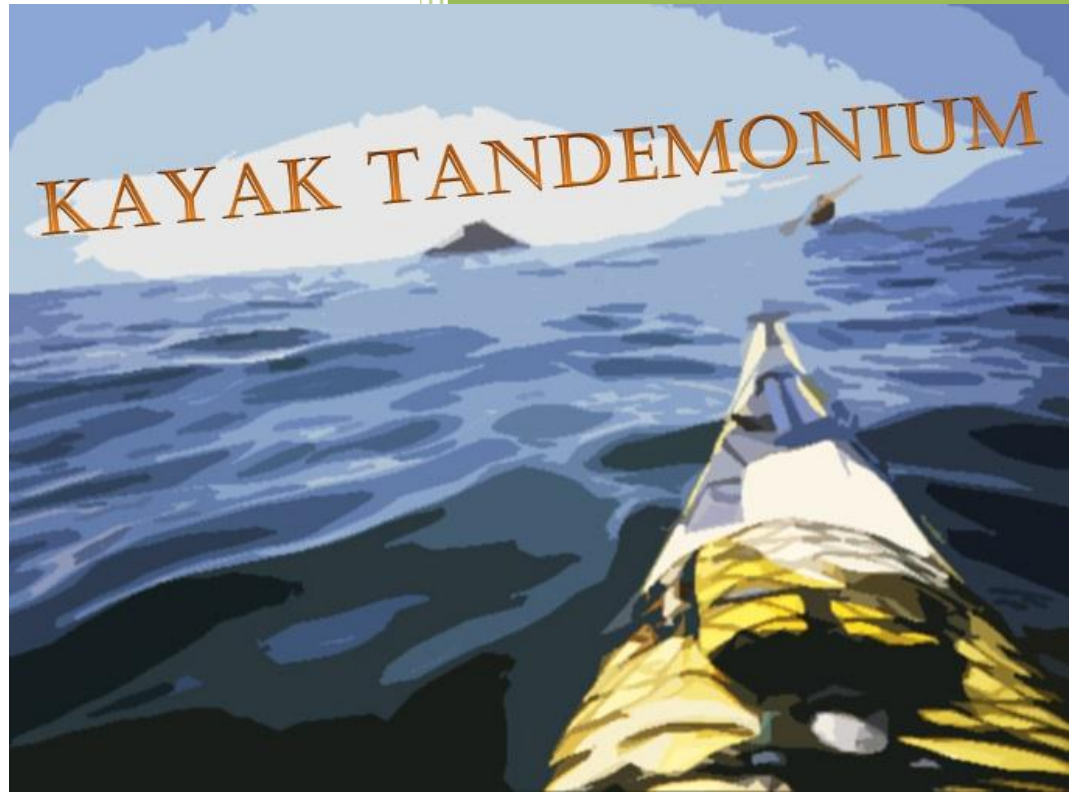


Unilateral Paddling Device for Kayaking



FINAL PROJECT REPORT

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Executive Summary

Disabled Sports Eastern Sierra (DSES), a nonprofit organization in Mammoth, California has a need for a device for someone with a unilateral disability to be able to paddle in a tandem kayak. Courtney Sheffield, Derek Brangham, and Geoff Ledbetter worked with Kinesiology students Kevin Bezerra and Jaime Santana, sponsor contact Maggie Palchak, and lab advisor Dr. Mello to design, build and test such a device. The following report describes the detailed final design along with background information and project requirements.

Chapter 1: Introduction

Disabled Sports Eastern Sierra is a non-profit organization that offers outdoor activities for people with various disabilities. Located in Mammoth Lakes, California, and their activities include both summer and winter sports. One of the many challenges inherent to their organization is adapting sporting to the participants.

Kayaking requires some unique adaptation issues. It is usually an ideal outdoor sport for people that are wheelchair bound – it is an equalizer. However, for participants with unilateral strength issues, paddling can be a challenge. Disabilities such as cerebral palsy can cause hemiparesis, or weakness on one side of the body. Accompanying this is usually a lack of trunk and grip strength, and low endurance. Cerebral palsy has a broad spectrum of ability, so participants in need of adaptation vary greatly in their range of motion and strength.

Disabled Sports Eastern Sierra pairs each participant with an able-bodied volunteer in a Malibu Two tandem kayak. The participant is seated in the bow of the kayak with the better view, and the volunteer is controls from the stern, where most of the power is generated. This way, no one kayaks alone, reducing the risk of injury. However, if a participant struggles with holding the paddle, the activity is not as pure and therapeutic as it can be.

An important part of any disability adaptation is to preserve the original activity as much as possible. For the project, the device should not be too bulky, motorized, or change the fundamental act of paddling. Safety is also of utmost importance, and capsizing is a real possibility. Therefore, the adaptation should not endanger the participant by entangling them or restricting their movement.

The team, Kayak Tandemonium, consisted of Geoffrey Ledbetter, Derek Brangham, and Courtney Sheffield. The project involved the designing, building, and testing of a unilateral paddling device for kayaking. Dr. Joseph Mello of the mechanical engineering department provided advising throughout the project term. Kevin Bezerra and Jaime Santana, both kinesiology students, were partners who helped the team with their unique perspective.

The goal was to manufacture a quality product for Disabled Sports Eastern Sierra that will allow participants to paddle in a tandem kayak. The National Science Foundation provided funding for the project through a grant.

Design Requirements

The overall project goal was to design, build, and test a kayak paddling device for the benefit of people with hemiparesis, or weakness on one side of the body.

After initial conversations with Maggie Palchak, Kevin Bezerra, and Jaime Santana, a list of requirements was developed:

- The device must be compatible with the Malibu Two tandem kayak.
- It must be removable from the kayak and cause no damage from its fixture method.
- It must be lightweight, durable, corrosion resistant, and able to withstand a variety of temperatures.
- The paddle itself cannot blister or chafe the user and it must provide grip assistance.
- The device must be adaptable to people with hemiparesis in either the left or the right side, require a low force of operation, and usable by people of different sizes (children to adults).
- Any strapping must have a quick-release mechanism.

- It must be inexpensive to repair by a non-profit organization.
- The device must not utilize a motor for power assistance.

To achieve these requirements, each component was analyzed to verify efficient use of resources. This analysis indicated whether a design will meet the specifications prior to the building phase. Table 1 below shows a list of the technical requirements for the project.

Table 1. Technical Specifications for the Paddling Device.

Spec	Description	Target/Limit Value	Tolerance	Risk	Compliance
1	Weight	10 pounds	MAX	M	A, I
2	Quick-release time	1 second	MAX	H	T, S
3	Force of operation	30 pounds	±5 pounds	L	A, T
4	User height range	56-77 inches	±1 inch	L	A, I
5	Cycles to failure	1.0E6 cycles	MIN	M	A
6	Cost	\$1000	MAX	L	A, S
7	Storage area	8.0 ft ²	±2 ft ²	L	A, I
8	Force applied by user on paddle (at paddle handle)	40	MAX	H	A, T

There are three levels of risk, (H)igh, (M)edium, and (L)ow for reaching these goals. For compliance, A represents Analysis, T represents testing, I represents Inspection, and S represents similar designs. The quick-release time is the highest risk specification to accomplish.

Chapter 2: Background

The primary disabilities addressed are those involving hemiparesis, which is weakness on one side of the body. It can be caused by cerebral palsy, a traumatic brain injury, or a stroke. In addition to having weakness on one side of the body, grip issues may also be present. Participants with an amputated arm will also be able to use this device.

Kinesiology student Jaime Santana showed a presentation detailing disability etiquette that also involved using a wheelchair. The team took turns riding the wheelchair around campus to understand how truly inaccessible certain areas are. The reactions of passersby were observed, including how some people went out of their way to assist the person in the wheelchair. This activity provided some insight to the daily challenges that people with disabilities face.

According to sponsor Maggie Palchak, active participation in sporting activities with minimal limitations is very therapeutic for disabled persons. Thus, the authenticity of the paddling motion must be preserved to achieve this result. This mindset was also very evident with the Adaptive Paddling Program at Cal Poly.

The kinesiology department at Cal Poly runs the Adaptive Paddling Program as part of a required class. Two students are paired with one disabled member of the community with a desire to kayak. The program is very similar to the one at Disabled Sports Eastern Sierra, in that the goal is provide disabled outdoor enthusiasts with the opportunity to kayak with a trained paddler. In the two days spent with the program, the team learned more about disability etiquette, and about the adaptations that the program makes for the participants. They make custom adaptations using foam, duct tape and bicycle inner tubes. This type of adaptation can

be advantageous because the participant can give instant feedback as to its effectiveness. The project was designed with this in mind, and provides the user with adjustability options.

The team also learned how to properly reenter a capsized kayak, and how to help participants as well. This experience allowed for understanding of how the device must perform in an emergency situation. Learning more about the kinematics of proper paddling made two things very evident: paddling a kayak requires the entire upper-body, and that paddling with unilateral strength adds an extra degree of difficulty.

Mark Theobald, founder of Disabled Adventurers, has developed various devices which accomplish a similar objective to this project. One of his solutions is a boom-type paddling fixture, shown below in Figure 1. This design supports the paddle, allowing the user to have more control and focus on paddling. This solution was designed for the Ocean Kayak Scrambler XT, which differs from the Malibu Two tandem kayak.



Figure 1. Boom-type paddling fixture from Disabled Adventurers (Theobald).

Another of Mr. Theobald's design is called the leg-type paddling fixture (Figure 2). This design is more compact and facilitates easy entry and exit from the kayak. The plywood base is held in place by the paddler's legs and requires no physical attachment to the kayak. The paddle pivot point can be adjusted, allowing for a wider range of users.



Figure 2. Leg-type paddling fixture from Disabled Adventurers (Theobald).

Similar to the leg-type fixture, Mr. Theobald designed a device using polyvinyl chloride (PVC) tubing (Figure 3). This design is held in place by the user's legs and allows for the same range of motion as the previous two devices. Although the tubing is not physically attached to the kayak, the design poses a possible entanglement risk.



Figure 3. PVC sit-on-top paddle fixture design from Disabled Adventurers (Theobald).

Creating Ability is another organization that makes adaptations for paddlers. Their primary products are grip assist devices. The back-of-the-hand adaptation shown below in Figure 4 sells for \$65 per pair. It has a quick-release button and is intended for users who can grip a paddle, but have difficulty pulling it through the water.

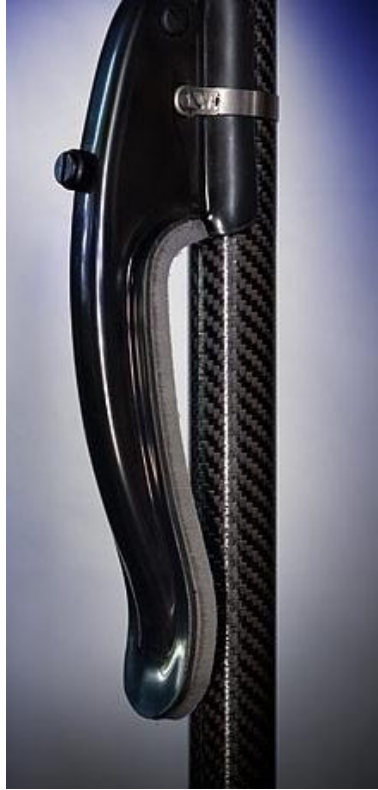


Figure 4. Back-of-the-hand grip (Creating Ability).

They also produce a model that attaches to a person's wrist. The quick-release aspect on this model, depicted below in Figure 5, allows the user to easily slide his or her wrist out of the mechanism. People with lack of grip strength benefit most from this design.



Figure 5. Wrist model (Creating Ability).

Another grip adaptation from Creating Ability works best for an amputee with full trunk strength. The user straps his or her forearm parallel to the paddle, and then holds the bar (Figure 6). The paddle effectively becomes an extension of the user's arm.



Figure 6. ProPel grip model (Creating Ability).

During the research stage, no applicable patents or previous senior projects specific to unilateral paddling were found.

Chapter 3: Design Development

Conceptual Designs

Method of Attachment

After analyzing the shape and features of the Malibu Two kayak, four main methods to attach were determined: clamping to the storage hatch, sliding a “sock” on the nose of the kayak, utilizing the kayak equipment straps, and taking advantage of the user's weight. These options were chosen because they do not damage the kayak and can easily be installed or removed. Most importantly, none of these options entrap the user should the kayak capsize.

Hatch

The Malibu Two has two eight inch diameter cylinders which can be converted into storage hatches. They are one inch in height and are located directly in front of user's seat. Clamping to this hatch provides a sturdy fixture which does not damage the kayak. The fixture would have a circular bottom made of carbon fiber with slits every few inches to allow flexing of the material. Figure 7 shows how the slits would be arranged at the bottom of the fixture. This would fit over the hatch and be tightened with an over-center latch, which is easy to install and remove. An example of this type of latch is shown in Figure 8.

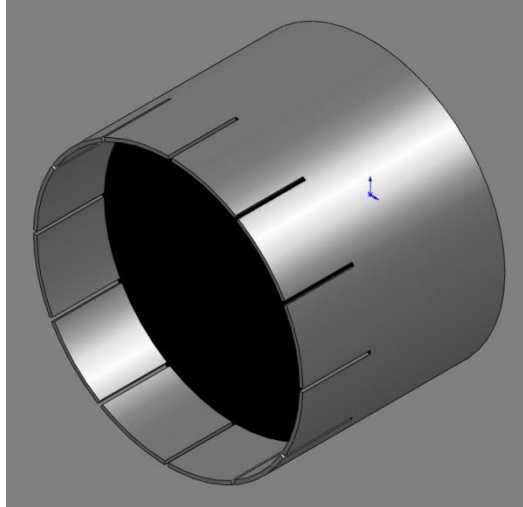


Figure 7. Example of storage hatch attachment end.



Figure 8. Over-center latch.

Sock on Nose

Another attachment method is similar to a sock. The device would slide over the nose of the kayak and attach to certain points at the bow. The material of the sock would be mesh, neoprene, or spandex. A solution involving mesh would be beneficial because it would not be able to fill with water. Mesh is advantageous because it would allow for water drainage. This attachment method would be coupled with a boom fixture to support the paddle weight for the user. The sock would be secured with a strap to prevent it from slipping forward and off the kayak, but its location is unknown.

Boom with Base

A variation of the sock idea would be to utilize the concave space in the bow of the kayak, shown below in Figure 9, by creating a mold which would mate to this space. This design would also utilize a boom fixture similar to the one required for the sock attachment method. This mold would be held in place by a non-slip surface on the mating side and the black equipment strap,

visible in Figure 9. Similar to Mark Theobald's boom-type fixture, the device would be held in place with this strap, as well as the standard eyelets.



Figure 9. Bow of kayak.

User Weight

Another idea is to make use of the user's weight to hold the device in place, similar to Mark Theobald's leg-type paddling fixture. This is a simple solution because we would not have to modify the kayak or create something to hold it in place. However, the fixture could slip if the user were to shift his or her weight while paddling. Again, this severity of this problem could be reduced by using a non-slip surface on bottom.

Method of Movement

This function deals primarily with how the paddle will move when being used. It also defines how the paddle will be connected to the kayak attachment. The primary options for the method of paddle movement include: a boom, a flexible pillar, a universal joint, a track, or a handle and strap for one arm.

Boom

The boom, shown below in Figure 10, holds the paddle in place and extends in front of the user, where it attaches to the kayak bow. The boom material dictates the overall rigidity and the user's freedom of movement. Using a stiff material like carbon fiber limits the paddle to rotation about its central pivot point and requires the paddle itself to be connected to the boom using a universal or ball-and-socket joint to allow for rotational motion. A good compromise involves using a material that provides support when necessary while also allowing for a full range of paddle motion, which also allows for the paddle to be rigidly attached to the boom using a bracket.

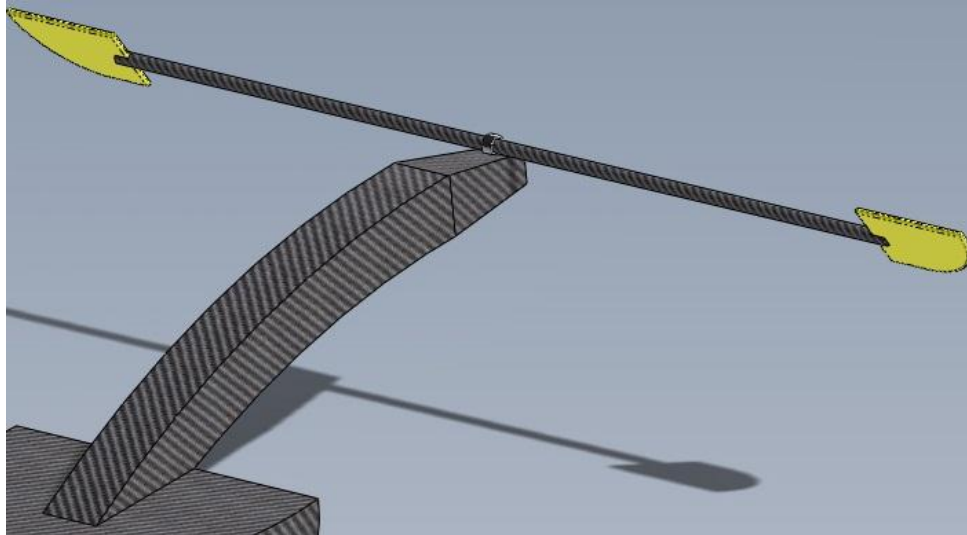


Figure 10. SolidWorks screenshot showing a rough model of the boom design.

Flexible Pillar

The flexible pillar design requires using the hatch clamp as the method of attachment to the kayak. As shown below in Figure 11, the pillar would be located between the user's legs with a contour for comfort. Similar to the boom design, the material choice for the pillar is between a rigid material and some sort of flexible material, or a combination of the two. Using a rigid material requires a universal joint or something similar to allow for paddle movement. A flexible material would most likely be paired with a rigid material at the base to ensure sturdy attachment to the kayak. The flexible upper part of the pillar would then permit the user to move the paddle around.

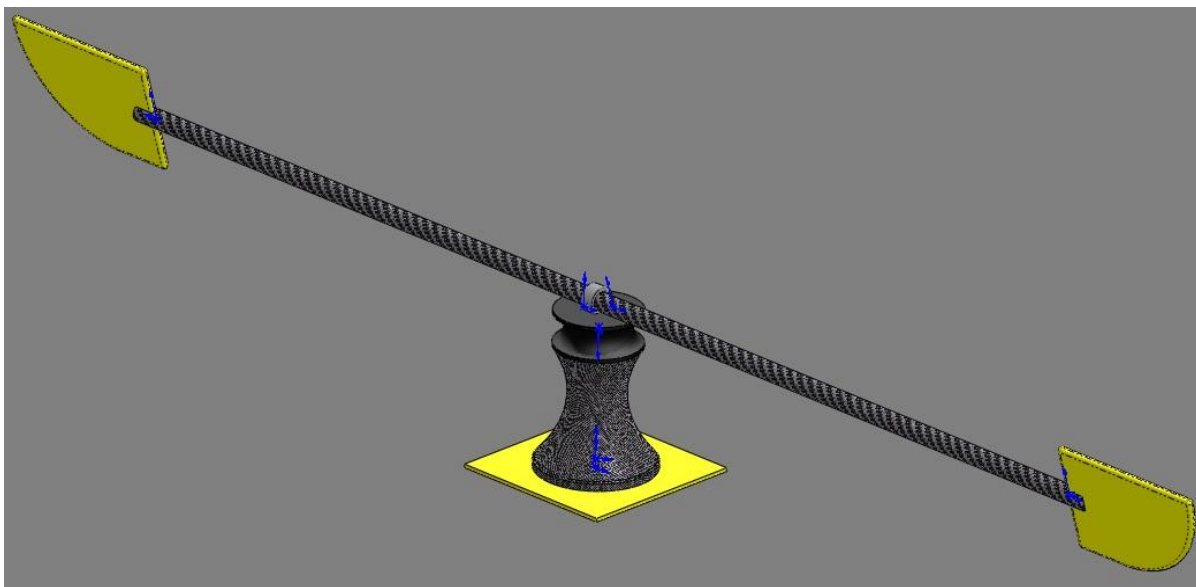


Figure 11. The flexible pillar design, shown with a universal joint connected to the paddle.

Track

Utilizing a track locks the center of the paddle and allows for more freedom of movement by the user. The paddle attaches to a bearing constrained within the track. The shape of the track, which was determined using video motion capture analysis, resembles half of an ellipse, as shown in Figure 12. Ideally, the paddle could be locked into place at the center of the track if the paddler is not able to complete the full paddling motion and/or does not have good trunk support. If the user does have full-body motion, then the paddle can move freely within the track, mimicking proper paddling technique. In order to meet the requirements, a quick-release mechanism is a necessary feature of the track system to guarantee that the user does not become trapped should capsizing occur.

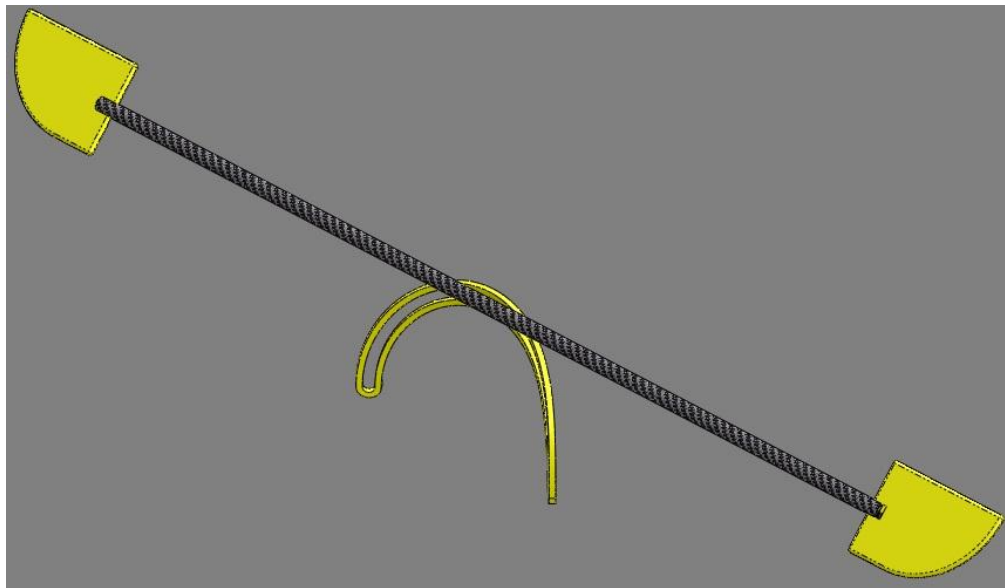


Figure 12. SolidWorks model showing the approximate shape of the track system.

Strap and Handle

The strap and handle attachment shown above in Figure 6 allows the user to control a standard kayak paddle using only one arm. The arm is strapped in using Velcro and the hand grips the handle. Both attachments are adjustable to allow for varied arm lengths and sizes. Once strapped in to the device, the user's upper body must be able to move in order to achieve both left and right paddle strokes. This could be problematic for some paddlers who require a lot of assistance or adaptation to kayak successfully. However, imitating proper paddling technique is beneficial to able-bodied users. Quickly releasing the paddle in case of an emergency is a necessity.

Material selection plays a direct role in the overall weight of the device as well as the corrosion resistance, so using carbon fiber or a similar material should keep the weight under ten pounds. Each of the methods of attachment will also include the ability for height adjustment for a wide range of users.

Grip Assist

Grip assist is a requirement that can be used with any design choice. Four options have been considered, all based on existing methods that work well, but a more permanent solution is necessary.

Strap

One idea is to create an adjustable strap that would hold the palm of the hand to the paddle. This design is based on the existing method that both Disabled Sports Eastern Sierra and the Cal Poly Adaptive Paddling Program use – bicycle inner tubes tied to the paddle, and wrapped around the back of the participants' hands. This method is not a permanent solution, and the lack of quick-release capability also creates a safety hazard. Should capsizing occur, everything attached to the participant must safely release. Since some participants have very delicate skin, this adaptation has the possibility of chafing.

Durable adaptations can be reused multiple times, which is advantageous. Instead of inner tube, Neoprene, commonly used for wetsuits, would be used because it is more gentle on a participant's skin. The strap would be sewn into two clamps, which can be quickly released with the user's thumb. The clamps are moveable to allow for larger or smaller hands. A rough solid model of this concept is shown in Figure 13.

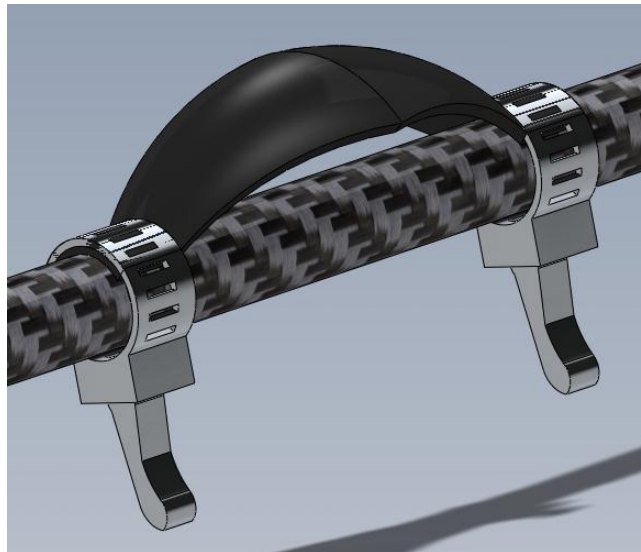


Figure 13. Solidworks Model of Neoprene strap grip assist.

Gloves

Another common solution is to use gloves lined with Velcro on the palm of the hand, which then mates to Velcro on the paddle. However, this presents two problems: the gloves must be able to fit a wide range of hand sizes, and the Velcro is not as easy to release if the participant must let go.

Existing Products

Other design options are similar to those made by Creating Ability, shown in Figure 4, Figure 5, and Figure 6. The team could construct devices at a lower cost than it would be to purchase them. Also, designs like the ProPel grip model in Figure 6 can only be used by people with trunk and upper body strength, so it will not be usable by a large amount of participants. The device is also difficult to quickly release in case of emergency.

Concept Selection

On January 3, 2012, the team created a decision matrix to determine the method of movement, which was closely related to kayak attachment. Shown below in Table 2, the design options were the flexible pillar, the boom with base, and the boom with the sock on the nose. The requirements included: movement allowed, adjustability for different heights and arm lengths, stability, secureness in attachment, difficulty to manufacture, and ease of installation and removal. Each team member individually graded the designs on a scale of 1-3 for each requirement, and the requirements were not weighted. The results were compared, and the same conclusion was reached: the boom with base and the flexible pillar on hatch designs were feasible, and the sock on nose design was not.

Table 2. Decision matrix for the final design choice, with 1 being the best choice, and 3 being the worst (i.e., the lowest score wins).

	Pillar	Boom with Base	Boom with Sock
Movement allowed	3	1	2
Adjustability for different heights	3	1	2
Adjustability for different arm lengths	1	2	3
Stability	2	1	3
Secureness in attachment	2	1	3
Manufacturability	1	2	3
Ease of installation/removal	1	3	2
TOTAL	13	11	18

Upon further review and consultation with Dr. Mello, the team decided to pursue the flexible pillar on hatch design. This design minimized the overall size, cutting down on weight. The moment arm would be decreased as well, reducing the necessary strength for device. The hatch is ideally located near the user, facilitating easy adjustment.

Supporting Preliminary Analysis

Attachment to Base

A proof-of-concept prototype was created to test the method of attachment to the hatch. A bulk-sized plastic pretzel container was obtained and one end was cut off at a diameter of eight inches. The team then cut slits in the end to guarantee a close fit to the hatch. A large worm-drive hose clamp (McMaster-Carr part number 5682K26) was purchased to secure the jar. The

clamp fit easily over the hatch with the container in between. As the clamp was tightened, the pressure kept the jar in place.

Four holes were drilled in the top of the makeshift pillar, and 30-lb-rated fishing line was threaded through the holes and tied together. After attaching the contraption to a kayak in Poly Escapes, vertical force measurement tests were completed. The fishing line broke at its rated load of 30 pounds, so the actual failure threshold of the clamp was uncertain. For the design requirement, 30 pounds is plenty.

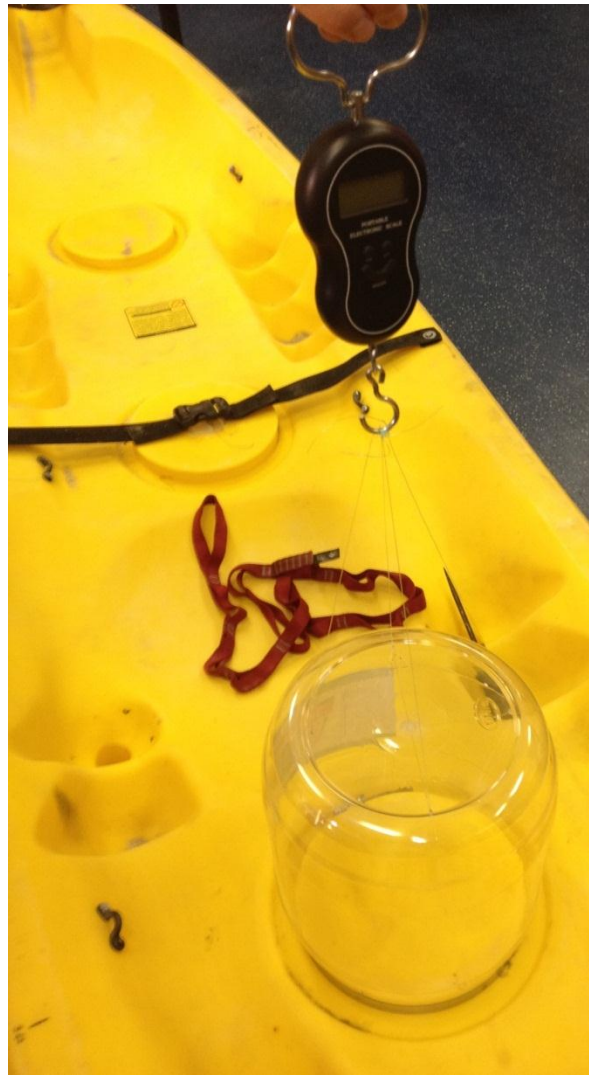


Figure 14. Proof-of-concept testing of hatch attachment. Taken by Courtney Sheffield on 1/12/2012.

The team then wrapped a daisy chain, a safety chain used for rock climbing, around the top of the jar, and pulled horizontally. The force gage reached 42 pounds before the far end of the jar started slipping out from under the clamp. The moment at the base corresponded to force of 28.5 pounds at the top of the device. A hand-pull force of 50 pounds, which corresponds to a top reaction force of 31.6 pounds, allows for a safety factor of 2. With this in mind, the team felt

confident that the hatch attachment would stay in place. Also, using a carbon fiber base molded to the kayak for maximum contact area, a factor of safety of 2 should be achievable.

Another aspect made clear by this proof-of concept testing was the difficulty of the worm-drive clamp to attach. Since it would be a good idea to avoid using tools near the water to install the device, this was problematic. A clamp with quick installation was important, but with the same strength as the worm-drive clamp. McMaster-Carr's quick-release zip-ties (part number 7134K81, Figure 15) were determined to be valid replacements for the clamp. However, once the team tested the zip-ties, it was found that their slippery material did not provide enough friction to hold the pretzel jar in place. In addition, the zip ties did not sit flush on the hatch and jar.



Figure 15. Closure of the zip ties. (www.cabletieszip.com)

After this testing, it was decided to purchase a quick-release worm drive hose clamp. This clamp is similar to the original testing clamp, but this version requires a screwdriver to adjust diameter and can then be quickly installed or removed. It is considerably more expensive than the first clamp, the higher strength rating and quick-release capability make this clamp the best choice.

Paddling Forces

The team took their proof-of-concept prototype onto the water, planning to attach it to a kayak and check performance during capsizing. Geoff and Courtney joined Kevin Bezerra at another Adaptive Paddling Program training weekend. Although the program does not have Malibu Two kayaks, it was assumed that the Malibu Two XL kayaks available would work fine, as the dimension differences do not affect hatch size or location.

However, it quickly became apparent that the dimensions of the kayak surrounding the hatch location were different for the Malibu Two XL than the Malibu Two. The gutter surrounding the edge of the hatch was narrower, so the worm drive section of the clamp would not fit around the hatch. Due to this, the team was unable to conduct a capsize performance test.

Instead, the team decided to take rough paddling force measurements. One team member sat in the kayak and the other stood at the edge of the pool holding a force gage attached to the paddle rod roughly near the spoon section. The person in the kayak moved the paddle as if they were paddling forward, pulling on the force gage. Using an average over several runs, this force was determined to be approximately 10 pounds. Therefore, the team felt confident that a design requirement of 50 pounds was more than enough to achieve a safety factor of 2.

Adjustability of Device

The team had access to an adjustable seat insert, which are commonly used to increase comfort in sit-on-top kayaks, and are also used by Disabled Sports Eastern Sierra. This seat allowed for the adjustment of the back angle, and provided some fore and aft adjustment as well. Using this seat, the only built-in adjustment required on the device would be vertical adjustment to allow for varied user height.

Geoff and Courtney, both on extremes of the anthropological spectrum in terms of height, each measured a comfortable paddling height using a daisy chain (Figure 16). Despite the height difference, the variation between paddle locations was minimal. This verified that although height adjustment is necessary, the required range would not be as extreme.

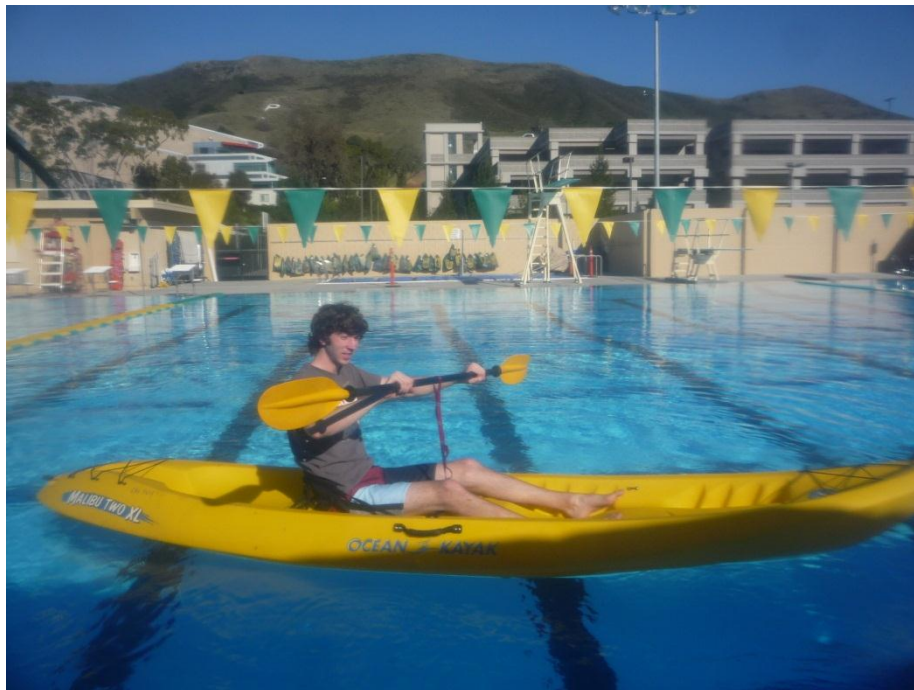


Figure 16. Measuring height of paddle for different heights. Taken by Courtney Sheffield on 1/28/2012.

Chapter 4: Description of the Final Design

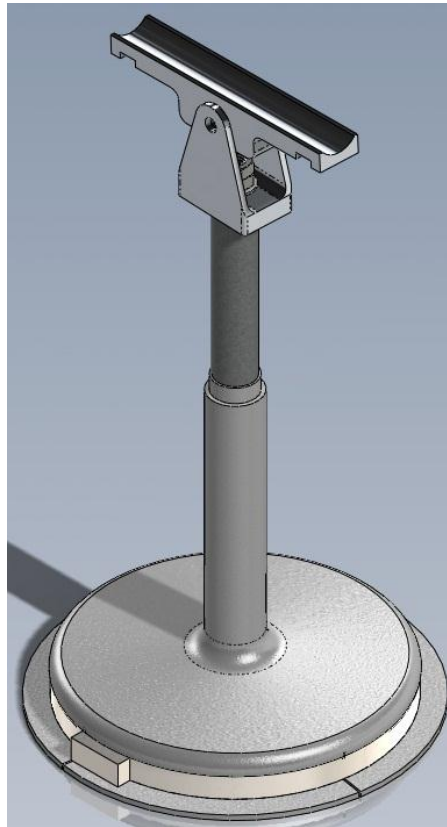


Figure 17. Assembly solid model of the final design.

Base

The unilateral paddling device was attached to the front storage hatch of the kayak using a composite fiberglass and carbon fiber in polyester resin base. The fiberglass and carbon cloths were placed in strategic locations to utilize their material properties. Using fiberglass was beneficial due to its low cost, usage in the marine and water sports arenas, and its high modulus of elasticity. The carbon fiber cloth was used for its high stiffness, high strength, and low weight.

The storage hatch is about 8 inches in diameter, with a height of 1 inch. It has a small lip around the edge to provide a gripping surface for a rubber lid. A mandrel was manufactured using medium-density fiberboard (MDF) to model the kayak hatch. This allowed for multiple composite layups to be done without damaging the kayak.

Opening this hatch to provide storage access inside the kayak is a custom modification. If made according to Malibu Kayak's specifications, a 6 inch diameter hole is cut on top of the protrusion. The lids made for storage are water resistant.

Disabled Sports Eastern Sierra uses kayaks with this custom modification. Although removing material weakens the strength of the hatch, the remaining area should still have enough structural stability to support the unilateral device. It was decided not to have the device extend inside the kayak opening due to the uncertainty in dimensions inherent to custom modification.

Because the hatch is proximal to the user, moment arms are minimized and the overall size of the device can be smaller and more lightweight. The attachment method also requires minimal force to install.

The team used hand layup techniques on the MDF mandrel, which mimicked the circular pattern of the hatch area. The mandrel has a centered hole for the bike seat tube. Fiberglass and carbon fiber cloth were laid over the entire part. During use, the bike seat tube can be adjusted vertically.

There are slits cut into the fiberglass to allow for expansion when placed on the kayak. A quick release, worm drive hose clamp is installed around the base of the protrusion. The clamp can be tightened with a screw driver one time. After that, it can be tightened with the quick-release clamp, allowing for speedy attachment to the kayak. This is a stainless steel clamp and has a very high allowable force. The pressure force it provides to the base, along with the high contact area provided by the direct molding process should be adequate in holding the device steady during use.

Due to the low anthropometric variation in forearm length, and the fore and aft adjustability of the fabric seat back, the base of the device does not need any horizontal adjustment.

A rubber gasket was placed between the device and the open hatch. For installation, the rubber lid for the hatch will have to be removed.

Pillar

The transition segment from the base to the joint and paddle, shown in Figure 18, is a modified bicycle seat tube, and allows for vertical height adjustment of the device. The range of adjustment covers from 50th percentile 4-year-old males to 95th percentile adult males.

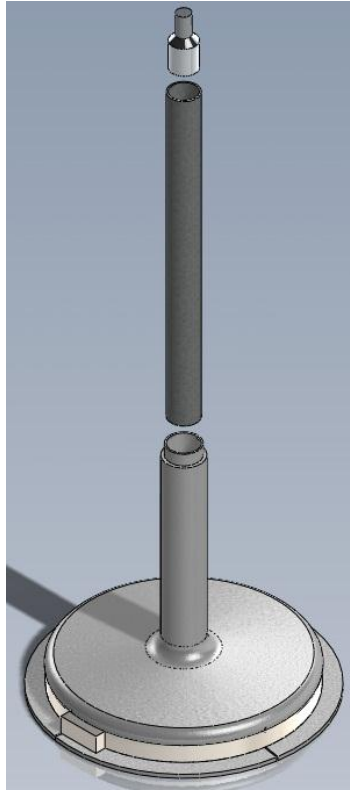


Figure 18. Exploded view of the transition segment.

The bicycle seat post allows for the use of a quick-release bicycle seat post clamp (Figure 19). This provides easy adjustability for a wide range of heights to accommodate many users.



Figure 19. Image of a quick-release bicycle seat clamp, which will provide easy vertical adjustability. (Pro Bike Shop)

Figure 20 below shows a detailed view of the base and transition interface. The piece extending out of the base contains dimensions equal to that of a typical carbon fiber bicycle. Since much engineering has already been completed to design and manufacture the bicycle, it can be assumed that the dimensions were chosen to withstand high loads. The device will be designed to similar load specifications, although it will primarily operate at lower values.

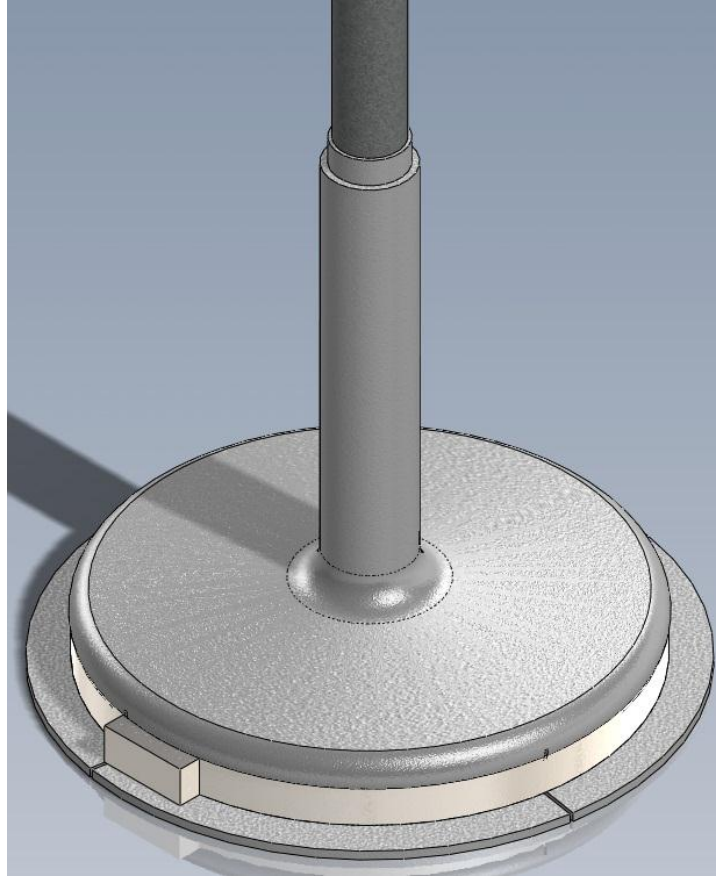


Figure 20. Detail view of the base and transition segment interface.

A previous design iteration utilized a fiberglass pultruded rod, which was thought to be ideal for this design because of their high strength-to-weight ratio, corrosion resistance, and dimensional stability. After deflection and force analysis, it was determined that practical strength in one direction with flexibility in another was impossible. The rods were too uniform in their stiffness. Detailed analysis is shown in Appendix F: Detailed Supporting Analysis.

At the top of the seat tube, an aluminum rod is press fit into the end. This piece is tapered and treaded to mate with two nuts. The top channel is tightened into place on this piece of hardware.

Pivot

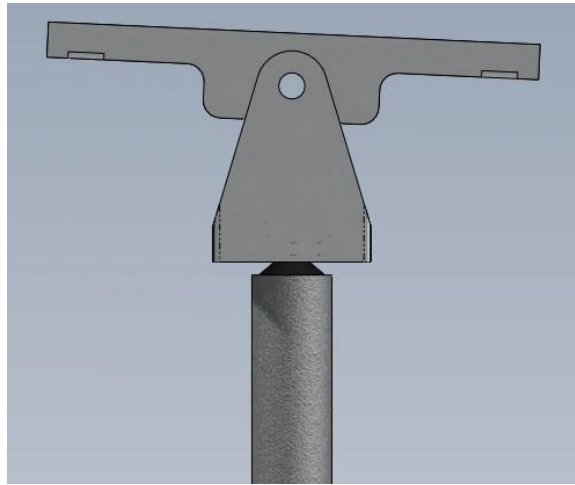


Figure 21. Final joint fixture design.

Above the connecting aluminum piece sits the joint which allows for paddle movement. This is connected by a 1/2-13 UNC thread machined into the aluminum press-fit piece.

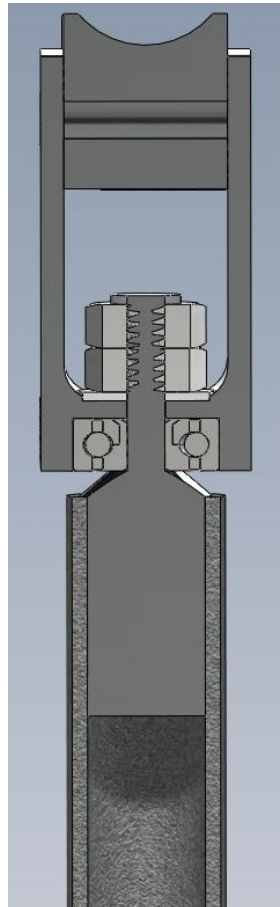


Figure 22. Section view of joint attachment.

Figure 22 shows a section view of how the joint will attach to the connecting aluminum piece. Between the two will be a plastic thrust bearing to facilitate sliding. The joint itself is separated into two pieces, a base and a top, and was made from 6061 aluminum. The base, shown in Figure 23, is rectangular, measuring 2.25 inches by 1.5 inches with rounded triangular pieces extending upwards on the sides. The height was compressed to 3 inches, which will still provide acceptable clearances.

The joint is allowed to spin due to a double shielded 316 stainless steel $\frac{1}{2}$ " ball bearing which was press fit into the base. The threaded shaft was affixed by two 316 stainless steel jam nuts to prevent loosening. A plastic thrust bearing was inserted between the bottom jam nut and the surface of the joint. The thrust bearings used are ultra-high molecular weight (UHMW) polyethylene and are made to withstand wet corrosive environments.

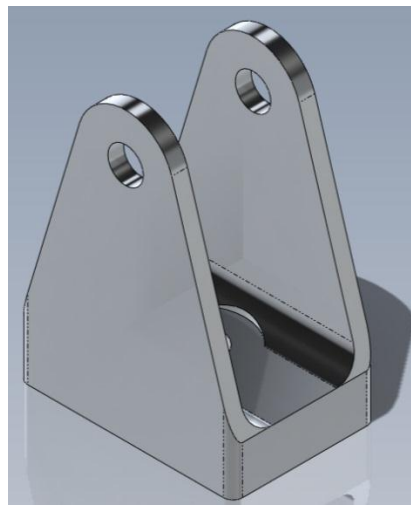


Figure 23. Base part of joint fixture.

The top joint section, shown below in Figure 24, is 6061 aluminum. It allows for teetering movement because of the use of an anodized aluminum shaft and a plastic UHMW sleeve bearing. The sleeve bearing was press fit into the hole of this piece. It has a $\frac{3}{8}$ inch inner diameter, $\frac{1}{2}$ inch outer diameter, and is $\frac{7}{8}$ inches long. The aluminum shaft has a clearance fit with the sleeve bearing to allow easy movement. Calculations have been performed assuming a 0.36 inch shaft to confirm that it will not yield with the desired safety factor. However, the shaft was press fit in the holes of the extending triangular sides from the joint base. UHMW thrust bearings were placed on the aluminum rod between the faces of the triangular piece and of the top joint section.

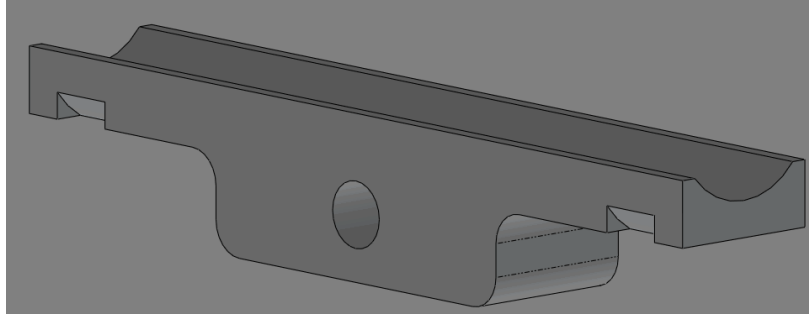


Figure 24. Top piece of joint fixture.

The top section of the joint has a cut out running along its length for the rod to be placed. The most common diameter of kayak paddle rods is 1 ¼“, but the other rod size of 1” will fit as well. On either end there are cutouts for the reusable zip ties to fit in. These zip ties will be tightened down before each use to hold the paddle to the fixture. The red tab shown in Figure 25 can easily be flipped by the user to allow the zip tie to be loosened and the paddle to be pulled free from the device.



Figure 25. Reusable zip ties which will hold down paddle

Grip Assist

The back-of-hand and wrist models were purchased from Creating Ability. Because the team was frugal with other areas of the budget, they were able to purchase these options already designed and built.

Chapter 5: Product Realization

Base

The base was manufactured using a hand lay-up technique. The team used a combination of E-glass (fiberglass) and carbon fiber cloth, taking advantage of the material properties of each.

Precise dimensions of a Malibu 2 kayak hatch were taken and recorded. Using those dimensions, a mandrel was manufactured out of medium-density fiberboard (MDF). The team then sealed the pores on with wood stain and finish, as well as caulk. The base of the mandrel was cut with a saw and then the diameter of the mandrel was turned on a lathe. A large O-ring was placed on the mandrel with the intention of mimicking the similar feature on the kayak hatch. The O-ring was beneficial because it provided the necessary feature, but was also easily removed from the final composite piece.

After creating the mandrel, the team prepped it for the layup by applying five coats of release wax and a coat of polyvinyl alcohol (PVA), shown below in Figure 26. The team tested if the method would work (i.e. if the part would release from the mandrel) on a small piece of MDF that had been prepared using the same method. When it worked, the first prototype was created.



Figure 26. Photo showing the application of PVA on the mandrel.

The team began by using 4 ounce E-glass (as it is commonly known in the surfboarding community) with surfboard sanding resin and chemical catalyst. The E-glass was chosen due to its reasonable price. The team aimed for a fiber-to-resin weight ratio of 0.5, which was not exact due to the manufacturing method. There was always some residual resin on the brushes and in the mixing cup.

In later iterations, the team used 6 ounce E-glass due to its higher strength. Several prototypes were made, with layup technique improving layup each time. It was also understood what kind of material properties were necessary in specific locations on the base.

It was determined that high strength at the tube-to-bottom interface was required to reduce the amount of deflection under normal use. However, thinness and flexibility were important in the area surrounding the lip and bottom diameter of the hatch. When the clamp is attached to the device, the base should deflect enough to provide a tight grip. Similarly to the top of the base, this section also needed to be strong enough to withstand normal use. Experimentally, it was determined that two plies of E-glass at this interface would be adequate.



Figure 27. Photo showing the application carbon fiber and fiberglass to the mandrel.

The tube-to-bottom interface was trickier to determine. Test coupons of the E-glass and carbon cloth and were made and tested for flexural modulus according the ASTM specification D 790-98: "Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials." Once the material properties were determined, the team was able to proceed with a final layup of the base, shown inside a vacuum bag in Figure 28.



Figure 28. Final base layup, inside a vacuum bag.

Tube

A standard bicycle seat tube was purchased and cut to length. A chamfered edge was machined to one side to facilitate the press fit.

A stock aluminum rod was turned down on the lathe to mate with the top hardware (Figure 29). A taper was added to reduce stress concentrations. A hand die was used to add 1/2-13 UNC threads.



Figure 29. The mating rod on the lathe.

To achieve the required press-fit tolerance, the seat tube was placed in an oven for two hours, and the mating aluminum piece was placed in the freezer overnight. Once it was determined that the proper temperature difference was achieved, the pieces were mated together, and as they came to thermal equilibrium, they created a very strong press fit.

Top Hardware

The team began machining the aluminum joint pieces by hand on a mill, but it was very time consuming (Figure 30). In order to finish the project in time and to achieve the required dimensions, a machinist was hired to make the parts using computer numerical control (CNC).



Figure 30. Using the mill to machine the joint top.

The final design differed slightly from the planned design. The dimensions of the joint base were decreased during the machining process to avoid excessive material removal and to minimize the weight of the entire device. The press-fit length of the mating rod was also decreased as a result of a failed mating attempt. A shorter press-fit length made it easier to mate the required pieces, while still providing structural rigidity.

For future manufacturing of the design, it is recommended to use CNC capabilities to make all machined parts. Unless performed by an experienced machinist, manufacturing the parts by hand was extremely time-consuming. It was also quite frustrating because of the difficulty in achieving tight tolerances.

Chapter 6: Design Verification (Testing)

Material Properties

Test Description

Composite material properties were attempted to be determined via the ASTM D790 test specification.

The team created test specimens of E-glass with hand lay-up and just vacuum bag, carbon cloth with hand lay-up and vacuum bag processes, and coupons with three layers of E-glass and one layer of carbon cloth. All coupons were made with polyester catalyst cured resin with a fiber-to-resin ratio of 0.5.

Detailed Results

The team created test coupons that were unfortunately too thin to get accurate results. The bend test was run in accordance with the specification. Knowing that the E-glass was purchased from Hexcel, team designed with the published values from Hexcel and ignored the experimentally determined values.

The tests determined that the vacuum bag samples were stiffer than the simple hand lay-up coupons. Therefore, the model was created using a vacuum bag.

Base Stability

Test Description

After the manufacturing of the base, the base was attached to the kayak. A 100 Newton force was applied to the device that induced a moment at the base that would be an equivalent paddling pulling arm force of 37.5 lb.

Still attached the kayak, a vertical pulling force was applied the top of the device.

Detailed Results

For the horizontal force, minimal deflection and no damage to the base were confirmed, showing that the base passed the test.

For the vertical force, the maximum force measured was 100 N, going to the maximum of the scale, and was deemed to be acceptable.

Specification Verification checklist

The base passed both of the force tests.

Chapter 7: Conclusions and Recommendations

In order to successfully design, build, and test the Unilateral Paddling Device for Kayaking, the team outlined the proposed specifications and produced a timeline showing the major project milestones. The importance of a sound method of approach at the early stages of the project was understood and many revisions were required throughout the course of the project.

Constant communication and feedback with Disabled Sports Eastern Sierra and the kinesiology team was vital to project success.

In hindsight, starting the build phase sooner would have greatly improved the end product as well as the mental well-being of the team members.

Works Cited

Theobald, Mark. *Disabled Adventurers*. Disabled Adventurers. Web. 18 October 2011.

Creating Ability. *Hand Adaptations*. Creating Ability. Web. 3 November 2011.

"TIOGA Quick Release Seat Clamp 31.8mm Black." *Pro Bike Shop*. N.p., n.d. Web. 5 February 2012.

Super Glue Corporation Interactive Glue Guide. Super Glue Corporation, 2009. Web. 2 March 2012.

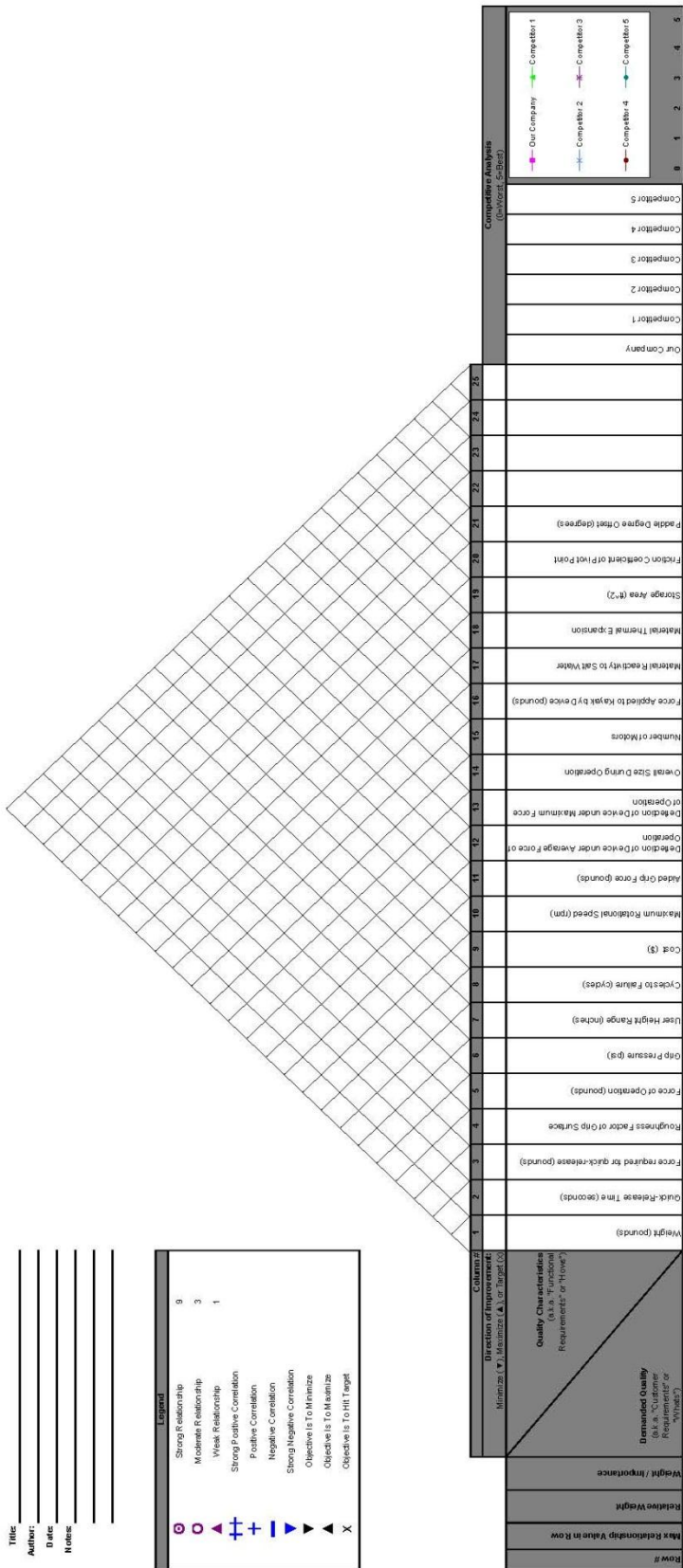
Appendix A: QFD, Decision Matrices

Table 3. Another copy of the decision matrix for the final design choice.

	Pillar	Boom with Base	Boom with Sock
Movement allowed	3	1	2
Adjustability for different heights	3	1	2
Adjustability for different arm lengths	1	2	3
Stability	2	1	3
Secureness in attachment	2	1	3
Manufacturability	1	2	3
Ease of installation/removal	1	3	2
TOTAL	13	11	18

Title: _____
 Author: _____
 Date: _____
 Release: _____
 _____
 _____

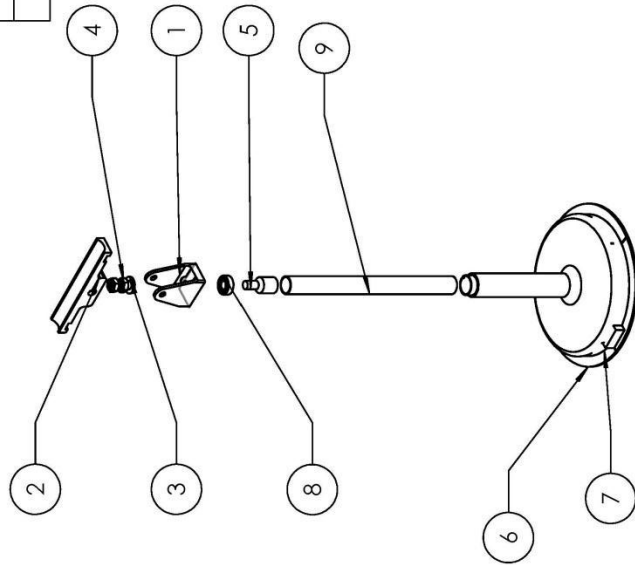
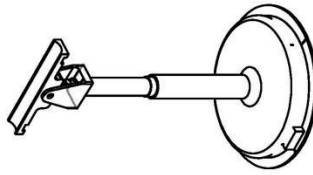
Legend	
Strong Relationship	9
Moderate Relationship	3
Weak Relationship	1
Strong Positive Correlation	+
Positive Correlation	+
Negative Correlation	-
Strong Negative Correlation	-
Objective is To Minimize	▲
Objective is To Maximize	▼
Objective is To Hit Target	X



[illegible]

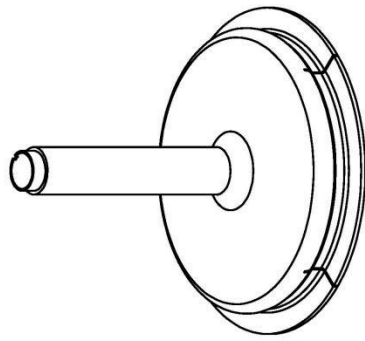
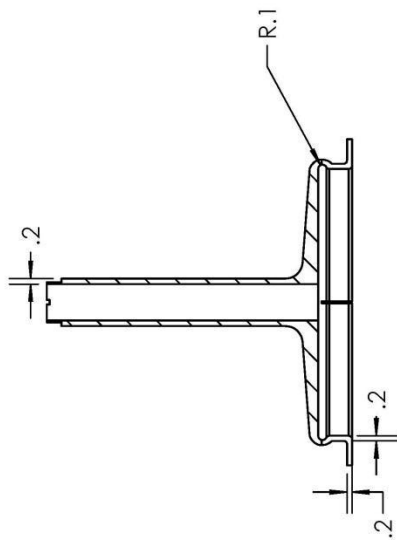
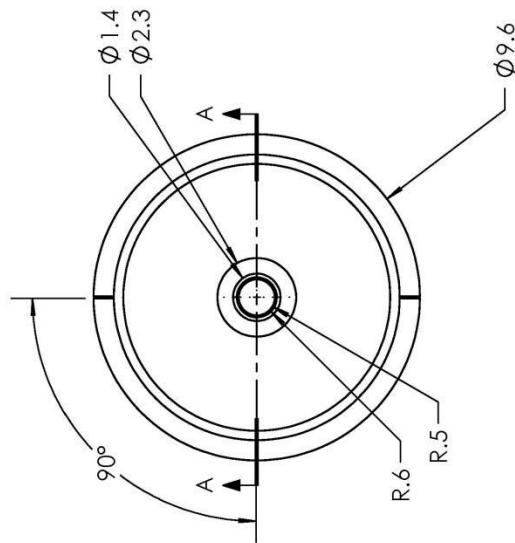
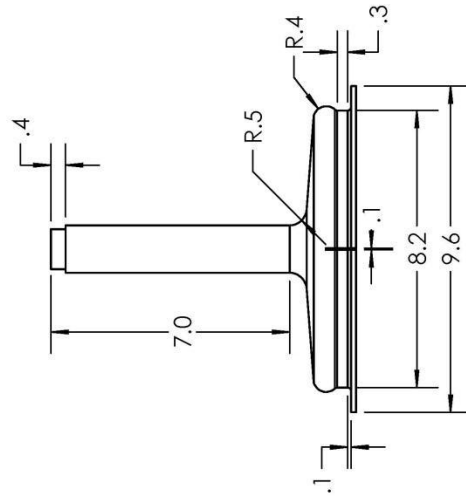
Appendix B: Drawings

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	06	JOINT BASE	1
2	07	JOINT TOP	1
3	2866T13	MCMaster PLASTIC THRUST BEARING	1
4	94805A125	MCMaster THIN HEX NUT	2
5	04	TOP CONVERTER	1
6	01	BASE	1
7	5215K14	MCMaster QUICK-RELEASE WORM-DRIVE DUCT AND HOSE CLAMP	1
8	6384K61	MCMaster DOUBLE-SHIELDED STEEL BALL BEARING	1
9	B002BW1C70	AVENIR 200 SERIES SEAT POST	1



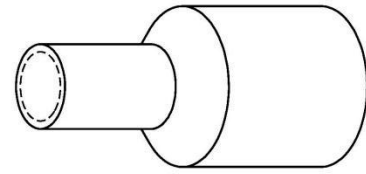
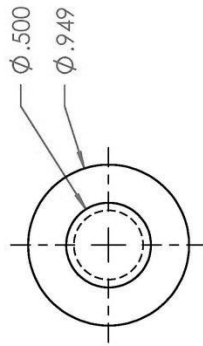
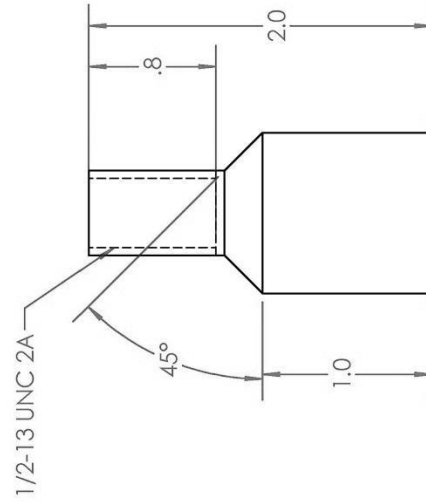
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TOLERANCE:	UNITS: INCHES	MATERIAL: VARIOUS		
* NEXT ASSY:	SCALE: 1:10	TITLE: PADDLING DEVICE ASSEMBLY		
DWG #: 10	DATE: 3-3-2012	GROUP: KAYAK TANDEMIONUM		

5 4 3 2 1

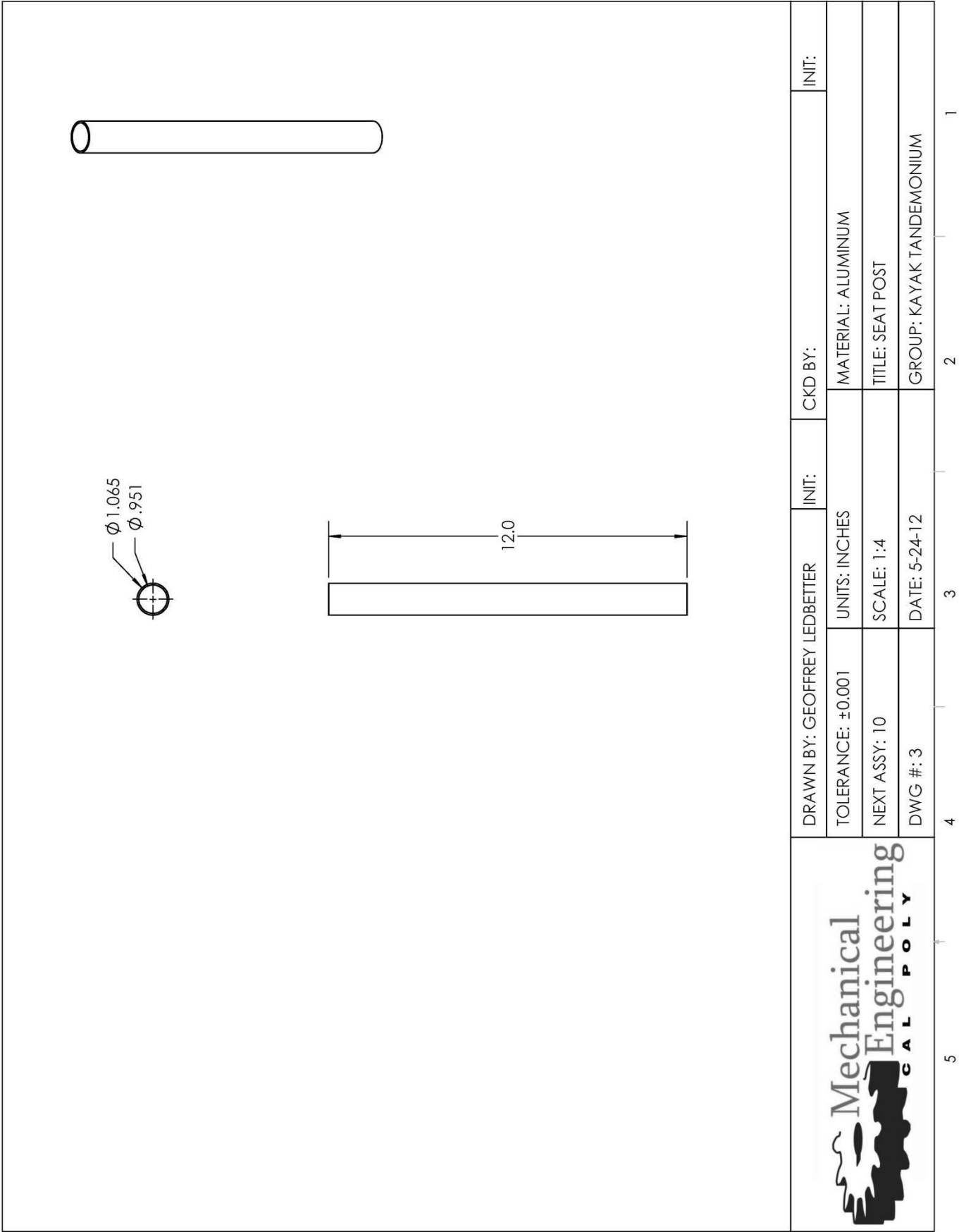


DRAWN BY: COURTNEY SHEFFIELD		INIT:	CKD BY:	INIT:
TOLERANCE: ± 0.05		UNITS: INCHES		
* NEXT ASSY: 10		SCALE: 1:10		
DWG #: 1		DATE: 3-8-2012		
MATERIAL: CARBON FIBER		TITLE: BASE		
GROUP: KAYAK TANDEMONIUM		1		



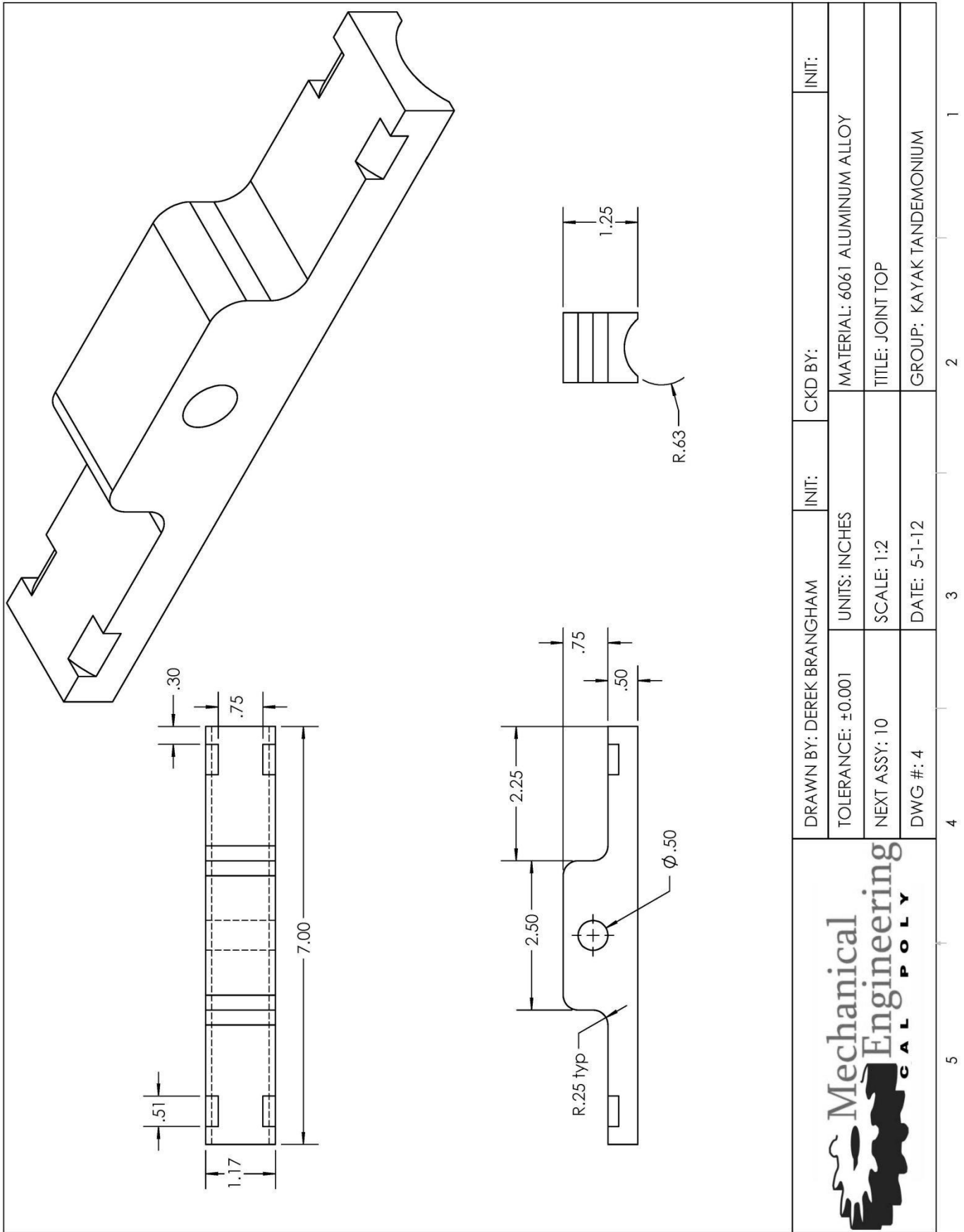


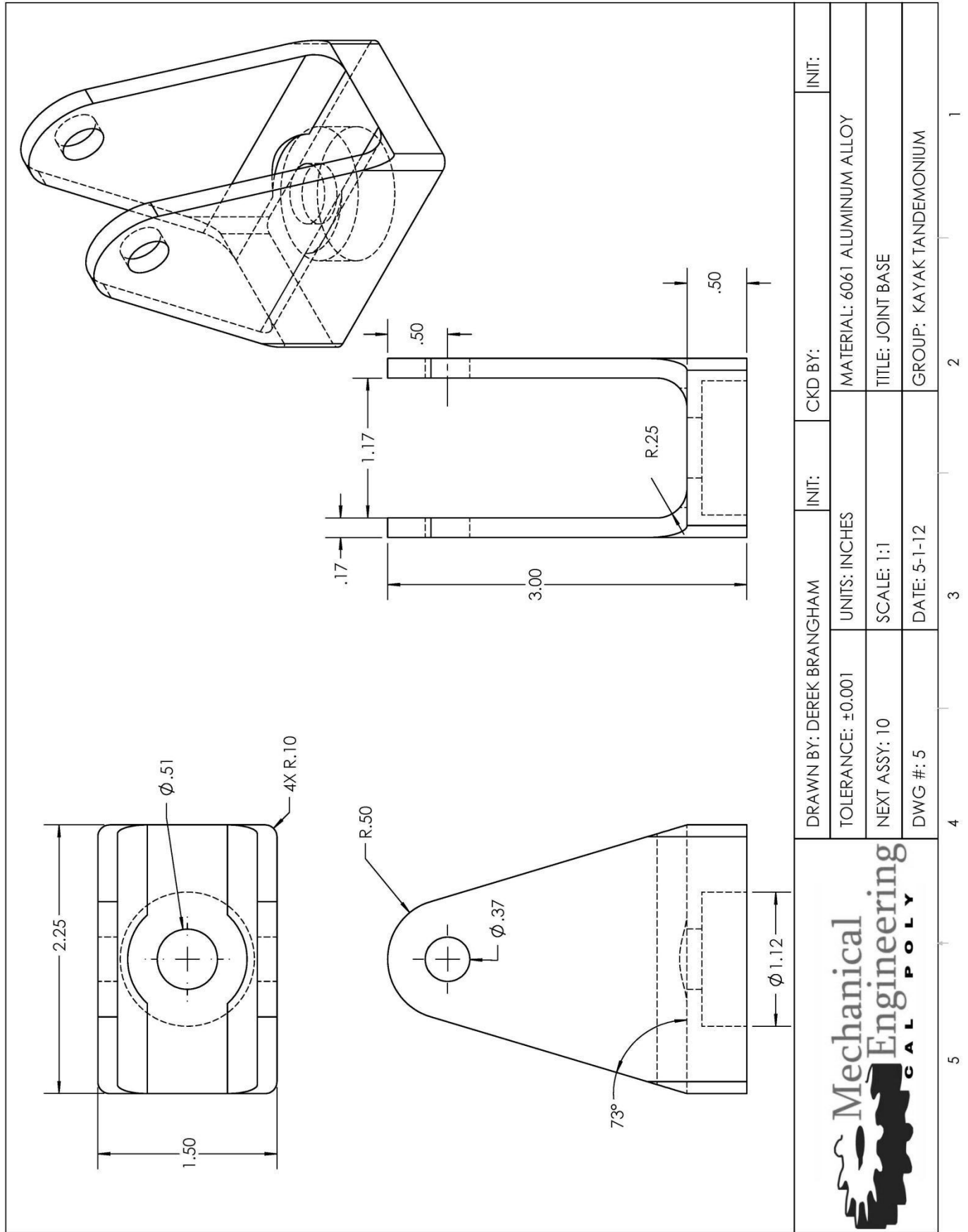
	DRAWN BY: GEOFFREY LEDBETTER		INIT:	CKD BY:	INIT:
	TOLERANCE: ± 0.001	UNITS: Inches		MATERIAL: 6061 ALUMINUM ALLOY	
	NEXT ASSY: 10	SCALE: 1:1		TITLE: MATING ALUMINUM	
	DWG #: 2	DATE: 5-24-12		GROUP: KAYAK TANDEMONIUM	
5	4	3	2	1	



DRAWN BY: GEOFFREY LEDBETTER		INIT:	CKD BY:	INIT:
TOLERANCE: ± 0.001	UNITS: INCHES		MATERIAL: ALUMINUM	
NEXT ASSY: 10	SCALE: 1:4		TITLE: SEAT POST	
DWG #: 3	DATE: 5-24-12		GROUP: KAYAK TANDEMONIUM	

5 4 3 2 1





Appendix C: List of Vendors and Contact Information

Table 4. List of vendors, with website and phone number.

Vendor	Website	Phone Number
McMaster-Carr	http://www.mcmaster.com/	(330) 342-6100
Third Coast Kite & Hobby	http://www.thirdcoastkites.com/	(231) 349-1905

Appendix D: Budget

The budget for this project was provided through a National Science Foundation (NSF) grant. The team had \$1000 to spend on all parts and materials. The next page contains a detailed budget including purchased parts.

Unilateral Paddle for Kayaking: Budget

Geoffrey Ledbetter, Derek Brangham, Courtney Sheffield

Funding source: NSF Grant
Total funding available: \$ 1,000.00
Current funding available: \$ 349.15

	ITEM	COST	DISTRIBUTOR	ITEM NO.	PURCHASER	REIMBURSED?
1	Worm Drive Clamp, 7-3/4" to 8-5/8" (2 pack)	\$15.99	McMaster-Carr	5682K26	Derek	N (1/12/12)
2	Fiberglass Rod, 5/16" D X 48" L	\$10.99	Third Coast Kite & Hobby	KP1001	Geoff	Y (5/9/2012)
3	Reusable Cable Tie, 29-1/2" L, 8-1/4" D (5 pack)	\$13.61	McMaster-Carr	7134K81	Courtney	N (2/21/12)
4	Quick-Release Worm-Drive Hose Clamp, 6-3/4" to 8-1/2"	\$43.30	McMaster-Carr	5215K14	Derek	N (2/28/12)
5	UHMW Thrust Bearing, 1/2" ID, 1" OD, 1/16" Thick (2X)	\$3.54	McMaster-Carr	2866T13	Derek	N (2/28/12)
6	316 SS Thin Hex Nut, 1/2"-13 (10 pack)	\$5.50	McMaster-Carr	94805A125	Derek	N (2/28/12)
7	Steel Ball Bearing, Double Shielded, 1/2" ID, 1-1/8" OD	\$7.98	McMaster-Carr	6384K61	Derek	N (2/28/12)
8	Tax and shipping for items 3-7	\$9.46	"	N/A	Derek	N (2/28/12)
9	Fiberglassing Supplies	\$33.02	The Craft	N/A	Courtney	Y (5/9/2012)
10	Fiberglassing Supplies	\$10.74	The Craft	N/A	Courtney	Y (5/9/2012)
11	Final Design Report Binding	\$9.92	Cal Poly Print and Copy	994T	Courtney	Y (5/9/2012)
12	Aluminum (Alloy 6061), 1-1/4" Square, 1' Length	\$16.18	McMaster-Carr	9008K151	Derek	N (4/26/12)
13	Aluminum (Alloy 6061), 1-1/2" Thick X 2-1/2" Width X 1' Length	\$31.61	McMaster-Carr	8975K167	Derek	N (4/26/12)
14	Aluminum (Alloy 6061), 1-1/4" Diameter, 1' Length	\$9.95	McMaster-Carr	8974K161	Derek	N (4/26/12)
15	Tax and shipping for items 12-14	\$10.38	"	N/A	Derek	N (4/26/12)
16	Precision Anodized Aluminum Shaft, 3/8" Diameter, 6" Length	\$11.90	McMaster-Carr	5911K12	Derek	N (5/8/12)
17	UHMW Thrust Bearing, for 3/8" Shaft Diameter, 3/4" OD, 1/16" Thickness	\$2.72	McMaster-Carr	2866T12	Derek	N (5/8/12)
18	UHMW Bearing, Sleeve, for 3/8" Shaft Diameter, 1/2" OD, 7/8" Length	\$7.41	McMaster-Carr	57785K2	Derek	N (5/8/12)
19	Tax and shipping for items 16-18	\$6.31	"	N/A	Derek	N (5/8/12)
20	Fiberglassing Supplies	\$25.16	The Craft	N/A	Courtney	N (5/29/12)
21	Fiberglassing Supplies	\$15.36	The Craft	N/A	Courtney	N (5/29/12)
22	Fiberglassing Supplies	\$6.82	Miners	N/A	Courtney	N (5/29/12)
23	Braided Sleeves	\$47.46	The Composites Store	CF9171, GBS760	Courtney	N (5/29/12)
24	Gasket	\$4.31	McMaster-Carr	8525T11	Courtney	N (5/29/12)
25	Vacuum Tape	\$31.25	The Composites Store	V195	Courtney	N (5/29/12)
26	Grip Assist	\$225.00	Creating Ability	N/A	Courtney	N (5/29/12)
27	XLC QR Alloy Seatpost Clamp, 31.8mm, Black	\$9.99	Amazon.com	B000NUEJPO	Geoff	Y (5/9/2012)
28	Avenir 200 Series Seat Post, Black, 27.2mm	\$24.99	Amazon.com	B002BW1C70	Geoff	Y (5/9/2012)
	TOTAL	\$650.85				

Appendix E: Component Specifications and Data Sheets



LIBERTY
PULTRUSIONS

Manufacturer of Engineered FRP Pultrusions

Liberty Pultrusions - East
1575 Lebanon
School Road
West Mifflin, PA
15122-3464
T: 412.466.8611
F: 412.466.8640
sales@libertypultrusions.com
www.libertypultrusions.com

Liberty Pultrusions - West
T: 760.744.6371
F: 760.744.0201

Export Sales
280 State Street
Suite 202
North Haven, CT
06473 USA
T: +1.203.230.4130
sales@exportdept.com

Pultruded Rod

Technical Data

Typical Property	Test Method	Condition	Units	Value		
Grade				Polyester	EHS	Supersil
Mechanical				Class F-155	Class F-155	Class H-200
Ultimate Tensile Strength	ASTM D-638	RT	PSI	70,000	100,000	70,000
Flexural Strength	ASTM D-790	RT	PSI	70,000	100,000	70,000
		100°C	PSI	25,000		35,000
		150°C	PSI	15,000		20,000
Flexural Modulus	ASTM D-790	RT	PSI	3 x 10 ⁶	6 x 10 ⁶	3 x 10 ⁶
		100°C	PSI	2 x 10 ⁶		2.5 x 10 ⁶
		150°C	PSI	1.5 x 10 ⁶		2.0 x 10 ⁶
Impact Strength	ASTM D-256	RT	Ft-lb/in notch	30	50	30
Compressive Strength	ASTM D-695					
Flatwise		RT	PSI	20,000	20,000	20,000
Lengthwise		RT	PSI	40,000	40,000	40,000
Electrical						
Electrical Strength	ASTM D-149					
Perpendicular (1/8 thick)		In Oil	VPM	300	300	300
Parallel		In Oil	KV/in	50	50	50
Power Factor 60 Hz	ASTM D-150			0.03	0.03	0.03
Dielectric Constant 60 Hz	ASTM D-150			5.0	5.0	5.0
Arc Resistance	ASTM D-495		Sec	100	100	120
Other						
Thermal Coefficient of Expansion	ASTM D-696		in/in/°F	3 x 10 ⁻⁶	3 x 10 ⁻⁶	3 x 10 ⁻⁶
Thermal Conductivity			BTU/hr/sq ft/in/°F	4	5	4
Weight Loss	200 hrs @ 150°C		%	1.00		0.17
	200 hrs @ 200°C		%	6.10		0.75
Extractables in Freon 22			%	1.05		0.19
Specific Gravity	ASTM D-792			1.95	1.95	1.95
Water Absorption	ASTM D-349	24 hrs	%	0.30	0.10	0.30
Color (standard)				White	Clear	Gray

Other Grades Available

FR Flame Retardant — Electrical Grade
TR Track Resistant — Flame Retardant
Electrical Grade

UL Listing E55403

Polyglas Polyester: General Purpose Grade for in-place temperatures up to 155°C (class F materials). Polyglas Polyester is a recognized component in most UL Listed insulation systems requiring 130C, 155C and 180C temperature ratings.

Polyglas Supersil: High Temperature Grade for in-place temperatures up to 200C (class H material). Polyglas Supersil is a recognized component in most UL Listed insulation systems requiring 180C, 200C and 220C temperature ratings.

Polyglas EHS: Extra High Strength - This grade provides very high flexural and tensile strength and modulus.

Polyglas FR and TR: UL Listed (File E55403) — Flame retardant and track resistant material.

Polyglas C: Corrosion Resistant — vinyl ester. Liberty Pultrusions stocks a number of sizes and grades of material in 96 in. lengths.

Special colors and resin systems available.

The above data is based on results achieved in the test methods indicated and is provided for information purposes only.

Figure 31. Pultruded rod technical data from Liberty Pultrusions.

Quick-Release Worm-Drive Duct and Hose Clamps



A quick-release latch allows you to access your line as often as you need while maintaining your original clamp size. Perfect for temporary connections and applications requiring repeated use. Use with flexible duct hose; not recommended for use with rigid hose. Clamps are reusable.

Note: When choosing a clamp, measure the outside diameter of your hose with the fitting installed.

Type 304 Stainless Steel

The band, housing, and latch are Type 304 stainless steel, which offers very good corrosion resistance. The screw is Type 410 stainless steel, which offers good corrosion resistance. The band is 5/8" wide and 0.031" thick. Tighten with a slotted screwdriver, 8 mm socket, or 8 mm hex nutdriver. Torque is 130 in.-lbs. Temperature range is -4° to +428° F.

220-lb. clamps have a latch that is 0.87" (22 mm) wide.
496-lb. clamps have a latch that is 0.96" (26.5 mm) wide.

Note: Work load limit is the maximum force the latch can withstand without affecting its operation or appearance.

Clamp ID Range			
Inch	mm		Each
220-lb. Work Load Limit			
2 3/4"-4 1/2"	70-115	5215K11	\$41.27
3 1/2"-5 3/8"	90-135	5215K12	39.03
5 1/8"-6 7/8"	130-175	5215K13	41.21
6 3/4"-8 1/2"	170-215	5215K14	43.30
Catalog Page Bookmark			
Quick-Release Worm-Drive Duct & Hose Clamp 6-3/4" to 8-1/2" Clamp Dia Range, 5/8" Band Width		☐ Each ADD TO ORDER	In stock
8 1/4"-10"	210-255	5215K15	45.61
9 7/8"-11 5/8"	250-295	5215K16	47.88
11 3/8"-13 1/4"	290-335	5215K17	49.74
13"-14 3/4"	330-375	5215K18	52.12

Figure 32. Clamp data sheet from McMaster-Carr.

Resilient Rubber Gaskets

All gaskets resist salts, water, and deformation after compression. Meet ASTM D2000. Ring gaskets cover the section of the flange just inside the bolt holes.

Sheet Gaskets



Cut with scissors or a utility knife. For more varieties of rubber, view our selection of rubber sheets.

SBR—Use this rubber when dealing with low-pressure applications. Temperature range is -20° to +170° F. Maximum pressure is 800 psi. Durometer hardness is A75. Color is red.

Buna-N—Ideal for oil applications. Also resists alkalies and detergents. Temperature range is -20° to +170° F. Maximum pressure is 1,000 psi. Durometer hardness is A60. Color is black, except FDA Buna-N is off-white.

Neoprene—Resists detergents. Temperature range is -20° to +170° F. Maximum pressure is 1,000 psi. Color is black. Durometer hardness is A70 for neoprene and not rated for reinforced neoprene. Neoprene meets MIL-R-3065, reinforced neoprene has a nylon insert.

Gum—When the pressure is on, this material can withstand up to 2,500 psi. Also resists detergents and steam. Temperature range is -20° to +160° F. Durometer hardness is A40. Color is tan.

Viton® Fluoroelastomer—Has better chemical resistance than other rubbers. Resists grease, oil, detergents, and some acids. Durometer hardness is A75. Temperature range is -20° to +400° F for Viton® and FDA Viton®, -40° to +400° F for low-temperature Viton® and 0° to 400° F for chemical-resistant Viton® (also known as Viton® ETP). Maximum pressure is 1,000 psi for Viton®, not rated for all other types of Viton®. Color is black, except FDA Viton® is white.

Silicone—A broad temperature range of -70° to +500° F makes silicone great for use in high-temperature applications. Also resists alkalies, acids, detergents, and steam. Maximum pressure is 1,000 psi. Durometer hardness is A60. Color is red.

Thickness	Size	Each	Reinforced Neoprene	Each	Thickness	Size	Each
SBR					FDA Viton® Fluoroelastomer		
1/16"	12" x 12"	8525T11 \$4.31	1/16" 12" x 12"	8525T55 \$7.17	1/16" 12" x 12"	9473K94	\$57.44
Catalog Page Bookmark				1/16" 24" x 24"	8525T56	12" x 12"	9473K95 102.57
1/16" Thick, 12" X 12", SBR Rubber Sheet				1/8" 12" x 12"	8525T57	12" x 12"	Low-Temperature Viton® Fluoroelastomer
Gasket				1/8" 24" x 24"	8525T58	12" x 12"	9473K96 101.02
				Gum		1/8" 12" x 12"	9473K97 184.17
				1/16" 12" x 12"	8525T51	12" x 12"	Chemical-Resistant Viton® Fluoroelastomer
				1/16" 24" x 24"	8525T52	12" x 12"	9473K92 385.89
				1/8" 12" x 12"	8525T53	12" x 12"	9473K93 708.73
				1/8" 24" x 24"	8525T54	12" x 12"	Silicone
				Viton® Fluoroelastomer		1/16" 12" x 12"	8525T41 16.90
				1/16" 12" x 12"	9473K61	24" x 24"	8525T42 48.04
				1/16" 24" x 24"	9473K62	12" x 12"	8525T43 24.91
				1/8" 12" x 12"	9473K63	24" x 24"	8525T44 77.54
				1/8" 24" x 24"	9473K64	12" x 12"	
				Buna-N			
				1/16" 12" x 12"	8525T21	24" x 24"	
				1/16" 24" x 24"	8525T22	12" x 12"	
				1/8" 12" x 12"	8525T23	24" x 24"	
				1/8" 24" x 24"	8525T24	12" x 12"	
				FDA Buna-N			
				1/16" 12" x 12"	8525T61	24" x 24"	
				1/16" 24" x 24"	8525T62	12" x 12"	
				1/8" 12" x 12"	8525T63	24" x 24"	
				1/8" 24" x 24"	8525T64	12" x 12"	

Figure 33. Gasket data sheet from McMaster-Carr.

Reusable Cable Ties



A



B



C

Whether you plan to change the bundle size or just need a temporary hold, these ties have a convenient release tab for easy removal and reuse. All are nylon. Temperature range is -40° to +185° F.

(A) Side tab ties are the easiest to release in most applications. UL recognized.

(B) Top tab ties are generally the most secure. UL recognized, unless noted.

(C) Flip tab tie acts as both the lock and the release. Flip the tab down to adjust and release; flip it up to lock when desired tension is reached. The high-visibility color allows ties to be easily seen.

						Per Pkg.	
Lg.	Max. Bundle Dia.	Tensile Strength, lbs.	Wd.	Pkg. Qty.		1-9	10-Up
(A) Side Tab							
White							
5 1/2"	1 1/4"	40	0.21"	50	7134K51	\$5.27	\$4.61
8"	2"	40	0.21"	50	7134K53	5.78	5.05
10 1/2"	2 1/2"	40	0.21"	50	7134K45	8.27	7.23
15 1/4"	4"	250	0.52"	25	7134K32	13.13	11.49
21 1/2"	6"	250	0.52"	10	7134K93	9.51	8.32
27 3/4"	8"	250	0.52"	5	7134K95	5.47	4.79
UV-Resistant Black							
5 1/2"	1 1/4"	40	0.21"	50	7134K52	5.77	5.05
8"	2"	40	0.21"	50	7134K54	6.32	5.53
10 1/2"	2 1/2"	40	0.21"	50	7134K46	9.09	7.95
15 1/4"	4"	250	0.52"	25	7134K33	14.45	12.64
(B) Top Tab							
White							
6"	1 1/2"	50	0.19"	100	7134K21	6.34	5.54
8"	2"	50	0.19"	100	7134K31	6.96	6.09
9"	2 1/8"	250	0.49"	25	7134K41	6.89	6.32
15 5/16"	4"	175	0.35"	10	7134K42 *	6.92	5.97
22 1/4"	5 7/8"	250	0.49"	10	7134K43	10.15	8.76
UV-Resistant Black							
6"	1 1/2"	50	0.19"	100	7134K2	7.29	6.38
8"	2"	50	0.19"	100	7134K3	7.73	6.76
9"	2 1/8"	250	0.49"	25	7134K4	7.36	4.77
15 5/16"	4"	175	0.35"	10	7134K5 *	8.25	7.48
22 1/4"	5 7/8"	250	0.49"	10	7134K6	11.27	9.73
(C) Flip Tab							
Yellow							
29 1/2"	8 1/4"	200	0.51"	5	7134K81	8.23	7.22

* Not UL recognized.

Figure 34. Data sheet for reusable zip tie from McMaster Carr.

Stainless Steel Ball Bearings—ABEC-1



Open



Double
Shielded



Double
Sealed

Strength is combined with corrosion resistance in these Type 440 stainless steel bearings. Made to meet ABEC-1 dimensional tolerance standards, all are quiet-running, electric-motor-quality bearings. They can handle radial (perpendicular to the shaft) loads and small amounts of angular misalignment. Temperature range is -40° to $+300^{\circ}$ F. **Double-shielded bearings** have steel shields that block out dirt. They come greased. **Double-sealed bearings** have Buna-N seals (except for 6153K69, which has PTFE) that block out dirt, preserve lubricants, and reduce noise. They come greased.

 For technical drawings and 3-D models, click on a part number.

Inch

Bearing No.	For Shaft		Dynamic Load Cap., lbs.	Double Shielded			Each
	Dia.	OD		Max. rpm	Wd.		
R2	1/8"	3/8"	142	56,000	5/32"	6138K52	\$5.26
R3	3/16"	1/2"	292	43,000	0.196"	6138K53	5.59
R4	1/4"	5/8"	332	38,000	0.196"	6138K54	5.76
R6	3/8"	7/8"	749	32,000	9/32"	6138K24	11.05
R8	1/2"	1 1/8"	1,148	27,000	5/16"	6138K25	18.29
R10	5/8"	1 3/8"	1,348	21,000	11/32"	6138K26	27.18
R12	3/4"	1 5/8"	1,627	17,000	7/16"	6138K71	30.97

Figure 35. Bearing data sheet from McMaster Carr.

Thin Hex Nuts



Also known as jam nuts and half-height nuts; perfect in tight spaces. Often used in pairs, one is "jammed" against the other to prevent loosening. All have a Class 2B thread fit. Sizes 1 1/2" and smaller have dimensions that meet ANSI/ASME B18.2.2 (unless noted).

Thread Size	Width	Height	Pkg. Qty.	Per Pkg.
Type 316 Stainless Steel				
1/4"-20	7/16"	5/32"	50	94805A029 \$5.38
1/4"-28	7/16"	5/32"	50	94805A209 7.26
5/16"-18	1/2"	3/16"	25	94805A110 4.29
5/16"-24	1/2"	3/16"	25	94805A213 5.35
3/8"-16	9/16"	7/32"	25	94805A115 5.38
3/8"-24	9/16"	7/32"	25	94805A217 8.25
7/16"-20	1 1/16"	1/4"	10	94805A221 8.41
1/2"-13	3/4"	5/16"	10	94805A125 5.50
1/2"-20	3/4"	5/16"	10	94805A224 7.77
9/16"-18	7/8"	5/16"	1	94805A228 2.88
5/8"-11	15/16"	3/8"	5	94805A130 5.76
5/8"-18	15/16"	3/8"	5	94805A231 8.67
3/4"-10	1 1/8"	27/64"	1	94805A135 1.45
3/4"-16	1 1/8"	27/64"	1	94805A233 2.14
7/8"-9	1 5/16"	31/64"	1	94805A037 3.06
7/8"-14	1 5/16"	31/64"	1	94805A041 8.59
1"-8	1 1/2"	35/64"	1	94805A038 6.24
1"-14	1 1/2"	35/64"	1	94805A237 6.96
1 1/4"-7	1 7/8"	23/32"	1	94805A247 11.53
Black-Oxide 18-8 Stainless Steel				
1/4"-20	7/16"	5/32"	50	98514A029 6.81
5/16"-18	1/2"	3/16"	25	98514A035 5.73
3/8"-16	9/16"	7/32"	25	98514A041 6.81
1/2"-13	3/4"	5/16"	10	98514A520 6.03
5/8"-11	15/16"	3/8"	5	98514A540 6.89
Plain 18-8 Stainless Steel				
1/4"-20	7/16"	5/32"	100	91847A029 4.99
1/4"-28	7/16"	5/32"	100	91847A429 6.12
5/16"-18	1/2"	3/16"	100	91847A030 7.47
5/16"-24	1/2"	3/16"	100	91847A430 8.54
3/8"-16	9/16"	7/32"	100	91847A031 9.56
3/8"-24	9/16"	7/32"	100	91847A431 10.96
7/16"-14	1 1/16"	1/4"	50	91847A510 11.67
7/16"-20	1 1/16"	1/4"	50	91847A515 12.73
1/2"-13	3/4"	5/16"	25	91847A520 5.99
1/2"-20	3/4"	5/16"	25	91847A525 8.20
9/16"-12	7/8"	5/16"	20	91847A530 13.39
9/16"-18	7/8"	5/16"	10	91847A434 7.47
5/8"-11	15/16"	3/8"	10	91847A540 6.38
5/8"-18	15/16"	3/8"	10	91847A545 7.14
3/4"-10	1 1/8"	27/64"	10	91847A550 9.73
3/4"-16	1 1/8"	27/64"	10	91847A555 10.56
7/8"-9	1 5/16"	31/64"	5	91847A560 9.09
7/8"-14	1 5/16"	31/64"	5	91847A565 10.75
1"-8	1 1/2"	35/64"	1	91847A570 2.62
1"-12	1 1/2"	35/64"	1	91847A436 3.43
1"-14	1 1/2"	35/64"	1	91847A438 3.24
1 1/8"-7	1 11/16"	39/64"	1	91847A039 4.13
1 1/8"-12	1 11/16"	39/64"	1	91847A439 6.32
1 1/4"-7	1 7/8"	23/32"	1	91847A040 5.41
1 1/4"-12	1 7/8"	23/32"	1	91847A440 8.50
1 1/2"-6	2 1/4"	27/32"	1	91847A041 7.99
1 1/2"-12	2 1/4"	27/32"	1	91847A441 11.68
1 3/4"-5	2 5/8"	31/32"	1	91847A051 23.86
2"-4 1/2	3"	1 3/32"	1	91847A071 29.65

Figure 36. Hex nut data sheet from McMaster Carr.

Plastic Sleeve Bearings



Nylon—A reasonably slippery, rigid, and abrasion-resistant material that handles light jobs without the need for lubrication.

MDS-Filled Nylon—The same qualities as nylon combined with wear-resistant molybdenum disulfide (MDS).

UHMW—Ultra-high molecular weight (UHMW) polyethylene is USDA approved and FDA compliant. It withstands wet, corrosive environments.

Acetal—An economical alternative to PTFE, this material is not only strong, but also resistant to chemicals and moisture.

PTFE—Has the lowest coefficient of friction of all our materials, so it's ultra-slippery. It also offers excellent chemical resistance and performs well at extreme temperatures.

View [tolerance information](#) for these bearings.

Bearing Material	Temperature Range	P max	V max	PV max
Nylon	-20° F to 250° F	400	360	3,000
MDS-Filled Nylon	-40° F to 176° F	2,901	118	3,400
UHMW	-200° F to 180° F	1,000	100	2,000
Acetal	-20° F to 180° F	1,000	1,000	2,700
PTFE	-350° F to 500° F	500	100	1,000

Plastic Sleeve Bearings

For Shaft Dia.	OD	Lg.	Pkg. Qty.	Nylon		MDS-Filled Nylon		UHMW		Acetal		PTFE	
				Pkg.	Each	Pkg.	Each	Pkg.	Each	Pkg.	Each	Pkg.	Each
1/8"	1/4"	1/4"	1	6389K1	\$3.59	6294K401	\$0.87	57785K86	\$7.03	2610T1	\$3.31	2639T1	\$3.13
1/8"	1/4"	3/8"	1	6389K2	3.62	6294K402	1.06	57785K85	7.06	2610T2	3.33	2639T2	3.09
3/16"	5/16"	1/4"	1	6389K3	4.05	6294K403	1.41	57785K84	7.03	2610T3	3.31	2639T3	3.13
3/16"	5/16"	1/2"	5	6389K353	3.01	6294K404	1.24	57785K41	7.12	2610T4	3.35	2639T4	3.11
1/4"	3/8"	1/4"	5	6389K352	2.60	6294K405	1.34	57785K82	7.16	2610T5	3.33	2639T5	3.11
1/4"	3/8"	3/8"	5	6389K351	2.44	6294K406	1.06	57785K81	7.19	2610T6	3.33	2639T6	3.18
1/4"	3/8"	1/2"	5	6389K113	2.96	6294K407	1.29	57785K11	5.30	2610T7	3.42	2639T7	3.28
5/16"	7/16"	1/2"	1	6389K4	4.00	6294K408	1.38	57785K42	7.22	2610T8	3.19	2639T8	3.40
5/16"	7/16"	5/8"	5	6389K114	3.39	6294K409	1.84	57785K78	7.25	2610T9	3.24	2639T9	3.53
5/16"	1/2"	1/4"	5	6389K111	4.46	6294K2	3.38	57785K1	7.31				
5/16"	1/2"	3/8"	1	6389K5	3.91	6294K1	3.66	57785K77	7.28	2610T11	3.17	2639T11	3.38
3/8"	1/2"	3/8"	5	6389K349	2.71	6294K411	1.27	57785K76	7.35	2610T12	3.17	2639T12	3.32
3/8"	1/2"	1/2"	5	6389K115	2.37	6294K412	1.35	57785K12	6.15	2610T13	3.26	2639T13	3.47
3/8"	1/2"	3/4"	5	6389K354	3.58	6294K413	1.31	57785K88	7.38	2610T14	3.26	2639T14	3.63
3/8"	1/2"	7/8"	5	6389K112	4.69	6294K3	4.36	57785K2	7.41				
3/8"	5/8"	3/4"	5	6389K348	4.97	6294K4	4.36	57785K43	7.44	2610T15	3.62	2639T15	3.92
7/16"	9/16"	1/2"	1	6389K8	3.93	6294K414	1.34	57785K71	7.48	2610T16	3.51	2639T16	3.61
1/2"	5/8"	3/8"	5	6389K355	3.70	6294K415	1.49	57785K89	7.51	2610T17	3.42	2639T17	3.47
1/2"	5/8"	1/2"	5	6389K347	3.70	6294K416	1.32	57785K89	7.55	2610T18	3.56	2639T18	3.61
1/2"	5/8"	5/8"	5	6389K116	3.07	6294K417	1.47	57785K13	7.15	2610T19	3.56	2639T19	3.78
1/2"	5/8"	3/4"	5	6389K346	4.57	6294K418	1.32	57785K87	7.58	2610T21	3.56	2639T21	3.86
1/2"	5/8"	1"	5	6389K117	4.99	6294K419	1.58	57785K14	7.61	2610T22	3.69	2639T22	4.15
1/2"	3/4"	1/2"	5	6389K345	4.29	6294K5	4.20	57785K86	7.65	2610T23	3.56	2639T23	3.61
1/2"	3/4"	3/4"	5	6389K118	4.04	6294K8	5.09	57785K87	7.69	2610T24	3.67	2639T24	3.78
1/2"	3/4"	1"	5	6389K119	5.69	6294K7	5.53	57785K15	7.96	2610T25	3.78	2639T25	4.03
5/8"	3/4"	3/4"	5	6389K222	4.07	6294K8	4.98	57785K16	7.96	2610T26	3.69	2639T26	3.84
5/8"	13/16"	5/8"	1	6389K7	4.13	6294K421	1.63	57785K44	7.69	2610T27	3.71	2639T27	4.46
5/8"	7/8"	5/8"	1	6389K8	5.19	6294K9	4.85	57785K3	7.72	2610T28	3.76	2639T28	4.94
5/8"	7/8"	3/4"	5	6389K344	4.86	6294K101	5.23	57785K83	7.76	2610T29	3.73	2639T29	4.67
5/8"	7/8"	1"	1	6389K9	5.67	6294K102	5.70	57785K64	7.79	2610T31	3.98	2639T31	5.17
3/4"	7/8"	1 1/4"	5	6389K225	5.61	6294K103	6.05	57785K85	7.83	2610T32	4.32	2639T32	6.75
3/4"	1"	1/2"	5	6389K343	5.61	6294K422	2.11	57785K81	8.34	2610T33	3.71	2639T33	4.40
3/4"	1"	3/4"	5	6389K342	5.61	6294K423	2.46	57785K59	8.38	2610T34	3.87	2639T34	5.02
3/4"	1"	1"	5	6389K226	4.97	6294K424	2.84	57785K17	9.81	2610T35	4.43	2639T35	5.92
3/4"	1"	1 1/2"	5	6389K341	6.39	6294K425	5.64	57785K58	8.67	2610T36	4.43	2639T36	6.95
7/8"	1 1/8"	1 1/8"	5	6389K227	11.33	6294K104	7.13	57785K55	8.71	2610T37	7.20	2639T37	10.21
1"	1 1/8"	1"	5	6389K228	12.75	6294K105	6.74	57785K54	8.75	2610T38	6.68	2639T38	9.38
1"	1 1/4"	3/4"	1	6389K11	8.39	6294K426	2.86	57785K53	9.61	2610T39	6.50	2639T39	9.01
1"	1 1/4"	1"	5	6389K229	13.81	6294K427	3.92	57785K18	8.80	2610T41	6.48	2639T41	10.00

Figure 37. Bushing data sheet from McMaster Carr.

Plastic Thrust Bearings



UHMW—Ultra-high molecular weight (UHMW) polyethylene is FDA compliant. It withstands wet, corrosive environments.

View [tolerance information for these bearings](#).

Bearing Material	Temperature Range	P max	V max	PV max
UHMW	-100° to 180° F	1,000	50	2,000

Plastic Thrust Bearings

UHMW				
For Shaft Dia.	OD	Thick.		Each
3/8"	3/4"	1/16"	2866T12	\$1.36

Figure 38. Bushing data sheet from McMaster Carr.

Appendix F: Detailed Supporting Analysis

Hatch Strength

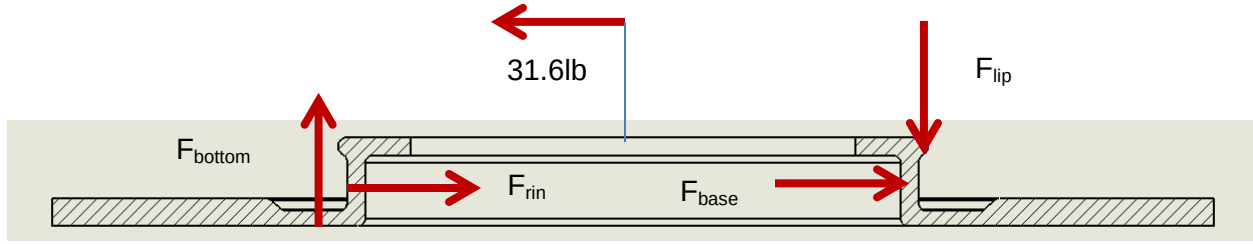


Figure 39. Free body diagram of base experiencing paddle force.

Assume: $F_{\text{bottom}} = F_{\text{lip}}$, $F_{\text{ring}} = F_{\text{base}}$, $\sigma_{\text{ut}} = 12.4 \text{ MPa}$ (Medium Density Polyethylene)

$$\Sigma M_B = 31.6lb * (22.6in) - F_{lip} * (8in)$$

$$F_{lip} = 89.27lb$$

$$p = \frac{F_{lip}}{A_{\text{applied}}}$$

$$= \frac{F_{lip}}{1/2 * (\pi * (r_o^2 - r_i^2))}$$

$$= \frac{89.27lb}{1/2 * \pi * ((7.943in/2)^2 - (7.719in/2)^2)}$$

$$p = 64.80psi$$

$$M_{\text{max}} = p * r * (d\theta) * L^2$$

$$\sigma_{\text{max}} = \frac{M_{\text{max}} * c}{I}$$

$$= \frac{prd\theta L^2 * (h/2)}{1/12 * (rd\theta) * h^3}$$

$$= \frac{6pL^2}{h^2}$$

$$= \frac{6 * (64.80psi) * (\frac{7.943in - 7.719in}{2})^2}{(0.256in)^2}$$

$$\sigma_{max} = 74.41psi * \left(\frac{6.89MPa}{10^3psi} \right)$$

$$\sigma_{max} = 0.513MPa$$

$$\sigma_{max} < \sigma_{ut}$$

$$\sum F_x = -31.6lb + F_{ring} + F_{base} = 0$$

$$F_{base} = \frac{31.6lb}{2} = 15.8lb$$

$$f = \frac{F_{base}}{\pi * r * y}$$

$$= \frac{15.8lb}{\pi(4in)(1in)}$$

$$f = 1.257psi$$

$$M = prd\theta L^2 + frd\theta y^2$$

$$\sigma_{max} = \frac{M_{max} * c}{I}$$

$$= \frac{(prd\theta L^2 + frd\theta y^2) * t/2}{1/12 * (rd\theta) * t^3}$$

$$= \frac{6 * (pL^2 + fy^2)}{t^2}$$

$$= \frac{6 * ((129.6psi) * (0.0125in)^2 + (1.257psi) * ((1in)^2))}{(0.25in)^2}$$

$$= 123psi$$

$$\sigma_{max} = 0.845MPa$$

$$\sigma_{max} < \sigma_{ut}$$

Therefore, the kayak hatch should be able to experience paddling forces without damage.

Pultruded Rod

Using the data found in Table 5, the required diameter was estimated for a certain amount of deflection. For the design, a $\sigma_{max}=70000$ psi and $E=3E6$ psi were chosen.

$$\sigma = \frac{My}{I}$$

$$M = PL, y = \frac{D}{2}, I = \frac{\pi}{64} D^4$$

$$\sigma = \frac{32PL}{\pi D^3}$$

$$D = \sqrt[3]{\frac{32PL}{\pi\sigma}}$$

Once the appropriate diameter is chosen for certain loading conditions, the deflection equation shown below can be used to find how much the rod end deflects.

$$\Delta = \frac{PL^3}{3EI}$$

$$\Delta = \frac{64PL^3}{3\pi ED^4}$$

Table 5. Sample calculation from spreadsheet used to choose the proper pultruded rod diameter.

Flexural Strength [psi]	Rod Diameter [in]	I (Circle) [in ⁴]	E [psi]	Moment Arm [in]	Force [lb]	Moment [in-lb]	Sigma [psi]	Delta [in]
70000	0.3125	0.00047	3000000	8	10	80	26701.769	1.215
					15	120	40052.653	1.823
					20	160	53403.537	2.430
					25	200	66754.421	3.038
					31.6	252.8	84377.589	3.840
					35	280	93456.19	4.253

*The entries highlighted in red indicate forces which exceed the maximum flexural strength.

Appendix G: Gantt Chart

WBS	Task Name	Duration	Start	Finish	Predecessors
1	Fall Quarter	50 days	Tue 9/27/11	Mon 12/5/11	
1.1	Intro Email to Sponsor	2 days	Tue 9/27/11	Wed 9/28/11	
1.2	Create Project Proposal	15 days	Mon 10/10/11	Fri 10/28/11	
1.2.1	Research Existing Solutions	14 days	Tue 9/27/11	Fri 10/14/11	
1.2.2	Review Proposal with Sponsor	0 days	Fri 10/21/11	Fri 10/21/11	
1.2.3	Update Project Proposal	5 days	Mon 10/24/11	Fri 10/28/11	5
1.3	Create QFD/ House of Quality	13 days	Tue 10/18/11	Thu 11/3/11	
1.3.1	Develop QFD to include in Project Proposal	4 days	Tue 10/18/11	Fri 10/21/11	
1.3.2	Update QFD	6 days	Mon 10/24/11	Mon 10/31/11	8
1.4	Observe KINE paddling program	7 days	Fri 10/28/11	Sun 11/6/11	
1.4.1	AI Weekend	2 days	Sat 10/29/11	Sun 10/30/11	
1.4.2	Participant Weekend	2 days	Sat 11/5/11	Sun 11/6/11	
1.5	Develop Conceptual Design Report	24 days	Tue 11/1/11	Fri 12/2/11	
1.5.1	Create Conceptual Model	24 days	Tue 11/1/11	Fri 12/2/11	
1.5.1.1	Brainstorm	8 days	Tue 11/1/11	Thu 11/10/11	
1.5.1.2	Evaluate concepts	5 days	Fri 11/11/11	Thu 11/17/11	15
1.5.1.3	Use QFD to evaluate remaining concepts	1 day	Fri 11/18/11	Fri 11/18/11	16
1.5.1.4	Proof of concept testing	10 days	Mon 11/21/11	Fri 12/2/11	17
1.5.2	Review report with instructor before turning in	5 days	Mon 11/21/11	Fri 11/25/11	
1.5.3	Turn in report to instructor	0 days	Mon 11/28/11	Mon 11/28/11	19

1.6	Review Report with Sponsor	5 days	Tue 11/29/11	Mon 12/5/11	20
2	Winter Quarter	50 days	Mon 1/2/12	Fri 3/9/12	
2.1	Update Design Report/Gantt Chart	5 days	Mon 1/2/12	Fri 1/6/12	
2.2	Re-evaluate solution ideas	10 days	Mon 1/2/12	Fri 1/13/12	
2.3	Choose Materials to use	35 days	Mon 1/2/12	Fri 2/17/12	
2.3.1	Research parts/bearings/materials	20 days	Mon 1/2/12	Fri 1/27/12	
2.3.2	Perform rough analysis on materials	10 days	Mon 1/30/12	Fri 2/10/12	26
2.3.3	Decide on parts/materials to use	5 days	Mon 2/13/12	Fri 2/17/12	27
2.4	Student Presentation (practice CDR)	0 days	Tue 1/24/12	Tue 1/24/12	
2.5	Design Report	21 days	Tue 1/3/12	Tue 1/31/12	
2.6	Critical Design Review	0 days	Tue 1/31/12	Tue 1/31/12	
2.7	Individual Ethics Memo	6 days	Tue 1/31/12	Tue 2/7/12	
2.7.1	Memo Topic Due	4 days	Thu 1/26/12	Tue 1/31/12	
2.8	Team Ethics Presentation	6 days	Tue 2/7/12	Tue 2/14/12	
2.9	Design Final Prototype	30 days	Mon 1/30/12	Fri 3/9/12	
2.9.1	Simple prototype development	15 days	Mon 1/30/12	Fri 2/17/12	
2.9.2	3D Modeling	15 days	Mon 2/20/12	Fri 3/9/12	
2.9.3	Develop Final Geometry and Aesthetics	10 days	Mon 2/27/12	Fri 3/9/12	36
3	Spring Quarter	61 days	Mon 3/12/12	Mon 6/4/12	
3.1	Prototype	40 days	Mon 3/12/12	Fri 5/4/12	
3.1.1	Order Materials	5 days	Mon 3/12/12	Fri 3/16/12	
3.1.2	Build Prototype	10 days	Mon 3/19/12	Fri 3/30/12	41
3.1.3	Test	6 days	Mon 4/2/12	Mon 4/9/12	42

3.1.4	2nd iteration possibly?	9 days	Tue 4/10/12	Fri 4/20/12	43
3.2	Project Update Memo To Sponsor	5 days	Mon 3/26/12	Fri 3/30/12	
3.3	Senior Project Design Expo	23 days	Tue 5/1/12	Thu 5/31/12	
3.3.1	Design Poster	16 days	Tue 5/1/12	Tue 5/22/12	
3.3.2	Put Poster Together Poster	6 days	Wed 5/23/12	Wed 5/30/12	47
3.3.3	Develop Talking Points	6 days	Wed 5/23/12	Wed 5/30/12	47
3.3.4	Design/Develop Display	12 days	Tue 5/15/12	Wed 5/30/12	
3.4	Final Report	25 days	Tue 5/1/12	Mon 6/4/12	
3.4.1	First Draft Due	14 days	Tue 5/1/12	Fri 5/18/12	
3.4.2	Develop Final Draft	11 days	Mon 5/21/12	Mon 6/4/12	52