Mustang Adaptive Nordic Sports
Conceptual Design Report

ME 430 Senior Design Project – Spring 2011

Sponsors

Jon Kreamelmeyer
Dr. Brian Self

Team Members

Krystina Murrietta
Tom Silva
Allen Thrift
Dan Murray

Team Advisor

Sarah Harding

June 2, 2011

Statement of Disclaimer

Table of Contents

List of Tables

List of Figures

Abstract

Mustang Adaptive Nordic Sports has undertaken a recreational sit ski as a mechanical engineering senior project. The team consists of four seniors: Daniel Murray, Krystina Murrietta, Tom Silva, and Allen Thrift. The goal of this project was to design, build, and test an adjustable sit ski that is lightweight and accommodates different users. The first half of this project focused on researching past senior projects and existing designs, defining the need and specifications, brainstorming, designing, and analyzing the validity of the final design. The second half of this project required the acquiring materials, building the prototype and testing it. The design presented in this report accommodates two leg positions, legs-out and teacup, where legs-out is a separate attachment. Removable footrests were manufactured in order to vary the rider's foot position for maximum comfort. The single binding system was modeled for NNN since it is the most common type of cross-country ski used. This design incorporated many of the benefits of the previous designs while minimizing the overall weight of the sit ski assembly. The main components of the design are the aluminum 6063 frame, the modular legs-out attachment, the single binding system, and the large bucket seat. All manufactured components met assessment calculations in stress and deflection.

Introduction

In order to develop real world engineering problem solving and team collaboration skills, we are designing a lightweight device which allows persons with lower extremity disabilities to participate in a seated form of cross country skiing. The coach of the US Paralympic Ski Team, Jon Kreamelmeyer (also known as JK), contacted Dr. Brian Self with the need for this device called the sit ski. Dr. Self of the Mechanical Engineering department at Cal Poly San Luis Obispo is our sponsor, with a grant from the Research to Aid Persons with Disabilities (RAPD) sponsored by the National Science Foundation (NSF).

Previous Cal Poly senior project groups have designed sit skis; however, a more lightweight design that has multiple leg positions is desired. After reviewing these past projects and other commercial sit ski designs, our team began generating ideas. Our goal is to construct a sit ski that weighs less than 10 pounds and will accommodate two leg positions; allowing individuals with varying disabilities to participate in Nordic cross country skiing.

Objectives

The goal of our project is to create a sit ski device that is simpler, lighter and less adjustable than previous senior project designs. The previous sit skis had multiple adjustments that were heavy and complicated. We aim to create a sit ski that weighs less than 10 pounds, requires less than $1500 to produce, and has two adjustable leg positions: teacup and legs-out. The teacup position is a sitting position where the knees rest against the rider's chest and the feet are resting next to the buttocks. The legs-out position is a sitting position where the rider's legs are extended with some knee flex for comfort. Our design also requires a functional and comfortable seat as well as safety devices to ensure that the rider is secure at all times. Through the use of a Quality Function Deployment (QFD) matrix, we have determined the specifications shown in Table 1 below. A QFD is a graphical representation of different specifications, their importance, and the relationships among them. The QFD translates the customer's needs and expectations into quantifiable engineering requirements. Our QFD is shown in Appendix A.

Table 1. Compliance Matrix

Specifications	Target	Tolerance	Risk	Compliance
Max Weight of Sit Ski	10 pounds	Max	H	A,T,S
Track Width	9 inches with + 1/2 inch adjustability	± 0.1 inch	L	A,T,S
Rider Weight	300 pounds	Max	M	A, T, S
Hip to bottom of foot measurement	39 inches	Max	L	A, T, S
Number of Leg Positions	2: Legs out and teacup	N/A	M	T,S
Assembly times	10 minutes	+ 2/-10 min	L	T
Distance between center of mass of frame and balance point of skis	0 inches	± 1 inch	M	A,T
Time to adjust leg position by coach	10 minutes	+ 2/-10 min	L	T
Restrained body parts movement restriction	0 inches	+ 0.5 inch	M	A, T, S
Padded contact region thickness	2 inches	± 1 inch	L	A, T, S
Number of sharp edges or pinch points	0	Max	M	I
Number of different bindings that sit ski attaches to	2	± 1	L	T
Rigid and safe	N/A	N/A	L	I
Number of Riders	1	Max	L	I, S

Background

Cross country skiing has been a part of the Winter Paralympic Games since the first Paralympic Games event in Sweden in 1976. There are many fans of the Paralympic Games who would like to recreationally use sit skis. The focus of this project is geared towards recreational cross country skiing while allowing users to adjust which sitting position they are using.

According to cccski.com, cross country skis are generally long and narrow, allow quick movement, and distribute weight effectively. Dimensions are generally about 2 m in length, 5 cm in width, and 1 to 4 cm in thickness at different sections. Skis are usually fitted to the skier based on height and weight. The toe of the skier's foot is attached to the ski with a binding while the heel remains free. This allows the skier to propel themselves forward and keep the ski in contact with the snow. A higher and more curved tip helps to cut through deep snow. Modern skis use synthetic foam technology as opposed to heavy wooden technology.

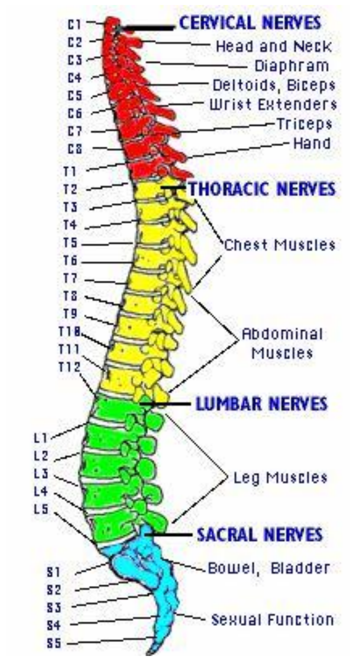


Figure 1. Locations of spinal injuries
Disabled-world.com

The sit ski is a device that is essentially a seat mounted to cross country skis. It enables individuals with lower extremity limitations such as paraplegia, multiple sclerosis, spina bifida, amputations, and cerebral palsy to participate in recreational or competitive skiing.

According to the Spinal Injury Network, "Paraplegia describes complete or incomplete paralysis affecting the legs and possibly also the trunk, but not the arms. The extent to which the trunk is affected depends on the level of spinal cord injury. Paraplegia is the result of damage to the cord at T1 and below." From Figure 1, we see that T1 is the upper-mid region of the spine. This shows that there is a large section of the spine that can lead to paraplegia if injured.

To learn about the particular requirements of a recreational sit ski, we held teleconferences with Jon Kreamelmeyer. According to JK, while there are three common positions, the riders primarily prefer one of two positions: legs-out or tea cup (shown in Figures 2 and 3 respectively). The legs-out position is generally preferred by riders with lesser disabilities who may have some partial movement in the legs. The tea cup position is usually preferred by riders with greater disabilities, such as paraplegia or amputations. The legs-under position, shown in Figure 4, is another way in which some riders choose to be positioned. Our design will allow variability between the legs-out and tea cup position. Dr. Self and JK have expressed that the inclusion of the legs-under option would be a desirable feature, but not necessary. While we have learned a great deal from the conferences with JK, we believe we still need to learn more about the anatomy of the human body and perform group testing in order to achieve comfort and ideal positioning.

JK also discussed the method of attaching to the skis. The two most common binding methods are New Nordic Norm (NNN) and Salomon Nordic System (SNS). The two methods work on the same principals, but with different shaped soles. NNN has two channels that fit into the binding, while SNS only has one channel.

Figure 2. Legs-out position
Picasaweb.google.com

Figure 3. Teacup position
Ablemanagement.com

Figure 4. Legs-under position
History-on-replay.blogspot.com

Spokes n' Motion, Sierra Sit Ski, and Teton (Figures 5, 6, and 7) are several companies that already produce sit ski designs for Paralympic athletes. These existing commercial products are very expensive and generally custom made with very little adjustability and no option of different sitting positions. There are also several existing Cal Poly senior project products that were deemed too heavy and overly adjustable without the option of different sitting positions. This project is focusing on a design which will fit a wide variety of riders and allow for the two different sitting positions, legs out or tea cup, to be chosen by the rider.

Figure 5. Spokes n' Motion Sit Ski
Spokesnmotion.com

Figure 6. Sierra Sit Ski
Sierrasitskis.com

Figure 7. Teton Sit Ski
Tetonsitski.com

Design Development

We started this project by conducting online research and interviewing Dr. Self and JK. This research was used to define the project requirements. We specifically looked at Nordic skiing, current sit skis in existence, varying levels of disabilities, and images and videos of sit skis in use. We exercised multiple brainstorming methods in order to obtain numerous ideas and created conceptual drawings of the different designs. The next step was to create decision matrices evaluating different components of the sit ski design in order to determine the most viable concepts. Further research was conducted after some final ideas were selected in order to determine their feasibility. We also conducted some preliminary testing and analysis by creating conceptual models of specific sit ski components, as shown in Figure 8. The final preliminary design was selected based on our results. At the beginning of winter quarter, the design concept was analyzed and test plans were drafted. During this phase, the drawings, layouts, and bill of materials were created. Once this analysis was complete, modifications were made to the design in order to minimize weight, increase manufacturability, and optimize the ability to accommodate persons of various heights. Once our design is approved, materials will be purchased and construction of the prototype will begin. This will continue through the remainder of the year.

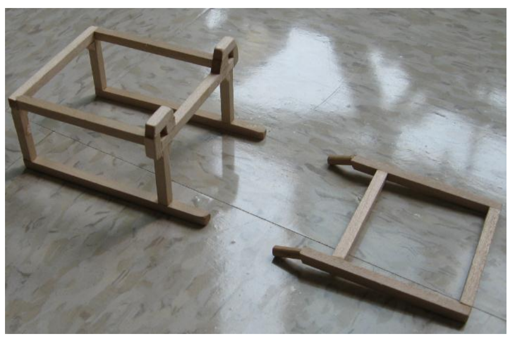


Figure 8. Small wooden model of frame with legs-out attachment.

Ideation

Our team used multiple techniques to generate as many ideas as possible. These ideas focused on how the sit ski will adjust to different leg positions, which materials work best, seat structure, and how the frame will attach to a cross country ski.

One technique we used for idea generation was to create a morphological attributes list. We chose several categories relevant to our overall design, listed many ideas for each category, and connected the different ideas together. This can generate some outrageous ideas that may not work in the real world, but it also produces some that we may not have come up with otherwise. Appendix B shows this list with an example of how a specific solution is chosen.

Another technique we used was plain and simple: brainstorming. This is when all our team members sit together and come up with as many ideas as possible for any aspect of the design. We build off each other’s ideas and at the same time come up with new ones. This process is fairly unorganized, but the quantity of ideas generated is substantial.

Structured Selection Process

In order to help guide us towards the best solutions, we used several weighted decision matrices in varying categories. Each matrix compares the feature in question to that of the sierra sit ski, as we believe it is the best currently available design. The matrix in Table 2 below shows the different options for the method of attaching the frame to the skis. Using different characteristics such as security, durability, and weight, we were able to determine that the free heel method of attachment was best. We did not consider epoxy as it is a permanent method of attaching.

Table 2. Ski attachment decision matrix

	Method of Attaching to Skis											
	weight factor	Free Heel		Bolts		Snap on		Epoxy		Two Bindings		Sierra
Security	4	+	4	0	0	-	-4	0	0	-	-4	0
Durability	3	0	0	0	0	0	0	0	0	0	0	0
Easily Attached	2	0	0	0	0	+	2	-	-2	+	2	0
Tools Required	1	0	0	0	0	+	1	+	1	+	1	0
Weight	5	0	0	0	0	0	0	+	5	0	0	0
Strength	3	0	0	0	0	0	0	0	0	0	0	0
Safety	5	0	0	0	0	-	-5	0	0	-	-5	0
Totals			4		0		-6		4		-6	

Table 3 shows the matrix for the different adjustability options for our design. Because the Sierra Sit Ski does not have adjustability, our options for adjustments seem less favorable in most areas such as weight and cost, which gives us negative totals. Since we must have an adjustable design, we had to choose the least negative total. Since pins and wing nuts are equal, we determined that using pins was best for attaching and removing the modular legs-out piece because they require less time to remove and will not come loose during use.

Table 3. Adjustability decision matrix

	Adjustability											
	weight factor	Pins		Clamps		Snap Lock Poles		Set Screws		Wing nuts		Sierra
Weight	5	-	-5	-2	-10	-	-5	-	-5	-	-5	0
Tools Required	1	0	0	0	0	0	0	-	-1	0	0	0
Cost	3	-	-3	-2	-6	-2	-6	-	-3	-	-3	0
Safety	5	-	-5	-	-5	-	-5	-	-5	-	-5	0
Security	4	-	-4	-	-4	-	-4	-	-4	-	-4	0
Durability	3	-	-3	-	-3	-	-3	-	-3	-	-3	0
Easily Adjusted	5	+	5	+	5	+	5	+	5	+	5	0
Totals			-15		-23		-18		-16		-15	

The matrix in Table 4 compares different options for the seat design that will be implemented. By using different requirements such as comfort and durability, we were able to conclude that no other seat option had an advantage over the standard plastic bucket that is used in many designs. Therefore we have chosen to use a plastic bucket seat for our design.

Table 4. Seat decision matrix

	Seat Structure											
	weight factor	Plastic Bucket		Nylon Mesh		Memory foam bench		Neoprene chair		Folding chair		Sierra
Security	5	0	0	-	-5	-	-5	0	0	-	-5	0
Comfort	4	0	0	0	0	+	4	-	-4	-	-4	0
Weight	5	0	0	+	5	-	-5	-	-5	+	5	0
Durability	3	0	0	+	3	0	0	0	0	-	-3	0
Versatile	3	0	0	0	0	+	3	0	0	0	0	0
Size	4	0	0	0	0	0	0	-	-4	0	0	0
Cost	1	0	0	-	-1	0	0	-	-1	+	1	0
Safety	4	0	0	-	-4	-	-4	0	0	-	-4	0
Readily Available	2	0	0	-	-2	-	-2	0	0	0	0	0
	Totals		0		-2		-9		-14		-10	

The decision matrix in Table 5 compares various frame materials. The matrix shows carbon fiber, steel, and Kevlar to be superior to aluminum. However, for the forces involved, our steel tubing will be very thin, which poses buckling problems. The aluminum will have thicker tubing which will be less prone to buckling. Further analysis will be done to prove this. We do not consider Kevlar and carbon fiber to be viable solutions due its high cost and low manufacturability. Considering cost, strength, and weight, our preliminary choice is aluminum.

Table 5. Frame material decision matrix

	Frame Material														
	weight factor	Aluminum		Carbon Fiber		Steel		Bamboo		Titanium		Kevlar		Sierra
Cost	4	0	0	-	-4	+	4	+	4	-	-4	-	-4	0
Strength	4	0	0	+	4	+	4	-	-4	+	4	+	4	0
Weight	5	0	0	+	5	-	-5	+	5	-	-5	+	5	0
Fatigue Stress	2	0	0	-	-3	+	2	-	-3	0	0	-	-3	0
Stiffness	3		0		0		0		-3		3		0	
Safety	4	0	0	0	0	0	0	-	-4	+	0	0	0	0
Ease of Fabrication	1	0	0	0	-1	+	1	-	-1	0	-1	0	-1	0
	Totals		0		1		6		-6		-3		1	

Preliminary Sketch Descriptions

We have included some initial design sketches below. These sketches show a few of our better ideas that we would like to further develop and analyze.

The sketch in Figure 9 shows a design utilizing a pinned rotating joint. This joint will allow the leg position to be changed from leg out to a tea cup like position. The legs-out position looks potentially weak and would have to be reinforced.

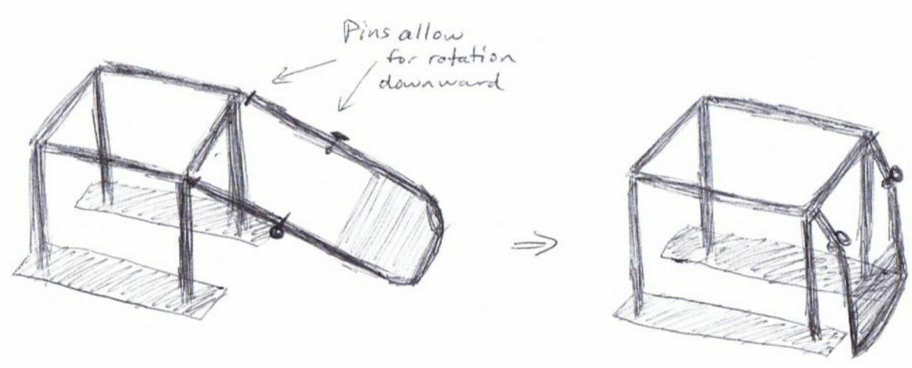


Figure 9. Pinned joint design.

Another design idea incorporates a sliding support member below the leg supports as shown in Figure 10. This would limit the amount of deflection at the feet.

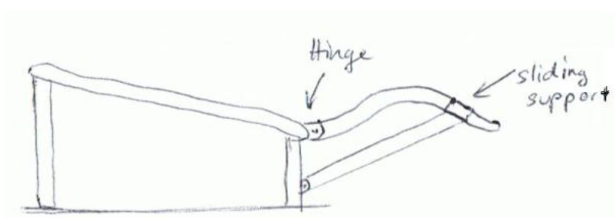


Figure 10. Sliding support design.

Figure 11 shows a sketch of some key features we think will work best. The legs-out position is an attachment that can be removed instead of a permanent fixture that is moved into position. The teacup position will be achieved by removing the attachment and resting the feet on the pads shown below. Because the legs-out piece can be removed when not in use, this design will be very lightweight for the teacup position. It also shows a potential design for our binding system.

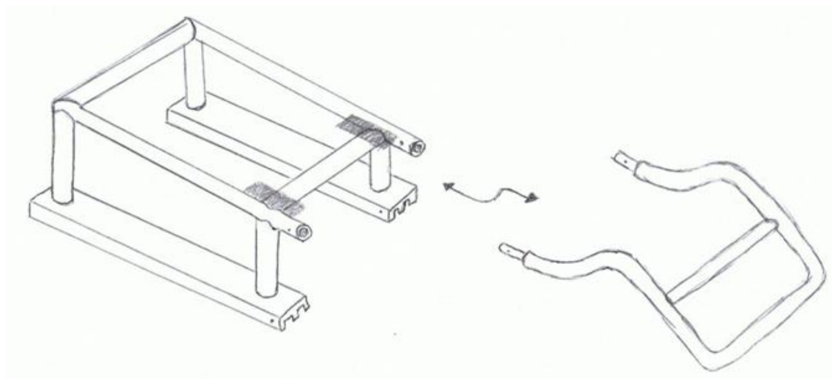


Figure 11. Modular design idea.

Figure 12 shows a sketch of a potential binding design. The bottom of the frame would be machined to match the shape of a standard NNN cross country ski binding. This will eliminate side to side play.

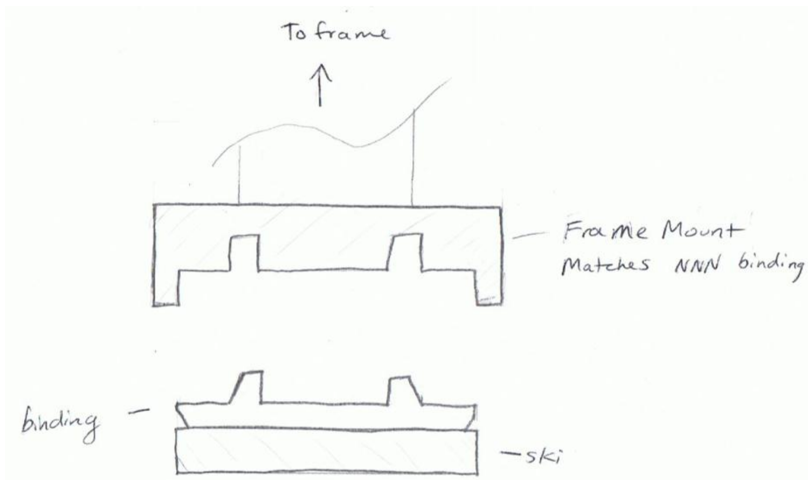


Figure 12. Sketch of potential binding design.

Final Design

Our chosen design concept is shown in Figure 13. The design is an aluminum frame with a large plastic bucket seat and a modular front attachment for legs-out position. We chose these materials for their light weight and strength characteristics. If the teacup position is desired, the attachment can be removed and the user's feet can rest on the flat plate shown across the width of the frame. We decided to purchase a premade plastic bucket seat from Enabling Technologies in lieu of creating a new one, as these seats are lightweight, durable, and have a proven design. The seat is lined with cushioning for comfort and height adjustment. This cushioning is closed-cell foam due to its medium density and resistance to water. The seat is situated to allow the user to sit in an upright sitting position, with the buttocks positioned above the level of the feet. The single binding system is modeled for NNN bindings and adjusts for varying track width. Technical drawings and detailed analysis for our design are shown in Appendices C and D.

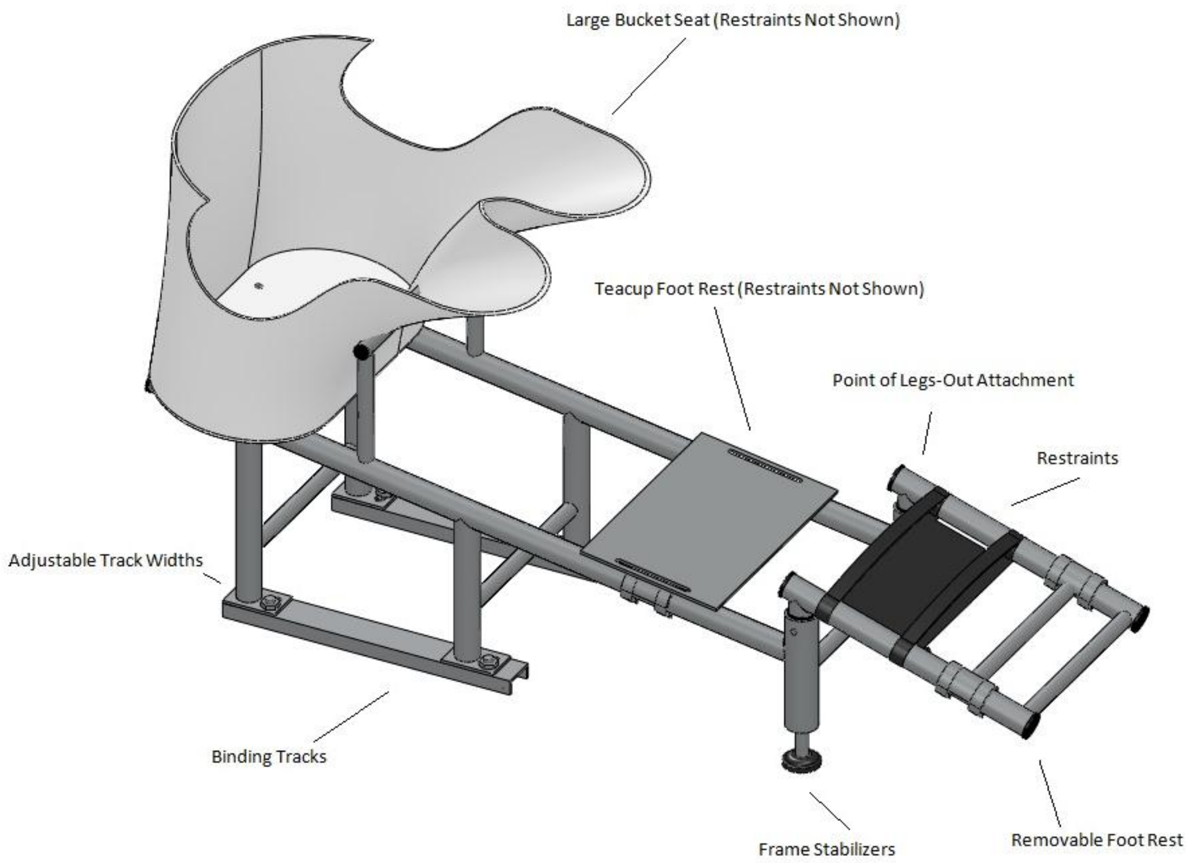


Figure 13. CAD model of design.

Frame

The aluminum frame consists of eight 1" diameter tubes and seven 5/8" diameter tubes. These tubes were welded together and plastic caps plug any open tubes. In order to size the aluminum tubes for the frame, axial loading was calculated. The worst-case scenario that was used concentrated the entire load on a single tube. With a factor of safety of three, we determined that the wall thickness for one inch diameter tubes needed to be 1/16th of an inch. We also calculated the critical buckling load for the aluminum tubes. We calculated that the critical load far exceeded the maximum load that would be applied. The four vertical "legs" of the frame were welded to small aluminum plates and are attached to the U-channel binding with hex screws and lock nuts. This hardware requires minimum tools and remains secure during use. A removable assembly consisting of an aluminum plate welded to a 5/8" diameter tube and attached foot restraints is used as the teacup footrest. Turn-key hose clamps secure the footrest and allow the rider to adjust his/her feet for the teacup position. Polyester seat belt webbing and plastic buckles provide comfort and security for the rider's ankles.

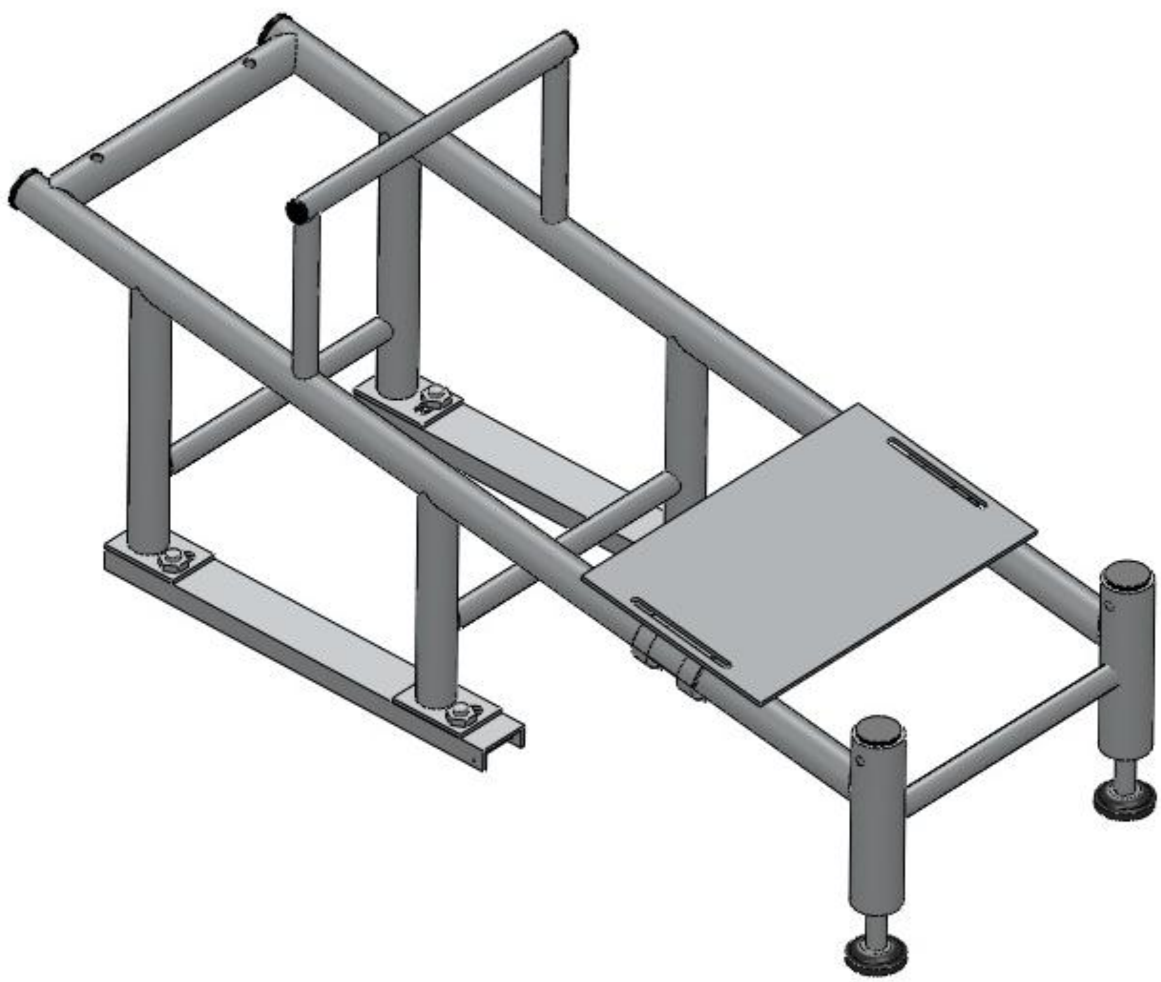


Figure 14. CAD model of frame.

Legs-Out Attachment

The modular attachment slides into the vertical tubes of the frame and is secured by rounded retainer snap safety pins. These retainer pins make the attachment and removal quick and easy since no tools are required. The attachment consists of four 1" diameter tubes and one 5/8" diameter tube. The 5/8" tube is a footrest for the legs-out position and an additional 5/8" tube can be added to the attachment in order to accommodate petite riders. This removable footrest is also secured with turn-key hose clamps. In order to size the aluminum tubes for the attachment, we calculated the maximum bending stress caused by a point load at the forward end of the footrest. The resulting stress was 5,510 pounds per square inch which was well below the 15,000 pounds per square inch yield strength of aluminum. The bending stress was entered into the Modified Goodman Fatigue Analysis Method in order to determine whether the design would fail under worst case loading conditions in fatigue. We calculated that our design will not fail and has a factor of safety of 2.27. We also calculated the deflection caused by this loading, which provided a result of 0.051 inches. This deflection is acceptable because it proves that the individual's feet will be supported during use. Separate leg restraints are attached for the legs-out position.

Figure 15. CAD model of attachment.

Single Binding System

The ski mounts on the bottom of the frame are constructed using a U-channel and a set of plastic inserts. The inserts modeled the bottom of a NNN ski boot. These inserts were rapid-prototyped in ABS plastic and are press-fit into place. This design only required a single binding which allows the sit ski to easily fit into standard cross country ski bindings. The ski mounts are also able to slide side-to-side to adjust the track width. The slots give the user the ability to vary the center-to-center distance. Our free heel design works by snapping a pin on the front of the base into the binding, like a standard boot. These pins are machine screws held to the frame with lock nuts. This makes them easy to replace should they ever break. The mounting area sits on top of the thick portion of the ski. This ensures that the weight of the rider is above the balance point of the skis. In front of the binding, we used all thread with rubber feet as frame stabilizers for the sit ski. This tightening system applies pressure downward on the skis which forces the free back end of the mounting area into the ski, keeping the skis secured to the frame.

Seat

A large bucket seat was purchased from Enabling Technologies. Abdomen and thigh restraints made of polyester webbing and plastic buckles are bolted to the seat. Closed-cell foam padding is used as cushioning and extra padding is provided should the rider need extra security. The seat is secured to the aluminum tube with hex screws and lock nuts.

Materials and Cost

The materials required for this design include 6063-T5 aluminum, the plastic bucket seat, closed-cell foam padding, polyester webbing, plastic buckles, rapid-prototyped plastic inserts, and various hardware. The complete list is in Appendix E. The total cost of these items was $595.56. In addition to the materials cost, $285 was spent on welding and powder coating. This adds up to a grand total of $880.56 for the sit ski prototype.

Safety Considerations

Safety has been and will continue to be the highest priority for this project. Providing a design that is safe will ensure that we provide a fun experience for everyone who uses it. During the design process, we selected aluminum that would far exceed the loads that an individual would apply and modeled our design after the proven concepts of previous senior projects and current products. We focused on eliminating pinch points and sharp edges and made sure to select hardware that would not come loose during use. Due to the lower extremity disabilities that our users have, we want to ensure that they do not fall out of the sit ski or develop pressure sores. For this reason, we have multiple restraints in our design and selected medium density foam for their support and comfort.

Product Realization

Frame

Our frame is made of 6063 T5 Aluminum tubes of varying diameters. We cut the tubes to length on a large horizontal band saw. This is accurate to 1/16". We then notched the tubes using the Tube Shark tubing notcher in the Mustang 60 shop. This allowed us to cut the notches at specific angles and diameters. Sharp edges and burrs were removed with a deburring tool and filed smooth. Figures 16 and 17 below show this process.

Figure 16 Close-up of tube notching.

Figure 17 Tube notching in action.

Once all the tubes were cut and notched, Chris Gentry of Gentry Welding and Fabrication TIG welded the frame and legs-out attachment together. The completed frame is shown in Figure 18.

Figure 18 Welded frame.

On a lathe, we drilled and tapped a solid aluminum rod to be welded into the two front vertical tubes of our frame. After cutting them to length, we welded them into the frame. We screw all-thread into these plugs to apply pressure on the skis.

Once the frame was complete, we took it to Central Coast Powdercoating for finishing. The blue powder-coated frame is shown Figure 19.

Figure 19 Powder-coated frame.

Ski Binding

Our binding system consists of 1/8” plates that are welded to the legs of our frame and bolted to 1/8” U channel. We cut the small plates and U-channel to length on a large horizontal band saw. Using a manual mill, we notched slots into each to allow them to be bolted together and adjusted side-to-side for varying track width. We then drilled a hole in the side of the U-channel for the machine screw that we use to clip into the ski’s binding. We had to round the edges of the U-channel to allow clearance for the shape of the binding.

Foot Restraints

Legs-Out Attachment

We made a sliding adjustable footrest that is clamped onto the legs-out attachment frame. This was made by cutting an aluminum tube in half lengthwise to create two half cylinders. These are then welded to a tube that we notched on the Tube Shark tube notcher. We attached them to the legs-out frame using turn-key hose clamps.

Teacup

For the teacup position, we welded a 6” X 10” to a U-channel with two half tubes on the end. This is attached to the main frame with turn-key hose clamps.

We cut the foot plate to length with a large horizontal band saw. Then using a manual mill, we notched two slots on either side to attach the restraints. On the face of the plate, we engraved our logo using a Haas CNC machine, as shown in Figure 20.

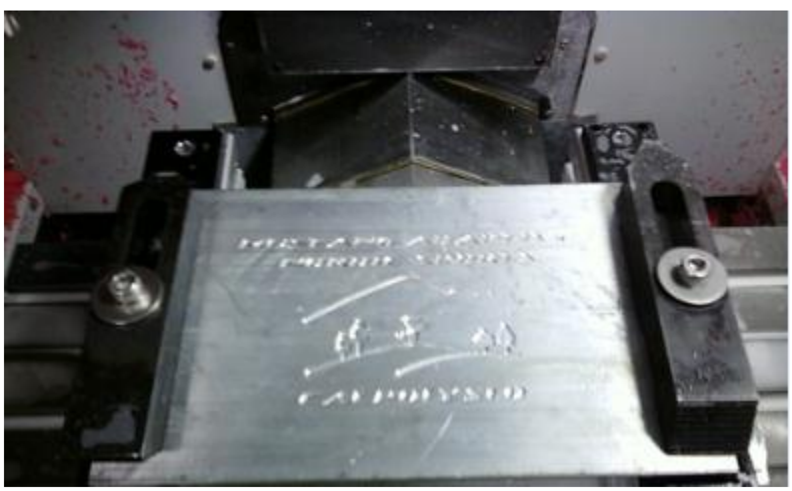


Figure 20 Engraved foot plate.

Straps

We used wide nylon seatbelt webbing for our foot restraints. We fed the straps through the plastic buckles, folded the strap back on itself, and sewed it in place with heavy duty nylon thread. This way the buckles cannot fall off and get lost.

Seat

We ordered the seat through Enabling Technologies. We drilled holes in the bottom of the seat to attach it to the frame. We also cut the closed cell foam to fit the shape of the seat and used Velcro to attach it. The legs of the seat were too long for our application, so we cut off the excess using tin snips and filed the edges smooth. This process is shown in Figure 21.

Figure 21 Seat material removal.

Design Verification

To verify that our final design met the initial requirements, we set up test plans to experimentally evaluate various aspects of the sit ski. A table of all tests and inspections is attached as Appendix G and detailed instructions of the test plans are in Appendix H. After completing all of the tests, we found that our prototype successfully met all of the specifications of this project. Our adjustable footrests exceeded our expectations as far as accommodating riders of various heights. We were able to comfortably accommodate a 5’4” and 6’6” rider, as shown in Figures 22 and 23. Figures 24 and 25 below show some of the other tests that were performed.

Figure 22 5’4” rider.

Figure 23 6’6” rider.

Figure 24 Timed assembly with non-group member.

Figure 25 Final inspection.

Conclusion and Recommendations

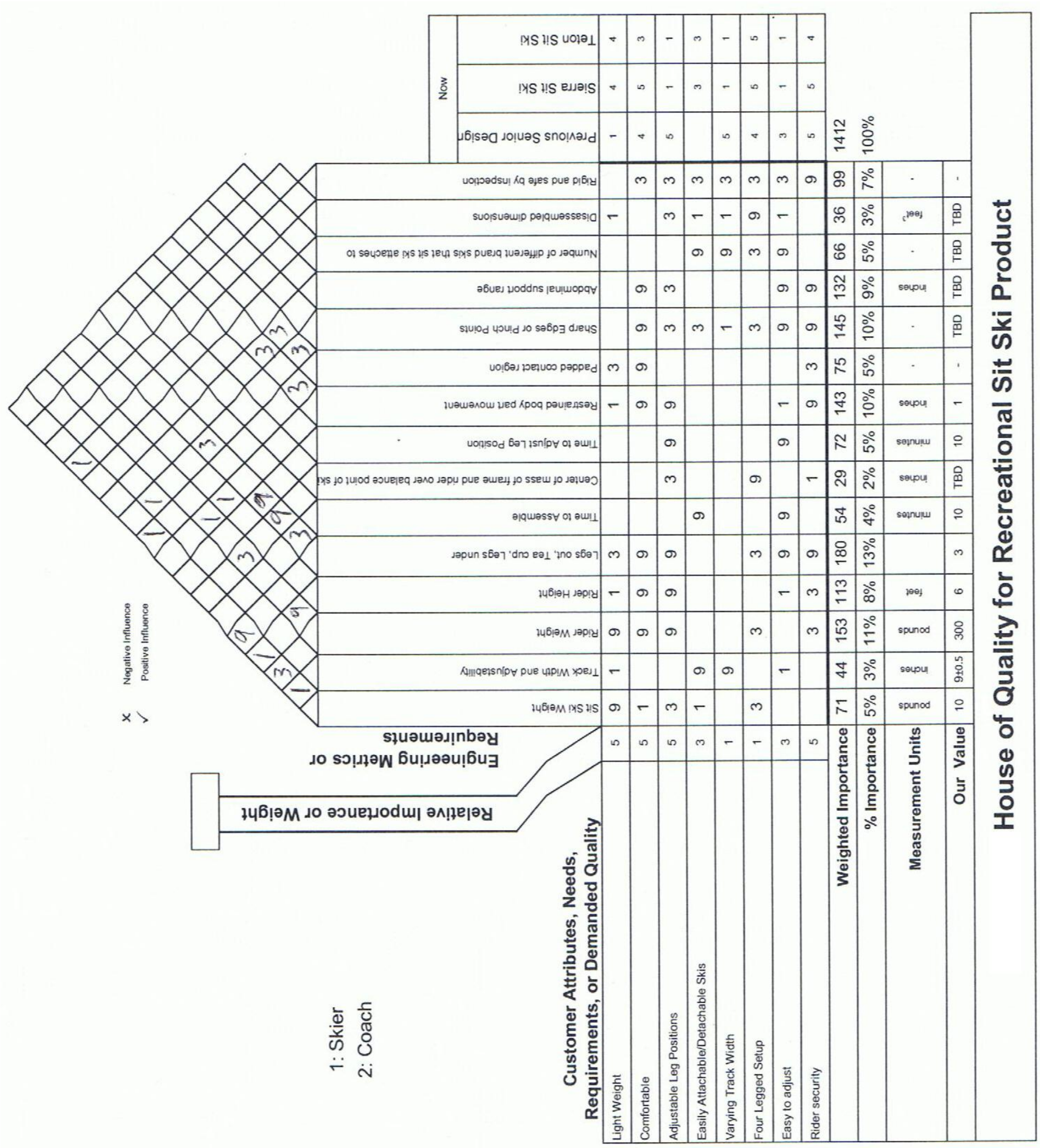
The goal of this project was to design, build, and test an adjustable sit ski that is lightweight and accommodates different users. Our design accommodates two leg positions, including legs-out and teacup, where legs-out is a separate attachment. The project was successful as a whole. We have achieved a final weight of 9.7 - 10.5 pounds, depending on the leg position of the rider. This essentially fulfills the weight requirement of 10 pounds or less.

The main thing that can be improved upon is the weight of the design. The plastic bucket seat and closed-cell foam weigh substantially more than we expected, which caused the final weight to exceed 10 pounds in some instances. Obtaining thinner foam would minimize the added weight.

Other recommendations include deeper U-channels used for the binding system in order to increase the ease of attachment. Angling the footrest of the teacup attachment toward the user or modifying the legs-out attachment so that it could be reversed would create a more comfortable riding position. These discoveries did not occur until the manufacturing and testing phases of the project.

Designing a new recreational sit ski was a great experience for our team and we enjoyed building and testing our final design.

Quality Function Deployment



Customer Attributes, Needs, Requirements, or Demanded Quality	Weight	Sit Ski Weight	Track Width and Adjustability	Rider Weight	Rider Height	Legs out, Tea cup, Legs under	Time to Assemble	Center of mass of frame and rider over balance point of ski	Time to Adjust Leg Position	Restrained body part movement	Padded contact region	Sharp Edges or Pinch Points	Abdominal support range	Number of different brand skis that sit ski attaches to	Disassembled dimensions	Rigid and safe by inspection	Previous Senior Design	Sierra Sit Ski	Teton Sit Ski
Light Weight	5	9	1	9	1	3				1	3				1		1	4	4
Comfortable	5	1		9	9	9				9	9	9	9			3	4	5	3
Adjustable Leg Positions	5	3		9	9	9		3	9	9		3	3		3	3	5	1	1
Easily Attachable/Detachable Skis	3	1	9				9					3		9	1	3		3	3
Varying Track Width	1		9									1		9	1	3	5	1	1
Four Legged Setup	1	3		3		3		9				3		3	9	3	4	5	5
Easy to adjust	3		1		1	9	9		9	1		9	9	9	1	3	3	1	1
Rider security	5			3	3	9		1		9	3	9	9			9	5	5	4
Weighted Importance		71	44	153	113	180	54	29	72	143	75	145	132	66	36	99	1412		
% Importance		5%	3%	11%	8%	13%	4%	2%	5%	10%	5%	10%	9%	5%	3%	7%	100%		
Measurement Units		pounds	inches	pounds	feet		minutes	inches	minutes	inches	-	-	inches	-	feet³	-			
Our Value		10	9±0.5	300	6	3	10	TBD	10	1	-	TBD	TBD	TBD	TBD	-			

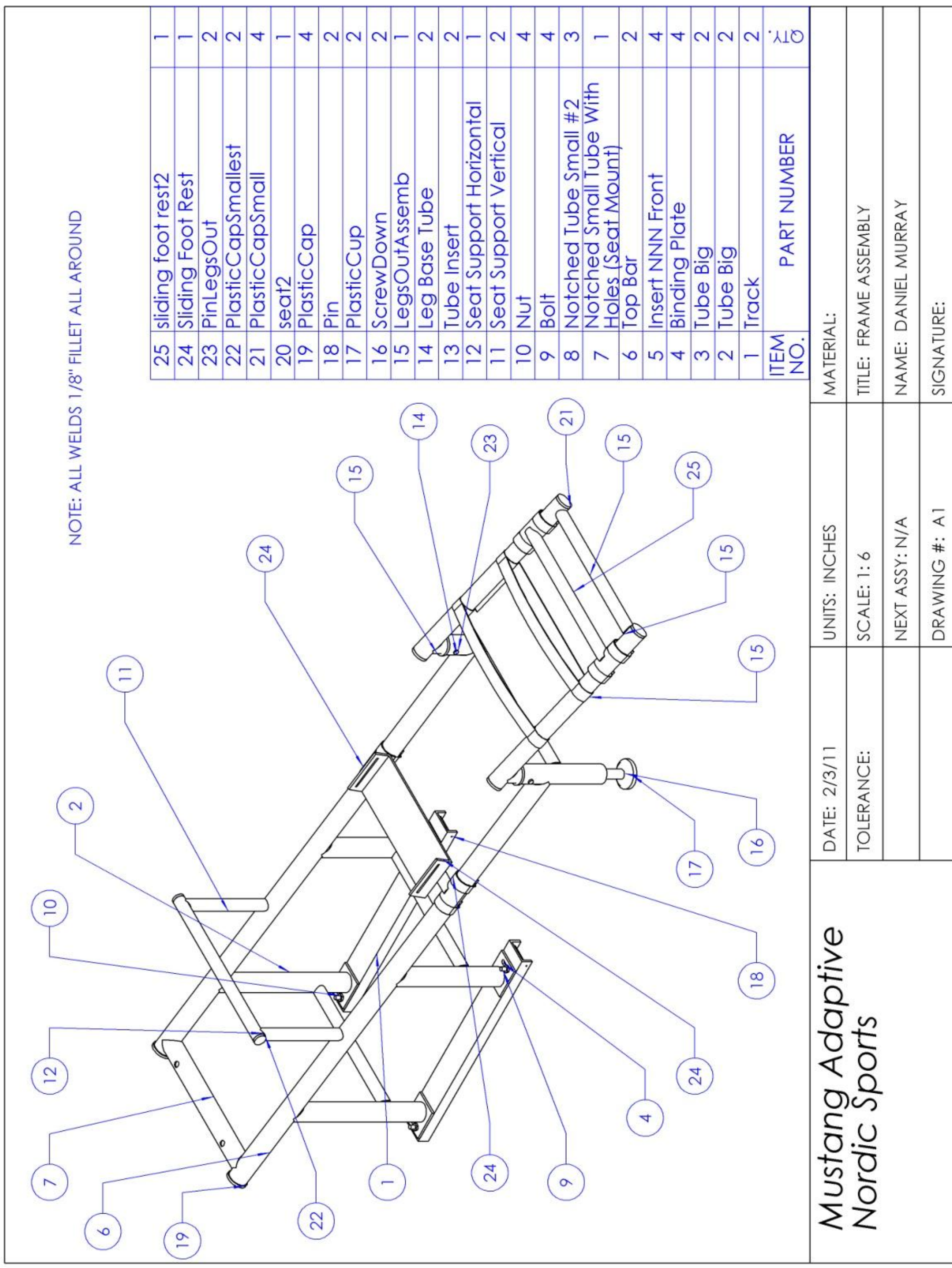
House of Quality for Recreational Sit Ski Product

Morphological Attributes List

Attach to Skis	Leg Position	Seat	Adjustability	Frame
2 bindings	gears	bucket	pins	aluminum
glue	rubber bands	foam	clamp	concrete
free heel	snap on attachmen	down feathers	gears	foam
bolts	carabiner	hammock	rubber bands	4 legged square structure
snap on attachment	screws	mesh	springs	carbon fiber
tape	springs	spider web	cotter pin	steel
clasps	bending rubber	pole holders	telescoping poles	ice
ropes	wheelchair clamp	ziplock bags	wheels	plastic
epoxy	zip tie	tempurpedic material	snap ring	particle board
rubber cement	clothes pin	rubber	power screw	triangulate
binding front	magnets	lazy boy	pulleys	PVC
bolt through hole for hee	stick on	toilet seat		french fries
zip tie	pin joint	plywood		bamboo
clay	hydraulics	seashell		titanium
maple syrup	bearings	starfish shape		balsa wood
rivits	ball and socket	bowl		welding
	telekinesis	5 point harness		glue
		bike seat		brazing
		car seat (baby style)		JB weld
		sliding row seat		epoxy
		ice cream		press fit
		ice cream cone		nuts and bolts
		cotton		twigs
		couch		pine needles
		barstool		spaghetti noodles
		bench		pennies
		nylon		platinum
		leather		playdoh (homemade)
		fingernails		ceramic
		tissues		foil
		waterfilled seat		paper clips
		neoprene		
		wool		
		silicone		

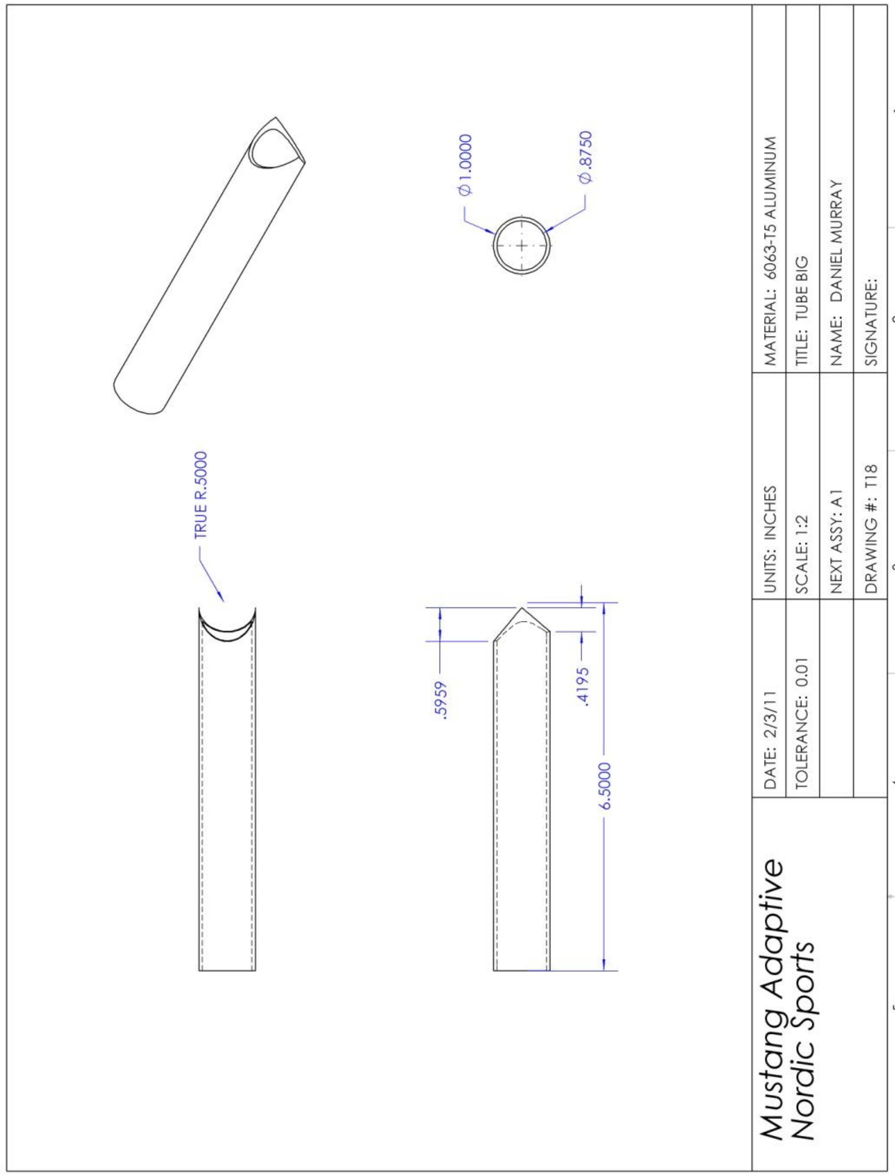
Appendix C

Technical Drawings



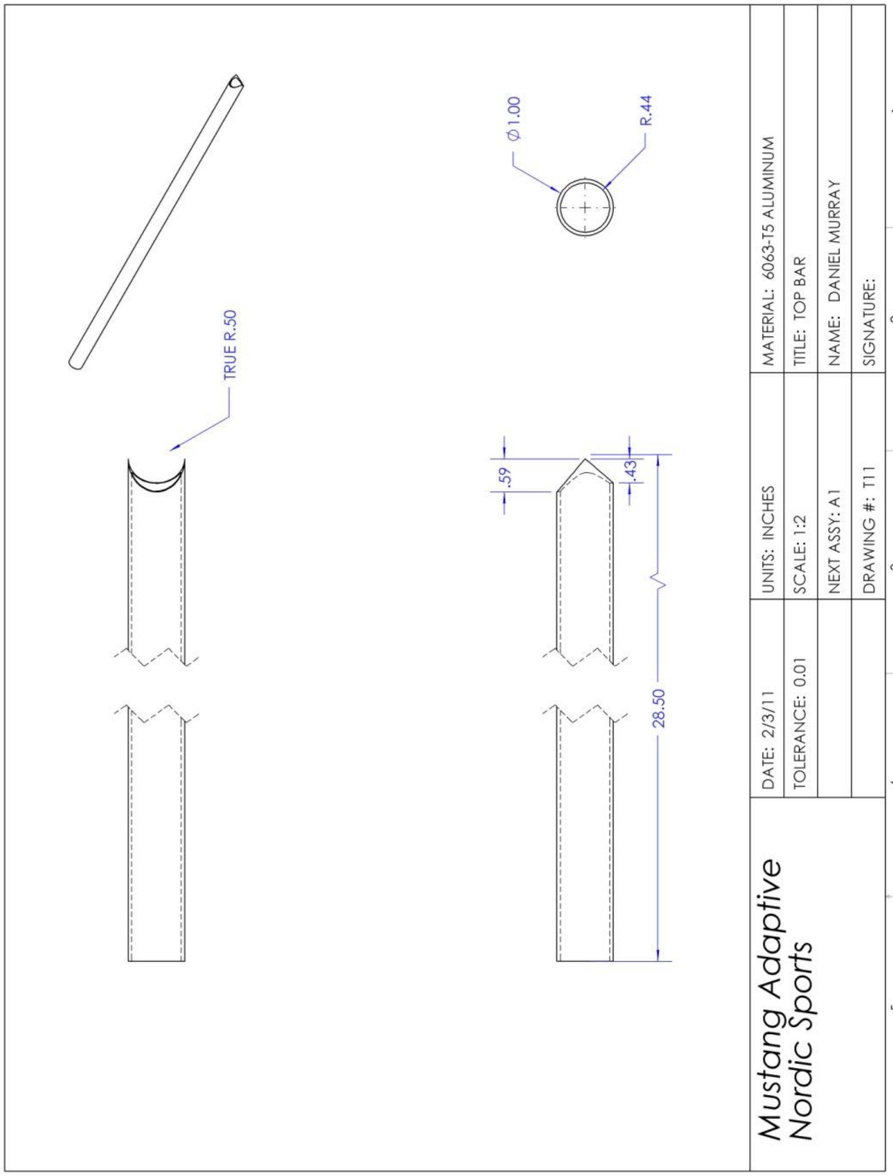
ITEM NO.	PART NUMBER	QTY.
25	sliding foot rest2	1
24	Sliding Foot Rest	1
23	PinLegsOut	2
22	PlasticCapSmallest	2
21	PlasticCapSmall	4
20	seat2	1
19	PlasticCap	4
18	Pin	2
17	PlasticCup	2
16	ScrewDown	2
15	LegsOutAssemb	1
14	Leg Base Tube	2
13	Tube Insert	2
12	Seat Support Horizontal	1
11	Seat Support Vertical	2
10	Nut	4
9	Bolt	4
8	Notched Tube Small #2	3
7	Notched Small Tube With Holes (Seat Mount)	1
6	Top Bar	2
5	Insert NNN Front	4
4	Binding Plate	4
3	Tube Big	2
2	Tube Big	2
1	Track	2

Appendix C



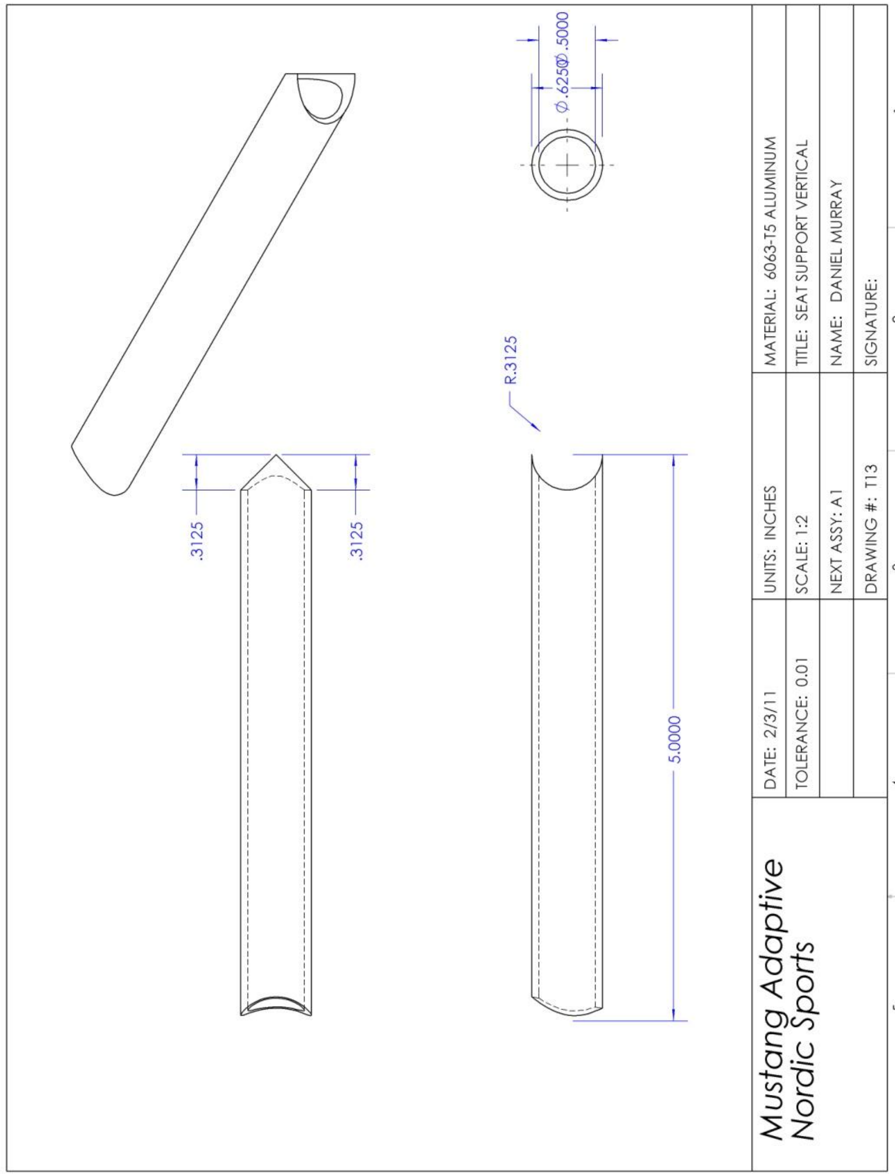
TRUE R.5000
Ø1.0000
Ø.8750
.5959
.4195
6.5000
Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:2
NEXT ASSY: A1
DRAWING #: T18
MATERIAL: 6063-T5 ALUMINUM
TITLE: TUBE BIG
NAME: DANIEL MURRAY
SIGNATURE:
1
2
3
4
5

Appendix C



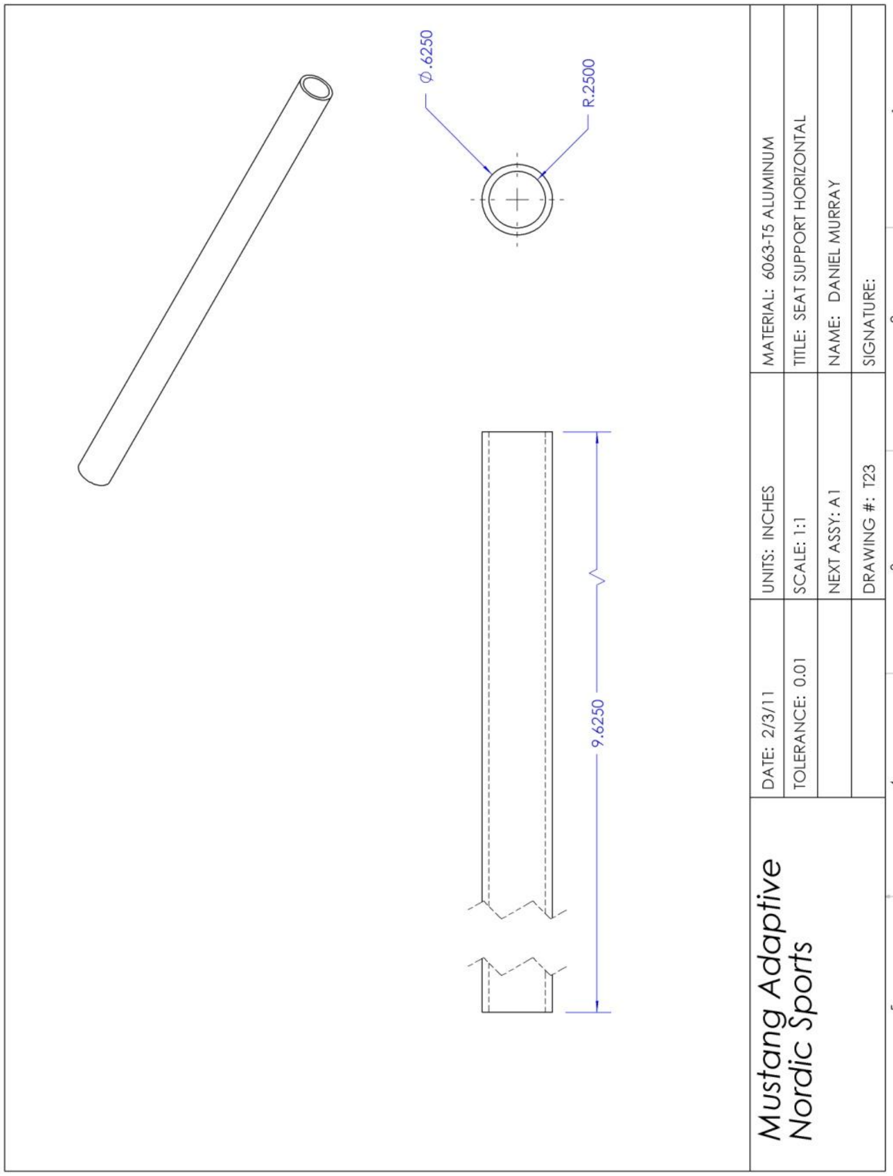
TRUE R.50
∅1.00
R.44
.59
.43
28.50
Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:2
NEXT ASSY: A1
DRAWING #: T11
MATERIAL: 6063-T5 ALUMINUM
TITLE: TOP BAR
NAME: DANIEL MURRAY
SIGNATURE:
1
2
3
4
5

Appendix C



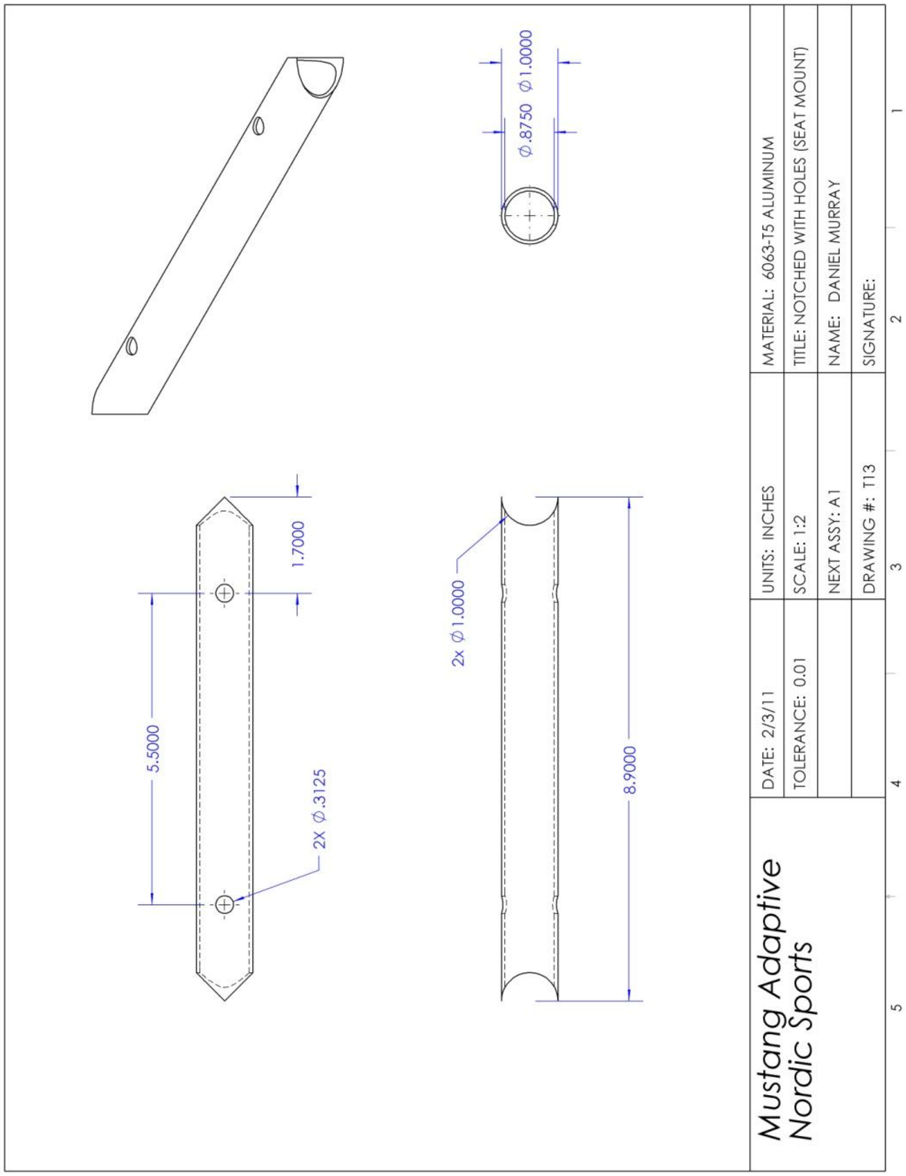
Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:2
NEXT ASSY: A1
DRAWING #: T13
MATERIAL: 6063-T5 ALUMINUM
TITLE: SEAT SUPPORT VERTICAL
NAME: DANIEL MURRAY
SIGNATURE:
.3125
.3125
R.3125
5.0000
Ø.6250
Ø.5000
1
2
3
4
5

Appendix C

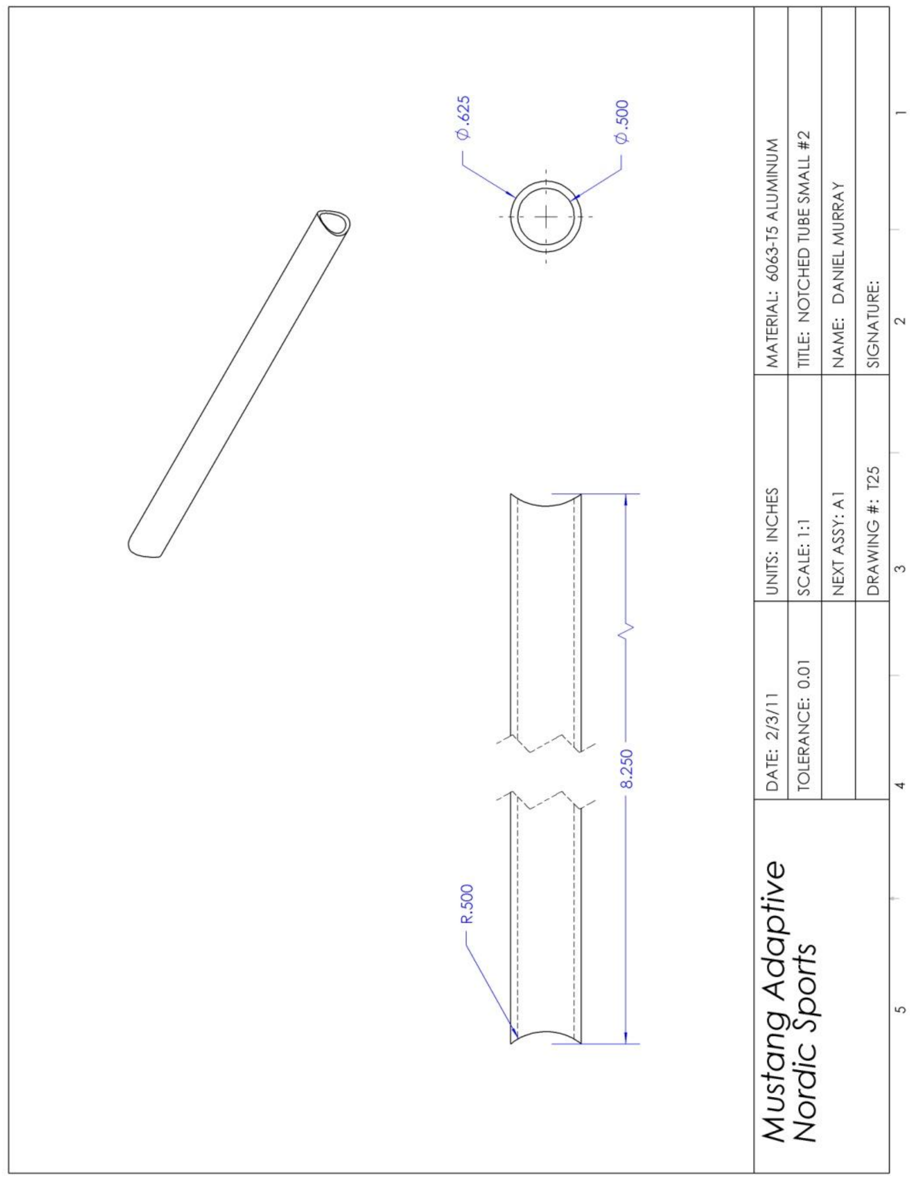


Ø.6250
R.2500
9.6250
Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:1
NEXT ASSY: A1
DRAWING #: T23
MATERIAL: 6063-T5 ALUMINUM
TITLE: SEAT SUPPORT HORIZONTAL
NAME: DANIEL MURRAY
SIGNATURE:
1
2
3
4
5

Appendix C

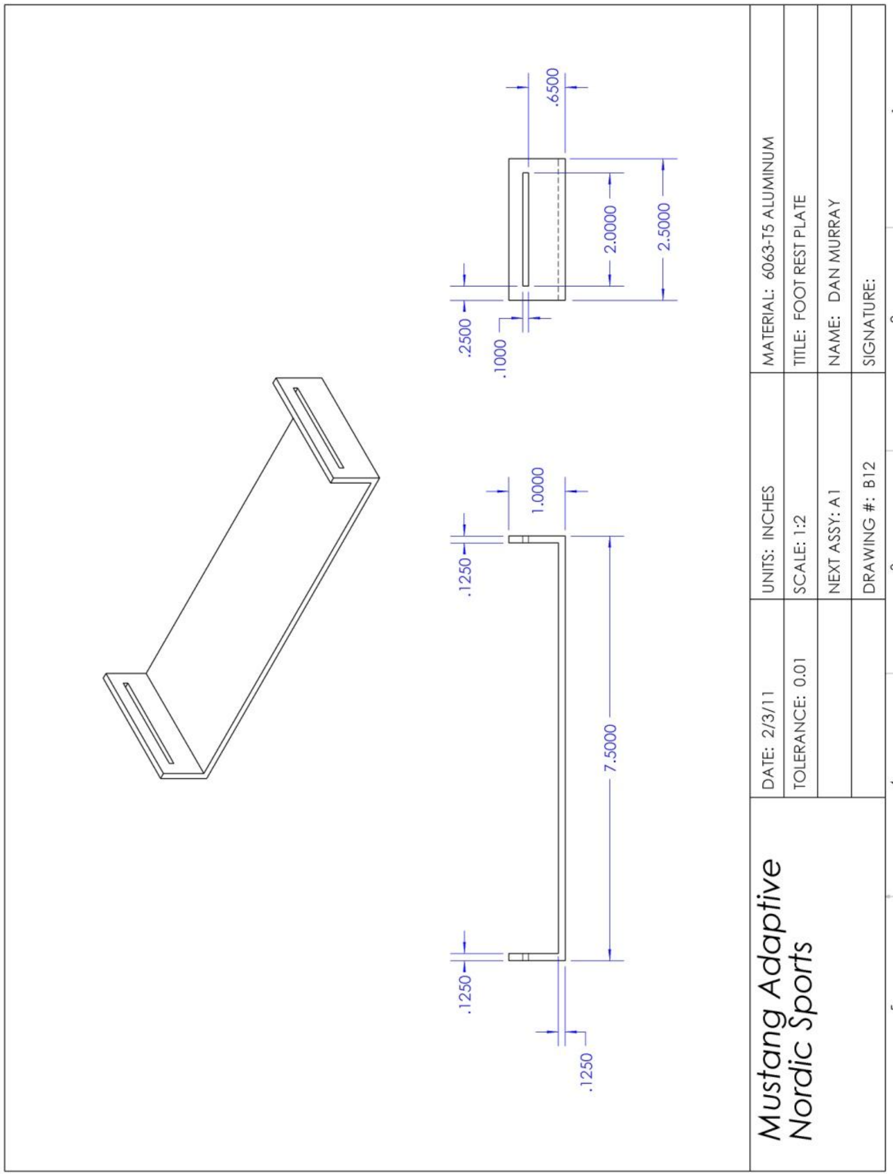

MATERIAL: 6063-T5 ALUMINUM
TITLE: NOTCHED WITH HOLES (SEAT MOUNT)
NAME: DANIEL MURRAY
SIGNATURE:
UNITS: INCHES
SCALE: 1:2
NEXT ASSY: A1
DRAWING #: T13
DATE: 2/3/11
TOLERANCE: 0.01
Mustang Adaptive
Nordic Sports
Ø.8750
Ø1.0000
1.7000
5.5000
2X Ø.3125
2x Ø1.0000
8.9000
1
2
3
4
5

Appendix C

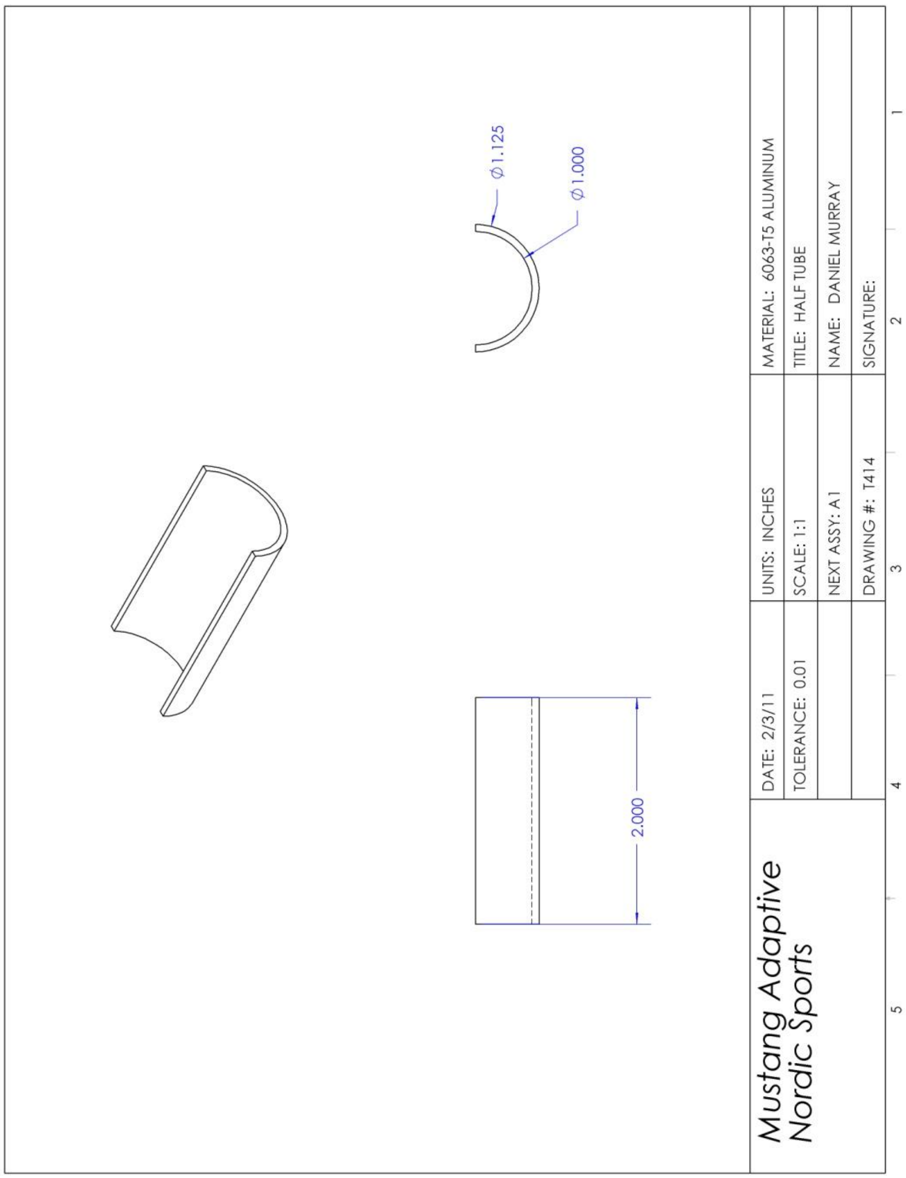


Ø.625
Ø.500
R.500
8.250
Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:1
NEXT ASSY: A1
DRAWING #: T25
MATERIAL: 6063-T5 ALUMINUM
TITLE: NOTCHED TUBE SMALL #2
NAME: DANIEL MURRAY
SIGNATURE:
1
2
3
4
5

Appendix C

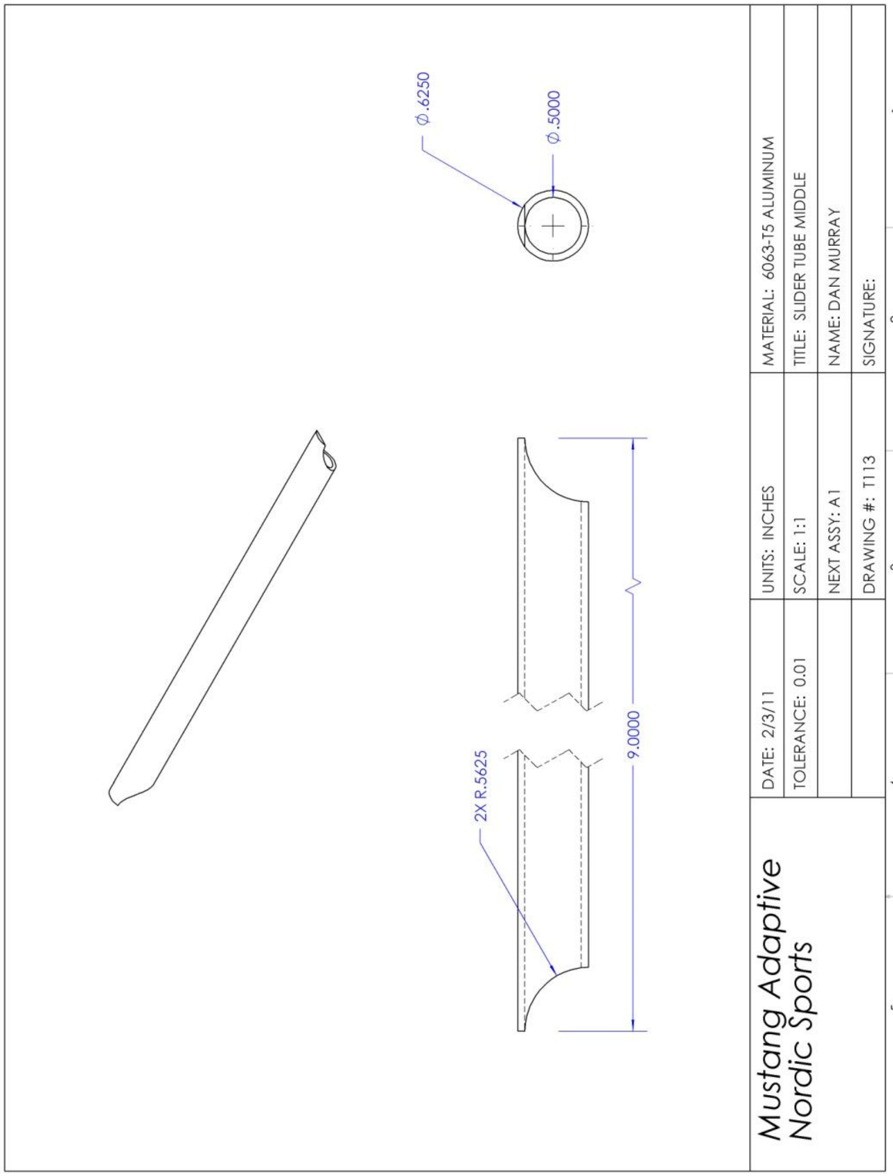

.6500
2.0000
2.5000
.2500
.1000
1.0000
.1250
7.5000
.1250
.1250
MATERIAL: 6063-T5 ALUMINUM
TITLE: FOOT REST PLATE
NAME: DAN MURRAY
SIGNATURE:
DATE: 2/3/11
UNITS: INCHES
TOLERANCE: 0.01
SCALE: 1:2
NEXT ASSY: A1
DRAWING #: B12
Mustang Adaptive Nordic Sports

Appendix C

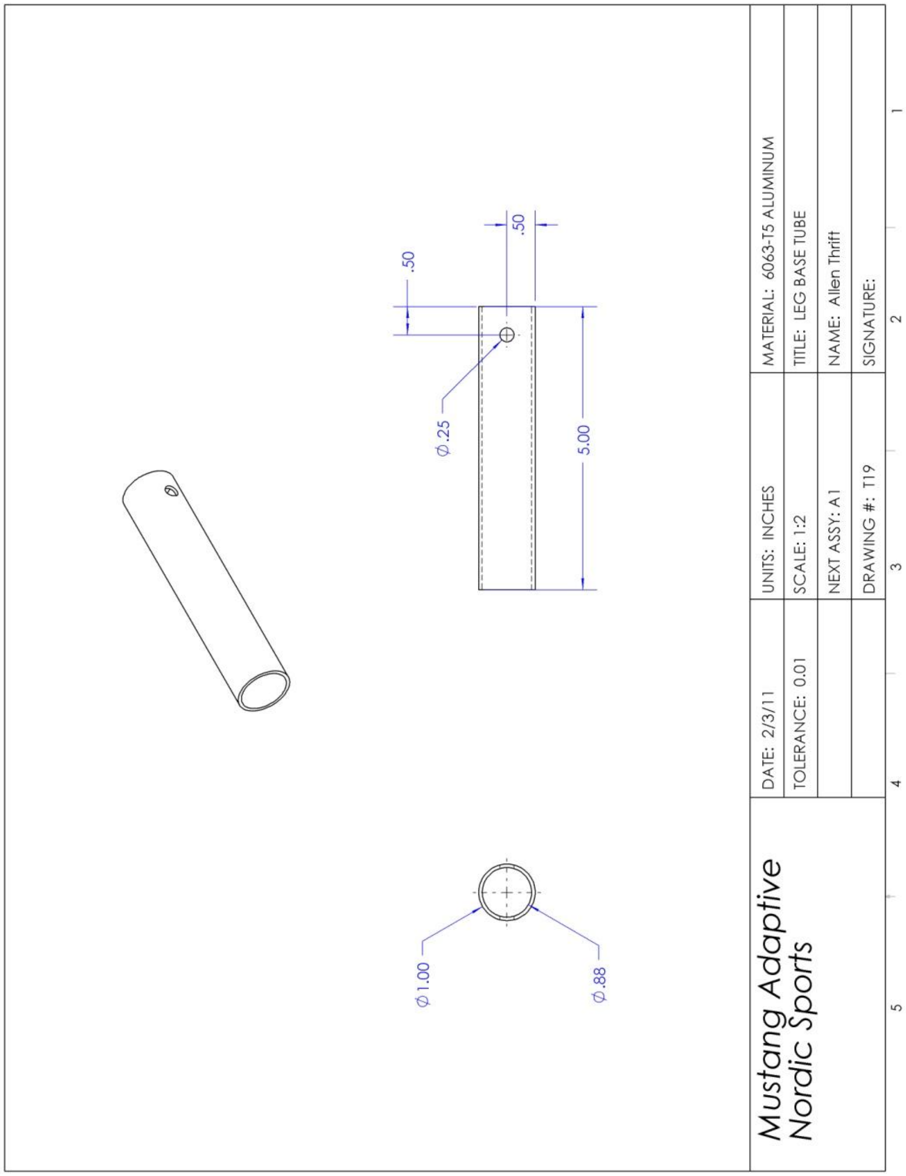


Ø1.125
Ø1.000
2.000
MATERIAL: 6063-T5 ALUMINUM
TITLE: HALF TUBE
NAME: DANIEL MURRAY
SIGNATURE:
UNITS: INCHES
SCALE: 1:1
NEXT ASSY: A1
DRAWING #: T414
DATE: 2/3/11
TOLERANCE: 0.01
Mustang Adaptive Nordic Sports
1
2
3
4
5

Appendix C

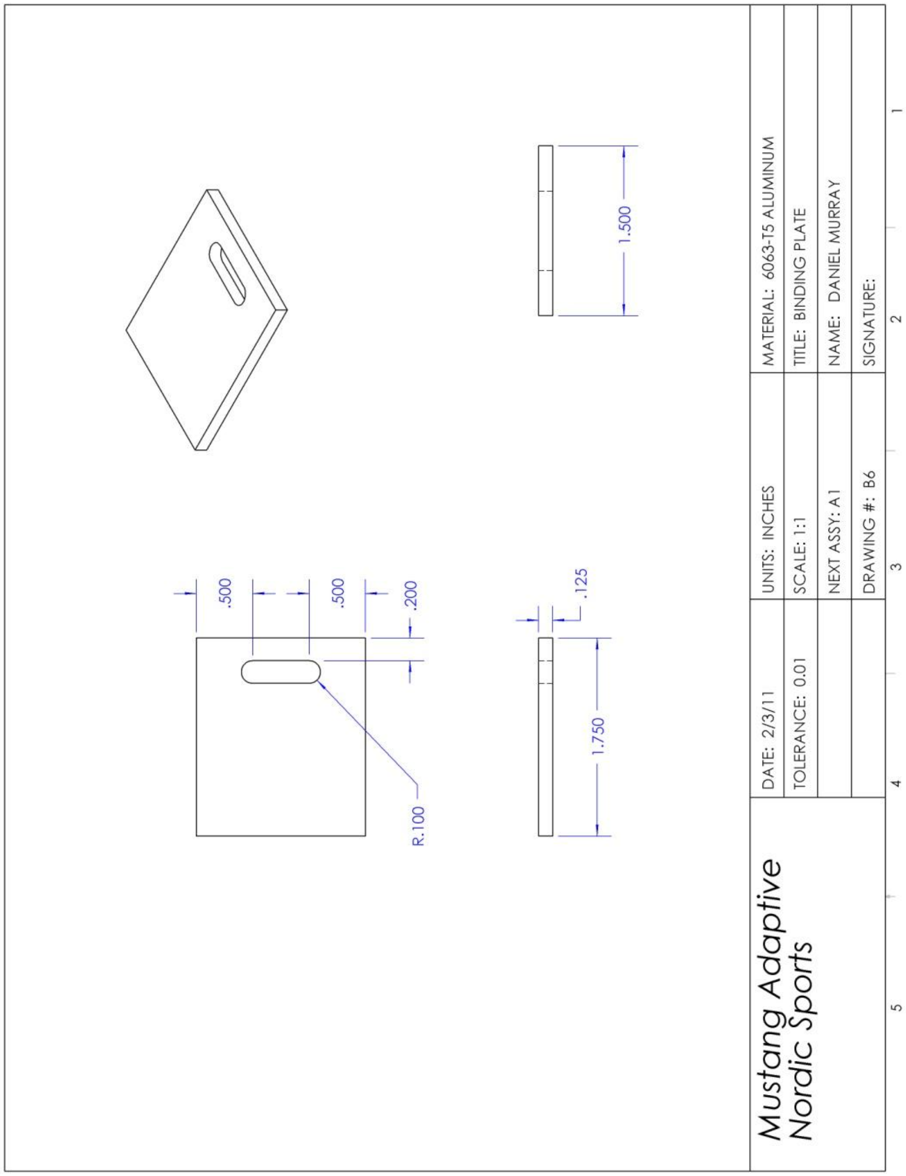

Ø.6250
Ø.5000
2X R.5625
9.0000
MATERIAL: 6063-T5 ALUMINUM
TITLE: SLIDER TUBE MIDDLE
NAME: DAN MURRAY
SIGNATURE:
UNITS: INCHES
SCALE: 1:1
NEXT ASSY: A1
DRAWING #: T113
DATE: 2/3/11
TOLERANCE: 0.01
Mustang Adaptive Nordic Sports

Appendix C



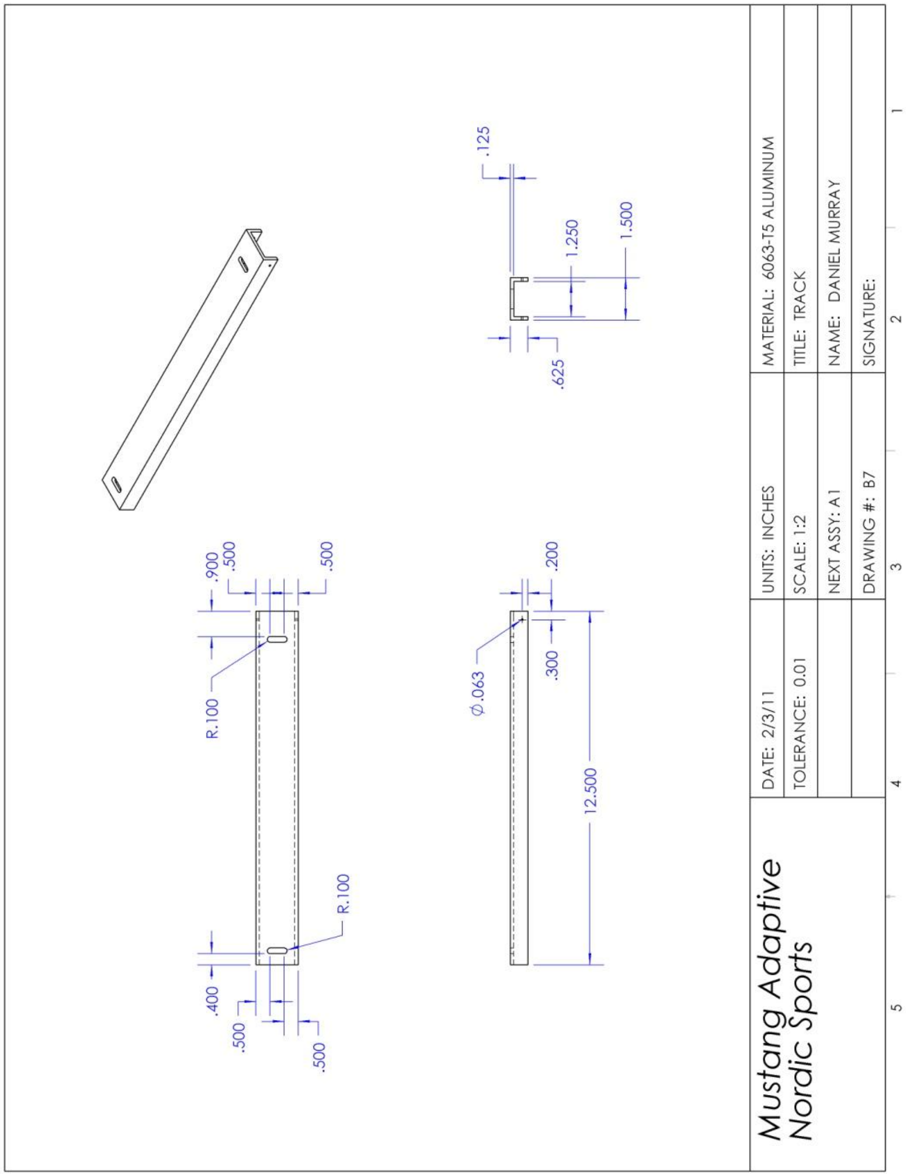
Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:2
NEXT ASSY: A1
DRAWING #: T19
MATERIAL: 6063-T5 ALUMINUM
TITLE: LEG BASE TUBE
NAME: Allen Thrift
SIGNATURE:
Ø1.00
Ø.88
Ø.25
5.00
.50
.50
1
2
3
4
5

Appendix C

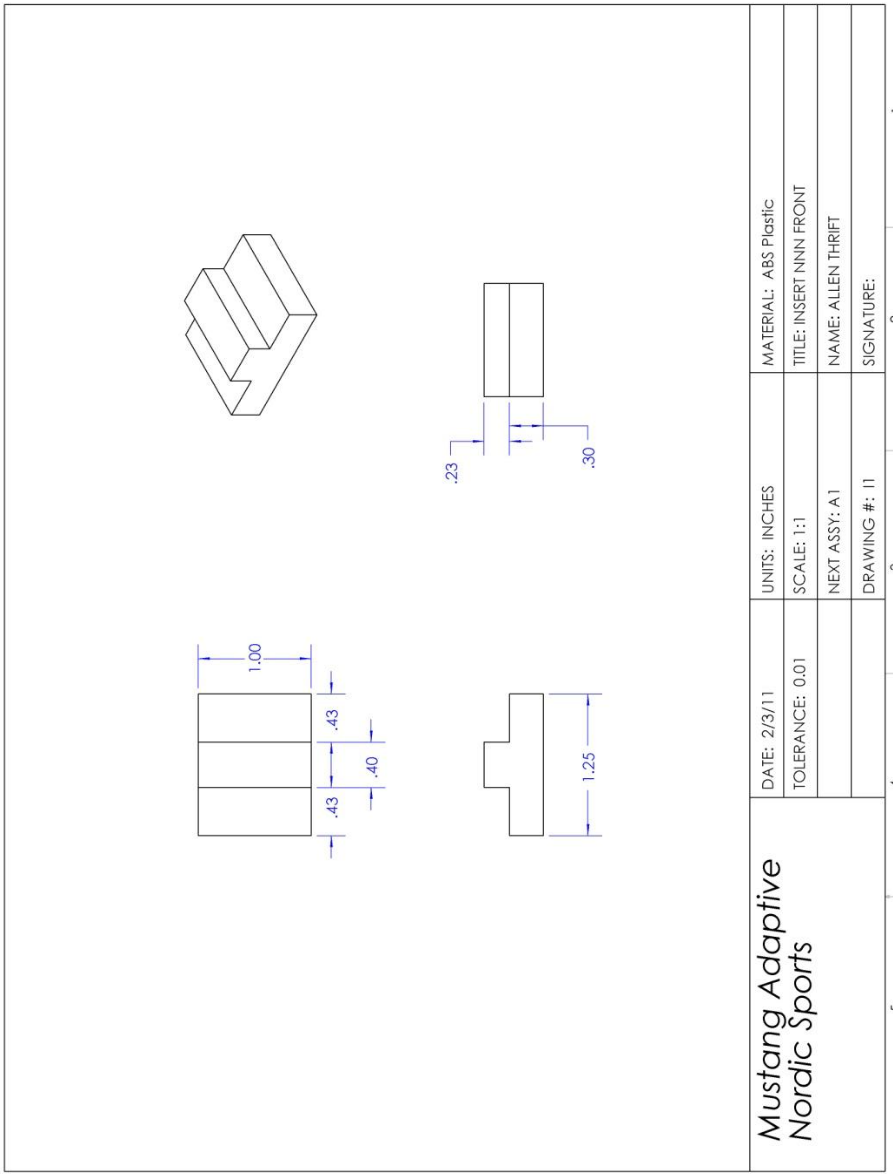


.500
.500
.200
.125
R.100
1.750
1.500
Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:1
NEXT ASSY: A1
DRAWING #: B6
MATERIAL: 6063-T5 ALUMINUM
TITLE: BINDING PLATE
NAME: DANIEL MURRAY
SIGNATURE:

Appendix C

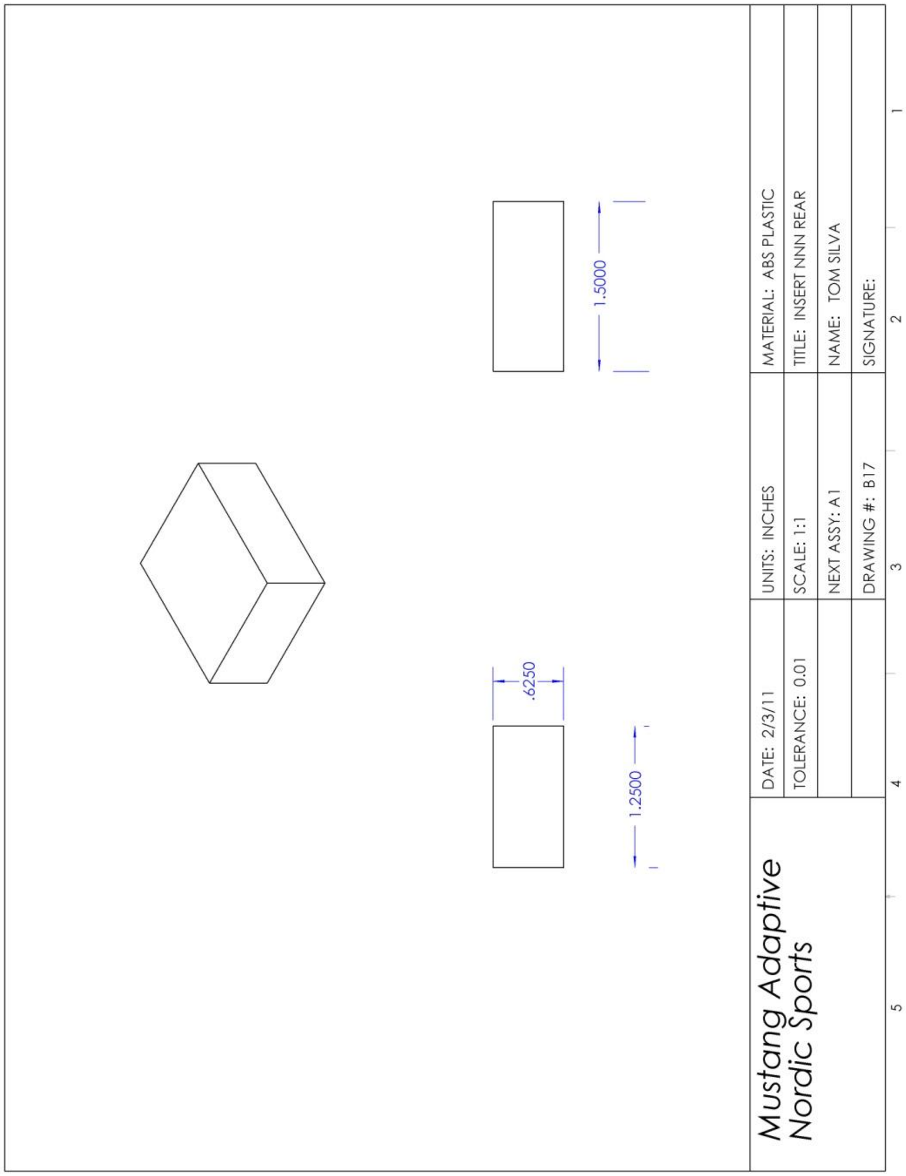

Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:2
NEXT ASSY: A1
DRAWING #: B7
MATERIAL: 6063-T5 ALUMINUM
TITLE: TRACK
NAME: DANIEL MURRAY
SIGNATURE:
.900
.500
.500
R.100
R.100
.400
.500
.500
.125
1.250
1.500
.625
.200
.300
⌀.063
12.500
1
2
3
4
5

Appendix C

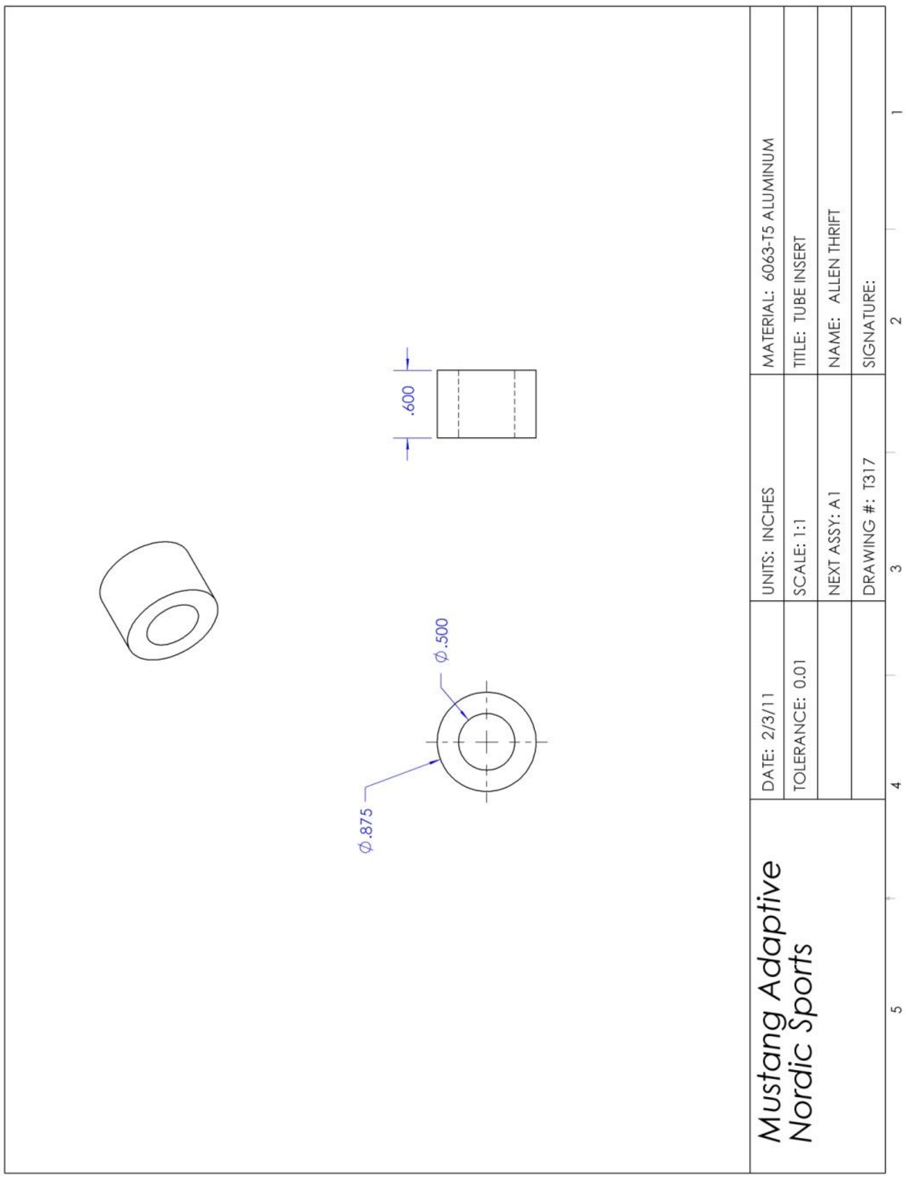


1.00
.43
.40
.43
1.25
.23
.30
Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:1
NEXT ASSY: A1
DRAWING #: 11
MATERIAL: ABS Plastic
TITLE: INSERT NNN FRONT
NAME: ALLEN THRIFT
SIGNATURE:

Appendix C

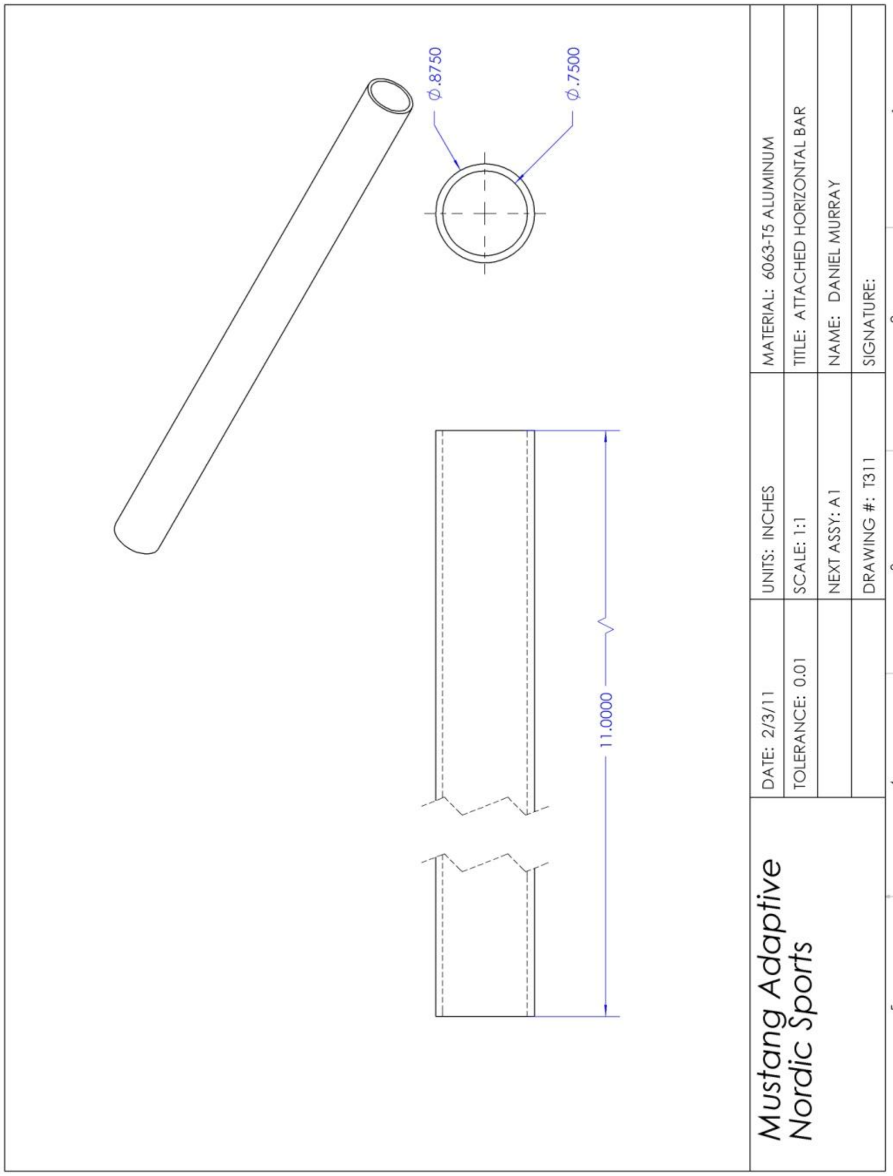

Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:1
NEXT ASSY: A1
DRAWING #: B17
MATERIAL: ABS PLASTIC
TITLE: INSERT NNN REAR
NAME: TOM SILVA
SIGNATURE:
.6250
1.2500
1.5000

Appendix C

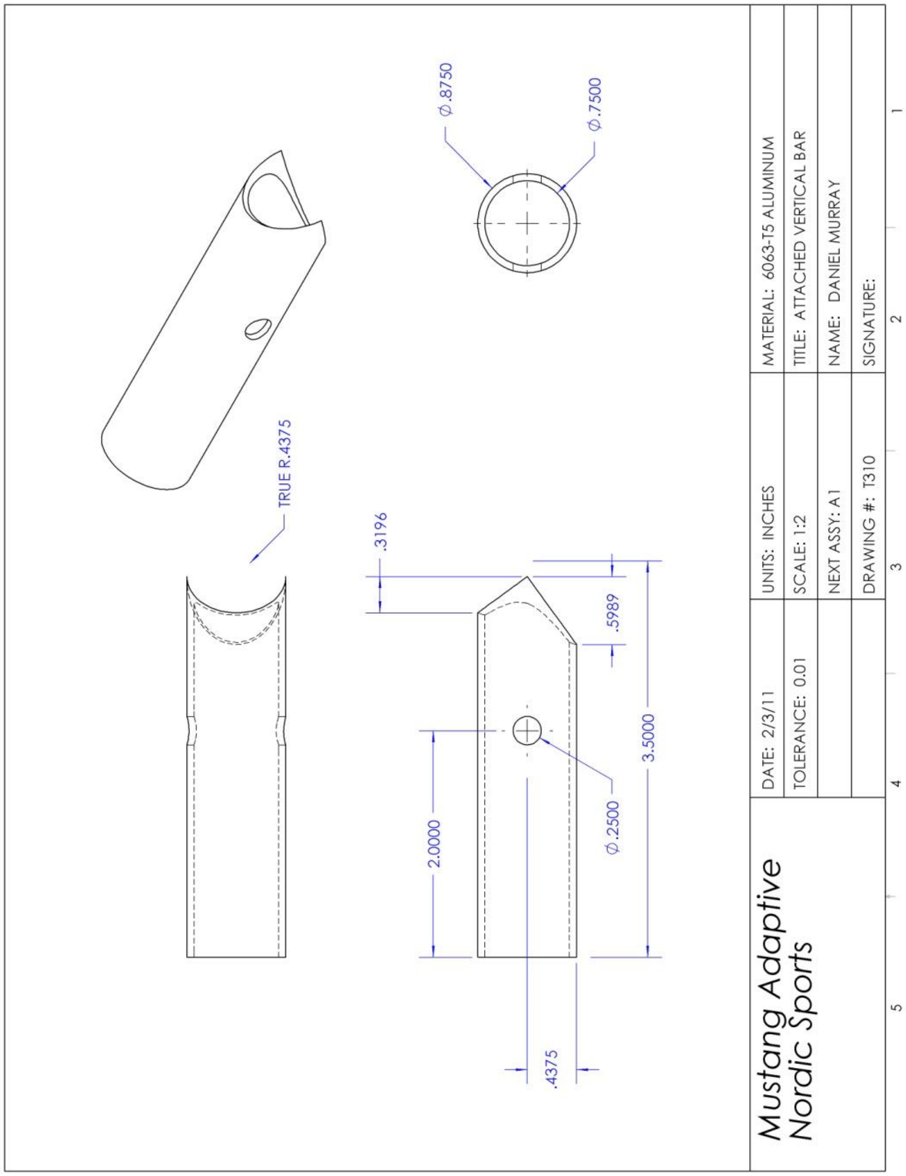


Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:1
NEXT ASSY: A1
DRAWING #: T317
MATERIAL: 6063-T5 ALUMINUM
TITLE: TUBE INSERT
NAME: ALLEN THRIFT
SIGNATURE:
.600
Ø.500
Ø.875

Appendix C


Ø.8750
Ø.7500
11.0000
MATERIAL: 6063-T5 ALUMINUM
TITLE: ATTACHED HORIZONTAL BAR
NAME: DANIEL MURRAY
SIGNATURE:
UNITS: INCHES
SCALE: 1:1
NEXT ASSY: A1
DRAWING #: T311
DATE: 2/3/11
TOLERANCE: 0.01
Mustang Adaptive Nordic Sports

Appendix C



Ø.8750
Ø.7500
TRUE R.4375
.3196
.5989
3.5000
2.0000
Ø.2500
.4375
Mustang Adaptive Nordic Sports
DATE: 2/3/11
TOLERANCE: 0.01
UNITS: INCHES
SCALE: 1:2
NEXT ASSY: A1
DRAWING #: T310
MATERIAL: 6063-T5 ALUMINUM
TITLE: ATTACHED VERTICAL BAR
NAME: DANIEL MURRAY
SIGNATURE:
1
2
3
4
5

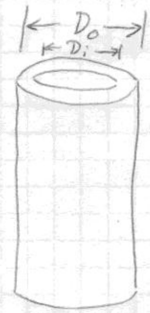
Detailed Analysis

Axial Loading

$D_o = 1\text{ in}$

$W = 300\text{ lb}$

$SF = 3$



$\sigma_y = 15000\text{ psi}$

$P = 900\text{ lb}$

$\sigma = \frac{P}{A}$

$A = \frac{P}{\sigma}$

$A = \frac{\pi(D_o^2 - D_i^2)}{4}$

$D_i = \sqrt{D_o^2 - \frac{4P}{\pi \sigma_y}}$

$D_i = \sqrt{(1'')^2 - \frac{(4)(900\text{ lb})}{(\pi)(15000\text{ psi})}}$

$D_i = .961$

$t = D_o - D_i$

$t = 1 - .961$

$t = .0389$

Choose

$t = .0625 = \frac{1}{16}''$

Tube Thickness $= \frac{1}{16}''$

Appendix D

Buckling

$E = 10.3 \text{ Mpsi}$

$I = \frac{\pi}{64}\left(D_o^4 - D_i^4\right)$

$I = \frac{\pi}{64}\left((1 in)^4 - (.875 in)^4\right)$

$I = .0203 \text{ in}^4$

$P_{cr} = \frac{\pi^2 E I}{L^2}$

$P_{cr} = \frac{\pi^2 (10.3\times10^6 \text{ psi})(.0203 \text{ in}^4)}{(8 \text{ in})^2}$

$P_{cr} = 32244 \text{ lb}$

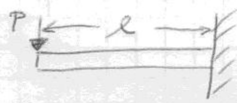
$P_{cr} >> P = 900 \text{ lb}$

Attachment Bending

$P = 45 lb$

$l = 12 in$

$I = .0203 in^4$



$$\sigma_b = \frac{Mc}{I}$$

$$M = Pl$$

$$\sigma_b = \frac{Plc}{I}$$

$$\sigma_b = \frac{(45 lb)(12 in)(\frac{1}{2} in)}{(.203 in)}$$

$$\sigma_b = 13300 \ psi$$

$$\sigma_b < \sigma_y = 15000 \ psi$$

Attachment Deflection

$P = 45\ lb$

$l = 12\ in$

$E = 10.3 \times 10^6\ psi$

$I = .0203\ in^4$

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

$$Y = \frac{(45\ lb)(12\ in)^3}{3(10.3 \times 10^6\ psi)(.0203\ in^4)}$$

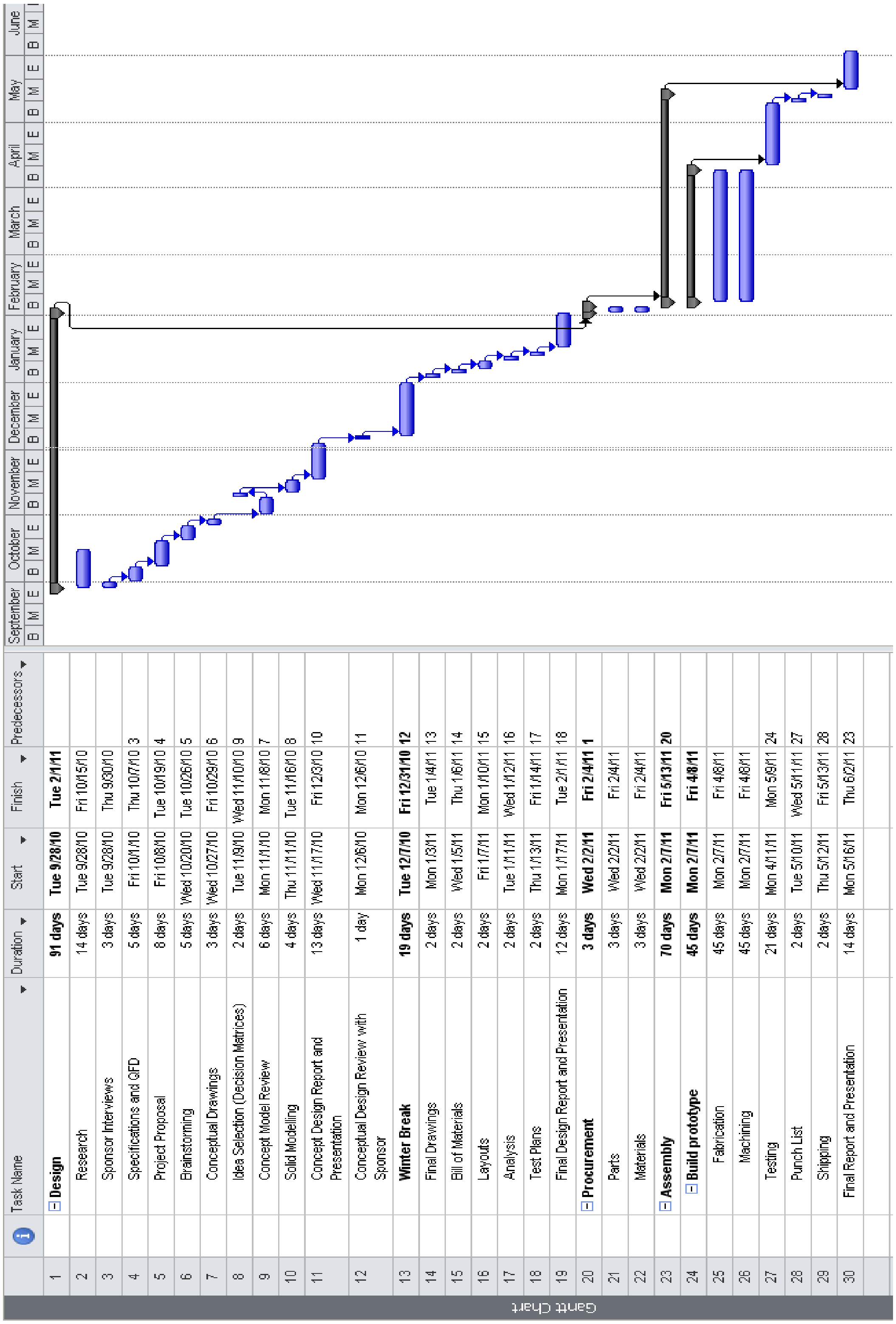
$$\underline{\underline{Y = .124\ in}}$$

Materials and Cost

Quantity	Item	Price	Total
1	1/8" x 1.5" x 0.5" U-Channel	$20.81	$20.81
2	1"OD 0.870"ID Aluminum Tube	$13.47	$26.94
2	5/8" OD 0.527"ID Aluminum Tube	$7.84	$15.68
1	1.5" OD 1" ID Aluminum Tube	$16.45	$16.45
1	1/8" x 1.5" x 6' Aluminum Rectangular Bar	$10.22	$10.22
1	Multipurpose Aluminum 1" Diameter	$19.73	$19.73
1	Multipurpose Aluminum 3' x 6" x 1/8"	$23.63	$23.63
1	1.049" ID 1.315" OD Al Pipe	$25.33	$25.33
2	Rounded Retainer Snap Safety Pin	$1.98	$3.96
1	All Thread	$1.37	$1.37
2	Rubber Stoppers	$4.80	$9.60
4	1/4" Hex Screws	$1.00	$4.00
4	1/4" Lock Nuts	$0.50	$2.00
2	#2 Socket Head Cap Screw	$0.75	$1.50
2	#2 Lock Nuts	$0.30	$0.60
4	Carriage Bolts	$0.24	$0.96
2	End Caps	$0.41	$0.82
10	Quick-Opening Tube Clamps	$50.26	$50.26
2	Seats, Leg and Chest Restraints	$250.00	$250.00
10	Polyester Seat Belt Webbing (2”)	$0.60	$6.00
3	2” Buckle	$1.77	$5.31
1	Velcro	$8.94	$8.94
1	Felt	$1.98	$1.98
4	Rapid Prototyped Plastic Inserts	$0.00	$0.00
N/A	Powder Coating	$30.00	$30.00
N/A	Welding	$255.00	$255.00
N/A	Tax and Shipping	$49.47	$49.47
N/A	Closed-Cell Foam Padding	$40.00	$40.00
		Total	**$880.56**

Appendix G

Gantt Chart



	Task Name	Duration	Start	Finish	Predecessors
1	**Design**	**91 days**	**Tue 9/28/10**	**Tue 2/1/11**	
2	Research	14 days	Tue 9/28/10	Fri 10/15/10	
3	Sponsor Interviews	3 days	Tue 9/28/10	Thu 9/30/10	
4	Specifications and QFD	5 days	Fri 10/1/10	Thu 10/7/10	3
5	Project Proposal	8 days	Fri 10/8/10	Tue 10/19/10	4
6	Brainstorming	5 days	Wed 10/20/10	Tue 10/26/10	5
7	Conceptual Drawings	3 days	Wed 10/27/10	Fri 10/29/10	6
8	Idea Selection (Decision Matrices)	2 days	Tue 11/9/10	Wed 11/10/10	9
9	Concept Model Review	6 days	Mon 11/1/10	Mon 11/8/10	7
10	Solid Modelling	4 days	Thu 11/11/10	Tue 11/16/10	8
11	Concept Design Report and Presentation	13 days	Wed 11/17/10	Fri 12/3/10	10
12	Conceptual Design Review with Sponsor	1 day	Mon 12/6/10	Mon 12/6/10	11
13	**Winter Break**	**19 days**	**Tue 12/7/10**	**Fri 12/31/10**	**12**
14	Final Drawings	2 days	Mon 1/3/11	Tue 1/4/11	13
15	Bill of Materials	2 days	Wed 1/5/11	Thu 1/6/11	14
16	Layouts	2 days	Fri 1/7/11	Mon 1/10/11	15
17	Analysis	2 days	Tue 1/11/11	Wed 1/12/11	16
18	Test Plans	2 days	Thu 1/13/11	Fri 1/14/11	17
19	Final Design Report and Presentation	12 days	Mon 1/17/11	Tue 2/1/11	18
20	**Procurement**	**3 days**	**Wed 2/2/11**	**Fri 2/4/11**	**1**
21	Parts	3 days	Wed 2/2/11	Fri 2/4/11	
22	Materials	3 days	Wed 2/2/11	Fri 2/4/11	
23	**Assembly**	**70 days**	**Mon 2/7/11**	**Fri 5/13/11**	**20**
24	**Build prototype**	**45 days**	**Mon 2/7/11**	**Fri 4/8/11**	
25	Fabrication	45 days	Mon 2/7/11	Fri 4/8/11	
26	Machining	45 days	Mon 2/7/11	Fri 4/8/11	
27	Testing	21 days	Mon 4/11/11	Mon 5/9/11	24
28	Punch List	2 days	Tue 5/10/11	Wed 5/11/11	27
29	Shipping	2 days	Thu 5/12/11	Fri 5/13/11	28
30	Final Report and Presentation	14 days	Mon 5/16/11	Thu 6/2/11	23

Appendix G

Design Verification Plan and Report (DVP&R)

Report	Date: February 4, 2011		Sponsor: Jon Kreamelmeyer						Component/Assembly		REPORTING ENGINEER:		
TEST PLAN										TEST REPORT			
Item	Specification or Clause Reference	Test Description	Acceptance Criteria	Test	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
No				Responsi		Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Max Weight of Sit Ski	Weigh complete sit ski with scale	> 10 lbs.	Allen	DV	1	B	5/2/2011	6/2/2011				
2	Track Width	Measure with ruler or tape measure	adjusts from 8 to 9 ±.0625 inches	Tom	DV	1	B	5/2/2011	6/2/2011				
3	Rider Weight	Measure for deflection with 300 lbs of sand in seat	< 0.125 inches	Dan	DV	1	B	5/2/2011	6/2/2011				
4	Hip to bottom of foot measurement	Measure from bucket to foot rest with ruler or tape measure	27 ± 0.5 inches	Dan	DV	1	B	5/2/2011	6/2/2011				
5	Number of Leg Positions	Test different leg positions	2	Krystina	DV	1	B	5/2/2011	6/2/2011				
6	Assembly times	Use stopwatch to measure time for complete assembly	< 10 minutes	Allen and Krystina	DV	1	B	5/2/2011	6/2/2011				
7	Distance between center of mass of frame and balance point of skis	Mark center of mass on ski and compare to center of mass of person in sit ski	0 inches	Tom	DV	1	B	5/2/2011	6/2/2011				
8	Time to adjust leg position by third party	Use stopwatch to measure time for leg position adjustments	< 10 minutes	Allen and Krystina	DV	1	B	5/2/2011	6/2/2011				
9	Restrained body parts movement restriction	Strap person in sit ski and test if movement is possible	no deflection	Dan and Tom	DV	1	B	5/2/2011	6/2/2011				
10	Padded contact region thickness	Measure with ruler or tape measure	< 2 inches	Tom	DV	1	B	5/2/2011	6/2/2011				
11	Number of sharp edges or pinch points	Inspection	0	Allen	DV	1	B	5/2/2011	6/2/2011				
12	Number of different bindings that sit ski attaches to	Attach to binding	≥1	Krystina	DV	1	B	5/2/2011	6/2/2011				
15	Rigid and safe	Inspection: Check quality of welds and fasteners	N/A	Dan	DV	1	B	5/2/2011	6/2/2011				
16	Number of Riders	Sit in sit ski	1	Dan	DV	1	B	5/2/2011	6/2/2011				
17	Accomodates riders of different sizes	Have a 95th percentile male (6' 2", 200 lbs) and 5th percentile female (5', 110 lbs) sit in sit ski	Fit Comfortably	Dan	DV	1	B	5/2/2011	6/2/2011				

Test Plans

Rider Weight

Equipment

- Assembled sit ski
- 300 lbs of sand in a bag
- Ruler
- Calculator

Instructions

1. Place assembled sit ski on solid, flat surface
2. Measure lengths of vertical tubes
3. Place bag of sand in seat
4. Re-measure lengths of vertical tubes
5. Calculate difference between measurements
6. Compare solution with allowable tolerance of 0.125 inches

Hip to bottom of foot measurement and inspection

Equipment

- Assembled sit ski
- Ruler
- Calculator

Instructions

1. Place assembled sit ski on solid, flat surface
2. Check quality of welds and fasteners
3. Have 6’2” rider sit in bucket seat and rest feet on legs-out footrest
4. Check for pinch points and sharp edges
5. Measure distance from hip to knee
6. Measure distance from knee to bottom of foot
7. Add measurements and verify that sum is within tolerance (27 inches $\pm$ 0.5 inches)
8. Repeat steps 2-5 for teacup footrest

Appendix H

Assembly time and time to adjust leg position

Equipment

- Sit ski parts
- Tools
- Stopwatch
- Drawing of sit ski with labeled parts
- Person not in group

Instructions

1. Place parts of sit ski on solid, flat surface
2. Provide person with drawing and tools
3. Start stopwatch
4. Have person build sit ski for legs-out position
5. Stop stopwatch
6. Verify time is under 10 minutes
7. Reset stopwatch
8. Start stopwatch
9. Have person remove the legs-out attachment and put on the teacup footrest
10. Stop stopwatch
11. Verify time is under 10 minutes

Padded contact region thickness and track width

Equipment

- Assembled sit ski
- Ruler

Instructions

1. Place assembled sit ski on solid, flat surface
2. Measure thickness of padding on bucket seat
3. Verify measurement is less than 2 inches
4. Measure center-to-center distance of track width
5. Compare to desired value of 9 inches
6. Adjust to other track width slots
7. Measure center-to-center distance of track width
8. Compare to desired value of 8.5 inches

Appendix H

Accommodates riders of different sizes and movement restriction

Equipment

- Assembled sit ski
- 5’, 110 lb female
- 6’2”, 200 lb male
- Ruler

Instructions

1. Place assembled sit ski on solid, flat surface
2. Have female sit in sit ski
3. Adjust legs-out position until she is comfortable
4. Fasten straps
5. Have female try to move around in restraints
6. Verify that feet, thighs, and abdomen have no deflection
7. Unfasten straps
8. Have female get out of the sit ski
9. Remove legs-out attachment and attach teacup footrest
10. Have female sit in sit ski
11. Adjust teacup footrest until she is comfortable
12. Have female get out of sit ski
13. Repeat steps 2-13 with male