Adaptive Stand Up Paddleboard

ME 429

Group 36

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Table of Contents

Executive Summary

The task of this project was to create an adaptive paddleboard capable of being ridden by someone who does not have full mobility in one or more of their lower extremities. This project was worked on by a team of five students - three mechanical engineers and two kinesiology students - to create an effective and robust design for the client. To do this, the team regularly met with the client and used individual and group expertise in various fields to bring the best product to the end user.

The client, Damien, was a firefighter who was injured in July 2015 after a tree fell on him while he was on duty. The incident left Damien with an incomplete spinal cord injury at level T12 and L1. An incomplete spinal cord injury differs from a complete spinal cord injury in that the spinal cord is not completely severed; instead, due to vertebrae compression or fracture, the axons of a nerve are crushed or destroyed, affecting the ability of motor or sensory information to be transmitted to the brain. However, because of the incomplete nature of the injury, some motor and sensory function is still preserved. The extent of sensory and/or motor preservation is highly varied from person to person because of the difference in the amount of damage on each person's nerve fibers. Injuries to the L1 vertebrae commonly result in mild loss of function in the hips and legs. As is typical with these types of thoracic injuries, Damien retained full function and strength in his arms and hands. Damien began working on strengthening his legs and reestablishing patterned neural activity in the Central Nervous System (CNS) through intensive therapy at Project Walk in the third quarter of 2015. The therapy is an intensive physical therapy regime; with the goal of being able to walk by the time his therapy is completed.

The project was meant to be used by the client for the entirety of his therapy and beyond. For this, the team went through many designs and ideas before all settling on one style, a rear folding, low profile support that could assist the client in a standing position. This design went through a multitude of design changes and iterations as proof of concept tests and analysis was done throughout the year. Consultation with the client, sponsors, advisors, and those interested in the project or working on something similar were paramount helping the team finalize the design.

The final chosen design is a modified version of the preliminary selected design. Upon presenting the final preliminary design to Damien, the team received valuable feedback regarding how he planned to use the board, as well as his progress in his ability to move his legs. The largest change Damien wanted to see in the design was the addition of a seating position on the board, which became a focus for the team. Furthermore, Damien expressed how he was very comfortable using dip bars to move his body up and down, as this is a very common movement for wheelchair users. The team took this feedback, in addition to other items, and integrated them into the design in an attempt to create the product so it uniquely fit Damien's desires.

One major breakthrough on the project was that of the insert design used to attach the structure to the board. Through research into methods to attaching structures to prefabricated paddleboards, there was no basis that could be found, as most products of this type were made building custom boards. For this project, and the help of SUP Think Tank and Ding King Surfboard Repair, the team used the "top hat" method, which consists of the following order for each of the four insert locations: two layers of carbon fiber sheets, three layers of 4 oz. fiberglass sheets, the wooden inserts, and then three more layers of 4 oz. fiberglass. Another major recognition was that of automated machining, where using CNC machines became a major help when having tried and failed and hand machining certain aspect of this project. All of this lead to the final design for the adaptive stand up paddleboard project.

The final design consists of three positions, kneeling, sitting, and standing. Movement between these positions is possible with the use of the dip bars Damien suggested, and the low profile idea from the initial concept was kept. This low profile concept allows the standing and sitting support to fold down against the paddleboard, also clearing room for a more comfortable kneeling position. The entire project was made marine compatible, with the structure being made of anodized aluminum, nylon straps, and stainless steel bolts and pins. This design was made modular, so it could be removed from the board if necessary, allowing the paddleboard to progress with the client throughout his recovery and more, assisting him in all areas necessary.

Chapter 1: Introduction

An Introduction to our Project

People have been venturing into the oceans and bays of California for years for work and play. Many vessels have been produced to allow for a variety of ways to travel through the water, some much more recently developed than others. For this project, the team focused on paddleboards. Paddleboarding is a sport that originated in Hawaii as an alternative to surfing. Paddleboarding was and currently can be done in the traditional sense of sitting, kneeling, or laying on a surfboard and paddling using a swimming motion with one's hands. More recently, stand up paddle boarding (SUP) has become prominent in the waters. This sport uses a paddle while standing on a board both longer and wider than traditional surfboards.

The task was to create an adaptive paddleboard capable of being ridden by someone who does not have full mobility in one or more of their lower extremities. This project was worked on by a team of five students - three mechanical engineers and two kinesiology students - to create an effective and robust design for the client. To do this, the team regularly met with the client and used individual and group expertise in various fields to bring the best product to the end user.

The main goal of the project, sponsored by Dr. Kevin Taylor through the National Science Foundation's Research to Aid People with Disabilities (RAPD), was to create a stand up paddleboard for the client, Damien. The stakeholders associated with the project were Dr. Taylor and Damien. Dr. Taylor was both the sponsor of the project as well as the representative for RAPD. He went in expecting a fully functional prototype that may be used for further development at a later time. Damien, being the end user and the one most affected by the project, was looking to experience a form of paddleboarding closely related to the sport with adjustments for his condition. This was the main focus of the project. The project solely focused on meeting the requirements agreed upon between our team, our sponsor and our client.

Method of Approach

The approach the team took upon acquiring the project was to immediately become comfortable with the topic. Extensive research was done on paddleboards - specifically stand up paddleboards - spinal cord injuries, and various forms of water vessels and adaptations to them. This process went alongside interviews with the client, Damien, and meetings with the advisors, Dr. Taylor and Dr. Haack. Gathering this information, a requirements list was made which can be seen in the Requirements section below.

Upon receiving approval of the engineering specification from the project stakeholders, the team began the ideation phase in which many potential solutions to the design problem described in this report were generated. During this stage, the team attempted to produce as many potential solutions as possible through a series of brainstorming sessions, during which various ideation methods were employed. In order to generate an adequate number and variety of potential solutions, it was essential that the brainstorming process took place without the evaluation of the generated ideas or the fixation on a particular solution.

Once a sufficient quantity and diversity of potential design solutions had been generated, the team moved into the concept evaluation stage of the design process. During that stage, the potential solutions generated during ideation were evaluated according to design criteria such as feasibility, cost, weight, etc. The design criteria were carefully selected to ensure the specifications that have been created by the team were met by the designs. From this evaluation process, a few potential design solutions were selected for further evaluation. The second round of evaluation was conducted using a more refined selection matrix along with a series of proof of concept prototypes designed to test specific aspects of the selected potential solutions. From the second round of evaluations, the team selected a single, preferred solution concept to recommend to the project stakeholders.

Upon the approval of the design, the team then moved into the design review and analysis phase of the project. During that stage, extensive mechanical analysis was performed on the selected design in order to refine the concept and ensure all the systems and interfaces encompassed by the design were optimized for the client's needs and specifications before prototype manufacturing and testing began.

A flowchart of the design process that was followed throughout the duration of the project is displayed in Figures 1.1 and 1.2.

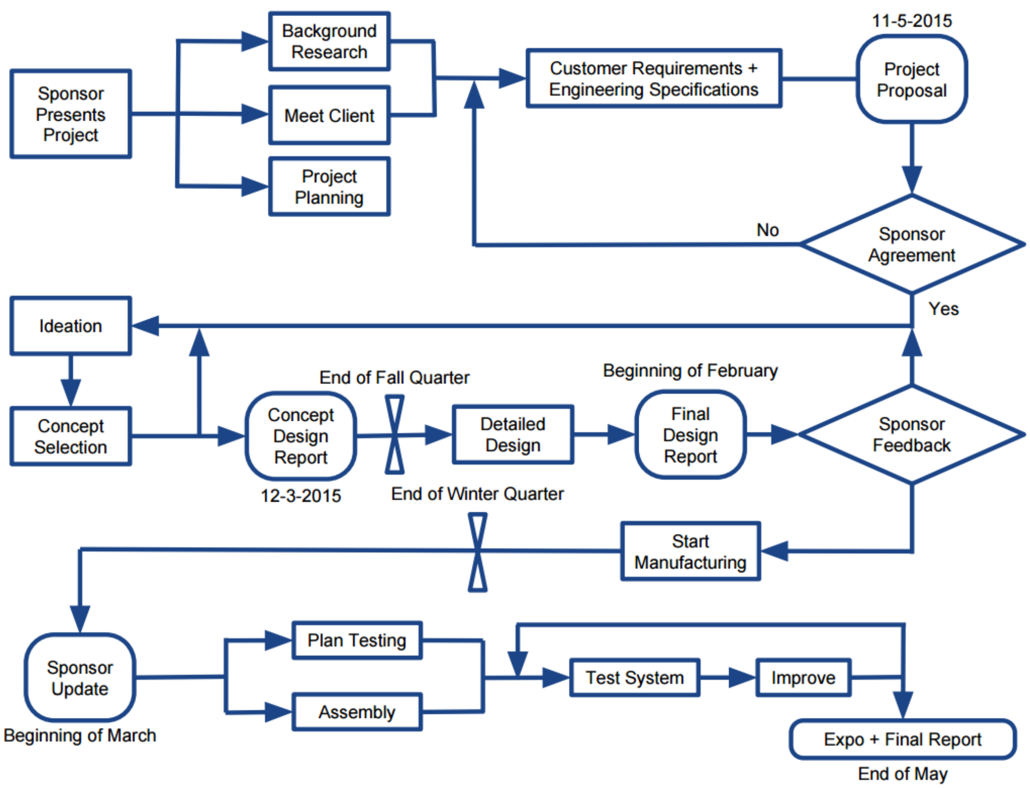

Figure 1.1. A detailed flowchart for the design process that was followed by the team until project completion in June 2016

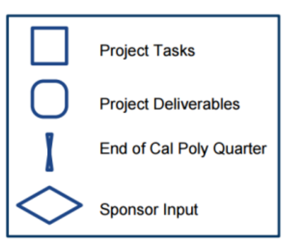

Figure 1.2. Flowchart Key

Chapter 2: Background and Project Objective

The team was assigned a project that brings multiple systems together in a single product. For information on these various subjects, our team conducted background information not only on paddleboards and stand up paddleboards, but also on adaptive paddleboards already on the market, other adaptive water vessels, and on various types of spinal cord injuries.

Stand Up Paddleboard Background

Stand up paddleboarding, or 'SUP', can be categorized into three basic types: Surf Specific, All Around, and Touring. Surf specific boards are short, narrow, less stable boards used to enter the surf zone of the ocean. All around boards are very versatile boards that can be used both in the surf and on flat water. Touring boards are designed for use on flat water only, and are typically used by first time boarders learning how to SUP.

When looking at the main features of a paddleboard, the three details commonly displayed by manufactures are the volume, the width and the length of the board. The volume of the board helps indicate weight capacity, where more volume represents a higher amount of buoyancy, but also less responsiveness. The width of the board also plays a role in the stability of the rider on the board, with thinner boards allowing for faster speeds. The length of the board helps divide the boards into their three categories: Surfing Specific (under 9'), All Around (9' to 12'), and Touring (12' and over).

The materials used to build a paddle board have a large effect of the price, weight, durability and performance of the board. The most common board type is an EPS foam core board wrapped with fiberglass and epoxy, with carbon fiber sometimes replacing the fiberglass. Polyurethane foam boards are heavier than their EPS foam counterparts, but are used to build cheaper, entry-level boards. Inflatable SUPs have an air core that must be inflated, and are desired for their increased durability, lighter weight and ease of storage.

There are few existing codes or standards in place for SUP manufacturing. Furthermore, in most areas, there are no regulations in place requiring a personal flotation device to be worn while using a SUP. The only time this can change is while navigating through internal or harbor waters.

Use Cases for Paddleboarding

Recreational Paddleboarding:

Figure 2. Photograph of an individual participating in recreational paddleboarding. [1]

The most common use of paddleboards is recreational paddle boarding. All paddleboard users start out by learning this type of activity, in which they learn how to stand on and navigate waters while on a paddleboard. This use is typically done in calm ocean waters, harbors, or lakes.

Paddleboard Surfing:

Another common use of paddle boards for more advanced users is paddle board surfing. This involves the user paddling into and riding waves in the ocean. The activity is very similar to normal surfing, but the rider has the advantage of having the paddle to help with stability and steering while riding the wave.

Figure 3. Photograph of an individual using a paddle board to surf. [2]

Yoga on Paddleboards:

Another use that has grown in popularity in the past decade is yoga on paddleboards. Users typically go out onto the water as a group and do yoga as if they were on land. The added challenge of balancing on the board while in certain yoga position helps promote strengthening the user's balance.

Figure 4. Photograph of a group of paddle board users using their boards to participate in yoga. [3]

Fishing on Paddleboards:

Fishing while on a paddle board has also become a popular use case for paddleboards. The user gains the ability to navigate the fishing waters to a desired spot to cast from quietly, while also allowing them complete maneuverability while on the board. It has become a common alternative to using a boat or other larger vessel.

Figure 5. Photograph of an individual fishing off of a paddle board. [4]

Paddleboard Racing:

Racing competitions on paddle boards are a growing area of use for paddleboards. Organized racing events have been growing in size and frequency over the past few years, after the first organized race was created in 2007. The races involve between seven to thirty mile courses and can now be found around the world.

Figure 6. Photograph of a paddle board race in progress. [5]

Client Background

The client, Damien, was a firefighter who was injured in July 2015 after a tree fell on him while he was on duty. The incident left Damien with an incomplete spinal cord injury at level T12 and L1. An incomplete spinal cord injury differs from a complete spinal cord injury in that the spinal cord is not completely severed; instead, due to vertebrae compression or fracture, the axons of a nerve are crushed or destroyed, affecting the ability of motor or sensory information to be transmitted to the brain. However, because of the incomplete nature of the injury, some motor and sensory function is still preserved. The extent of sensory and/or motor preservation is highly varied from person to person because of the difference in the amount of damage on each person's nerve fibers. Injuries to the L1 vertebrae commonly result in mild loss of function in the hips and legs. As is typical with these types of thoracic injuries, Damien retained full function and strength in his arms and hands. Damien began working on strengthening his legs and reestablishing patterned neural activity in the Central Nervous System (CNS) through intensive therapy at Project Walk in the third quarter of 2015. The therapy is an intensive physical therapy regime; with the goal of being able to walk by the time his therapy is completed.

Damien physical abilities on 10/13/2015 included performing flexion and extension in his right leg, however there was very minimal movement in his right foot. Damien could also move his left leg quadriceps; however, he did not have function past his left knee due to both the injury and a recent tear of his left MCL. Damien was able to stand on his own, but not for extended periods of time, due to challenges with balance and muscular strength.

Before his injury, Damien loved to participate in water activities and he hoped to keep fulfilling his aquatic passions in an adapted way with the help of this project. His goal with the stand-up paddleboard was to be as independent as possible to make for an authentic paddleboard experience. There are paddleboards with wheelchair attachments on the market; however Damien was seeking a more independent option that would accommodate his abilities and progress with him as he recovered.

Existing Products

Figure 7. The Onit Ability Board with a wheelchair locked in and the aluminum ramp for user boarding. [6]

In the research conducted by the team, Onit Ability Boards had been identified as an existing product that enabled individuals who are paraplegic, amputees or with related disabilities to traverse across bodies of water in a similar fashion to traditional paddleboarding. The Onit Ability Board is designed so that the user remains seated in an "all-terrain surf chair", or what is essentially a specially designed wheelchair, while operating the craft. A removable nine foot long aluminum ramp and chair locking system integrated into the board's surface allows the user to wheel the chair directly onto the board from the launch point or dock and secure the chair to the surface of board. Once secured, the chair remains fixed to the board until the locking mechanism is released. An example of the aluminum ramps that are provided with the Onit Ability Board is shown in Figure 7.

The Onit Ability Board also comes equipped with two outriggers constructed in a similar fashion to the body of the board. These outriggers are designed to dramatically increase the stability of the board and prevent it from rolling or capsizing. However, the outriggers are removable and are therefore not essential to functionality of the board. Figure 8 provides an image of the outriggers that the Onit Ability Boards are equipped with.

Figure 8. The Onit Ability Board shown clearly with its two outriggers. [6]

The construction of the Onit Ability Board is unique when compared to traditional paddleboards and surfboards. The body of the board is constructed of expanded polystyrene (EPS) wrapped in two layers of fiberglass. The layers of fiberglass are separated by a thin layer of bamboo wood. Epoxy resin is used to laminate the layers together. Onit claims this design distributes loads to a much larger area of the internal fiberglass layer, increasing the strength of the board without compromising weight.

Onit Ability Boards retail for $5000 plus applicable taxes, shipping, and handling. The boards are available in four different colors and come with the modified board, outriggers, the "all-terrain surf chair", aluminum ramp, and a custom paddle.

Another existing product that the team had identified is the CruiserBoard. The CruiserBoard was designed with the intent of allowing individuals who are paraplegic, amputees, or have related injuries to enjoying paddleboarding. It is primarily advertised as an alternative to a traditional paddleboard design to be used for recreation, fishing, or as a learning tool for those beginning to paddleboard. It sets itself apart from traditional paddleboards in three ways: board shape, external features, and construction material. A picture of the CruiserBoard in use can be seen in Figure 9.

Figure 9. Picture of two individuals riding CruiserBoards in the Pacific Ocean. [7]

The shape of the CruiserBoard hull is designed both to increase the stability of the paddleboard as well as keeping the deck of the board dry. To keep the deck dry, the sides or rails of the board are considerably higher than on a traditional paddleboard. To improve the stability of the board, the CruiserBoard hull is shaped into what is commonly know as a cathedral hull. Cathedral hulls are commonly a feature of many modern boats, usually power-driven. A cathedral hull is most often defined as a vee-bottom hull with two parallel sponsors, or small side hulls, that extend almost as far forward as the main hull. The space between the hulls may be small or nonexistent. As with boats, the cathedral offers the CruiserBoard improved stability in calm waters, but may not offer the same mobility that a shallow or flat hull has. A picture of a cathedral hull of a boat can be seen in Figure 10.

Figure 10. Front view of a cathedral hull of a boat. [7]

Unique to the CruiserBoard are its external features, the most prominent of which is the adjustable folding chair. This chair can be mounted at almost any position along the length of the board with the use to two parallel flush mounted tracks built into the surface of the board. The seat of the chair folds upwards into the back of the chair transforming the sitting surface into a concave surface on which the user can lean against while standing. The angle of the seat back is adjustable and the seat is supported at two points mounted to the board at the base of the seat back and two more points located about a foot and a half behind the seat. This folding chair allows for the user to be supported in either a sitting or standing position and can be transitioned during use. Additionally, the folding chair has a fishing rod holder and cup holder built into its frame. The external features and hull shape of the CruiserBoard are depicted in Figure 11.

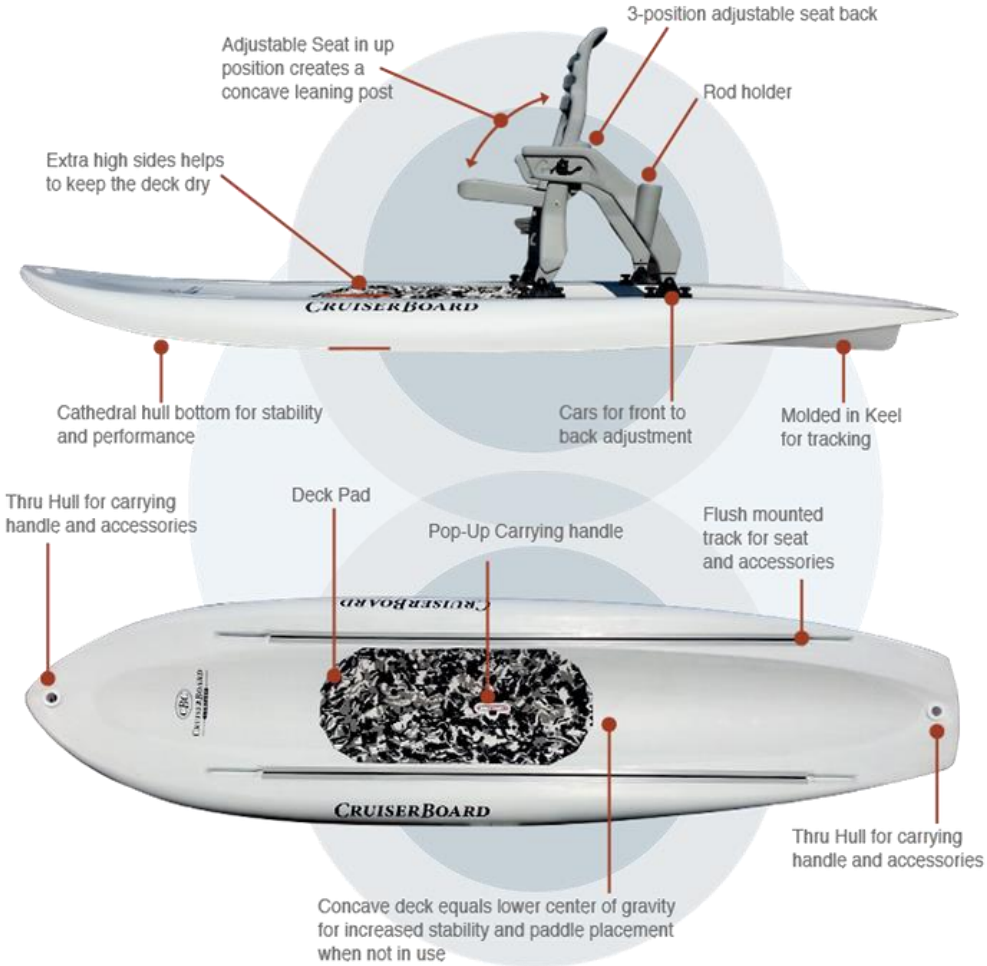

Figure 11. Diagram of CruiserBoard external features and hull shape. [7]

The construction method and material of the CruiserBoard are one of the primary features that set it apart from most other paddleboard designs, although CruiserBoard Company does not include this feature in the prominent advertising on the company website. The hull of the board is constructed from fiberglass cloth infused with thermoplastic resin instead of the more traditional fiberglass and thermoset resin construction with a foam core. This patented use of Thermal Composite Technology or TCT is owned by Bounce Composites, a company located in Oceanside, California. The use of a thermoplastic resin instead of a thermoset resin in the construction of the hull makes the board much more durable without sacrificing much of the performance features associated with traditionally crafted boards. The durability and impact resistance of the CruiserBoard design parallels that of an inflatable board.

Although many of the design features of the CruiserBoard may not be optimal for the design requested by the client, there are a number of innovations from which inspiration can be drawn. In addition to this, the commercial viability of the CruiserBoard for user that do not suffer from disabilities or motion impairment shows that a product designed to assist those with disabilities paddleboard may also be marketable to user without disabilities.

Objectives

The primary goal of this project was to complete a design of an adaptive paddle that met the needs of the client. With this goal in mind, the team developed the following problem statement to focus the efforts of the team:

Problem Statement

> Using a paddle while standing on various marine vessels has been practiced by people for centuries in order to navigate bodies of water. In recent years, this technique has been adapted into a new sport and recreational activity, paddleboarding. For those with physically inhibited mobility or partial paralysis, his sport is difficult to participate in and enjoy. Our client requires a paddleboard design that will enable him to participate in traditional paddleboarding activities throughout the duration of his recovery. Such a design will allow the client to enjoy the water sport from beyond the seat of a wheelchair.

With the problem statement in mind, the team then targeted the following project and team goals:

<u>Project Goals:</u>

1) Design and provide a working prototype of an adaptive paddleboard to the client that meets the client's needs and requirements by June 2016

2) Deliver project documentation containing project findings, processes, and deliverables to appropriate stakeholders and appropriate university representatives

<u>Team Goals:</u>

3) Gain experience with product development design processes - from problem definition to prototype testing - with a focus on end user needs and requirements

4) Exercise necessary project management techniques to achieve effective communication and appropriately allocate team time and resources to successfully complete the project

5) Meet and exceed the expectations of project stakeholders and end users in communication, product quality, and project outcome

In order to meet the team's project goals, it was of the utmost importance that we had a thorough understanding of the client's needs and requirements and develop appropriate engineering specifications to ensure that final design met the client's requests. The team employed a method known as Quality Function Deployment (QFD) to ensure that this was achieved.

Customer Requirements

Quality Function Deployment is a process developed to help engineering teams define the relationship between the customer's desires and the functional requirements of the final project. The process involved compiling user needs from research and interviews, evaluating competitor designs, and developing quantifiable and testable engineering requirements that fulfilled the user's needs. The QFD House of Quality table the team derived can be found in the Preliminary House of Quality

Table (Appendix A). More information about QFD is readily available via other resources and will not be described further in this report, however the products of the process are described below.

The initial step of QFD is to develop a customer requirement list that reflects the needs specifications the client has made for the product. This list can be seen in Table 1.

Table 1. Customer requirement list

Customer Requirements
Board must not incorporate a wheelchair
Board must allow for user to kneel on the board
Board must be operable by one person
Board must not lock/attach user to the board
Board must be ocean capable
Board must assist user's stability while on the water
Board must allow for user to stand on the board
Board should appear as close to a classic SUP as possible
Board must assist user's ability to climb onto the board from the water.

Engineering Specifications

The team developed the engineering specifications for the adaptive paddleboard design by interpreting the results of the conducted research and interviews. The engineering specifications are listed in Appendix A. These specifications were carefully developed to ensure the customer requirements seen above were met. Client and sponsor approval was paramount for continuation of the project, as was the agreement and understanding on deliverables and specifications for the project. Changes to the engineering specifications list that occurred during the project's duration required agreement by all parties involved.

Chapter 3: Design Development

Idea Generation

Before going into the ideation phase of the project, the team recognized that there was a strong correlation between time spent on ideation and the quality of the final product. To ensure the time that was allocated to ideation was used efficiently, various problem solving techniques were implemented. This way, a wide variety of creative and functional ideas could be generated.

The first activity the team did was the 3-3-5 method, where the 3 team members created 3 different sketches for 5 minutes. The sketches were then circulated between members, and each member got the other two sketches for 5 minutes to add their own ideas onto the pre-existing sketches. This activity encouraged each member to build their own unique ideas on top of ideas from the other team members. Allowing complete freedom while drawing these concepts all encourage creativity in the ideas, and prohibited from too much focus centering on one particular area of the solution. However, after this broad approach to brainstorming, the team decided it was necessary to focus on individual aspects of the board. An example of a drawing from this activity can be seen in Figure 12.

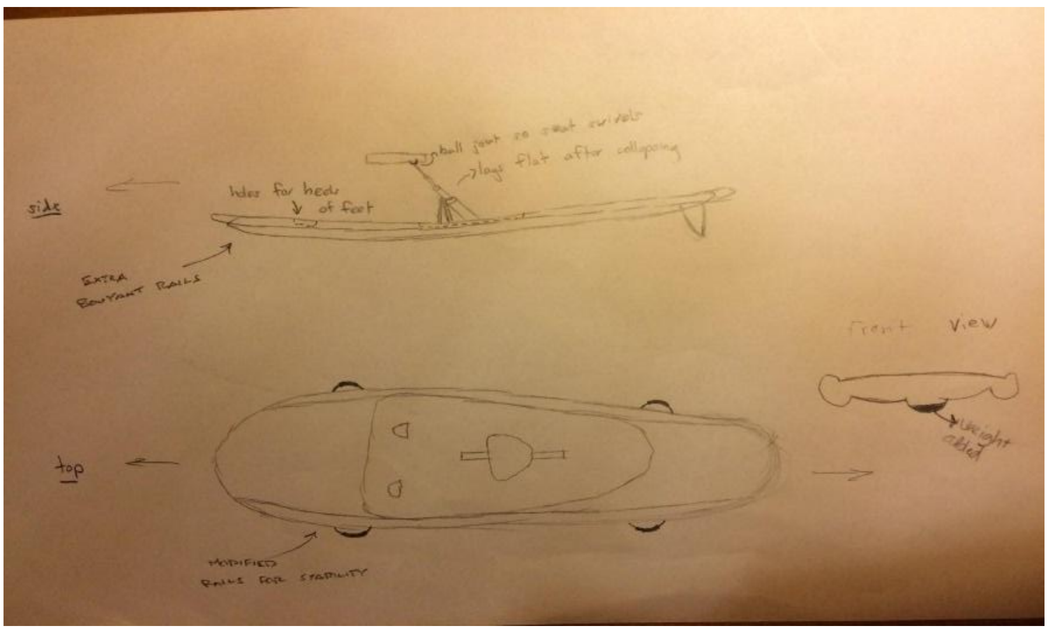

Figure 12. Drawings created during the team's 3-3-5 brainstorming activity.

To help address each design challenge individually on the board, the team created five different functions to focus on. This helped the team focus on these five main design challenges, rather than attempting to create entire design solutions. These five categories included Kneeling, Standing, Stability, Raising and Lowering, and Additional Features. Together as a team, the team then brainstormed for each of the five categories. During this brainstorming session, the team focused on generating a large quantity of ideas, and was successful in doing so.

The team then moved on to a different approach of ideation. The chosen method started with generating a list of alternative actions, which was done using a random verb generator from online. Each member generated 20 random verbs, and then chose their top five verbs. As a team, the members then went through each verb and generated solutions based on integrating that action word into the idea.

After these various brainstorming activities, in addition to smaller sessions, the team began to combine ideas and draw up different complete concepts ideas. These ideas are detailed below, and are all products of the different brainstorming activities done.

Generated Concepts for Topside User Interface

Below are the rough ideas generated for what could be used for user interface. This portion of the design would help with both kneeling and standing on the paddleboard, as well as the transition between the two.

The rear folding topside user interface design separates the modes of kneeling and standing. Kneeling will be achieved using a pad attached directly to the board. A bar would be flush with the board behind the user, able to be raised and set into a standing position through the use of a pin on each side. This system allows the user's silhouette to be used to disguise the board, while helping with stability in the standing position. The bar could also be used for transitioning from kneeling to standing; however sitting would not be possible. This would also keep the front of the board clear, allowing for clean falls without obstruction. This design can be seen in Figure 13.

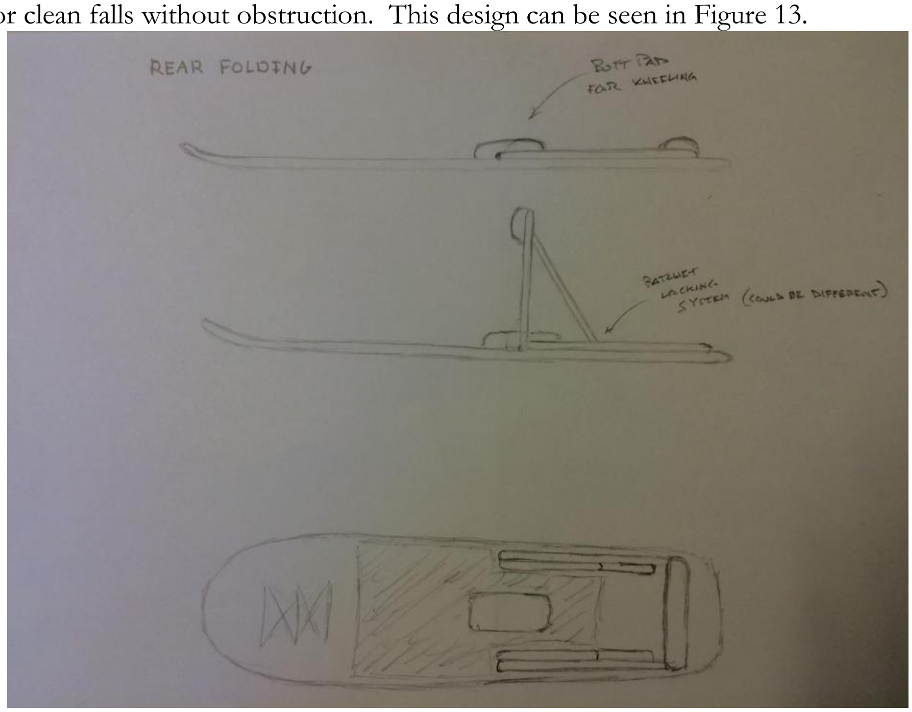

Figure 13. Rear folding topside user interface concept.

The front folding design, seen in Figure 14, follows the same parameters as the pinned bar that folds behind the user, however has different benefits and disadvantages. With it folding in front of the user, it would be easier to set up, as there would be no torqueing of the body to reach a system situated behind. There would also be a lower chance of failure in terms of failing in the standing position. The user would be leaning on the system at the peak of its extension, where failure of collapsing back down into the kneeling position would not be possible. However, this design takes space at the front of the board, leading to more possibilities of injury, as well as taking away from the traditional look of a paddle board.

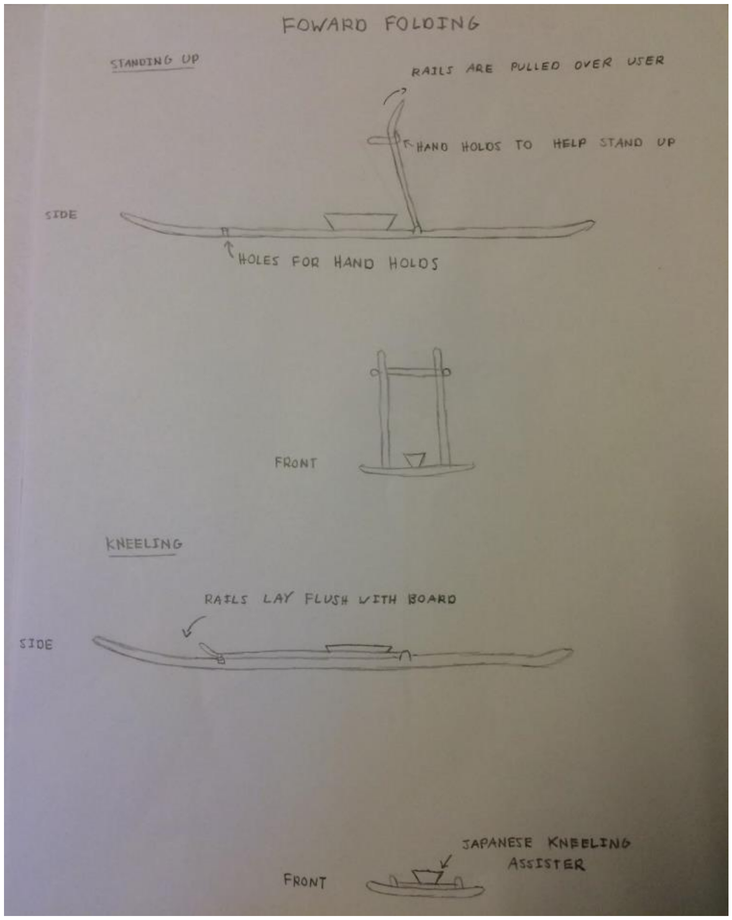

Figure 14. Forward folding topside user interface concept.

The ratchet system design, seen in Figure 15, would be situated on the back of the board. It would use linear hooks, similar to that of a chaise lounge chair. It would be helped by gravity, making the transition from kneeling to sitting to standing easy; however lowering the system may pose a problem. One noticeable problem is that the center of gravity of the user will change based on the position of the pad, as it will raise and lower in the shape of an arc. It could also pose the problem of significant injury if the user were to step on the ratchet system.

The scissor lift design includes a pad located on top of a series of crossing beams, raised and lowered by a linear actuator. This design is quite complex with many pinch points, however it would create an easy way to transition between kneeling, sitting, and standing. It would also have a small footprint on the board. Some negative sides of this design include a longer amount of time dedicated for the user to raise and lower the system, as well as a higher possibility one of the many parts will fail. The scissor lift design in Figure 16.

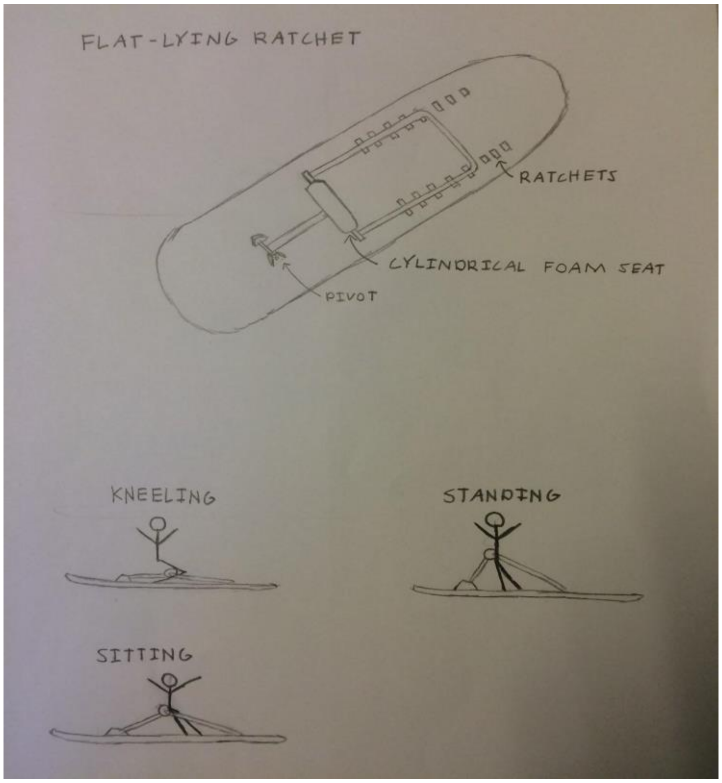

Figure 15. Flat-Lying Ratchet topside user interface concept.

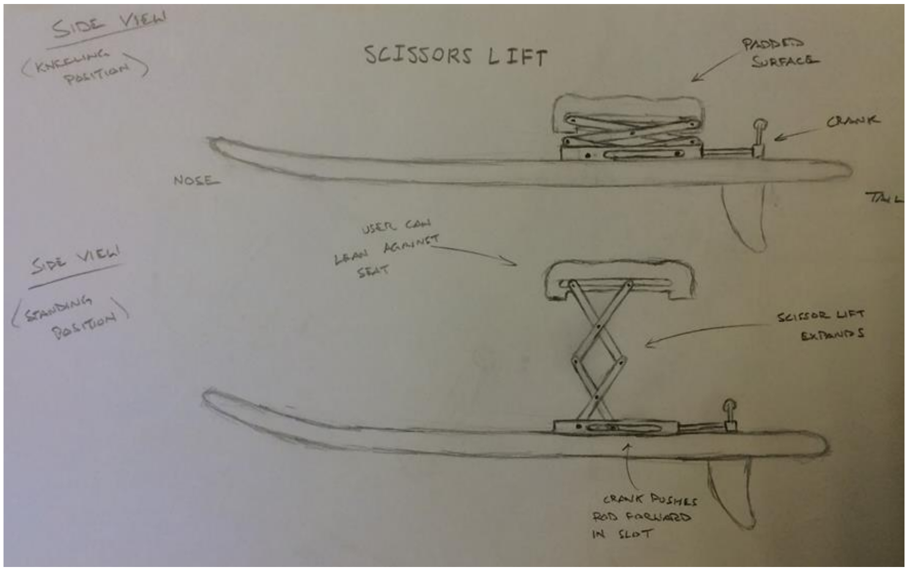

Figure 16. Scissors Lift topside user interface concept.

Generated Concepts for Increased Stability

The following section describes the top ideas generated to help increase stability of the board. Many of the ideas the team generated were from background research on more than just paddleboards and surfboards. Some of the ideas, such as the bilge keel design, came from looking at ship hulls. This idea would help with increasing stability against a rolling motion along the lengthwise centerline of the paddleboard. However, this design has many drawbacks, including a large fin near the front of the board changing the point that is turned about, as well as decreasing the mobility and agility of the board. The bilge keel would also influence where one could ride with this paddleboard as a system deeper than the fins would not allow for shallow waters to be navigated. This idea can be seen in Figure 17.

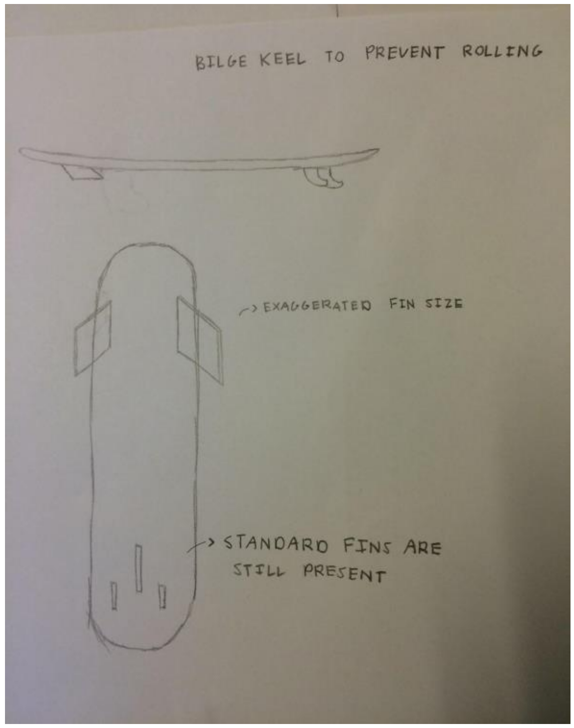

Figure 17. Bilge Keel for increased board stability concept.

A cathedral hull is a design generated from background research on modern boards, and would require a rework of the board's lower surface. To achieve this type of hull, channels would need to be fabricated into the board, giving the board more buoyancy, again countering possible rolling. Along with additional manufacturing costs, a cathedral hull will affect the maneuverability of the system as a whole. This hull design could also change the look of the board, again missing the mark on one of the requirements. This cathedral hull design can be seen in Figure 18.

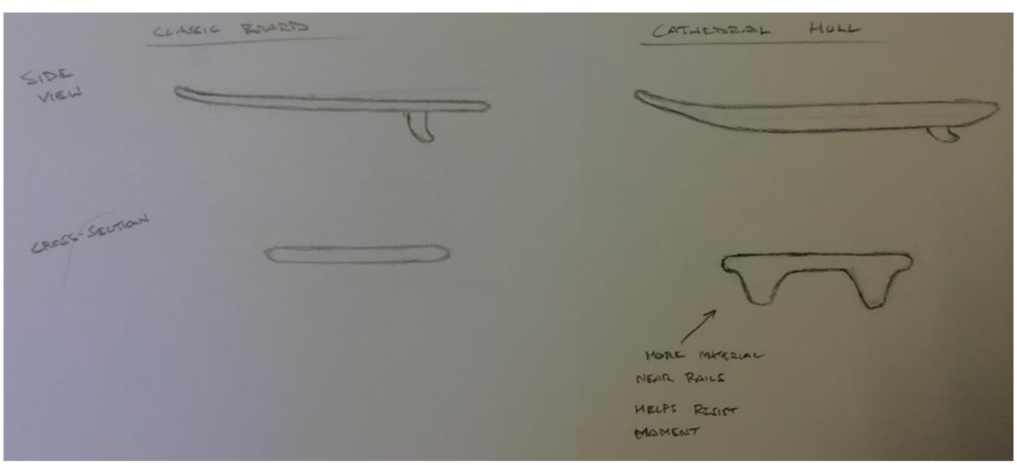

Figure 18. Cathedral Hull for increased board stability concept.

Outriggers would be similar to that seen on the Onit Ability Board. This would create a very stable riding surface; however it has been made clear by the client that something that detracts so much from the original design would not be accepted. Apart from being bulky, the extra storage as well as loss of maneuverability decreases the probability of using this design. Also taken into account is the transition of the user from kneeling to standing. If the user were to fall on an outrigger, it could cause significant damage to their person. The Outriggers can be seen in Figure 19.

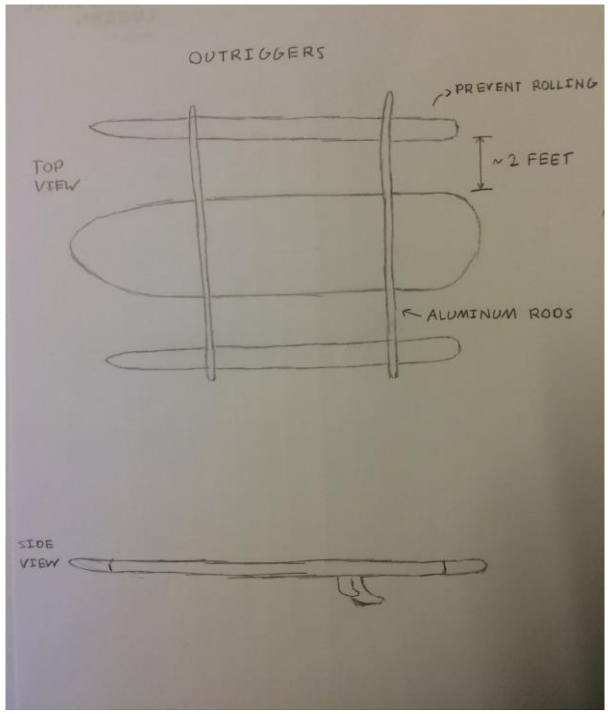

Figure 19. Outriggers for increased board stability concept.

Inflatable Rails would be a detachable option for helping stability while on the board. Attached by hook and loop closures or something similar, it would help counter rolling while also not requiring a total rework of the board. With them being removable, it also allows the user to progress through stages of stability, where if necessary, the user can not use them to ride on a classic paddleboard. The downside is that they may take away from the look of a traditional board while in use, and may also require a bit of work to make sure they will remain attached. The other problem would be inflating them while on the board if progression was being tested. The inflatable rails idea can be seen in Figure 20.

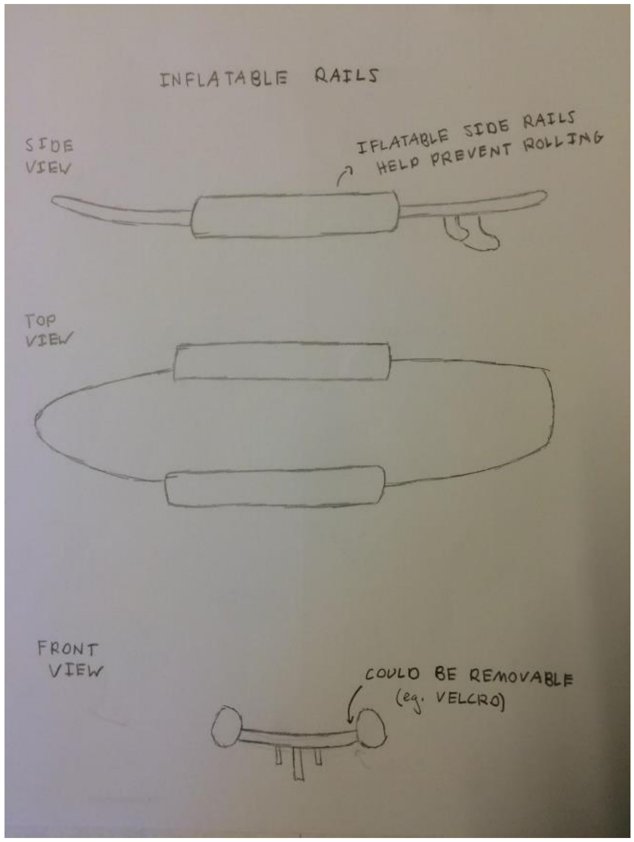

Figure 20. Inflatable Rails for increased board stability concept.

Another option for stability is to not add stability features, thus keeping the board unchanged. This standard board design would be the cheapest solution for this system. It would require a certain amount of personal stability by the user, where they would feel comfortable riding a standard board without rolling. This would keep the traditional look that is desired while also not affecting the maneuverability of the board.

Topside User Interface Concept Selection

The creation of concept selection matrices were critical for the team to accurately choose which concepts to move forward with. The agreed upon method included creating two separate matrices, one addressing the user interface on the topside of the board, and a second matrix for added stability features on the board. This was done because the two aspects of the board act independently from each other, and therefore the choices made for each category needed to be independent as well.

The first decision matrix created, seen in Table 3, was for the user interface on the topside of the board. First, the top four concepts for this category were chosen and input into the matrix (Flat Lying Ratchet, Forward Folding, Rear Folding and Scissor Lift.) The team then generated a list of criteria to grade each of these concepts by. These criteria are designed to encompass the entire use and design of this feature of the product. That was, the grade for each concept that is generated from the matrix is accurate. After creating these criteria, the next step was deciding on a scoring weight for each criteria, based on a scale from 1-10. This process involved a substantial amount of discussion within the team, due to the importance and impact of these weights.

Table 3. Concept Selection Matrix for user interface on the topside of the board.

User Interface / Topside Decision Matrix									
Criteria	Scoring Weight	Concepts							
		Flat Lying Ratchet		Forward Folding		Rear Folding		Scissor Lift	
Weight	5	2	10	3	15	3	15	1	5
Ergonomics	9	1	9	2	18	3	27	4	36
Kneeling Appearance	7	3	21	2	14	3	21	4	28
Standing Appearance	6	3	18	4	24	4	24	1	6
Ease of Use	8	3	24	4	32	3	24	1	8
Cost	1	3	3	4	4	4	4	2	2
Maintenance	3	2	6	3	9	3	9	1	3
Safety	10	3	30	4	40	4	40	3	30
		Sum	**121**	*Sum*	**156**	*Sum*	**164**	*Sum*	**118**

The highest weight of 10 was given to safety, as Damien's safety during the use of the topside user interface was the team's top concern. The second highest rated criterion was ergonomics, which was given a weight of 9. The team decided that the topside interface must be comfortable during the long periods of use that Damien requires; otherwise he simply wouldn't want to use the board. The next criterion chosen was ease of use, and was given a weight of 8. The ability to use the chosen topside interface easily is very critical to the success of the product. However, the team also decided that the transition between the kneeling position and the standing position represents a small portion of the overall time spent on the board.

Another critical aspect of the topside interface is its appearance during use while in both the kneeling and standing positions. The team decided to split these two positions into two different criteria, as the appearance of the board could change dramatically after transitioning from the kneeling position to the standing position. The appearance of the topside user interface while the user is kneeling was given a weight of 7, while the appearance while standing was given a 6. The kneeling position appearance was given a higher rating because the board will be used more in the kneeling position. Furthermore, the kneeling position of the board is also the configuration of the board during transport. The appearance of the board while in the standing position is also very important to Damien, but the team believes the appearance of the board while kneeling takes precedence over the appearance while standing.

The least important criteria include the weight, maintenance and cost of the topside user interface. The weight criterion was given a value of 5 because as long as the board is under the maximum weight given in the engineering requirements, it is acceptable. The maintenance of the topside interface was given a weight of 3 because while maintenance of the board must be easy, it is not at all crucial to the product. Finally, cost received the lowest weight of all the criteria, and was given a value of 1. The team was confidence that the cost to build to topside user interface on the board would not significantly impact our budget.

Additional Stability Concept Selection

Initial concept selection was done by compiling the various ideas generated through brainstorming and separating them into two categories, stability and user interface. For the stability decision matrix, Table 4, brainstormed concepts were pitted against each other in a matrix with attributes chosen by the team based on the requirements list, background research, and customer wants and needs. This matrix allowed the team to narrow the selection to one or two systems to start prototyping by assigning weights to the attributes chosen, such as overall stability, appearance, cost, safety, transportation, maneuverability, and shallow water limitations.

Safety is the primary concern for the team. This attribute to the stability of the board was given the highest weight because no matter how stable the board is, if the user was to be injured while using it, the system wouldn't be worth it. The next attribute was the stability of the board. This was weighted just below safety because it is the overall goal of the attachments in this part of the system. Maneuverability and shallow water capabilities were given a seven in weight due to the ability to act like a normal board. Damien wants to paddleboard, so if the team made something that wasn't able to do what a paddleboard can do, or as close as possible, the system will not be used. Along those same lines, appearance comes up just behind maneuverability and shallow water capabilities, as acting and looking like a normal paddleboard are a primary concern of Damien's. Transport of the system was lower on the list because while the system must be transported to and from the chosen launch spot as well as fit in a vehicle, ease of transport could be sacrificed if necessary. Lastly, cost makes the list, as a budget was decided in the requirements according to competing products, and the ideas selected should be well below what has been estimated.

After assigning each attribute its weight between 1 and 10, a baseline concept was chosen – the classic board. When comparing concept ideas to the baseline, each idea was designated with a -2, -1, 0, 1, or 2, depending on team member's thoughts on feasibility, background research, and technical knowledge of the systems. These scores were then multiplied by the given weight of the attribute and each concept was given its total at the end of the exercise. As seen in Table 4, the wide board and inflatable rails came out above the classic board.

Table 4. Concept Selection Matrix for the stability features of the board.

Stability Feature Decision Matrix													
Criteria	Scoring Weight	Concepts											
		Classic Board		Outriggers		Bilge Keel		Cathedral Hull		Inflatable Rails		Wider Board	
Stability	9	0	0	2	18	1	9	1	9	1	9	1	9
Appearance	6	0	0	-2	-12	0	0	0	0	-1	-6	0	0
Cost	1	0	0	-1	-1	-2	-2	-2	-2	-1	-1	-1	-1
Safety	10	0	0	-2	-20	0	0	0	0	0	0	0	0
Transportability	2	0	0	-2	-4	0	0	0	0	0	0	0	0
Maneuverability	7	0	0	-1	-7	-1	-7	-1	-7	0	0	0	0
Launching/Shallow Limitations	7	0	0	-1	-7	0	0	0	0	0	0	0	0
		Sum	**0**	*Sum*	**-33**	*Sum*	**0**	*Sum*	**0**	*Sum*	**2**	*Sum*	**8**

Preliminary Selected Design Description

The preliminary concept selected by the team was a combination of ergonomic features to support the user of the paddleboard while in both kneeling and standing positions as well as features to improve the stability of the paddleboard itself. The exact dimensions, materials, and construction techniques of these features were undetermined at the time this preliminary design was submitted for feedback.

The primary stability improving feature selected for the adaptive paddleboard design was increased board width. When the board begins to tilt on the water the center of buoyancy, or the point at which the buoyancy force applied to the board, it will move toward the rails of the board as will the center of gravity of the combined board and rider. As long as the center of buoyancy remains closer to the rails than the center of gravity, the board and rider will experience a torque that both resists further tilting and drives the board back to its neutral, flat position of the water. If the center of gravity moves closer to the board's rails than the center of buoyancy, then the restoring torque changes direction and will cause the board to capsize. By increasing the width of the board, the restoring torque is both stronger and exists at steeper tilt angles than a paddleboard with a typical board width. This feature ensured that our design met requirement 2.4 of the Engineering Specifications.

Increasing the width of the board had the possibility of bringing the dimensions of the board beyond requirement 1.2 in the Engineering Specifications. However, the intention of requirements 1.1, 1.2, 1.3, and 1.4 were to ensure the selected design maintained an appearance similar to a traditional paddleboard. By changing the width by about 10%, the team believed that the appearance would not be compromised.

The increase in displacement volume that results from increasing the width of the board will serve to increase the maximum carrying weight or vertical load that the board can support while maintaining buoyancy. The additional volume of the board also results in an increased hull mass, but this increase is negligible compared to the rider's weight when considering the maximum carrying weight. This means that widening the board will help the selected design to achieve requirements 2.1 and 2.2 of the Engineering Specifications.

To support the user while riding in a kneeling position, the board will be outfitted with a pad located along the centerline of the board and about four feet from the edge of the tail. The pad will be approximately half a foot wide so that it may reside between the rider's legs in both the kneeling and standing positions. This will help to support the rider's tailbone while in the kneeling position. Additionally, the surface of the board will be similarly padded to prevent discomfort in the rider's knees and feet while riding in the kneeling position for extended periods of time. This feature is one of the two primary components that enable the design to meet requirement 5.1 of the Engineering Specifications.

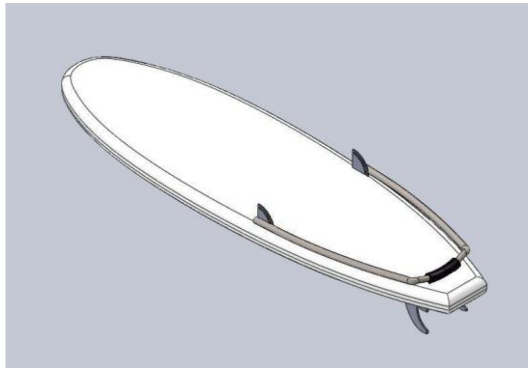

Figure 21.1 Preliminary model of folding standing support concept in down position.

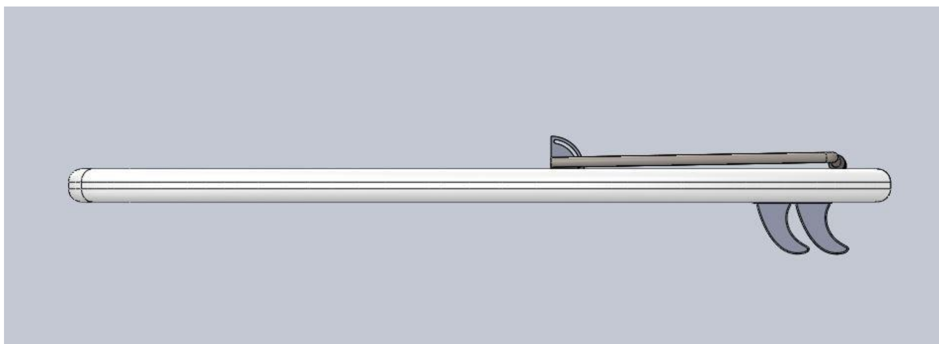

Figure 21.2 Preliminary model of folding standing support concept in down position.

It is imperative that the pad does not create any discomfort for the user or impede the rider's motion in any way. Thus it will need to be properly shaped and positioned on the board. In addition to this, the material of the pad will need to be carefully selected to be both comfortable and perform well in aquatic conditions. The team required a firsthand experience with the different possibilities for the pad in order to make these decisions; and were therefore made during the prototyping stage of the project.

To support the user while riding in a standing position, the board will be outfitted with a folding support. The support will fold about two, collinear pivot points, or hinges, located at the surface of the board, near the rails of the board and about four feet from the edge of the tail. The support will travel 90° about the pivot points from lying flat on the surface of the paddleboard to perpendicular to the board's surface. Therefore, the support will have two primary positions: upright and flat or stowed. The joints or hinges that the support pivots about will lock in the two primary positions to ensure the support is stable and static during use in either position. The upper, forward facing surface of the support will be padded in a similar fashion to the kneeling support. This feature, along with the kneeling pad described above, allows the design to meet requirement 5.1 of the Engineering Specifications. A preliminary model of what the team envisions this feature might look like can be seen in Figures 21.1, 21.2, 22.1, and 22.2.

Figure 22.1 Preliminary model of folding standing support in upright position.

When locked into the upright position, the support will provide a stable surface for the user to lean against. In addition to this, the support can be used by the user to assist with transitioning between a standing and kneeling positions. This feature will ensure the design meets requirement 2.4 of the Engineering Specifications. The greatest advantage to this feature is that it will provide the required support for the user, but stows flat against the board when not in use. When in use, the support frame will not extend far past the silhouette of user which will help to mask the use of the support from the casual onlooker. The low profile appearance of the folding support meets requirement 1.4 of the Engineering Specifications.

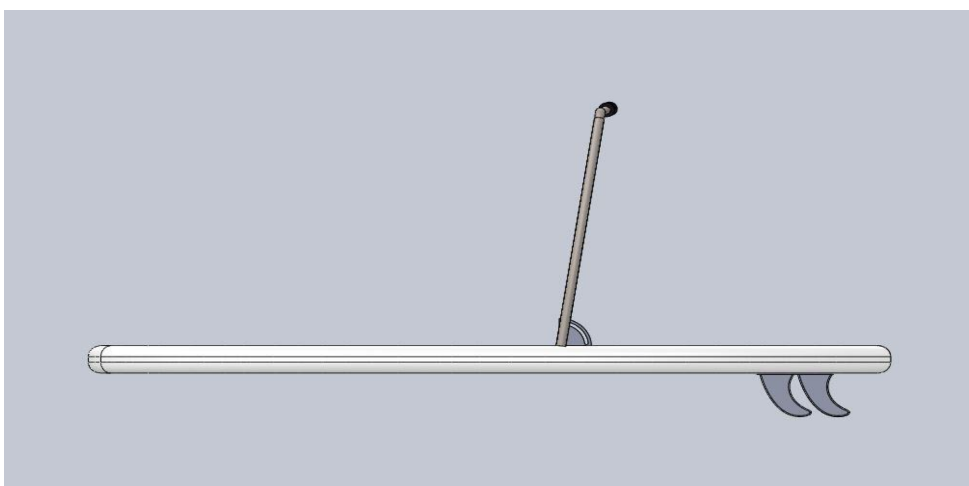

Figure 22.2 Preliminary model of folding standing support in upright position.

The combinations of all features described in this report are balanced about the centerline of the board. This will ensure that the design meet requirement 2.5 of the Engineering Specifications.

Chapter 4: Description of Final Design

Overall Description of Final Design

The final chosen design is a modified version of the preliminary selected design. Upon presenting the final preliminary design to Damien, the team received valuable feedback regarding how he planned to use the board, as well as his progress in his ability to move his legs. The largest change Damien wanted to see in the design was the addition of a seating position on the board, which became a focus for the team. Furthermore, Damien expressed how he was very comfortable using dip bars to move his body up and down, as this is a very common movement for wheelchair users. The team took this feedback, in addition to other items, and integrated them into the design in an attempt to create the product so it uniquely fit Damien's desires. The final design can be seen in Figure 23.

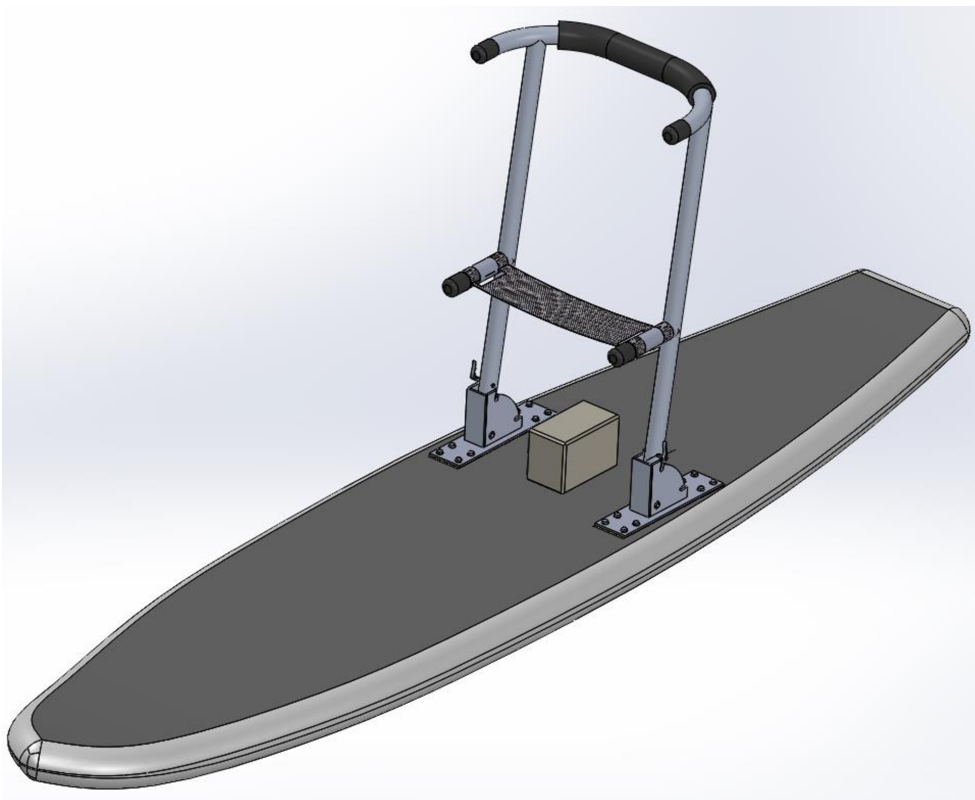

Figure 23. Final chosen design for the adapted paddle board for Damien.

Detailed Design Description

Description of Collapsing Joint

For the final collapsing joint, the team took inspiration from the same type of joint used in the Razor Scooter. A plate with two cuts and an internal rod allows the structure to adjust between two secured positions. A lever on the outside of the structure legs engages the pin and removes it from the cut in the plates, allowing the user to then pull or push on the entire structure until the pin slides into the other cut, automatically locking the structure into its new position. This design allows the structure to be easily moved, and ensures the structure is securely locked into the new position by not requiring any action by the user to lock it. A close-up of this collapsing joint can be seen in Figure 24.

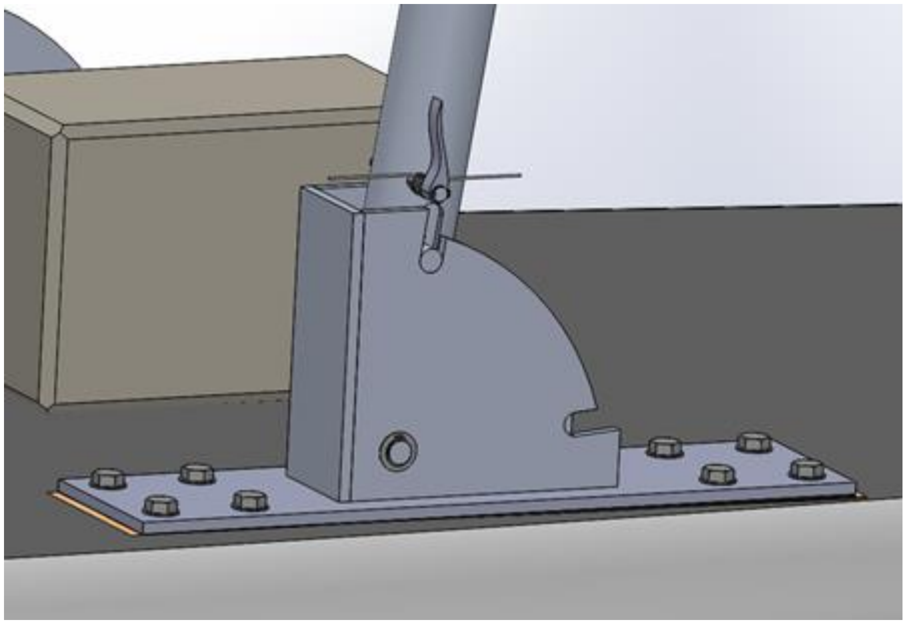

Figure 24. Close-up view of the collapsing joint.

Description of Kneeling Position

The most basic position the board offers is the kneeling position. Damien expressed confidence that he would be able to remain in this position for prolonged periods of time, so the team simply wanted to make it comfortable for him. A foam yoga block was chosen to help the user sit in a kneeling position without having to sit on their legs, which would limit blood flow to the legs and become uncomfortable after a longer period of time.

Due to Damien's prohibited leg motion, the team decided to attach the foam block to the board using a fabric hook and loop fastener. This way, the block would remain stationary during use and not move around the board when not in use. The polyester loop strip will be attached to the board, while the hooked strip will be attached to the block, to help prevent abrasion of the user's skin against the hooks. The loop strip will extend beyond where the user sits to allow the block to be placed and secured out of the way when the user decides to sit or stand instead.

Description of Sitting Position

The sitting position was requested by Damien upon meeting him for the first time during the team's face-to-face meeting with him in January. After additional idea generation and analysis, the team decided on using a mesh fabric chair supported by bars extruding from the main structure, seen in Figure 25. These extruded bars double as dip bars which will help Damien get into and down from the sitting position. These dip bars were also requested by Damien, as that type of lifting motion is very common for wheelchair users.

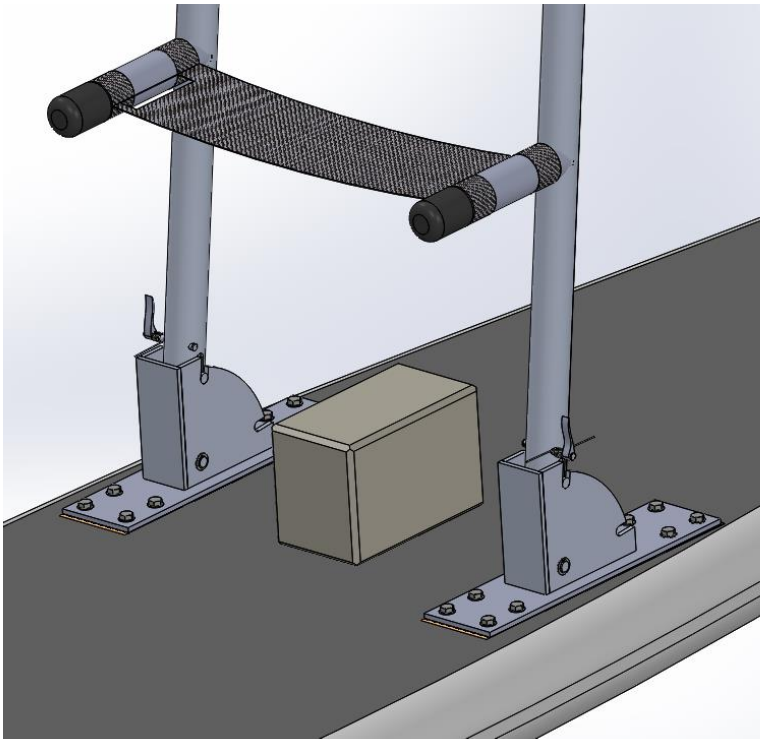

Figure 25. The seat of the board.

The chair fabric is designed so that it can be easily pushed and crumpled back towards the structure supports. This way, when the chair is not in use while the user is either sitting or standing, the fabric does not inhibit their motion or rub against the back of their legs. The fabric has two loops on each short end to loop around each dip bar twice, allowing it to be crumpled and pushed back easily. The stitching configuration to create these loops was tested to ensure it does not fail under the project's specified loads, this is detailed later in the manufacturing section of the report.

Description of Standing Position

The standing position is the third user position of the structure, with the goal of providing lateral support to Damien. The U-shaped bar on top surrounds the user around their waist, providing support if the user sways to their side, as seen in Figure 26. This design was created due to Damien expressing his concern of his ability to control his own side-to-side movements. This bar on top will be outfitted with foam cushion to provide comfort and soften any impact the user has with it. The low placement of this bar around the user's waist was done to allow the user to paddle without any hindrance.

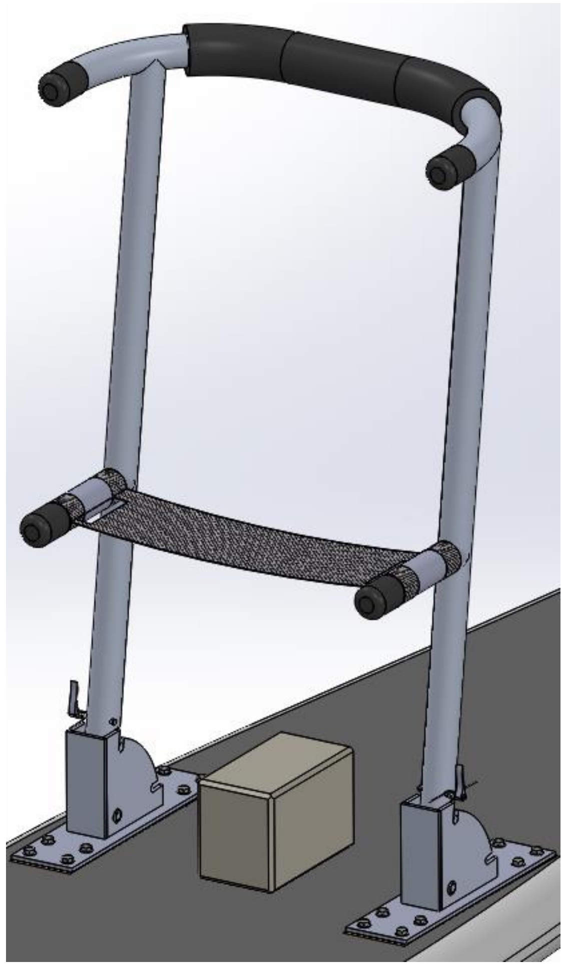

Figure 26. The structure locked in place for the user to use to help stand.

Analysis Results

Structural analysis was conducted on each of the critical locations identified by the team. These included the weld of the cantilevered dip bars of the seat, failure of the hexagonal and round pins due to shear and bending, deflection and failure of the support structure due to bending, and the failure of the cap screws. The results of this analysis can be seen in Table 5. Greater detail on the conducted analysis can be found in Appendix D.

Table 5. Summary of analysis results.

Critical Feature	Analysis Technique	Maximum Value	Factor of Safety
Hexagonal Pin	Principle Stress	7,900 psi	3.8
Round Pin	Principle Stress	12,400 psi	2.4
Support Structure	Bending Stress	16,000 psi	2.17
	Deflection	0.33 in	1.52
Cap Screws	Tensile Stress	27,400 psi	2.73
Dip Bars	Principle Stress	4,150 psi	10.2

The first item analyzed was the strength and deflection of the structural support beams due to bending caused by the structure experiencing a maximum load of 250 pounds acting normal to the support at the back rest. This creates a large moment at the base of the support. The size of the tubing used in the support structure was selected to ensure that the structure will not fail under this maximum load nor will it deflect beyond the maximum value. In this analysis, the stress concentration due to the holes for the pins was ignored because the presence of the pins will mitigate any significant stress concentration.

The hexagonal and round pins that are used to lock the structure in its upright and downward positions were each analyzed with the corresponding reaction forces from the bending analysis of the structure. In this analysis, the stress concentration factor caused by the change in cross-sectional area in the hexagonal pin near its ends was ignored. The pins were then sized in order to ensure that they would not fail due to bending or shear loading when the structure is subjected to the maximum loading conditions.

The cap screws used to secure the structure's base to the board inserts were analyzed using the reaction forces of the structure's base caused by the loading transferred from the pins. This loading was mitigated by extending the length of the base to 16 inches which reduced the loading on each screw cluster. The cap screws were then sized to ensure that screws that experience the greatest loading would not fail. The sizing of the cap screws was kept uniform to simplify assembly, aesthetics, and for redundant strength.

The cantilevered dip bars of the seat were analyzed under a maximum load of 150 lbs on each bar to represent the client lifting himself using just the bars. In this analysis, the weld joining the dip bars to the main structure was assumed to be uniform and rigid, making the location of maximum bending stress just before the weld. This is safe to assume because welding will increase the thickness of the cross-section at those locations as well as improve the internal strength of the aluminum.

Another area of concern for the failure of the design is the bonding of the alder inserts to the internal structure of the board. The team was unable to conduct numerical analysis of the strength of the inserts due to the elusive nature of the epoxy resin bonding method. Instead, the team opted to employ an installation method recommended by a representative of the SUPThinkTank referred to as the "top hat" installation method, which is commonly used to increase the strength of embedded structures in experimental surfboards. Additionally, the number of inserts had been in increased from two to four in order to increase the bonding surface area and add redundancy to the structure as well as take advantage of the extended length of the structure's base.

Cost Analysis with Bill of Materials

A cost estimate was created to ensure the final design fit appropriately into the team's budget. The most expensive component of the project was going to be the paddleboard, which can cost anywhere between $1000 and $1500, however, a board was generously donated by Matt Freidman from SUP Think Tank. With the board donated, the most costly component of the project was all the needed aluminum piping to construct the main structure. Each individual part is listed in Table 6, along with its material name, quantity and cost. The total cost of the project will be around $1000, with a built in contingency of 10%. This contingency was added to account for unseen shipping expenses, changes in part prices and anodizing costs.

Table 6. Cost estimate created for manufacturing phase of project.

Part #	PART	Material Name	Quantity	Cost per Unit	Item Cost
1	PADDLEBOARD HULL	SUPATX Adventure XL	1	$ -	$ -
2	CAP SCREWS	316 SS 3/8"-16 UNC 2A x 1.25" CAP SCREW	2	$ 6.12	$ 12.24
3	THREADED INSERT	SELF-TAPPING THREADED INSERT	8	$ 5.28	$ 42.24
4	INSERT BODY	SHAPED ALDER RECTANGLE	1	$ 50.00	$ 50.00
5	PLATES	6061 Al 1/4"x8"x8" PLATE	7	$ 5.64	$ 39.48
6	STRUCTURAL PIPE	6061 AL Sch 40 PIPE	4	$ 64.33	$ 257.32
7	CAP SCREW WASHERS	316 SS 3/8" WASHER, 0/406" ID, 0.750" OD (25 pack)	1	$ 9.71	$ 9.71
8	ROUND PIN	316 SS 1/2"x2.8 MACHINED ROUND PIN	1	$ 6.64	$ 6.64
9	HEX PIN	316 SS 1/2"x2.5 MACHINED HEX PIN	1	$ 14.02	$ 14.02
10	ROUND PIN WASHER	PTFE 1/2" FLAT WASHER, 0.531" ID, 1.25" OD	1	$ 6.31	$ 6.31
11	ROUND PIN SNAP RING	15-7 SS 1/2" EXTERNAL RETAINING RING	1	$ 9.37	$ 9.37
12	RETAINING SPRING	.96" SPRING OD, .121" WIRE DIA 302 STAINLESS STEEL EXTENSION SPR	2	$ 5.53	$ 11.06
13	HANDLE PIN	316 SS 5/16"x2.5" MACHINED ROUND PIN	1	$ 3.06	$ 3.06
14	HANDLE SNAP RING	15-7 SS 5/16" EXTERNAL RETAINING RING (10 PACK)	1	$ 8.59	$ 8.59
15	HANDLE	ANODIZED ALUMINUM HANDLE	2	$ -	$ -
16	HANDLE SPRING	SPRING OD, .051" WIRE DIA 302 STAINLESS STEEL TORSION HANDLE SI	2	$ 3.02	$ 6.04
17	HANDLE FOLLOWER	ANODIZED ALUMINUM FOLLOWER	2	$ -	$ -
18	ANODIZING	LABOR COST	1	$ 150.00	$ 150.00
19	FIBERGLASS CLOTH	6oz E CLOTH	-		
20	EPOXY RESIN	2:1 2000 RESIN	-		
21	NEELING SUPPORT SURFAC	9"x6"x5" FOAM YOGA BLOCK	1	$ 10.00	$ 10.00
22	NEELING SUPPORT FIXTUR	3' x 2" MARINE GRADE HOOK AND LOOP STRIP (LOOPS)	1	$ 19.78	$ 19.78
23	NEELING SUPPORT FIXTUR	3' x 2" MARINE GRADE HOOK AND LOOP STRIP (HOOKS)	1	$ 19.78	$ 19.78
24	BACK REST FOAM	FOAM ROLLER 6"x4"ODx20mmID	1	$ 20.00	$ 20.00
25	BACK REST END CAPS	EPDM 1.187" ID x 1.5" BLACK	4	$ 5.00	$ 20.00
26	BASE GASKET	36" x 12" x 1/8" NEOPRENE SHEET	2	$ 15.00	$ 30.00
27	FABRIC SEAT	PHIFERTEX PLUS POLYESTER YARN (BLACK)	1	$ 60.00	$ 60.00
				Subtotal	$ 805.64
				Tax	$ 64.45
				Contingency	$ 80.56
				Total Cost	$ 950.66

For a more compressive detailed list of all the components used in the manufacturing of this board, including supplier and catalog number, the Bill of Materials can be found in Appendix B.

Material and Component Selection

When the team began looking at materials to use for the construction of board, it was important to keep in mind where the product was going to be used. The use of any product in a marine environment puts the quality of the product to the test. Long hours of direct sunlight and corrosion due to saltwater are just two of the main factors that needed to be considered. For this reason, finding marine grade materials was very important to the team during the material selection process.

The first material question that was addressed was what to make the main frame of the structure out of. The team knew a type of metal would be the most likely candidate, due to their high strength and low price. Stainless steel was eliminated due to its heavy weight, as well as untreated aluminum due to corrosion. Anodized aluminum then became the top choice due to aluminum's low cost, malleability, and light weight. By using anodized aluminum, the aluminum structure will not rust even while being in a marine environment. The structure shape will need to be manufactured first, however, due to the harmful effect welding has on the anodized surface.

Another very important material decision was what type of material to use for the board inserts. The material needed to be lightweight, porous and strong. If the material was not porous, it would not bond well with the added epoxy and fiberglass needed to keep the insert in the board securely. Furthermore, because the insert will be tapped with threaded insert sleeves to allow the structure to be bolted down to the board, the material of the insert needed to be strong as well.

Initially the team planned to use a dense plastic, such as HDPE, but the plastic was found to perform poorly when bonded to fiberglass using epoxy. Recognizing that a more porous material was needed, dense foams were looked into, but none found were strong enough to safely tap the threaded inserts into. These learnings then lead to the team choosing wood as the final insert material.

Different types of woods were looked at for their porosity and hardness qualities, as well as availability. After the initial search, Mahogany, Douglas Fir, Alder and Cherry were the frontrunners. All of these woods can be easily tapped and would bond well with the added epoxy layers. Douglas Fir was chosen for its superior hardness compared to the other woods, as well as its inexpensive price.

For the seat of the paddleboard, a fabric needed to be chosen that could sustain the weight of Damien, withstand the harsh sea environment it would be used in, and be able to easily be crumpled. To determine the best fabric to use, the team conducted testing of various fabric samples. All of the samples tested were high strength mesh fabrics from Seattle Fabrics. Once a mesh fabric was found to easily be crumpled, the team tested the fabric's strength and the effect of seawater on their performance. The chosen fabric for the seat was found to be PhiferTex Plus, a PVC vinyl coated polyester yarn. The fabric was chosen for its high durability and performance in outdoor applications.

When the team began looking at which type of epoxy to use, the team knew the impact of saltwater on the strength of the bond was critical. Upon first searching, many ocean grade epoxy resins were found. However, due to the team's relative inexperience with composites, the team decided to rely on Matt Friedman from SUP Think Tank to provide assistance during the insert installation process. The epoxy used by SUP Think Tank is used to securely attach small board inserts and should prove to be a more than adequate choice of epoxy.

Finally, adaptations to the surface level of the board also involved some material considerations. For the kneeling position use of the board, a yoga block was chosen to support the user. To ensure a standard foam yoga block would perform in a marine environment, the team submerged a yoga block under sea water for one hour and used it to kneel. This test proved to be successful, and the block was shown to Damien. While Damien agreed using a yoga block was a great idea and could use it to help him easily kneel, he commented on the hardness of the block and the lack of comfort it provided to his testicles. Due to this, the final yoga block chosen will be softer and provide sufficient cushion. The other components on the surface of the board includes loop and hook style fasteners as well as board surface padding, which both simply need to be marine grade quality.

Failure Mode and Effects Analysis

Once the final design was completed, the team created a Failure Modes & Effects Analysis (FMEA). By doing this type of analysis, the team was able to learn which components of the paddleboard matter the most so that design efforts could be focused on certain areas. This is a critical step during the design process whenever the design involves new equipment, as it helps understand the risk of failure.

The first task completed was brainstorming all the ways the paddleboard could fail. For each of these failure modes, a failure effect and failure cause was then generated. After looking at each component and all possible failures, the team decided to divide the FMEA into its primary features, and then divide each primary feature into separate functions. As seen in Appendix D, each component was given a rating for severity, probability of occurrence and ability to detect, of which were then multiplied to create a Risk Priority Number, or RPN. This RPN number helped the team recognize which failure modes had the highest risk of happening. In addition to descriptions within the table for why each component was given its respective rating, recommended actions were created to explicitly describe how each risk would be addressed.

After creating the table, the failure modes with the highest RPN's received further design attention. The highest rated component was the seat fabric, with a potential failure mode of ripped stitching. This failure mode was given a high rating of 8 for severity due to the possibility of user injury. Furthermore, the probability of occurrence received a high rating because it could either rip due to fatigue of the stitching or the user accidentally tearing the fabric with their clothing. The chosen recommended action for this failure mode was testing of different stitching configurations under different loads and purposeful tearing.

Another failure mode that received a high RPN number was the epoxy of the board insert. Shear tearing or peeling of the epoxy could result in the board inserts being torn from the board and the support structure failing, with the possibility of user injury. Potential causes of this failure include unseen additional forces applied to the bars, or a tear in the seal on the board surface, allowing water the leak into the epoxy layer. To address this potential failure mode, the team worked with Matt Friedman from SUP Think Tank LLC in Encinitas, CA, a company that specializes in paddleboard inserts and accessories, to ensure the board inserts are correctly installed into the board.

Manufacturing and Assembly Plan

The manufacturing of this design began as quite the extensive project, however with further research, off the shelf parts have been found to reduce required manufacturing while also keeping the price relatively low. The starting point for manufacturing was ordering the stock materials and off-the-shelf parts. Once everything on the bill of materials arrived, organization into component groups was the next step. The chosen groups were as follows: Insert, Collapsing Joint, Kneeling Support, Sitting Support, and Upright Standing Support. These groups all needed different manufacturing techniques to complete.

The insert work was planned to primarily be done with Matt Friedman from SUP Think Tank. As he has experience cutting into foam core boards, and has generously donated one for our project, the team planned to rely on him as a consultant and expert on the subject matter. The team cut the insert to size and assembling it, but then brought the insert to him in San Diego, where the team worked at the Ding King Repair Shop to assemble the insert into the board.

The collapsing joint uses a few off-the-shelf parts such as snap rings, scooter parts, cap screws, and washers. These were planned to be assembled with the machined guide rails. The guide rails would require a CNC mill to create. The sweep on the outside as well as the precision of the holes for the pins required heavy attention to detail. The guide rails will then be welded to a back and base plate. The base plate will have eight countersunk holes for two bolt patterns, four in the front and four in the rear of the collapsing joint, which will create the main interface between the insert and the collapsing joint. The pins will be machined on a lathe, making the hex pin rounded on the ends for the ability to roll along the guide. Snap ring levels will also be done on the lathe. Key ways will be manufactured on an end mill. Springs and pins will then be inserted through the guides, and will serve as the main interface between the upright standing support and the collapsing joint.

The upright standing support uses stock aluminum pipe cut to size and welded together, with an end mill being used for drilling the holes required for the pin connection interface. The curved beam at the top of the support was be ordered pre-bent, requiring only welding in the manufacturing process. Dip bars will also be welded to the main down tubes of the support, after being cut to size. The team plans to use a tube shark to create the correct diameter required for welding to go as smooth as possible. Assembling the upright standing support with the collapsing joint will require feeding pins through the drilled holes. Finally assembling foam onto the support and removing sharp edges, as well as covering pinch points will finalize this stage of the assembly.

The sitting support required sewing of a fabric that will be cut to size. This fabric was then stretched across the dip bars located on the upright standing support. This cloth serves as the entirety of the sitting support and the interface between the sitting support and upright standing support.

The kneeling support is planned to be a standalone assembly with its own interface with the board. This will include a hook and loop closure interface with the board and a pre-fabricated foam block that has been ordered to size. This allows for easy assembly and removability of this feature.

Through consulting experts on less certain subject matter, as well as having shop experience throughout the team, manufacturing and assembly of this design will be accomplished as efficiently and correctly as possible. Following the manufacturing plans as well as technical drawings will be tantamount to the success of the design.

Maintenance and Repair Considerations

The goal of this project was to provide Damien with a board that inhibits him to paddleboard during the entirety of his recovery. However, the team also wanted the added features of the board to be removable, so that the board could become nearly identical to a standard paddleboard if desired. With this possible extended use of the board in mind, the team put significant design efforts towards the usable life of the board.

The team expects only a few components will ever need repair or replacement during Damien's use of the board. The fabric seat of the board could possibly be ripped or torn during use and need to be completely replaced. To make it possible for Damien to acquire a new seat if this occurred, the team plans to provide information on where exactly to purchase the needed seat fabric material, as well as a local business to get the correct stitching done. Instructions will be prepared beforehand for Damien to provide to the stitching company to ensure the stitch is done correctly.

The paddleboard must also be subject to standard paddle board maintenance to ensure it continues to perform well. This includes putting the board in a board bag when not in use, keeping the board out of direct sunlight when possible, and washing the board with freshwater after going into saltwater. These basic maintenance tips and more will be outlined to Damien before the final product handoff.

Safety Considerations

When the board is in use, the safety of the user is the top concern of the team. To ensure the user safely and correctly uses the board, safety guidelines have been written to give to Damien before his first time using the board. Claire and Haley have written up a comprehensive safety procedure that can be found in Appendix F.

Chapter 5: Product Realization

Manufacturing Processes Employed

The wooden inserts were cut from a 4 x 6 inch Douglas Fir beam (actual dimensions of cross-section were 3.5 x 5.5 inch). The rough cuts were made using a chop saw and the dimensions were finalized using a belt sander. The starter holes for the self-tapping tapped inserts were then made using a drill press, and the tapped inserts were installed by hand using an allen wrench. Shallow channels were cut into two sides of the wooden blocks using a pneumatic sanding wheel. These channels were added so that excess epoxy would be able to flow to the surface during the layup process.

The wooden inserts were brought to the The Ding King surfboard repair shop in Encinitas, CA to be installed into the board. This process involved finding the center of gravity of the board and then the board's centerline from nose to tail using a laser. The insert locations were then marked with masking tape and the cavities for the inserts were created using a router. The foam traction pad was then removed around the desired insert locations. A photograph of the first routed cavity can be seen in Figure 27.

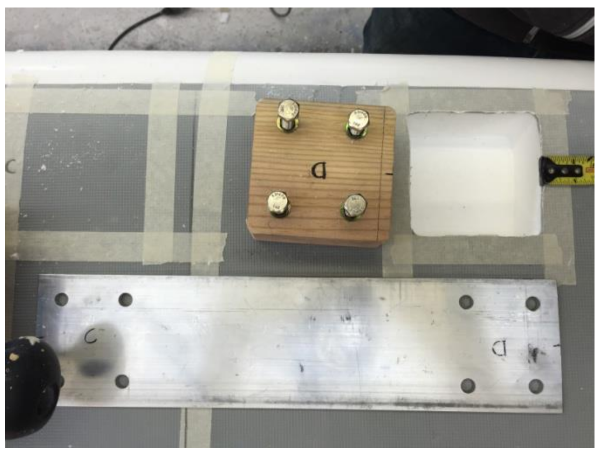

Figure 27. The first routed insert cavity in the paddleboard at The Ding King surfboard repair shop in Encinitas, CA.

The insert layup was accomplished in the following order for each of the four insert positions: two layers of carbon fiber sheets, three layers of 4 oz. fiberglass sheets, the wooden inserts, and then three more layers of 4 oz. fiberglass. The two layers of carbon fiber placed at the bottom of the cavity were cut into equal squares so that the layers would lie flush underneath the proceeding layers. The addition of carbon fiber at the base of the layup was made to create a thermal sink in order to protect the EPS core of the board from the heat created during the curing of the epoxy. The next three layers of fiberglass were cut in a cross-shaped pattern so that each sheet would sit flush on top of the carbon fiber layers and come up along the walls of the cavity and onto the surface of the board. These three layers were cut with 1 inch incremental increases in arm length so that the portion that reached the surface of the board would overlap the layer beneath it to create a seamless surface for easy sanding after the epoxy had cured. This layup configuration is commonly referred to has a "top hat" layup. The tapped holes of the wooden inserts were sealed with wax before application of the epoxy to protect the functionality of the threads. The final three fiberglass layers were cut into squares of increasing size for the same reason as the previous "top hat" layers. A photograph taken during the layup process can be seen in Figure 28. Once the epoxy had cured, the surface of the layup was sanded with a pneumatic sanding wheel to create an even surface with the top of the paddleboard. A countersunk drill bit was used to remove the fiberglass layers covering the bolt patterns. A new section of traction pad was then glued to the exposed board surface with contact cement and the corresponding bolt pattern holes were cut with a knife.

Figure 28. Epoxy resin being applied to the bottom layers of the "top hat" lay up before the wooden inserts are positioned.

The hexagonal pin and bottom pins were roughly cut to length from bar stock using a chop saw and then faced to the desired length on a lathe. The ends of the hexagonal pins were turned down to a diameter of 1.485 ± 0.05 inches so that they would have clearance in the guide slots. The slots in the bottom pin for the retaining rings were cut using a custom ground 0.035 inch parting tool. The slot for the spring hook end was cutting using a 0.1 inch parting tool. During the later stages of testing, the team deemed it desirable to have a similar slot cut into the hexagonal pin to prevent the upper end of the spring from sliding to one side, making operation of the latching mechanism uneven. This slot was also achieved using a 0.1 inch parting tool on a lathe. A photograph of the lathe used to complete the facing operations can be seen in Figure 29.

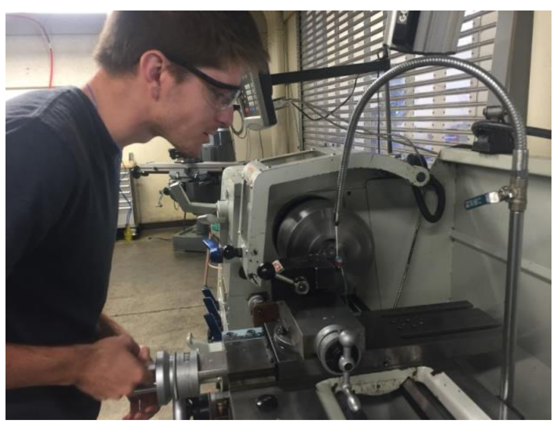

Figure 29. A lathe was used to face the bottom pins to the specified length.

The base plates, guide plates, and vertical structural plates were all rough cut from ¼ inch 6061 aluminum bar stock. The base plate and vertical structure plate dimensions were finalized by hand using a disk sander. The bolt patterns in the base plates were created with a drill press by stepping up bit sizes until the desired size of 7/32 inch diameter holes were achieved.

The manufacturing of the guides for the support structure became quite complicated, as the arc and slots proved to be hard to manufacture by hand. A paper template was taped to the 6 x 6 inch square guides. The arcs were then sanded by hand, after having used a vertical band saw to cut a multitude of small steps up to the arc on the template. A photograph from this process can be seen in Figure 30. Once the arc was sanded, the plates were placed on a roto-table upon a mill. This required specific placement of the center hole in the guide, as well as the center of the roto-table. The angle of the slot was then set on the roto-table, and then cut by the mill. A problem arose when two guides had to be re-manufactured, as the roto-table used on the mill had moved during cutting of the slots, leaving the slots larger than designed, and with improper angles. With the help of the Cal Poly shop technicians, a CNC machine was used, allowing for a precise arc and extremely accurate placement of the holes and slots. The remaining two guides were then put into the CNC machine, with the center hole step skipped in the program, allowing for the arc to be refaced and the slots to be cut correctly.

Figure 30. The team initially used a vertical band saw to rough cut the round edge of the guide plates.

The 90 degree long radius elbow, schedule 40, 1.5 inch 6061 aluminum pipes were obtained from Sharpe Products, a handrail manufacturing company that specializes in pipe bending. The entirety of the remaining standing structure was cut from stock schedule 40, 1.5 inch 6061 aluminum pipe. The dips bars, vertical supports, and backrest connecting piece were all roughly cut to length with a horizontal band saw. One end of the dip bars was notched at an 8 degree angle in preparation for welding using a tube notcher. This operation also allowed for the length of the dip bars to be adjusted to within specified tolerances. The lower end of the vertical supports was shaped using a disk sander and the upper end was notched at an 8 degree angle with a tube notcher. Again, this operation allowed for the length of the supports to be adjusted to within specified tolerances. The holes at the base of the vertical supports were cut using a drill bit in a mill for maximum concentricity. A photograph of the milling setup used to achieve this can be seen in Figure 31. The slots in the vertical supports were cut in a mill in two stages. First the ends of the slots were cut with a drill bit through the entire diameter of the pipe, each in a single operation. The slots were then cut using a ½ inch end mill, but the tool was not long enough to pass through the entire pipe diameter, requiring the pipe to be rotated. This caused issues aligning concentricity of the slots and resulted in additional machining during the later assembly stages for the hexagonal pins to move in the slots.

Figure 31. The centerline of the vertical supports were found to ensure the accuracy of milling operations.

The base plate assemblies were TIG welded using 5356 aluminum filler rod. This selection of filler rod was not critical to the structural integrity of the welds, but unlike other common filler rod materials such as 4043, 5356 better matches the base color of the material after anodizing. To ensure accuracy of weld placement, the proper locations for the components were marked on the base plates prior to tacking and tacking was completed with the hexagonal pins inserted in their corresponding slots.

The standing support structure components were also TIG welded together using 5356 aluminum filler rod for the same reasons as the base plate assemblies. To ensure the accuracy of the joint locations, the parts were tacked together while the assembly was fixed to the board with a wooden jig. A photograph of this setup can be seen in Figure 32. For ease of welding and to eliminate any risk of damaging the board, the structure was removed from the board after tacking to complete the full welds.

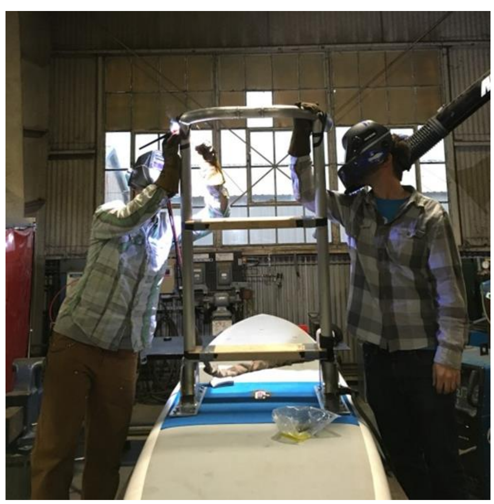

Figure 32. The standing support structure was installed on the board using a wooden jig in order to accurately tack weld the components together.

After welding, the three aluminum assemblies were cleaned and polished using ScotchBrite to create a relatively smooth surface finish. The parts were then given to Pacific Coast Anodizing Inc. for sulfuric anodizing to achieve both a corrosion resistant finish and a matte black color.

The nylon webbing seat was created using a series of 1 inch wide, military grade webbing strips: three longer horizontal strips and seven shorter strips configured orthogonal to the other three in an alternating weave. All connection points were sewn with a box stitch using polyester Gutermann upholstery thread and a 1956 Bernina machine.

Variations from Planned Design

One significant change from the planned design was the lifting mechanism of the standing support structure. This change required a new design late in manufacturing, however did not majorly affect other parts of the structure. The initial torsional spring, pin, and lever connection was found to not have the clearance required once the pipe was fully manufactured. Due to this clearance issue, the lever was not able to lift the top pin of the interface out of its slot, making the folding feature of the structure unattainable. This was remedied by abandoning the spring, pin, and lever connection, and changing to a looped strap design. The looped strap design required a simple manufacturing change, which was cutting holes and tapping holes into the ends of the hexagonal pins. Finally, a strap was sewn and bolted to the ends of each pin. This design change allowed for easy grasping and maneuvering of the hexagonal pin, enabling the structure to be raised and lowered easily.

Another change from the planned design occurred in the fabric seat. After doing sewing pattern strength testing, it was found that military grade nylon could withstand the weight specifications and could fold to have a smaller profile of that of the full-fabric seat design that the team had originally developed. Therefore, the design was changed to a webbing of nylon straps as seen in Figure 33.

Figure 33. The nylon webbing seat that was selected instead of a full-fabric design.

A final variation that was made to the planned design was the size and strength of the pin retention spring. The spring initially selected by the team was too strong to operate with one hand. The team then tested a series of spring sizes, finally settling on the spring listed in the bill of materials in Appendix B.

Recommendations for Future Manufacturing

If this design were to be replicated, the primary change to the manufacturing procedure that the team would recommend is to have all the milling operations completed using a CNC mill. This would apply to all the aluminum parts except for the long radius elbows. The use of CNC would greatly reduce inaccuracies in the dimensions of the base plate assembly, especially in the bolt patterns and the hexagonal pin slots. In addition to this, with the use of a 3 inch long, ½ inch end mill, the inaccuracies in the concentricity of the slots cut into the vertical supports would be eliminated. The manufacturing of the pins could be completed with a CNC lathe, but this is would not achieve any significant improvement in the part quality, but might improve production throughput if the parts were to be mass produced.

Another recommendation that the team would offer is to create a more accurate and permanent welding jig for the standing support structure and base plate assemblies. This would ensure the accuracy of the weld locations and would greatly increase the speed of the welding process, although the creation of the jigs may be costly and time consuming to ensure accuracy.

It may be possible to improve the process of installing the tapped, wooden inserts into an existing paddleboard, but from the research conducted by the team, this process is relatively new and little to no examples of a similar procedure exist in literature. Major improvements to the process and design could be made if the system were to be installed during the manufacturing of the paddleboard itself and not retrofitted to an existing product. For the case detailed in this report, the team believes that the process could not have worked much better and the potential for retrofitting and adapting other existing foam structures with structurally sound bolt patterns is relatively unexplored.

Chapter 6: Design Verification Plan

Test Descriptions and Results

For verification of our design, each requirement listed in the engineering specifications was tested. The tests done throughout manufacturing include simple tests that only require a pass/fail grade, as well as more extensive and complicated tests, such as live loading the project while afloat in the Recreation Center's pool. The following were the testing criteria and results for each engineering specification:

1.1-1.3 The length, width, and thickness of a paddleboard are predetermined by the manufacturer; however for this project, a standard size paddleboard was specified for use. A paddleboard has been generously donated for this project by SUP Think Tank, and the board meets these specifications. These dimensions were checked by the team using length measurement tools such as a measuring tape to ensure dimensions met the specifications when the design was completed.

Results: The board length, width, and thickness were measured to be 12', 32.5", and 5", respectively, meeting the criteria set for this specification.

2.1 A total system weight of less than 35 pounds was a goal set by the team. This total system did include the board, rather just the system installed upon it. To verify this specification, the board was weighed with and without the system attached.

Results: The total system weight was measured at 32 pounds, 3 pounds under the specification set at 35 pounds. This passes the verification checklist.

2.2 The buoyancy maintained while supporting an exterior weight of 250 pounds was tested in the Cal Poly Recreation Center's pool. This required the fully developed prototype to be attached to the board, followed by load testing. Weight was loaded onto the board until the maximum required weight outlined in the specifications was met. For use of the recreation pool, required statements of release and purpose were filed with the recreation center at Cal Poly, as well as an extensive safety protocol. Lifeguards were informed of the testing procedures and were stationed accordingly, with one keeping a specific eye on those involved in testing. Other safety precautions were taken, such as making sure the team members testing knew how to swim, and were protected from possible injury by applying rubber caps to possible sharp edges. The testing done first involved the full design to actually float. This was done by placing the standup paddleboard in the water with the structure attached. Then the board was loaded with over 250 pounds, which was done by multiple members standing on the board at one time.

Results: The board was fully functional and afloat upon loading once in the water. Loading of over 250 pounds showed no signs of reduction of buoyancy, clearing all testing specifications. Further loading past 280 pounds was not tested.

2.3 A spring was used along the upper surface of the board after machining to make sure no point in the board plastically deformed at less than 2 psi.
Results: The board had no deformation at any point up to a pressure of 2 psi.

2.4 Supporting the stability of the user was a non-quantifiable specification that was answered with a pass/fail after the design had been tested.

Results: Stability testing was done in the recreation center pool at Cal Poly. The structure passed the test, as the user was able to lean on the structure to provide support and stability while paddling in both the sitting and standing positions. The stability of the user was also increased by attaining a larger board meant for tandem riding that displaces more volume than that of a single rider paddleboard.

2.5 Center of gravity was tested by loading the board about its theoretical center of gravity. The user will need to be standing over the center of gravity, so the location of the designed system and user is of utmost importance. This testing was done out of water by shifting the board along a single point, until the board balanced without external support.

Results: The center of gravity was found and marked on the board by balancing the board on a single sawhorse. The board was then shifted until the center of gravity was found, when the board no longer needed external support to remain balanced. The mark was used for attachment of the support structure, which was balanced around the found center of gravity.

3.1 The surface coating was verified by looking at material safety data sheets and using known material that doesn't react with skin.

Results: Anodized aluminum was used for the entire support structure, with the seat being made of nylon straps, and the kneeling support being made of EVA foam. These materials are known not to react with skin or salt water, and have been tested and passed by the team.

3.2 Chemical reactions with salt water were tested by looking at the material safety data sheets prior to use of any chemicals, as well as during prototyping by submerging pieces into salt water baths.

Results: This was done with all materials used on the board, which all passed the criteria. Material of the kneeling pad and seat were changed due to failure of this test. All final materials chosen and implemented on the final project passed the salt water bath test.

Figure 34. First trial of foam yoga block during salt water testing.

3.3 The board surface material was verified through the board manufacturer, with the team checking to make sure the correct board was received. This verification was a pass/fail test.

Results: The board passed specification 3.3, as the board was not a "soft-top" or inflatable paddleboard. This was verified by the team, the donor, and the manufacturer.

4.1 The specification created to not confine or attach the user to the board was of significant importance to the client. The testing done in this area was pass/fail testing, and included the ability to safely fall off of the board during tipping and easy maneuverability between all three supported positions.Testing required board tipping and ease of escape. To do this, all positions (kneeling, sitting, and standing) were performed. While the design was in the pool with proper safety measures and safety personnel, the board was tipped and the test user tried to get away safely from the design.

Results: The test user was able to fall, unimpeded, into the water when the board tipped, and was able to switch between positions without feeling confined or restricted in mobility. The team has passed the design in this specification. For each of the initial starting positions, it was never a problem for the user to escape from the support structure.

Figure 35. Test user falling from the paddleboard, using their arms to push free from the support.

4.2 Federal Regulation 33 has been documented and gone through extensively for safety of the device. A safety manual was created to comply with the code to verify this specification, which can be seen in Appendix F.

Results: A safety manual was created for the user of the board, which outlines Federal Regulation 33 and other safety concerns of the team and advisors. This safety manual includes recommendations for safety equipment such as the use of a personal floatation device and for a helmet to be worn while using this paddleboard. The manual also notifies the user of potential hazards and precautions, such as no climbing on the structure, and using the paddleboard with a group of others, rather than being on the water alone. This manual can be seen in Appendix F.

4.3 Deburring, sanding, and smoothing of all edges was done to verify that there were no sharp edges or pinch points in the design. All moving parts were tested for safety, requiring visual inspection.

Results: Any joint deemed unsafe by the team was outlined by the team, or fixed. This included the addition of rubber caps to the ends of both sets of dip bars, as well as additional sanding and deburring done once testing was complete.

4.4 While stationary and fixed in an upright position, weight was applied to the structure to test attached parts. A force of more than 50 pounds was applied to all points near their attached location as well as at the point furthest from the point of attachment. This was used to check for weld, bolt, and epoxy strength, as well as overall design integrity. All points of attachment were verified through this test.

Results: All attachment points of the structure and the point furthest from the point of attachment were loaded with 75 pounds to make sure all features could withstand the user's weight. This test was passed twice, both in and out of water, with live loading.

Figure 36. Loading of the support structure at the furthest moment arm from the joint to check for joint integrity.

5.1 Test rides were done to ensure the ability of using the device for a duration of longer than two hours in the standing, seated, or kneeling positions.

Results: With testing done on the design, it was in agreement of the team that the ergonomic features allow for extended riding of the paddleboard in any of the positions available. Testing was done in the Cal Poly Recreation Center pool for an extended period of time, with multiple users testing the ergonomic features on the board.

Figure 37. During testing at the Cal Poly Recreation Center pool, a variety of users rode the board in each of the multiple riding positions for a prolonged period of time to test the board's ergonomic features.

6.1 Lifting points were built in by the manufacturer, and after working with the SUP Think Tank, additional lift points were added and tested for ease of use for the user.

Results: Testing included the ability to lift the structure and the board separately. Both pieces of the design were able to be transported by a single person comfortably, without putting strain on the user's body. This test passed, as the product was able to be transported as two pieces from the mode of transportation to the loading point.

6.2 The board was tested for fitting in vehicles such as the client's truck, as well as being accessible from a wheelchair. This verification was a pass/fail test.

Results: The product was loaded and transported as traditional surfboard and paddleboards commonly are. This was tested by strapping the board to the top of different models of cars, specifically a Nissan Altima and a Subaru Legacy, as well as placing the board in the truck bed of a Toyota Tundra and strapping it down. The support structure was removed and able to fit in the trunk or bed of all three vehicles.

The loading of the user onto the product was testing in the Cal Poly Recreation Center's pool, where the test user transferred from a chair to the board with help from one individual holding the board stable in the water. This test was considered a pass, as the user has agreed that some help will be necessary to get on the board as well as for safety while using the board. This is outlined in the safety manual, seen attached as Appendix F.

7.1 Washing and storage was tested to be as similar to a "classic" paddleboard as possible. For this, material safety data sheets were consulted for information on reaction with air, water, salt water, and other debris or particles that may come in contact with the board. The design was tested for integrity after having been used, hosed down, and cleaned with rags multiple times.

Results: The materials chosen stood up to the standard cleaning process of hosing the board down and using soap, water, and rags to clean the product after use.

8.1 The final cost of the design was required to be under $5,000. This was preliminarily achieved through consultation with material vendors and the building of a cost estimate before ordering began. The final cost was determined at the completion of the build.

Results: The final cost of the design was $1,232, which is well under the budget of $5,000. If the additional price of the paddleboard that was donated was added to the final cost, the price would be $2,182, still under the $5,000 requirement. This goal sets this design apart from the competitors in this market.

9.1 The board must not incorporate a wheelchair; therefore the testing was the ability to use the designed system without the assistance of a wheelchair. This verification was a pass/fail test.

Results: This test was completed upon testing in the recreation center pool. As there is no way to incorporate a wheelchair on this product, this test was passed. Furthermore, all positions were achieved by the test user without the assistance of a wheelchair while in the water. The test user was able to maneuver between all three positions using the supports designed by the team.

9.2 Features assisting with climbing onto the board were tested while in the recreation center pool. This verification was a pass/fail test based on the ability of the test user to achieve each position on the board after having fallen off. The safety manual contains outline precautions to take when using the paddleboard if the user falls off.

Results: The test user was easily able to use the designed structure for assistance when climbing back onto the board from the water. Having tested the kneeling, sitting, and standing position, the test was deemed a pass by the team when all positions were achieved by the user. The dip bars provided more support than intended and, with no instruction given to the test user, were used for mounting the board after the user had fallen in the water. This allowed the team to bypass any additional features that may have been needed to climb onto the board from the water.

9.3 The user must be able to use the board without being pushed, pulled, or paddled for by another individual. This was a pass/fail test conducted in the pool.

Results: The user was able to use the paddleboard without external support in all positions. This was tested in the Cal Poly Recreation Center's pool.

Other testing outside of engineering specifications was done for complete analysis of the structure, as well as addressing concerns of those attached to the design. Testing was done on materials and manufactured parts to allow the team to evaluate the design and make changes as needed. Certain parts and concepts such as the inserts into the board and the seat were of concern to the team, sponsors, and advisors, so proof of concept testing was done to solidify the design.

For initial part testing, extensive work was done related to measurements and tolerance fitting, but the team's main focus was on the insert design within the board. To analyze and prove the concept of the insert, the team acquired a surfboard blank (surfboard foam shaped and ready to be fiberglassed) for testing. This blank was cut into two halves, which were used for two different tests, one using a wooden insert and epoxy, the other using a wooden insert, epoxy, and fiberglass. Holes for the inserts were cut into the blank, and wooden inserts were cut from a stock beam. The blanks were taken into the paint booth, where the first half was painted with epoxy, and the wooden block inserted into the hole. On the second blank, the fiberglass was placed in the epoxy that had been painted in the hole, under the insert, with two more sheets of fiberglass placed over the insert and epoxied to the blank. Six hours of cure time was given to let the epoxy set. Once set, the self-tapping tapped inserts were fixed into the wooden inserts, with bolts inserted into them. A pipe was attached to the bolt to be used as a moment arm. Loads were then applied to the bolt.

Results: Failure occurred in the bolt before the insert or foam failed. This was remedied by using a larger bolt. Once the larger bolt was installed, testing using a moment arm was done, however there was not an adequate amount of space for this test. Next, approximately 120 pounds were loaded onto the foam, and the bolt was pulled straight up. The foam was the first component to fail, not the epoxy, bolt, or insert. This gave the team assurance that the insert design would work, and clear all testing specifications.

Figure 38. The results of the surfboard blank and wooden insert test, which shows the torn foam and intact wooden insert after loading 120 pounds onto the test rig.

The seat was tested extensively before the final design was chosen. First, material tests were done, and military grade nylon was chosen as the best material to use after applying axial loads to strips of material, which also allowed for the changed seat design from a solid material to a webbing. For holding the straps together and around the pipe, rivets and sewing patterns were tested. Sewing patterns used ranged from straight lines to cross-stitches.

Results: The rivets failed to stay flush against the nylon, which failed test criteria as they would hinder the movement of the user and possibly catch on material or create sharp edges. The straight line sewing was not strong enough to endure testing of pulling the material apart, nor was the cross-stitching. Polyester Gutermann upholstery thread was then used in a cross stitching pattern, which resulted in no failure at any point on the strap. Once the seat was complete, it was loaded with full body weight and no failure was seen.

Figure 39. Failed rivet in the nylon strap that was to be used for the seat.

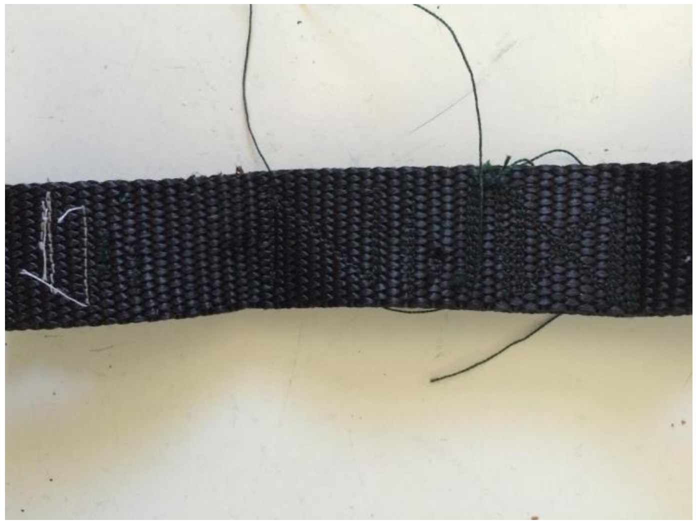

Figure 40. Failed stitching patterns and thread in nylon straps.

Another test done was applying loads to the support structure to test the pipe strength and weld integrity. The first part of this test was done by fully loading a team member's weight onto both sets (upper and lower) of dip bars. Next, weight was applied to the rear of the structure, which was done by a team member leaning on the support, allowing for the weight to be applied at the point furthest from the pin connection. Finally, the seat was tested, again by fully loading it with a team member's weight.

Result: The entire structure passed all loading tests. The welds remained solid, not showing signs of cracking or failing, and remained water tight. The interface between the paddleboard and structure remained sound after testing, showing no signs of failure. Modifications to the finish were required on sharp edges of the bottom plate for the interface between the board and standing support.

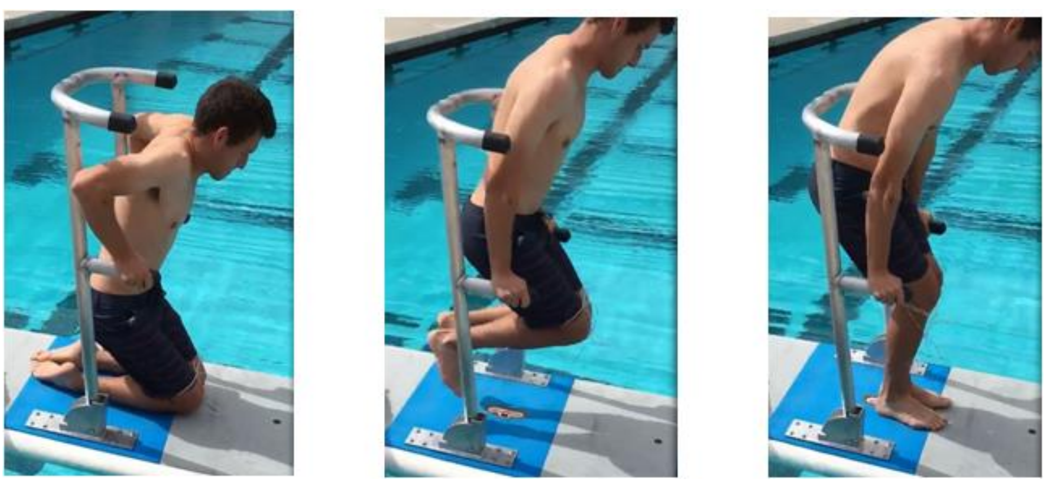

Figure 41. The dip bars of the structure were tested by loading the entire weight of the user onto them to get from the kneeling position to the standing position, shown here as a sequence of photos

Specification Verification Checklist

Table 8. Engineering Specification Checklist for use while testing all requirements.

Engineering Specification Test Checklist							
Type	No.	Feature	Acceptance Criteria	Unit	Team Member Responsible	Measured Test Value	Pass/Fail
(1) Geometry							
	1.1	Length of board	10 to 11	ft.	Spencer		
	1.2	Width of board	30 to 34	in.	Spencer		
	1.3	Thickness of board	4.25 to 6	in.	Spencer		
(2) Forces							
	2.1	Total system weight	< 35	lbs.	Curtis		
	2.2	Buoyancy maintained while supporting exterior weight	250	lbs.	Team		
	2.3	Applied surface pressure must not plastically deform board	<2	psi.	Stephen		
	2.4	Support stability of user	n/a		Team		
	2.5	Center of gravity must lie within 1 in from the centerline from nose to tail	<1	in.	Stephen		
(3) Materials							
	3.1	Non-toxic, non-irritant surface coating	n/a		Curtis		
	3.2	Must not chemically react with salt water (ocean)	n/a		Curtis		
	3.3	Board must not be "soft top"	n/a		Curtis		
(4) Safety							
	4.1	User not attached to board (leash acceptable)	n/a		Stephen		
	4.2	Meets US Code of Federal Regulation 33 (Requires whistle and PFD)	n/a		Stephen		
	4.3	No sharp edges, sharp points, or pinch points	n/a		Stephen		
	4.4	Attached board features must withstand a pulling force	50	lbs.	Stephen		
(5) Ergonomics							
	5.1	Includes ergonomic features that allows for comfortable kneeling and standing	2	hrs.	Curtis		
(6) Transportation							
	6.1	Lifting point divot allows one person to lift comfortably	n/a		Spencer		
	6.2	Adaptability with other wheeled transportation devices			Spencer		
(7) Maintenance							
	7.1	Washing and proper storage after normal use	n/a		Curtis		
(8) Cost							
	8.1	Cost of final design	<5000	USD	Spencer		
(9) Other							
	9.1	Board must not incorporate a wheelchair	n/a		Spencer		
	9.2	Should have features that assist with climbing onto the board from the water	n/a		Curtis		
	9.3	User must be able to operate paddleboard on water without the assistance of another individual	n/a		Stephen		

Chapter 7: Project Management Plan

Team Member Roles

Team roles were assigned according to each team member's relative experience. Spencer was the team lead for mechanical analysis including failure mode analysis and material selection. Stephen was responsible for developing solid models and manufacturing plans. Curtis took charge of cost estimation, material procurement, and developing design verification procedures. Claire and Haley provided valuable insight to the team on the functionality of the design and were responsible for ensuring that the standup paddleboard would ultimately be usable by the client. Their main task was also to create thorough safety guidelines for use of the board that are specific to our client.

Gantt Charts

To help the team plan out the entire school year and the different phases of the project, three Gantt charts were created. Due to the class breaks in between each quarter and the nature of the system, the Gantt chart was broken up into three different sections to help the team transition between each quarter. Each chart includes what type of work will be ongoing at that time and the main reports or task due dates. These schedules can be seen in Figures 42, 43, and 44.

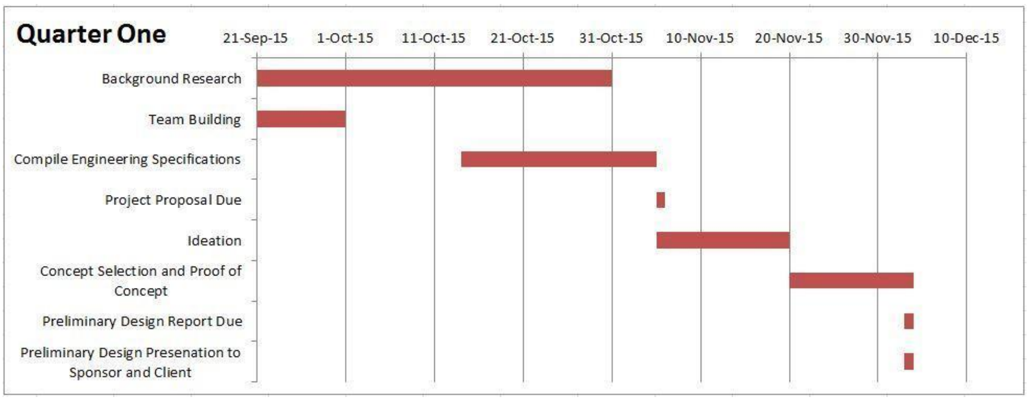

Figure 42. Gantt chart detailing team work and major milestone dates for quarter one.

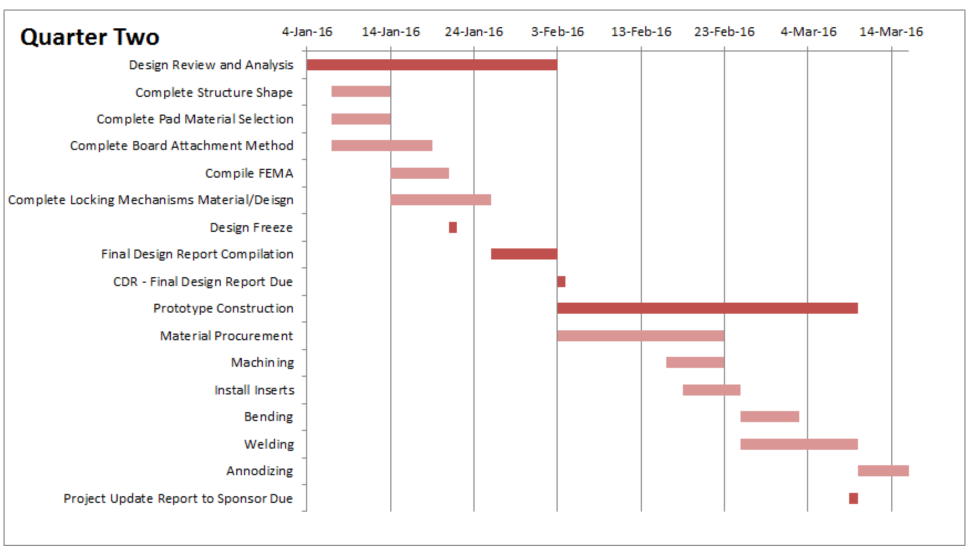

Figure 43. Gantt chart detailing team work and major milestone dates for quarter two.

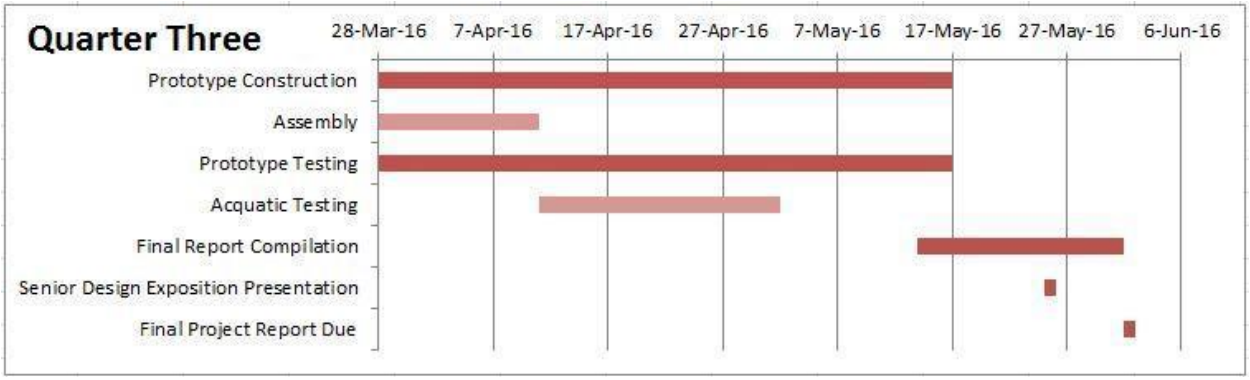

Figure 44. Gantt chart detailing team work and major milestone dates for quarter three.

The focus of the Quarter Two Gantt chart was to help the team effectively plan out the manufacturing of the board structure. Major manufacturing processes are outlined in the chart, with goal beginning and ending dates. Material procurement time and access to the correct workshop equipment impacted these dates greatly. A more detailed Gantt chart of the team's manufacturing plan is included in Appendix E.

Chapter 8: Conclusions and Recommendations

From the testing results, user feedback, and the public response received at the Cal Poly College of Engineering Senior Project Expo, the project was successful. The final product of this project provided a physically disabled member of the local community the means to continue his participation in the sport of paddleboarding. However, the total cost of the project was $1232 which was $282 over the preliminary estimate made prior to the beginning of manufacturing. This cost does not include the price of the paddleboard, which was donated to the project.

Although the design was created with a specific client in mind, the result may have applications beyond that of assisting users with disabilities to enjoy stand up paddleboarding. The design has the potential to be marketed to the elderly, early learners and users looking to paddle for extended lengths of time. Furthermore, the method of attaching the structure to the board developed by the team using wooden inserts in an epoxy - fiberglass layup may very well enable many designs centered around retrofitting paddleboards, surfboards, and other foam core vessels. From the testing conducted, the insert to board interface is much stronger than the structure of the existing board and allows for highly customizable attachment configurations and relatively easy and low cost installation.

If this design were to be developed further, the team recommends developing a method to make the system adjustable to the physical dimensions of the user. The team developed the current product for the physical dimensions of the client, therefore the existing design would only be ergonomic for a limited range of users with height and weight similar to that of the client. In addition, due to the curved nature of the edges of the board where the inserts were located, the team ran into minor difficulties when installing the structure onto the board. A further developed design could mitigate this issue by changing either the geometry of the baseplate or the method in which the structure is bolted onto the board. Even with these design changes, the most valuable and critical design changes would only come to light after months of regular use of the board.

Figure 45. The completed adaptive paddleboard at the Senior Project Expo.

Bibliography

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Munson, Bruce R. Fundamentals of Fluid Mechanics. 7th ed. Hoboken: John Wiley & Sons, 2013. Print.

Shigley, Joseph Edward., and Charles R. Mischke. Mechanical Engineering Design. New York: McGraw-Hill, 1989. Print.

Figure Sources

[1] Figure 2:

"SUP Paddle Board Lagoon Tour." Stand Up Paddle Board Tour, Moorea Activities. Web. 12 Nov. 2015.

[2] Figure 3:

"Surfing & SUP." Surfing & SUP. Web. 12 Nov. 2015.

[3] Figure 4:

"Paddle Board Yoga -- I Absolutely Love It!" Mom Loves Water. 3 Nov. 2014. Web. 12 Nov. 2015.

[4] Figure 5:

"Stand Up Paddle Board Fishing." Stand Up Paddle Board Reviews. Web. 12 Nov. 2015.

[5] Figure 6:

"The Euro Tour: A New SUP Race Series To Unify Europe's Paddling Community (And Settle The Board Class Debate?)." SUP Racer. Web. 12 Nov. 2015.

[6] Figure 7 and 8:

"Adaptive Sports Equipment | Murrieta, CA." Adaptive Sports Equipment | Murrieta, CA. Web. 12 Nov. 2015.

[7] Figure 9, 10, and 11:

“Cruiser Board Company” A New Category of Paddlecraft Web. 3 Dec. 2015 http://cruiserboard.com/

Appendices

Appendix **[A]** Engineering Requirements and House of Quality QFD Table

Appendix **[B]** Bill of Materials and Engineering Drawings

Appendix **[C]** List of Vendors

Appendix **[D]** Detailed Supporting Analysis and Failure Mode and Analysis Table

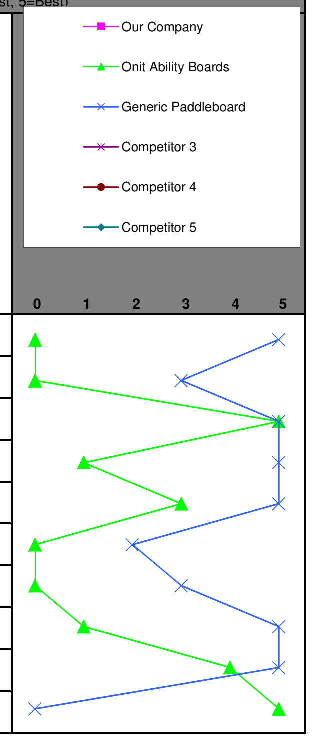
Appendix **[E]** Detailed Third Quarter Gantt Charts

Appendix **[F]** User Safety Manual

Title:	Adaptive Padelboard QFD V1
Author:	Spencer Shotts
Date:	10/14/2015
Notes:	Reviewed by:
	Stephen Eldridge

Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)					
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	x	x	x	x	▼	x	x													
Row #	**Max Relationship Value in Row**	**Relative Weight**	**Weight / Importance**	**Quality Characteristics** (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Between 10' and 12' from nose to stern	Board + 250 lbs must float	Board must be balanced along centerline from nose to stern	Board must not incorporate a wheelchair	External surface of board must not contain or produce toxic materials or skin irritants when in contact with fresh or salt water	Board must not whiegh more than 40 lbs	User must be able to operate paddleboard on the water without assistance	Board must comply with Code of Federal Regulations number 33 (CFR 33)								Our Company	Onit Ability Boards	Generic Paddleboard	Competitor 3	Competitor 4	Competitor 5
1	9	19.0	19.0	No wheelchair				Θ													0	5			
2	3	15.0	15.0	Kneeling capabilities		O															0	3			
3	9	14.0	14.0	One person board	▲						Θ										5	5			
4		13.0	13.0	User not locked/attached to the board																	1	5			
5	9	12.0	12.0	Ocean Capable		O	O		Θ	▲		O									3	5			
6		9.0	9.0	Unassisted loading and launching																	0	2			
7	3	8.0	8.0	Standing capablilities		O															0	3			
8	9	7.0	7.0	Roughly standard SUP dimensions	Θ					O											1	5			
9		3.0	3.0	Utilize standard SUP paddles																	4	5			
10				Assists User's Stability																	5	0			
				Target or Limit Value																					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)																					
				Max Relationship Value in Column	9	3	3	9	9	3	9	3													
				Weight / Importance	77.0	105.0	36.0	171.0	108.0	33.0	126.0	36.0													
				Relative Weight	11.1	15.2	5.2	24.7	15.6	4.8	18.2	5.2													

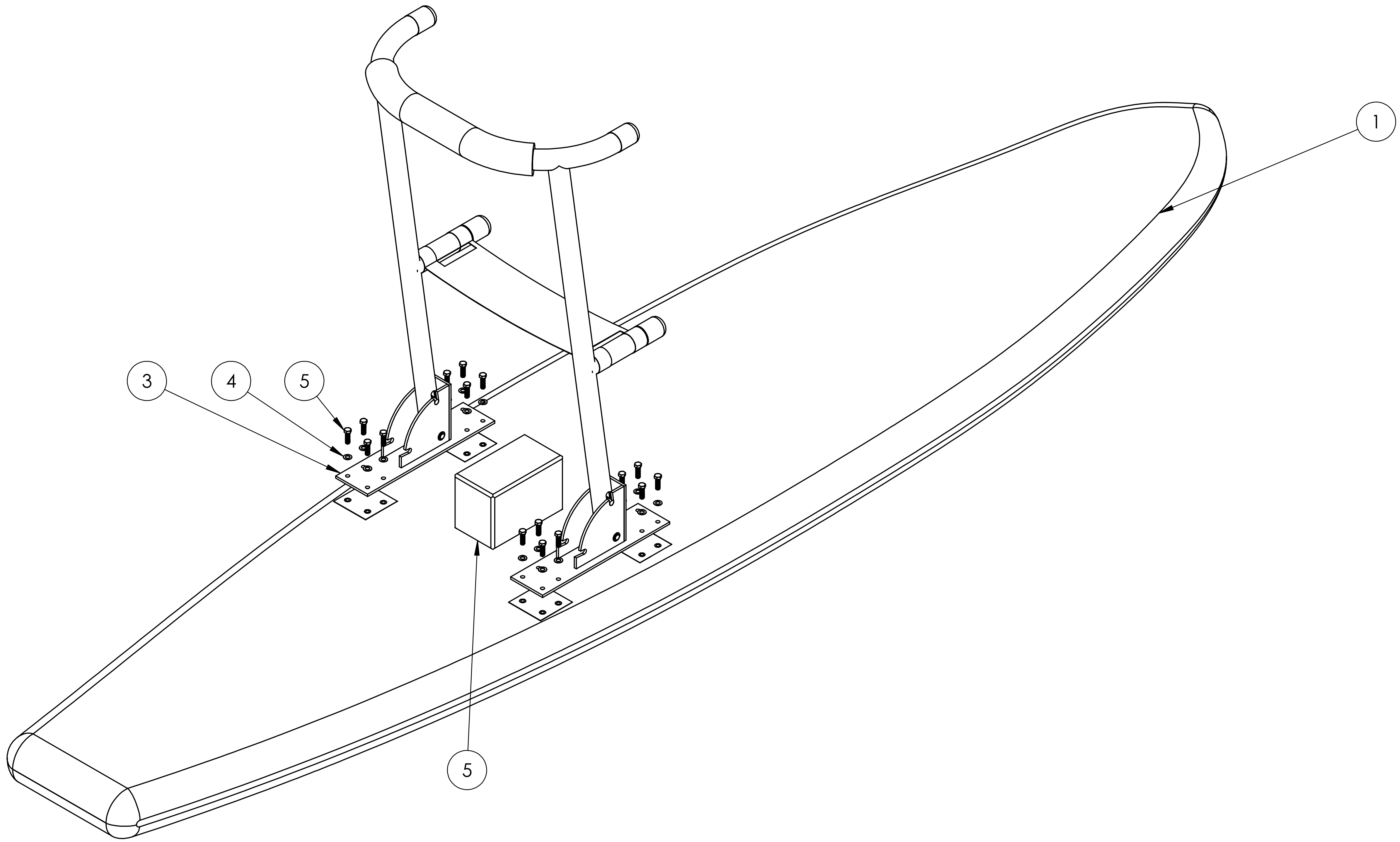


Powered by QFD Online (http://www.QFDOnline.com)

Engineering Specification List								
Type	No.	Feature	Measured Value	Unit	Demand or Wish (D/W)	Source (Team/Sponsor/Client)	Verification (A/T/S/I)	Difficulty (H/M/L)
(1) Geometry								
	1.1	Length of board	10 to 11	ft.	W	Client	I	L
	1.2	Width of board	30 to 34	in.	W	Client	I	L
	1.3	Thickness of board	4.25 to 6	in.	W	Client	I	L
	1.4	Adaptive feature(s) dimension limitations	*TBD	in.	W	Client	I	H
(2) Forces								
	2.1	Total system weight	< 35	lbs.	W	Team	I	M
	2.2	Bouyancy maintained while supporting exterior weight	250	lbs.	D	Client	I/T	L
	2.3	Applied surface pressure must not plastically deform board	<2	psi.	D	Team	I	L
	2.4	Support stability of user	n/a		D	Sponsor/Client	A	H
	2.5	Center of gravity must lie within 1 in from the centerline from nose to tail	<1	in.	D	Team	I	L
(3) Materials								
	3.1	Non-toxic, non-irratant surface coating	n/a		D	Team	I/T	L
	3.2	Must not chemically react with salt water (ocean)	n/a		D	Team	I/T	L
	3.3	Board must not be "soft top"	n/a		D	Client	I	L
(4) Safety								
	4.1	User not attached to board (leash acceptable)	n/a		D	Client	I/A/T	M
	4.2	Meets US Code of Federal Regulation 33 (Requres whistle and PFD)	n/a		D	Team	I	L
	4.3	No sharp edges, sharp points, or pinch points	n/a		D	Team	I	L
	4.4	Attached board features must withstand a pulling force	50	lbs.	D	Team	I/T	L
(5) Ergonomics								
	5.1	Includes ergonomic features that allows for comfortable kneeling and standing	2	hrs.	D	Sponsor/Client	I/A/T	H
(6) Transportation								
	6.1	Lifting point divet allows one person to lift comfortably	n/a		W	Team	I/A/T	L
	6.2	Adaptability with other wheeled transportation devices						
(7) Maintenance								
	7.1	Washing and proper storage after normal use	n/a		W	Team	T	L
(8) Cost								
	8.1	Cost of final design	<5000	USD	D	Team	A	L
(9) Other								
	9.1	Board must not incorporate a wheelchair	n/a		D	Client	I	M
	9.2	Should have features that assist with climbing onto the board from the water	n/a		W	Client/Team	I/T	M
	9.3	User must be able to operate paddleboard on water without the assitance of another individual	n/a		D	Client	I/T	L

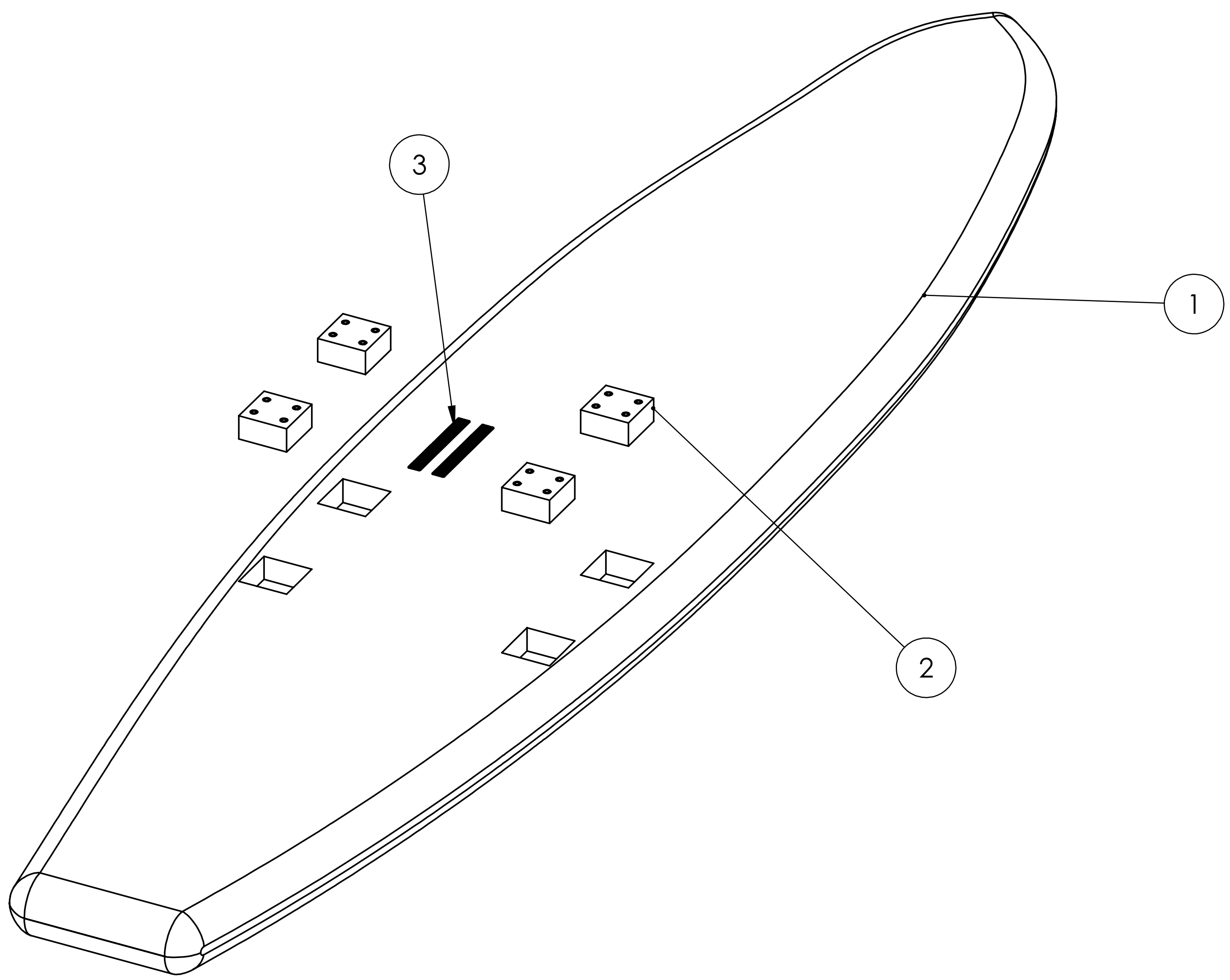
PART #	QTY	PART	FUNCTION	DRAWING #	SUPPLIER	CATALOG #	LEVEL				
1.0.0.0.0	1	**FINAL ASSEMBLY**		**A10000**			X				
1.1.0.0.0	1	**PADDLEBOARD**		**A11000**				X			
1.1.1.0.0	1	SUPATX Adventure XL	PADDLEBOARD HULL	NA	SUPThinkTank	NA			X		
1.1.2.0.0	2	3' x 2" MARINE GRADE HOOK AND LOOP STRIP (LOOPS)	KNEELING SUPPORT FIXTURE	NA	MCMASTER CARR	8200K256			X		
1.1.3.0.0	2	**STRUCTURAL INSERT**		**A11300**						X	
1.1.3.1.0	4	DOUGLAS FIR RECTANGLE	INSERT BODY	P11310	HAYWARD LUMBER CO	502140608				X	
1.1.3.2.0	16	SELF-TAPPING THREADED INSERT	THREADED INSERT	NA	YARDLEY PRODUCTS CORP	37516L36-60BR				X	
1.1.3.3.0		6oz E CLOTH	FIBERGLASS CLOTH	NA	DING KING	NA				X	
1.1.3.4.0		CARBON FIBER CLOTH	CARBON FIBER CLOTH	NA	DING KING	NA				X	
1.1.3.5.0		2:1 2000 RESIN	EPOXY RESIN	NA	DING KING	NA				X	
1.2.0.0.0	1	**FOLDING SUPPORT**		**A12000**				X			
1.2.1.0.0	1	**FOLDING SUPPORT STRUCTURE**		**A12100**					X		
1.2.1.1.0	1	**BACKREST STRUCTURE**		**A12110**						X	
1.2.1.1.1	1	6061 AL Sch 40 PIPE, MACHINED	BACK REST CENTER	P12111	MCMASTER CARR	5038K53					X
1.2.1.1.2	2	6061 AL 90° Sch 40, BUTT WELD	LONG RADIUS ELBOW	NA	SHARPE PRODUCTS	1596					X
1.2.1.2.0	2	6061 AL Sch 40 PIPE, MACHINED	LOWER DIP BARS	P12120	MCMASTER CARR	5038K53				X	
1.2.1.3.0	1	6061 AL Sch 40 PIPE, MACHINED, LEFT	VERTICAL SUPPORTS	P12130	MCMASTER CARR	5038K53				X	
1.2.1.3.1	1	6061 AL Sch 40 PIPE, MACHINED, RIGHT	VERTICAL SUPPORTS	P12140	MCMASTER CARR	5038K53				X	
1.2.1.4.0	1	THERMACEL 2" ID PIPE INSULATION	BACK REST FOAM	NA	THERMACEL	6XP038200				X	
1.2.1.7.0	2	EPDM 1.875" ID x 1.5" BLACK	BACK REST END CAPS	NA	STOCKCAP	770803				X	
1.2.1.8.0	1	1" NYLON WEBBING, 0.075" THICK (BLACK)	FABRIC SEAT	NA	MCMASTER CARR	87425K76				X	
1.2.1.9.0	2	EPDM 1.875" ID x 1.5" BLACK	DIP BAR END CAPS	NA	STOCKCAP	770803				X	
1.2.2.0.0	2	**MECHANISM BASE**		**A12200**					X		
1.2.2.1.0	2	6061 AL 1/4" PLATE, MACHINED	BASE PLATE	P12210	MCMASTER CARR	8975k142				X	
1.2.2.2.0	2	6061 AL 1/4" PLATE, MACHINED	VERTICAL PLATE	P12220	MCMASTER CARR	8975k142				X	
1.2.2.3.0	4	6061 AL 1/4" PLATE, MACHINED	GUIDE PLATES	P12230	MCMASTER CARR	8975k142				X	
1.2.3.0.0	2	316 SS 1/2"x2.5 MACHINED HEX PIN	HEX PIN	P12800	MCMASTER CARR	89205K86			X		
1.2.4.0.0	2	316 SS 1/2"x2.8 MACHINED ROUND PIN	ROUND PIN	P12900	MCMASTER CARR	89325K85			X		
1.2.5.0.0	4	15-7 SS 1/2" EXTERNAL RETAINING RING	ROUND PIN SNAP RING	NA	MCMASTER CARR	91590A122			X		
1.2.6.0.0	4	PTFE 1/2" FLAT WASHER, 0.531" ID, 1.25" OD	ROUND PIN WASHER	NA	MCMASTER CARR	95630A500			X		
1.2.7.0.0	2	302 SS 4" 0.500" SPRING OD .063" WIRE DIA EXTENSION SPRING	RETAINING SPRING	NA	MCMASTER CARR	94135K29			X		
1.3.0.0.0	1	**KNEELING SUPPORT**		**A13000**				X			
1.3.1.0.0	1	9"x6"x5" FOAM YOGA BLOCK	KNEELING SUPPORT SURFACE	NA	SPORTI (YOGA OUTLET.COM)	8132002			X		
1.3.2.0.0	2	3' x 2" MARINE GRADE HOOK AND LOOP STRIP (HOOKS)	KNEELING SUPPORT FIXTURE	NA	VELCRO BRAND (AMAZON)	8200K251			X		
1.4.0.0.0	16	316 SS 3/8"-16 UNC 2A x 1.25" CAP SCREW	CAP SCREWS	NA	MCMASTER CARR	93190A626		X			
1.5.0.0.0	16	316 SS 3/8" WASHER, 0/406" ID, 0.750" OD	CAP SCREW WASHERS	NA	MCMASTER CARR	90107A127		X			

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1.1.0.0.0	PADDLEBOARD	1
2	1.3.1.0.0	KNEELING SUPPORT	1
3	1.2.0.0.0	FOLDING SUPPORT	1
4	1.5.0.0.0	CAP SCREW WASHERS	16
5	1.4.0.0.0	CAP SCREWS	16



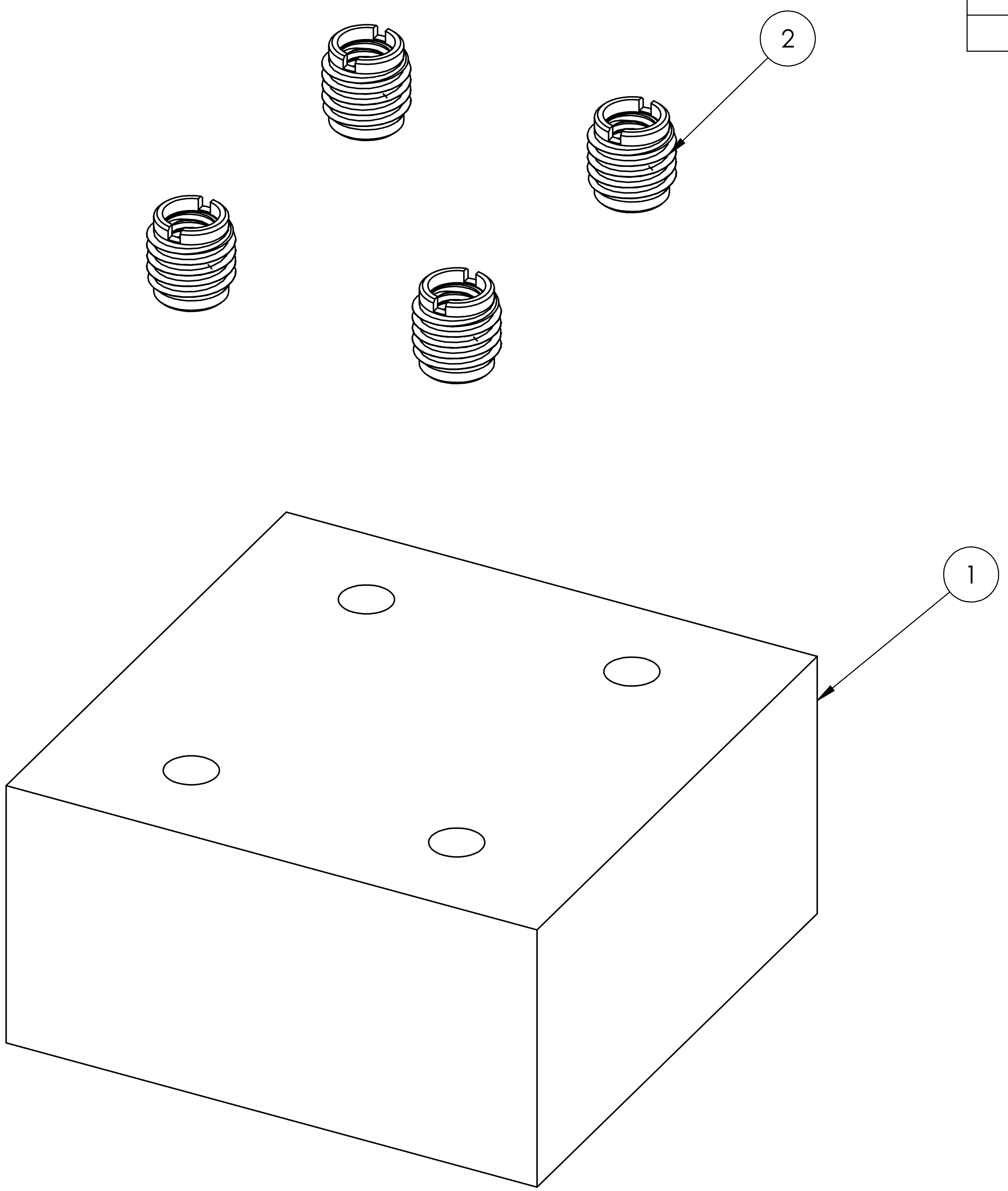
Cal Poly Mechanical Engineering ME 430 - SPRING 2016	Lab Section: 03	Assignment #	Title: FINAL ASSEMBLY	Drwn. By: STEPHEN ELDRIDGE
	Dwg. #: A10000	Nxt Asb:	Date: 5/30/2016 / Scale: 1:10	ADAPTIVE PADDLEBOARD

ITEM NO.	PART NUMBER	DESCRIPTION	exploded view/QTY.
1	1.1.1.0.0	SUPTAX Adventure XL	1
2	1.1.3.0.0	STRUCTURAL INSERT	4
3	1.1.2.0.0	MARINE GRADE HOOK AND LOOP STRIPS	2

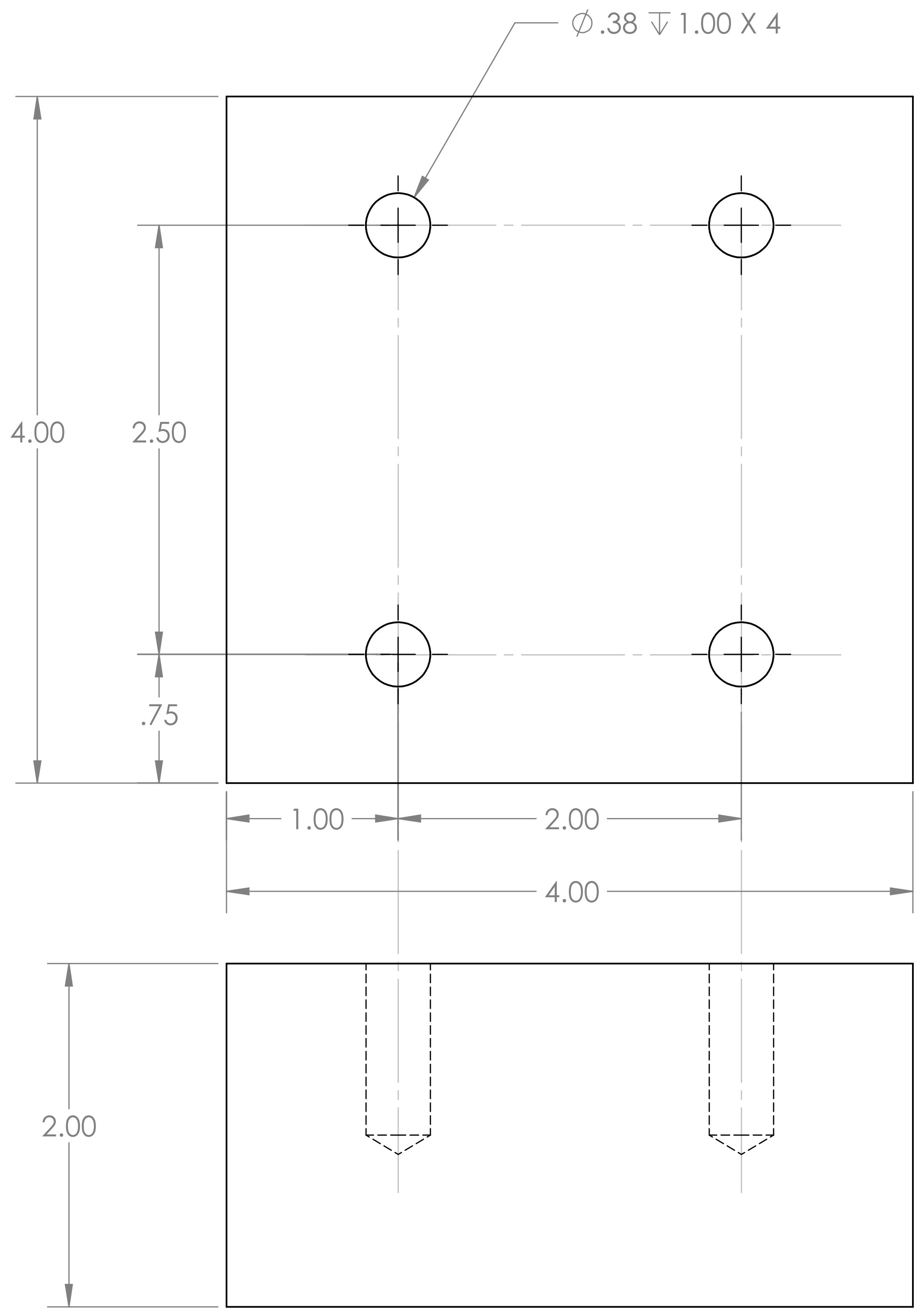


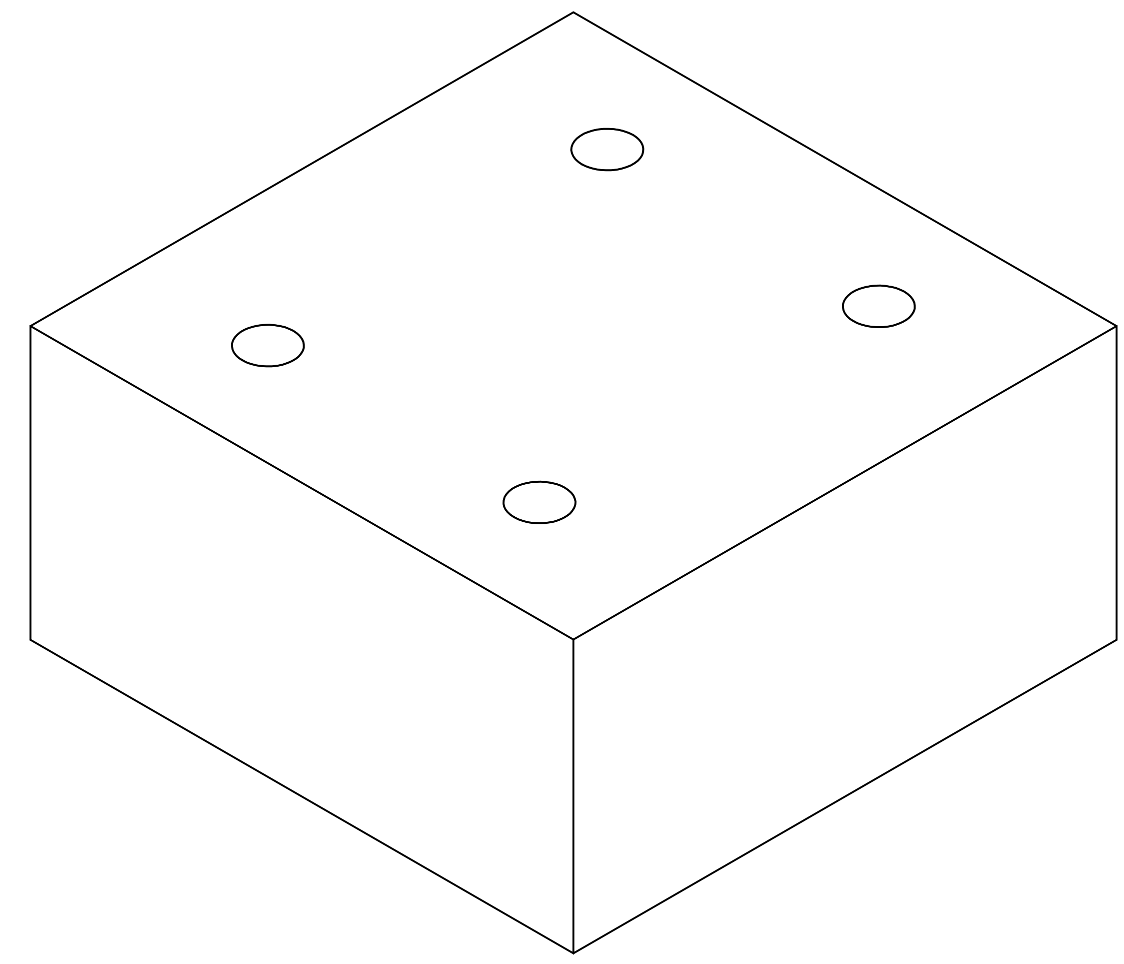
Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: PADDLEBOARD		Drwn. By: STEPHEN ELDRIDGE
ME 430 - SPRING 2016	Dwg. #: A11000	Nxt Asb:A10000	Date: 5/30/2016	Scale: 1:12	ADAPTIVE PADDLEBOARD

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1.1.3.1.0	INSERT BODY	1
2	1.1.3.2.0	THREADED INSERT	4



Cal Poly Mechanical Engineering	Lab Section:03	Assignment #	Title: STRUCTURAL INSERT		Drwn. By: CURTIS HODGSON
ME 430 - SPRING 2016	Dwg. #: A11300	Nxt Asb:	Date: 5/30/2016	Scale: 1:1	ADAPTIVE PADDLEBOARD





NOTE:

MATERIAL: ALDER HARDWOOD

ALL DIMENSIONS IN INCHES

ALL DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED: ±0.05

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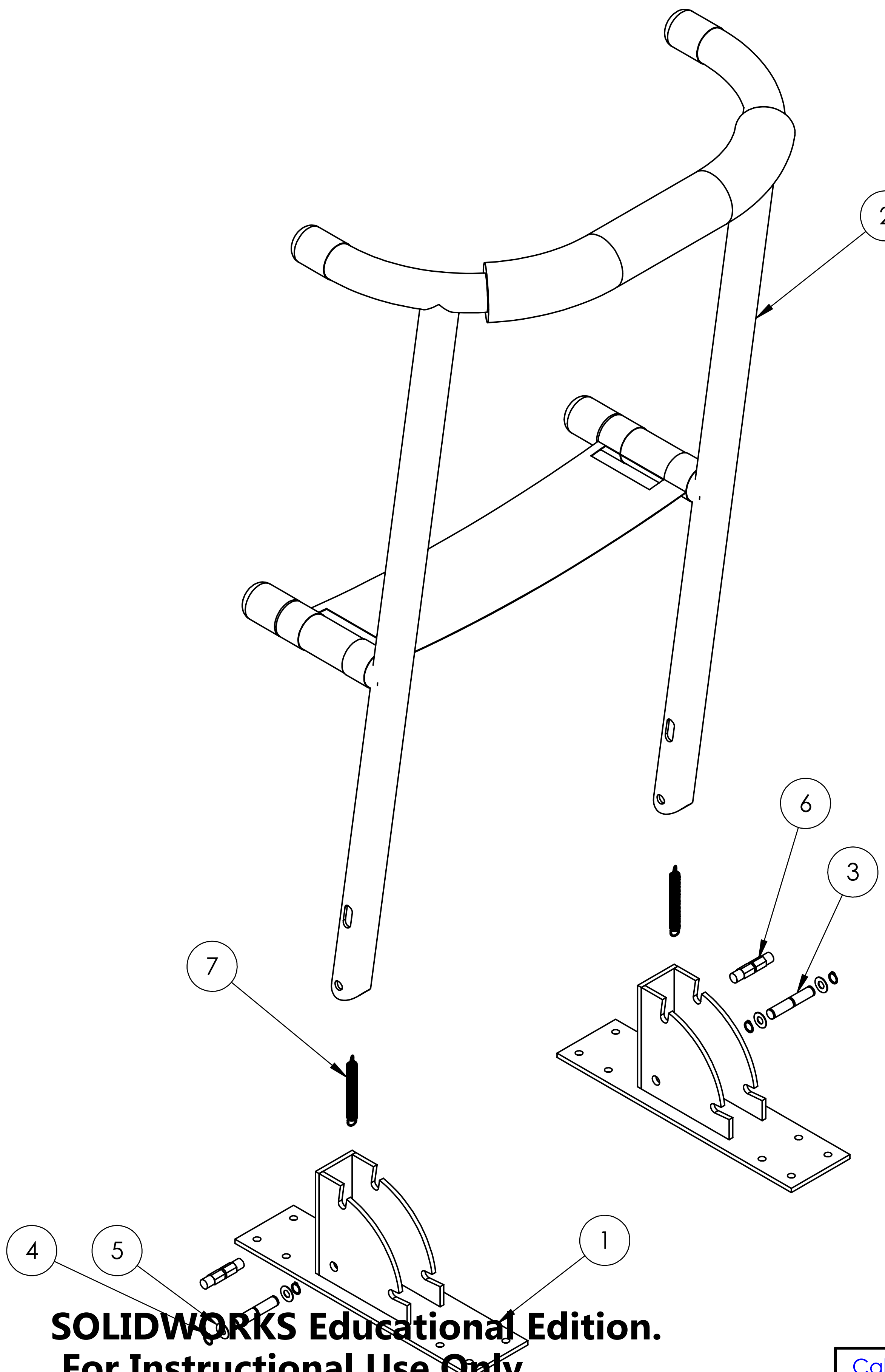
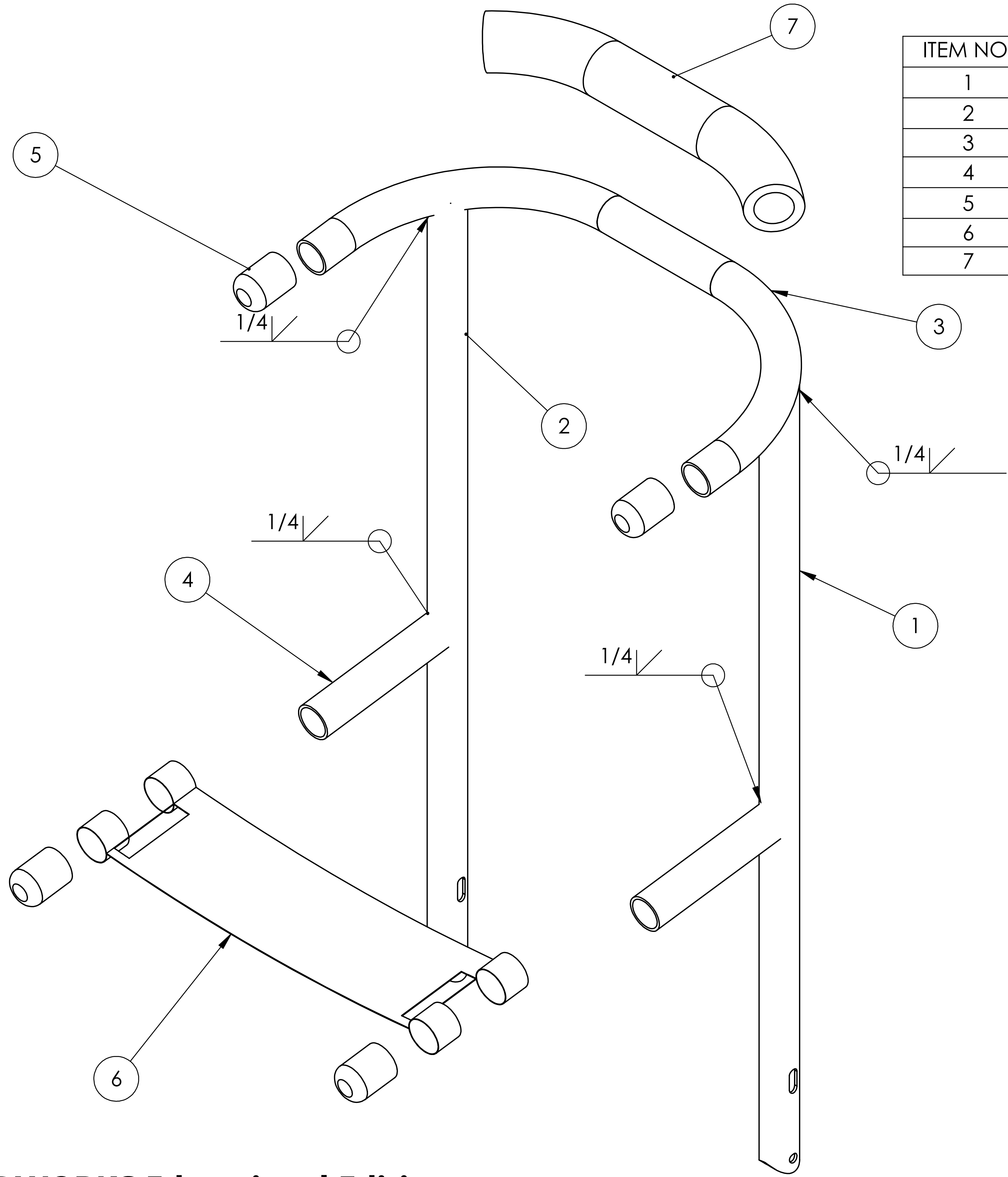
Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: INSERT BODY		Drwn. By: CURTIS HODGSON
ME 430 - SPRING 2016	Dwg. #: P11310	Nxt Asb: A11300	Date: 5/30/2016	Scale: 1:1	ADAPTIVE PADDLEBOARD



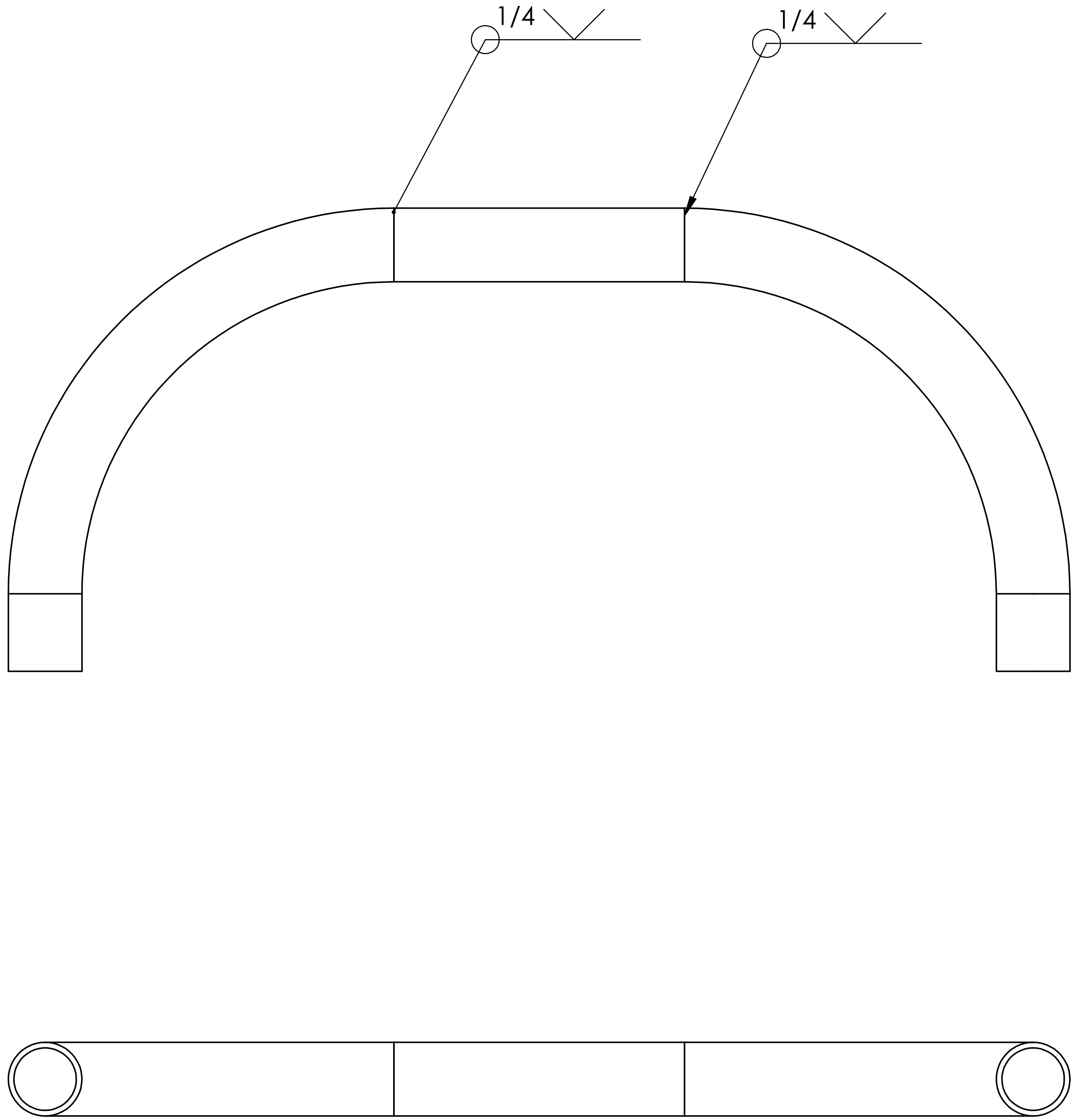
ITEM NO.	PART NUMBER	DESCRIPTION	Default/ QTY.
1	1.2.2.0.0	MECHANISM BASE	2
2	1.2.1.0.0	FOLDING SUPPORT STRUCTURE	1
3	1.2.4.0.0	ROUND PIN	2
4	1.2.5.0.0	ROUND PIN SNAP RING	4
5	1.2.6.0.0	ROUND PIN WASHER	4
6	1.2.3.0.0	HEX PIN	2
7	1.2.7.0.0	RETAINING SPRING	2

Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: FOLDING SUPPORT	Drwn. By: SPENCER SHOTTS
ME 430 - SPRING 2016	Dwg. #: A12000	Nxt Asb: A10000	Date: 5/30/2016 — Scale: 1:7	ADAPTIVE PADDLEBOARD



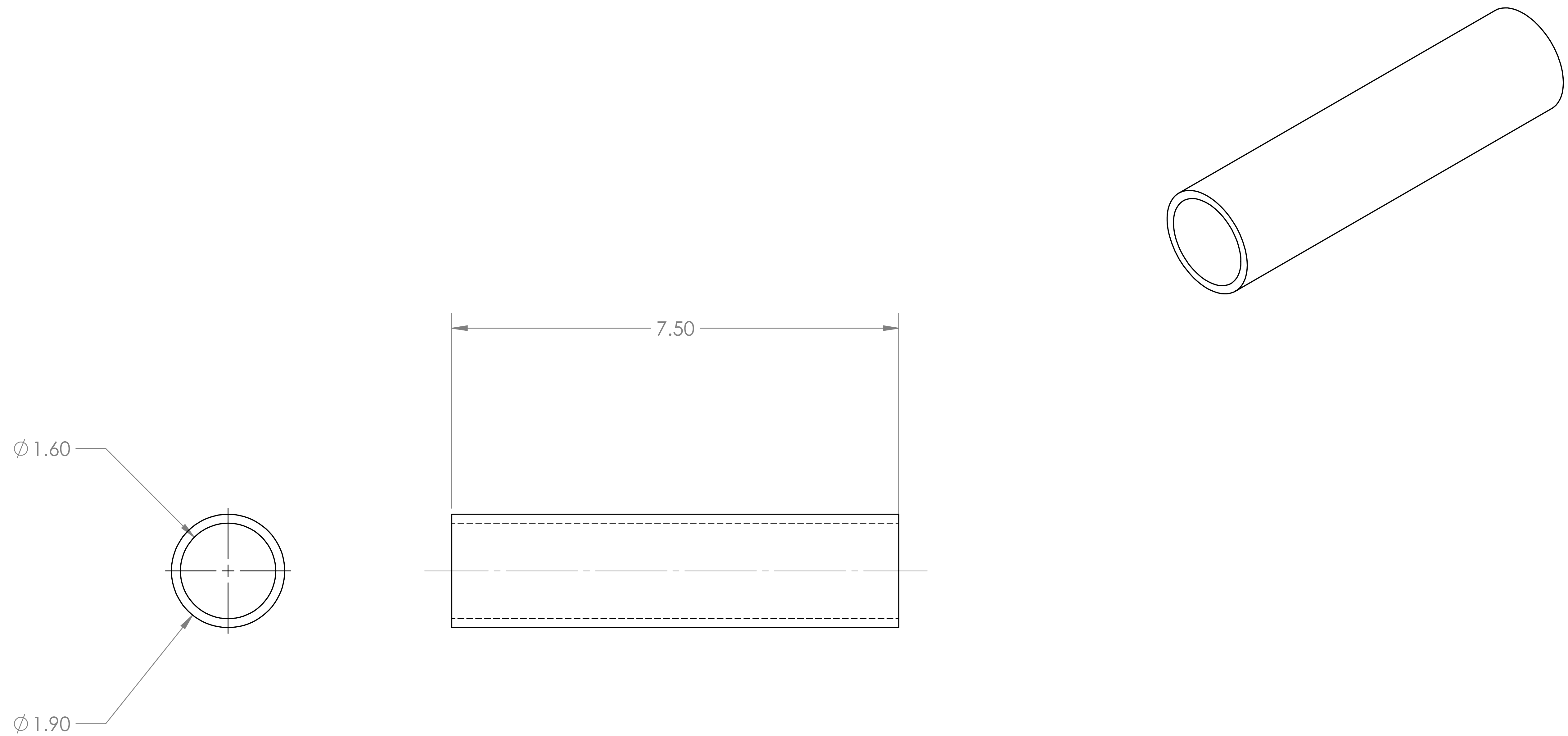
ITEM NO.	PART NUMBER	DESCRIPTION	exploded view/QTY.
1	1.2.1.3.1	RIGHT VERTICAL SUPPORT	1
2	1.2.1.3.0	LEFT VERTICAL SUPPORT	1
3	1.2.1.1.0	BACKREST STRUCTURE	1
4	1.2.1.2.0	LOWER DIP BARS	2
5	1.2.1.9.0	END CAPS	4
6	1.2.1.8.0	FABRIC SEAT	1
7	1.2.1.4.0	BACKREST FOAM	1

Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: FOLDING SUPPORT STRUCTURE	Drwn. By: SPENCER SHOTTS
ME 430 - SPRING 2-16	Dwg. #: A12100	Nxt Asb: A12000	Date: 5/30/2016	Scale: 1:6	ADAPTIVE PADDLEBOARD



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1.2.1.1.1	BACK REST CENTER	1
2	1.2.1.1.2	LONG RADIUS ELBOW	2

Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: BACKREST STRUCTURE	Drwn. By: STEPHEN ELDRIDGE
ME 430 - SPRING 2016	Dwg. #: A12110	Nxt Asb: A12100	Date: 5/30/2016 / Scale: 1:4	ADAPTIVE PADDLEBOARD



NOTE:

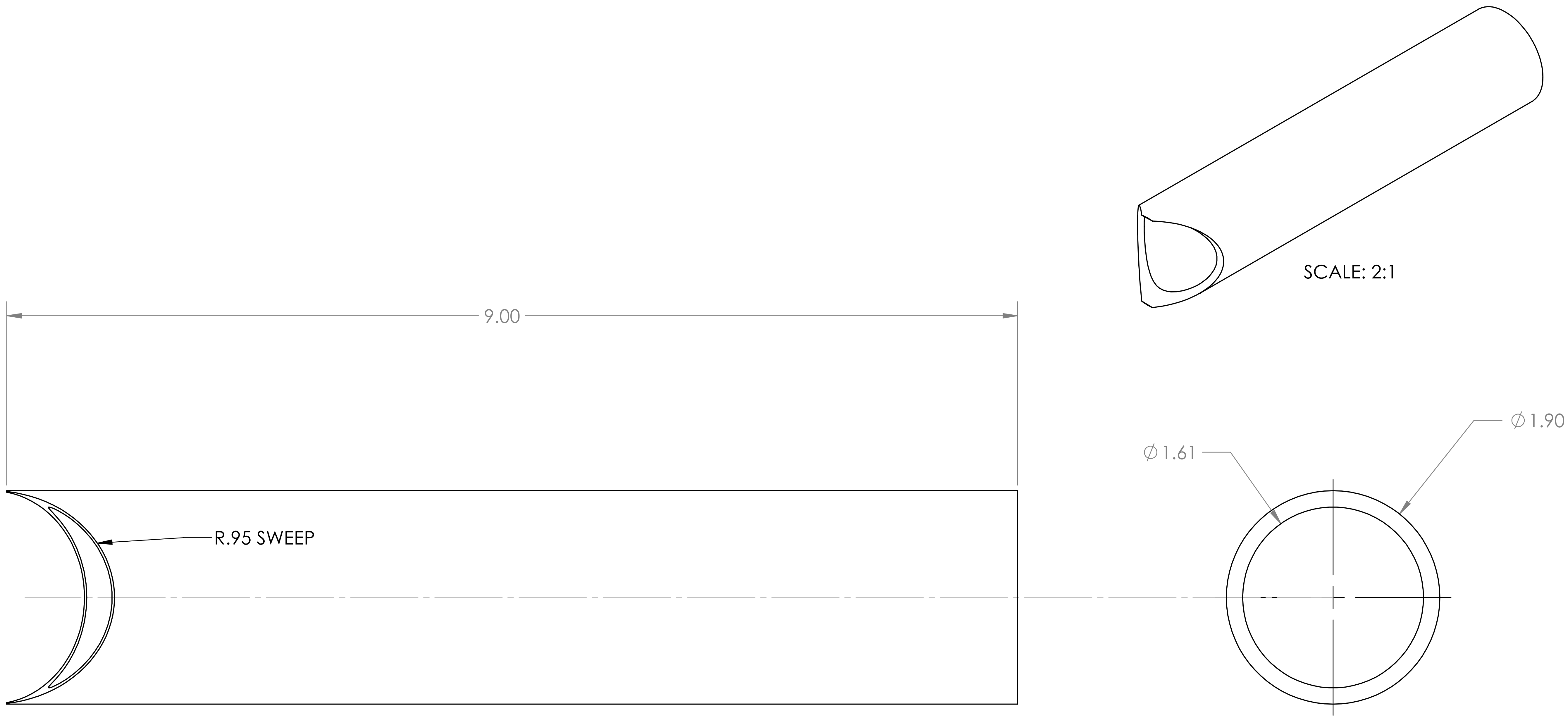
MATERIAL: 6061 ALUMINUM

ALL DIMENSIONS IN INCHES

ALL DIMENSION TOLERANCES UNLESS
OTHERWISE SPECIFIED: ±0.05

OTHER: PART IS SCHEDULE 40 PIPE

Cal Poly Mechanical Engineering	Lab Section:03	Assignment #	Title: BACKREST CENTER		Drwn. By: CURTIS HODGSON
ME 430 - SPRING 2016	Dwg. #:P12111	Nxt Asb: A12110	Date:5/30/2016	Scale: 1:2	ADAPTIVE PADDLEBOARD



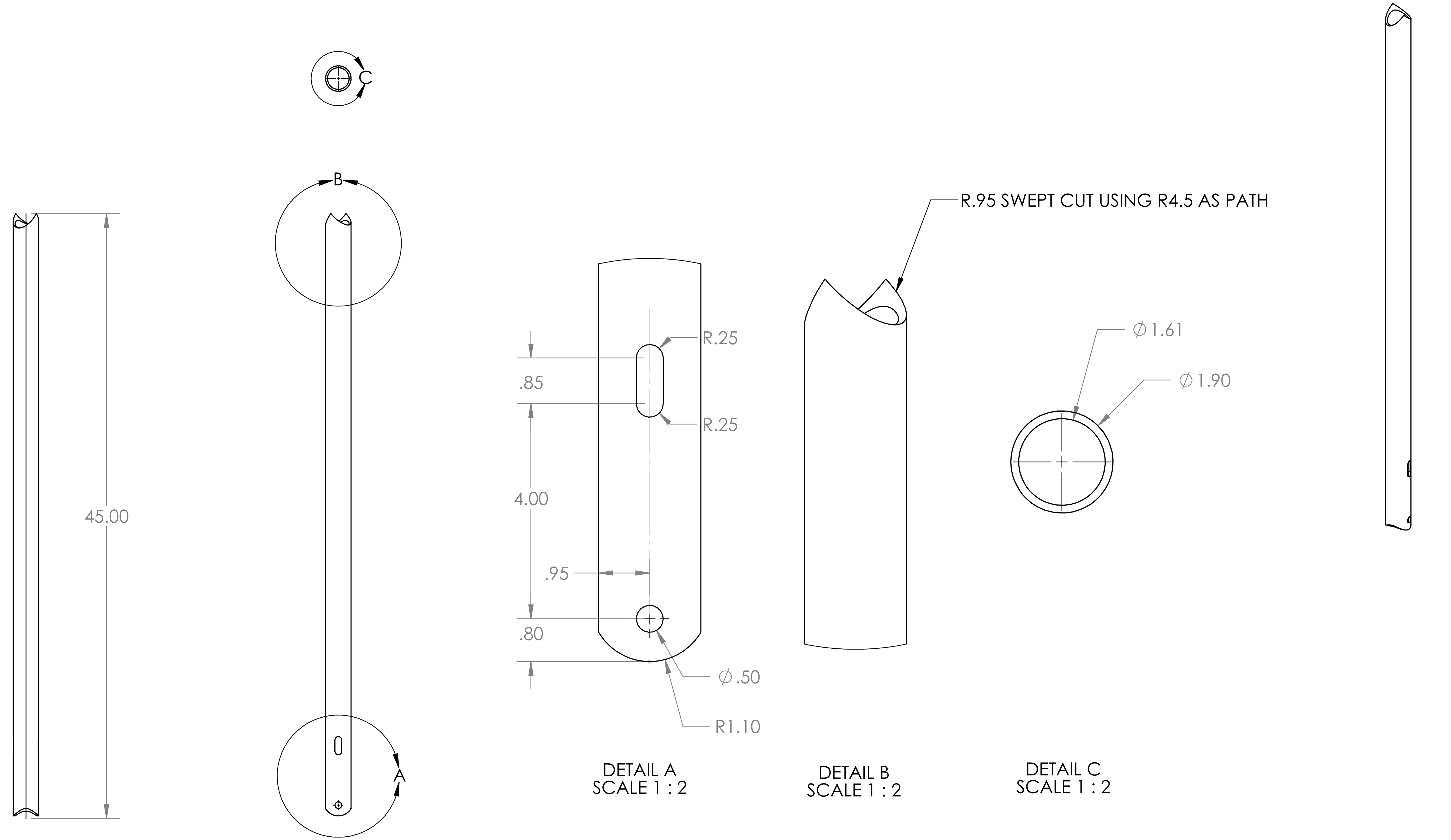
NOTE:

MATERIAL: 6061 ALUMINUM

ALL DIMENSIONS IN INCHES

ALL DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED: ±0.05

Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: LOWER DIP BARS		Drwn. By: CURTIS HODGSON
ME 430 - SPRING 2016	Dwg. #: P12120	Nxt Asb: A12100	Date: 5/30/2016	Scale:	ADAPTIVE PADDLEBOARD



NOTE:

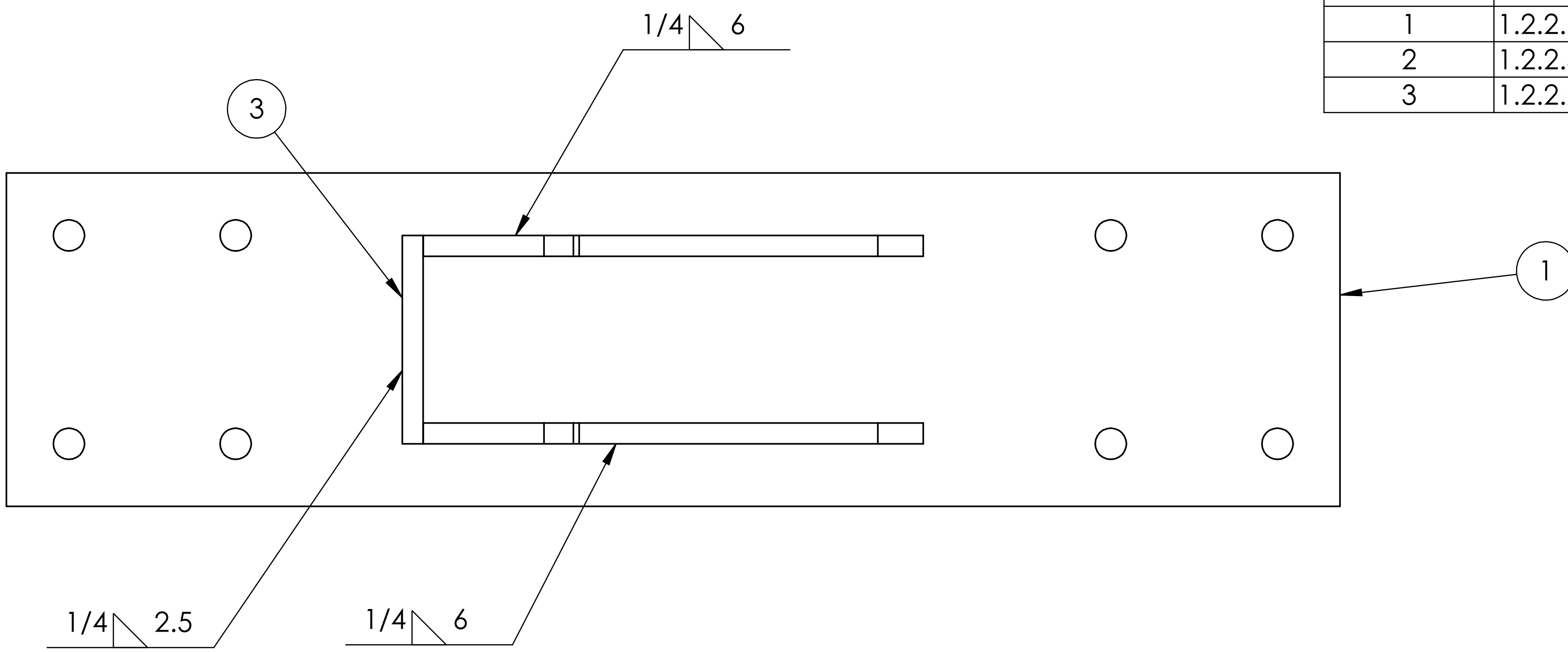
MATERIAL: 6061 ALUMINUM

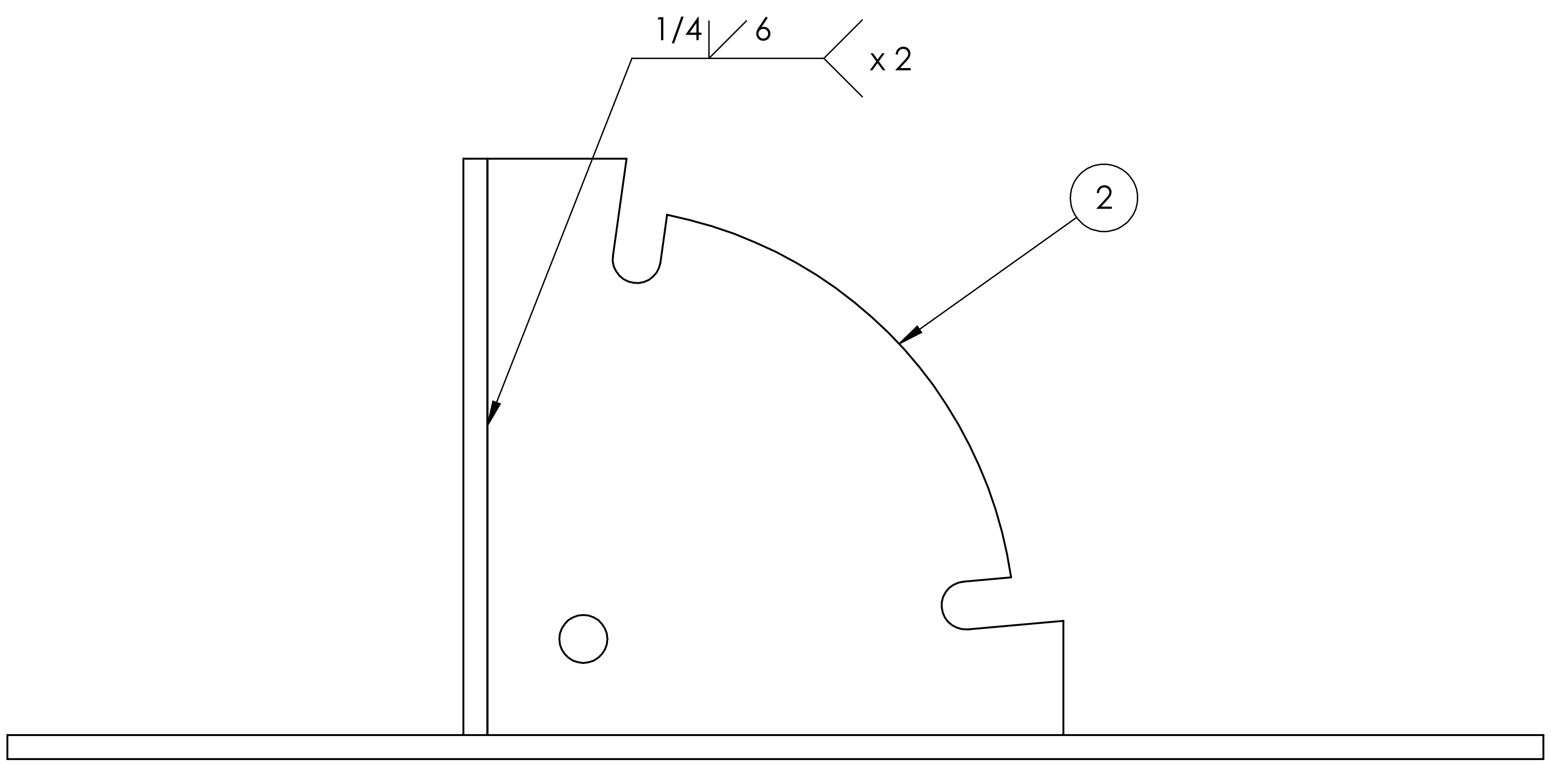
ALL DIMENSIONS IN INCHES

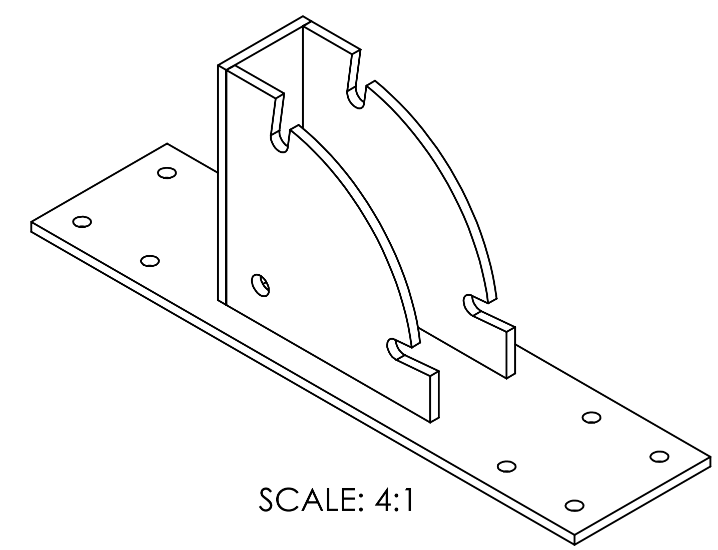
ALL DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED: ±0.05

Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: VERTICAL SUPPORT - LEFT		Drwn. By: CURTIS HODGSON
ME 430 - SPRING 2016	Dwg. #: P12130	Nxt Asb: A12100	Date: 5/30/2016	Scale: 1:8	ADAPTIVE PADDLEBOARD

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1.2.2.1.0	BASE PLATE	1
2	1.2.2.3.0	GUIDE PLATE	2
3	1.2.2.2.0	VERTICAL PLATE	1







SCALE: 4:1

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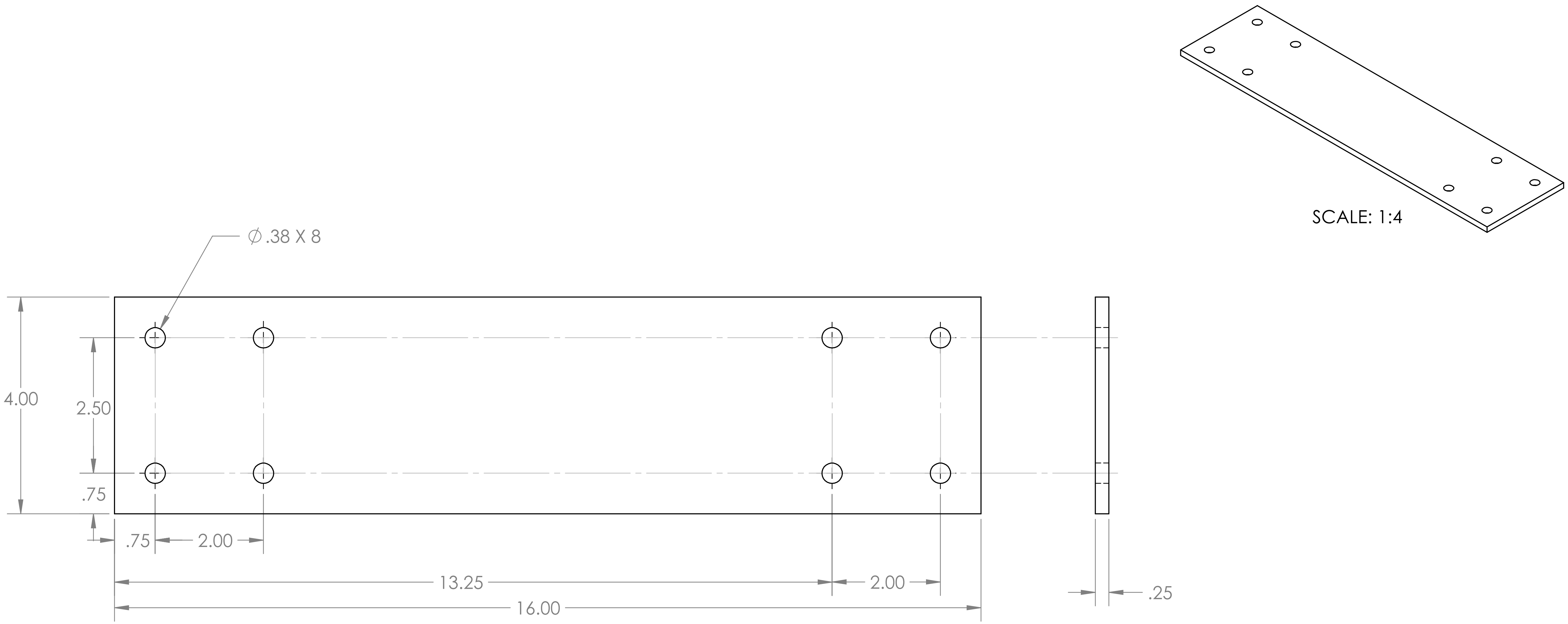
Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: MECHANISM BASE	Drwn. By: SPENCER SHOTTS
ME 430 - SPRING 2016	Dwg. #: A12200	Nxt Asb: A12000	Date: 5/30/2016 Scale: 1:2	ADAPTIVE PADDLEBOARD



NOTE:

MATERIAL: 6061 ALUMINUM

ALL DIMENSIONS IN INCHES

ALL DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED: ±0.05

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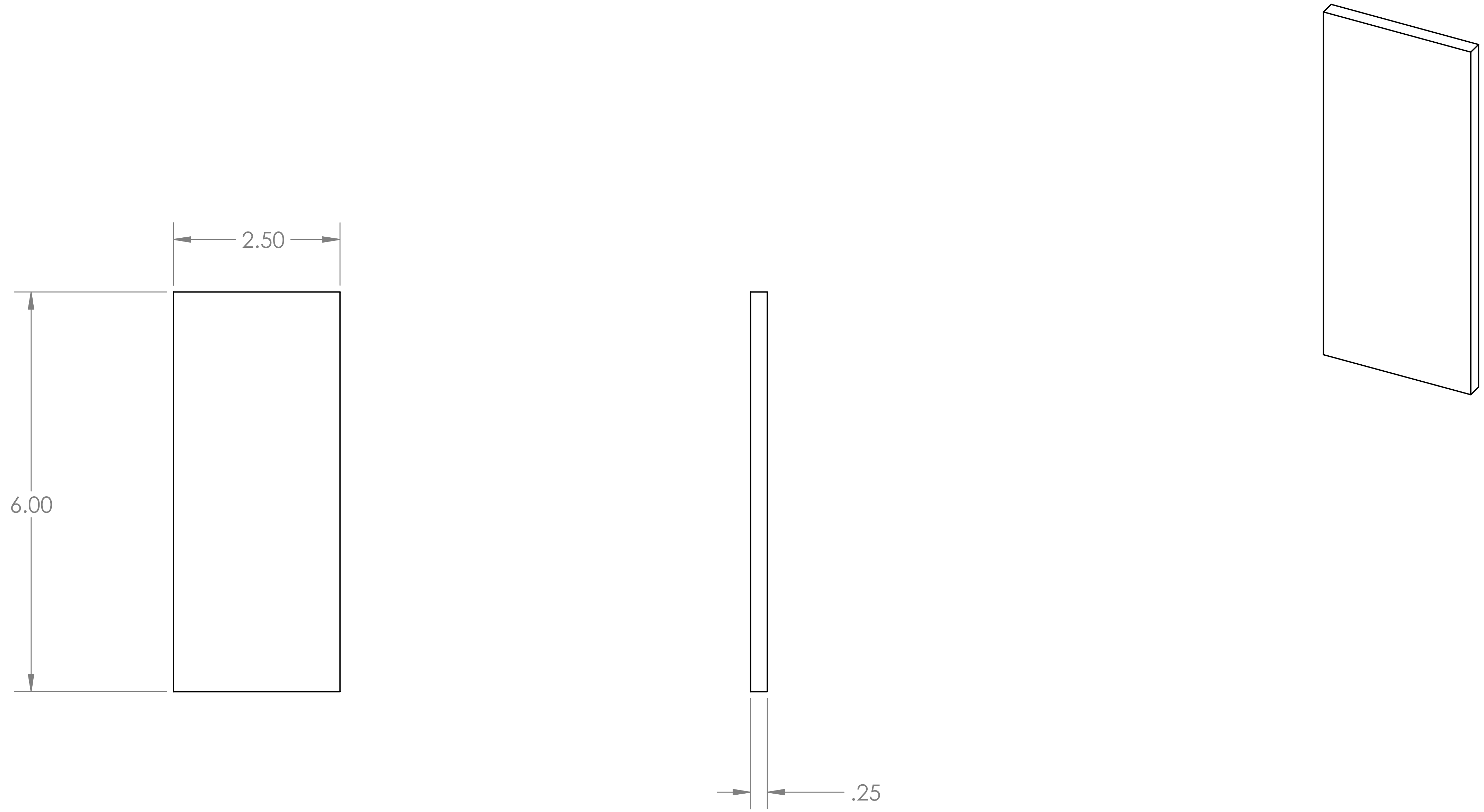
Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: BASE PLATE		Drwn. By: SPENCER SHOTTS
ME 430 - SPRING 2016	Dwg. #: P12210	Nxt Asb: A12200	Date: 5/30/2016	Scale: 1:2	ADAPTIVE PADDLEBOARD



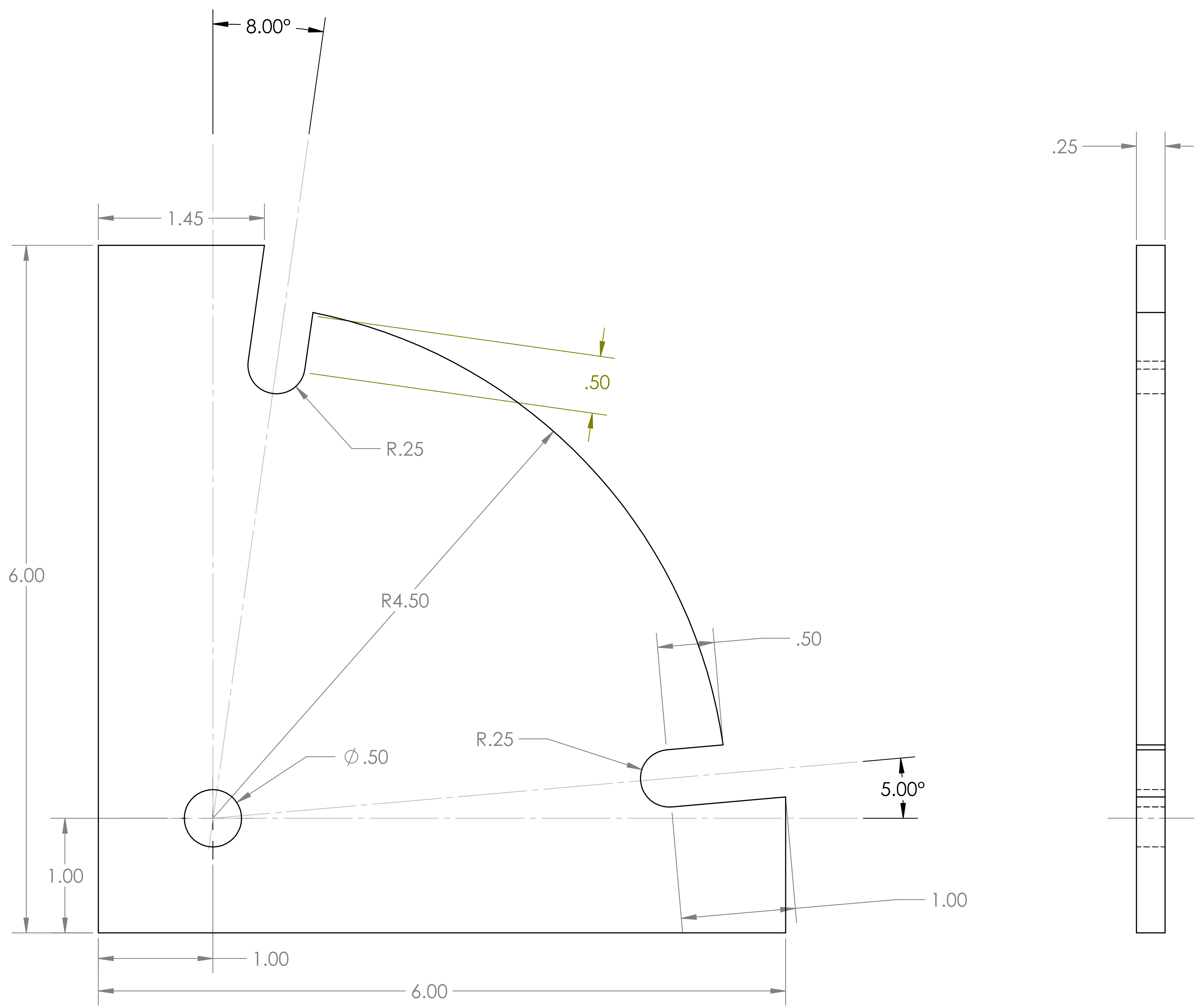
NOTE:

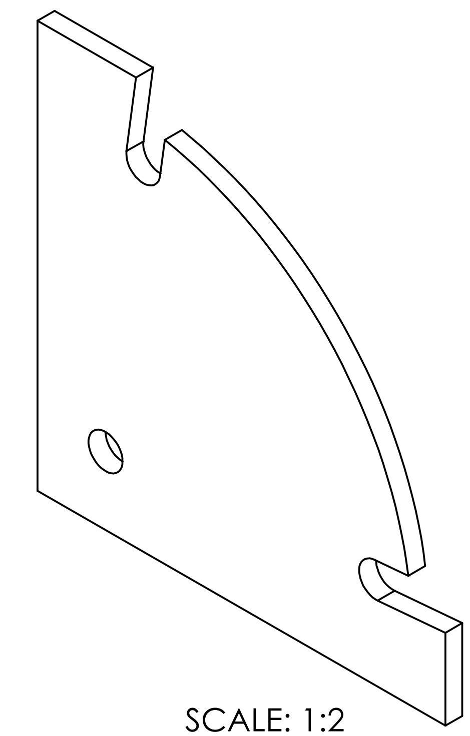
MATERIAL: 6061 ALUMINUM

ALL DIMENSIONS IN INCHES

ALL DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED: ±0.05

Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: VERTICAL PLATE		Drwn. By: STEPHEN ELDRIDGE
ME 430 - SPRING 2016	Dwg. #: P12220	Nxt Asb: A12200	Date: 5/30/2016	Scale: 1:2	ADAPTIVE PADDLEBOARD





SCALE: 1:2

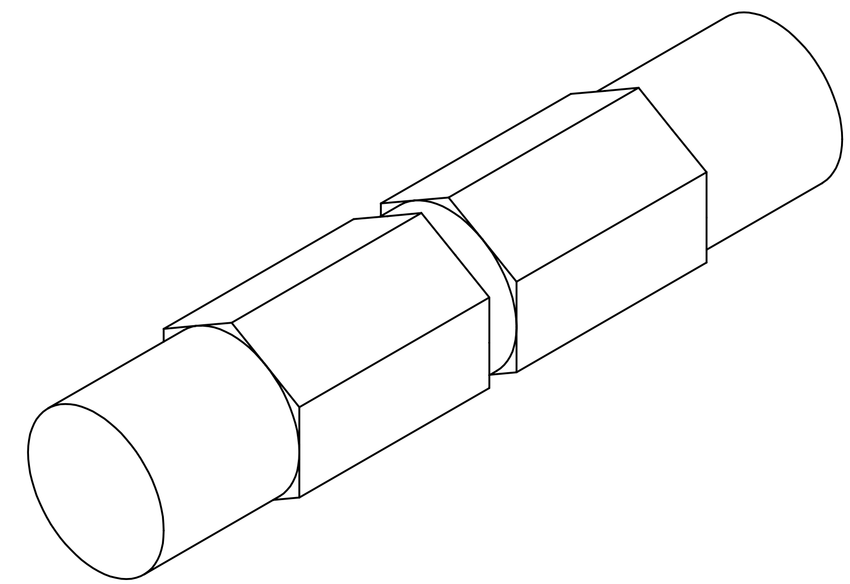
NOTE:

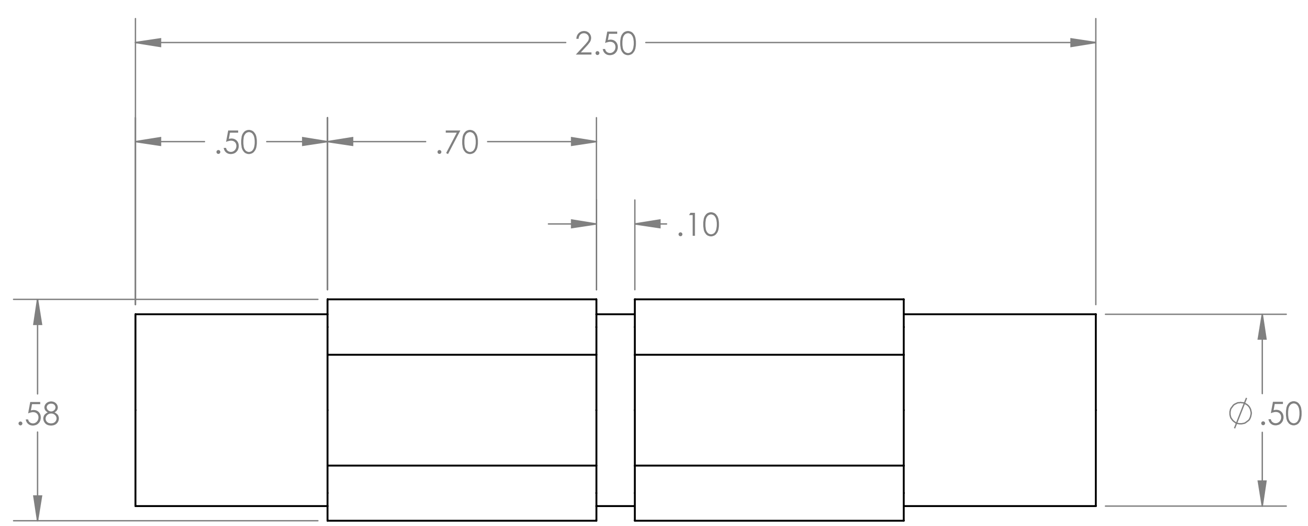
MATERIAL: 6061 ALUMINUM

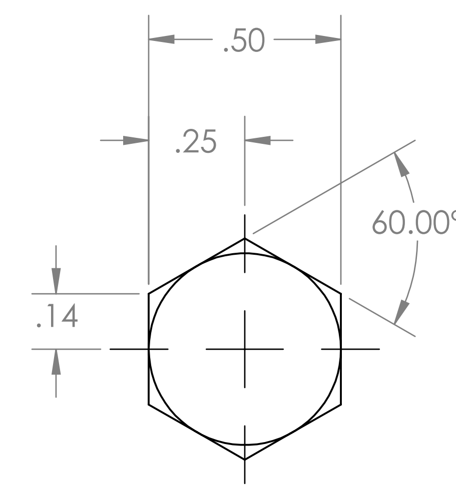
ALL DIMENSIONS IN INCHES UNLESS OTHERWISE SPECIFIED

ALL DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED: ±0.05 OR ±0.1 °

Cal Poly Mechanical Engineering	Lab Section:03	Assignment #	Title: GUIDE PLATES		Drwn. By: STEPHEN ELDRIDGE
ME 430 - SPRING 2016	Dwg. #:P12230	Nxt Asb: A12200	Date: 5/30/2016	Scale: 1:1	ADAPTIVE PADDLEBOARD







NOTE:

MATERIAL: 316 STAINLESS STEEL

ALL DIMENSIONS IN INCHES UNLESS
OTHERWISE SPECIFIED

ALL DIMENSION TOLERANCES UNLESS
OTHERWISE SPECIFIED: ±0.05 OR ±0.1°

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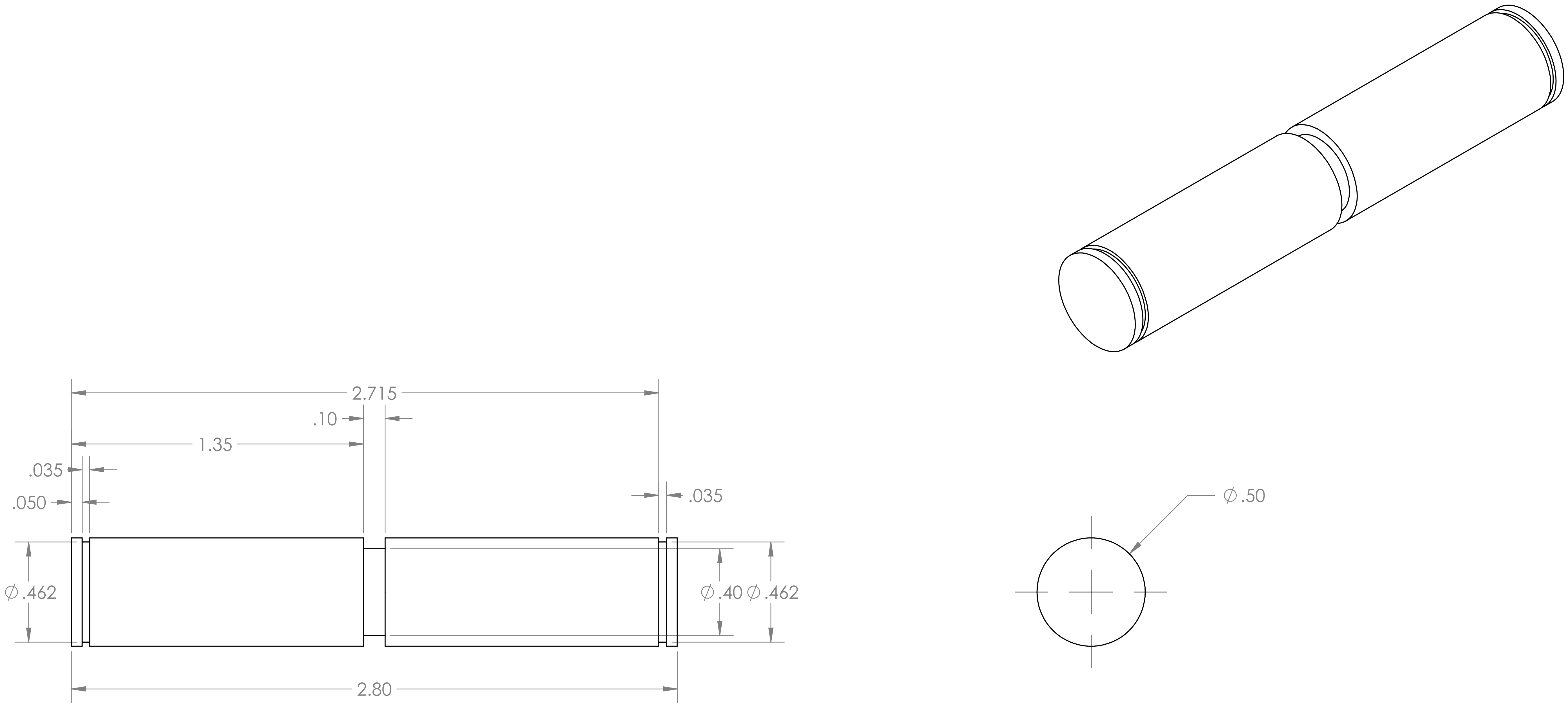
Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: HEX PIN		Drwn. By: SPENCER SHOTTS
ME 430 - SPRING 2016	Dwg. #: P12300	Nxt Asb: A12000	Date: 5/30/2016	Scale: 2:1	ADAPTIVE PADDLEBOARD



NOTE:

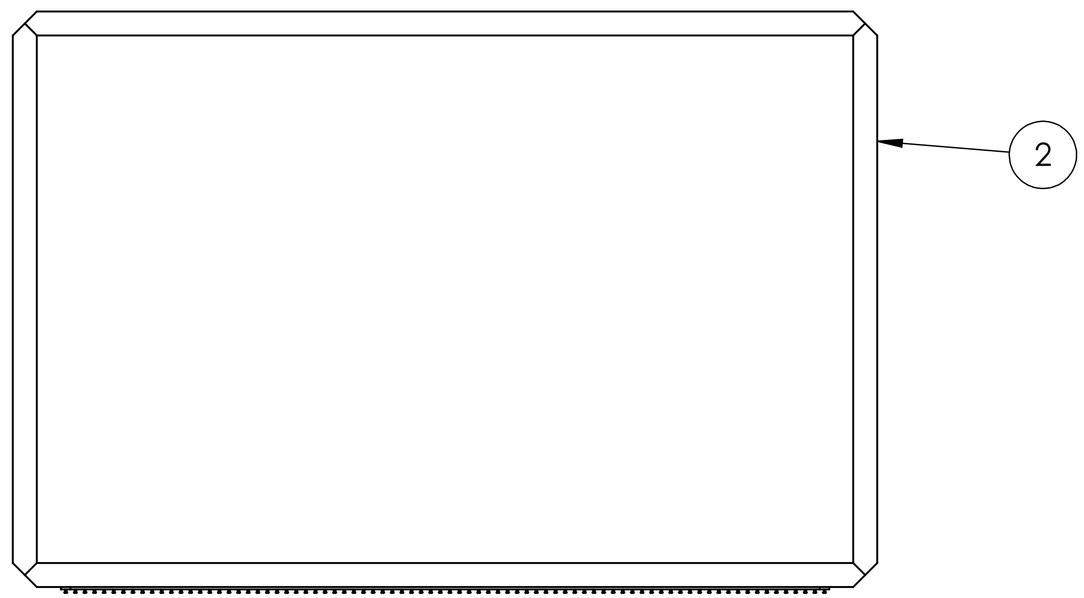
MATERIAL: 6061 ALUMINUM

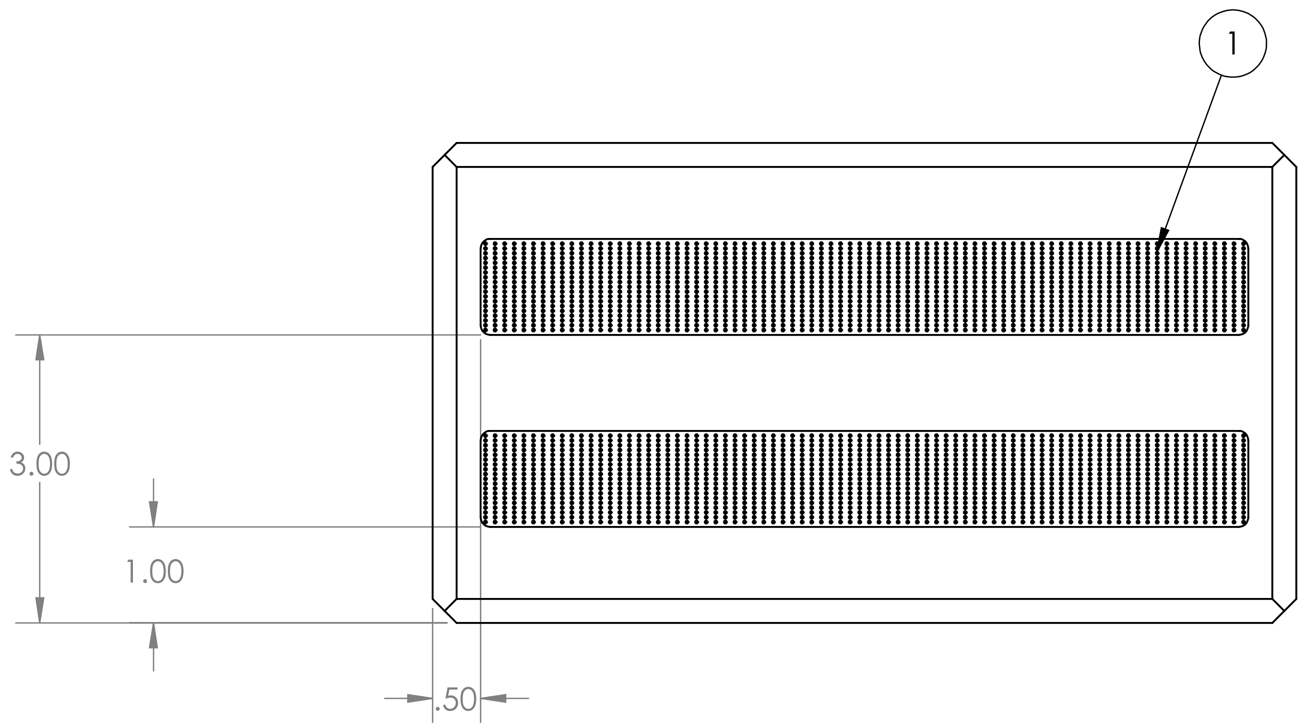
ALL DIMENSIONS IN INCHES

ALL DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED: ±0.05

Cal Poly Mechanical Engineering	Lab Section: 03	Assignment #	Title: ROUND PIN		Drwn. By: SPENCER SHOTTS
ME 430 - SPRING 2016	Dwg. #:P12400	Nxt Asb: A12000	Date: 5/30/2016	Scale: 2:1	ADAPTIVE PADDLEBOARD

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1.3.2.0.0	MARINE GRADE HOOK AND LOOP STRIP (HOOKS)	2
2	1.3.1.0.0	FOAM YOGA BLOCK	1



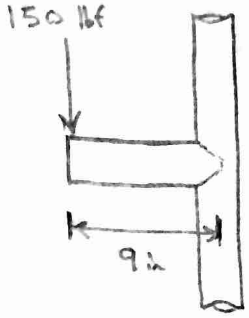


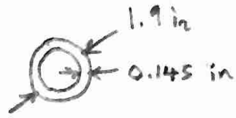
Cal Poly Mechanical Engineering	Lab Section: 06	Assignment #	Title: KNEELING SUPPORT		Drwn. By: CURTIS HODGSON
ME 430 - SPRING 2016	Dwg. #:A13000	Nxt Asb: A10000	Date:5/30/2016	Scale: 1:2	ADAPTIVE PADDLEBOARD

Appendix C:

Table C1. Vendors used to purchase project materials.

Company:	*Phone:*	*E-mail:*	*Street Address:*
McMaster	562-692-5911	la.sales@mcmaster.com	P.O. Box 54960 Los Angeles, CA 90054-0960
Pacific Coast Anodizing	559-441-0789	sales@pacano.com	1616 W Pine Ave. Fresno, CA 93728
Sharpe Products	262-754-0369	sales@sharpeproducts.com	2550 S. 170th Street New Berlin, WI 53151
StockCap	636-282-6800	stockcap@stockcap.com	123 Manufacturers Dr. Arnold, MO 63010
SpeedyMetals	866-938-6061	sales@Speedymetals.com	2505 S. 162nd Street New Berlin, WI 53151
Amazon	888-280-4331	cis@amazon.com	n/a





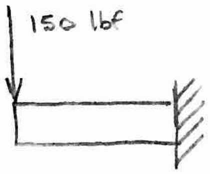
$$A = \pi\left[\frac{(1.9\ \text{in})^2}{4} - \frac{(1.61\ \text{in})^2}{4}\right]$$

$$A = 0.7995\ \text{in}^2$$

$$I = \frac{\pi}{4}\left[\frac{(1.9\ \text{in})^4}{16} - \frac{(1.61\ \text{in})^4}{16}\right]$$

$$I = 0.3099\ \text{in}^4$$

ASSUME WELD IS RIGID

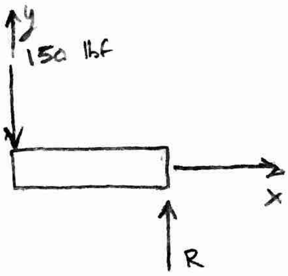


6061 AL:

$\sigma_y = 42{,}000$ psi

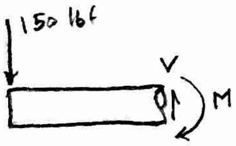
$E = 10{,}000{,}000$ psi

FBD



$\Sigma F_y = 0$: $R = 150$ lbf

CUT AT WELD



$V = 150$ lbf

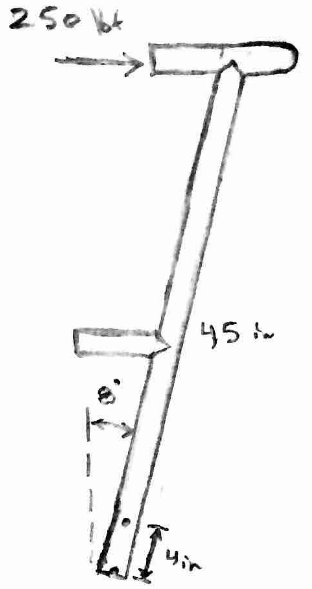
$M = 1350$ lbf·in

$$\sigma_{BEND} = \frac{(1350\ \text{lbf}\cdot\text{in})\left(\frac{1.9}{2}\ \text{in}\right)}{0.3099\ \text{in}^4} = 4138\ \text{psi}$$

SHEAR CAN BE NEGLECTED BECAUSE OF ITS MAGNITUDE

$$n = \frac{\sigma_y}{\sigma_{BEND}} = \frac{42{,}000\ \text{psi}}{4{,}138\ \text{psi}} = 10.15$$

SAFETY FACTOR = 10.15



6061 AL Sch 40 PIPE

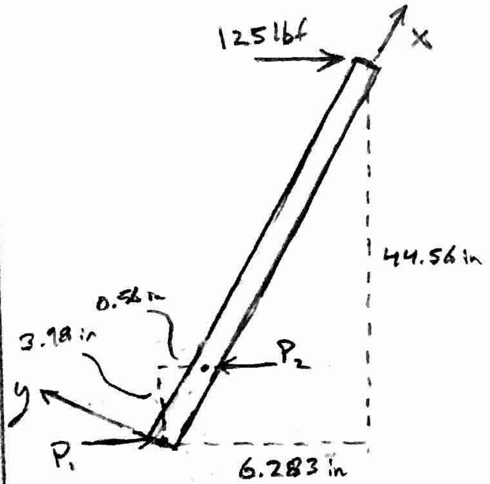
$\sigma_y = 42{,}000$ psi

$E = 10{,}000{,}000$ psi

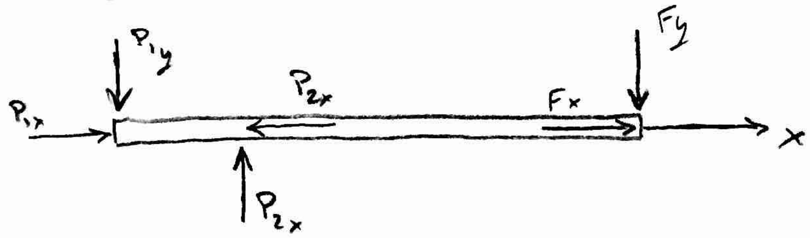
$A = 0.7995 \text{ in}^2$

$I = 0.3099 \text{ in}^4$

NOTE: LOADING WILL BE EVENLY DIVIDED BETWEEN SUPPORTS



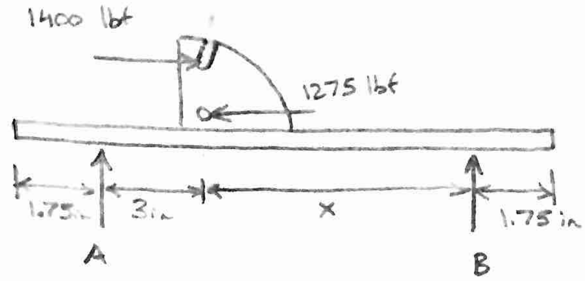
SIMPLIFIED FBD



$\sigma = \sigma_{BEND} + \sigma_{AXIAL}$ $\qquad n = \dfrac{\sigma_y}{\sigma}$

SEE EXCEL SPREADSHEET FOR CALCULATIONS

APPENDIX D | CAP SCREW LOADING | ME 429



$X = \text{TOTAL LENGTH} - 6.5 \text{ in}$

$$\Sigma F_y = 0: \quad A = -B$$

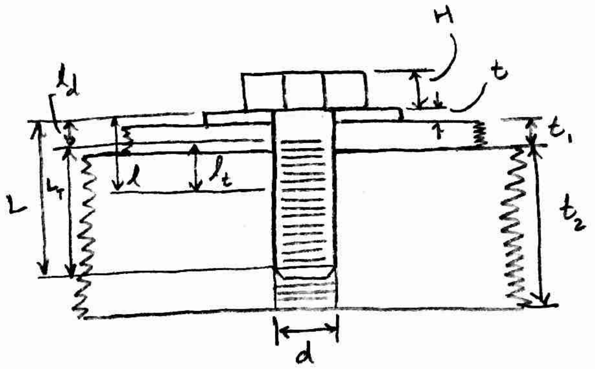
$$\Sigma M_A = 0: \quad A = -\frac{4325}{x+3}$$

TOTAL LENGTH	x	A	B
12 in	5.5 in	-509 lbf	509 lbf
14 in	7.5 in	-412 lbf	412 lbf
16 in	9.5 in	-346 lbf	346 lbf
18 in	11.5 in	-298 lbf	298 lbf
20 in	13.5 in	-262 lbf	262 lbf
22 in	15.5 in	-233 lbf	233 lbf

SELECT $x = 9.5$, TOTAL LENGTH = 16 in BECAUSE OF GEOMETRY LIMITATIONS ON BOARD

EACH BOLT WILL EXPERIENCE A FORCE: $F \approx \frac{B}{4}$

$F \approx 86.5$ lbf



$$L = h + 1.5d$$

$$h = t + t_1$$

$$l = \begin{cases} h + t_2/2 & t_2 < d \\ h + d/2 & t_2 \geq d \end{cases}$$

$$L_T = \begin{cases} 2d + \frac{1}{4}\text{ in} & L \leq 6 \text{ in} \\ 2d + \frac{1}{2}\text{ in} & L > 6 \text{ in} \end{cases}$$

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$$

$$k_m = \frac{0.5774 \pi E d}{2 \ln\left(5 \frac{0.5774 l + 0.5 d}{0.5774 l + 2.5 d}\right)}$$

$$l_d = L - L_T$$

$$l_t = l - l_d$$

$$A_d = \pi \frac{d^2}{4}$$

A_t FROM TABLE 8-1

$$F_{BOLT} = P_{BOLT} + F_i$$

$$P_{BOLT} = \frac{k_b P}{k_b + k_m}$$

$$F_{MEMBER} = P_M - F_i$$

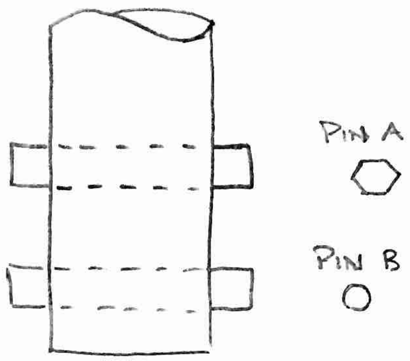
$$P_M = P - P_{BOLT}$$

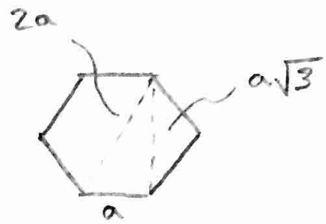
$$T = k F_i d \qquad k \cong 0.2$$

$$\sigma_{BOLT} = \frac{F_{BOLT}}{A_t} \qquad n_p = \frac{S_{PROOF}}{\sigma_{BOLT}}$$

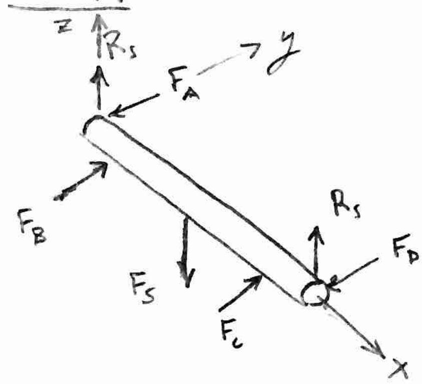
$$n_L = \frac{S_{PROOF} A_t - F_i}{\left(\frac{k_b}{k_b + k_m}\right) P}$$

SEE EXCEL SPREADSHEET FOR CALCULATIONS

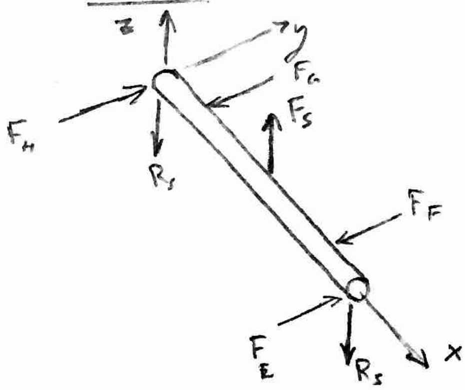




PIN A



PIN B



$$y = a\frac{\sqrt{3}}{2} \qquad y = \frac{D}{2}$$

$$I = a^4\frac{\sqrt{3}}{2} \qquad I = \frac{\pi}{4}r^4$$

$$Q = \frac{2}{3}r^3 \qquad Q = \frac{3a^3}{2}$$

$$\sigma_B = -\frac{My}{I} \qquad \tau_s = \frac{VQ}{It}$$

MHOR'S CIRCLE

$$\sigma_{AVG} = \frac{\sigma_y + \sigma_z}{2} \qquad \tau_{MAX} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$\sigma_{MAX/MIN} = \sigma_{AVG} \pm \tau_{MAX}$$

SEE EXCEL SPREADSHEET FOR CALCULATIONS

Primary Feature	Component/Function	Item Number	Potential Failure Mode	Potential Effects of Failure	Next higher level effect	System level end effect	SEV-Severity	Potential Causes	OCC-Probability of Occurrence	Processes in place to prevent failure	Processes in place to detect failure	Recommended Action(s)	DET-Ability to Detect	RPN-Risk Priority number
Seating	Seat Fabric	1.1	Ripped Stitching	Seat fails to hold weight	User falls through seat and impacts board	Possible injury to user, seat loses function	8	User's garment/accessories tear fabric, fatigue on stitching	7	Regular Visual Inspection	n/a	Test of stitching configurations	2	112
Structure	Dip Bars	2.1	Failed weld	Dip bars fail to support weight of lifting user	Dip bars bend and user cannot lift themselves	Dip bars cannot be used	6	Improperly welded, Fatigue Loading *(unlikely)	1	Inspect all welds	n/a	Design proper welds, inspect finished welds, Safety Factor > 2	2	12
	Standing Support Beams	2.2	Piping plastically deforms due to bending	Standing Support loses original function	Standing experience for user becomes less comfortable	Standing support cannot be used to support standing	4	Unseen additional force is applied to bars	1	n/a	n/a	Safety Factor > 2	2	8
	Structural Beams	2.3	Corrosion	Loss of structural strength and desirable aesthetics	Structure loses some strength	Structure may fail and loss of desirable aesthetics	5	Exposure to salt water and removal of anodizing layer	1	Regular Visual Inspection	n/a	Professional Marine Grade Anodizing	1	5

Primary Feature	Component/Function	Item Number	Potential Failure Mode	Potential Effects of Failure	Next higher level effect	System level end effect	SEV-Severity	Potential Causes	OCC-Probability of Occurrence	Processes in place to prevent failure	Processes in place to detect failure	Recommended Action(s)	DET-Ability to Detect	RPN-Risk Priority number
Collapsing Joint	Lever Assembly	3.1	Corrosion	Structure position becomes unadjustable	Loss of function of lever arm	Unable to adjust structure position	7	Exposure to salt water and removal of anodizing layer	3	Regular Use	n/a	Professional Marine Grade Anodizing	1	21
	Pin	3.2	Shearing	Structure falls down	User falls backwards	Loss of function, potential of user impacting board	8	Unseen additional force is applied to bars, Misuse	2	n/a	n/a	Safety Factor > 2	1	16
	Unlocking Lever	3.3	Lever becomes stuck/jammed	Structure position cannot be adjusted	User cannot adjust position structure	Loss of ability to change position	6	Foreign objects/material present, spring force too large, friction between components	5	Regular Use	n/a	Ensure max spring force is less than 10/15 lbs	3	90
	Spring	3.4	Plastic Deformation	Structure position cannot be adjusted	User cannot adjust position structure	Loss of ability to change position	6	Misuse	1	Regular Use	n/a	Safety Factor > 2	2	12
	Bracket Weld to Baseplate	3.5	Weld Failure	Structure falls down	User falls backwards	Loss of function, potential of user impacting board, exposed shard edges	9	Improperly welded, Fatigue Loading *(unlikely), Unseen additional force is applied to bars, Misuse	2	Inspect all welds	n/a	Design proper welds, inspect finished welds, Safety Factor > 2	1	18

Primary Feature	Component/Function	Item Number	Potential Failure Mode	Potential Effects of Failure	Next higher level effect	System level end effect	SEV-Severity	Potential Causes	OCC-Probability of Occurrence	Processes in place to prevent failure	Processes in place to detect failure	Recommended Action(s)	DET-Ability to Detect	RPN-Risk Priority number
Board Insert	Epoxy	4.1	Shear/peeling of epoxy	Inserts are torn from board	Support structure fails, user falls	Board is destroyed, possible injury to user	9	Unseen additional force is applied to bars, seal on board surface tears allowing water into epoxy layer	5	n/a	n/a	Use proper epoxy and install insert with under supervision of experienced	2	90
	Bolts	4.2	Bolt Shear	Possibility of structure falling down if more than one bolt fails	Support structure fails, user falls	Board use suspended, most replace bolts or insert	8	Unseen additional force is applied to bars, Misuse	1	n/a	n/a	Safety Factor > 2	2	16
	Board Foam	4.3	Compression of Internal Board Foam	Epoxy layer is torn, inserts are torn from board	Support structure fails, user falls	Board is destroyed, possible injury to user	7	Unseen additional force is applied to bars	3				3	63
Kneeling	Yoga Block	5.1	Yoga Block rips off board	Yoga block falls into water and cannot be used	User loses ability to kneel comfortably	User must stop use of board and grab yoga block, loss of ability to kneel comfortably	3	User accidentally hits block	8	Regular Use	n/a	Allow easy attachment method to board and instruct user how to best do it	1	24

ID	Task Name	Duration	Start
0	**Manufacturing Project Management Plan**	**67 days**	**Thu 3/3/16**
1	**Manufacturing Plan**	**38 days**	**Thu 3/3/16**
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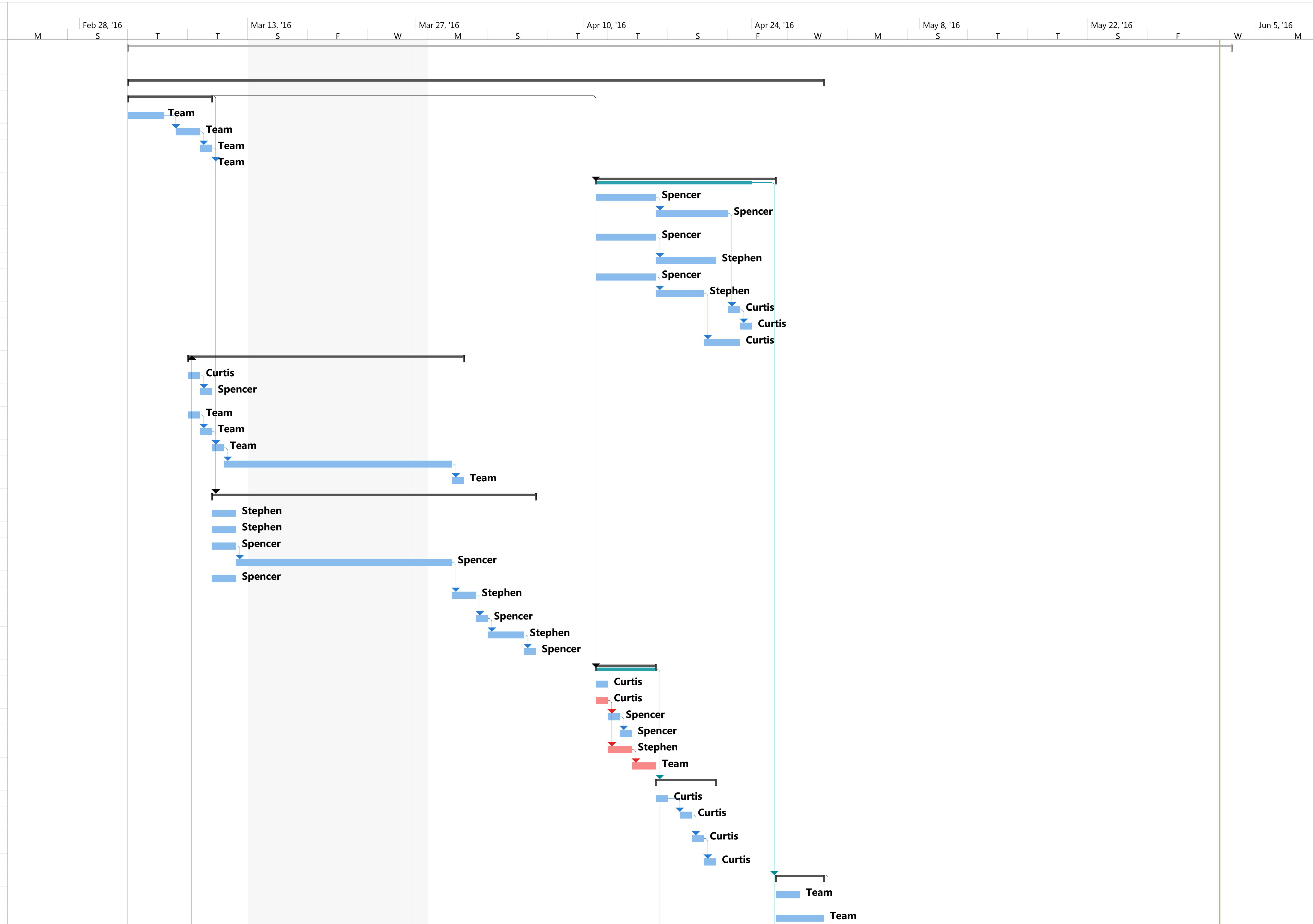
5	Take Inventory of Aquired Parts	1 day	Tue 3/8/16
6	Assign Manufacturing Processes	0.5 days	Wed 3/9/16
7	**Folding Support Structure**	**13 days**	**Mon 4/11/16**
8	Cut Stock Pipe to Backrest Size	5 days	Mon 4/11/16
9	Weld Backrest 90's and Cut Stock	5 days	Sat 4/16/16
10	Cut Stock to Vertical Support Size	5 days	Mon 4/11/16
11	Machine Vertical Support	4 days	Sat 4/16/16
12	Cut Stock to Lower Dip Bar Size	5 days	Mon 4/11/16
13	Machine Lower Dip Bars (Seat)	3 days	Sat 4/16/16
14	Cut Foam Rollers to Size	1 day	Fri 4/22/16
15	Attach Backrest End Caps	1 day	Sat 4/23/16
16	Cut and Sew Fabric Seat	3 days	Wed 4/20/16
17	**Structural Insert**	**8 days**	**Tue 3/8/16**
18	Cut Wood for Insert Body	1 day	Tue 3/8/16
19	Install Self-Tapping Threaded Insert	1 day	Wed 3/9/16
20	Cut Insert into Board	1 day	Tue 3/8/16
21	Fiberglass Insert	1 day	Wed 3/9/16
22	Epoxy Insert	1 day	Thu 3/10/16
23	Cure Time	4 days	Fri 3/11/16
24	Post Installation Machining	1 day	Wed 3/30/16
25	**Mechanism Base**	**11 days**	**Thu 3/10/16**
26	Cut Stock for Base Plate	2 days	Thu 3/10/16
27	Cut Stock for Vertical Plate	2 days	Thu 3/10/16
28	Cut Stock for Guides	2 days	Thu 3/10/16
29	Machine Guides	3 days	Sat 3/12/16
30	Machine Base Plate	2 days	Thu 3/10/16
31	Weld Guides to Vertical Supports	2 days	Wed 3/30/16
32	Machine Welded Guides	1 day	Fri 4/1/16
33	Weld Base Plate to Guides	2 days	Sat 4/2/16
34	Machine Welds	1 day	Tue 4/5/16
35	**Machine Joint Assembly**	**5 days**	**Mon 4/11/16**
36	Cut Stock to Size for Pins	1 day	Mon 4/11/16
37	Cut Hex Pin Stock to Size	1 day	Mon 4/11/16
38	Machine Pin Snap Ring Guides	1 day	Tue 4/12/16
39	Machine Pin Keyway	1 day	Wed 4/13/16
40	Machine Hex Pin	2 days	Tue 4/12/16
41	Assemble Joint	2 days	Thu 4/14/16
42	**Kneeling Position**	**4 days**	**Sat 4/16/16**
43	Cut Hook and Loop Stock to Size	1 day	Sat 4/16/16
44	Cut Kneeling Block to Size from Stock	1 day	Mon 4/18/16
45	Attach Hook and Loop to Kneeling Block	1 day	Tue 4/19/16
46	Attach Hook and Loop to Board	1 day	Wed 4/20/16
47	**Assemble Full Design**	**4 days**	**Tue 4/26/16**
48	Bolt Mechanism Base to Structural Insert	2 days	Tue 4/26/16
49	Attach Standing Support to Machanism Base	4 days	Tue 4/26/16



Project: Manufacturing Project
Date: Thu 6/2/16

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

ID	Task Name	Duration	Start
50	Assemble Joint Assembly within Support Structure	3 days	Tue 4/26/16
51	Install Snap Rings on Joint Assembly	1 day	Tue 4/26/16
52	Attach Kneeling Position to Board	1 day	Tue 4/26/16
53	**Testing**	**34.99 days**	**Thu 3/3/16**
54	**Structural Insert**	**4 days**	**Thu 3/3/16**
55	Test Bar in Foam	2 days	Thu 3/3/16
56	Test Bar in Fiberglassed Foam	2 days	Thu 3/3/16
57	Test Bolts and Plate	2 days	Sat 3/5/16
58	**Folding Support Structure**	**0.99 days**	**Tue 4/26/16**
59	Perform Quality Control	0.33 days	Tue 4/26/16
60	Check Integrity	0.33 days	Tue 4/26/16
61	Bending Check	0.33 days	Tue 4/26/16
62	**Machine Joint Assembly**	**1 day**	**Sat 4/16/16**
63	Test Joint	1 day	Sat 4/16/16
64	**Design Verification**	**44 days**	**Thu 3/3/16**
65	**DVP Plan**	**44 days**	**Thu 3/3/16**
66	1.1	0.1 days	Mon 3/28/16
67	1.2	0.1 days	Mon 3/28/16
68	1.3	0.1 days	Mon 3/28/16
69	2.1	0.5 days	Sat 4/30/16
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72	2.4	1 day	Mon 5/2/16
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74	3.1	0.1 days	Thu 3/3/16
75	3.2	0.1 days	Thu 3/3/16
76	3.3	0.1 days	Thu 3/3/16
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81	5.1	1 day	Thu 5/5/16
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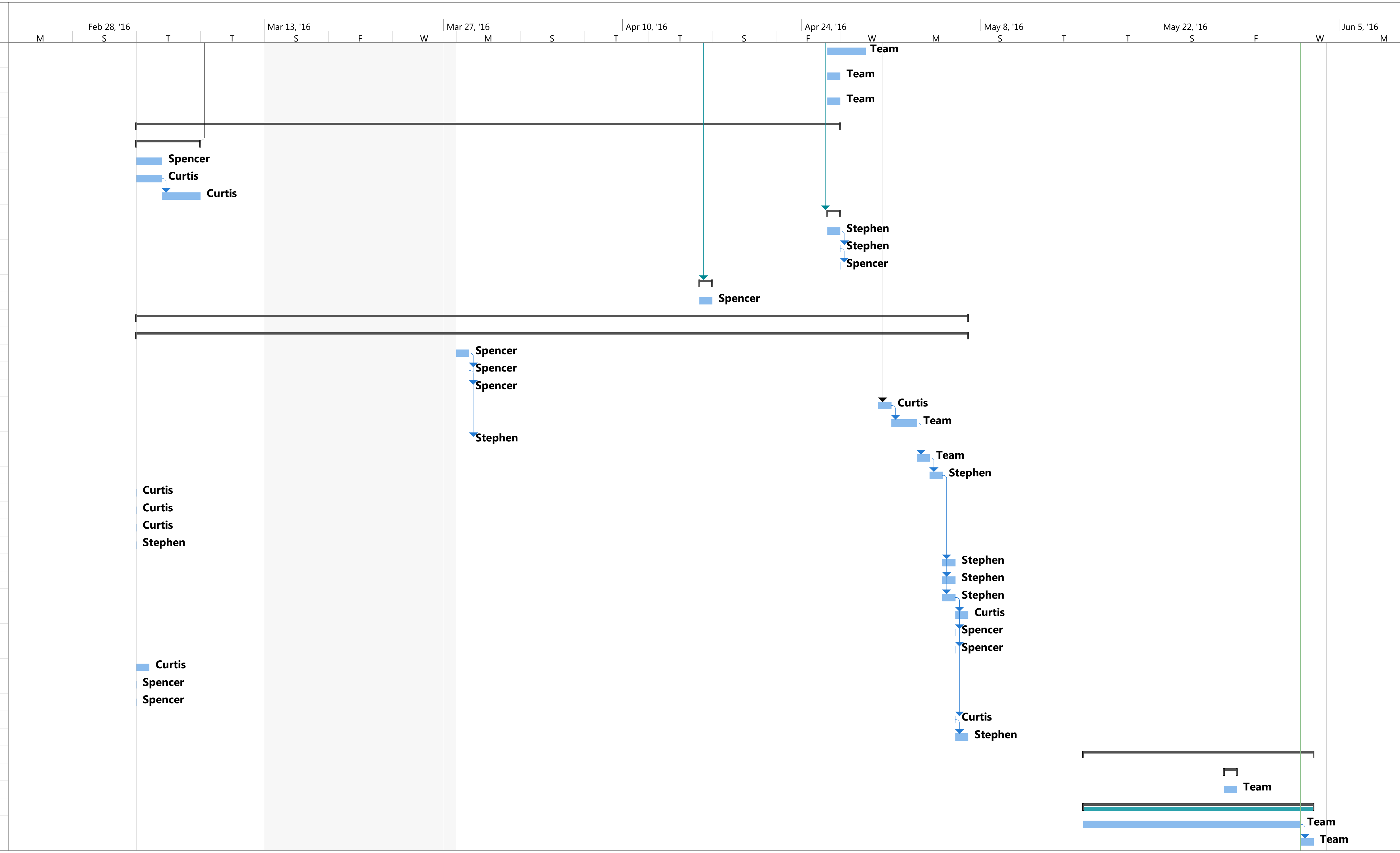
83	6.2	0.1 days	Thu 5/5/16
84	7.1	1 day	Thu 3/3/16
85	8.1	0.1 days	Thu 3/3/16
86	9.1	0.1 days	Thu 3/3/16
87	9.2	0.5 days	Thu 5/5/16
88	9.3	1 day	Fri 5/6/16
89	**Expo and Report**	**15.75 days**	**Mon 5/16/16**
90	**Senior Expo**	**0.5 days**	**Fri 5/27/16**
91	Senior Expo	0.5 days	Fri 5/27/16
92	**Final Report**	**16.5 days**	**Mon 5/16/16**
93	Final Report Work	15 days	Mon 5/16/16
94	Final Report Due	0.5 days	Thu 6/2/16



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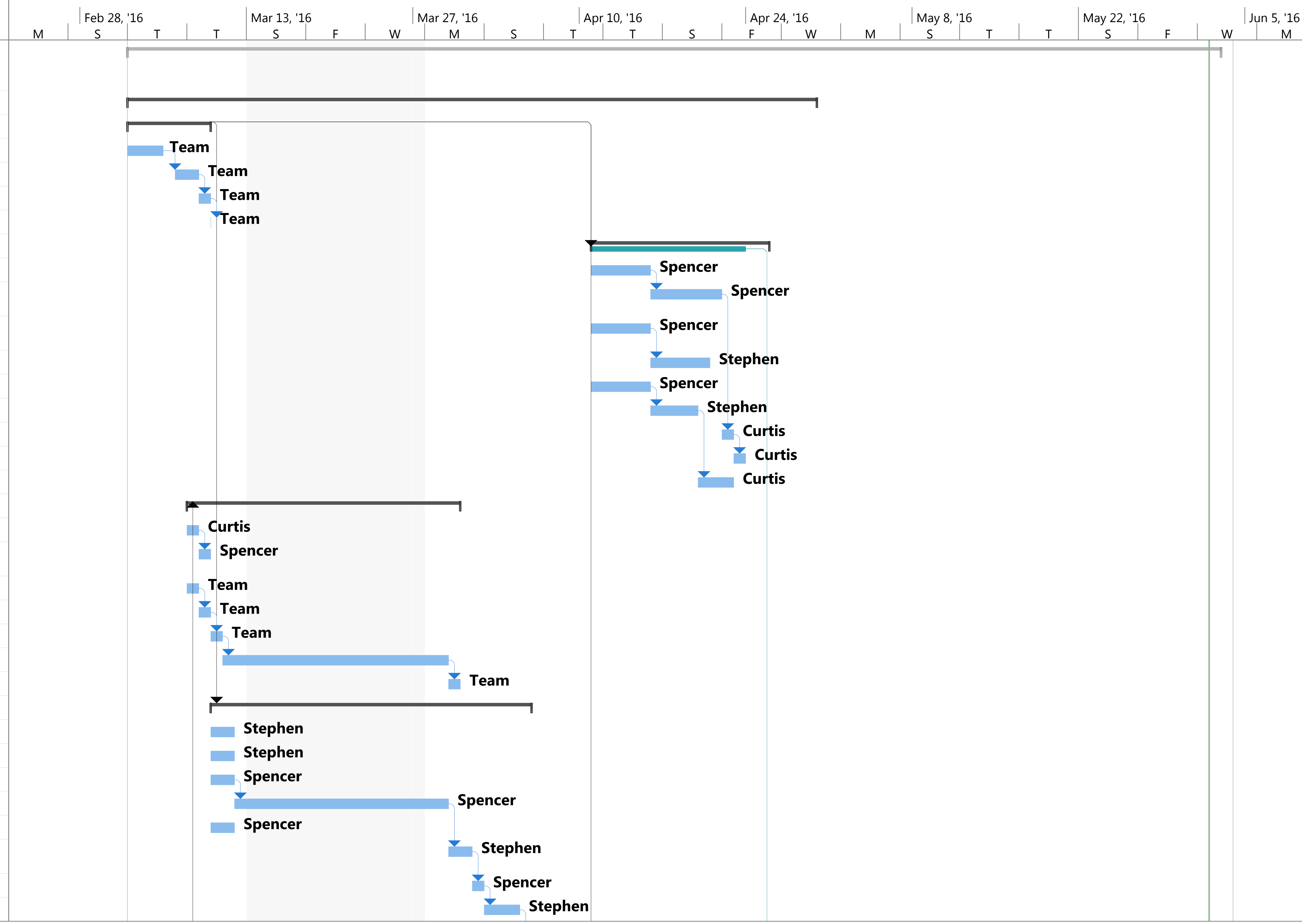

Project: Manufacturing Project
Date: Thu 6/2/16

Legend				
Task	Inactive Task	Manual Summary Rollup	External Milestone	Manual Progress
Split	Inactive Milestone	Manual Summary	Deadline	
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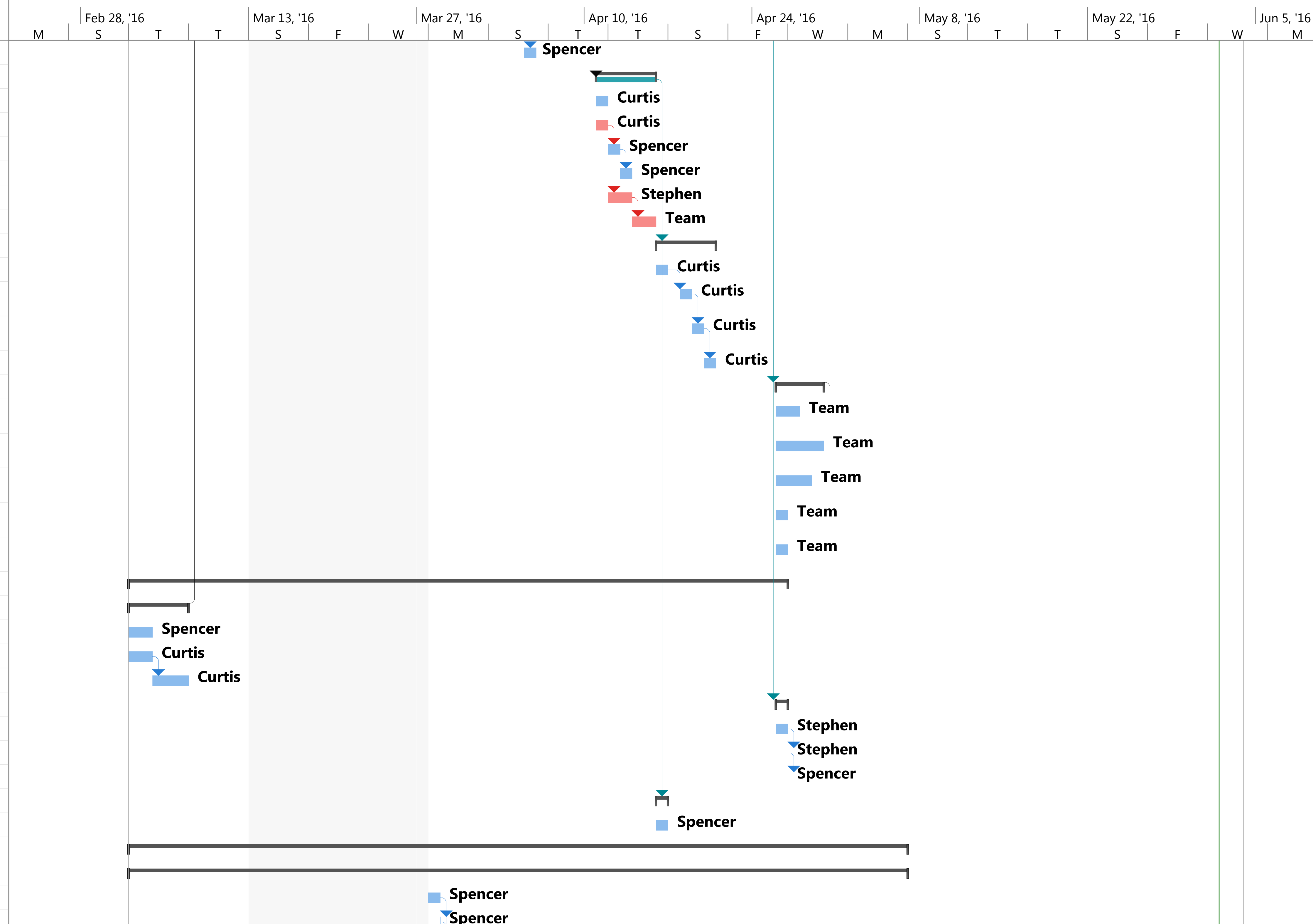

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Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline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

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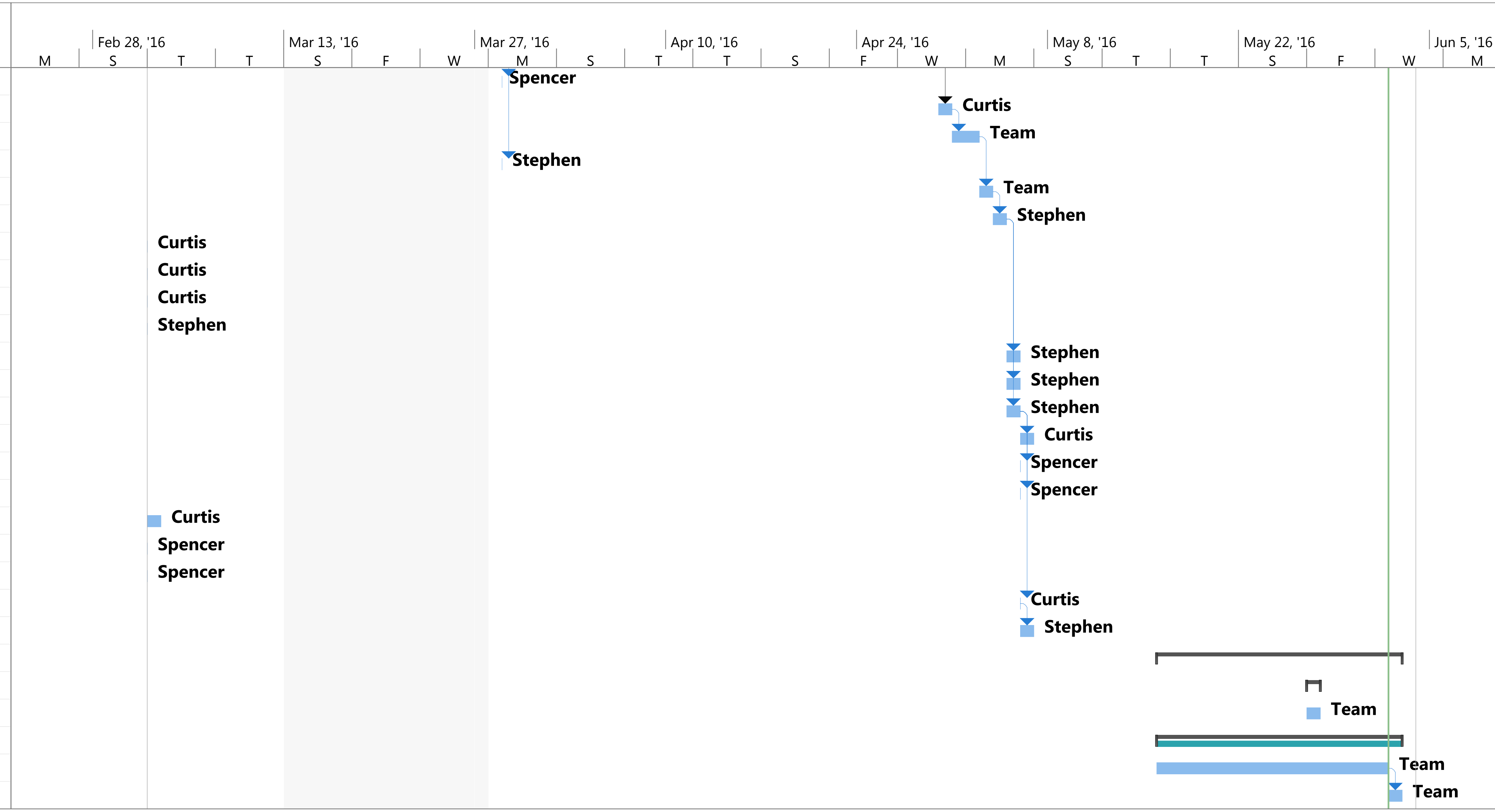

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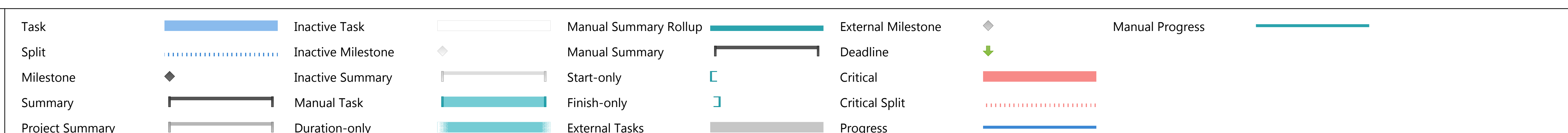


Adapted Stand Up Paddle Board Safety Manual

Claire Francis
and
Haley Rentfro

Table of Contents

Summary

Damien is a fireman in the San Luis Obispo area. He was injured in July of 2015 after a tree fell on him while he was on duty. The incident left Damien with an incomplete spinal cord injury at level T12 and L1. Damien is currently working on strengthening his legs and reestablishing patterned neural activity in the Central Nervous System (CNS) through therapy at Project Walk, an intensive physical therapy regime; his goal is to be able to walk by the time his therapy is completed. As of December 2015, Damien can perform flexion and extension in his right leg and plantar/dorsiflexion in his right foot. Damien's left leg is weaker, but he is still able to perform slight knee flexion and extension. He currently has no movement in his left foot. Damien is able to stand with assistance, but not for extended periods of time, due to challenges with balance and muscular strength. Before his injury, Damien loved to participate in water activities and he hopes to keep fulfilling his aquatic passions in an adapted way with his current abilities. His goal with the stand up paddleboard is to be as independent as possible, to make for an authentic paddleboard experience.

Protective Gear

Personal Flotation Device

First and foremost, Damien should always be wearing a personal flotation device (PFD) when using the stand up paddleboard (SUP). A personal flotation device will aide the participant if he falls into the water by inflating and keeping him above the surface and safe from the dangers of drowning until further aide can be provided. It is important that the PFD is the proper size, fit and condition for the participant. In addition, the PFD must also be appropriate for the activity for which it is worn.

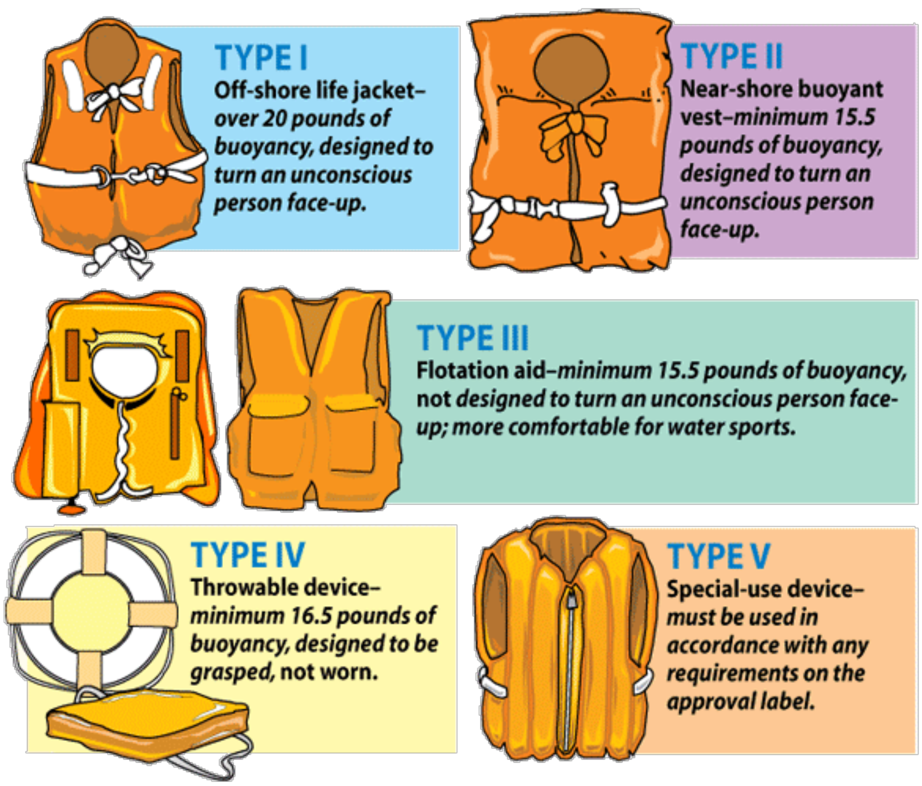


Figure 1

Whistle

If the personal flotation device is not equipped with a whistle, the participant should have one at all times while out on the water. A whistle will allow Damien to signal for assistance if he becomes separated from other paddlers. The whistle should be able to be heard for a least one-half nautical mile. "Referee-type" whistles or other similar devices that can be attached to your life jacket or wrist should work well.

Figure 2

Helmet

The other component for ultimate safety is a helmet. This is of great importance because Damien does not have complete sensation or mobility in his legs, so in case he falls, he may be unable to transfer his weight to land in the water. Damien's injury along with the unpredictable nature of water could lead to a fall directly backward or forward onto the board. This could be very dangerous due to the aluminum frame supporting him and the potential to hit his head. Therefore, wearing a safety helmet is vital.

Figure 3

Leash

Another important aspect for maximal safety is to wear a leash while stand up paddleboarding. Since the board is the best flotation device there is, remaining attached to the board and not being in danger of losing the board is vitally important. It is recommended that the leash be at least a foot longer than the board and it is up to user preference whether the leash be attached to the user at the ankle or at the knee. In Damien's case, it may be better for him to attach the leash at his knee for easier access and quicker adjustments if necessary.

Figure 4

Useful Items

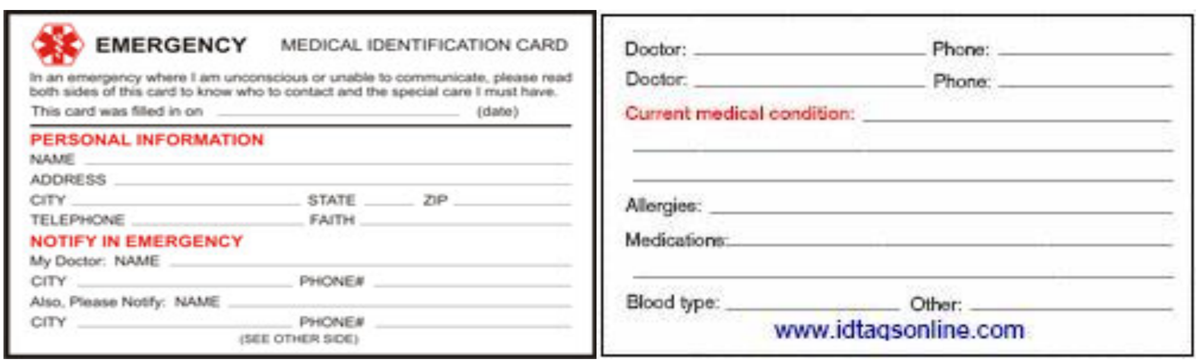
Wetsuit

A wetsuit should be worn to increase buoyancy and maintain warmth while paddling in cold temperatures. People with spinal cord injuries have a difficult time thermoregulating, so in cold temperature water the body may not be able to receive the signals that it's temperature is lowering and thus the risk for hypothermia is greater. Since wetsuits can be an arduous task to put on, a helpful tip is to find a wetsuit that has zippers down legs to allow for easability of getting in and out.

Figure 5

Information card

In a pocket of the personal flotation device should be a ziploc bag that contains the user's personal identification information, emergency contact information, allergies and any other pertinent medical information. This is an important backup in case the user is paddling alone; in case of a serious emergency, important information such as what is listed above should be readily usable for others to find.



EMERGENCY MEDICAL IDENTIFICATION CARD

In an emergency where I am unconscious or unable to communicate, please read both sides of this card to know who to contact and the special care I must have.

This card was filled in on ____ (date)

PERSONAL INFORMATION

NAME ____

ADDRESS ____

CITY ____ STATE ____ ZIP ____

TELEPHONE ____ FAITH ____

NOTIFY IN EMERGENCY

My Doctor: NAME ____

CITY ____ PHONE# ____

Also, Please Notify: NAME ____

CITY ____ PHONE# ____

(SEE OTHER SIDE)

Doctor: ____ Phone: ____

Doctor: ____ Phone: ____

Current medical condition: ____

Allergies: ____

Medications: ____

Blood type: ____ Other: ____

www.idtagsonline.com

Figure 6

Helpful Tips

Paddle partner(s)

Damien should always be paddling with at least two other paddle boarders so in case of an emergency situation, adequate assistance can be provided. This ensures that paddler A can assist paddler B and paddler A and B can assist paddler C or vice versa. Universal safety behaviors include holding the paddle still and upright to signal to others the location for help to be sent, depicted in Figure 7. Moving the paddle from side to side is indicative of urgent need for help, as seen in Figure 8. To aid in the rescue of a conscious person, the rescuer paddles next to the person in need and points their board towards the shore, the victim is then pulled from the water and is laid down on the tail of the board. The rescuer then moves to the front of the board for stabilization and, once stabilized, the rescuer kneels behind the victim with legs between the victim, holding them onto the board. This rescue process is depicted in Figure 9.

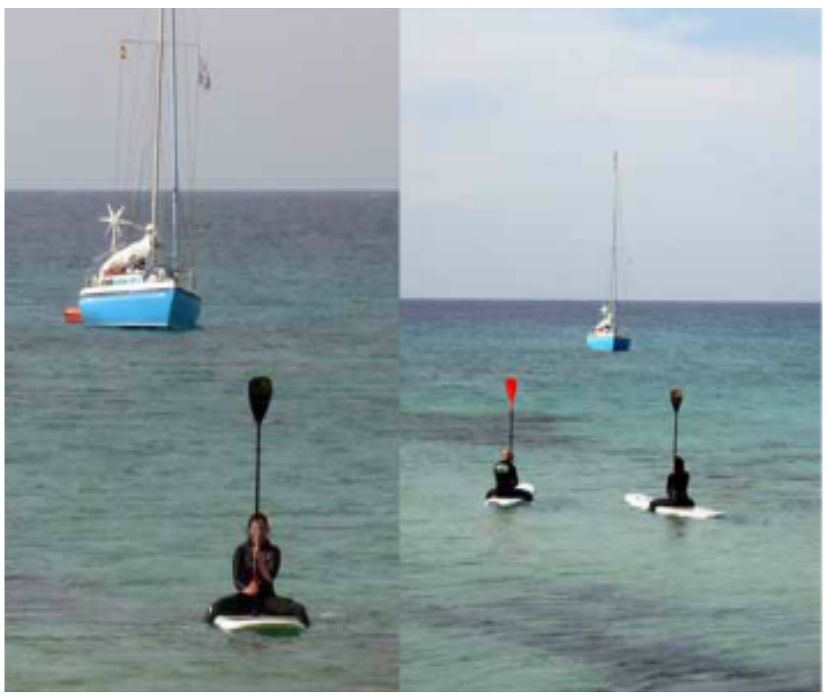


Figure 7 - Holding Paddle Still

Figure 8 - Paddle in Motion

Figure 9 - Rescue Process

Reference List

Figure 1: http://fishandboat.com/boatcrs/03boathandbook/chap2_06_pfd.htm

http://myfwc.com/boating/regulations/paddleboard/

Figure 2: http://www.dickssportinggoods.com/graphics/product_images/pDSP1-966934 2p275w.jpg

Figure 3: http://www.northshoreinc.com/store/pc/catalog/pthdrwbkgrd_748_large.jpg

Figure 4 http://ecx.images-amazon.com/images/I/81Qh2Ds0QpL._SL1500_.jpg

Figure 5: http://university.tri-sports.com/wp-content/uploads/2012/05/Orcashoot210.jpg

Figure 6: http://www.idtagsonline.com/images/free_medical_ID_card_back.jpg

Figures 7, 8, 9: http://issuu.com/iosup/docs/safety_rescue__webiosup