenance
Anchor Strap	Strap failure due to wear	Replace straps with NRS strap (see Appendix X for vendor sourcing)	Inspect strap integrity after each use
	Bolt loosens on attachment frame	Retighten bolt using wrench	Inspect bolts after each use
	Velcro no longer sticks	Replace straps with NRS strap sewn with Velcro (see fabrication instructions in manufacturing section)	Inspect Velcro integrity after each use
Stabilizing Outrigger	Pin breaks	Replace straps with new pin (see Appendix X for vendor sourcing)	Inspect pins after each use
	Pontoon damage	Do not continue use if damage is found. Do not attempt to repair.	Inspect pontoons after each use for cracks.
Loading Ramp	Hinge breaks	Unscrew hinges and replace (see Appendix X for vendor sourcing)	Inspect hinges after each use
	HDPE Sheet wear	Replace HDPE sheet (see Appendix X for vendor sourcing and manufacturing plan for dimensions)	Inspect ramp quality after each use

Appendix J: Design Verification Plan & Report

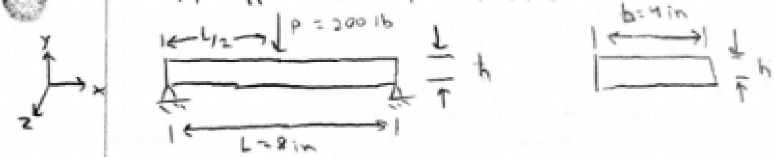
DVP&R														
Date			Team: Adaptive Paddleboard			Sponsor: Randy Coffman								
Test Plan										Test Report				
Item No.	Spec no.	Test Description	Acceptance Criteria	Test Resp.	Test Stage	Samples		Timing		Results				
						Qty	Type	Start	Finish	Test Result	Qty Pass	Qty Fail	Notes	
2	1	Tipability	200lb/ pontoon	AH	FP	1	COMP	4-May	5-May	350 lb	2	0	Could not tip with a person jumping on each pontoon	
3	3	Loadability	< 5 mins	GH	FP	1	SUB	11-May	12-May	3 mins	2	0	Came in well under the expected time	
4	6	Balance	±7 in longitudinal	GJ	FP	1	SYS	4-May	5-May	Center	1	0	Paddleboard retained same center of gravity	
5	-	Drag	±10% max	GJ	SP	-	SUB	12-Jan	12-Jan	PASS	1	0	Drag negligible	
6	3	Ramp Strength	Visual Inspection	AH	SP	1	SUB	2-Feb	2-Feb	FAIL	0	1	Ramp deflects excessively	
7	7	Strap Strength I	>500 lb	SY	SP	3	COMP	13-Jan	13-Jan	650 lb	3	0	Strap fails at a much higher force than the predicted maximum force	

Appendix K: HDPE Ramp Calculation

Ramp Flexing Analysis

Cross section:

Simply supported beam at both ends



$E = 225{,}000$ psi from Seaboard Materials

- for $h = 1$ in

$I = \frac{1}{12} b h^3$

$= \frac{1}{12}(4\,in)(1\,in)^3$

$I = 0.333\ in^4$

$\frac{dy}{dx} = \frac{-PL^3}{48EI}$

$\delta_{max} = \frac{dy}{dx}$

$\delta_{max} = \frac{-(200\,lb)(8\,in)^3}{48(225{,}000\ lb/in^2)(0.333\ in^4)}$

$\delta_{max} = -0.028$ in

$M = (200\,lb)(4\,in) = 800$ in lb 66.67 lbft

$\sigma_{max} = \frac{Mc}{I}$

$c = 0.5$ in

$\sigma_{max} = \frac{(800\ in\,lb)(0.5\,in)}{0.333\ in^4}$

$\sigma_{max} = 1201.2$ psi

$\sigma_y = 4600$ psi from Seaboard Materials

$\sigma_{max} < \sigma_y$ ✓

- for $h = 0.75$ in

$I = \frac{1}{12}(4\,in)(0.75\,in)^3$

$I = 0.1406\ in^4$

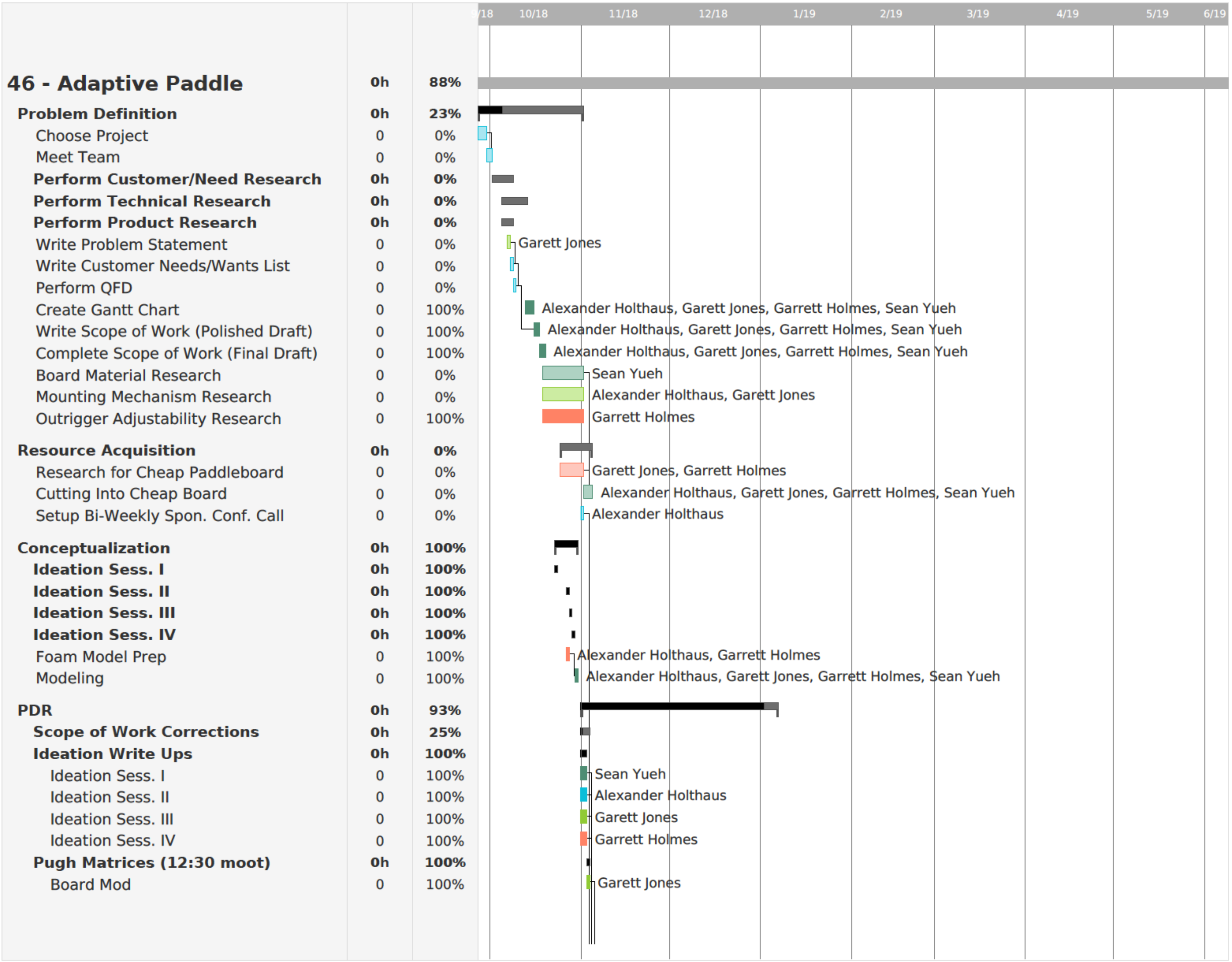
$\delta_{max} = \frac{-(200\,lb)(8\,in)^3}{48(225{,}000\ lb/in^2)(0.1406\ in^4)}$

$\delta_{max} = -0.067$ in

$\sigma_{max} = \frac{(800\ in\,lb)(0.5\,in)}{0.1406\ in^4}$

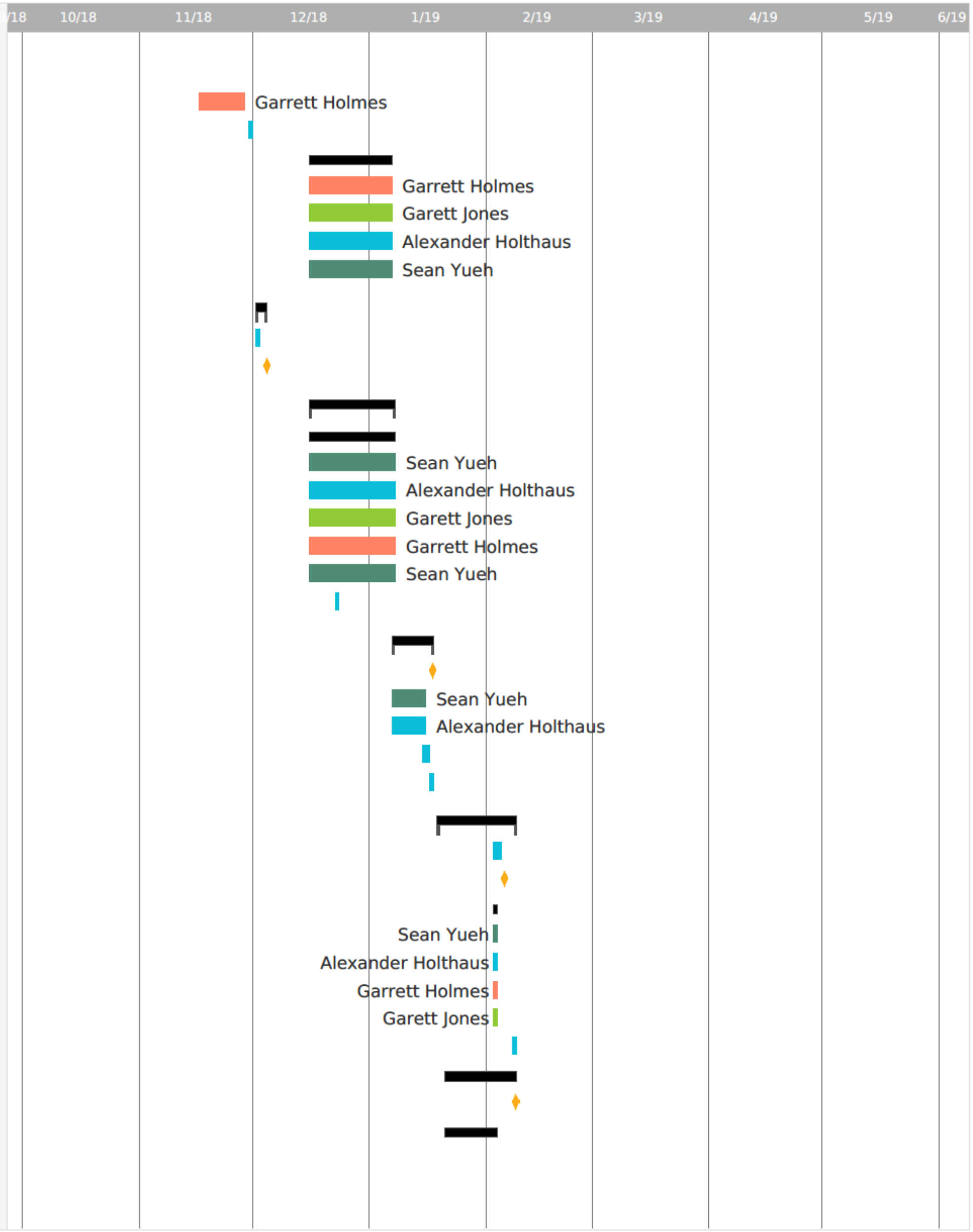
$\sigma_{max} = 2844.95$ psi $< \sigma_y$ ✓

Appendix L: Gantt chart

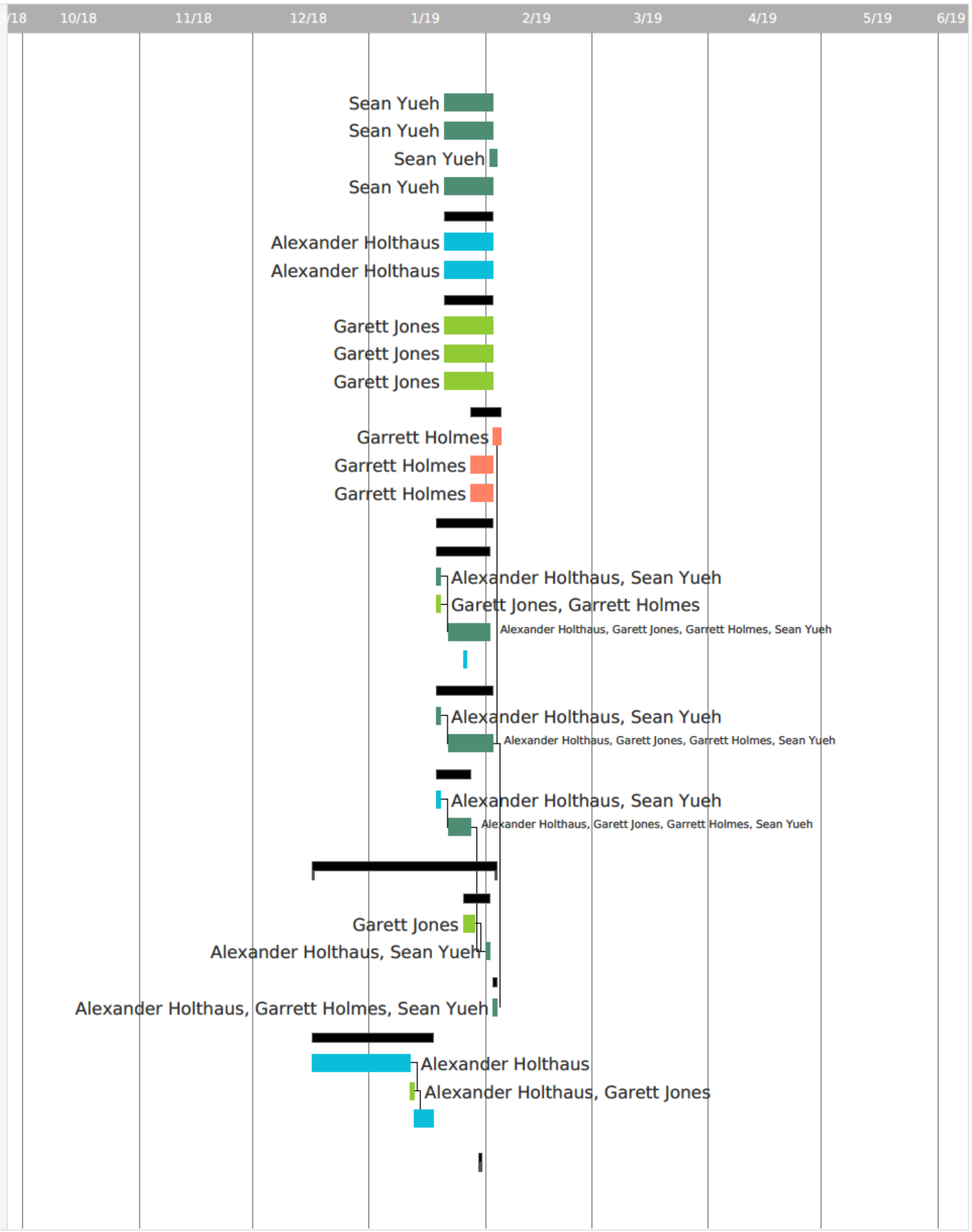


W/C Attachment	0	100%
Loading System	0	100%
Stabilization	0	100%
Baker Koob Grant App	**0h**	**33%**
Decision Matrix (5pm Moot)	0	100%
PDR Document Sections	**0h**	**100%**
Concept Design	**0h**	**100%**
Top 5 Concept Drawings	0	100%
Top 5 Concept Description	0	100%
Final Weight Decision Matrix Proc...	0	100%
Top Concepts Evaluation Process	0	100%
Concept Prototype	**0h**	**100%**
Solid Modeling	0	100%
Manufacturing Process/ Materials	0	100%
Prelim. Analyses/Tests and Caclulatio...	0	100%
Design Hazard Checklist	0	100%
Project Management	0	100%
PDR Document Done	0	100%
Concept Prototype	**0h**	**100%**
Build Plan	0	100%
Build Day	0	100%
Finished Prototype	0	100%
PDR Presentation	**0h**	**100%**
Slides: Next Steps	0	100%
Slides: Potential Issues	0	100%
Slides: Design Direction	0	100%
Slides: Alternatives	0	100%
Slides: Introduction	0	100%
PDR Presentation Rehearsal	0	100%
PDR Presentation	0	100%
PDR Extension	**0h**	**98%**
PDR Final Draft Due	0	0%
Ideation Sess. V	0	100%
Pugh Matrix Generation	0	100%
Morphological Table/Weighted Decis...	0	100%
PDR Edits: Top Concepts	0	100%
PDR Edits: Prototype Solid Model	0	100%
PDR Edits: Concept Design	0	100%

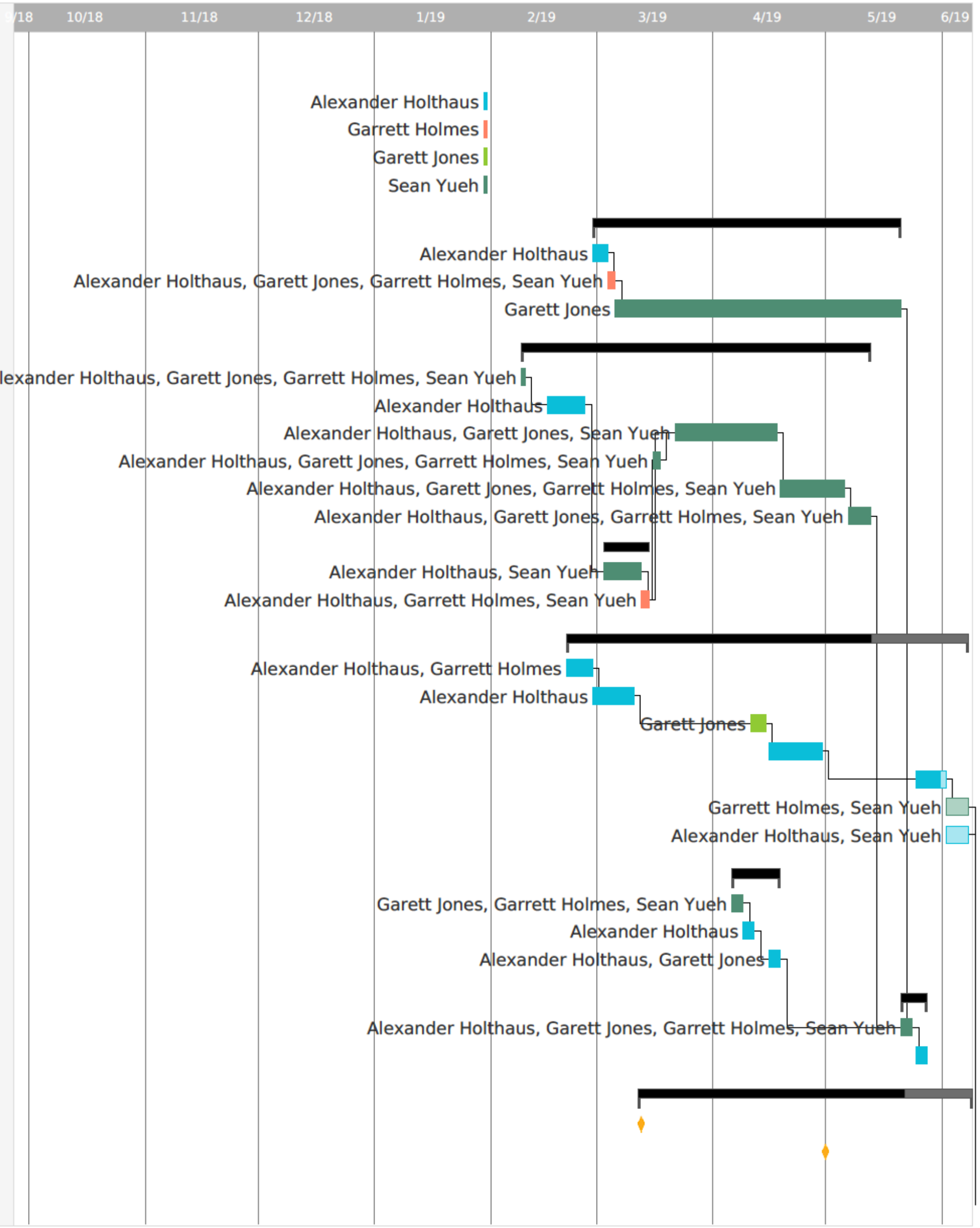
PDR Edits: Update for Remaining Se...	0	100%
Presentation to Sponsor	0	100%
PDR Revision	**0h**	**100%**
Idea Generation	0	100%
Design Selection Process	0	100%
Design Sketches/Selected Concept	0	100%
CAD Models	0	100%
Failure Mode and Effects Analysis	**0h**	**100%**
FMEA Session	0	100%
FMEA Submission	0	100%
Design for Manufacturing and Ass...	**0h**	**100%**
Research For Manufacturing	**0h**	**100%**
Foam Pontoons	0	100%
Materials	0	100%
Methods of Manufacturing	0	100%
Build Plan	0	100%
Analyses and Tests	0	100%
Team Video Chat	0	100%
Interim Design Review (IDR)	**0h**	**100%**
Interim Design Review Presentation	0	100%
Complete CAD Models for Subsystems	0	100%
Stress Analysis	0	100%
Generate Condensed Presentation of ...	0	100%
Post IDR Processing	0	100%
Conceptual Design Review (CDR)	**0h**	**100%**
CDR Presentation Rehearsal	0	100%
CDR Presentation	0	100%
CDR Presentation Slides	**0h**	**100%**
Subsystem: Strap Connection/Cost ...	0	100%
Subsystem: Stabilization/Testing Pl...	0	100%
Subsystem: Ramp/Potential Issues	0	100%
Subsystem: Frame/Next Steps	0	100%
CDR Sponsor Presentation	0	100%
CDR Report Content	**0h**	**100%**
CDR Report Due	0	100%
Sean Yueh	**0h**	**100%**



CAD/Bill of Materials	0	100%
Summary Cost Analysis	0	100%
Tensile Loading Test Write Up	0	100%
Subsystem: Frame	0	100%
Alexander Holthaus	**0h**	**100%**
Fiberglassing Test Write Up	0	100%
Subsystem: Outriggers	0	100%
Garett Jones	**0h**	**100%**
Detailed Manufacturing Plan Edit	0	100%
Hydrodynamic Test Write up	0	100%
Subsystem: Strap Attachment	0	100%
Garrett Holmes	**0h**	**100%**
Ramp Loading Test Write Up	0	100%
Safety, Maintenance, Risk Write Up	0	100%
Subsystem: Ramp	0	100%
Structural Prototyping	**0h**	**100%**
Outrigger Fiberglassing	**0h**	**100%**
Material Purchase	0	100%
Scrap Foam	0	100%
Construction	0	100%
Fiberglassing Tutorial (George Le...	0	100%
Ramp	**0h**	**100%**
Material Purchase	0	100%
Construction	0	100%
Strap Connection	**0h**	**100%**
Material Purchase	0	100%
Construction	0	100%
Testing	**0h**	**100%**
Strap Loading Test	**0h**	**100%**
Contact Materials Lab For Testing	0	100%
Strap Loading Test (Dry)	0	100%
Ramp Loading Test I	**0h**	**100%**
Ramp Loading Test	0	100%
NRS Strap Dynamic Test	**0h**	**100%**
Contact Randy For Straps	0	100%
Dynamic Test At Rec Center Pool	0	100%
Documentation of Results/Data	0	100%
Manufacturing Plan	**0h**	**100%**



Outriggers	0	100%
Ramp	0	100%
Frame to Board/Frame to Wheelchair	0	100%
CAD/BOM	0	100%
Frame	**0h**	**100%**
Order/Recieve Parts	0	100%
Welding Preparation	0	100%
Welding	0	100%
Pontoons	**0h**	**100%**
Fiberglassing Materials With George	0	100%
Pontoon Foam Layer CAD Drawings	0	100%
Fiberglassing Preparation	0	100%
Fiberglassing Material Purchase	0	100%
Fiberglassing and Curing	0	100%
Strut Housing/Alignment	0	100%
Foam Preparation	**0h**	**100%**
Foam Cutting	0	100%
Foam Assembly	0	100%
Ramp	**0h**	**76%**
Material Research	0	100%
Order/Receive Aluminum Brackets	0	100%
Ramp Calculation	0	100%
Order/Receive/Test Garage Tile	0	100%
Order/Recieve HDPE	0	80%
Ramp Construction	0	0%
Pontoon Painting	0	0%
Strap	**0h**	**100%**
Strap Sewing Preparation	0	100%
Practice Sewing With Sarah	0	100%
Final Configuration Assembly	0	100%
Overall System	**0h**	**100%**
Assemble System	0	100%
Testing	0	100%
Deliverables	**0h**	**80%**
Manufacturing and Test Review	0	100%
Confirmation Prototype Review	0	100%



Test Results Review	0	100%
Expo	0	100%
Project Handoff	0	0%