Recreational Nordic Sit Ski

Final Design Report

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Statement of Disclaimer

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Introduction

The purpose of this project is to design, build, and test a recreational Nordic sit ski for use by Disabled Sports Eastern Sierra. The goal is to improve adjustability and reduce weight compared to previous sit ski designs. The project is to be completed by Cal Poly Mechanical Engineering seniors Mathew Bissonnette, Johnathon Gorski, and Kevin Izumiya. Kinesiology seniors Harpreet Saini and Carl Anderson will be providing discipline support and disability etiquette training.

The project is sponsored by the National Science Foundation Research to Aid Persons with Disabilities (RAPD) grant. The grant was proposed by and awarded to Dr. Brian Self and Dr. James Widmann of the Mechanical Engineering Department, Dr. Lynne Slivovsky of the Computer Engineering Department, and Dr. Kevin Taylor of the Kinesiology Department at Cal Poly San Luis Obispo.

Our primary contact at Disabled Sports Eastern Sierra is Maggie Palchak. She has provided phone interviews and some of the pictures presented in this report. Ms. Palchak is a full time instructor and trainer, as well as the Paralympics Sport Program Coordinator.

Existing Products

Currently, Disabled Sports Eastern Sierra utilizes sit skis manufactured by Central Cross Country and Sierra Sit Ski, seen below in Figures 1 and 2.

Figure 1: Sierra Sit Ski

The Sierra Sit Ski is designed and built by Michael Byxbe. The ski is tailored for average sized users who ride with their legs extended outwards. Disabled Sports Eastern Sierra currently possesses 2 of these models. The design is lightweight and comfortable, but lacks the ability to adjust for different rider sizes and leg positions. The rider is limited to sitting in the legs out front position and the seat back is fixed.

Figure 2: Central Cross Country Recreational Sit Ski

The Central Cross Country ski is designed for greater adjustability. It can fit a variety of riders, as well as accommodate different leg position preferences. Disabled Sports Eastern Sierra is satisfied with the design's adjustability, ease of maintenance, and ability to comfortably fit large riders. The torso is less restrained in this model, which allows riders with a lower spinal cord injury a greater range of motion in their upper body. This does not work as well for riders with higher spinal cord injuries, who have limited mobility in the upper body. The frame has several downsides that could be improved upon in future designs. The frame weighs 18 pounds, which is heavier than desired. This makes it difficult for new riders to enjoy their skiing experience. In addition, Disabled Sports Eastern Sierra has reported problems with the foot straps not being secure enough to prevent riders' legs from slipping off the foot rest. Problems have also occurred where straps have failed at the connection to the frame and had to be replaced. Finally, riders have complained of discomfort due to a lack of padding in the upright seat posts.

In addition to commercially available options, several past Cal Poly senior projects have been directed towards developing new sit ski designs; however, the focus of these projects was to design for a specific athlete. Existing designs are generally customized for individual users and not intended for the adjustability required by Disabled Sports Eastern Sierra. Though the specific designs were not applicable to our goals, each group made recommendations for future improvements that we found useful.

Figure 3: Mustang Adaptive Sit Ski

The Mustang Adaptive Sit Ski was designed as a senior project in 2011. It is lightweight, weighing a total of 10 pounds. The design offers two adjustable foot positions for the rider to select based on their style. These include legs out front and the teacup position. In the legs out front position, the rider's feet are strapped into the black straps located at the front. In the teacup position, the rider's feet are strapped into the aluminum plate. In both positions, the foot location can be moved forward and backwards. In addition, in the teacup position, the forward foot rest can be removed to reduce the weight of the sit ski.

This design does come with some drawbacks. The only option for the seat is a fixed mount bucket seat, which does not allow for larger riders to fit comfortably. In addition, smaller riders require additional padding for a more secure fit, which increases the total weight of the sit ski. This design also does not allow for the legs under position, which is desired by Disabled Sports Eastern Sierra. Last, the foot rest for the teacup position is reversed. The toes point towards the snow rather than towards the sky, making for an uncomfortable foot position.

The Mustang Adaptive Sit Ski team suggested using deeper U-Channels in the bindings to reduce the difficulty of attaching the frame to the skis. They also advised that closed-cell foam adds significant weight. Less dense or thinner foam could be used to reduce this problem. Finally, if a teacup sitting position is desired, the foot rest should be angled towards the rider for comfort.

The 2010 team that designed Marlon Shepard's competition sit ski advised that 0.035 in. wall thickness tubing is too thin. They recommended choosing thicker tubing, but saving weight in the seat by cutting holes in the padding where it isn't needed.

Project Objectives

Our team plans to develop a lightweight sit ski for a wide range of recreational users. Users will vary in size, weight, skill level, and extent of disability. Our product will allow for a wide variety of riders to fit comfortably and securely in the ski by developing a method of quickly altering the seat. Each rider will be able to choose his/her preferred rider position, which includes adjustments in leg placement and seat back height. Available leg positions will include legs in front of the rider or folded underneath the sit ski as illustrated in Figure 4.

Figure 4: Riders demonstrating the legs under (left) and legs out front (right) positions.

The seat back height must be adjustable to accommodate a range of disabilities. Riders with lower spinal cord injuries prefer a lower seat back because it allows for greater range of motion in the upper body. Riders with injuries higher on the spinal cord require a higher seat back and additional upper body restraints. Our design will include a system that allows riders to adjust the level of restraint provided by the seat back.

Disabled Sports Eastern Sierra caters to a wide variety of users, ranging from first time skiers to competitive athletes. The ski must be usable for both cross country and biathlon events as a leisure sport and in competition. To do this, the sit ski must be as light as possible. This will make the experience more enjoyable for first time users and more competitive for athletes. In addition, a lightweight ski allows biathlon competitors to tip the ski sideways to allow them to shoot from the prone position.

By the end of the project, we plan to deliver a working recreational sit ski that will fulfill Disabled Sports Eastern Sierra’s needs as described above.

Competition Standards and Rules

In order to be eligible for competition in official events, our sit ski must comply with current Paralympic standards. The standard dictating the Nordic sit-ski event is Code 222.7 from the IPC Nordic skiing rules & regulations document, 2011-2012 edition. This edition has not yet been published, but our sponsor, Maggie Palchak, has provided us the information that she received from the Paralympic Nordic Skiing committee. The new requirements are as follows:

- *The Nordic sit-ski shall consist of a sitting device mounted on a pair of cross-country skis or rolling devices (summer competition).*
- *The Nordic sit-ski shall consist of a sitting device with a fixed seat, which is not adjustable during the race, mounted on a pair of cross-country skis or rolling devices (summer competition).*
- *No springs or flexible articulations are allowed in any segment of the sit ski, including the connection with the skis.*
- *The connection with the skis must be rigid.*
- *The maximum allowable height difference between the point of contact of the buttock with the seat and the bottom of the ski is 40cm (including the cushion segment without load).*
- *The sit-ski athlete shall be seated on the sit-ski at all times during the race, meaning that the athlete's buttocks shall remain in contact with the seat. (See IPC Nordic Skiing Classification Handbook.)*
- *To prevent movement of the buttocks off of the seat, the hip joint must be strapped to the seat using a non-flexible material.*

Engineering Specifications

Interviews and background research revealed preliminary requirements that our sit ski must achieve in order to improve upon existing models. Some requirements were explicitly stated by the customer, while others were implied based upon desired performance attributes. Through the use of the Quality Function Deployment (QFD) method, these initial requirements were translated into engineering specifications.

The QFD table can be found in Appendix A, along with a more in depth explanation of the QFD method. Below, in Table 1, is a list of formal engineering requirements with their target values and acceptable tolerance. Engineering requirements must be assessed using a variety of compliance methods. Requirements may be assessed by analysis (A), test (T), similarity to existing designs (S), and inspection (I). In addition, the risk of meeting these engineering targets or specifications is evaluated as being high (H), medium (M), or low (L). Requirements with higher risk are more difficult to meet and will be analyzed in greater detail.

Table 1: Formal Engineering Requirements for the Nordic Sit Ski

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Weight of Sit Ski	11 lbs	± 2 lbs	H	A,I,S
2	Time to attach frame to skis	1 min	± 30 sec	M	T,S
3	Time to adjust seat/legs	10 min	± 1 min	L	T,S
4	Largest rider that can fit (weight)	300 lbs	Max	M	A,T,S
5	Cost to produce	$1,000	± $200	L	A, I
6	Number of leg positions available	2	Min	M	I, S
7	Height of bottom of seat	15.75 in (40 cm)	Max	M	I
8	Centerline distance of skis	8.85 in	± 1”	L	I
9	Ski Binding Pin	0.16” Diameter Pin	±0.02	L	I
10	Ski Binding Distance	12.25” from front pin ℄ to back pin ℄	$\pm\frac{1}{16}$ “	L	I
11	Parallel Ski Alignment	Parallel	±1°	H	I
12	Leg Rest Deflection	0.5” at the far end	±0.1”	H	T, A

Design Development

The design process for the Nordic Sit Ski followed the flowchart seen in Figure 5. Initially, Disabled Sports Eastern Sierra established the need for a product. This led to background research, which clarified rider needs, requirements, and the abilities of existing designs to meet these needs. We then developed a list of product requirements and target goals along with their corresponding tolerances, as seen in Table 1. Included in our research was an interview with Maggie Palchak, the Paralympic Sports Coordinator for Disabled Sports Eastern Sierra. Her experience in working with people with disabilities helped to better define the project requirements.

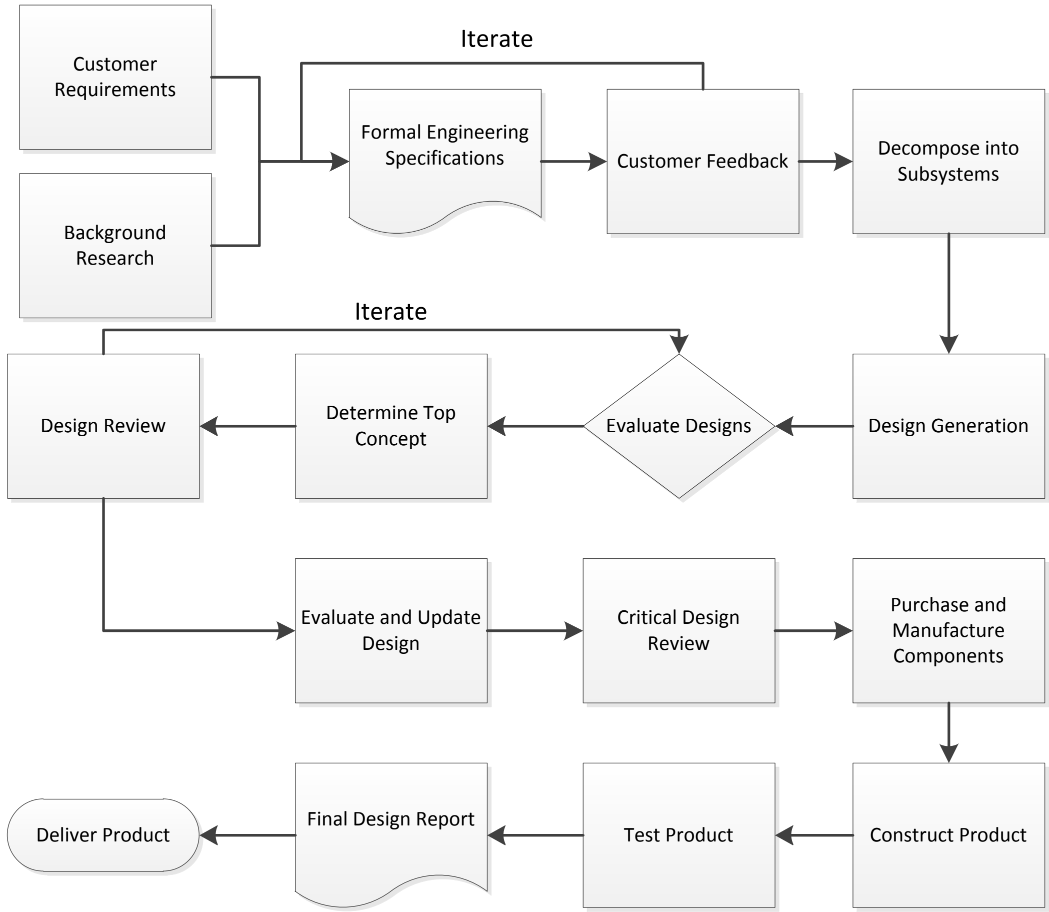


Figure 5:Project Design Process

The next step the project was to generate a series of ideas that satisfy the needs listed in the project proposal. These ideas were analyzed using a trade study to help define the best product suited to fit all established requirements. Ideas were evaluated using engineering intuition, analysis, and relative ability to meet design requirements.

Seat Selection

The best choice of seat was determined by weighing the different options relative to one another. A score of 4 in the table represents the best choice relative to the other viable options. The seat decision matrix is shown below in Table 2.

Table 2: Seat Type Decision Matrix

	Weight Factor (1-10)	Bucket	Bench Seat	Carbon Fiber	Interchangeable Buckets/Bench
Weight	10	2	1	3	1.5
Adjustability	8.5	2	3	1	4
Security	7	3	2	2	2.5
Manufacturability	6	3	2	1	2.5
Durability	5	4	3	1	2
Largest Rider Size	4	1	3	2	3
Cost	3	3	3	1	2
	Total	**109**	**97.5**	**74.5**	**109.5**

Four options were chosen from our brainstorming as viable candidates for further consideration. In choosing the best option, weight and adjustability were determined to be the most important features. As the interchangeable seats option only varies slightly from the bucket or bench seats, the average score of both was used when no distinguishing factor seemed obvious.

Figure 6: A carbon fiber seat built by the 2011 Cal Poly Competition Sit Ski team.

Though the carbon fiber seat was the best choice on the basis of weight alone, it placed poorly in cost and manufacturability. Disabled Sports Eastern Sierra does not have the capability to reproduce another carbon fiber seat if more sit skis are desired in the future.

Figure 7: The bucket seat as used by the Teton Sit Ski.

The most common type of seat in use is the bucket seat. The bucket seat made of molded plastic and can be adjusted through the addition or removal of foam padding. The bucket seat is preferred by most riders, as it is very comfortable and secure. A snug seat is important because it allows the rider to transfer most of their efforts into forward motion. If the seat is not snug, riders may jostle back and forth, wasting energy in the process. The downside to the bucket seat is that it is limited in terms of the largest rider that can fit. As riders are constrained on either side by the seat walls, larger riders cannot fit comfortably. Additionally, the height of the seat back is not adjustable.

Figure 8: The bench seat as used by the Central Cross Country ski.

The bench seat addresses the problem of fitting larger riders, but at the cost of rider comfort and security. Riders are less constrained by the seat itself, and are held in with straps for their thighs, shins, and feet. Because the bench seat requires a larger metal frame to support the fabric, it is heavier than the bucket seat. On an unweighted scale, the bench seat only performed moderately worse than the bucket seat.

Our final design decision was to use both the bucket and the bench seats in an interchangeable configuration. This decision allows us to combine the security and comfort of the bucket seat with the rider capacity of the bench seat. Our design will feature a standard bucket seat, a bucket seat with a low cut back, and a bench seat. Between these three choices, a majority of rider sizes and preferences will be accommodated.

Seat Attachment

Table 3 shows the decision matrix for the viable options for attaching the seat to the sit ski frame. Each method of attachment is ranked from 1 to 6, where a score of 6 represents the best option relative to the others. We decided that security and ease of adjustability were the most important characteristics for the seat attachment.

Table 3: Seat Attachment Decision Matrix

	Weight Factor (1-10)	Shaft Collars	Draw Latch (Horizontal)	Draw Latch (Vertical)	Bike Post	Quick Release Pin	Bolted
Ease of Adjustability	10	6	5	4	3	2	1
Security	9	4	1	2	3	5	6
Durability	7	3	4	5	1	2	6
Ease of Maintenance	7	6	3	2	1	5	4
Weight	4	6	2	1	3	6	5
	Total	**183**	**116**	**111**	**83**	**138**	**154**

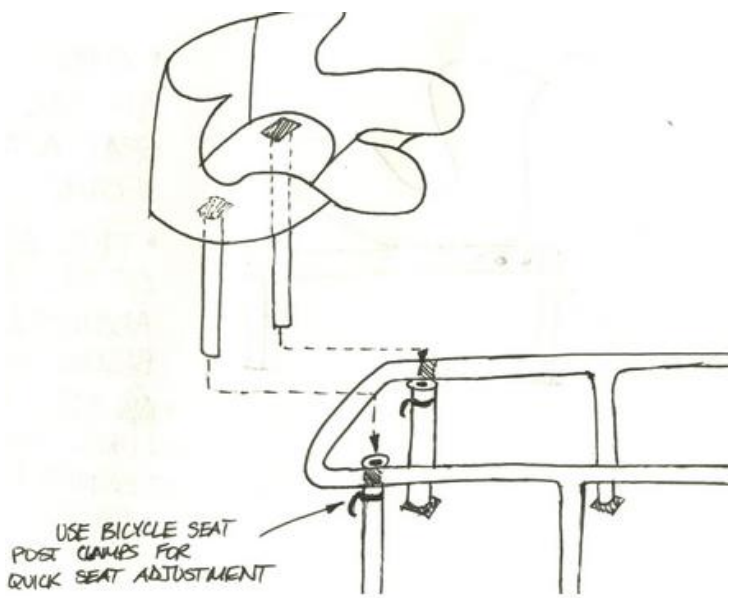


Figure 9: Bike Post Attachment Method

The bike post method scored the lowest out of all the options because it placed poorly in ease of maintenance and durability. This method lacks the necessary durability because the use of long concentric tubes can be prone to misalignment.

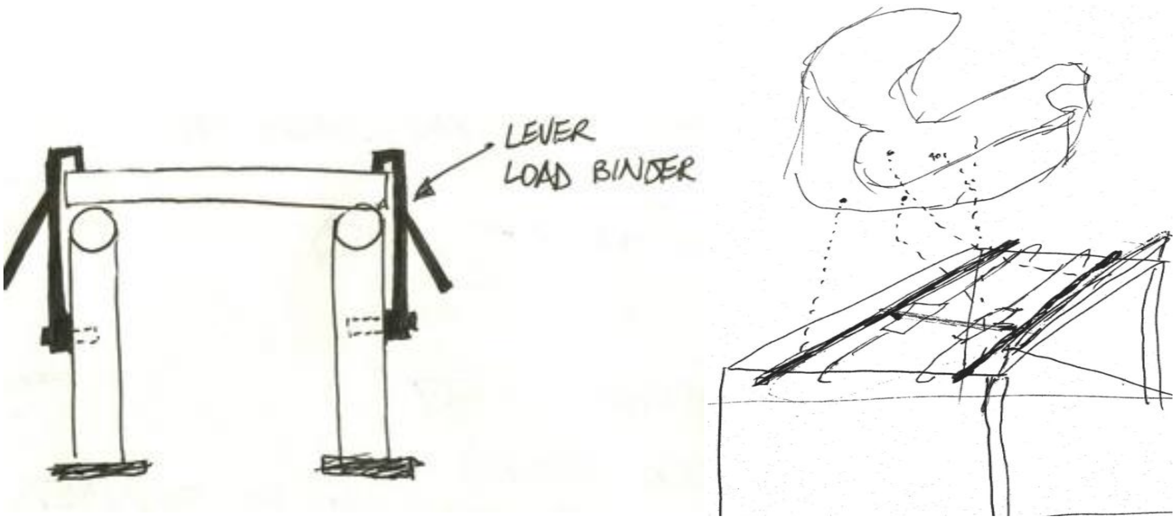


Figure 10: The Draw Latch Vertical (left) and Horizontal (right) Attachment Methods

Two methods were developed using draw latches to attach a seat to the frame. Both the vertical and horizontal draw latch methods lack security. Additionally, both methods require additional mounting material, which would add unnecessary weight to the sit ski.

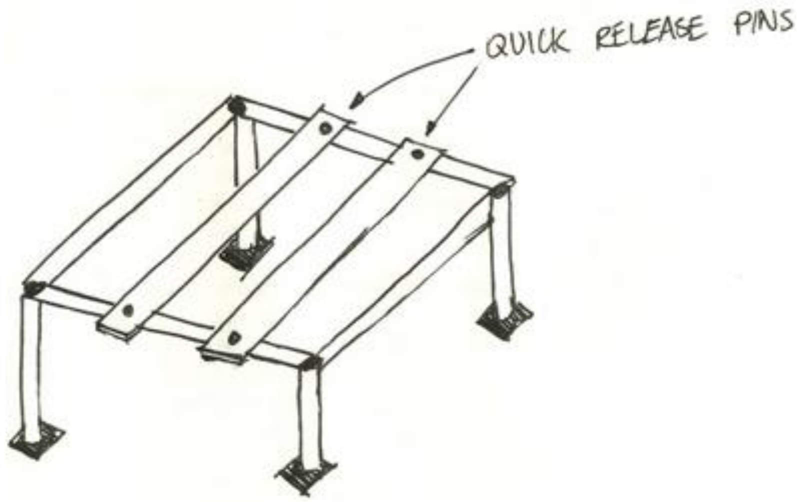


Figure 11: The Quick Release Pin Method of Seat Attachment

A fairly simple method of attachment was developed using quick release pins to attach a seat mounting plate to the frame. The use of quick release pins scored well in three categories, but lacks ease of adjustability while wearing a pair of gloves. The quick release pins may not provide as secure an attachment as some of the others developed.

The traditional method of attaching the seat to the frame is by bolting the seat directly to the frame. This method scored well for all characteristics except for ease of adjustability,and was the second best

option overall. It was ranked lowest for adjustability, since it was the only component that required the use of tools for adjustment.

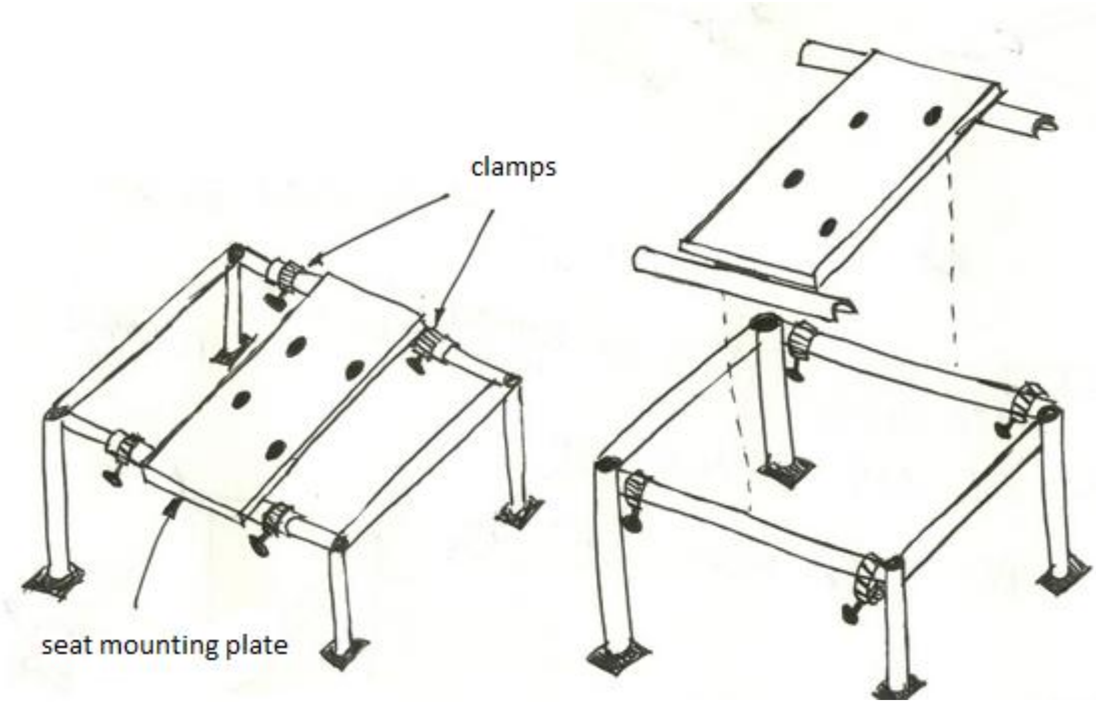


Figure 12: Shaft Collar Method of Attachment. Shown Attached (left) and Detached (right).

Hinged shaft collars were determined to be the best method to attach the seat to the frame. It was ranked highest for ease of adjustability, ease of maintenance, and weight. The hinged clamps provide secure seat attachment at a relatively low cost.Additionally, hingedclamps can be adjusted while wearing a pair of gloves. An example of a hinged clamp can be seen below in Figure 13.

Figure 13: A hinged shaft collar produced by Stafford.

A more in depth explanation of this method can be found in the Final Design Decision section of this report.

Frame Material

Aluminum, steel, and titanium were all considered as materials for the sit ski frame. We based our decisions on three main categories: cost, specific stiffness, and manufacturability. A higher score in the table reflects a material more suited to our needs.

Table 4: Frame Material Decision Matrix

	Weight Factor (1-10)	Aluminum	Steel	Titanium
Relative Cost per Volume	5	3.33	1	0.038
Relative Stiffness/Density	10	1.00	1.00	1.00
Relative Manufacturability	8	8	10	1
	Total	**91**	**95**	**18**

To determine how cost effective each material would be, we looked at the relative cost per unit weight based on the values given in the CES EduPack. As the most suitable material will be the one with the lowest cost, we took the inverse of the cost values. While aluminum and steel performed well in the cost category, titanium may prove to be too expensive for our project budget.

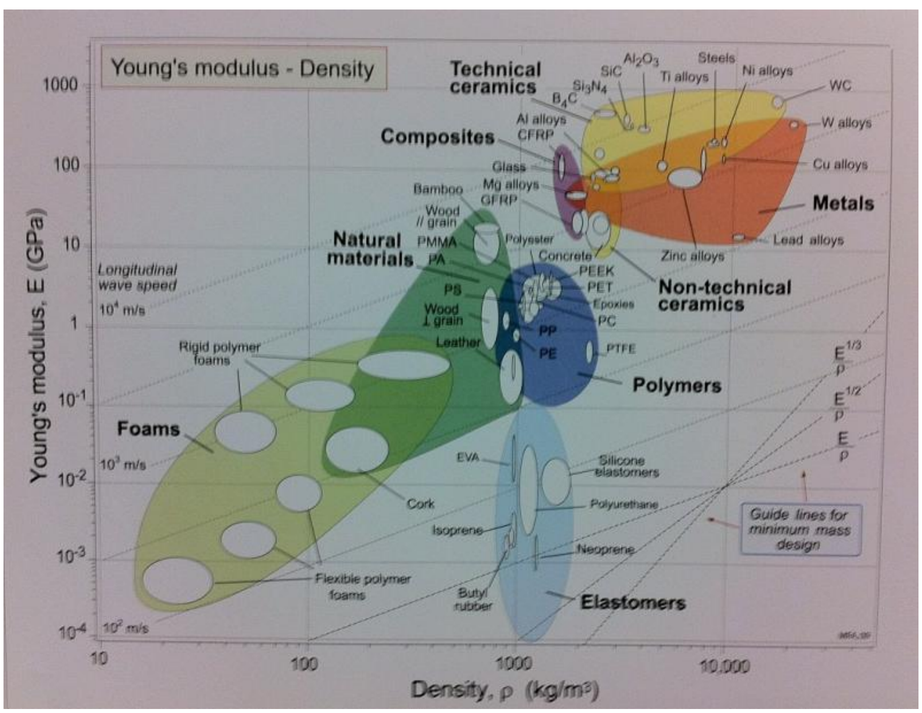


Figure 14: Specific stiffness as output by CES EduPack

The specific stiffness is the stiffness to density ratio of a material. The CES EduPack was again used as the basis of our tabulated values, which were obtained from the graph of specific stiffness shown in Figure 14. The graph has parallel diagonal lines along the length of the graph. Materials falling along the same line are said to be equivalent in their stiffness to weight ratio. Aluminum, steel, and titanium fall along the same line, and thus are equal in stiffness to weight ratios. We feel that this is an important characteristic because it also dictates the weight of the final product. A higher stiffness to density ratio should allow for a lighter sit ski.

The next important characteristic is the manufacturability. For this, we based our ratings on what we can do in the machine shops on campus, how skilled a fabricator needs to be, and what equipment Disabled Sports Eastern Sierra is likely to have access to. Steel was determined to be the best in this category, since it is readily available and easy to weld compared to the other two materials. Aluminum is a close second because it is easier to work with than steel, but requires a more skilled welder to build the frame. With aluminum, it is also important to consider aspects such as heat treatment and warping. Titanium was determined to be worst in this category, since it is not readably available and requires special treatment to weld. The special manufacturing requirements further increase the cost of a titanium frame.

Calculations were performed to determine whether steel or aluminum is a better choice. This decision came down to manufacturability. Since steel is stronger, the steel tube wall thickness can be thinner than aluminum for the same loads. While this would mean a decrease in weight, there is a minimum weldable thickness that must be considered.

For the loads considered, the thinnest weldable thickness of aluminum was selected for each member. Under the same conditions, comparable thickness steel tubes were also able to withstand the loading, but at an increased frame weight. Thinner steel tubes were also passable, but were not within the range of weldable thicknesses.

Final Design Decision

After determining the individual components, we compiled them into our top design concept. The concept, shown below in Figure 15, should adequately meet all engineering specifications.

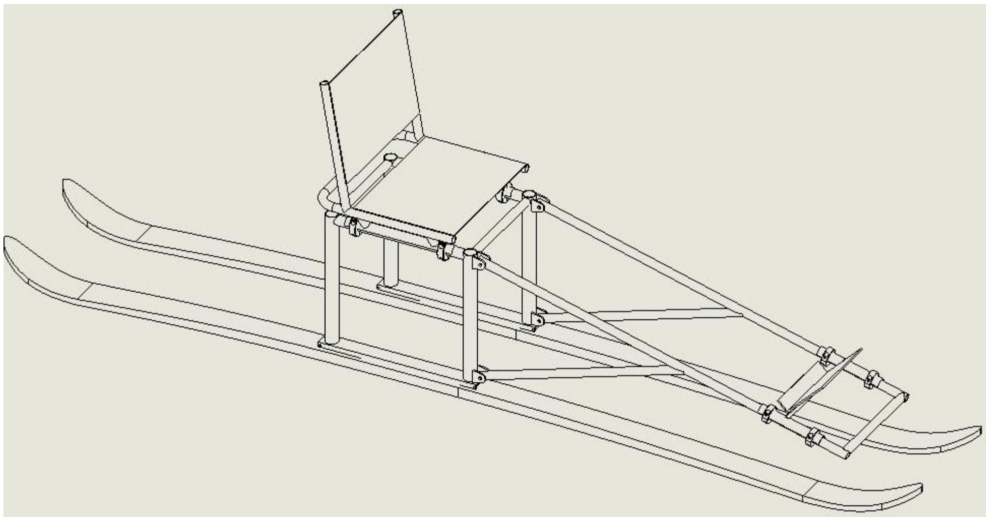


Figure 15: Isometric View of Design Concept

Our design includes several features that will improve adaptability and rider comfort. These features include a sliding foot rest, removable leg rest, and interchangeable seats.

Leg Rest

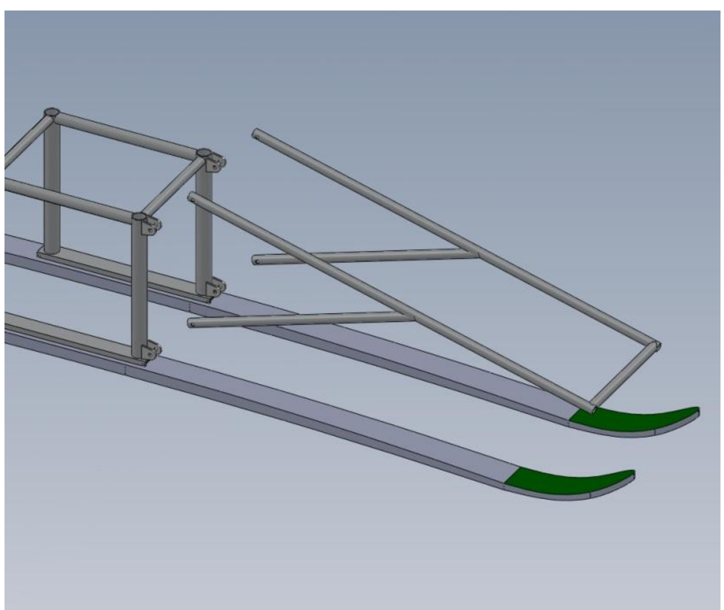


Figure 16: Solidworks Model of Removable Leg Rest

For riders that prefer the legs underneath position, the leg rest can be completely removed to reduce the overall weight of the sit ski. In addition, the removal of the leg rest allows for the legs to be more

easily positioned underneath the seat. The leg rest will be attached to the frame using 4 quick release pins.

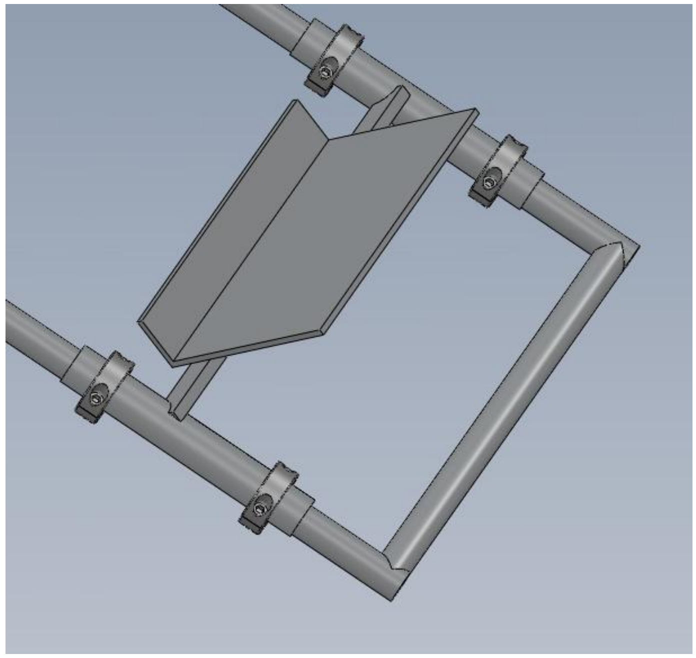


Figure 17: Solidworks Model of Sliding Footrest

The sliding foot rest can be moved up and down along the leg rest. This feature allows the rider to adjust the position of the foot rest, along with the leg angle. Since the foot position defines the leg angle, an adjustable seat angle is not necessary to include. This feature can be used to help relieve pressure points that develop on the underside of the thighs. A heel support was also included on the foot rest, which will provide extra security in addition to the straps that will be added. This feature also simplifies the seat choice because it can be used with both the bench and bucket style seats.

Seat

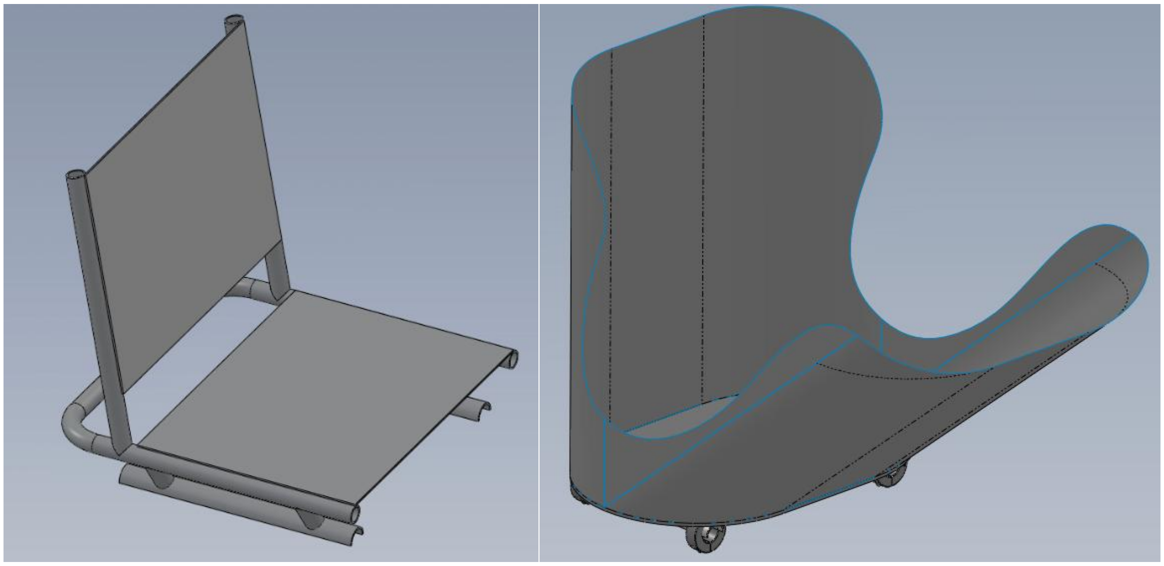


Figure 18: Solidworks Models of the Bench Seat (left) and Bucket Seat (right).

The frame of the bench seat is to be constructed from 0.625" OD x 0.065" 6061 Aluminum tubes. The seating portion will be nylon fabric that will be attached directly to the frame. The bucket seat is to be ordered from Enabling Technologies. The seat will be attached to the frame using the assembly shown in Figure 19.

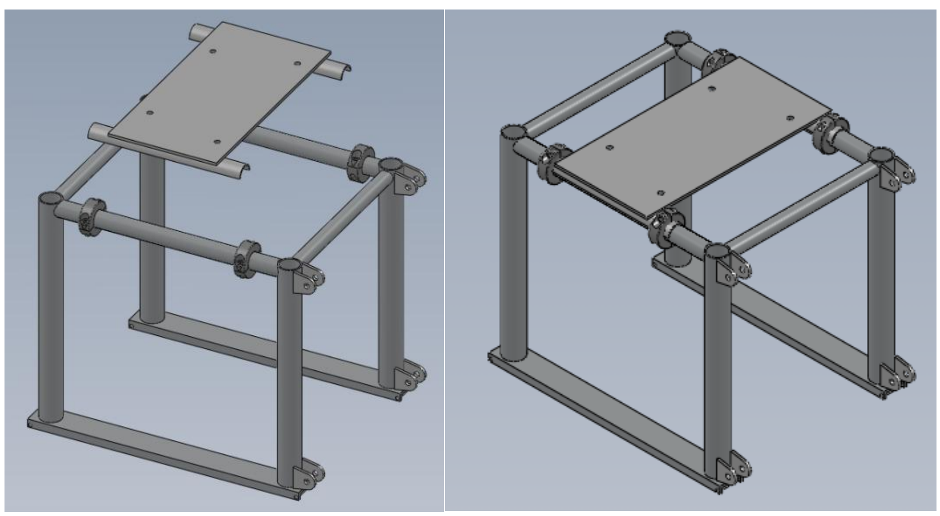


Figure 19: Solidworks Model of Seat Mounting Plate

The most innovative feature of our design is the interchangeable seats, which is made possible with our seat mounting plate. The seat mounting plate will be attached to each of the seats, allowing them to be attached and removed to accommodate rider preferences. The mounting plate is attached to the seats via 4 bolt holes, which closely matches how most seats are currently attached to frames. The plate is welded to a half-tube as shown, with slight extensions beyond the plate on either end. These extensions are used to secure the plate assembly to the frame using hinged clamps as shown in Figure 20. The

clamps remain on the frame even after the seat is removed, reducing the chance that they will be lost. Initial testing shows that this assembly is very stiff once tightened.

Figure 20: A hinged shaft collar produced by Stafford.

Ski Bindings

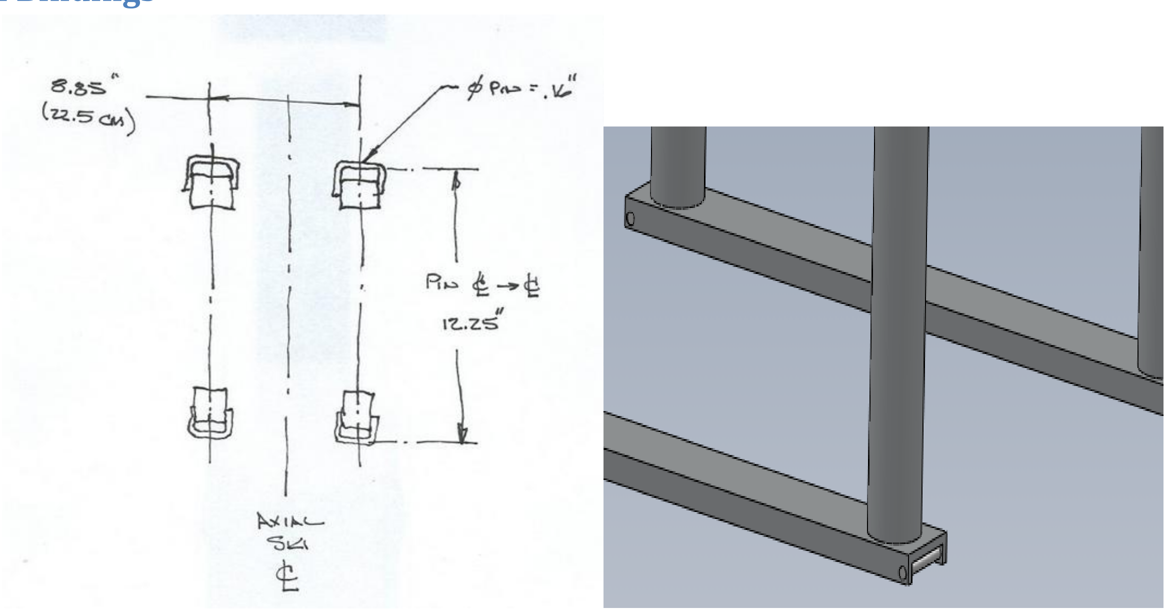


Figure 21: Central Cross Country Binding Spacing (left) and our Binding Method (right)

Disabled Sports Eastern Sierra currently has several sets of cross country skis in use at their program. These skis use two Rossignol NNN bindings to attach the skis to the sit ski frame. Typical cross country skis have one binding, which the toe of the skier clips into. This allows for the skier to “walk” along the snow easily. For stability purposes, Disabled Sports Eastern Sierra has added two bindings, one to

connect the front and one to connect the back of the sit ski. They would like our Sit Ski to be compatible with their existing skis to reduce cost, meaning that we will have to abide by the spacing shown in Figure 21 (left).

The Central Cross Country binding uses a u-shape pin that is welded to a base bracket. They have four of these brackets, one for each binding attachment point. The drawback of this design is that it requires a welder to fix if the pin happens to break. Our design, also shown in Figure 21, allows for the attachment to the ski through a press fit pin. Our binding attachment is welded to the frame, minimizing the number of parts. To ensure the skis remain parallel during manufacturing, a jig will be constructed to prevent warping during the welding and heat treatment process.

Straps

Straps are to be attached at the chest, hip, and thigh on each of the seat options as shown in Figure 22. 2” nylon straps will be used for the seat straps, and 1” nylon straps will be used for the legs and feet.

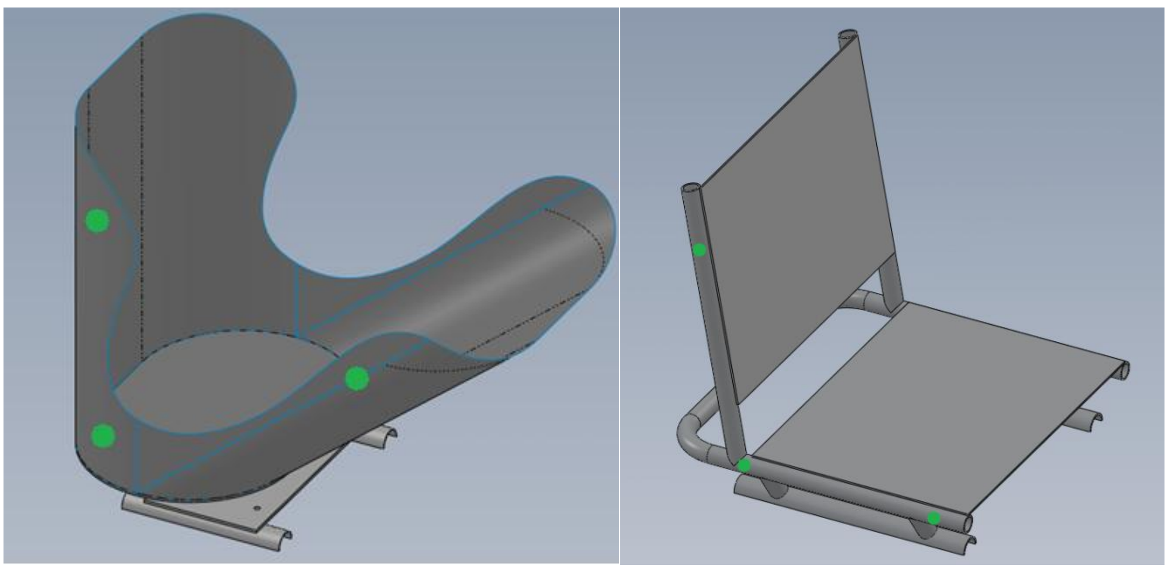


Figure 22: Strap Location for the Bucket Seat (left) and Bench Seat (right)

Straps will be attached to the seat using 1” and 2” footman loops, as shown in Figure 23. The footman loops will be bolted directly to the seat. The bolt head will be beneath the padding (not shown) on the bucket seat, so no decrease in comfort is anticipated.

Figure 23: A 2” Footman Loop

A 1” strap will be attached to the frame so it is capable of sliding between points A and B shown in Figure 24. A strap will also be attached to the foot plate at location C.

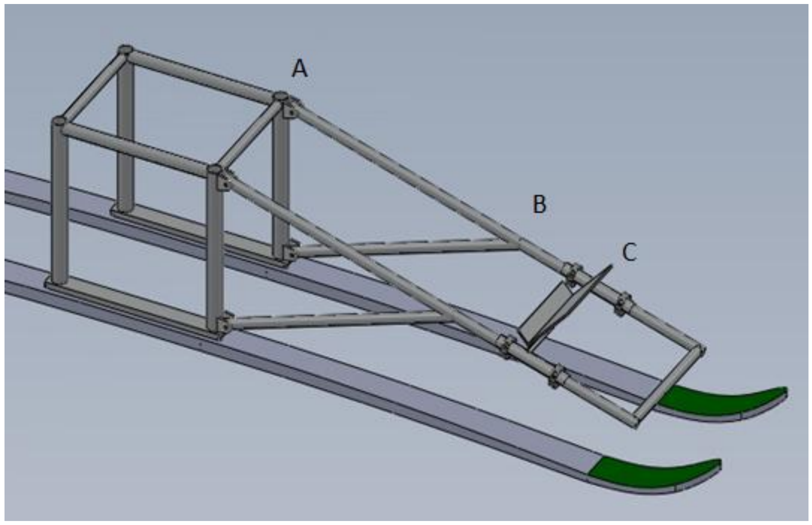


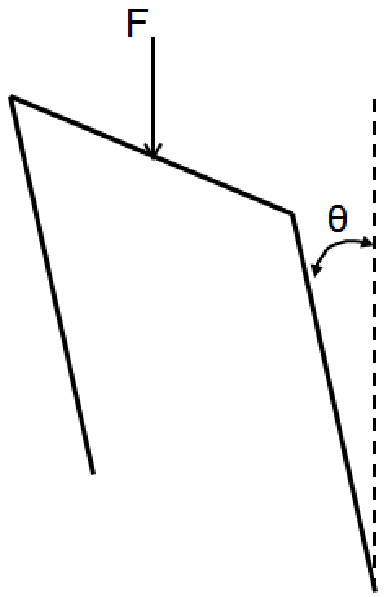
Figure 24: Strap Locations on the Leg Rest

Analysis

A detailed analysis was performed on the entire sit ski. Since the structure is statically indeterminate, the frame was simplified and separated into components so that hand calculations could be performed. For each model, an EES code was developed and iterated for standard tube sizes. Detailed analysis and EES code can be found in Appendix D.

Vertical Frame Members

The vertical members in the main frame will be subjected to a compressive axial stress and moment load during tipping.Failure due to buckling is not anticipated for the predicted loading conditions.



Loading

- $F=300lb_f$
- $\Theta=60°$ at tipping
- Stress concentration of 1.8 at the weld [Shigley]

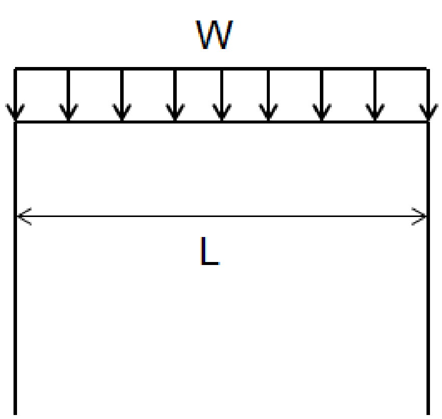
Fatigue using Miner's Rule

- Obtained fatigue curve from MIL handbook
- 5 years of life under assumed riding schedule
- Fully reversed load while tipping (conservative)
- Static load of $150lb_f$

Figure 25: Analysis Model for the Vertical Frame Members in Tipping

Horizontal Frame Members

The horizontal members will undergo a distributed load where the seat mount rests on the frame.The non-load bearing horizontal members will be sized the same as the load bearing members for simplicity of construction.



Loading

- $W=300lb_f$
- L=11 in
- Simply supported

Fatigue Analysis

- 5 years of life under assumed riding schedule
- Static load of $W=150lb_f$

Figure 26: Analysis Model for the Horizontal Frame Members

Leg Rest Members

Stress and deflection analysis on the leg rest are important, since critical bending stresses are expected to occur in this member. Joints A, B, and C are pin connections, so that portion of the structure was analyzed as a truss. Member CD was analyzed as a cantilevered beam of length L. An EES code was developed to determine the optimal lengths for L and X to minimize frame weight. The cross members (not shown) are sized the same as member AD for simplicity.

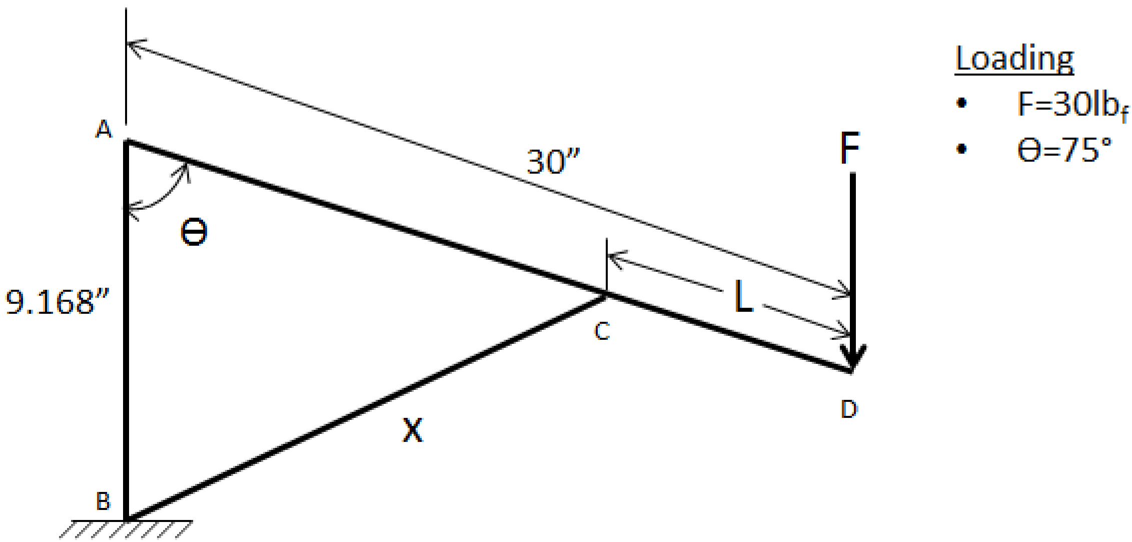


Figure 27: Analysis Model for the Leg Rest Members

Results

EES code was used to iterate the analysis with standard tube sizing. The results are shown below in Table 5.

Table 5: Tube Sizing Results From Analysis

	Diameter (in)	Thickness (in)	Weight (lb)
Vertical Frame Members	1	0.065	0.764
Horizontal Frame Members	0.750	0.065	0.555
Leg Rest Member AD	0.625	0.065	0.686
Leg Rest Member BC	0.625	0.065	0.391
Leg Rest Cross Members	0.625	0.065	0.101
	Total		2.497

Final Design Realization

The final design realization is shown below. The portions of the design that were altered after the final design decision are detailed in the following sections.

Leg Rest

In the final version of the sliding foot rest, the size was increased to better accommodate the increased bulk of snow boots.

In order to allow the legs under position, a new foot rest attachment was designed and built. It was discovered late in the build process that the frame is too narrow to fit snow boots on the inside, but too wide to comfortably attach straps to the outside. The new leg rest attachment eases these problems, and still allows for the legs under position.

Figure 28: The updated leg rest configuration

Padding

The padding used in the bucket seat is ½" chemical resistant polyurethane foam. The foam was chosen because it lightweight and appropriate for the expected weather conditions.

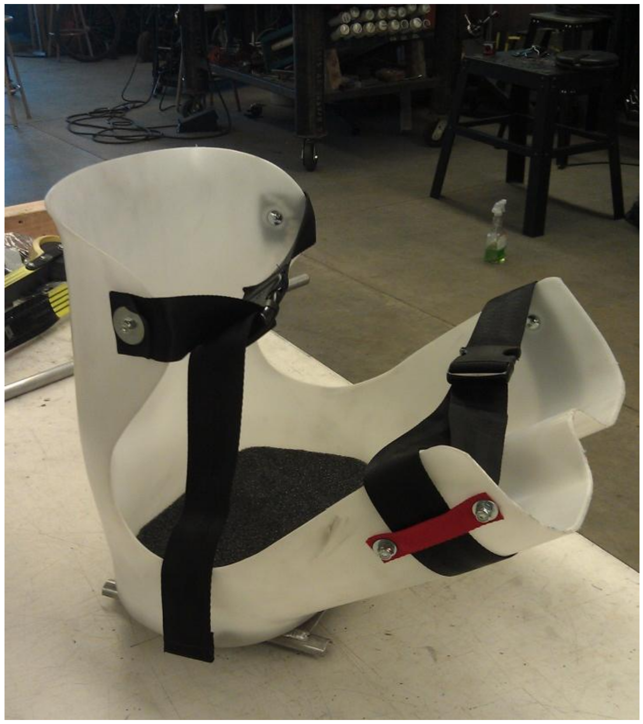


Figure 29: The bucket seat with padding

Bench Seat

The width of the bench seat was increased from 12" to 18" to improve rider comfort. Minor changes in the supporting structure were made to accommodate the increased size and to simplify construction.

Figure 30: The bench seat as built

The bench seat was canvased by Central Coast Sail and Canvas, located locally in San Luis Obispo. The company generously donated their time and materials at no cost.

Heat Treatment

The heat treatment of the bench seat and frame was outsourced to Ventana Mountain Bikes USA, located in Rancho Cordova, California.

Design Verification (Testing)

In order to guarantee that the final design has met our engineering specifications, several tests were performed after manufacturing. These tests are to ensure rider safety and comfort, as well as compatibility with Disabled Sports Eastern Sierra's existing Nordic skis.

Vertical Frame Members

In order to simulate the loads during tipping, the sit ski was subjected to a moment load of 1000 in-lb. To simulate the predicted moment, the ski was supported with the frame hanging over the edge of a table. Weights werethen attached to the top of the frame. The test was considered successful, asthe

vertical members did not permanently deflect. Elastic deformation of 0.350" occurred at the max loading condition.

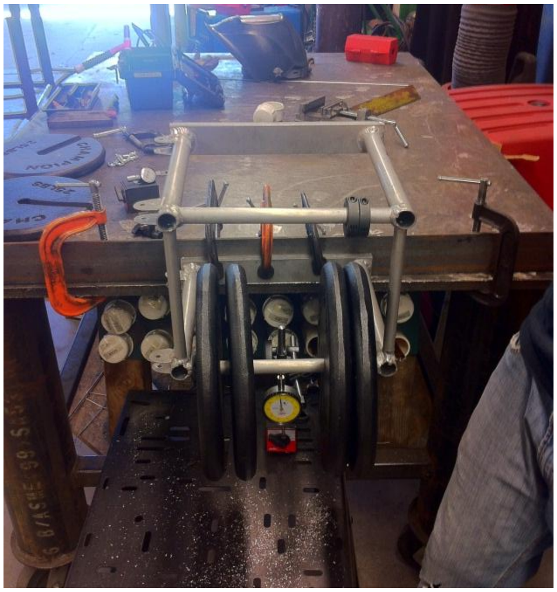


Figure 31: Testing the vertical frame members

Horizontal Frame Members

The horizontal members were tested by attaching the seat mounting plate and loading it with 300 pounds of weight. The horizontal members did not permanently deflect under this loading condition.

Figure 32: Testing the horizontal frame members

Leg Rest Members

The leg rest was tested by attaching 50 pounds of weight at the furthest point from the main frame. The test originally called for a 60 pound load, but the 0.5" deflection occurred before this, so testing was halted. The final deflection at 50 pounds was 0.615".

Figure 33: Testing the leg rest deflection

Drop Test

To ensure the system is robust, weperformed drop test from a height of 3 feet. This simulated any accidents that may occur in transferring the sit ski from storage or cars. The sit ski survived the drop test with minimal damage. All components are still in working condition.

Ski Binding Compatibility

The skis were attached to a pair of road skis, and the alignment was measured. The skis are parallel to within 0.3°, which is within our ±1° tolerance.

Adjustment Time

The sit ski was given to a novice user, who was instructed to change from a bucket seat with the long leg rest attached to a bench seat with the legs under attachment. The user was able to complete the change in 11 minutes, which is within our tolerances.

Figure 34: Changing the seating configuration

Rider Comfort

Several users were asked to sit in the sit ski and evaluate its comfort in all 3 expected configurations. The configurations will be:

- Bucket seat with long leg rest attached
- Bench seat with long leg rest attached
- Bench seat with legs under attachment

There were no excessive pressure points and the straps fit comfortably and securely.

Figure 35: A rider demonstrating the legs out front, bench seat configuration

Strap Security

The strap security was tested by tipping the sit ski with a rider strapped in. The test was considered successful, as the skiwas able to tip without the rider being dislodged from the seat or straps. The straps did not noticeably loosen during this test.

Figure 36: Testing the strap security while tipping

Verification of Requirements

Spec. #	Parameter Description	Requirement or Target	Tolerance	Actual Value	Compliance
1	Weight of Sit Ski	11 lbs	± 2 lbs	12.14 lbs	Pass
2	Time to attach frame to skis	1 min	± 30 sec	30s	Pass
3	Time to adjust seat/legs	10 min	± 1 min	11:00	Pass
4	Largest rider that can fit (weight)	300 lbs	Max	300+	Pass
5	Cost to produce	$1,000	± $200		Pass
6	Number of leg positions available	2	Min	2+	Pass
7	Height of bottom of seat	15.75” (40 cm)	Max	≈14.5”	Pass
8	Centerline distance of skis	8.85”	± 1”	9”	Pass
9	Ski Binding Pin	0.16” Diameter Pin	±0.02	0.16”	Pass
10	Ski Binding Distance	12.25” from front pin ℄ to back pin ℄	$\pm\frac{1}{16}$ “	12.25”	Pass
11	Parallel Ski Alignment	Parallel	±1°	0.3°	Pass
12	Leg Rest Deflection	0.5” at the far end	±0.1”	0.615”	Fail

Conclusions and Recommendations

Though our sit ski did not meet all design requirements, we consider this project to be a success. The requirements that were not met were non-critical, and the sit ski still functions as intended. Minor improvements could be made in the following areas.

Aesthetics

To improve aesthetic appeal, the sit ski should be painted, preferably by powder coating. This also has the benefit of giving the sit ski additional corrosion resistance. If the sit ski was painted, an additional rubber insert should be added between the half tube attachments to prevent the paint from scratching. This would require using the next larger standard sized tube for the mounts, along with larger shaft collars.

Bench Seat

The bench seat could be made longer, and the back supports should be made more vertical. Both changes would improve rider comfort.

Clamps

Time permitting, we would like to have been able to develop a clamp that does not require full removal from the frame for adjustment. Ideally, this clamp could be removed without tools to improve the transition between configurations. The hinged collars currently in use are much heavier than we anticipated, and weigh approximately ¼ lb each.

Leg Rest

Additional support members could be added to the leg rest to improve its rigidity. In its current configuration, the leg rest oscillates slightly from side to side, which may eventually cause failure in the support tabs.

Appendix A: Quality Function Deployment

Quality Function Deployment (QFD) is a method that we used to convert customer requirements to engineering specifications. The output of the QFD method is a “house of quality”. The results can be found on the next page.

The left “wall” of the house lists demanded qualities. These are the customer requirements that describe what the customer wants, usually in their own words. These can include things like functional performance, human interaction, and manufacturing concerns. These requirements are the assigned weights based on relative importance.

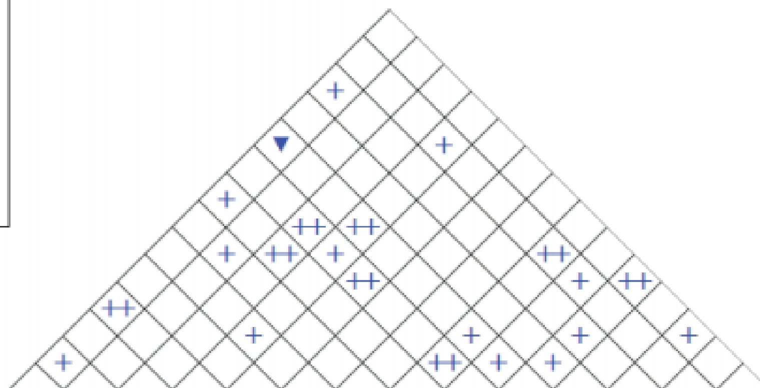
The “ceiling” lists quality characteristics. These are functional requirements, including how the design will achieve the customer requirements. Included in this section is the direction of improvement for each characteristic. This could be to minimize or maximize a value, or to hit an intended target.

The “roof” of the house correlates engineering requirements to each other. Correlations are rated as strong positive, positive, negative, and strong negative.

In the middle of the “house” is the relationship of the demanded qualities and the quality characteristics. Relationships can be strong, moderate, or weak. For example, the ability of the ski to tip has a moderate relationship with the seat height.

The “floor” lists the target or limit values for each quality characteristic and the estimated difficulty of obtaining it. These are the requirements that must be met for a design to be considered 100% successful.

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



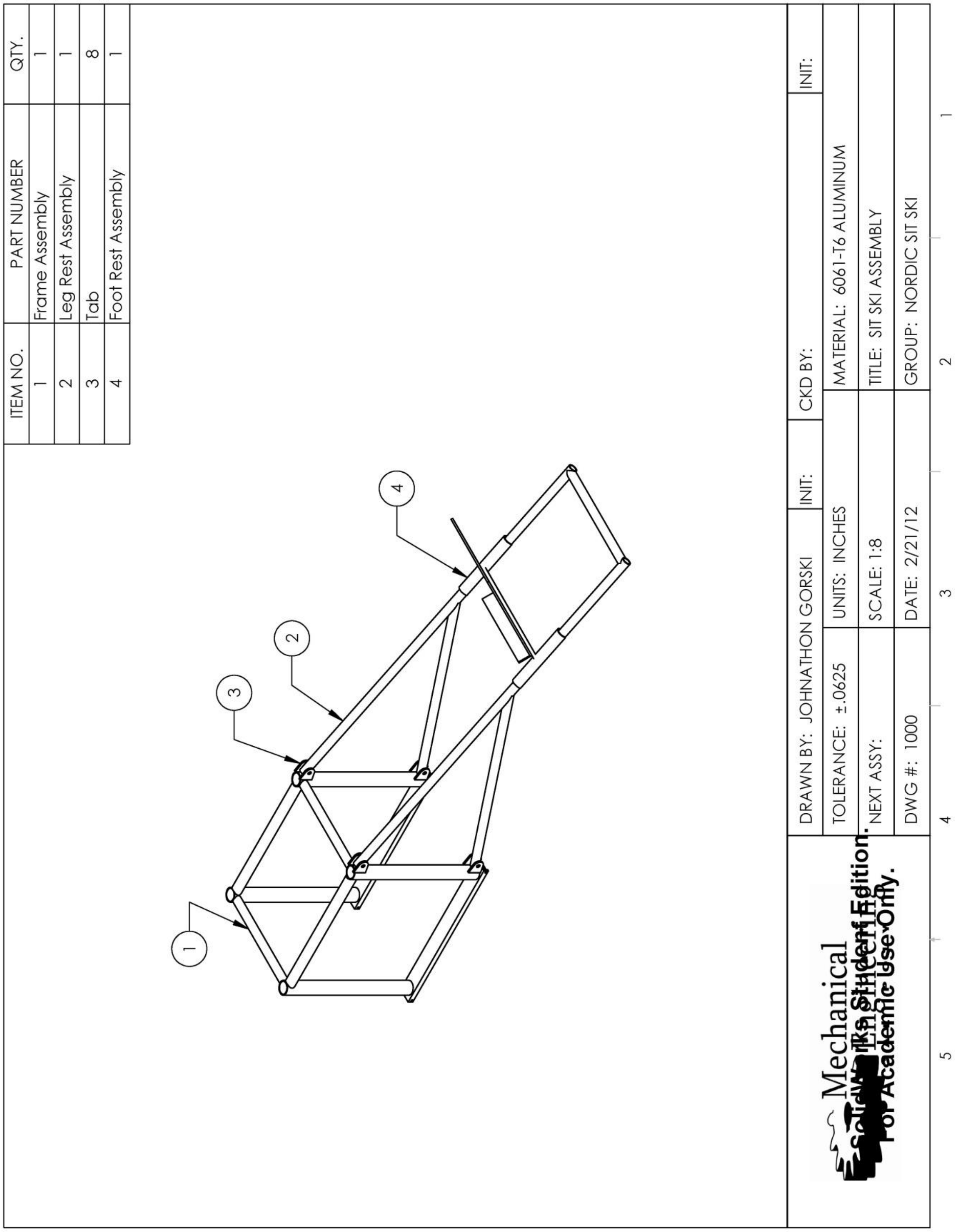
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Weight of Sit Ski	2 Time to attach frame to skis	3 Time to adjust seat/legs	4 Largest rider that can fit (weight)	5 Smallest rider that can fit	6 Height of bottom of seat	7 Ski Binding Method	8 Number of straps	9 Number of possible strap combinations	10 Cost to produce	11 Number of leg positions available	12 Centerline distance of skis	13 Max Load on Straps	14 Parallel Ski Alignment
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	▼	x	x	x	x	x	▲	▼	x	x	x	x
1	9	6.4	85.0	Lightweight*	Θ	▲		O	O	▲		▲		O				
2	9	8.3	110.0	Seat must fit a variety of rider sizes*	▲			Θ	Θ	▲		O	O	O	O			
3	9	6.4	85.0	Legs in forward or kneeling position*			O			O			▲		Θ			
4	9	4.9	65.0	Padding to prevent pressure sores	O		Θ	Θ	Θ					▲				
5	3	4.5	60.0	Easy to maintain and clean	▲	O						O	O					
6	3	3.4	45.0	Long Life/Durability	▲			O				▲		▲			O	
7	3	3.4	45.0	Easy ingress/egress				O	O	O					O			
8		0.0	0.0	Accessible to towing harness*														
9	9	5.6	75.0	Include lap, chest, quad, and shin belt	▲		O	Θ	Θ			Θ	Θ	O				
10	9	8.3	110.0	Secure rider attachment*							O	Θ	Θ					
11	3	2.6	35.0	Ability to tip ski for Biathlon	O					O								
12	9	6.4	85.0	Must attach to existing bindings*							Θ							
13	1	2.3	30.0	Ability to reproduce the design	▲							▲		▲				
14	9	4.9	65.0	Low Cost	Θ													
15	9	3.4	45.0	Quick to assemble		Θ	Θ											
16	3	8.3	110.0	Rider comfort								O	O		O			O
17	9	6.0	80.0	Rider must be able to brake (reach the ground)*						Θ								
18	3	7.5	100.0	Adjustable Seat Back*				▲	O									
19	9	7.5	100.0	Fits in existing ski tracks												Θ		O
				Target or Limit Value	12 lbs	3 min.	10 min.	350 lbs	5th Percentile Female	11.8 in (30 cm)	SSS Binding Type (pass/fail)	5	10	$1,000	2	9 inches	50 lb	+/- 1 degree
				Difficulty (0=Easy to Accomplish, 10=Extremely	8	3	6	4	2	5	1	1	2	5	4	2	3	3
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	3	9	9	3	3
				Weight / Importance	148.1	50.4	110.5	216.2	221.1	106.0	82.3	200.4	194.7	71.4	117.3	67.7	10.2	47.4
				Relative Weight	9.0	3.1	6.7	13.2	13.4	6.5	5.0	12.2	11.8	4.3	7.1	4.1	0.6	2.9

Appendix B: Bill of Materials

	Quantity	Unit Cost	Total Cost	McMaster Part Number	Aircraft Spruce Part Number	StrapWorks Part Number
Frame						
0.625" OD x 0.065" 6061 Tube	2	$3.45	$6.90		03-36100-Length	
0.750" OD x 0.065" 6061 Tube	2	$2.99	$5.98		03-36350-Length	
1.000" OD x 0.065" 6061 Tube	4	$4.35	$17.40		03-36800-Length	
0.375" x 1.25" x 36" 6061 Bar (Bindings)	1	$15.34	$15.34	8975K466		
Pin (11/64" Diameter x 3')	8	$3.91	$31.28	95255A263		
Leg Rest						
0.625" OD x 0.065" 6061 Tube	2	$3.45	$6.90		03-36100-Length	
0.750" OD x 0.065" 6061 Tube	5	$2.99	$14.95		03-36350-Length	
0.875" OD Bar Stock	2	$4.60	$9.20		03-46010-Length	
Foot Rest						
0.875" OD x 0.065" 6061 Tube	1	$4.40	$4.40		03-36450-Length	
0.25" x 0.5" x 60" 6061 Bar	1	$9.79	$9.79	8975K13		
0.125" x 6" x 36" 6061 Bar (From Bucket Seat Mount)	0	$26.78	$0.00	8975K926		
Bench Seat						
0.625" OD x 0.065" 6061 Tube	5	$3.45	$17.25		03-36100-Length	
0.875" OD x 0.065" 6061 Tube	2	$4.40	$8.80		03-36450-Length	
Canvasing by SLO Sail and Canvas	1	$0.00	$0.00			
Bucket Seat						
0.875" OD x 0.065" 6061 Tube	2	$4.40	$8.80		03-36450-Length	
0.125" x 6" x 36" 6061 Bar	1	$26.78	$26.78	8975K926		
Bucket Seat	2	$190.00	$380.00			

Hardware						
Quick Release Pin 1/4" Diameter 0.8" Long	4	$1.45	$5.80	98320A130		
Hinged Shaft Collar3/4" Bore	4	$11.07	$44.28	57145K74		
Hinged Shaft Collar7/8" Bore	4	$11.65	$46.60	57145K75		
Slotted Spring Pin, M4 Diameter	1	$4.52	$4.52	91610A515		
Polyethylene Foam, 1/2" Thick, 24" X 54"	1	$22.60	$22.60	9334K23		
2" Footman Loop	10	$1.59	$15.90			
#10-32 Machine Screw	12	$0.41	$4.92			
#10-32 Machine Washer	12	$0.10	$1.20			
#10-32 Machine Nut	12	$0.38	$4.56			
Straps						
2" Polypropylene Strap	30	$0.27	$8.10			HWP2
1" Polypropylene Strap	10	$0.18	$1.80			HWP1
2" Plastic Slide	18	$0.56	$10.08			PS
1" Plastic Slide	5	$0.30	$1.50			PS
2" Double Adjust Buckle	10	$1.77	$17.70			SRBDA
1" Double Adjust Buckle	3	$1.27	$3.81			SRBDA
Heat Treatment						
Ventana Mountain Bikes USA	1	$203.00	$203.00			
Grand Total	**$960.14**					

Appendix C:Part Drawings



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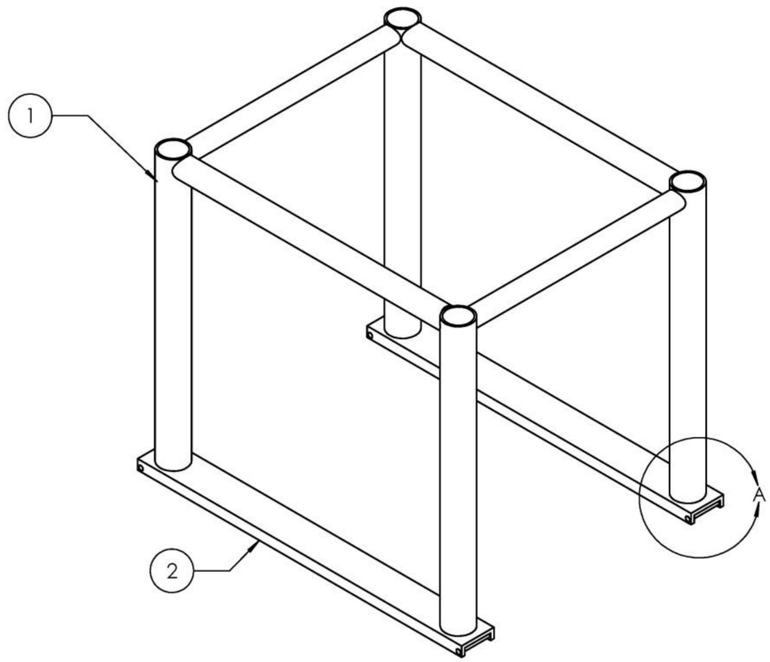
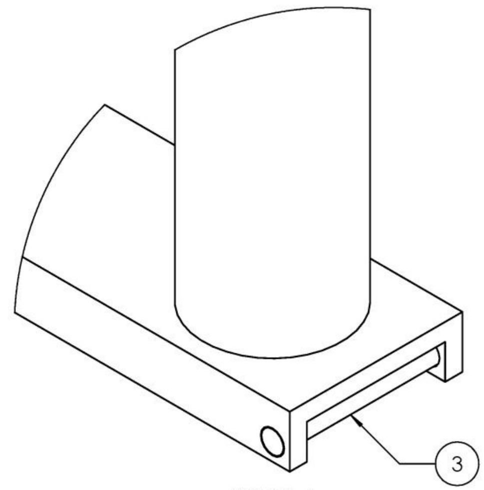
2	Binding -Bolt	2
3	Pin	4





DETAIL A
SCALE 4 : 3

Pin is pressed in

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DWG #: 1100	DATE: 2/9/12		GROUP: NORDIC SIT SKI	

5 4 3 2 1

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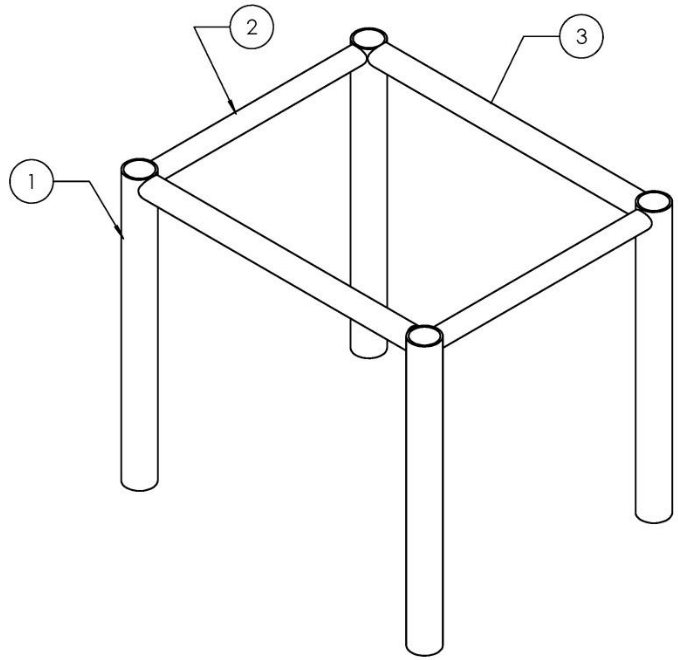
2	Frame Tube 2	2
3	Frame Tube 3	2

Reference Drawing #1111 for dimensions



Mechanical Engineering

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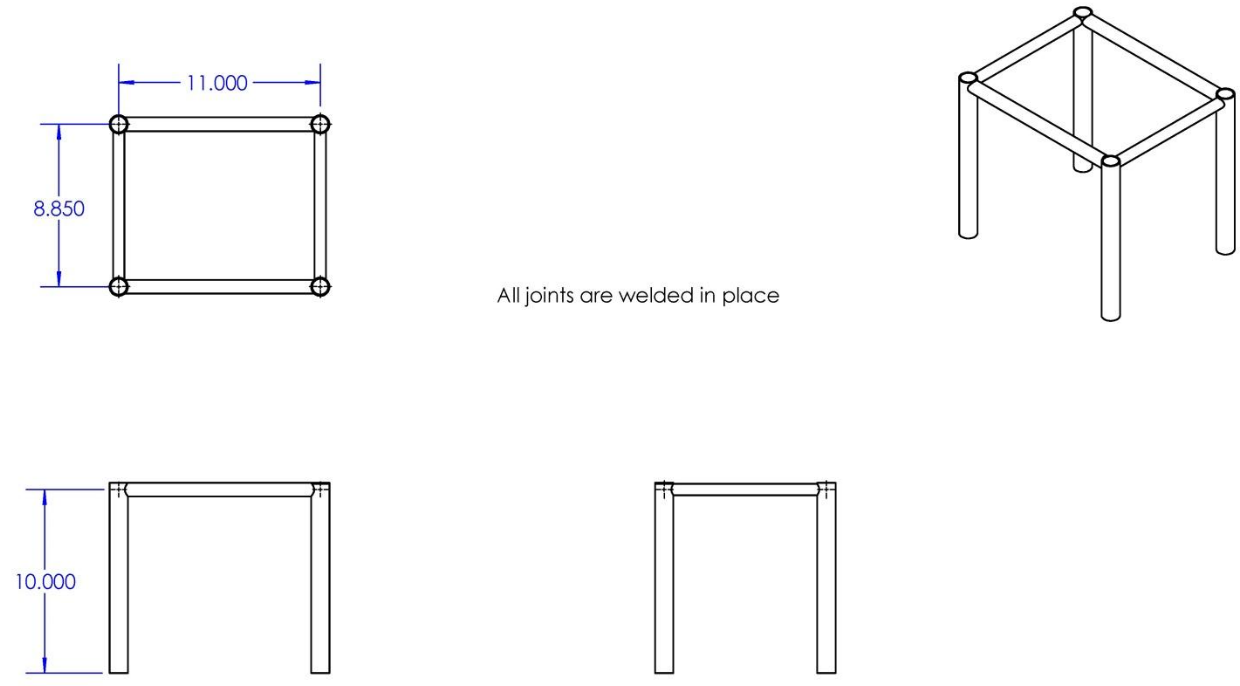

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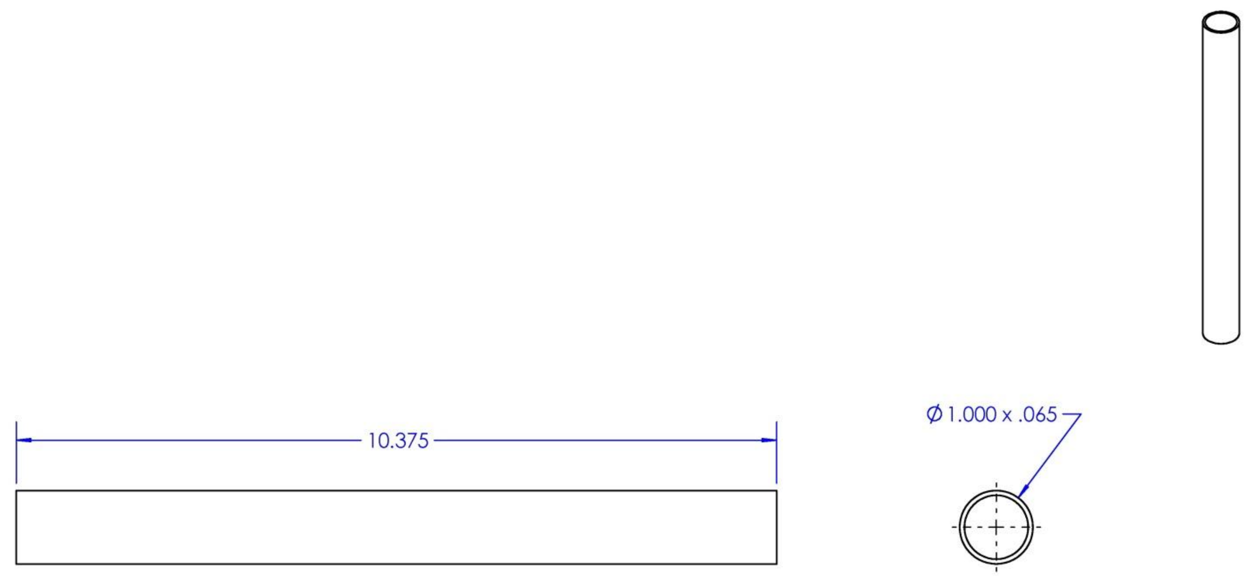
5 4 3 2 1



Mechanical Engineering

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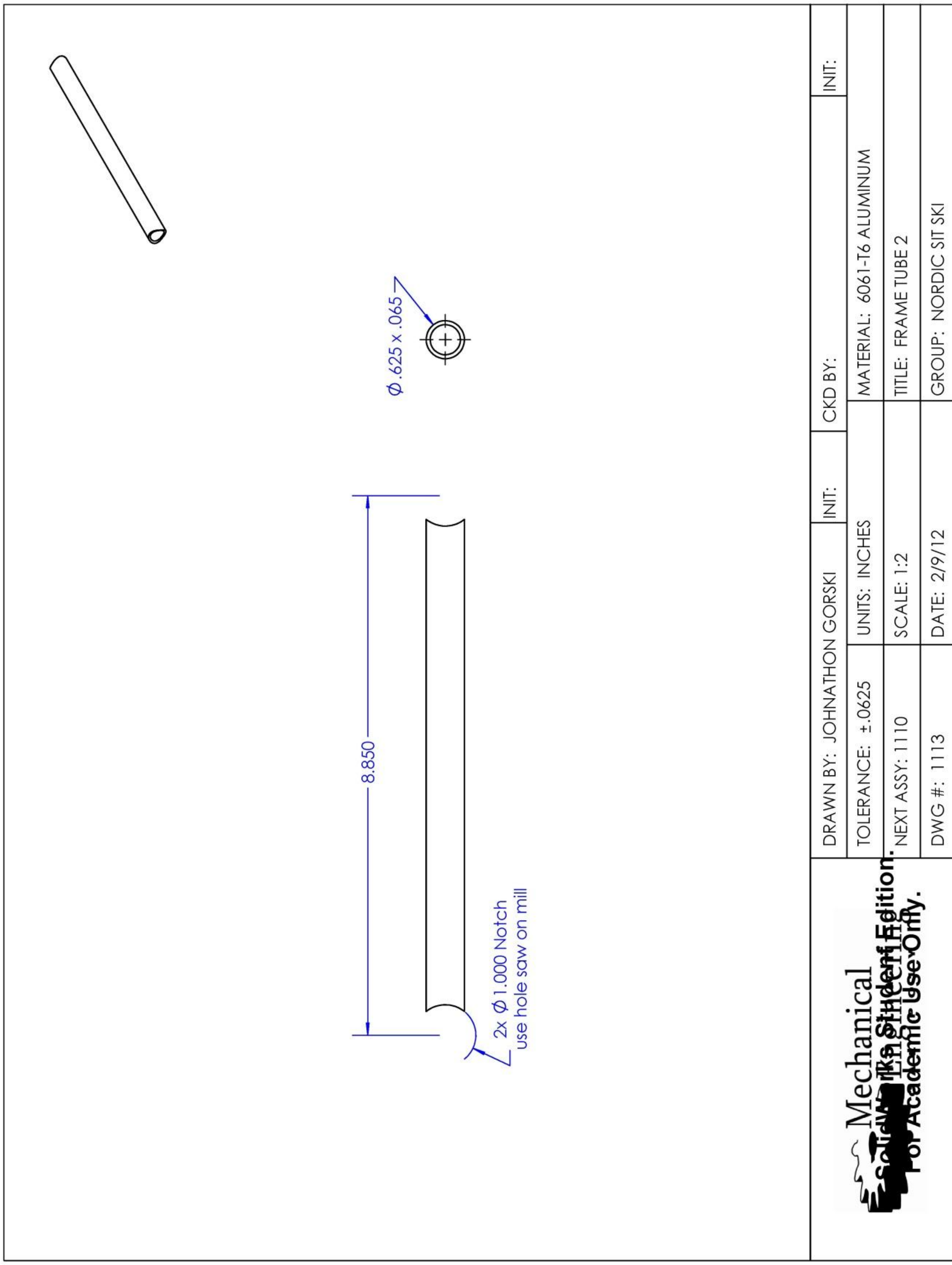
5 4 3 2 1



Ø.625 x .065
8.850
2x Ø1.000 Notch
use hole saw on mill
Mechanical
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DWG #: 1113
DATE: 2/9/12
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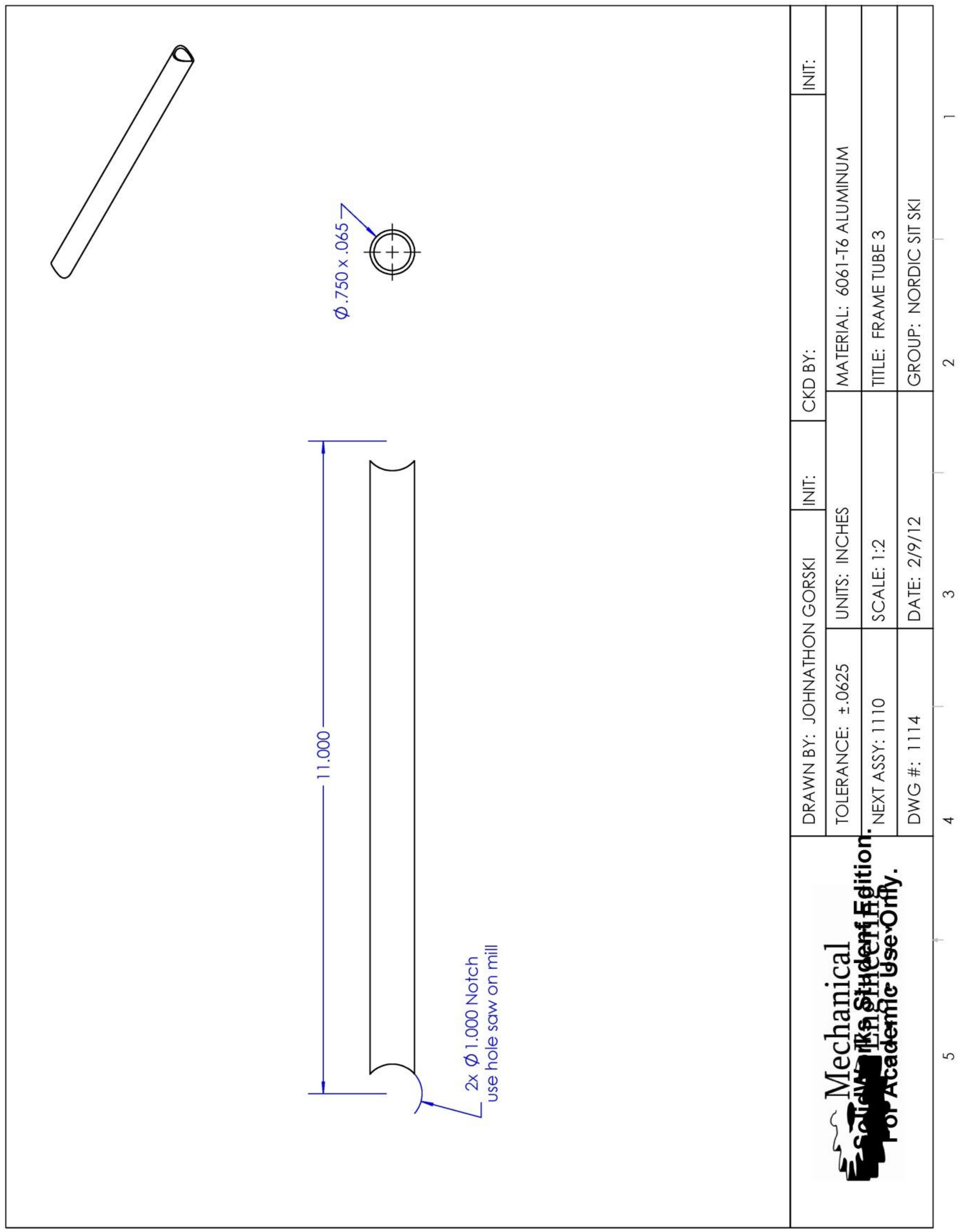
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11.000
2x Ø1.000 Notch
use hole saw on mill
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SCALE: 1:2
TITLE: FRAME TUBE 3
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DATE: 2/9/12
GROUP: NORDIC SIT SKI
Mechanical
For Academic Use Only.
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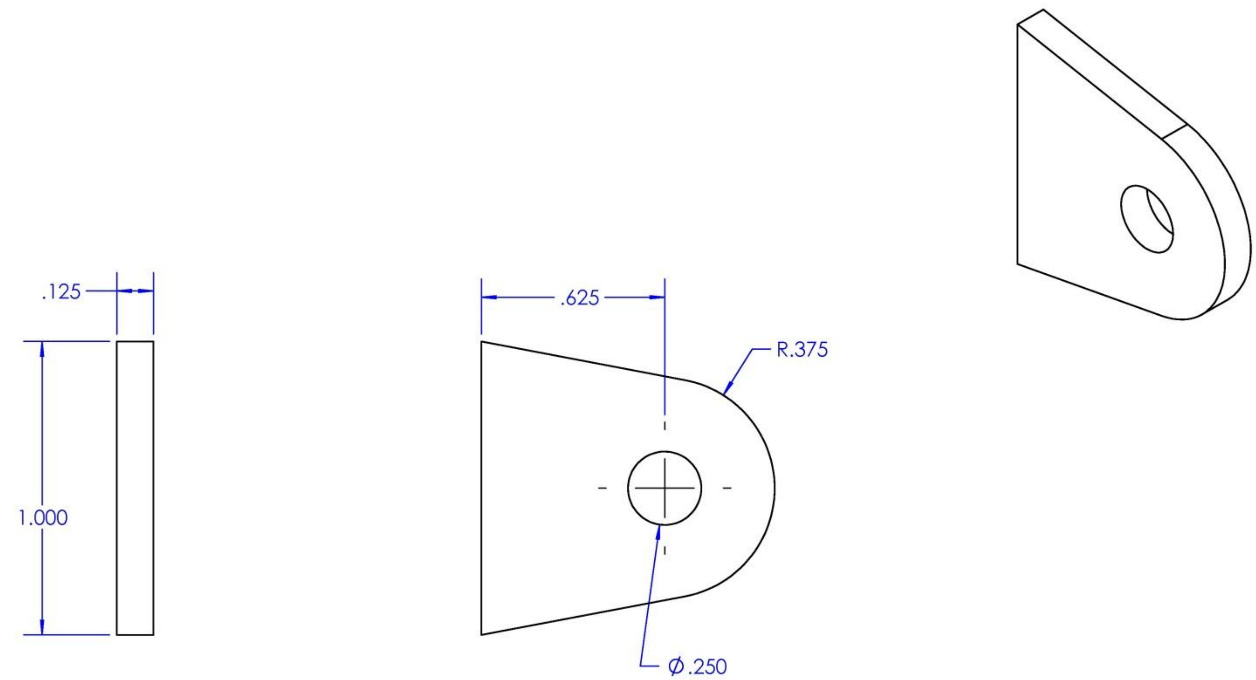

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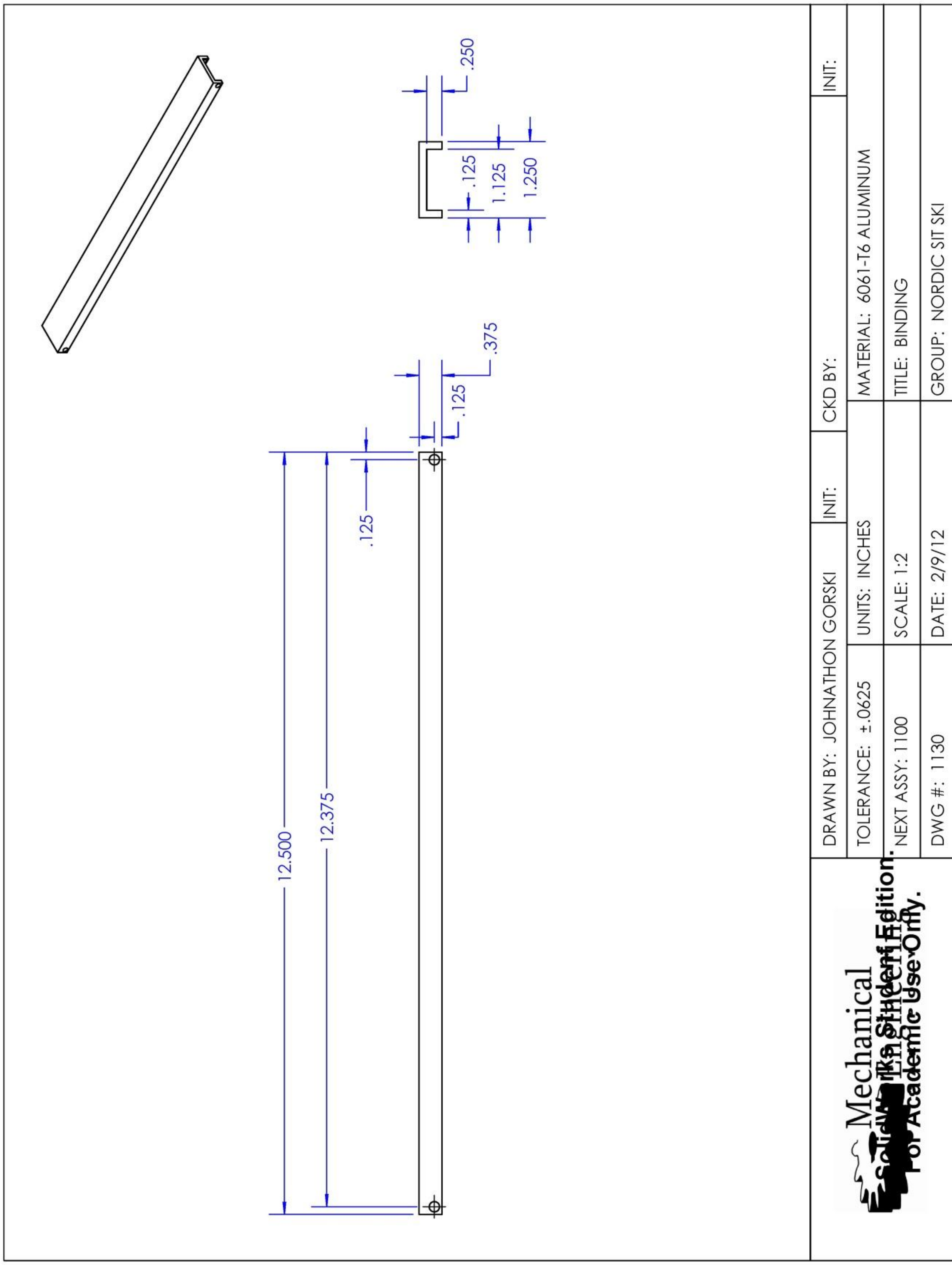
Mechanical Engineering

5 4 3 2 1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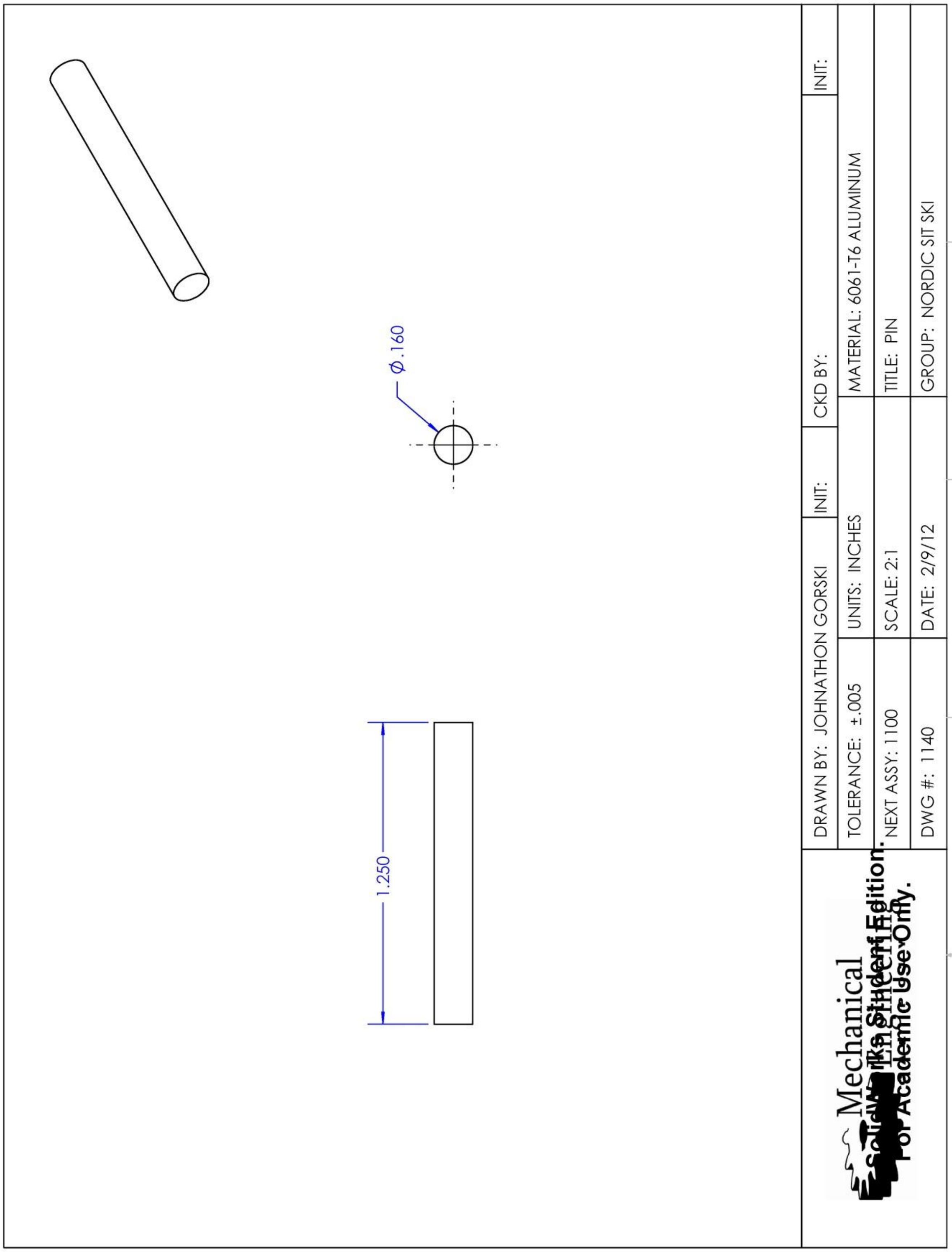

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DWG #: 1140
DATE: 2/9/12
GROUP: NORDIC SIT SKI
Mechanical
For Academic Use Only.
1
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5

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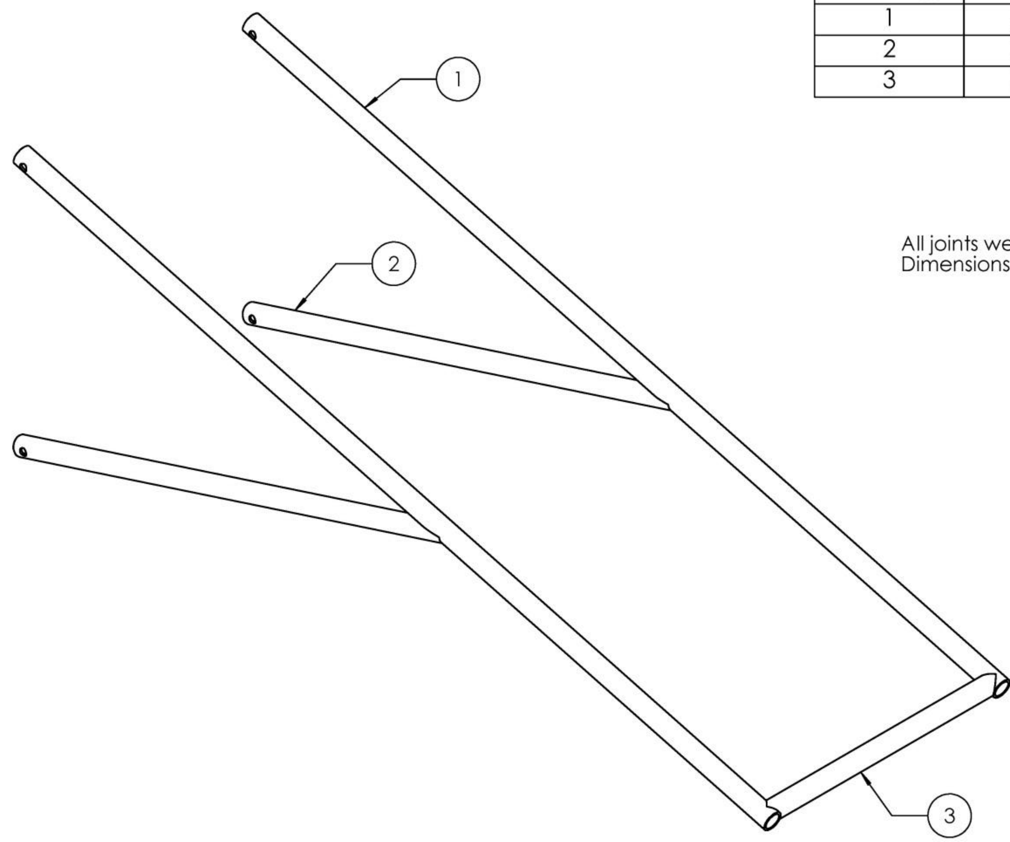
2	Leg Rest Tube 2	2
3	Leg Rest Tube 3	1



All joints welded in place
Dimensions referenced in drawing # 1210

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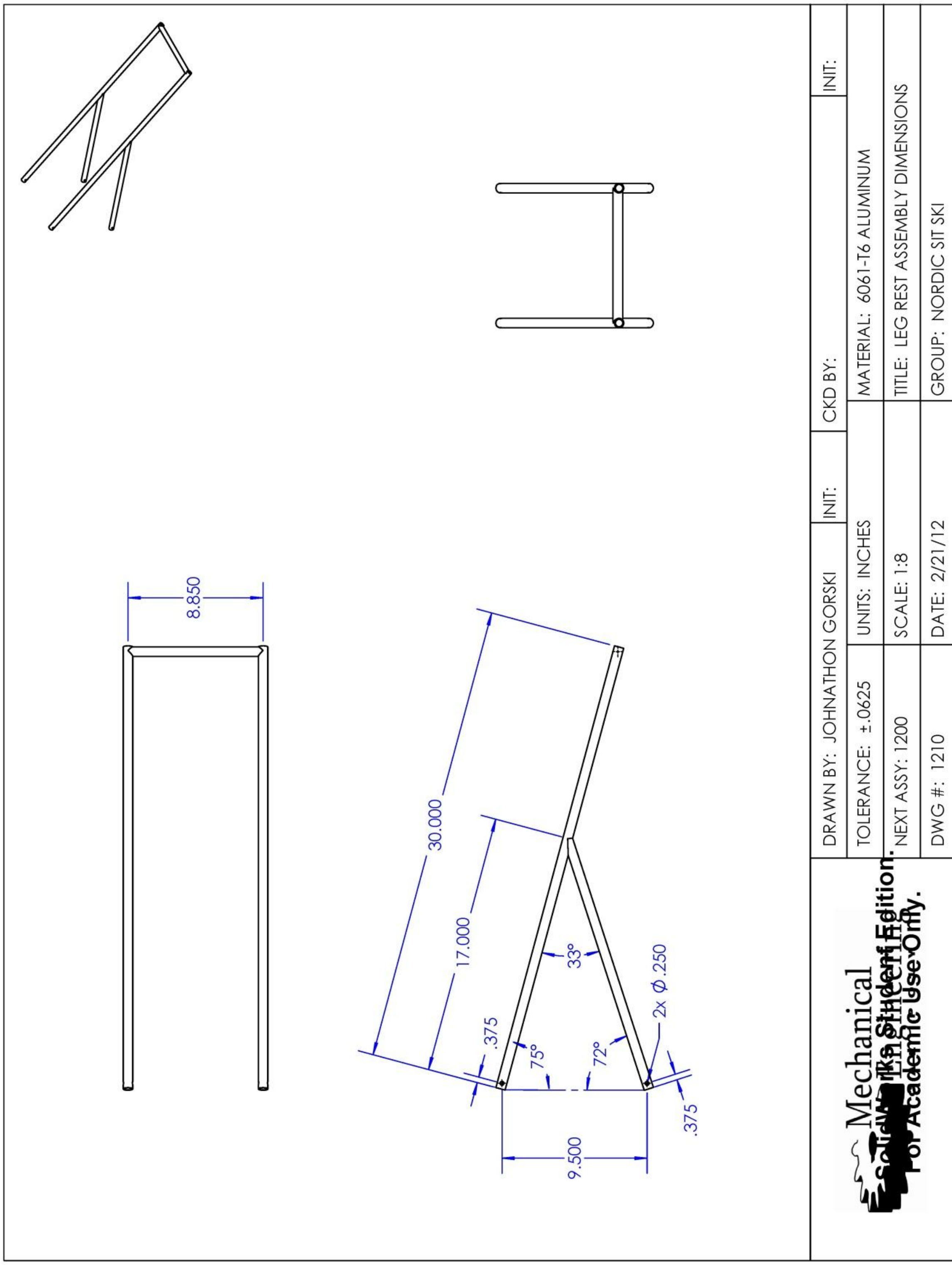
Mechanical Engineering

5 4 3 2 1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17.000
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75°
72°
33°
2x Ø.250
.375
9.500
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CKD BY:
INIT:
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Mechanical
For Academic Use Only.
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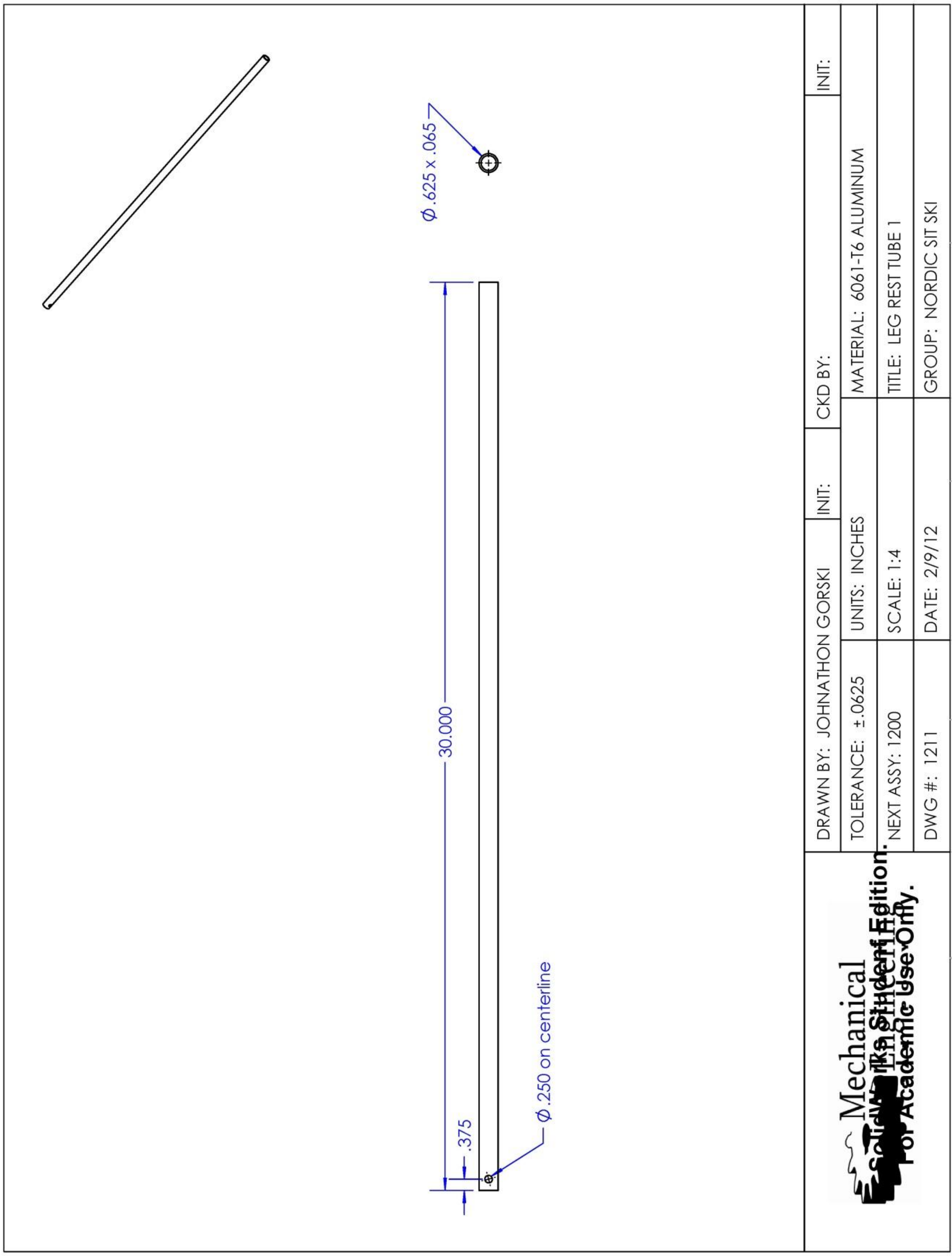
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30.000
.375
Ø.250 on centerline
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CKD BY:
INIT:
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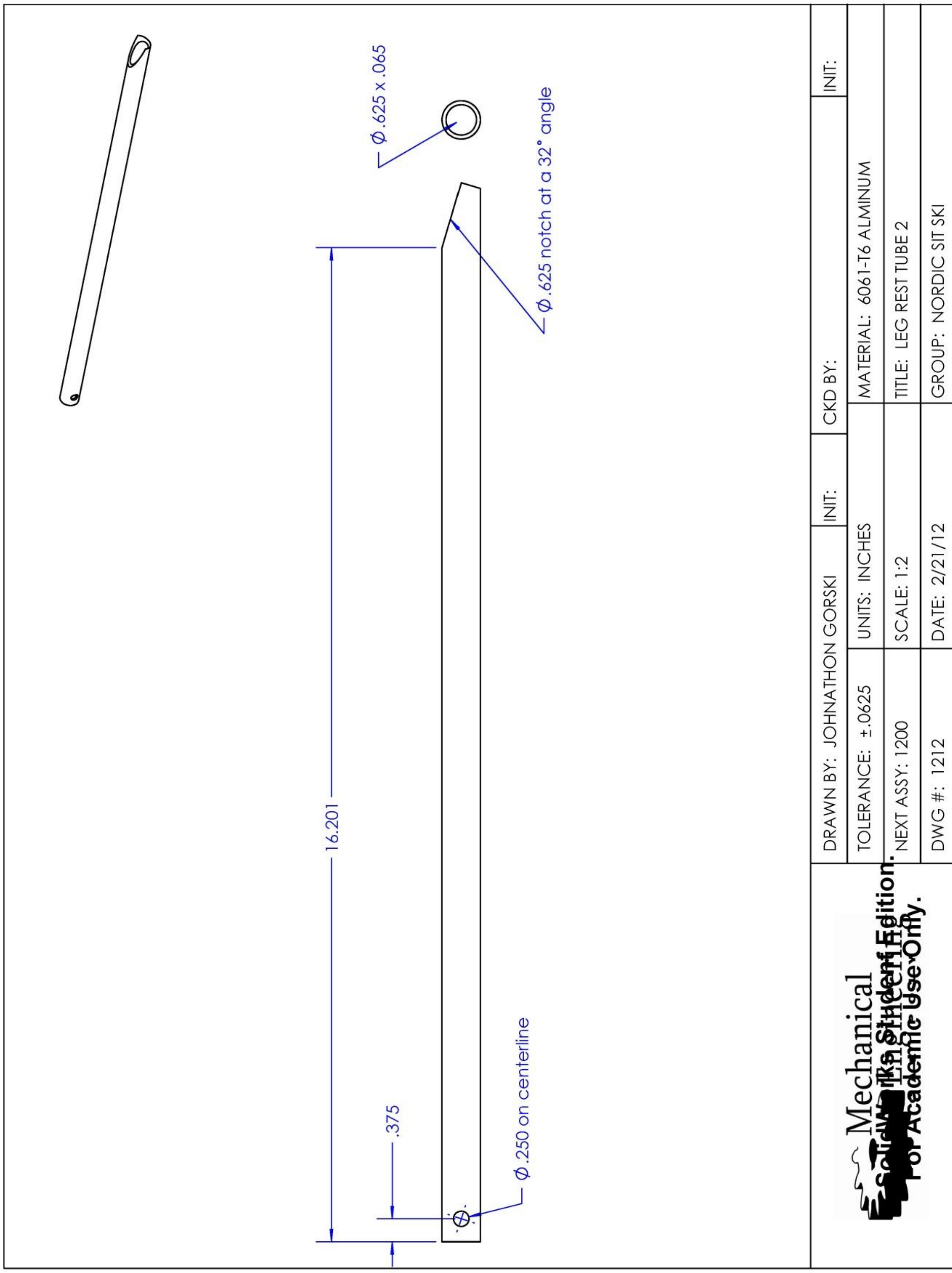
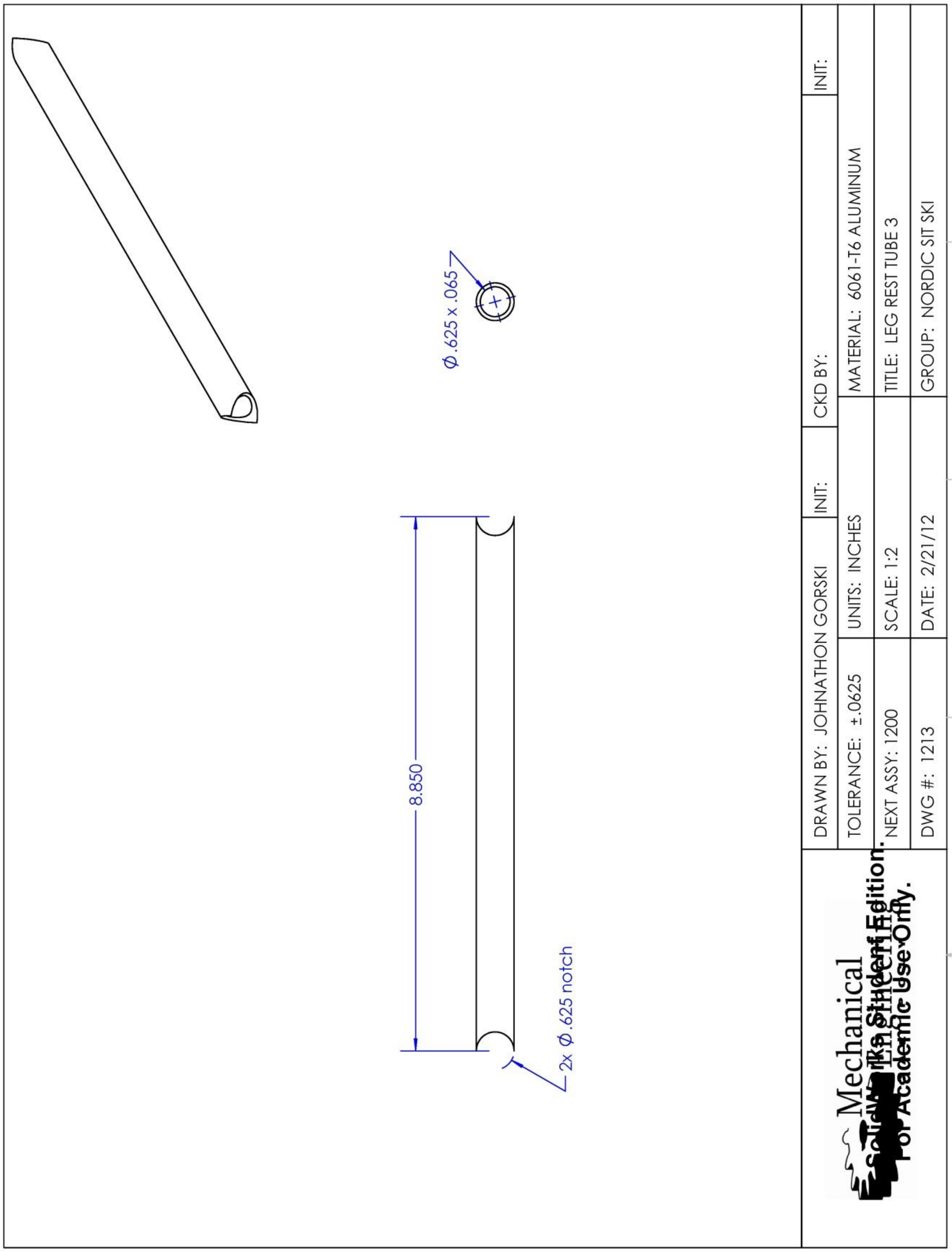
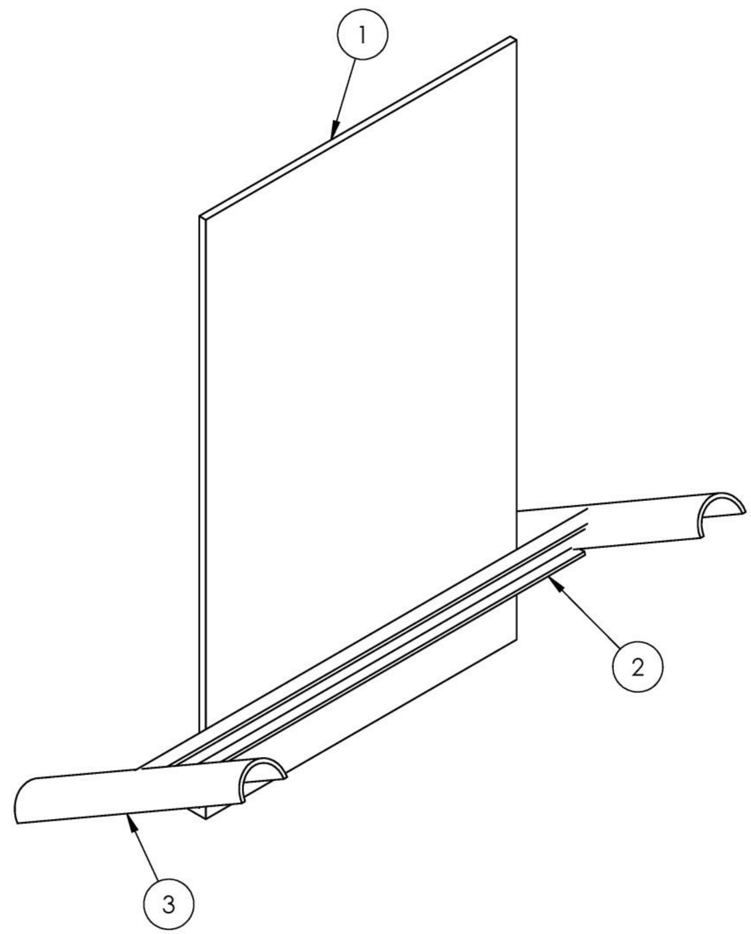
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1200
SCALE: 1:4
TITLE: LEG REST TUBE 1
DWG #: 1211
DATE: 2/9/12
GROUP: NORDIC SIT SKI
Mechanical
1
2
3
4
5


Ø.625 x .065
Ø.625 notch at a 32° angle
16.201
.375
Ø.250 on centerline
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALMINUM
NEXT ASSY: 1200
SCALE: 1:2
TITLE: LEG REST TUBE 2
DWG #: 1212
DATE: 2/21/12
GROUP: NORDIC SIT SKI
1
2
3
4
5



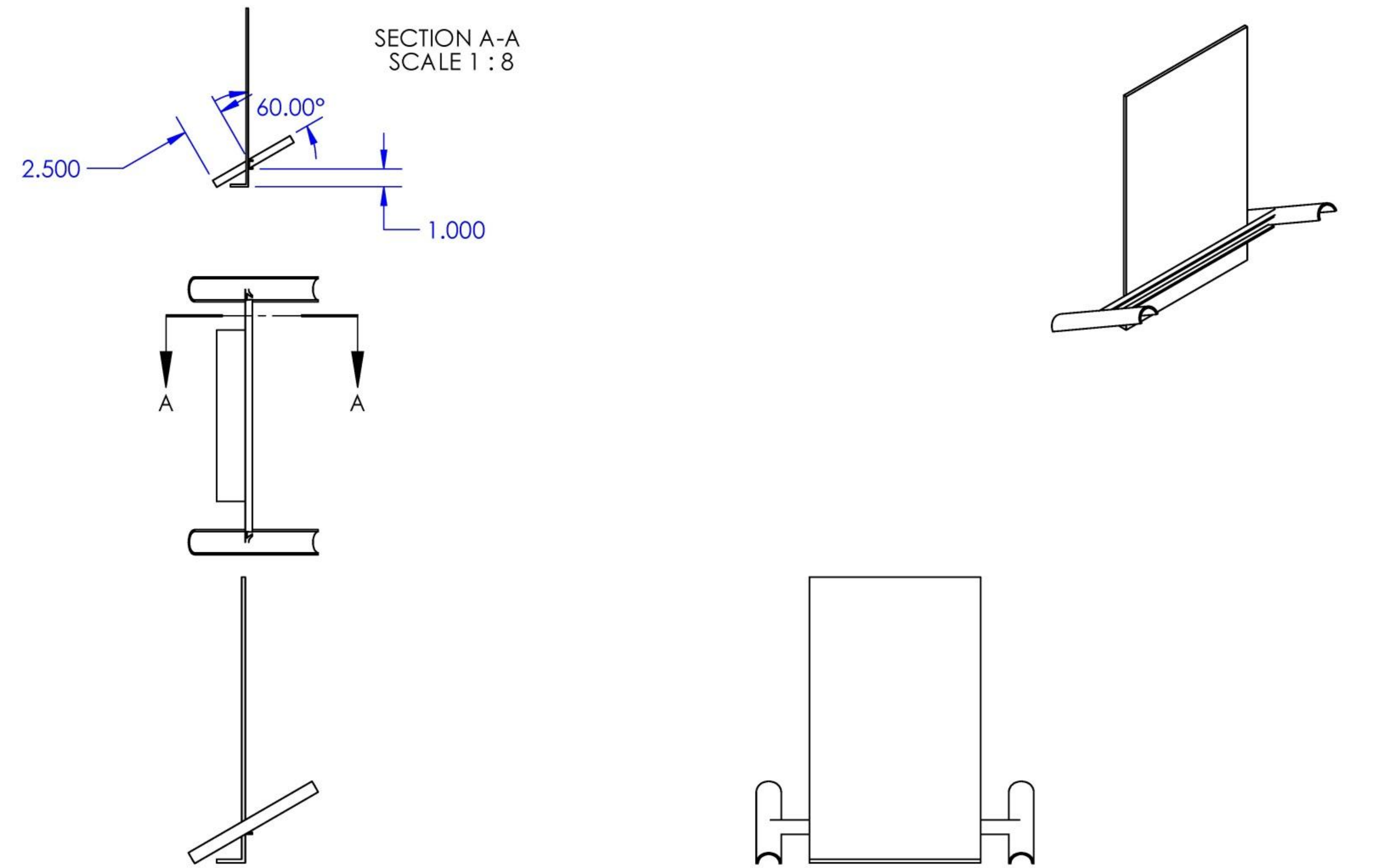
Ø.625 x .065
8.850
2x Ø.625 notch
Mechanical
For Academic Use Only.
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1200
SCALE: 1:2
TITLE: LEG REST TUBE 3
DWG #: 1213
DATE: 2/21/12
GROUP: NORDIC SIT SKI
5
4
3
2
1

ITEM NO.	PART NUMBER	QTY.
1	Foot Plate	1
2	Cross Bar	1
3	Half Tub	2



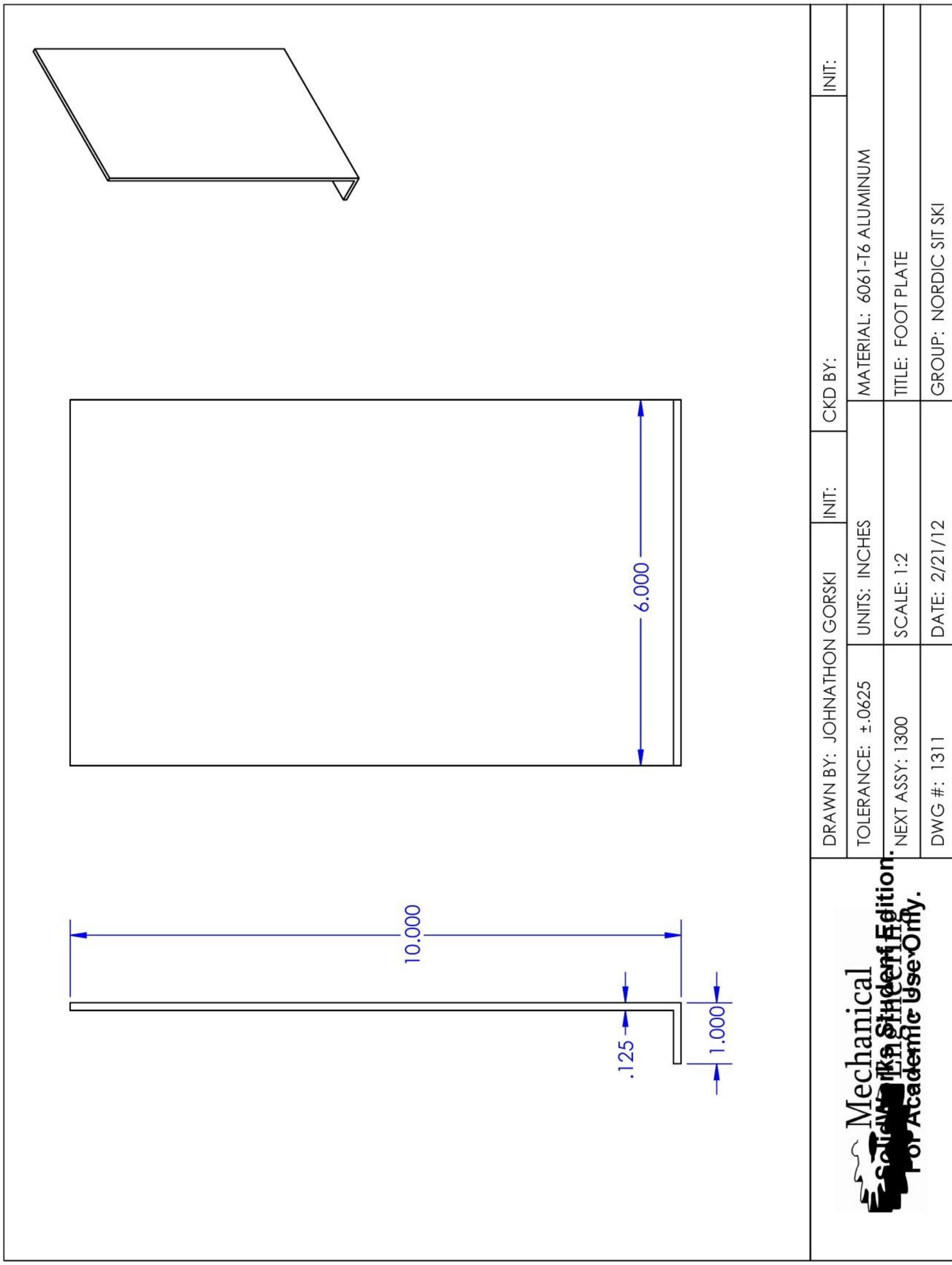
DRAWN BY: JOHNATHON GORSKI	INIT:	CKD BY:		INIT:
TOLERANCE: ±.0625	UNITS: INCHES	MATERIAL: 6061-T6 ALUMINUM		
NEXT ASSY: 1000	SCALE: 1:2	TITLE: FOOT REST ASSEMBLY		
DWG #: 1300	DATE: 2/21/12	GROUP: NORDIC SIT SKI		

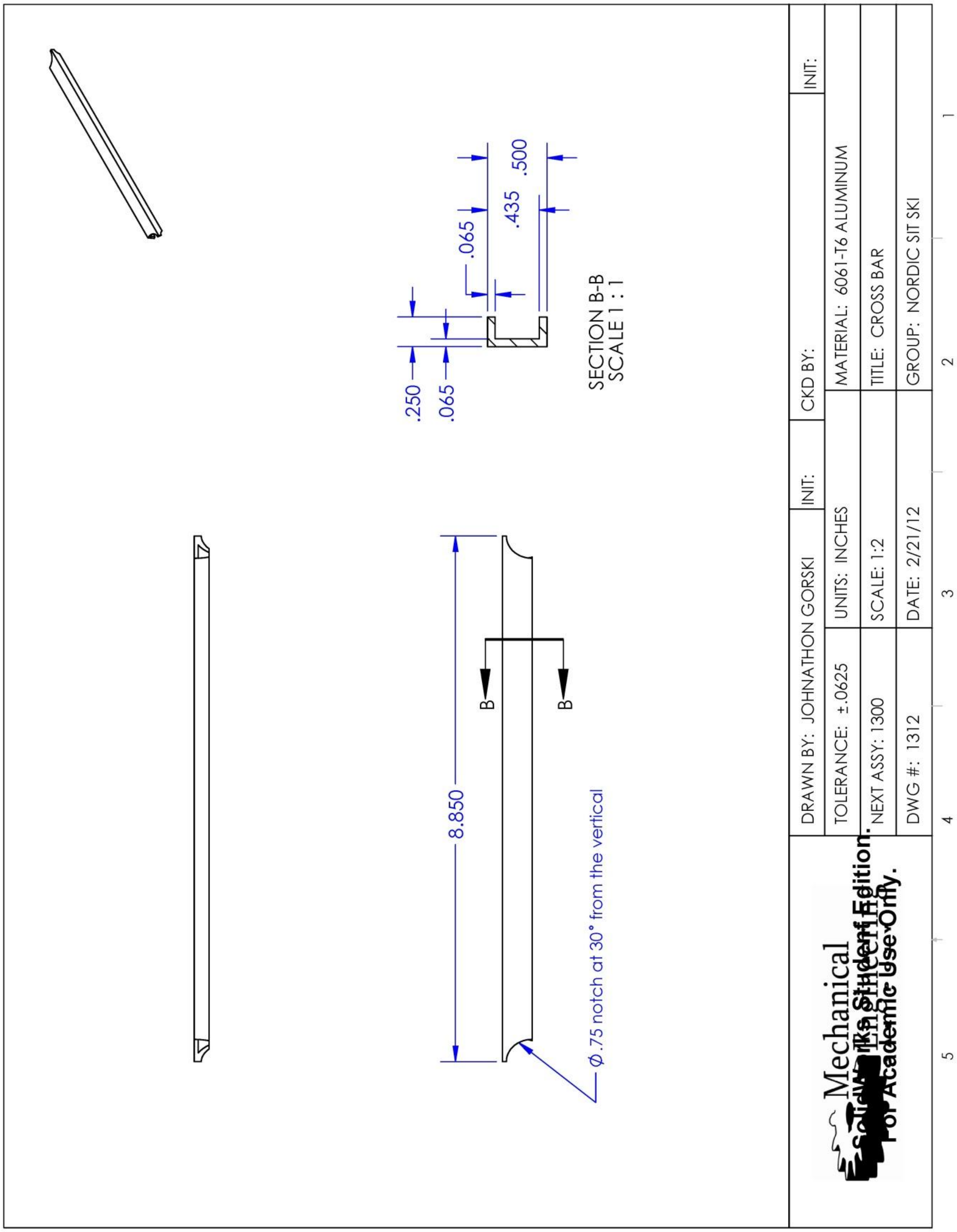
5 4 3 2 1



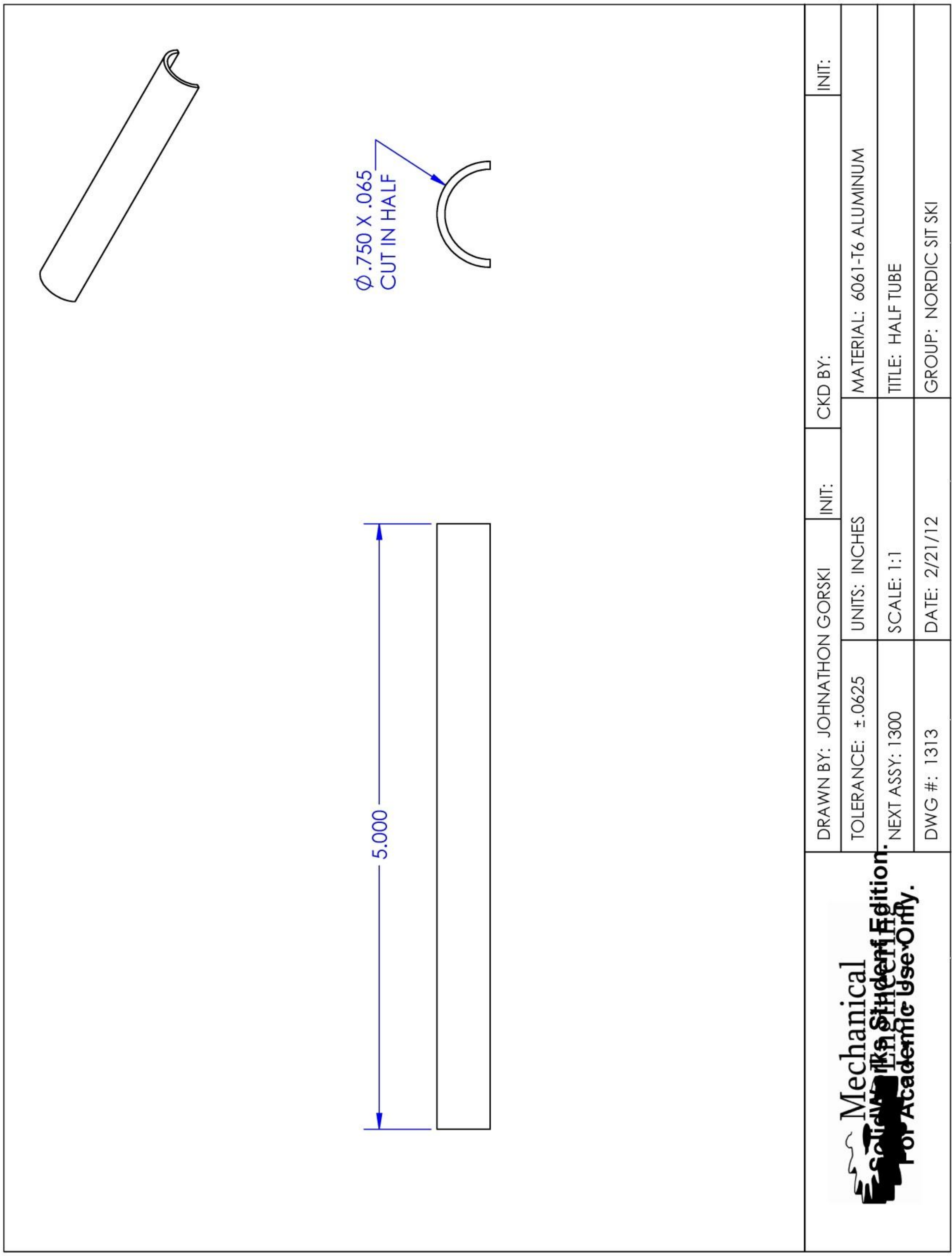
DRAWN BY: JOHNATHON GORSKI		INIT:	CKD BY:	INIT:
TOLERANCE: ±.0625	UNITS: INCHES		MATERIAL: 6061-T6 ALUMINUM	
NEXT ASSY: 1300	SCALE: 1:4		TITLE: FOOT REST ASSEMBLY DIMENSIONS	
DWG #: 1310	DATE: 2/21/12		GROUP: NORDIC SIT SKI	

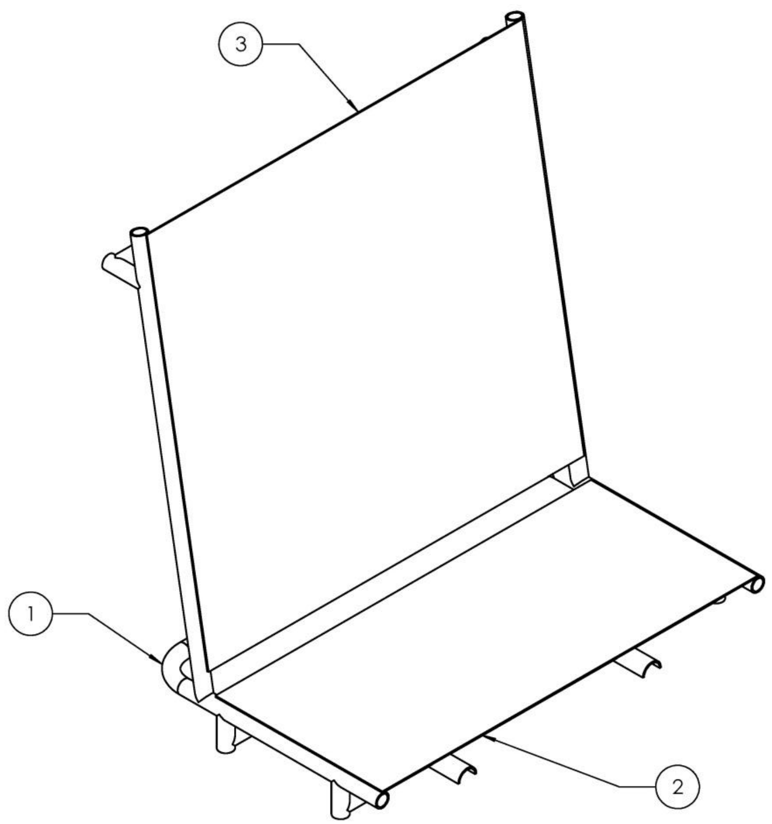
Mechanical Engineering


10.000
.125
1.000
6.000
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1300
SCALE: 1:2
TITLE: FOOT PLATE
DWG #: 1311
DATE: 2/21/12
GROUP: NORDIC SIT SKI
Mechanical
[redacted] Student Edition.
For Academic Use Only.
1
2
3
4
5



.065
.435
.500
.250
.065
SECTION B-B
SCALE 1 : 1
8.850
B
B
Ø.75 notch at 30° from the vertical
Mechanical
[redacted]
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1300
SCALE: 1:2
TITLE: CROSS BAR
DWG #: 1312
DATE: 2/21/12
GROUP: NORDIC SIT SKI
5
4
3
2
1


Ø.750 X .065
CUT IN HALF
5.000
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1300
SCALE: 1:1
TITLE: HALF TUBE
DWG #: 1313
DATE: 2/21/12
GROUP: NORDIC SIT SKI
1
2
3
4
5
Mechanical



ITEM NO.	PART NUMBER	QTY.
1	Bench Seat	1
2	Bench Seat Base Plate	1
3	Bench Seat Back Plate	1

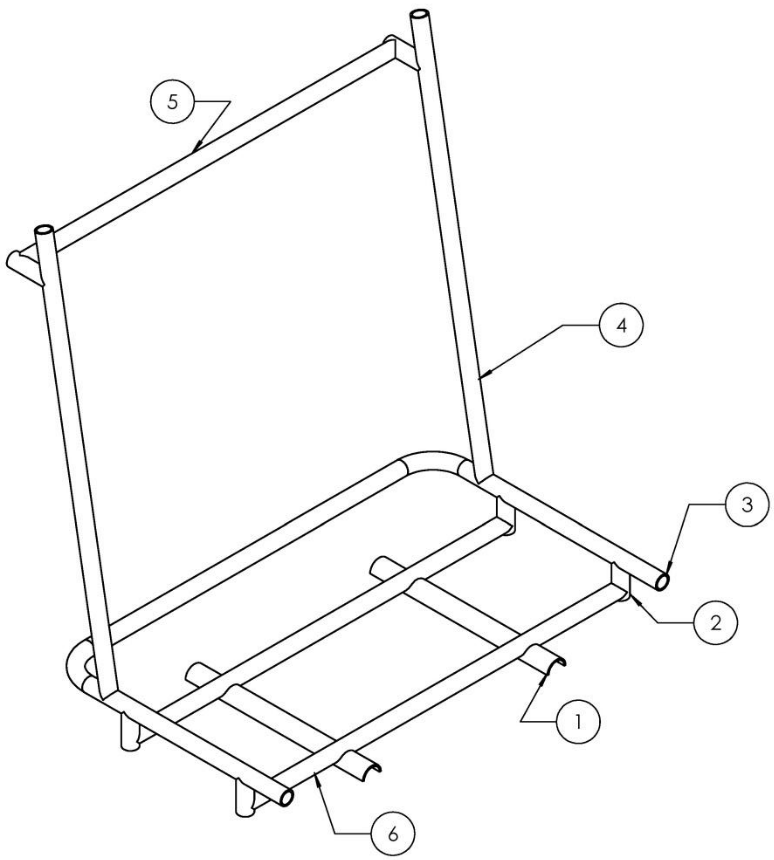
Items 2 and 3 will be nylon sewn and laced in place

Mechanical Engineering

DRAWN BY: JOHNATHON GORSKI	INIT:	CKD BY:	INIT:	
TOLERANCE: ±.0625	UNITS: INCHES	MATERIAL: 6061-T6 ALUMINUM		
NEXT ASSY: 1000	SCALE: 1:5	TITLE: Bench Seat Assembly		
DWG #: 1400	DATE: 2/21/12	GROUP: NORDIC SIT SKI		

5 4 3 2 1

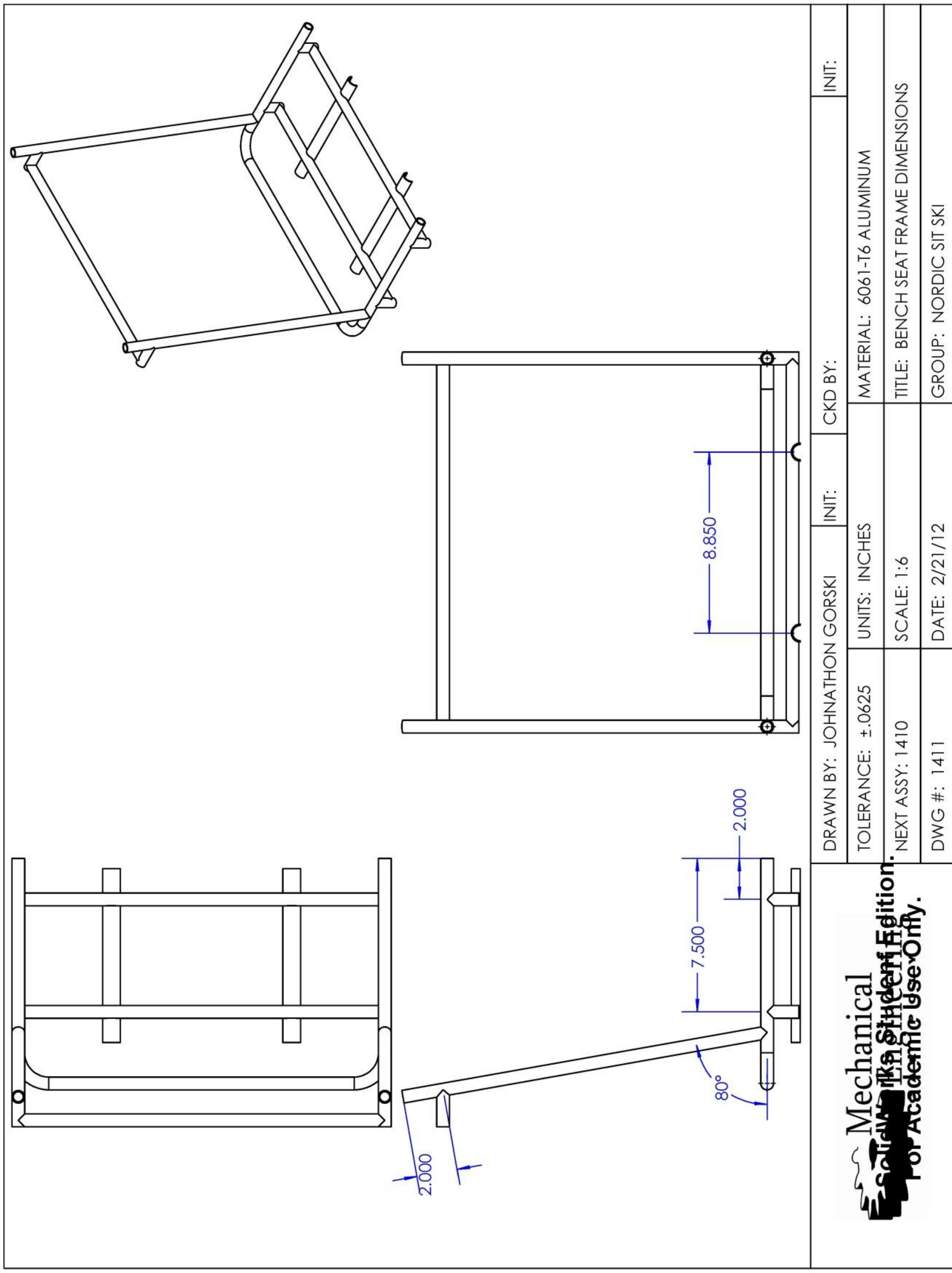
ITEM NO.	PART NUMBER	QTY.
1	Bench Seat Tube 1	2
2	Bench Seat Tube 2	6
3	Bench Seat Tube 3	1
4	Bench Seat Tube 4	2
5	Bench Seat Tube 5	1
6	Bench Seat Tube 6	2



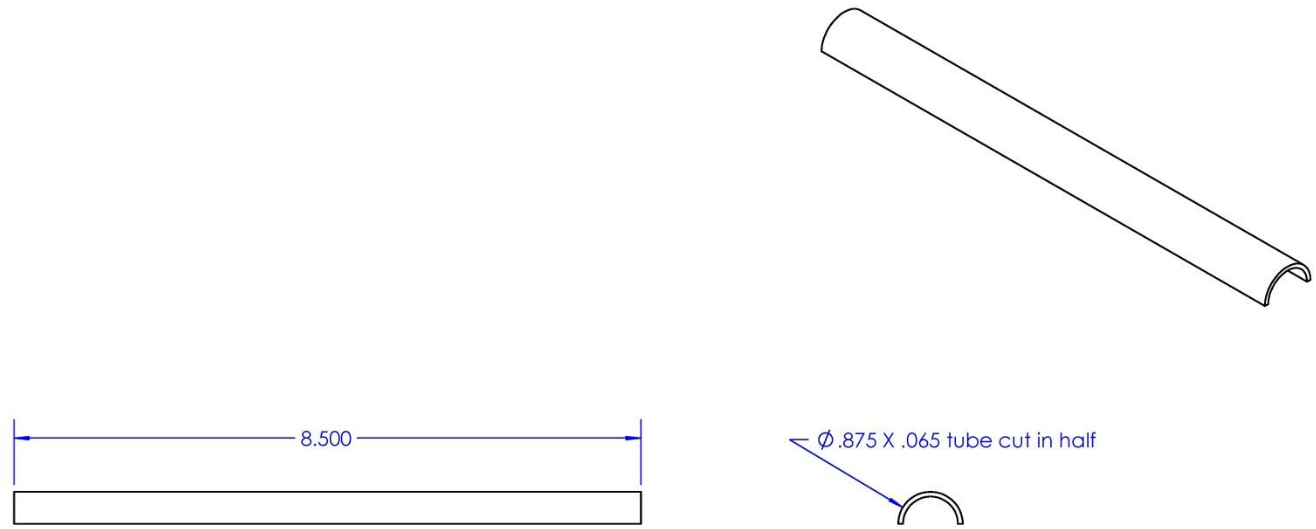
Dimensions of frame are referenced in drawing # 1411

DRAWN BY: JOHNATHON GORSKI	INIT:	CKD BY:	INIT:
TOLERANCE: ±.0625	UNITS: INCHES	MATERIAL: 6061-T6 ALUMINUM	
NEXT ASSY: 1400	SCALE: 1:5	TITLE: BENCH SEAT FRAME	
DWG #: 1410	DATE: 2/21/12	GROUP: NORDIC SIT SKI	

5 4 3 2 1

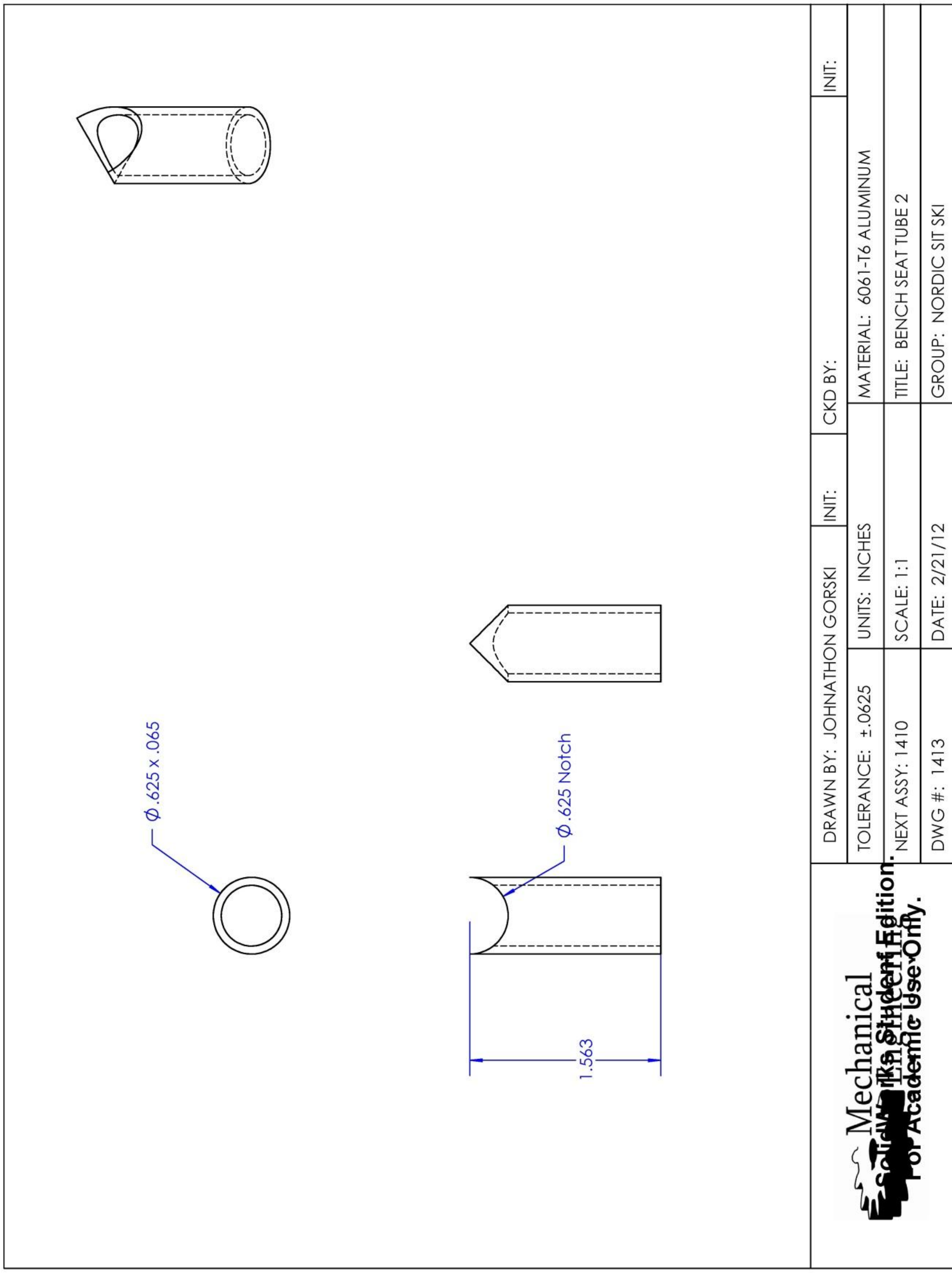


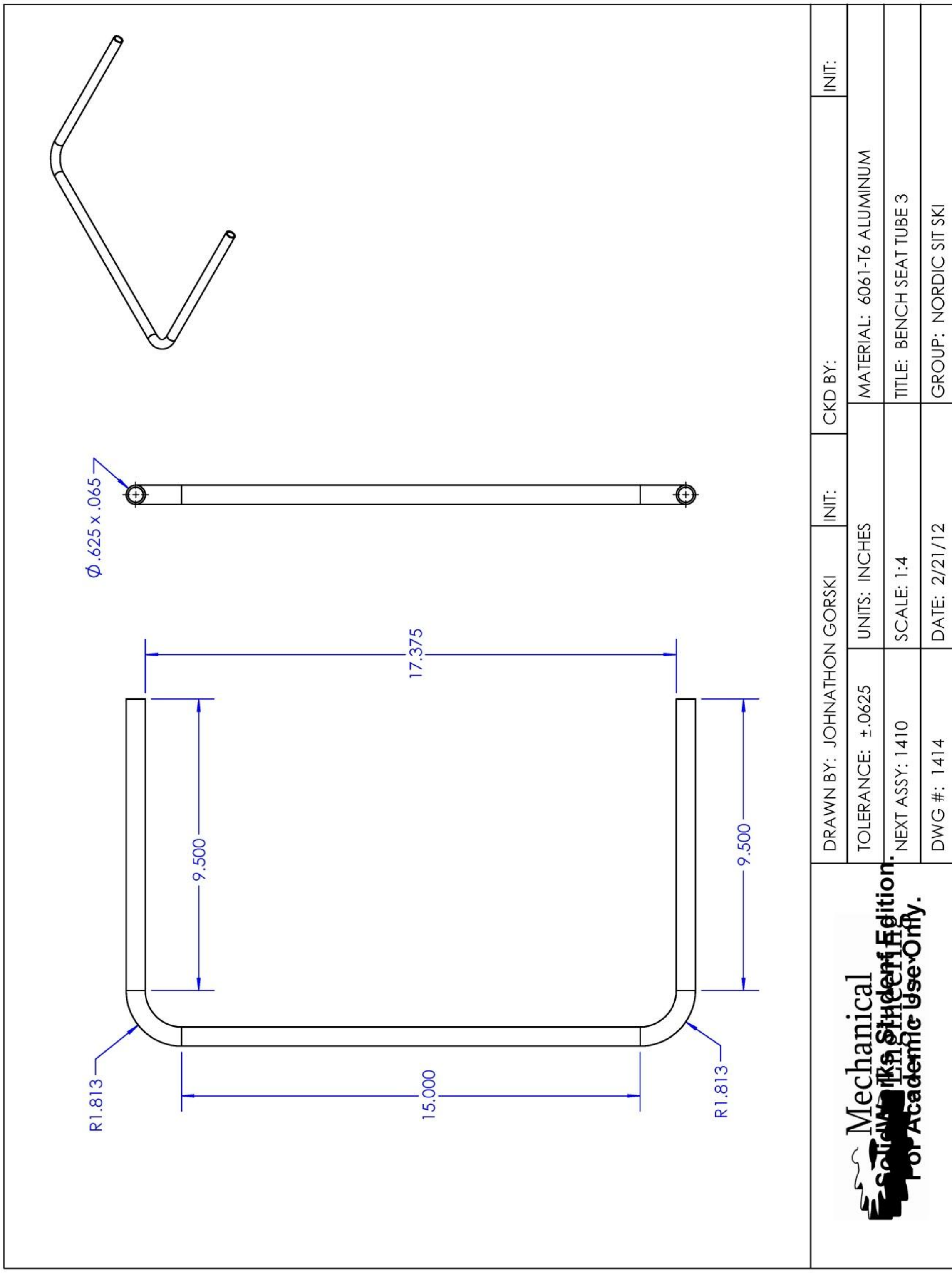
2.000
7.500
2.000
80°
8.850
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1410
SCALE: 1:6
TITLE: BENCH SEAT FRAME DIMENSIONS
DWG #: 1411
DATE: 2/21/12
GROUP: NORDIC SIT SKI
Mechanical
Student Edition.
For Academic Use Only.
1
2
3
4
5

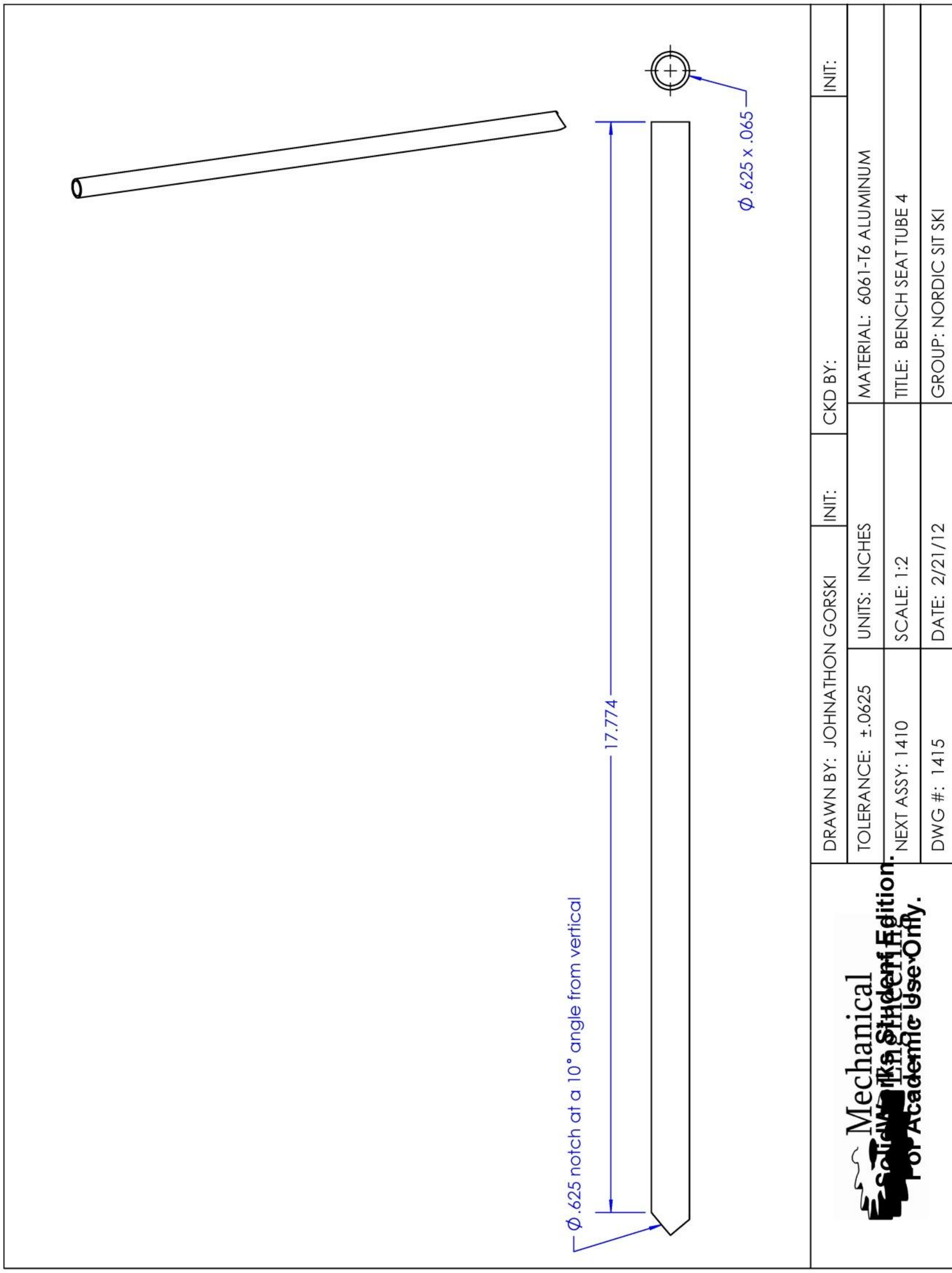


DRAWN BY: JOHNATHON GORSKI		INIT:	CKD BY:	INIT:
TOLERANCE: ±.0625	UNITS: INCHES		MATERIAL: 6061-T6 ALUMINUM	
NEXT ASSY: 1410	SCALE: 1:2		TITLE: BENCH SEAT TUBE 1	
DWG #: 1412	DATE: 2/21/12		GROUP: NORDIC SIT SKI	

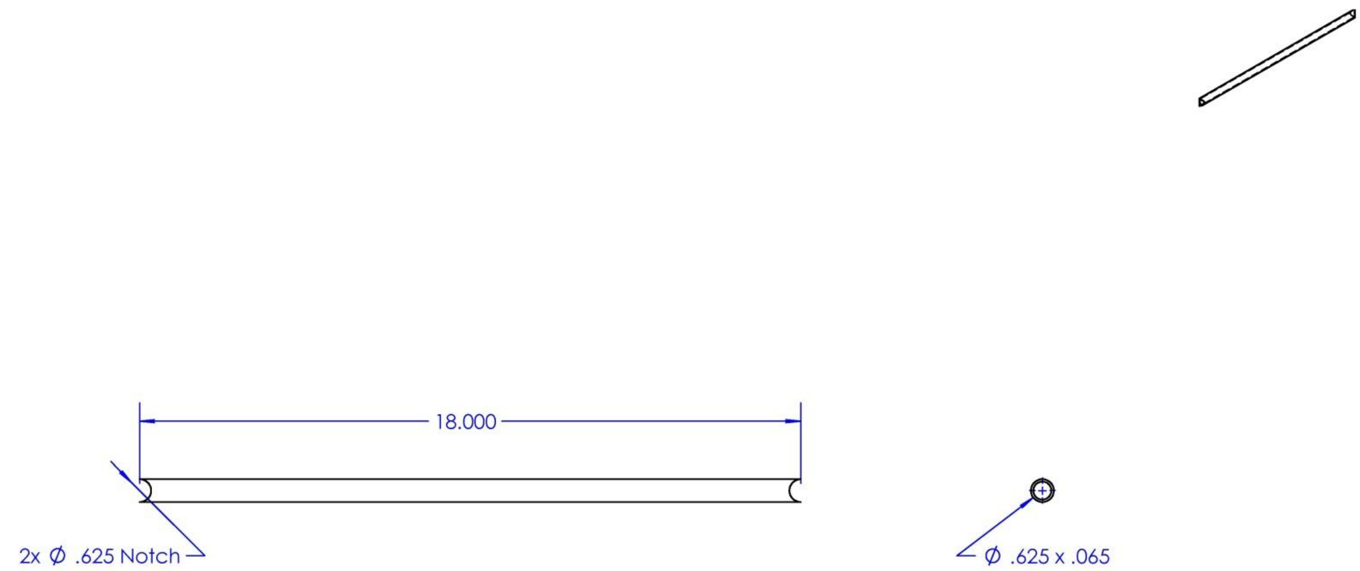
Mechanical Engineering


Ø.625 x .065
Ø.625 Notch
1.563
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1410
SCALE: 1:1
TITLE: BENCH SEAT TUBE 2
DWG #: 1413
DATE: 2/21/12
GROUP: NORDIC SIT SKI
5
4
3
2
1


Ø.625 x .065
17.375
9.500
9.500
R1.813
15.000
R1.813
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1410
SCALE: 1:4
TITLE: BENCH SEAT TUBE 3
DWG #: 1414
DATE: 2/21/12
GROUP: NORDIC SIT SKI
Mechanical
For Academic Use Only.



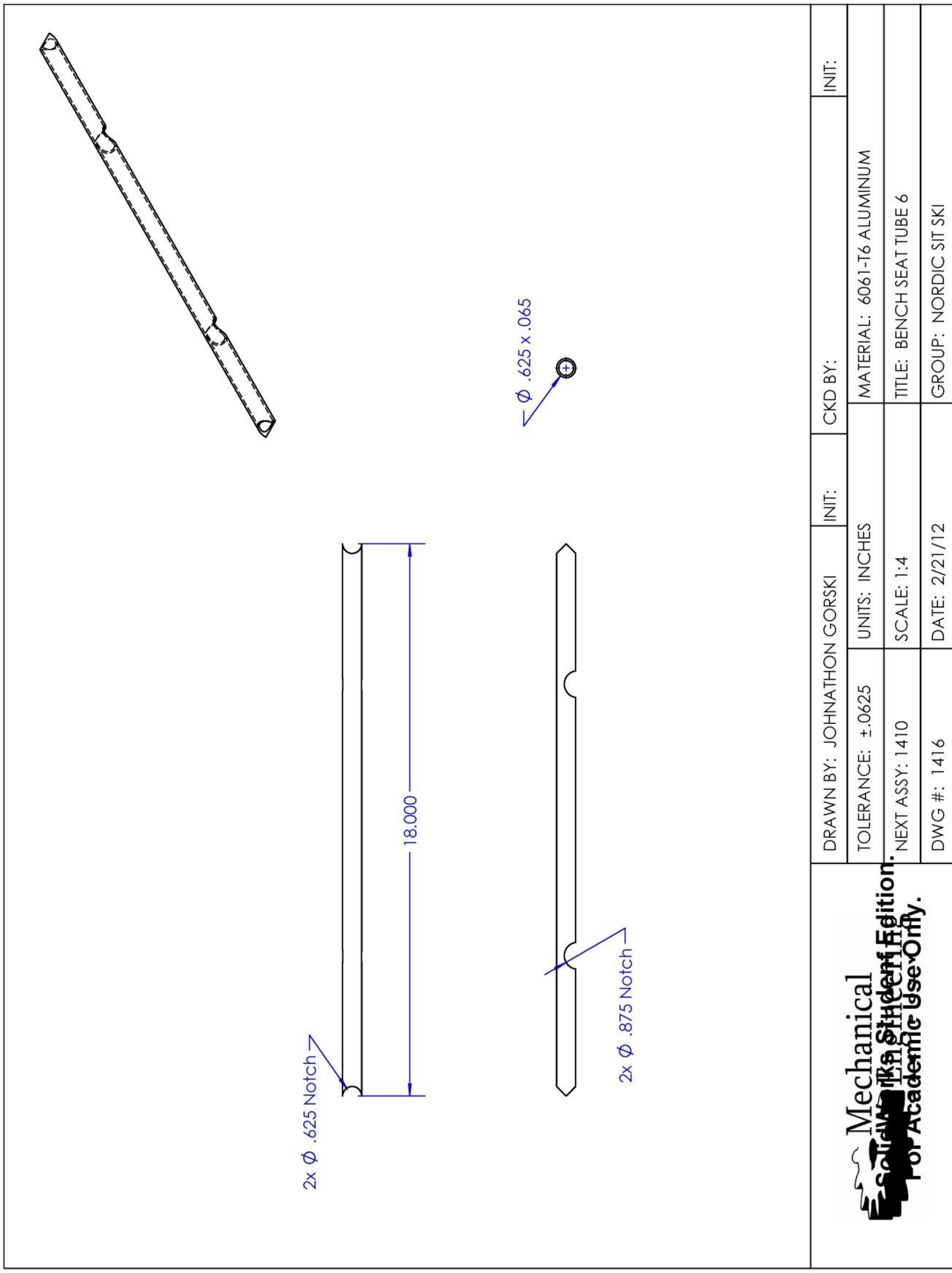
Ø.625 notch at a 10° angle from vertical
17.774
Ø.625 x .065
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1410
SCALE: 1:2
TITLE: BENCH SEAT TUBE 4
DWG #: 1415
DATE: 2/21/12
GROUP: NORDIC SIT SKI
Mechanical
For Academic Use Only.
1
2
3
4
5



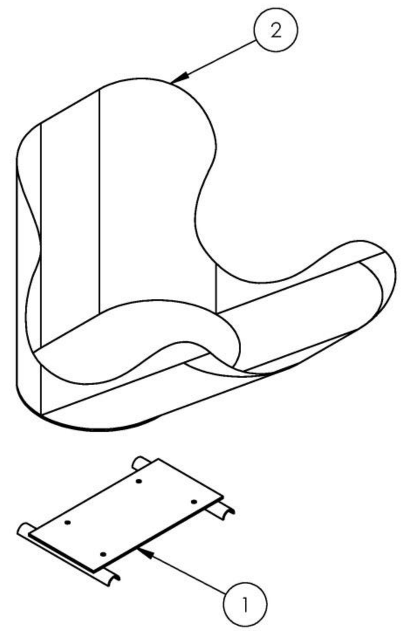
Mechanical Engineering

DRAWN BY: JOHNATHON GORSKI	INIT:	CKD BY:	INIT:
TOLERANCE: ±.0625	UNITS: INCHES	MATERIAL: 6061-T6 ALUMINUM	
NEXT ASSY: 1410	SCALE: 1:4	TITLE: BENCH SEAT TUBE 5	
DWG #: 1416	DATE: 2/21/12	GROUP: NORDIC SIT SKI	

5 4 3 2 1

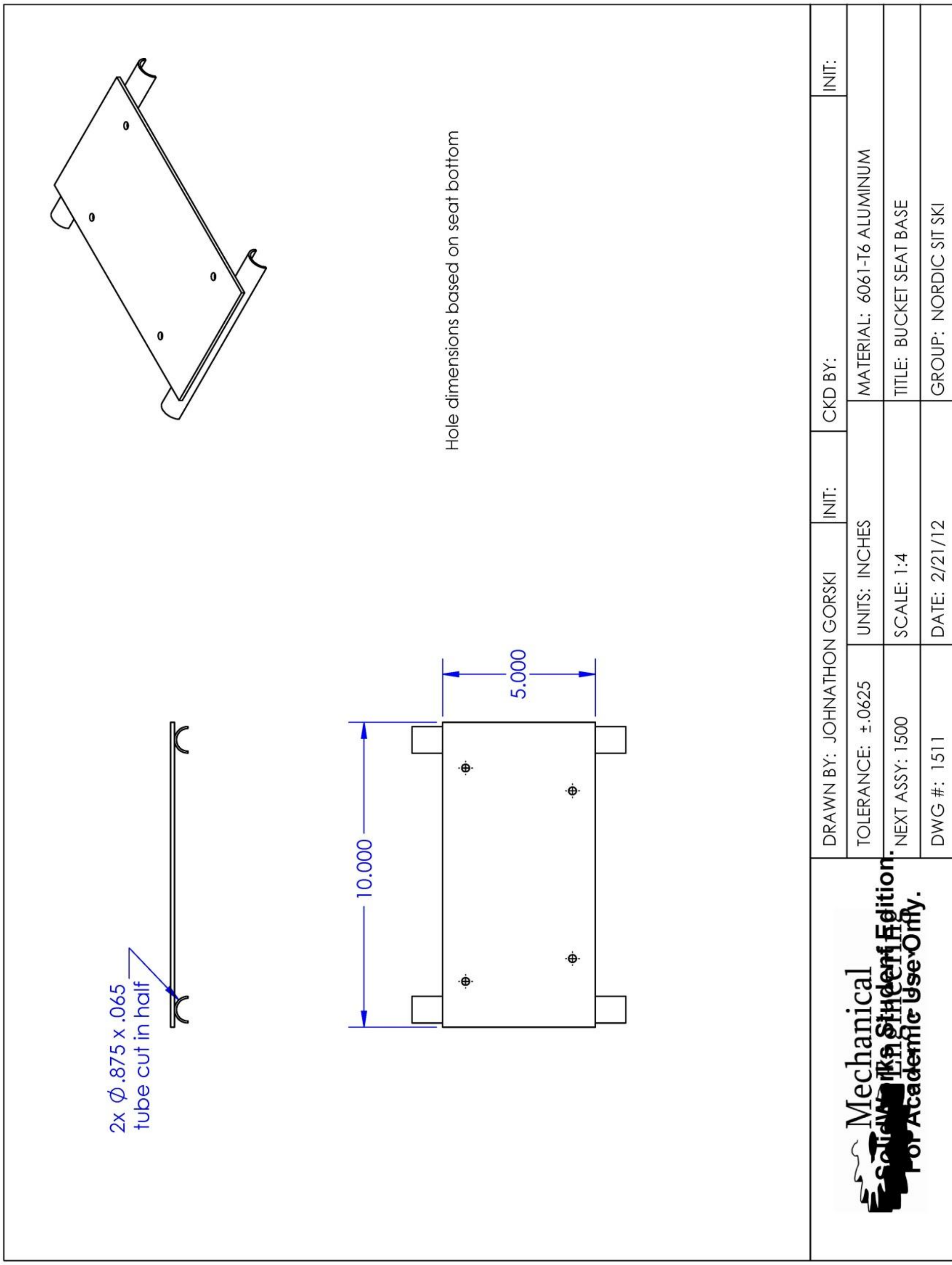

Ø .625 x .065
18.000
2x Ø .625 Notch
2x Ø .875 Notch
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1410
SCALE: 1:4
TITLE: BENCH SEAT TUBE 6
DWG #: 1416
DATE: 2/21/12
GROUP: NORDIC SIT SKI
Mechanical
1
2
3
4
5

ITEM NO.	PART NUMBER	QTY.
1	Seat Base	1
2	Seat	1



Mechanical Engineering	DRAWN BY: JOHNATHON GORSKI	INIT:	CKD BY:	INIT:
	TOLERANCE: ±.0625	UNITS: INCHES	MATERIAL: 6061-T6 ALUMINUM
	NEXT ASSY: 1000	SCALE: 1:8	TITLE: BUCKET SEAT ASSEMBLY
	DWG #: 1500	DATE: 2/21/12	GROUP: NORDIC SIT SKI

5 4 3 2 1



2x Ø .875 x .065
tube cut in half
10.000
5.000
Hole dimensions based on seat bottom
Mechanical
For Academic Use Only.
DRAWN BY: JOHNATHON GORSKI
INIT:
CKD BY:
INIT:
TOLERANCE: ±.0625
UNITS: INCHES
MATERIAL: 6061-T6 ALUMINUM
NEXT ASSY: 1500
SCALE: 1:4
TITLE: BUCKET SEAT BASE
DWG #: 1511
DATE: 2/21/12
GROUP: NORDIC SIT SKI

Appendix D: Analysis

Nordic Sit Ski
2D Model of Horizontal Members
Analyzed for Bending and Fatigue
1/10/2012

Declaration of Constants

$L = 11$ [in]

$F = 0.5 \cdot 300$ [lb_f]

$A = \frac{\pi}{4} \cdot (D^2 - (D - 2 \cdot Thickness)^2)$ Area of tube

$E = 10.4 \cdot 10^6 \cdot 1$ [psi] Young's Modulus

$I = \frac{\pi}{64} \cdot (D^4 - (D - 2 \cdot Thickness)^4)$ Area Moment of Inertia

$c = \frac{D}{2}$

$Cycle_1 = 10$ [cycles/day] $\cdot$ 5 [day/week] $\cdot$ 52 [week/year] $\cdot$ 0.25 $\cdot$ 5 [year/lifetime] Cycles of static loading

$Cycle_2 = 3$ [cycles/day] $\cdot$ 5 [day/week] $\cdot$ 52 [week/year] $\cdot$ 0.25 $\cdot$ 5 [year/lifetime] Cycles of tipping

Stress Analysis--Distributed Load

$W = \frac{F}{L}$ Assume evenly distributed load

$x = \frac{L}{2}$

$M_{max} = W \cdot \frac{x}{2} \cdot (L - x)$

$\sigma_b = M_{max} \cdot \frac{c}{I} \cdot \left| 0.001 \cdot \frac{ksi}{psi} \right|$

$\sigma_{tip} = 2 \cdot \sigma_b$

Deflection Analysis--Distributed Load

$y_{max} = -5 \cdot W \cdot \frac{L^4}{384 \cdot E \cdot I}$

Weight

$weight = 4 \cdot 1.6$ [oz/in^3] $\cdot L \cdot \frac{A}{16 \text{ [oz/lb}_f]}$

Maximum Stress vs. Fatigue Life Exponential Curve Fits

$N_1 = 7 \cdot 10^{47} \cdot \sigma_{tip}^{-9.492}$ Stress Ratio = -1.0, fully reversed stress from tipping loads

$N_2 = 2 \cdot 10^{50} \cdot \sigma_b^{-9.622}$ Stress Ratio = 0.0, loads range 0-->max for static loading

Miner's Rule / Damage Law

$\frac{Cycle_1}{N_1} + \frac{Cycle_2}{N_2} = LIFE$

Nordic Sit Ski
2D Model of Frame
Analyzed in Fatigue Using Miner's Rule
1/5/2012

Declaration of Constants

$L = 10$ [in]

$F = 300$ [lb$_f$]

$\alpha = 30$ [degrees] Estimated that frame will tip over at ~60 degrees

$A = \frac{\pi}{4} \cdot (D^2 - (D - 2 \cdot Thickness)^2)$ Area of tube

$Cycle_1 = 6$ [cycles/day] $\cdot$ 3 [day/week] $\cdot$ 52 [week/year] $\cdot$ 0.25 $\cdot$ 4 [year/lifetime] $\cdot$ 0.5 Cycles of tipping

$Cycle_2 = 3$ [cycles/day] $\cdot$ 5 [day/week] $\cdot$ 52 [week/year] $\cdot$ 0.25 $\cdot$ 5 [year/lifetime] Cycles of static loading

Statics

$R_y = 0.5 \cdot F$

$M_x = 0.5 \cdot F \cdot L \cdot \mathbf{sin}(\alpha)$

Stress Analysis

$\sigma_b = K_t \cdot M_x \cdot \frac{C}{I}$ Alternating Load due to tipping

$C = 0.5 \cdot D$

$I = \frac{\pi}{64} \cdot (D^4 - (D - 2 \cdot Thickness)^4)$

$K_t = 1.8$ Stress concentration estimate, Shigley T. 7-1

$\sigma_{static} = 0.5 \cdot \frac{R_y}{A}$ Static Loading

Maximum Stress vs. Fatigue Life Exponential Curve Fits

$N_1 = 7 \cdot 10^{47} \cdot \sigma_b^{-9.492}$ Stress Ratio = -1.0, fully reversed stress from tipping loads

$N_2 = 2 \cdot 10^{50} \cdot \sigma_{static}^{-9.622}$ Stress Ratio = 0.0, loads range 0-->max for static loading

Miner's Rule / Damage Law

$\frac{Cycle_1}{N_1} + \frac{Cycle_2}{N_2} = LIFE$

Weight

$weight = 4 \cdot 1.6$ [oz/in^3] $\cdot L \cdot \frac{A}{16 \text{ [oz/lb}_f\text{]}}$

Nordic Sit Ski
2D Model of Leg Rest with Truss
Analyzed for Bending
1/10/2012

Declaration of Constants

$$F = \frac{60}{2} \ [lb_f]$$

$$A = \frac{\pi}{4} \cdot \left(D^2 - (D - 2 \cdot Thickness)^2 \right)$$ Area of tube

$$A_2 = \frac{\pi}{4} \cdot \left(D_2^{\,2} - (D_2 - 2 \cdot Thickness)^2 \right)$$

$$E = 10.4 \cdot 10^6 \cdot 1 \ [psi]$$ Young's Modulus

$$I = \frac{\pi}{64} \cdot \left(D^4 - (D - 2 \cdot Thickness)^4 \right)$$ Area Moment of Inertia

$$D = \frac{5}{8} \ [in]$$

$$D_2 = \frac{5}{8} \ [in]$$

$$Thickness = 0.065 \ [in]$$

$$C = \frac{D}{2}$$

Stress Analysis--Static Point Load

$$M = F \cdot L$$

$$\sigma_{static} = M \cdot \frac{C}{I} \cdot \left| 0.001 \cdot \frac{ksi}{psi} \right|$$

Weight

$$weight = 2 \cdot 1.6 \ [oz/in^3] \cdot 30 \cdot \frac{A}{16 \ [oz/lb_f]}$$

$$weight_2 = 2 \cdot 1.6 \cdot L_2 \cdot \frac{A_2}{16}$$

$$weight_3 = 1.6 \cdot 8.85 \cdot \frac{A}{16}$$

Geometry--Law of Cosines

$$L_2^{\,2} = (30 - L)^2 + 9.168^2 - 2 \cdot 9.168 \cdot (30 - L) \cdot \cos(75)$$

Safety Factor

$$S_f = \frac{40 \ [ksi]}{\sigma_{static}}$$

Deflection

$$y_{max} = F \cdot \frac{L^3}{3 \cdot E \cdot I}$$

Appendix E: Gantt Chart