Design of a Crawling Aid for Child with Limited Mobility

Project #11 – Final Report
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EXECUTIVE SUMMARY

Spina bifida is a birth defect that can have a huge effect on the life of a child. Lincoln is a spina bifida patient at MedRehab Milestones at the University of Michigan Health Center. He is only 21 months old, and has no feeling or sensation from his hips and below due to his spina bifida. Lincoln has very limited mobility due to his condition, and has a tough time crawling. Our sponsor, Leah Hagamen, is a physical therapist with MedRehab Milestones, and has approached our engineering team with the task of designing and manufacturing a crawling device to aid Lincoln.

We have determined a list of customer requirements with Leah, and developed engineering specifications for our crawling device. The top customer requirements were determined to be safety, head support, and leg support, from the results of QFD chart. The engineering specifications were based on target values that we wanted to achieve for things such as the board incline angle, the length of the board, and the weight and height range of the device.

Once these benchmarks were put into place, we conducted numerous brainstorming sessions to generate concept ideas. Specific concepts for certain features of the device were generated first. The features that were considered included a headrest design, safety harness, length adjustability options, ideas for both the front and rear wheels, and different designs for the method of incline. There were several possibilities for each feature, and they were used to come up with seven different crawler concepts. In order to compare and contrast the seven crawler concepts with one another, we utilized a Pugh chart to rank the concepts from 1 to 7. The Pugh chart is based on assigning a weight to each of the customer requirements, and then rating the qualifications for each concept on a scale of 1 to 5 for each customer requirement. In the end, a weighted value was determined for each concept, and these values were compared to determine the overall ranking comparison for the different crawler designs. We created a design that incorporated the best features to meet each design criteria, taking from the highest ranking concept variations. The result was our Alpha design, a hybrid of the best designs and features proposed.

Through our engineering analysis, we refined our Alpha design, and generated an initial prototype. With moment balances, bending stresses and the information gathered from meeting with Lincoln, we were able to determine proper dimensions for our engineering specifications, and select appropriate materials.

Detailed features of the final design including the front platform, rear platform, extension inserts, adjustability method, rear wheels and attachment, front wheels and attachment, incline method, rotation method and the head rest are also discussed. Additionally, we have provided our fabrication plan and bill of materials detailing the cost analysis for our final design concept.

Our design was validated based on specific engineering analysis that we conducted. The geometry and dimension goals were met, and we were within range of the desirable level of incline. The final prototype weighed 12.7 lbs and was weight tested to safely hold up to 80 lbs.

Our final prototype was presented to Lincoln several times, in order for him to test it and receive feedback from his parents. Every time that Lincoln used the device, he seemed to become more comfortable on it, and it appears that it will be a great tool for him to learn and build muscle strength. Lincoln and his family were present during our design expo, where we displayed our crawler device. He was able to use the crawler in front of crowds of people, demonstrating its usefulness.

We will be turning our completed project over to Lincoln and his family on April 21st. We hope that all of our work this semester will be put to good use, and that the device will benefit Lincoln with every use. It was a great experience for our team to design and manufacture this product that can be used in this real life application.

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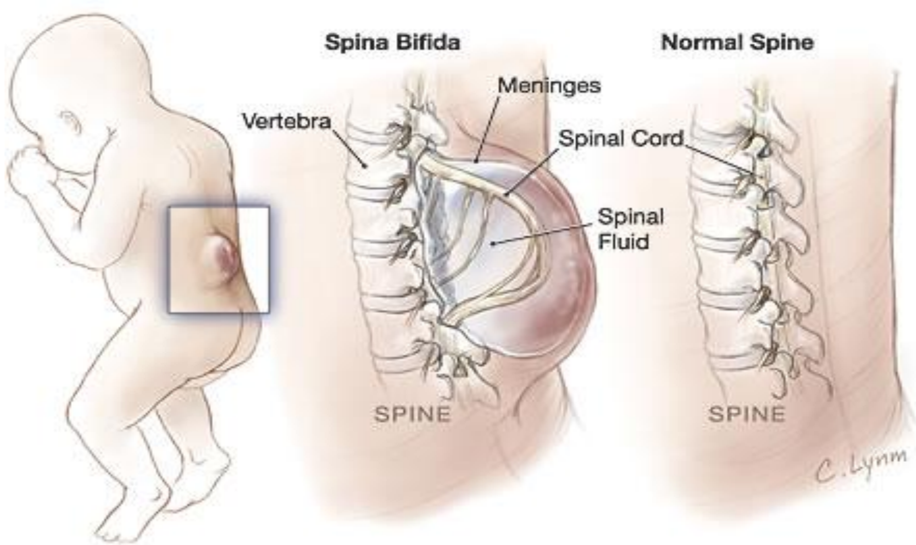
INTRODUCTION

As a child is maturing from infant to toddler, it is normal for them to learn to crawl, walk, and talk. However, a birth defect called spina bifida can make these elementary tasks very challenging, or in some cases impossible. Leah Hagamen, a physical therapist with MedRehab Milestones at the University of Michigan Health Center, has a patient who is affected by spina bifida. The patient is named Lincoln and he is 21 months old. Leah came to our engineering design team and asked for our help in coming up with a newly designed device to aid Lincoln in crawling.

Spina bifida is a birth defect where the spinal cord does not completely develop in the first to second month of pregnancy. When two sides of the spine do not join together like they normally should, it leaves an open area in the embryo's back. Sometimes the spinal cord will push through the open area along with other membranes. Severe cases of spina bifida can result in paralysis in the feet, legs, and below the waist. The following figure shows the difference between a normal spine, and the spina bifida birth defect.



In order for Lincoln to develop both mentally and physically, it is crucial that he has the ability to see an object and then crawl to get that object. It is difficult for him to develop strength and higher mental capacity while he is immobile. Leah is currently working with Lincoln using existing crawling devices, but they are not very easy for him to use. He has a hard time keeping his head in an upright position while supporting himself with his arms. With Leah as our sponsor, we worked to develop a new device that will be more specific to Lincoln. It will help him learn to crawl using just his arms, and will provide more support for his head and neck. Our design will tremendously help Lincoln's mobility, and allow him to further develop as a child.

Our group was able to meet with Leah Hagamen in order to discuss problems with the current products and goals for our design. We were able to watch video footage of Lincoln trying to crawl which helped us obtain more insight that was useful for our design process.

Following the meeting with Leah, a quality function deployment (QFD) diagram was completed (Appendix D), and the following customer requirements were identified in order of importance:

1. Safe
2. Head supporting
3. Leg supporting
4. Mobile
5. Adaptive to child development/skill
6. Adaptive to child growth
7. Muscle developing
8. Cognitive developing
9. Comfortable
10. Easy to use
11. Lightweight
12. Portable, easy to store/transport
13. Low cost
14. Aesthetically pleasing

In this report, we will discuss the process which we have gone through to design a device to aid Lincoln in crawling. This will include a brief recap of our target engineering specifications and our initial component designs. We will then discuss our concept selection process, leading to our Alpha design. A parameter analysis will be discussed detailing validation process of our prototype and final design. The final design is described, including a fabrication plan and validation. We have successfully manufactured our final design, and have tested the design to validate it and prove that it meets our engineering specifications. Testing has been conducted to prove that the device is safe, and Lincoln has used the crawler several times. Pictures of Lincoln using the prototype are shown in the figures below. We will discuss our final prototype and give recommendations detailing what we would change if we were to produce more crawling devices.

ENGINEERING SPECIFICATIONS

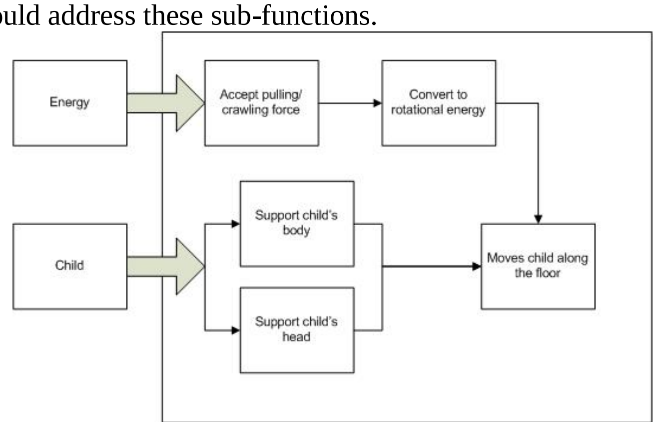
Using our QFD, we translated the list of customer requirements into correlated engineering specifications for our design, which are shown on the next page with their quantitative target values.

Engineering Specifications	Target Value
Inclined Platform	5-15 degrees
Length of Board	Adjustable, Min >18", Max <36"
Weight	Less than 12 pounds
Minimum back platform height	<5"
Front platform height range	Adjustable, 6”-16”
Width of board	6-18"
Wheel Degrees of Freedom	Adjustable, 0-2
Wheel Resistance	Yes
Wheel Locks	Yes
Weight Capacity	Up to 80 lbs

Having an inclined platform in our device making it easier for Lincoln to support his head would make the device more comfortable and make the device easier for crawling and muscle development. Having an adjustable length for our device would add much needed leg support and make the design more adaptable to the growth of a child, as would having a tapered width. Similarly, an adjustable incline will accommodate the growth and development of the child, and will aid in the portability of the device. In order to make our device easier to use and greatly improve its mobility, we will design the device to be as lightweight as possible. The wheels will have two degrees of freedom, allowing for movement in any direction along the floor. Having wheel locks will significantly improve safety. The geometry of the platform must allow Lincoln's hands to reach the ground in order to crawl and an angle greater than 15 degrees would not allow for this.

FUNCTIONAL DECOMPOSITION

In the beginning of our concept generation, we developed the functional decomposition seen below showing what our device will accomplish at its final stage. The device must first adequately support Lincoln's body and head. It must also be able to convert Lincoln's crawling input into movement along the floor. We then broke the user functions down into smaller sub-functions and were able to brainstorm ideas for features that would address these sub-functions.



CONCEPT GENERATION

In order to develop component and overall design concepts, we first generated a functional decomposition which gave an overview of how the final design would work. We then generated component designs that were categorized in six major groups, listed below.

1. Safety Features
2. Head/Neck Support Designs
3. Leg Support Designs
4. Mobility
5. Adjustable Incline Methods
6. Adaptability Features

From these component drawings, we decided which concepts were the best and most vital to the accomplishment of our project requirements. Considering various designs for each component, we created multiple designs and discussed them as a group. In using these concept sketches, we created a final Alpha Design drawing which included all of our best ideas. Each aspect of our concept generation will be discussed further in the following sub-sections.

Brainstorming Component Concepts

We generated concepts for individual components of the device, which are listed under their associated customer requirements. Sketches of these concepts and descriptions can be viewed in Appendix F & G respectively.

Brainstorming Main Design Concepts

In Appendix H, we discuss the top overall concept designs. The advantages and disadvantages are highlighted for our top concepts. Detailed pictures of each overall concept are shown in Appendix I.

CONCEPT SELECTION PROCESS

In an effort to identify the best design features of each complete concept, we used a Pugh chart to compare different designs with each other, and with two benchmarks – the Southpaw Enterprises Scooter Board, and the Red Barn Enterprises Creepster Crawler. The designs were rated on a scale of one to five in each of the critical design criteria. Each criteria was given a different weight, and based on the individual weighted scores, each concept variant received a total score.

Examining the different scores, we identified the best existing design, and discussed the features that made this design desirable, in addition to the features of the other designs that resulted in high scores.

						Concept Variants													
		Creepster Crawler		Scooter		A		B		C		D		E		F		G	
Criteria	Weight	R	WS	R	WS	R	WS	R	WS	R	WS	R	WS	R	WS	R	WS	R	WS
Safe	0.1	3	0.3	3	0.3	4	0.4	3	0.3	3	0.3	4	0.4	4	0.4	3	0.3	3	0.3
Head Supporting	0.1	1	0.1	2	0.2	4	0.4	4	0.4	4	0.4	4	0.4	4	0.4	3	0.3	4	0.4
Leg Supporting	0.1	1	0.1	3	0.3	3	0.3	4	0.4	4	0.4	4	0.4	4	0.4	4	0.4	4	0.4
Mobile	0.09	3	0.27	3	0.27	4	0.36	4	0.36	4	0.36	3	0.27	4	0.36	4	0.36	3	0.27
Skill Adaptive	0.09	1	0.09	1	0.09	4	0.36	4	0.36	4	0.36	4	0.36	5	0.45	4	0.36	3	0.27
Growth Adaptive	0.09	1	0.09	2	0.18	3	0.27	4	0.36	4	0.36	4	0.36	4	0.36	4	0.36	4	0.36
Muscle Developing	0.08	1	0.08	2	0.16	4	0.32	4	0.32	4	0.32	4	0.32	4	0.32	4	0.32	4	0.32
Cognitive Developing	0.08	1	0.08	2	0.16	4	0.32	4	0.32	4	0.32	4	0.32	4	0.32	4	0.32	4	0.32
Comfortable	0.07	1	0.07	2	0.14	4	0.28	4	0.28	4	0.28	4	0.28	4	0.28	4	0.28	4	0.28
Easy to use	0.05	1	0.05	3	0.15	3	0.15	3	0.15	4	0.2	3	0.15	4	0.2	4	0.2	3	0.15
Lightweight	0.05	2	0.1	4	0.2	2	0.1	3	0.15	3	0.15	2	0.1	3	0.15	3	0.15	2	0.1
Portable	0.04	1	0.04	4	0.16	3	0.12	3	0.12	4	0.16	3	0.12	4	0.16	4	0.16	3	0.12
Low cost	0.05	1	0.05	2	0.1	2	0.1	3	0.15	3	0.15	3	0.15	3	0.15	3	0.15	3	0.15
Aesthetically pleasing	0.01	3	0.03	2	0.02	3	0.03	4	0.04	3	0.03	4	0.04	4	0.04	3	0.03	3	0.03
	TOTAL		**1.45**		**2.43**		**3.51**		**3.71**		**3.79**		**3.67**		**3.99**		**3.69**		**3.47**
	Ranking	9		8		6		3		2		5		1		4		7	

After identifying desirable features, we broke down our analysis into the separate design criteria, selecting the best design features that met the specifications. Focusing on safety, head support, leg support, mobility and adaptability, we selected the design features we wanted to see in the final design.

Combining these features we created a design that incorporated the best features to meet each design criteria, taking from the previously generated concept variations. The result was our Alpha design, a hybrid of the best designs and features proposed by each team member.

SELECTED CONCEPT DESCRIPTION: "ALPHA DESIGN"

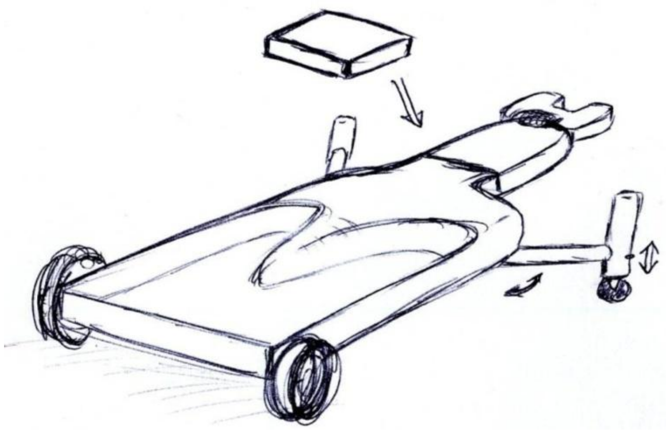
The selected Alpha design incorporated the best features of each initial concept variant, and included components that best met each of the design criteria. To meet the safety criteria, the design featured a hybrid three-point safety harness. This feature was padded and supportive like a diaper, holding the child in place. Adding to the safety of the device, the rear wheels featured locking mechanisms and were placed outside of the leg containment area to avoid accidental pinching. Also, the front wheels were angled out to the sides, allowing Lincoln freedom to play and move without worrying about his hands getting caught in the wheels.

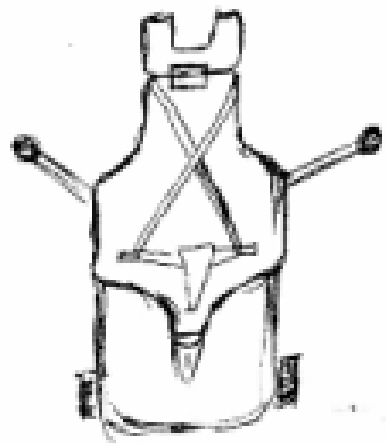
The head support mechanism was a padded jaw pillow with neck support that offered Lincoln both visibility and stability when his head and neck were weak or tired, but was removable to adapt to growth. Also, this head support was inclinable to better accommodate Lincoln's use.

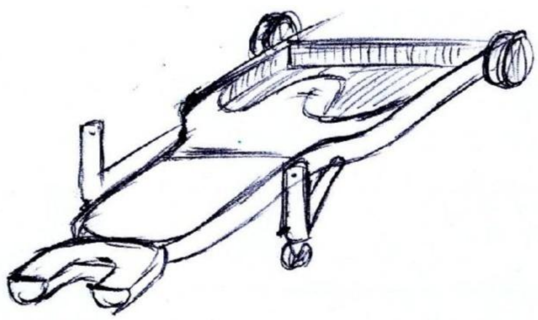
The rear leg containment area offered the support and protection needed for Lincoln to prevent his legs from abrasion or injury from dragging.

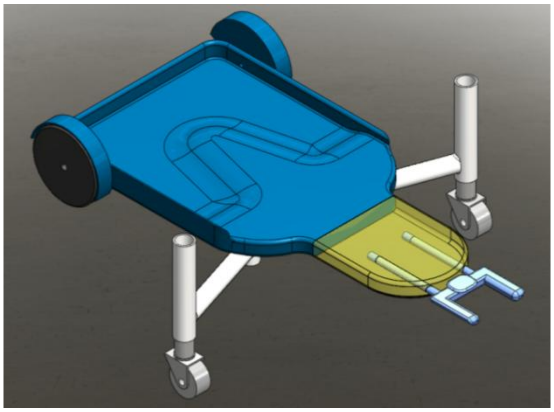
To assist with the mobility of the device, the rear wheels had a wide wheel base while the front wheels were caster wheels allowing for motion in all directions. The rear wheels would be placed on an axle, to allow the platform to incline when the front wheels are raised. The front wheels would rise with a modified "spider-leg" wheel design that would adjust the height of each leg relative to the ground. Furthermore, the front wheels would have an adjustable position to create additional play space for Lincoln or to challenge his balance as he matures, and so that the device can store easily.

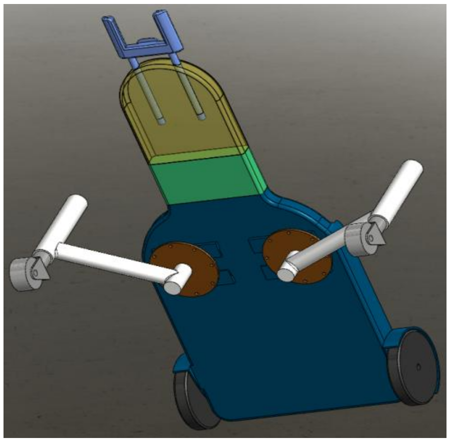
The device would be adaptable to both skill level and growth through several design features. The platform extended and had an insert to create a longer support system for Lincoln as he gets taller. The specialized Rifton wheels used at the back of the device also offered adjustable resistance, to accommodate Lincoln's skill development with the crawler.











ENGINEERING DESIGN PARAMETER ANALYSIS

To complete this project in a thorough and legitimate manner, we will need to use our problem solving skills and draw upon all of our previous engineering coursework and experience to create a robust, practical prototype. Considering our engineering specifications, we will need to employ our knowledge of solid mechanics, dynamics and materials to successfully meet the challenges posed by the customer. With approximations for Lincoln's weight distribution, we can analyze the design to ensure the stability of the device. Furthermore, these weights will allow us to calculate the bending stresses in the headrest, front platform and wheel shafts.

Another key consideration will be the material of the device. It is best for the design to be lightweight to facilitate mobility, but the material chosen must be easy to work with and manufacture, and must be sturdy enough to create a safe device for crawling. We can use the bending stresses calculated and the CES EduPack material selection software to select appropriate materials for each component.

The first step in analyzing our design is determining feasibility of the concept with a CAD model. The CAD model will help us to determine proper dimensions and space constraints, and help us make decisions that will allow for the device to be safe and secure. Using our initial CAD drawing, a preliminary prototype was created to further tailor our dimensions and engineering specifications to meet Lincoln's needs. Using this prototype we can refine our CAD model, and plan our manufacturing process.

Before fabricating our design in the machine shop, Designsafe will be utilized to analyze our potential risks involved with this project. It will provide us with the proper risk assessment that we need to move forward with the manufacturing process. After completing a Designsafe assessment we can compile a safety report that will guide our manufacturing process in the machine shop.

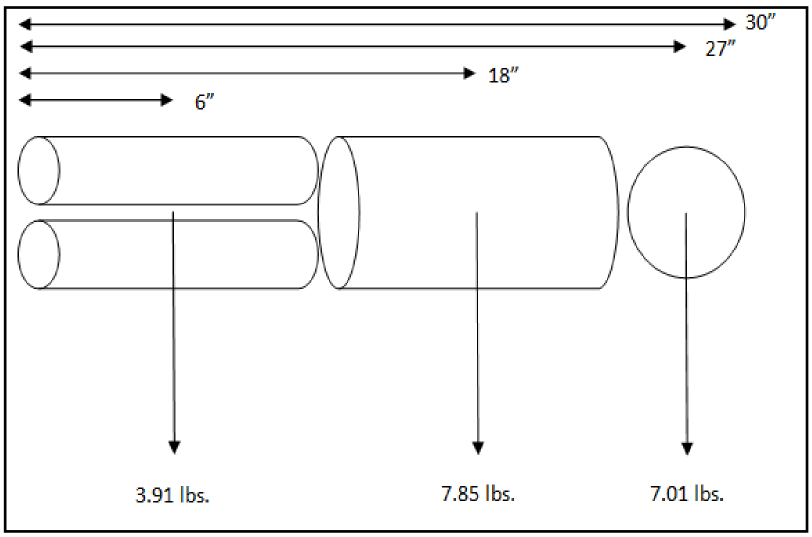
After creating a prototype, the next critical step will be testing. This stage in our design process may prove the most difficult as our access to the patient will be limited. To properly test our device, we will need to simulate the loading conditions of supporting a patient, and subject the crawler to various test conditions including; different floor surfaces, different incline angles, and different weights to support. The testing process will be the most critical step in our design, as ultimately we aim for this concept to be implemented for actual use by Lincoln. The testing process will be covered in the Validation Plan section on page 24.

Moment Calculation for Placement of Front Wheels

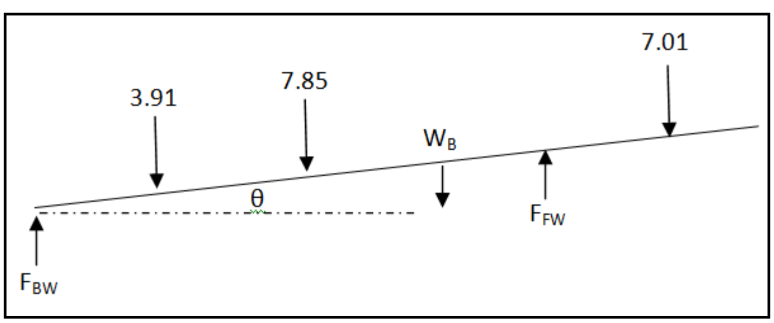
One of the most important safety precautions that we must take is ensuring that the crawler does not tip over. Because of the geometry of the device, if the front wheels are placed too close to the back wheels, the device could tip forward while supporting Lincoln. We needed to perform static force analysis on our device to prevent the possibility of this from happening.

We first made estimations on the distributions of Lincoln's body weight. We took values for human bone and muscle densities and the weight of an infant brain [9] to estimate the weight of Lincoln's legs, torso, and head. Modeling the legs and torso as cylinders and the head as a sphere, we then estimated that each of these weights would act in the horizontal center of each of the body parts. The calculation estimates are shown in the table on page 11 and a physical representation is shown as well.

	Legs	**Torso**	**Head**
Length	12”	12”	N/A
Diameter	2 * 3”	8”	6”
Bone Density	0.0541 lbs/in^3		
Muscle Density	0.0382 lbs/in^3		
Bone volume/weight	9.425 in^3/0.51 lbs.	84.823 in^3/4.6 lbs.	113.1 in^3/6.13 lbs.
Muscle volume/weight	37.699 in^3/1.44 lbs.	84.823 in^3/3.25 lbs.	Brain : 0.88 lbs.
Weight	3.91 lbs.	7.85 lbs.	7.01 lbs.
TOTAL	**18.77 lbs.**		



Once we have these weight forces and their locations, we can sum the moments around the location of the back wheels to solve for the force that the front wheels exert on the device, F_{FW}, as shown below. The equation following the diagram was used to determine this front wheel force.



$$\sum M = 3.91 * 6\cos\theta + 7.85 * 18\cos\theta + 7.01 * 27\cos\theta + W_B * COM\cos\theta - F_{FW} * x\cos\theta = 0$$

Where θ is the angle between the platform and the ground, W_B is the weight of the platform, COM is the center of mass of the platform, and x is the distance to the front wheels from the back wheels.

After solving for F_{FW}, we could then do a vertical force balance to solve for the force that the back wheels exert on the device, F_{BW}, shown in the equation below.

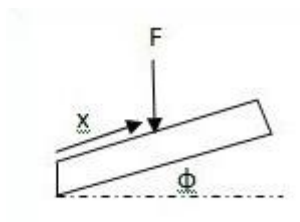
$$\sum F_y = 3.91 + 7.85 + 7.01 + W_B - F_{FW} - F_{BW} = 0$$

As long as the force that the back wheels exert on the device is positive, the crawler will not tip forward. However, if this force comes out to be negative, this means the back wheels will have to exert a downward force on the device to keep it stable. This would be impossible and therefore would result in the device tipping forward.

Using this force balance, and a safety factor of four, we were able to make decisions on the placement of the front wheel, such that the crawler device will not be prone to tipping. In the worst case, the platform will be horizontal (θ = 0), and the forces from the legs, torso and head will be 15.6 lbs, 31.4 lbs and 28.0 lbs respectively. This scenario results in a distance of 18" between the rear and front wheels.

Bending Stress Calculation – Headrest, Front Platform, Wheel Shaft

To design the headrest attachment method, front platform and wheel attachments, we must consider the bending stresses induced by the loading of the platform. All three components use the same equation to determine the bending stress, with the bending moment, distance and moment of inertia depending on the geometry and loading condition for each feature. The figure below is a representation of the moment created by a force acting on a moment arm.



The bending moment caused by Lincoln's weight on the board can be calculated using the equation below, where F is the weight of Lincoln, x is the distance from the attachment to the center of mass of the distributed weight force, and ϕ is the angle between the feature and the horizontal.

$$M = Fx\cos\phi$$

After calculating this moment M, the bending stress σ can be calculated using the equation below, where y is the distance along the vertical of the stress, and I is the moment of inertia of the attachment.

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

For the headrest, the moment is caused by the weight of Lincoln's head acting on the removable headrest. The moment of inertia is found from the supporting rods, and the distance is the radius of the supporting rods. Using the above equations with a safety factor of four and the dimensions of the headrest, we can estimate the bending stresses to be 2,280 psi, which will guide our material selection.

The front platform incurs bending stresses from the weight of Lincoln's head and torso at the platform's center of mass. With this moment and the geometry of the platform, a bending stress of 440 psi is calculated.

Similarly, the shaft that attaches the front wheels to the underside of the front platform will experience bending stresses from the weight of Lincoln and the board acting on a moment arm. The moment of inertia and distance calculated from the shaft cross-section, and the length of the shaft allow for the calculation of the moment and bending stress, where each front wheel is assumed to carry one-fourth of the total weight and a safety factor of four is used. This calculation gives a bending stress of 4,140 psi.

With the known values for the critical bending stresses in the crawler device, a material analysis can be performed to select appropriate materials for each component.

Material Analysis

The components that will be subjected to the majority of Lincoln's body weight have been thoroughly analyzed and the stresses on critical components have been accounted for. The bending moments have been calculated using simple static equations for the headrest attachment joint, the narrow section of the front platform, and the horizontal front wheel shafts.

The following table shows the bending stress values that were determined.

Component	Bending Stress, σ (psi)
Headrest Attachment	~2,280
Front Platform	~440
Horizontal Front Wheel Shafts	~4,140

The CES Material Selection software was used to help determine the best materials for the headrest attachment, platform, and the horizontal wheel shafts. A detailed material selection analysis for the platform and wheel shafts can be found in Appendix C.

The bending stresses were calculated using approximate values for the shape and cross-sections of the components, and the worst case scenario was used for each component with a safety factor of four used for the weight of Lincoln on the device. The materials that can be used for certain components can be validated as long as the bending stress for a specific component is lower than the yield strength for said materials.

Comparing the costs, yield stresses, and densities of various materials, we decided that the best material for both the headrest attachment and the horizontal front wheel shafts is aluminum. The best material for the platform was determined to be wood. Again, a more detailed analysis of this material selection can be found in Appendix C.

PROTOTYPE DESCRIPTION

The initial prototype created was used as to assess the feasibility of the design, and address specifications to fit Lincoln. The prototype is a simplified version of our Alpha design, made with a piece of plywood cut to the initial dimensions of the Alpha design, with straight lines and 45˚ angles instead of dramatic contours. The board was then covered with padding foam of varying thickness to produce the drop off from Lincoln's mid-section to his legs. The shaped foam was then covered with vinyl to provide a smooth, uniform surface, and to protect Lincoln from exposed wood. This vinyl is convenient in that it will be very easy to keep clean and sterilized. The headrest for the prototype was fabricated in the same fashion as the platform, with a board as the base, padded with foam, and covered in vinyl. Pictures of Lincoln on our initial prototype can be seen below.


With our prototype fabricated, we were able to present our initial design to Leah, Lincoln and Lincoln's family. This offered us the opportunity to show them the direction the design is heading, and to receive feedback. Furthermore, we were able to use the prototype as a measuring tool to precisely size the crawling device to Lincoln's body. The key specifications acquired from our prototype after meeting with Lincoln were minimum length, minimum wheel heights, and the extent of foam drop off to fit the curvature of his legs. We determined a range of feasible incline angles, and most importantly we were able to get a good approximation of Lincoln's center of mass while lying on the crawler. These key dimensions provided us with appropriate values to use for our engineering analysis calculations, and simplified the fabrication of our final design.

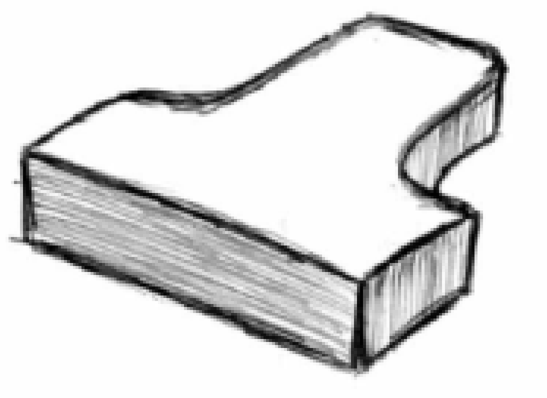
The prototype addresses the critical dimensions that ensure functionality for Lincoln, but does not include several final design features. The wheels, length adjustability, platform incline and safety mechanisms were omitted from our initial prototype for simplicity. However, with the data gathered using our prototype, the fabrication and implementation of these features will be manageable and straightforward when we are manufacturing the final design.

Due to the successful results gathered from our "prototype trial" meeting with Lincoln, we were able to make proper adjustments for our final design. The required geometry and dimensions to meet Lincoln's body size and shape were confirmed for us after the testing. Since the prototype provided us with accurate data to use for our engineering analysis of the final device, it helped validate the feasibility and performance of our final design.

FINAL DESIGN DESCRIPTION

Our final design embodies all of our customer requirements in order to best help Lincoln crawl and explore his surroundings. In the following subsections, we will discuss the different aspects of our final design with detail regarding our engineering conclusions, material choices, and layout drawings. Dimensioned engineering drawings have been included with CAD drawings in Appendix K.

Front platform
The front part of the board will have a 0.5" thick birch plywood base covered in an even height of higher density foam with a top cover of vinyl for easy cleaning. It will have a narrower front end where Lincoln will place his chest. This will allow more space for his arms to move while crawling.

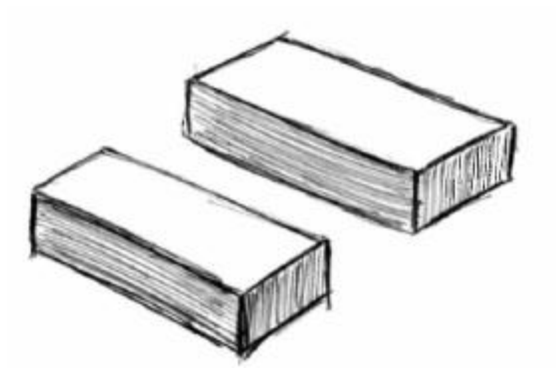


As described in our parameter analysis section, we determined the bending stress to be approximately 440 psi in the front platform. We used these calculations as our reasoning in choosing a wooden board as the base.

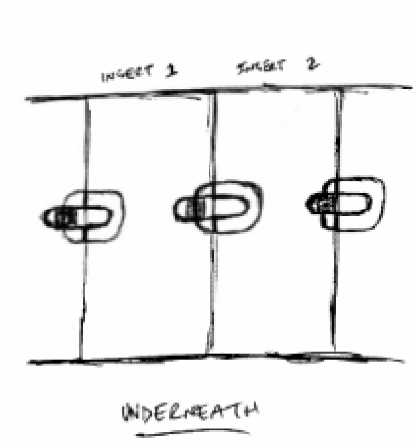
Rear platform
This piece consists of a 0.5" thick birch board base, cut to shape, with a similar layer of higher density foam on top. The foam will be distributed about the board strategically with different heights, allowing for gradual slopes where Lincoln's hips and legs will rest. This will provide a more natural position for him while lying on his stomach, especially since his muscles around his hips are stiff and are in an almost permanent angled position, and his legs will not have to wing out as much to the sides. The entire piece will be covered with the same vinyl material, making it comfortable and easy to clean.

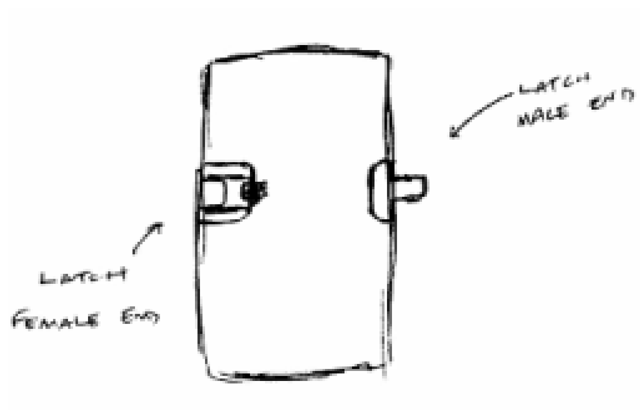
Adjustability Inserts

There will be two inserts that will be optional pieces of the device. As Lincoln gets older and grows in length, they can be used to make the board longer. Materials identical to the front and rear platforms will be reapplied to these extra inserts.



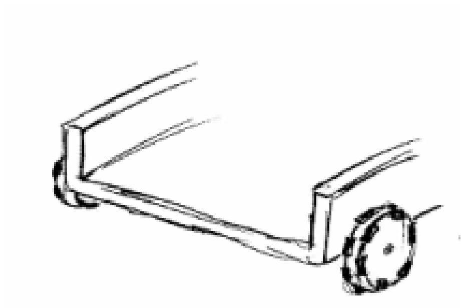
In order to adjust the length of the board, a track system on the underside of the device will be built. Sections of the track will be attached to the bottom of both the front and rear platform, and will fit into each other. After unlatching a lock, the track will be able to slide on itself and the front and rear platforms will separate. The inserts will be placed between the two pieces, and locked to both sides. One or both inserts can be used at once. This will allow for the maximum adjustability possible. The track system on the underside will also have stops so the front and rear platforms do not completely separate.

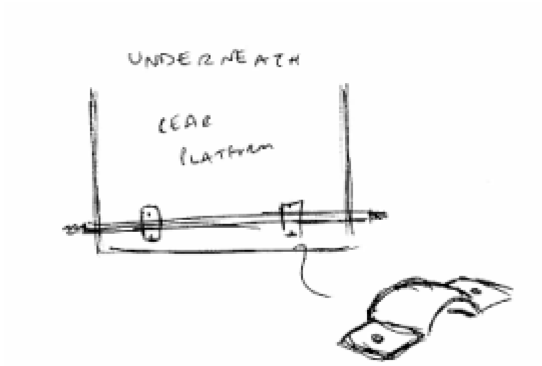


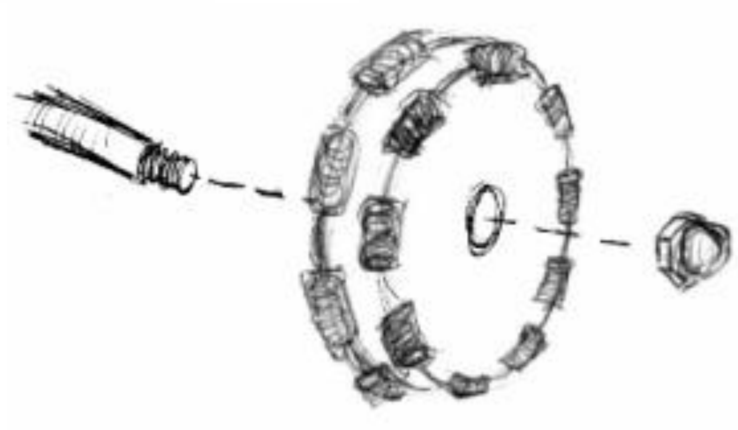


Rear wheels

Omni-wheels have been ordered to be used for the rear wheels. They will be attached with an axle located beneath the rear board. This axle will be attached to the bottom of the rear component. This will allow the wheels to retain their mobility when the platform is inclined.

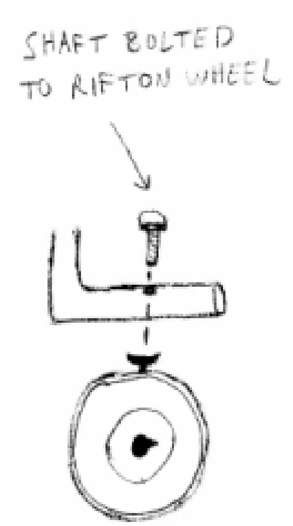






Front wheels

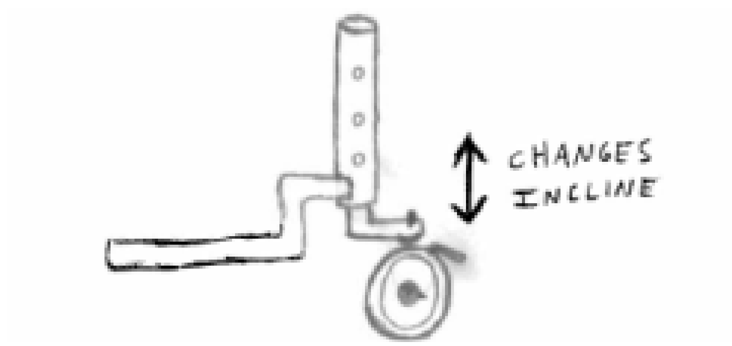
The Rifton wheels will be used for the front wheels. They are equipped with resistance variation capabilities, directional locks, and general wheel locks. They come with a shaft housing that entails bolting the shaft horizontally to the wheel's housing. This is how we will attach our shaft to the wheel. The shaft will then be attached to the front of the board using our "spider-leg" technology.



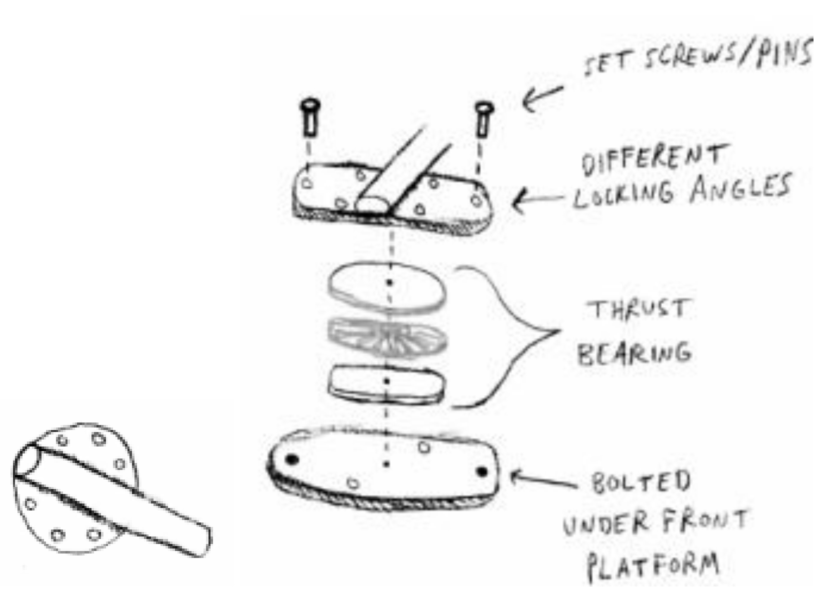
From our parameter analysis, we determined an approximate bending stress of 4140 psi on the front horizontal wheel shafts. This calculation, as well as the density and price factors, aided us in choosing aluminum alloy as our shaft material. It was the best option that was lightweight, strong, and adequately priced.

We also put together some force and moment equations for the entire board in order to determine the best location of the front wheels in order to minimize the risk of the entire platform tipping while Lincoln is lying upon it. These equations are shown in the Moment Calculation for Placement of Front Wheels section.

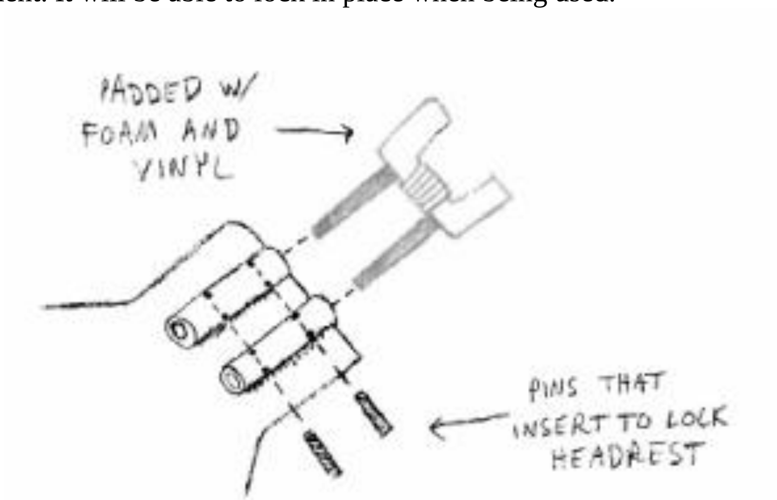
Inclination and Rotation Method
The front wheels will be bolted to a shaft which will be fitted into a vertical housing leg. The shaft will be able to lock into different vertical positions, which will vary the incline of the unit. This method is reapplying the technology usually used in crutches to adjust their height.



The shaft used in the front wheel design will be welded underneath the platform to a rotating disk hinge. The disk hinge will be attached to the bottom of the front board component, and will lock in different locations by using set screws or pins. This will allow the front wheels to be out perpendicular to the board, at a 45 degree angle, and also parallel to the board for easy storage.



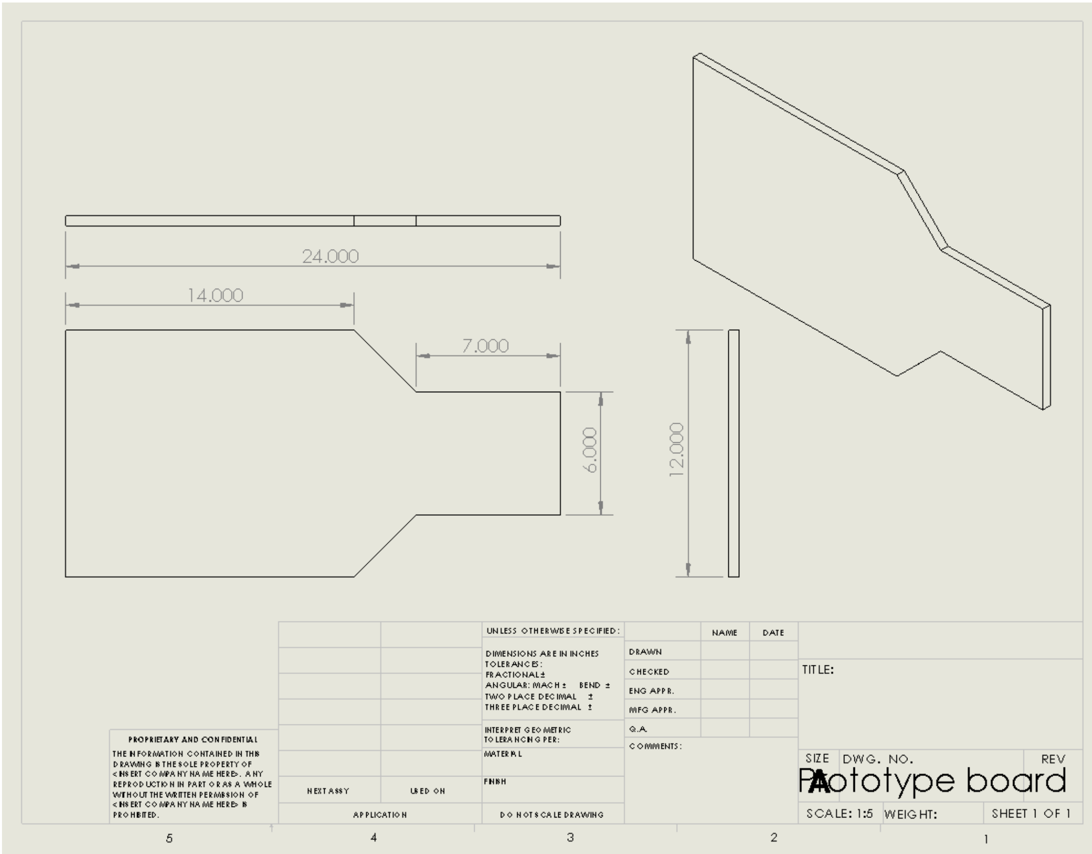
Headrest
The headrest will be designed to support Lincoln's head and neck. It will have a frame made from aluminum rods, bent into a supporting v-shape. The vinyl material will be used to cover the inner materials to make it more comfortable for Lincoln and easier to clean for his parents. Its attached position will be fixed at an angle for maximum support of Lincoln's head and neck. There will be support on the bottom for his chin and also on the sides for his cheeks. The headrest will be detachable so Leah or Lincoln's parents can detach it if he does not need it at the time. The headrest will have two shafts, similar to the technology used for a car seat headrest, which will be inserted into cylindrical holes on the bottom of the front component. It will be able to lock in place when being used.



From our parameter analysis, we approximated a bending stress of 2280 psi upon the headrest. From comparing this value to the material property table in the Material Analysis section, we decided to use aluminum 3/8" in diameter as the headrest base material.

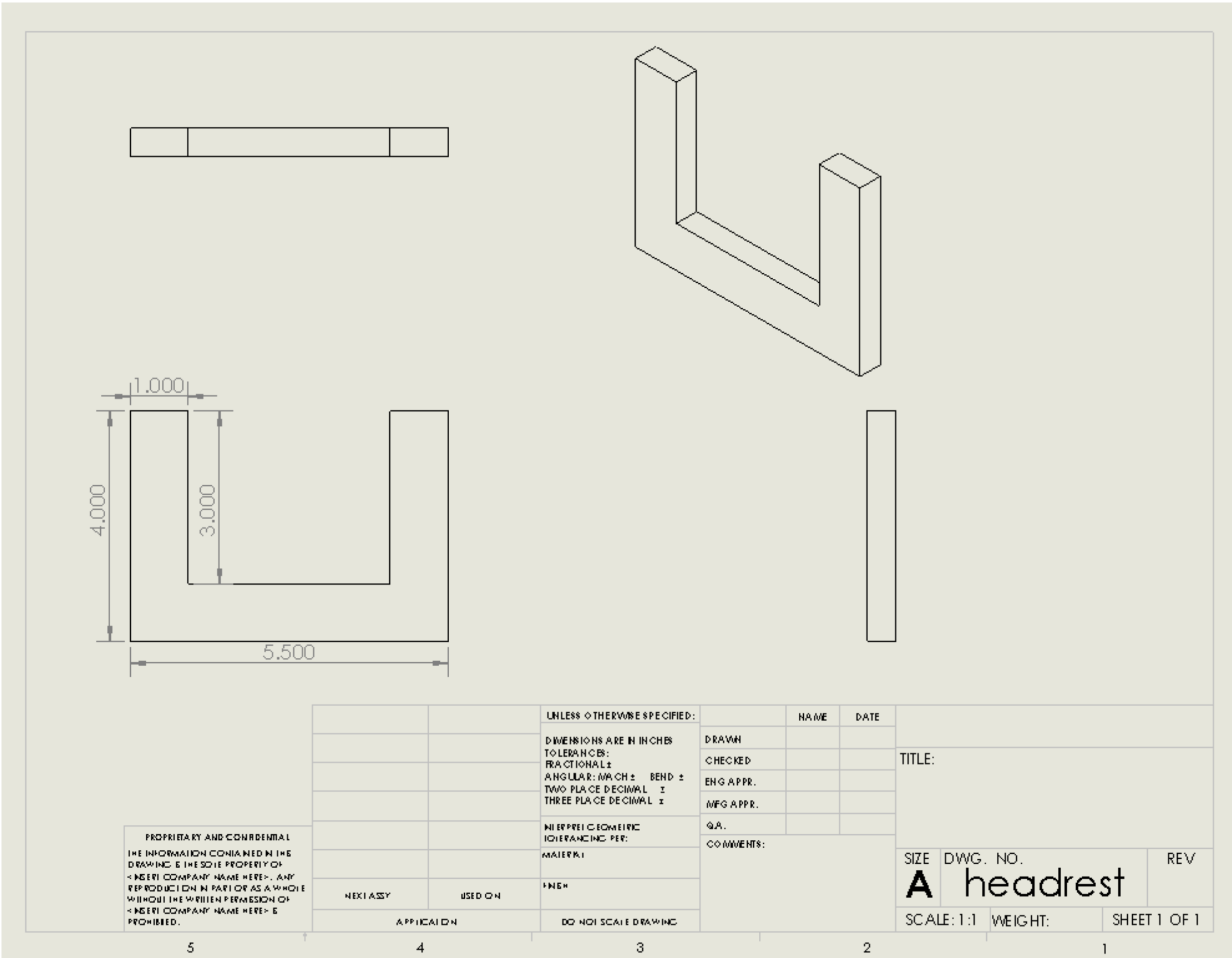
INITIAL FABRICATION PLAN

For our initial prototype, we used wood as the base material then covered the top side with foam, stapling vinyl upholstery over the top for a finished appearance. We started with a large piece of 0.5" thick particle board, which we cut down to a rectangular shape having rough dimensions of 24" x 12" using a circular saw. We then worked on adding the taper features to the front of the platform, creating space for Lincoln's arms by cutting away material at the front end with the circular saw. The dimensions of the top plank are 6" wide, and 7" long as seen in the CAD diagram below, with chamfered corners for safety. The tolerances for these dimensions were fairly large (± 0.25") as this prototype was used primarily as a measuring tool, and not a finished product. Also, large tolerances allow us to save time and money on the prototype fabrication.



After completing the initial shape, we covered the surface in foam ranging in thickness from 0.5” to 2” to create the desired design contours on the platform. The foam that was purchased featured a glue adhesive on one side, which allowed us to stick the foam in place on top of the board. To create a finished appearance, we covered the top of the board with soft vinyl, and pulled tight to give a smooth finish. We stapled the vinyl to the underside of the board to hold it in place. After it was stapled in place, the excess vinyl was cut away using scissors.

The prototype headrest followed a similar fabrication process. We started by using the circular saw, cutting the particle board into a rectangle 5.5” wide and 4” long while maintaining tolerances of ± 0.25”. We then cut the face support into a U-shape, leaving 1” of material on each side. The dimensions of the head rest are shown in the CAD diagram below. We then covered the particle board by winding layers of 0.5” thick foam, until a satisfactory thickness was achieved (approximately 1.5”). The foam was then covered in the same vinyl material used for the platform, and stapled to the back side of the head rest.



The initial prototype was useful in obtaining the key specifications desired for the proper fit and comfort of Lincoln; however several key components were omitted for simplicity. These include the front and rear wheels, and the length adjustability. Furthermore, some of the fabrication processes will vary from the initial prototype to the final design. A detailed fabrication plan for the final design is given in the next section for all components.

FINAL FABRICATION PLAN

The final device will be more complex than the previously described prototype. We plan to hold tighter tolerances to ensure a more accurate design. These tolerances will take longer to achieve and may be more expensive to hold, but will provide us with more reliable fits during assembly. Each component of the design is detailed in this section complete with manufacturing speeds and feeds tables. The assembly process that we followed is also included.

Rear Platform
The rear platform will be fabricated with 1/2" thick birch plywood, using a band saw in the ME shop to cut the desired shape. The platform will be covered with self-adhering 1/2" thick foam. Vinyl will be used to cover the foam, giving a safe surface that can be cleaned easily, by pulling tight and stapling on the underside of the plywood platform. The platform will be cut using tolerances of ± 0.1".

Rear, Front, Middle, Insert Platforms					
Step	**Operation**	**Machine**	**Cutting Tool**	**Cutting Speed**	**Notes**
1	Cut ½” thick birch wood to size for all pieces	Band Saw	Band Saw	200 fpm	
2	Sand platform pieces	N/A	Sand Paper (220 grit)	N/A	Work all rough edges and corners
3	Apply Foam with sticky adhesive	N/A	N/A	N/A	Variable foam thickness
4	Cover individual platforms with vinyl	N/A	N/A	N/A	

Front Platform
Similar to the rear platform, the front platform will consist of plywood, foam, and vinyl. The 1/2” plywood will be cut to shape with a band saw. The platform will then be covered with self-adhering 2” thick foam. To finish, the platform will be covered with vinyl, pulled tight and stapled to the board. The platform will be cut using tolerances of ± 0.1”.

Platform Inserts
As with the front and rear platforms, the inserts will be simple plywood boards covered in foam and vinyl. The 1/2” plywood will be used, and cut with a circular saw into rectangular sections. The 2” foam will be used, and will be covered with vinyl stapled underneath. To add the adjustable inserts, a latching system will be used on the underside of the boards. Each insert will have a female-end on one side and a male-end on the other side, to mate with existing latches on the front and rear platforms. Draw latches have been purchased for this, and they will be screwed onto the bottom of their respective platform pieces. The cuts will be made using tolerances of ± 0.1”. Tolerances will be especially important for the location of the draw latches, as they will need to attach accurately.

Length Adjustability Tracks
The platform will adjust by releasing the latches on the underside of the front and rear platforms. The crawler will slide apart, with purchased steel tracks. Two sets of tracks will run parallel to each other underneath the board. The tracks will attach with specialized mounting brackets fabricated from aluminum on the mill. As the tracks extend, they allow space for the inserts and support the inserts, which are set into place and secured with latches to both the front and rear platforms. The tracks will be cut to length using a band saw, and bolted to the plywood platforms.

Rear Wheel Attachment
A solid cylindrical aluminum shaft 3/8” in diameter will extend the width of the board, through both of the rear Omni-wheels, serving as an axle. Each end will be threaded, to allow for an end cap nut, holding each wheel in place. The axle will attach to the bottom of the rear platform with three two-hole mount metal clamps. Tight tolerances of ± 0.02” will be held to ensure concentricity.

Rear Wheel 3/8” Diameter Axle					
Step	**Operation**	**Machine**	**Cutting Tool**	**Cutting Speed**	**Notes**
1	Cut rod to size	Band Saw	Band Saw	300 fpm	
2	Thread both ends of axle	N/A	Threading Tool	N/A	

Front Wheel Attachment
The front wheels will be caster wheels provided by Rifton, which attach using a vertical bolt. The vertical bolt will attach through a 3/4” diameter aluminum tube, which will connect the wheels to the telescoping shaft. The telescoping shaft is then attached with TIG welding to the legs, and the 7/8” diameter aluminum tubing is also welded to the rotational plates. The aluminum legs will be TIG welded on 3-1/2” diameter aluminum plates, which then attach to the platform. Tolerances of ± 0.02” will be held.

Front Wheel Incline Variability
The platform will incline with the telescoping front wheels. These will be fabricated with concentric aluminum tubing, with the outer diameter being 7/8”. The height will adjust in increments of 1” with 1/4” diameter holes drilled through the shaft, and will be held in place with quick release buttons. The shaft fit will have tight tolerances of ± 0.02”. The tolerances of the button holes are not as important.

(2) Front Wheel 3/4” Diameter Vertical Shafts					
Step	**Operation**	**Machine**	**Cutting Tool**	**Cutting Speed**	**Notes**
1	Bend 90 degree angle in pipe	Pipe Bender	N/A	N/A	Must Compensate for elasticity
2	Cut pipe to size on both ends	Band Saw	Band Saw	300 fpm	
3	Drill Center holes for incline location pins/Rifton Wheel bolt.	Mill	1/4” Diameter Drill Bit	850 fpm	
4	Drill holes	Mill	1/4” Diameter Drill Bit	850 fpm	

(2) Front Wheel 7/8” Diameter Vertical Shafts					
Step	**Operation**	**Machine**	**Cutting Tool**	**Cutting Speed**	**Notes**
1	Cut pipe to size	Band Saw	Band Saw	300 fpm	
2	Drill Center holes for incline location pins	Mill	1/4” Diameter Drill Bit	850 fpm	
3	Drill holes	Mill	1/4” Diameter Drill Bit	850 fpm	

(2) Front Wheel 7/8” Diameter Horizontal Shafts					
Step	**Operation**	**Machine**	**Cutting Tool**	**Cutting Speed**	**Notes**
1	Bend Pipe	Pipe Bender	N/A	N/A	Must Compensate for elasticity
2	Cut pipe to size on both ends	Band Saw	Band Saw	300 fpm	

Front Wheel Rotation Plates
The front wheels will adjust to two different positions using overlaid 3- 1/2” diameter aluminum plates. The top plate will be attached to the leg, and will feature two holes on opposite sides. The bottom plate will have two sets of two holes spaced 45° apart, to allow for rotational adjustability. The top plate will

rotate relative to the bottom plate, and will line up to the desired position with two thumb screws. Between the plates, a needle-roller thrust bearing will be located to allow easy movement relative to each other. Two bolts will hold the bottom plates in place on the board. The tolerances of the hole locations on the plates are extremely important and will be held to ± 0.02”.

(4) Cylindrical Rotation Plates					
Step	**Operation**	**Machine**	**Cutting Tool**	**Cutting Speed**	**Notes**
1	Cut approximate thickness from stock	Band Saw	Band Saw	300 fpm	
2	Plane face of plate	Mill	½” End Mill	850 RPM	
3	Plane opposite face	Mill	½” End Mill	850 RPM	
4	Drill center hole	Mill	½” Drill	850 RPM	After welding
5	Drill locating holes	Mill	¼” Drill	850 RPM	After welding

Headrest and Attachment Collars
The headrest will be manufactured from 3/8” diameter aluminum. Two identical pieces will be cut to length, and bent to a 45° angle. An aluminum support collar will be TIG welded between the two bars, giving the headrest shape and structure. The shape will then be covered in 1/2” thick, self-adhering foam, which will be wrapped around the shape. The foam will then be covered with vinyl, which will be sewed into place. To make the headrest removable, the design will feature two shafts extending from the bottom of the headrest. These shafts will slide through two metal collars, which will be mounted to the underside of the front platform using bolts. Tolerances are important for shaft locations and concentricity with the collars. They will be held to ± 0.02”.

3/8” Diameter Headrest Frame					
Step	**Operation**	**Machine**	**Cutting Tool**	**Cutting Speed**	**Notes**
1	Bend 45 degree angle into 2 pieces	Vise	N/A	N/A	Must Compensate for elasticity
2	Cut 2 pieces to shape	Band Saw	Band Saw	300 fpm	
3	Cut square collars to 3” long pieces	Band Saw	Band Saw	300 fpm	
4	Drill holes in 3/8” pipe/square collars for pins	Mill	1/8” Diameter	850 fpm	

Assembly

All of the components were assembled in the ME shop after they were fabricated. Each of the components was assembled from the center outwards in order to ensure that everything fit together properly and was safely assembled.

Each piece was attached in the following order:

- Each of the wooden pieces, including the inserts and headrest, will have the foam specifically molded to their shapes and then covered individually with the vinyl fabric.
- The two aluminum tracks will be attached with screws to the bottom of the front, middle and rear wooden pieces. The two inserts will not be permanently attached to the two tracks.
- The rear axle will be attached with the metal clamps and then the two rear wheels will be attached to the axle by threading.
- The front wheel shafts will be welded to the outer rotating disks on one side and to the telescoping front wheel shafts on the other. The Rifton wheels will be attached to the telescoping front wheel shafts on the outermost side with screws.
- Two front rotating disks will be attached to the wooden board on the underside with screws. The other two rotating disks will attach to the first two with thumb screws, in specific holes for each location, and a thrust bearing in between to ensure easy rotation. These latter two rotating disks are the ones with the front wheel shafts attached to them.
- Two hollow square shafts will be attached to the bottom of the front wooden platform. These will house the two solid round shafts from the headrest so that can be inserted and held in place while in use.
- The final touch will be to add the latches on the underside of the wooden pieces. They will be attached with screws in between each of the inserts to make sure that they stay in place while in use and that the device will have the ability to be adjusted at any time.

We have done many calculations in order to make sure that our device is safe and will not fail. These include moment and free body diagrams, calculations for tipping, as well as dimension calculations from our meeting with Lincoln to guarantee that our device specifically works for him. During use, we expect Lincoln to be fully supported by our device and be able to be mobile in his environment for him to explore and interact with his surroundings. Afterwards, the front Rifton wheels will lock for him to be detached from the device’s harness, and the front wheels will be able to be rotated inwards for storage. A CAD figure of the assembled device is shown below.

VALIDATION PLAN

The length of the board, width of the board, and minimum and maximum platform height specifications can all be validated easily by measuring with a tape measure. The incline angle range can be determined by applying trigonometry using these dimensions. The weight of the device can be validated with a scale.

The Rifton wheels validate our wheel requirements. These wheels have two degrees of freedom, as they are designed to swivel around one point. They also provide various levels of resistance, and come equipped with locks. We plan to use two of these wheels in our final design. We also purchased two Omni-wheels for the rear axle. They have two degrees of freedom, and will be fixed on an axis. The Omni-wheels do not require any locking mechanisms, since the Rifton wheel locks provide so much stability.

The last specification that we will need to test for will be weight capacity. Currently, Lincoln only weighs 20 lbs, but we would like our device to have a weight capacity of at least 80 lbs. This has been validated by placing weights on our prototype when it was finished. Analysis has been done calculating stresses at critical points in the device helping us select materials that will not fail under these stresses. The selected materials prevented failure from occurring during our 80 pound weight test, and we are very confident that it will be safe for Lincoln to use.

DISCUSSION

Although our team was able to develop a functional prototype for Lincoln, in hindsight, there are several aspects of the design that could have been tweaked to make the final product even more successful. With respect to our target engineering specifications, the requirements for weight and wheel positional locks were not met. A better design would have been slightly lighter, and would have had the ability to restrict the crawling aid to move only in the fore/aft direction or only side to side. Also, although our prototype passed the 80 pound weight validation test, in hindsight, our requirement should have been higher to consider possible use by Lincoln's older sisters. By modifying a few aspects of our design, these requirements could have been met.

The weight of the crawling aid could have been reduced with a simpler track system for the length adjustment. The length adjustable tracks were not originally designed for use with our crawler, and a lighter design could have achieved the same results. Also, by using these tracks, complex attachment methods had to be designed, which added additional weight to the board. Instead of drawer slides, a pair of simple sliding beams, without locks or ball bearings, could have been utilized, improving overall weight, simplicity of design, and ease of use.

Another aspect of the design that could have been improved was the Rifton wheel assembly. We implemented the specialized Rifton wheels for their wheel locks, adjustable resistance, and adjustable direction of motion. However, these features proved too sophisticated for practical use, as Lincoln is still learning to crawl and needs the simplest, lightest wheel design possible. It is for this reason that we omitted the option of allowing adjustable direction of motion. By focusing too intently on the complex features of the Rifton wheels, we overlooked the immediate needs of the design, although these specialized wheels may prove to be useful in the near future.

Other general improvements could also be made if the design were to be marketed for a broader customer base. The tolerances on all dimensions would have to be tighter, to prevent the slight misalignment faced in our design. By bending the tubing with conduit benders, it was difficult to achieve perfectly straight, symmetrical designs. This misalignment resulted in the wheels being slightly pitched when in contact with the ground, making it more difficult for the caster wheels to rotate. Also, the overall aesthetics of the design could be improved, primarily with respect to material choice and finishing. The vinyl used for the headrest and platform were of different colors and styles, and the sewing used to finish the headrest did not give a clean appearance, or accurate representation of the underlying design.

With these minor modifications to the design, our crawling device would perform slightly better, and would be ready for mass production.

RECOMMENDATIONS

There are several aspects of our design that the sponsor should take note of to ensure the optimal performance and functionality of the crawling device. From a maintenance standpoint, all four wheels should be kept clean to prevent particulate buildup, increasing resistance. Also, the platform should be cleaned with disinfecting wipes or similar cleaning solvent, especially if used with multiple patients. All bolts should remain in place, but if necessary, they should be fully tightened. Similarly, the adjustable tracks should slide easily, however they may need to be lubricated with WD-40 or similar oil to ensure easy sliding.

In terms of functionality, it is important to use the included safety features to ensure dependable operation. The safety harness should first be securely attached underneath the board and tightened such that the strap feeds between the sets of thumb screws. With the wheels locked, the patient should be set in place. Then the safety strap should be pulled up to just beneath the child's armpits. If necessary, the harness may need to be rolled up on itself, effectively shortening it. With the upper harness in place, the buckles should be fastened underneath the board, and securely tightened. At this point, the wheel locks can be released. Other safety considerations include applying the wheel brakes before removing the child from the crawler and before any adjustments to length, safety harness, or incline.

The platform should be used at the lowest feasible setting to prevent the misalignment in the wheel shafts from being magnified. With the platform raised higher, the front wheels will contact the ground at a further angle from perpendicular, making the caster wheels more difficult to move and rotate. Additionally, the incline should be set to the same setting for both wheel shafts.

For storage, the thumbscrews should be removed, and then the legs should be rotated into the parallel position. Once in position, the thumbscrews should be replaced. To adjust the resistance of the wheels, the child should be removed, then the resistance indicators should be slid into the desired position. We recommend that the resistance of the wheels be set to the same setting, although if focusing on specific movements, a mismatch may be appropriate. For an added challenge, we suggest applying the direction locks on the opposite side of the Rifton wheels. With the direction locks in place, the wheels will only roll in one direction, and this setting may provide an increased level of difficulty for the patient.

We recommend this device be used primarily on hardwood or tiled floors, as the functionality has not been tested on carpeting. Additionally the device should be used strictly as intended, with the child securely fastened chest down on the board, with respect to the 80 pound weight capacity.

CONCLUSION

Lincoln is severely debilitated by spina bifida, a birth defect that has left him without feeling below his waist. Because of this handicap, Lincoln has limited mobility, and at 21 months old, cannot crawl. Through collaboration with our physical therapist sponsor, Leah Hagamen, we have developed design concepts that aim to assist Lincoln in learning how to crawl and developing both physically and cognitively.

Working with Leah, we developed a list of customer requirements, and from those requirements generated engineering targets for our design to meet. Top criteria of safety, head support, leg support and mobility have led to specifications on the device's angle of incline, weight, and wheel degrees of freedom, among others.

We created a functional decomposition, then considering our design criteria, we developed particular components that meet the different customer requirements. Focusing on safety, head support, leg support, mobility, adjustable incline, and adaptability to growth, we generated concepts several specific design components. Among these we developed safety harnesses, headrests, leg containment features, wheel implementations, inclined platform options and extension possibilities.

Using these component designs, we generated a total of seven overall design concepts. We then ranked these design using a Pugh chart, analyzing each main design against the fourteen weighted customer requirements. With this tool, we identified one prevailing design and verified that the benchmarked designs were inadequate. Borrowing the best ideas from each concept we generated our Alpha Design that we felt best met all of our customer requirements.

A prototype model was fabricated based on a simple design. It was made with no wheels or adjustability features so that we could test the geometry and shape features on Lincoln at one of his appointments at MedRehab Milestones. Using this data, we performed an engineering parameter analysis to determine moments within components and to analyze the materials that can be used.

Following this analysis, our final design was decided upon along with a fabrication plan and validation methods. The final prototype was then fabricated and went through safety testing before we brought it to another one of Lincoln's appointments. During this time, we collected any final feedback from Leah and Lincoln's family in order to finalize our prototype for the Design Expo on April 15th. With the completion of the prototype by the Design Expo, we were able to demonstrate the functionality of our device to the crowd and our professors through Lincoln being able to crawl and explore his surroundings while using our device.

While Lincoln is on our device, he is able to move around in his surroundings much better than he was able to before. He also smiles a lot and he seems to enjoy the features of the device, especially the headrest. With only four times on the device, he is still adjusting to the new idea of the device and moving in that way. However, he is taking to it very well and we expect for the device to greatly increase his muscle and cognitive development in the future. Photographs of Lincoln enjoying the crawling device are found in Appendix L.

ACKNOWLEDGEMENTS

We have had a great semester going through a real experience of applying our engineering education from the past four years here at the University of Michigan. We would like to thank all of the instructors of Mechanical Engineering 450, GSI, Phil Bonkoski, Russ Pitts, and project co-sponsor, Professor Shih, for making this semester very educational and life changing. We would also like to thank Bob Coury and Marv Cressey for all of their help in the machine shop this semester.

We would like to acknowledge Rifton Equipment, for donating the specialized Rifton wheels for use in our final design.

Our special thanks go out to our section instructor, Professor Wineman, physical therapist sponsor, Leah Hagamen, MedRehab Milestones, and Lincoln and his family. Without them, our semester would not have been successful.

Lincoln's family generously allowed us to use videos and photographs for presentations and reports. They also spent a full day at the Design Expo helping us show off the success of our final design. For this they deserve additional recognition and thanks.

It was a great experience for our team to design and manufacture this product that can be used in this real life application. We are very thankful to Lincoln's family for letting us come into his life and we hope that Lincoln benefits as much as he can from the use of our device.

INFORMATION SOURCES

Our design will need to meet the needs of Lincoln and other children with spina bifida, addressing ways in which current designs fail. From our research and meeting with our expert, Leah Hagamen, we have identified current designs and patented designs that attempt to address the crawling difficulty faced by babies with spina bifida [2].

The first device we were introduced to was the Creepster Crawler [1], made by RedBarn Enterprises. This design features a harness from which the child's hands and legs reach the ground and are free to move. The shortcomings of this design, specifically with our patient Lincoln, were the Creepster Crawler's lack of head support and failure to adjust to different sized children. Additionally the design unsafely left the child's legs to drag along the floor. However the design is secure, mobile, and allows interactivity between the parent and child.

The second device presented was the Scooter Board [3], from Southpaw Enterprises. The device is essentially a flat, padded board on four wheels with a safety strap. The Scooter Board is easy to use and has adjustable length. Unfortunately, it too lacks the head support needed for a child with a comparatively heavy head and relatively weak neck muscles.

A patent search conducted revealed a "Crawling Aid for Handicapped Infants" (Patent No. 7182351) dated February 27, 2007 [6]. This device, similar to the Scooter Board, features a cushioned platform with safety strap, but only three wheels. Additionally this device has a center portion that supports the head and allows the child to see off either side, and is narrow enough to allow the child's arms to hang off the sides and maneuver. Another safety feature is the leg support preventing the child's legs from dragging on the floor. However this device limits the child's visibility, hindering his ability and motivation to explore his environment.

One of the devices that we will be using in our final design is a wheel from a company called Rifton Equipment [7]. We encountered this company at our first visit at MedRehab Milestones at the University of Michigan Health Center with Leah Hagamen. She showed us one of the devices that they used there, called a Rifton Pacer Gait Trainer. This device used specific wheels that had variable resistances and locking capabilities. We were very interested in these wheels and decided to use them in our design due to their alignment with our safety protocols that we want to implement in our final product.

REFERENCES

[1] "Creepster Crawler." *RedBarn Enterprises*. N.p., n.d. Web. 23 Jan. 2010. <http://redbarn-enter.com/redesign.html/pages/creepster.html>.

[2] Hagamen, Leah. Personal interview. 14 Jan. 2010.

[3] "Scooter Board with Backrest." *Southpaw Enterprises*. N.p., n.d. Web. 23 Jan. 2010. <http://www.southpawenterprises.com/Adjustable-Scooter-Board-with-Backrest-P369.aspx>.

[4] "Students with a Neurological Impairment - What is an NI? - JCU." *James Cook University in Tropical Northern Queensland, Australia*. N.p., n.d. Web. 20 Jan. 2010. <http://www.jcu.edu.au/disability/JCUPRD_050716.html>.

[5] "Spina Bifida Information Page: National Institute of Neurological Disorders and Stroke (NINDS)." *National Institute of Neurological Disorders and Stroke (NINDS)*. N.p., n.d. Web. 17 Jan. 2010. <http://www.ninds.nih.gov/disorders/spina_bifida/spina_bifida.htm>.

[6] Williams, M. E. *Crawling aid for handicapped infants* (280/87.02 ed.). U.S.: B25H 5/00.

[7] "Rifton Equipment, makers of high quality adaptive equipment.." *Rifton Equipment, makers of high quality adaptive equipment.*. N.p., n.d. Web. 2 Feb. 2010. <http://www.rifton.com/index.html>.

[8] "Bone density - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. N.p., n.d. Web. 21 Mar. 2010. <http://en.wikipedia.org/wiki/Bone_density>.

[9] "Brain Facts and Figures." *UW Faculty Web Server*. N.p., n.d. Web. 21 Mar. 2010. <http://faculty.washington.edu/chudler/facts.html>.

[10] "Sign In — Philosophical Transactions B ." *Philosophical Transactions of the Royal Society B: Biological Sciences* . N.p., n.d. Web. 21 Mar. 2010. <http://rstb.royalsocietypublishing.org/content/365/1543/1093.full>.

APPENDIX A – BILL OF MATERIALS

The following table lists the materials used in the initial prototype and the materials that will be used to construct the final design.

Design Step	Material/Item	Manufacturer/Seller	Part Number	Cost
Initial Prototype	Wooden Particle Board	Ann Arbor Reuse Center	N/A	$2.12
	Car Seat Headrest	Ann Arbor Reuse Center	N/A	$3.18
	High Density Foam, Vinyl Cover, & Tie Strap	Ann Arbor Scrap Box	N/A	$12.99
	Staples	Ace Hardware	N/A	$4.02
Final Design	Wooden Board – Birch Wood	Fingerle Lumber Co.	N/A	$22.10
	High Density Foam & Vinyl Covers	Ann Arbor Scrap Box	N/A	$6.36
	Front Wheels	Rifton	K509	Donated
	Rear Wheels : Omni-wheels	Vex Robotics	2762185	$32.94
	Fleece & Nylon Mesh	Jo-Ann Fabrics	N/A	$12.71
	Copper Channel Trim	Ace Hardware	N/A	$14.36
	Tracks & Axle	Home Depot	N/A	$18.08
	Aluminum Piping and Cylinders	Alro Metals	N/A	$86
	Latches & Thrust Bearings	McMaster-Carr	1889A34 5909K31	$23.96
	Aluminum Blocks	Alro Metals	N/A	$17.49
	Clamp, Latches, & Quick Release Pins	McMaster-Carr	8874T15 1889A34 94282A330	$23.37
	Tracks	Home Depot	N/A	$12.17
	Acorn Nuts, Thumb Screws, Rubber Caps, and Safety Buckles	McMaster-Carr	90507A250 98816A266 6448K85 6448K84 29705T86	$46.63
	Nuts & Bolts	Ace Hardware	N/A	$4.77
	Nuts & Bolts	Ace Hardware	N/A	$7.93
	Wing nuts, Pipe Insulation, Casters, & Velcro	Home Depot	N/A	$31.45
	Bike Bell	Meijer	N/A	$4.23
	Bolts	Ace Hardware	N/A	$0.98
	Vinyl Cover	Scrap Box	N/A	$3.18
	Needles	Meijer	N/A	$2.64

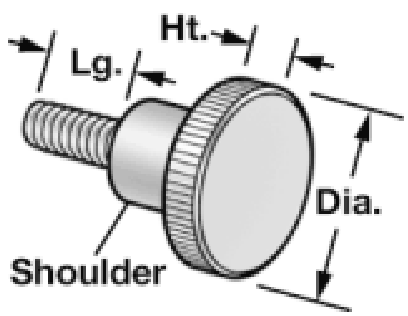
TOTAL COST	**$393.66**

APPENDIX B – DESCRIPTION OF ENGINEERING CHANGES SINCE DESIGN REVIEW #3

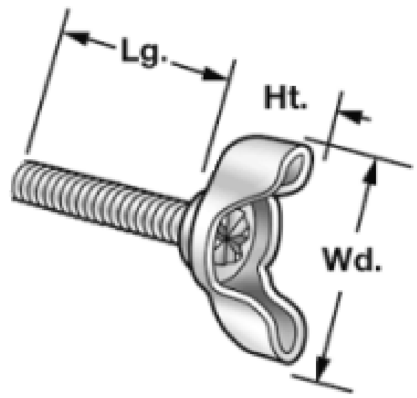
Several engineering changes had to be made since Design Review #3. These changes were made over the course of our manufacturing process while building the crawler device. First, there were several parts that we purchased to use on our design that we were not satisfied with, and they were replaced with different purchased parts. Second, there were a few components that we purchased that did not provide sufficient results, so we manufactured the parts on our own in the machine shop. The following details all of our changes, complete with before and after pictures, as well as change notes.

Thumb Screws

WAS: ¼”-20 x ¾” Thumb Screws



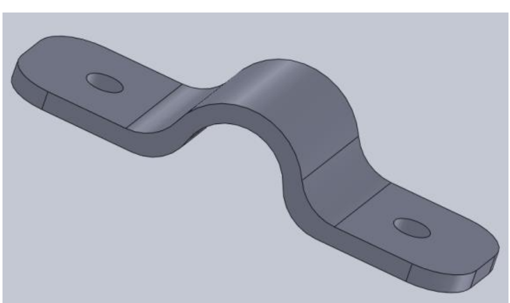
IS: ¼”-20 x 1 ½” Wing Bolts



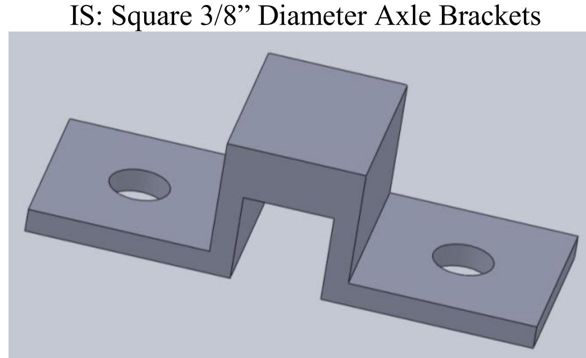
Notes: The Thumb screws on the bottom of our rotational front leg disks were replaced with wing bolts. These new bolts helped more with changing the front leg angle. They are much easier to use, and the longer length makes them more accessible.

Rear Axle Brackets

WAS: Round 3/8” Diameter Axle Brackets



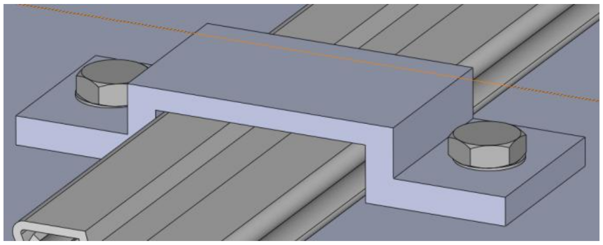
IS: Square 3/8” Diameter Axle Brackets



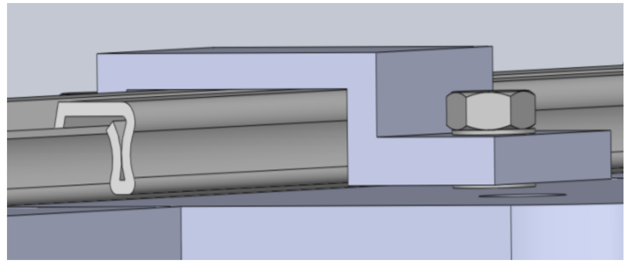
Notes: The round axle brackets were purchased originally from McMaster, and they did not provide the tight fit that we needed in order to lock the rear axle in place. We decided to manufacture our own square brackets made out of aluminum, which locked the rear axle into place.

Track Bracket Assembly

WAS: Bracket Holding Track to Tight



IS: Bracket Holding Track in Place with Additional Washer

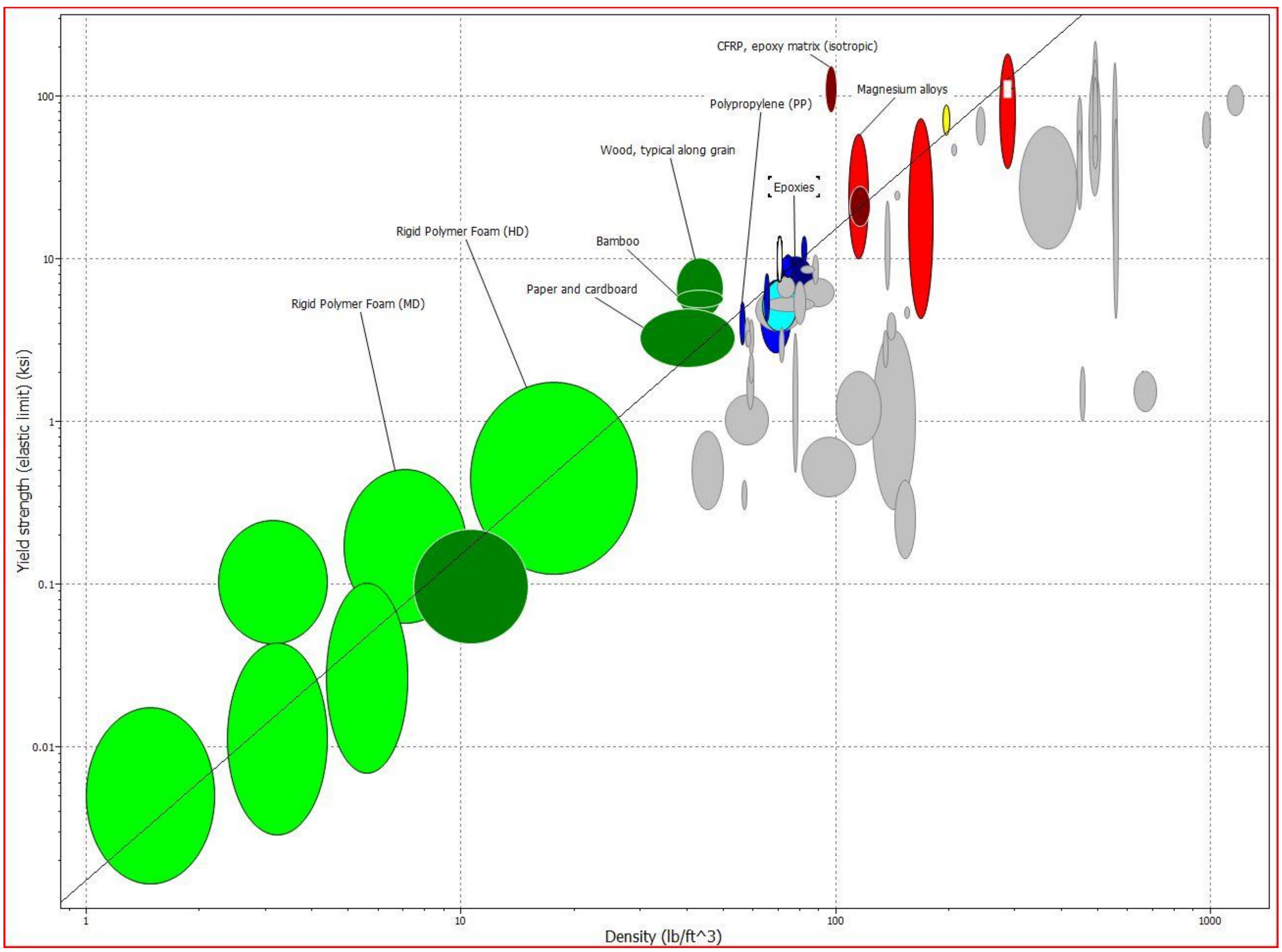


Notes: Originally the brackets that we manufactured fit well around the tracks, but when bolted down, held the tracks so tight that they could not be adjusted to add inserts onto the platform. We added a washer on each side beneath the mounting bracket, which gave a better fit, and allowed for track adjustability.

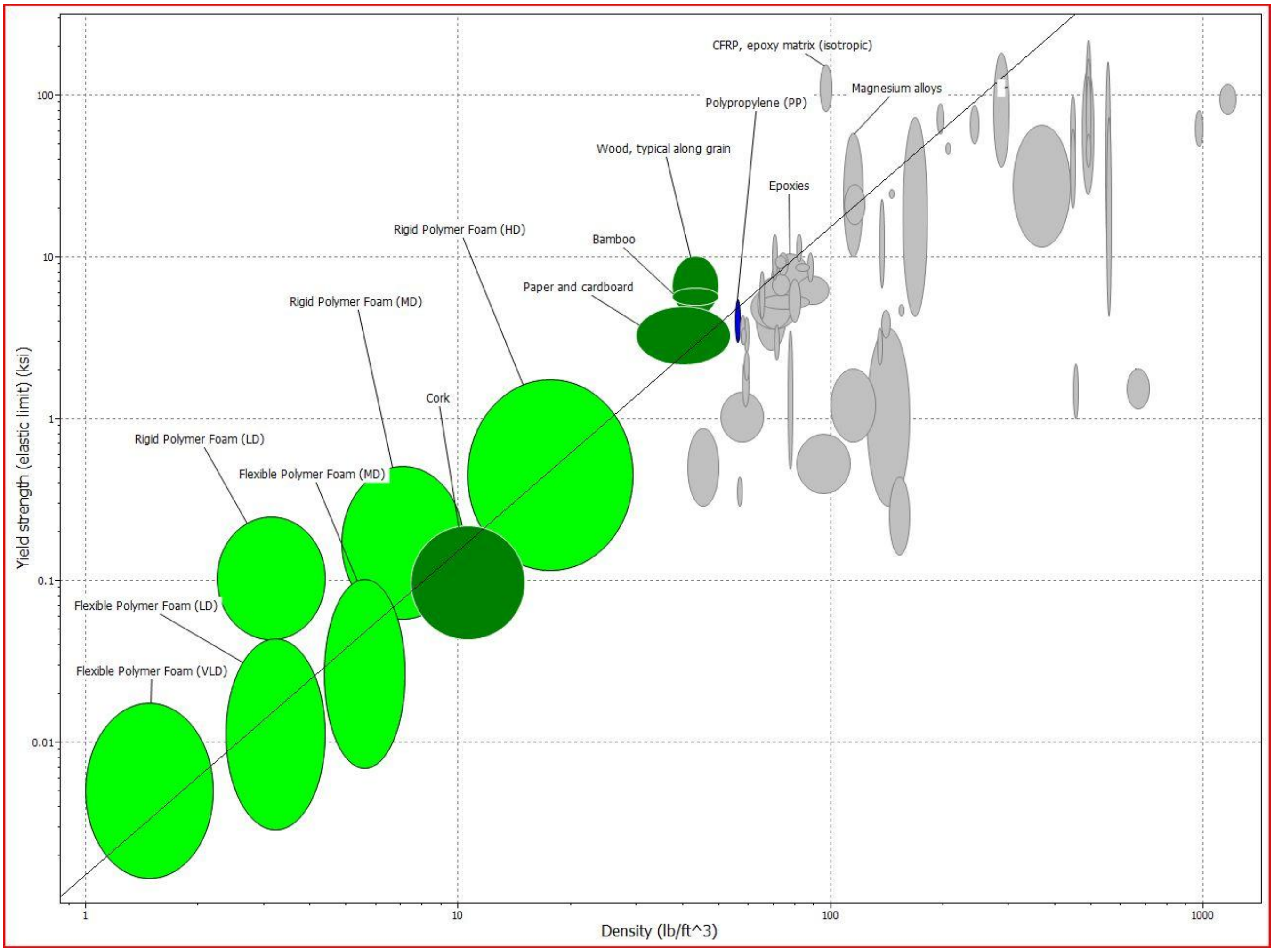
APPENDIX C – DESIGN ANALYSIS ASSIGNMENT FROM LECTURE

Material Selection
We used the CES material selection software to determine the best materials for two components of our product: the platform and the spider legs. The following section discusses this material selection process.

Platform Material Selection
Our goal for the platform is to select a material that will maximize its strength, while minimize its weight. Therefore our material index will be $\frac{\sigma_y^{2/3}}{\rho}$, where σ_y is the yield strength and ρ is the material density. Below is a graph applying the material index to the CES database of materials. The materials in color satisfy the index.



We will be using approximately 111 in^3 of material for our platform, which is equal to .064 ft^3. If we wanted the platform to weigh no more than 4 lbs, we will select a material with a density no higher than about 60 lb/ft^3. The materials in color in the following graph meet the constraint of a density of 60 lb/ft^3or less.



Selecting the five materials with the highest yield strength we can narrow our possible materials down to wood, bamboo, rigid polymer foam, polypropylene, and paper/cardboard. The yield strengths are all well above our calculated maximum bending stress of 0.4 ksi. The table below shows the density, yield strength, and cost for each material.

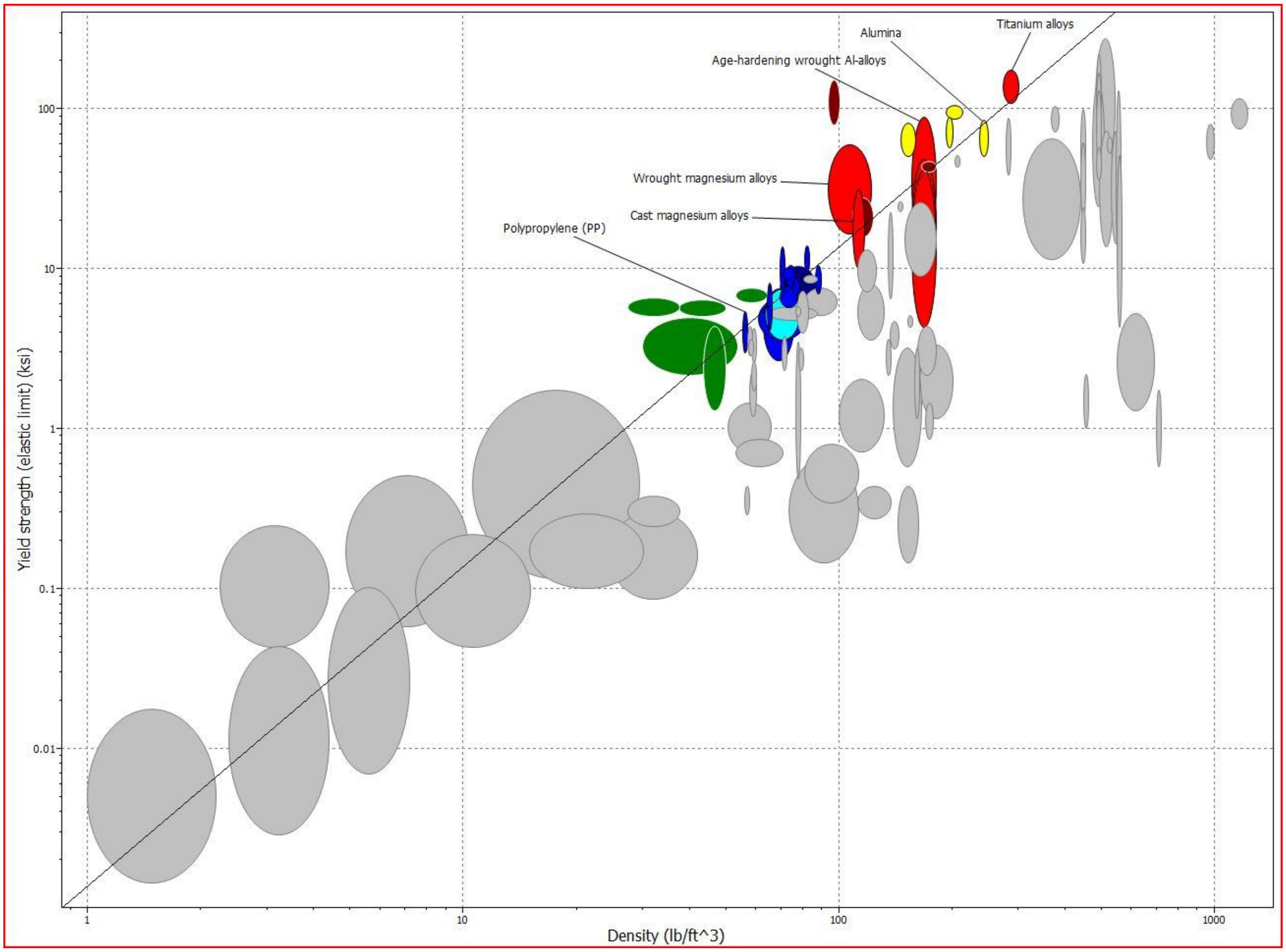
	Density (lb/ft^3)	**Yield Strength (ksi)**	**Cost (USD/lb)**
Wood	37.5 – 49.9	4.35 – 10.2	0.358 - 0.431
Bamboo	37.5 – 49.9	5.08 – 6.38	0.64 - 0.961
Rigid Polymer Foam	10.6 – 29.3	0.116 – 1.74	5.64 - 11.3
Polypropylene	55.6 – 56.8	3 – 5.4	0.522 - 0.574
Paper & Cardboard	30 – 53.7	2.18 – 4.93	0.449 - 0.54

Due to its low cost and adequate density and strength, we should select wood for the platform of our device.

Spider Legs Material Selection

For the horizontal wheel shafts, or spider legs, our goal was also to select a material that maximized strength while minimizing weight of the component. Therefore our material index was again $\frac{\sigma_y^{2/3}}{\rho}$. Our calculated maximum yield stress, including the safety factor of four, was about 4140 psi or roughly 4.14

ksi. The figure below shows the materials that meet both the material index as well as the minimum yield strength. Materials that meet these constraints are shown in color.



The table below compares the properties of five materials that meet all constraints: Titanium alloys, Alumina, age hardened wrought Aluminum alloys, Wrought Magnesium alloys, and Polypropylene.

	Density (lb/ft^3)	**Yield Strength (ksi)**	**Cost (USD/lb)**
Titanium Alloys	275 - 300	109 - 174	30.5 - 33.5
Alumina	237 - 248	50.8 – 85.3	8.28 - 12.4
Age hardened wrought Aluminum alloys	156 - 181	13.8 – 88.5	0.697 - 0.766
Wrought Magnesium alloys	93.6 - 122	16.7 – 59.5	2.37 -2 .6
Polypropylene	55.6 – 56.8	3 – 5.4	0.522 - 0.574

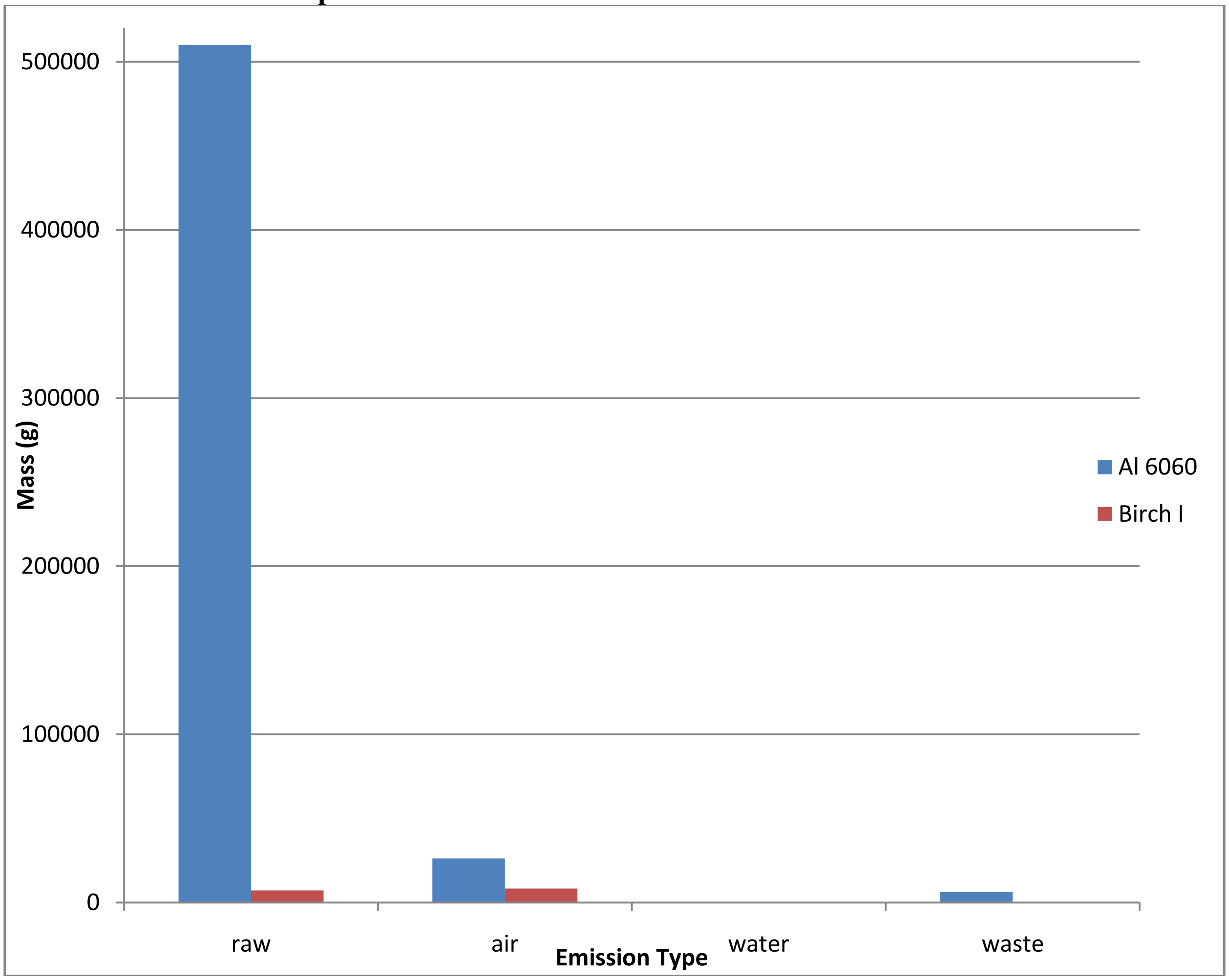
Because of its high yield strength, relatively low density, and low cost, we should select an aluminum alloy for the spider legs.

Environmental Performance
The two materials selected for environmental impact analysis were 6060 Aluminum Alloy and Birch I. We will use an estimated 2.6 kg of Aluminum alloy and 1.3 kg of birch wood on our product. Inputting this information into SimaPro, we were able to analyze the impact these materials had on the environment. The following table and graph demonstrate the emission breakdown from each material.

Emission Breakdown Table

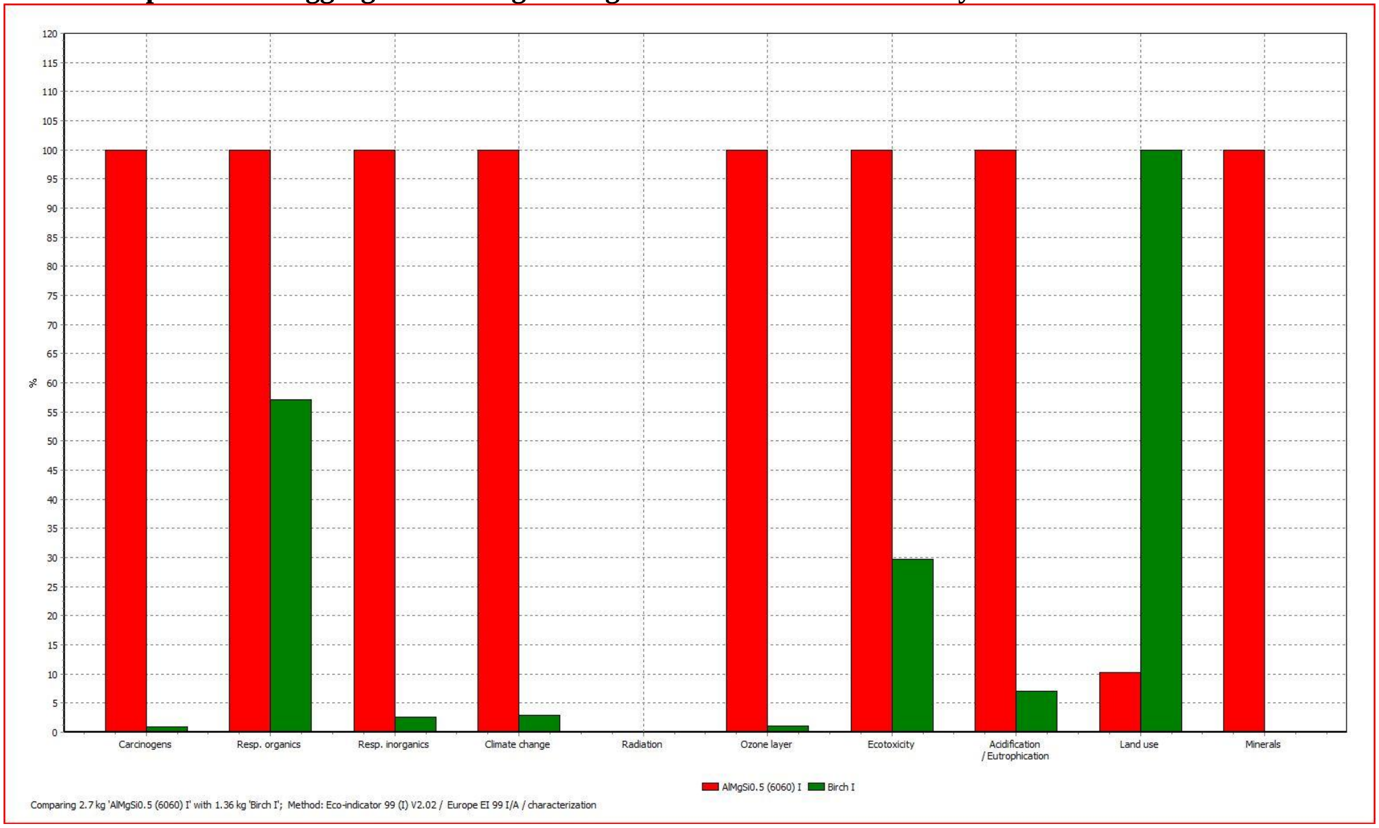
	Al 6060	Birch I
Raw mass (g)	509945	7173
Air mass (g)	26223	8449
Water mass (g)	377	4
Waste mass (g)	6231	157

Emission Breakdown Graph

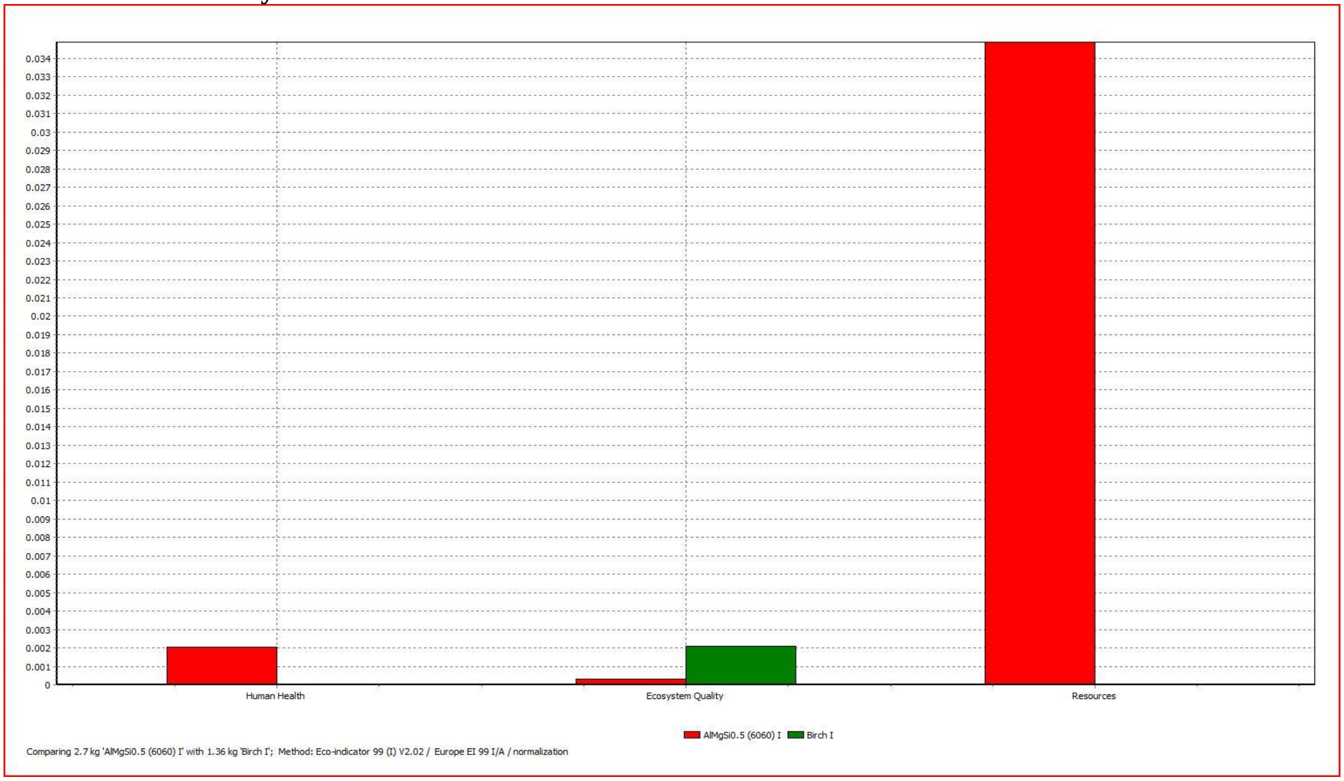


As seen in the previous graph, the greatest impact is the impact of Aluminum 6060 alloy on the raw materials used. The EcoIndicator99 in SimaPro helped us to generate the following graphs to further analyze the environmental impact of these materials.

Relative Impacts in Disaggregated Damage Categories: 6060 Aluminum Alloy vs. Birch



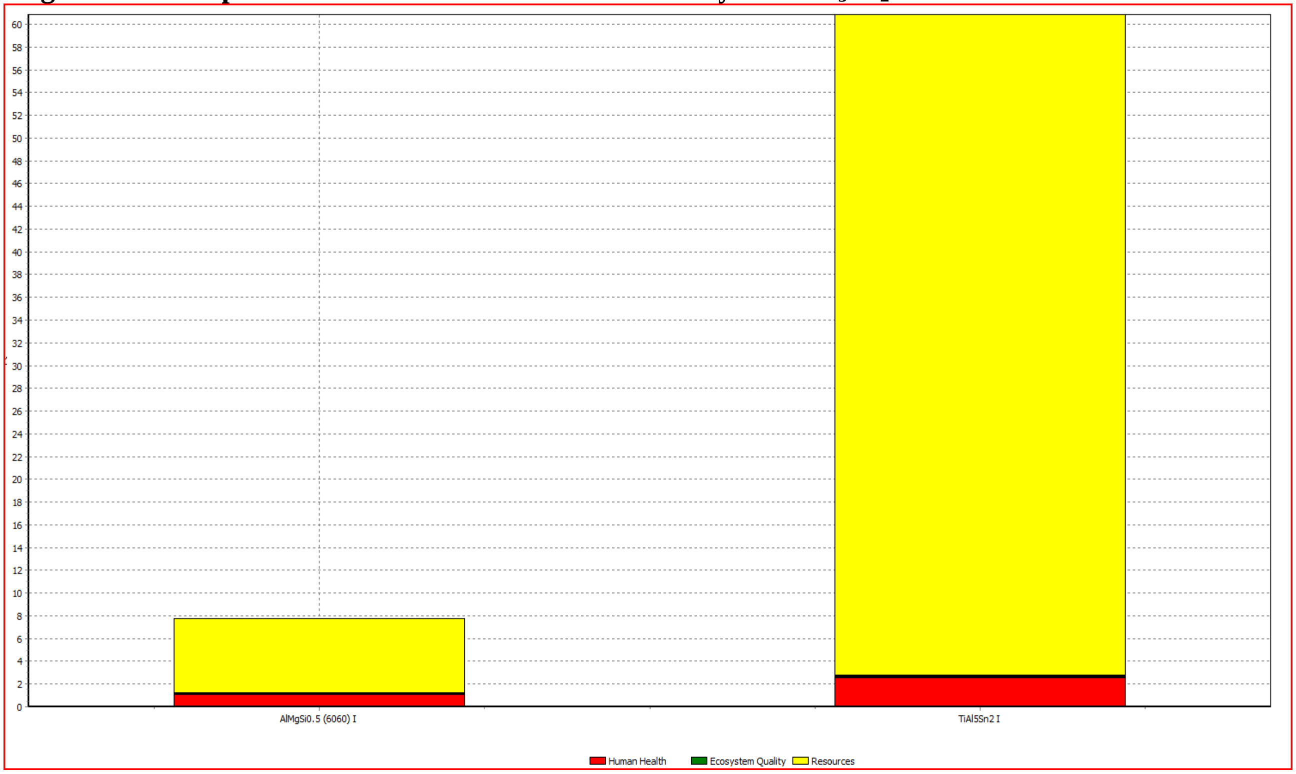
Normalized Score Human Health, Eco-Toxicity, & Resource Categories: 6060 Aluminum Alloy vs. Birch



Single Score Comparison in Points: 6060 Aluminum Alloy vs. Birch

From these graphs, a few observations can be made. 6060 Aluminum Alloy has a greater impact on the environment than Birch. Most of this impact is due to use of resources. Its impact is not nearly as significant on human health or the ecosystem. Birch actually has a greater impact on the ecosystem than 6060 Aluminum alloy. We ran another analysis comparing 6060 Aluminum alloy, to the titanium alloy $TiAl_5Sn_2$. Titanium alloy was another suggested material for the spider legs while performing the CES analysis. The single score comparison can be seen below.

Single Score Comparison in Points: 6060 Aluminum Alloy vs. $TiAl_5Sn_2$



As shown in the graph, the Titanium alloy has an even greater impact on the environment than the Aluminum alloy. Therefore, we will stay with our choice of Aluminum alloy for the spider legs.

Manufacturing Process Selection

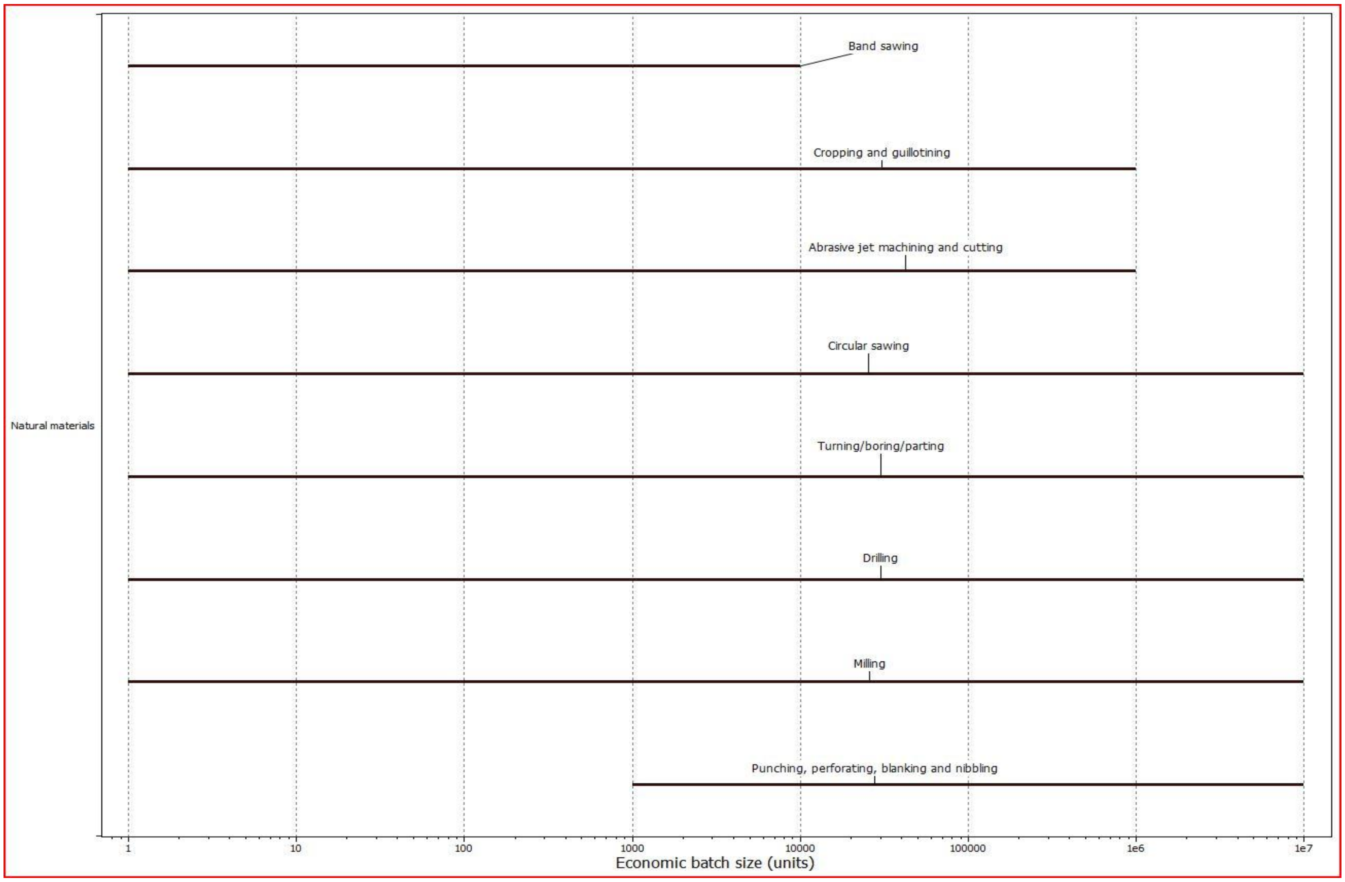
We used the CES manufacturing process selection software to determine the best manufacturing process for shaping the platform and joining the spider legs. The following section discusses this manufacturing process selection.

Estimated Production Volume

Seven out of 10000 babies born in the US will have spina bifida. There are an estimated 10,800 births per day in the US, which means that there are about seven babies with spina bifida born in the US per day. We will estimate that three out of these seven babies will demand our crawler device. If we wanted to produce a year's worth of crawlers, we would produce about 1095 crawlers. We will therefore estimate our batch size to be 1000 crawlers.

Platform Manufacturing Process Selection

We constrained the manufacturing processes for shaping the platform to those that could only handle natural materials with a batch size of at least 1000. On the next page is a chart showing the possible processes determined by the CES software.



According to CES, band sawing has a low tooling cost, as well as medium equipment costs and medium labor intensity. It is a common process used on wood and can handle batch sizes up to 10,000. Therefore, band sawing is the best manufacturing process option for shaping the platform.

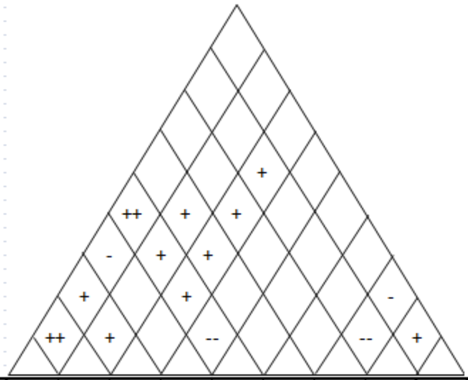
Spider Legs Manufacturing Process Selection

We used CES to determine the best manufacturing process for joining Aluminum alloy components of the spider legs. Because our economic batch size of 1000 is relatively small, we would like to limit our tooling costs, equipment costs, and labor intensity as much as possible. Due to the geometry of the legs, we need a joining process that will produce a product that can withstand shear, bending, torsion, and peeling loads. After inputting these constraints into CES, we were left with the following seven possible processes:

- Brazing
- MIG
- TIG
- Resistance Welding
- Rigid Adhesives
- Soldering
- Ultrasonic Welding

Researching these processes on CES and speaking with Bob Coury, we found that TIG welding is the best process for welding Aluminum. According to CES, TIG welding is commonly used for thin sections and precisely made joints.

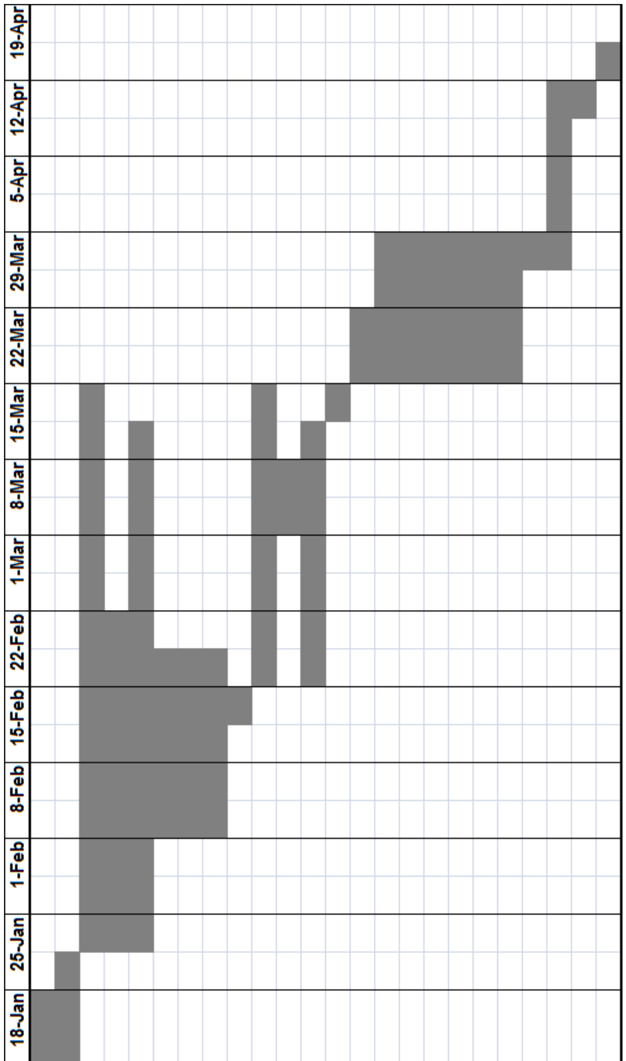
APPENDIX D – QFD DIAGRAM



Weight/Importance	Relative Weight	Column # / Demanded Quality \ Quality Characteristics	1 Inclined Platform	2 Length of Board	3 Weight of device	4 Minimum Height/Back Wheel Height	5 Maximum Height of Front Wheels	6 Width	7 Wheel Degrees of Freedom	8 Wheel Locks	9 Adjustable Wheel Resistance	Competitors: Creepster Crawler	Competitors: Scooter
2	1.9	Head Support	9	3			9	1				1	2
3	2.9	Leg Support	1	9		1	1	9				1	3
11	10.5	Lightweight		3	9		1	1				2	4
12	11.4	Portability/Storage	3	1	3	9	1	3		3		1	4
4	3.8	Mobility		1	9	1	3	3	9	9	3	3	3
13	12.4	Cost	1	1	3		1	1	3		3	1	2
5	4.8	Changing/Variable Skill Level	3	1			3		3		9	1	1
6	5.7	Adaptability to Child Growth	9	9			9	1			1	1	2
9	8.6	Comfort	9	3			3	3				1	2
1	1.0	Safety	3	3	1	3	9	3	3	9	1	3	3
14	13.3	Aesthetics	1	1			1	1				3	2
10	9.5	Ease of Use	1	3	3		3		3	3	1	1	3
7	6.7	Muscle Development	9	1	3		3		9		9	1	2
8	7.6	Cognitive Development	3	1	1		3		3		3	1	2
		Target or Limit Value	10-30 Degrees	Min >18", Max <36"	Less than 12 pounds	Less than 5"	Max <16", Min>6"	6-18"	Adjustable, 0-2	Yes	Yes		
		Raw Score	334	243	270	118	263	151	210	111	200		
		Scaled	1	0.728	0.808	0.353	0.787	0.452	0.329	0.332	0.599		
		Relative Weight	18%	13%	14%	6%	14%	8%	11%	6%	11%		
		Rank	1	4	2	8	3	7	5	9	6		

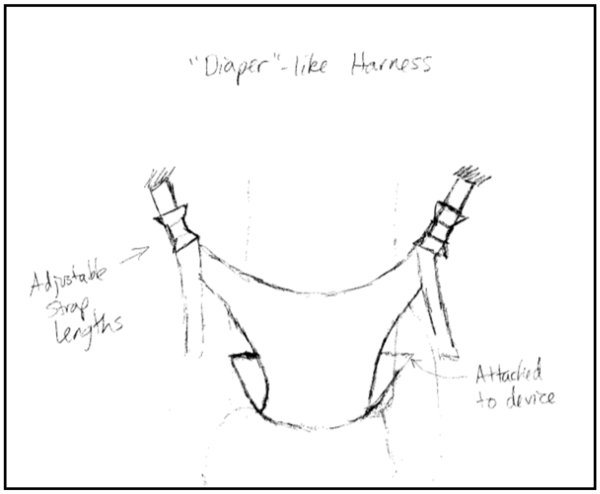
APPENDIX E – GANTT CHART

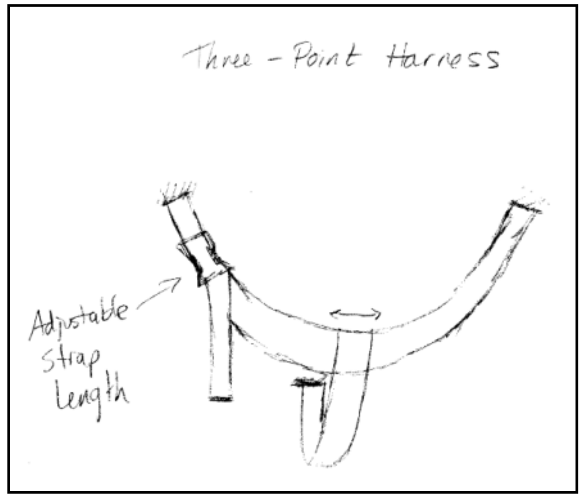
Name	Start Date	End Date
Finalize Customer Demand Qualitie	1/19/10	1/25/10
DR #1 - Engineering Specs	1/19/10	1/26/10
Finalize Wheel Inclining Method	1/28/10	3/18/10
Meet Lincoln & Parents	1/28/10	2/26/10
Finalize CAD Design	1/28/10	3/18/10
Design Head Rest	2/9/10	2/23/10
Design Leg Support	2/9/10	2/23/10
Design Adjustable Length Insert	2/9/10	2/23/10
DR #2 - Alpha Design	2/18/10	2/18/10
Safety Report	2/19/10	3/18/10
Welding Training	3/9/10	3/12/10
Finalize Attributes of Design	2/22/10	3/18/10
DR #3 - Final Design	3/18/10	3/18/10
Order Wheels - Rifton & Casters	3/19/10	3/26/10
Assemble Frame	3/19/10	4/1/10
Create Cushion for Platform	3/19/10	4/1/10
Create Adjustable Length Insert	3/19/10	4/1/10
Create Back Wheel Axle System	3/19/10	4/1/10
Create Head Support System	3/19/10	4/1/10
Create Inclining Wheel System	3/19/10	4/1/10
DR #4 - Alpha Prototype	4/1/10	4/1/10
Finalize Details of Prototype	4/2/10	4/15/10
Design Expo	4/15/10	4/15/10
Final Report Due	4/20/10	4/20/10

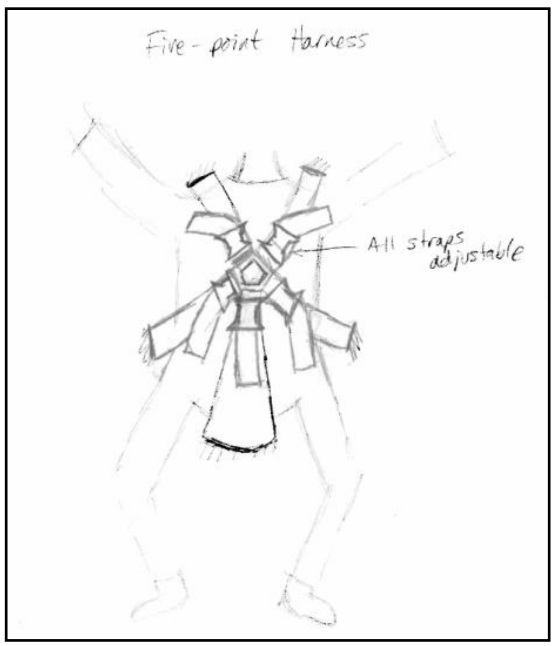


APPENDIX F – COMPONENT CONCEPT DRAWINGS

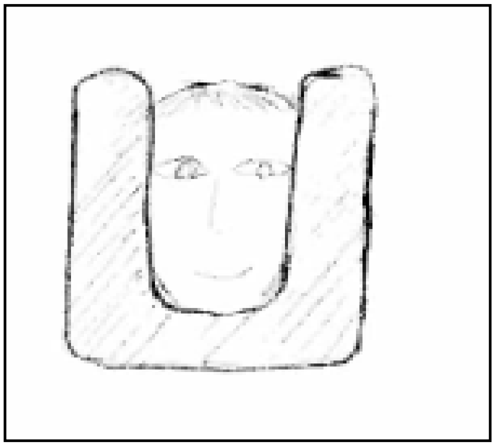
HARNESSES

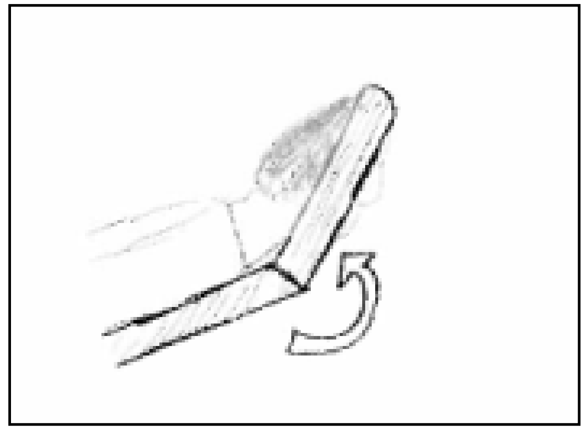


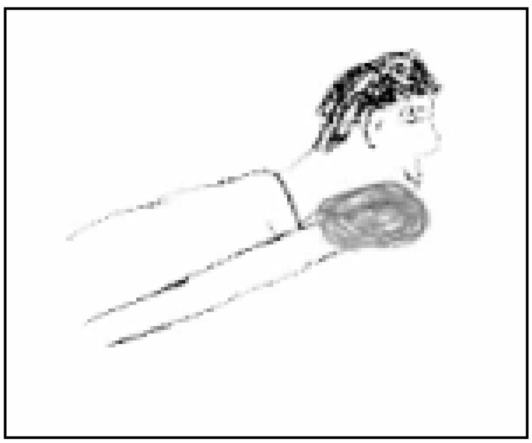


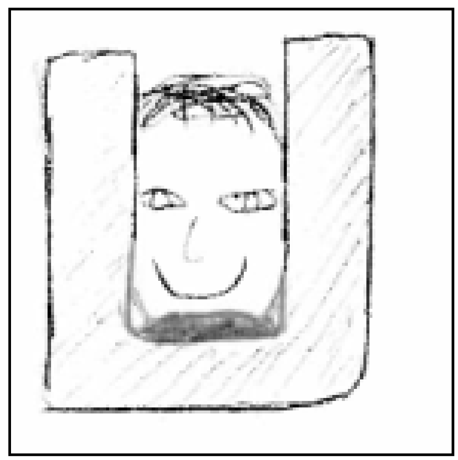


HEAD RESTS

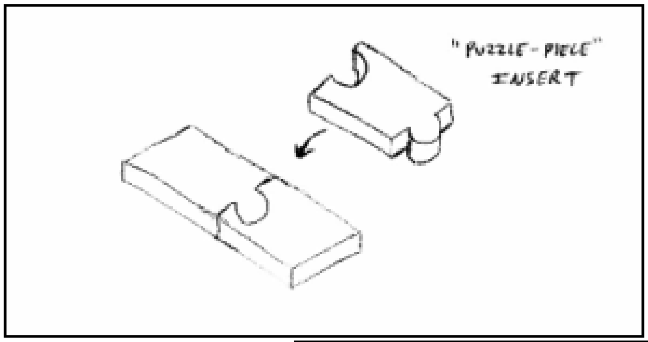


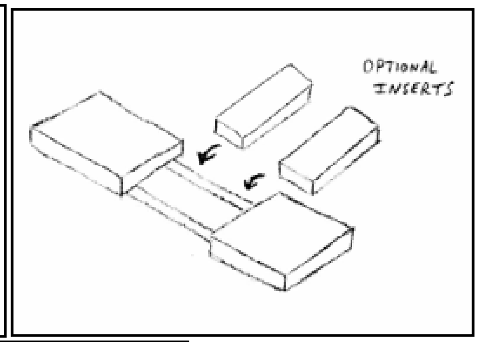


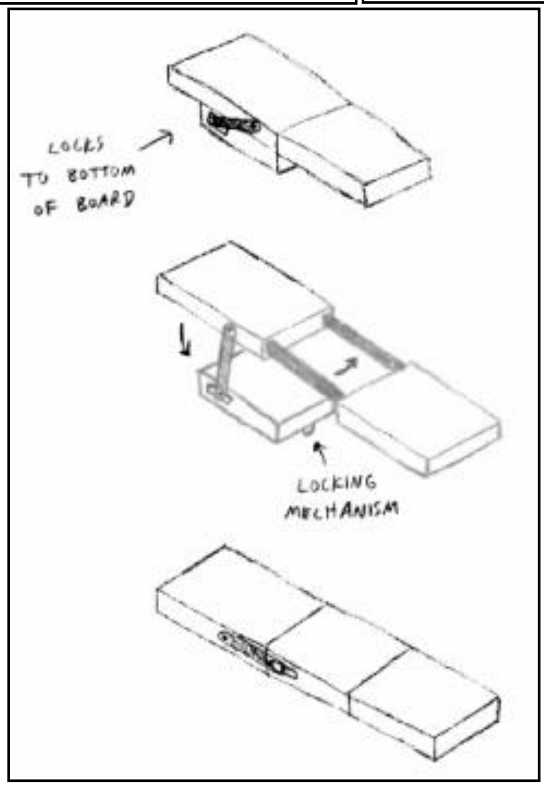




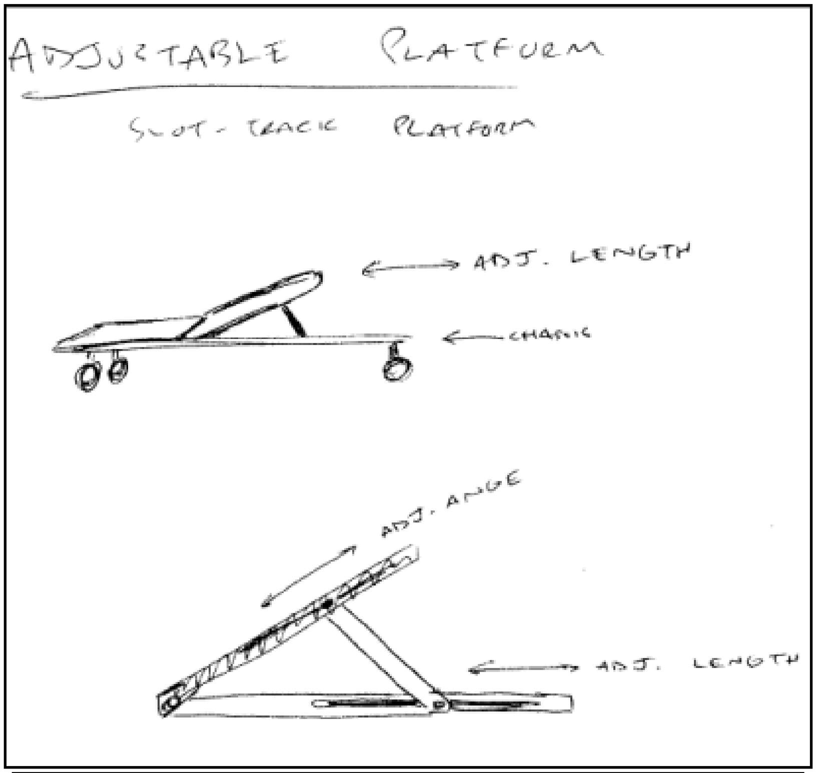
LENGTH ADJUSTABILITY

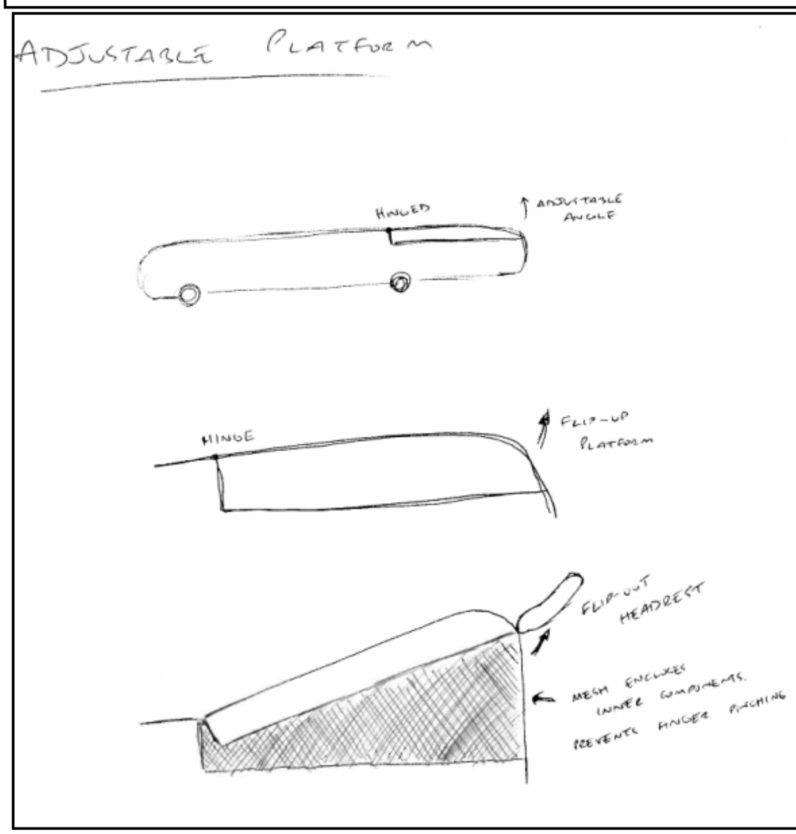




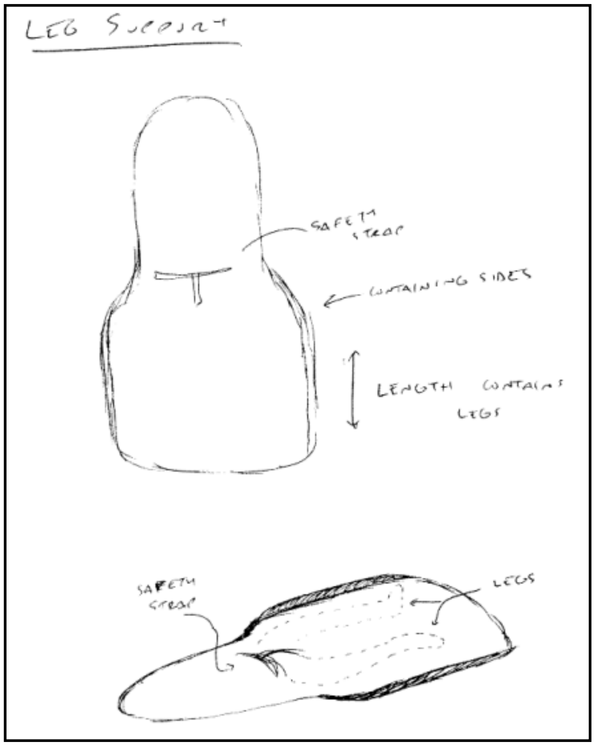


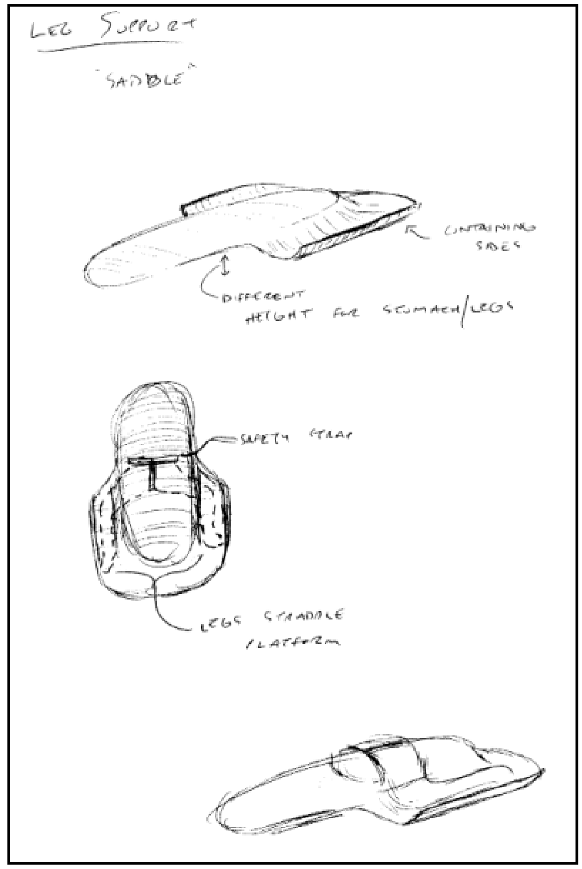
INCLINED PLATFORMS



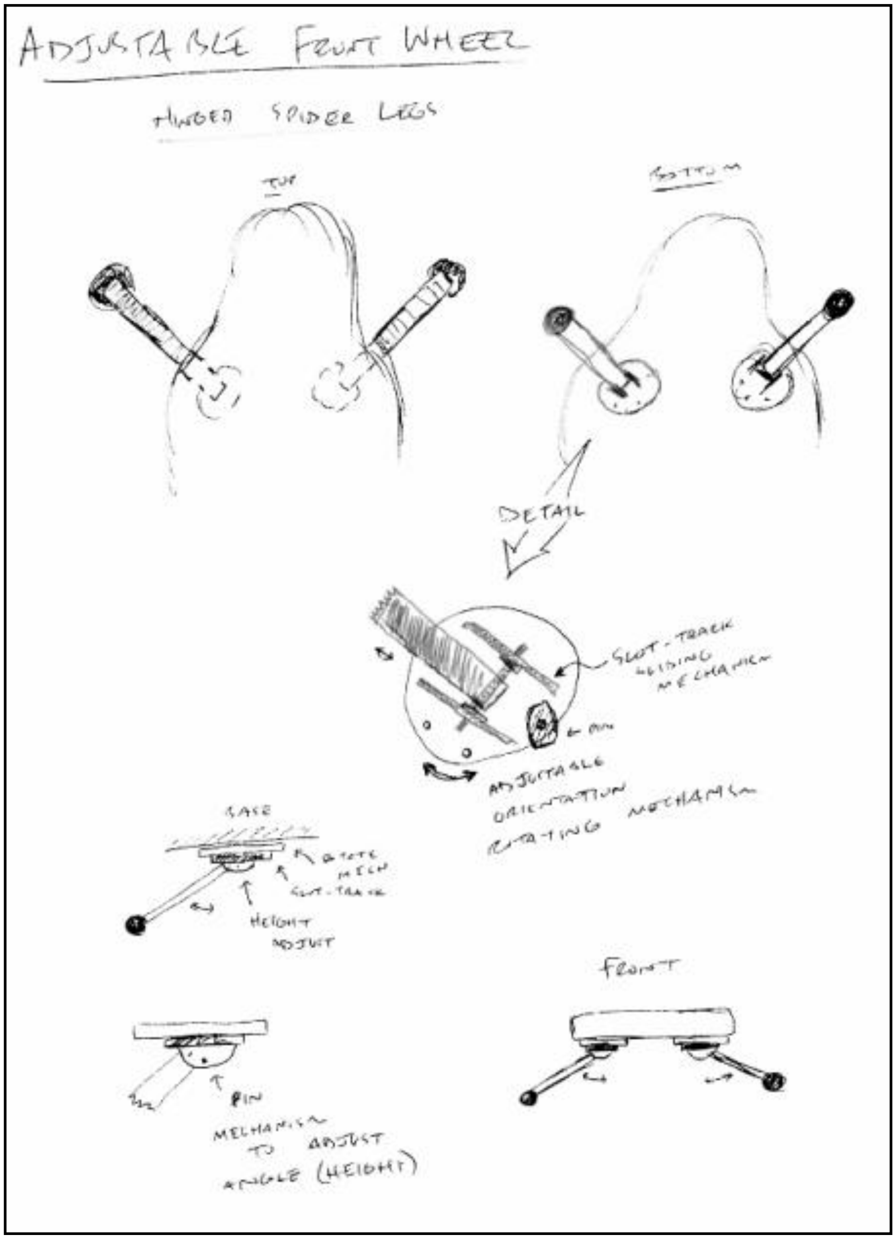


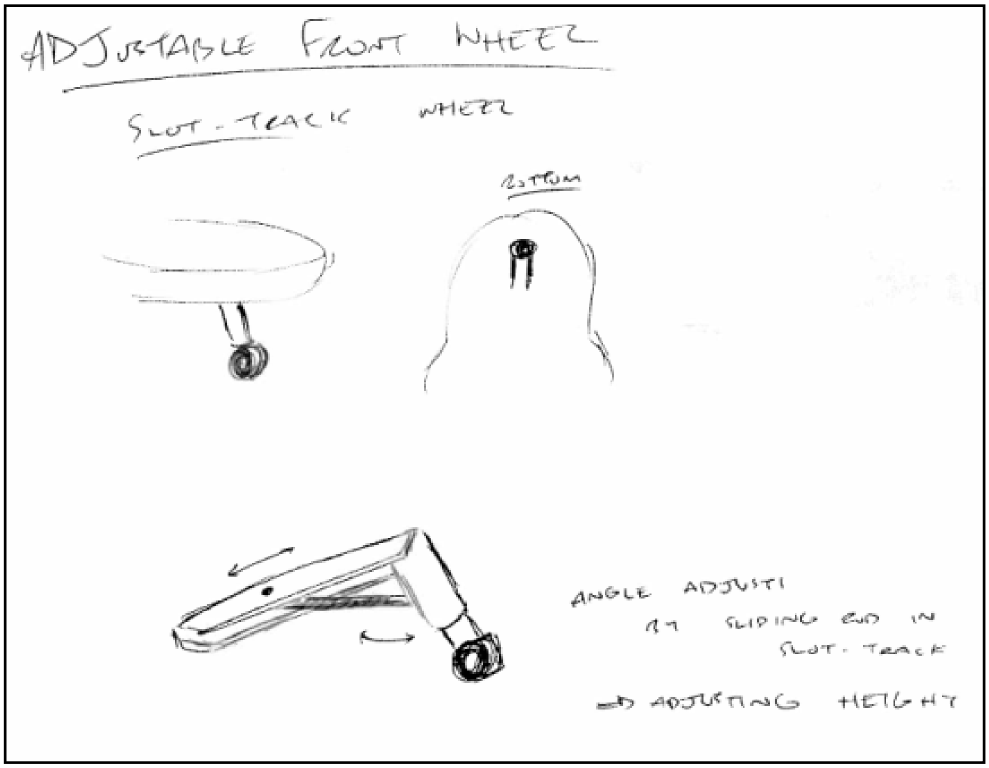
LEG SUPPORT

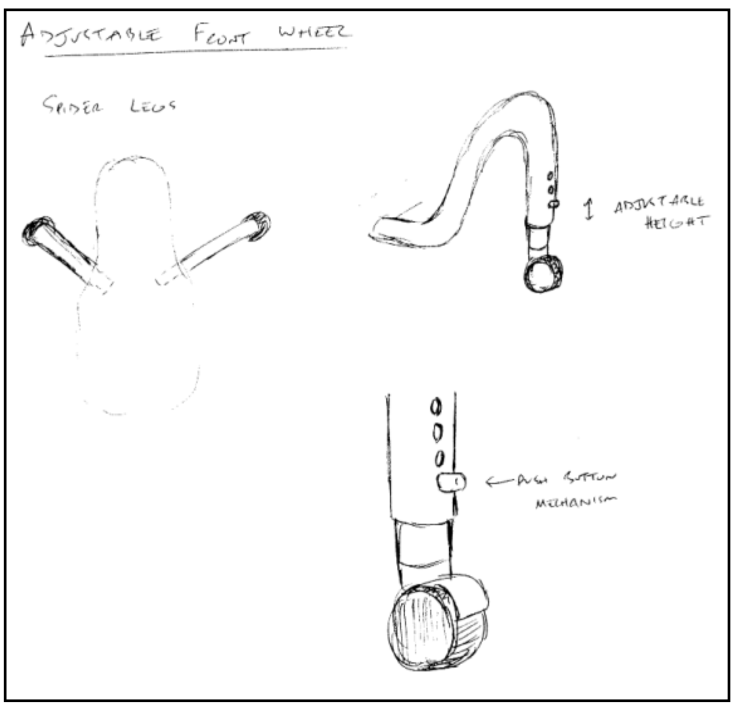

LEG SUPPORT
SAFETY STRAP
CONTAINING SIDES
LENGTH CONTAINS LEGS
SAFETY STRAP
LEGS

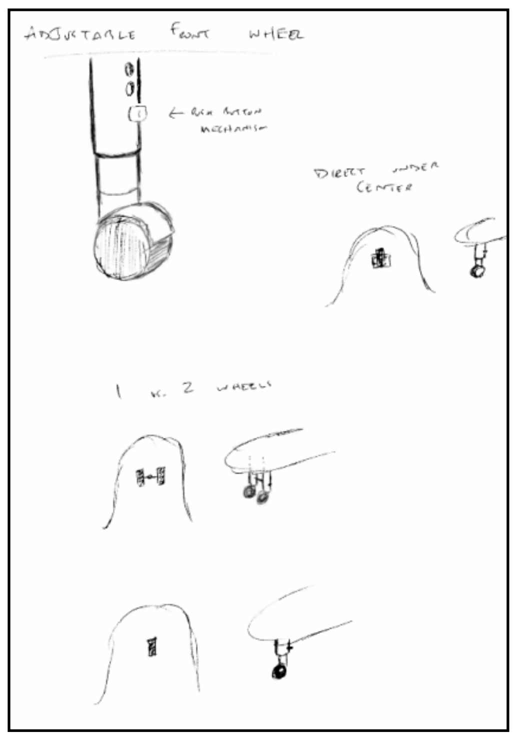

LEG SUPPORT
"SADDLE"
CONTAINING SIDES
DIFFERENT HEIGHT FOR STOMACH/LEGS
SAFETY STRAP
LEGS STRADDLE PLATFORM

FRONT WHEELS

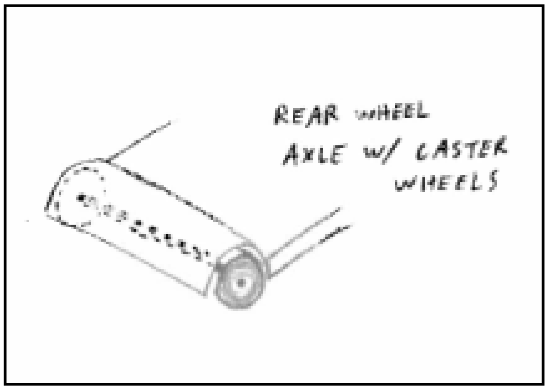


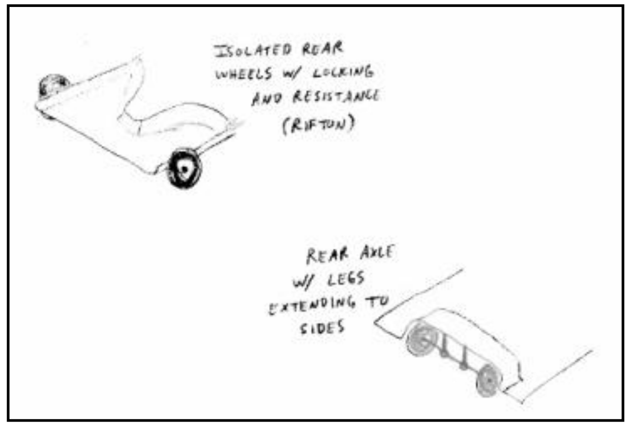

ADJUSTABLE FRONT WHEEL
SLOT-TRACK WHEEL
BOTTOM
ANGLE ADJUST!
BY SLIDING END IN
SLOT-TRACK
⇒ ADJUSTING HEIGHT


ADJUSTABLE FRONT WHEEL
SPIDER LEGS
ADJUSTABLE
HEIGHT
PUSH BUTTON
MECHANISM


ADJUSTABLE FRONT WHEEL
DIRECT UNDER
CENTER
1 v. 2 WHEELS

REAR WHEELS


REAR WHEEL
AXLE W/ CASTER
WHEELS


ISOLATED REAR
WHEELS W/ LOCKING
AND RESISTANCE
(RIFTON)
REAR AXLE
W/ LEGS
EXTENDING TO
SIDES

APPENDIX G – COMPONENT CONCEPT DESCRIPTIONS

Safety

As stated previously, safety is our number one concern in this device's design. In the following sections, we will discuss the different features that we have generated to make our design safe for Lincoln's use.

With Lincoln's limited movement, it would be best to keep his lower half secure on the device, only allowing movement for his torso and hands. Thus, we will add a harness to our design to secure him on the device's platform in order to keep his lower half from harm. Having a harness will also be beneficial in preventing Lincoln from sliding down the inclined device.

One of our harness concepts, the three-point harness, utilizes a very simple design which attaches to the device in three places. There will be two straps: one that goes around Lincoln's waist and another which will keep him from falling down the platform when it is inclined. The latter strap will be able to slide across the first strap, while the first one has a plastic latch where it attaches to the device's bottom platform and has adjustable length.

Another harness design is similar to the three-point harness, but has five places in which it attaches to the device's platform. Each strap will connect via a plastic latch to a center piece with an adjustable strap for each. There will be an attachment for each strap to the platform in each of the following spots: between Lincoln's head and both arms, between both arms and legs, and between his legs for maximum support.

Our last harness design is a padded wide support which will cover Lincoln's entire behind. There will be three attachments to the device: one at the bottom which will not be adjustable and one on either side of Lincoln with a plastic latch and an adjustable strap for each side.

Design safety can also be incorporated into the wheels. Lincoln could be very unsafe or unstable in his device during placement or while unsupervised. Therefore, we think that wheel locks should be added to our design to ensure the safety and security of Lincoln in his device and protect him from his surroundings.

With Lincoln's arms being his main mode of transportation while using our device, his fingers could get caught in the wheels while he is moving. We have decided to place covers on all wheels used in this device's design to ensure the safety of Lincoln and the other children who will play near him with his newfound freedom.

Head/Neck Support

Supporting the head is one of the most important functions that our design must have. Our plan is to develop some type of headrest that will support the head without limiting visibility. We did some lateral thinking and came up with one possibility similar to a massage chair headrest. We could make this removable or retractable if the user no longer needed head support. We considered making it inclinable to maximize support and making the face width adjustable to adapt to the user's face. Another idea we generated was a pillow-like pad for Lincoln to rest his chin on. In combining our first two ideas, we came up with a hybrid concept that was a massage chair style headrest with additional padding for the chin.

Leg Support

Our design criteria specify that Lincoln's legs must be adequately supported to avoid accidental injury from dragging on the floor. Our team generated several concepts that attempt to address this issue and improve the safety and ease of use of our device. The first proposed method is a long flat region of the platform with containing edges, giving plenty of room for Lincoln's legs to lay flat behind him. Another design is shaped similarly to a saddle, with a raised portion for the mid-section to rest, but a receded area on Lincoln's sides and behind him, with containing edges to provide optimal safety, comfort and protection. Another option discussed is the possibility of this leg-containing section to extend, adapting to Lincoln's growth.

Mobility

The design requirement of mobility presents specific challenges to the wheels used in our design. We need to consider both the front and rear sets of wheels, determining the type of wheels, their location, and their specific design features. For the rear wheels, we considered stability, safety, and mobility and proposed several concepts with different wheel types, wheel bases, and features that protect Lincoln from the wheels. Rifton brand wheels offer adjustable degrees of freedom, variable resistance, and a locking safety feature. A wide wheel base would provide greater stability to the device. Incorporating an axle on the rear wheels will allow for easier platform incline and increased mobility.

Adjustable Incline

To achieve the proper head, neck and back support for Lincoln when using the crawler, the platform of the device must have an adjustable incline, but must also allow him to reach the ground to crawl. Several methods were proposed for achieving this incline, while retaining the flexibility to adapt to Lincoln's growth and skill. Initially, we considered adjusting a portion of the platform independently of the base and wheels of the crawler. The options for this method involved a separate portion of the device that could adjust its angle relative to the base either with a sliding slot-track mechanism to change both length and angle, or a simpler adjustable incline angle with safety mesh to protect against pinched fingers. Eventually we determined that for safety and manufacturing feasibility, the device should incline at the front wheels.

The first consideration was whether the wheels would be directly underneath the platform or spread out to the sides. A design that featured the wheels underneath would adjust the front height of the platform either with a push-button mechanism to extend the length of the wheel connecting shaft, or with a slot track that would adjust the angle of the wheel shaft relative to the platform, which would also fold for storage. We ultimately decided that a wider wheel base would offer more stability for the crawler, and proposed several methods of adjusting the incline from this position. One execution, dubbed the "spider-legs", featured legs that curved up from the base, but returned to the ground giving a long, straight portion to adjust the height using a push-button mechanism. Another method, the hinge and track system, also had the legs reaching out to the sides, but instead of adjusting their length to adjust the incline, this hinged-leg design adjusts the angle of the legs to adjust the height.

Adaptability

Another major design requirement is adaptability for both child growth and child skill/development. A growing child is going to demand variability with size in a crawling device. As a child grows in height, the length needs to be extendable. Having the board attached in two pieces will allow them to slide apart, and the parent can insert additional length pieces of board. A second option would be to have the insert attached to the device at all times, being stowed underneath when not in use. By means of a rotating arm, the insert could swing up into place when additional length is desired. Also, as Lincoln becomes stronger and develops muscle strength, mobility should become easier for him. In order for his strength to continue to improve, the wheels could be equipped with resistance options that will make it tougher to pull the crawler.

APPENDIX H – MAIN CONCEPT DESCRIPTIONS

Concept A

This concept focuses on the safety, mobility and ease of use of the crawler. The shape is wide through the rear, but thinner near the child's chest so that the arms can reach the floor and easily crawl or access toys. A removable padded head rest supports the child's face and neck, and has a variable width to accommodate different face sizes and shapes. For comfort, the rear portion is receded to cradle the child's legs. Also, a three-point buckle strap secures the child for safety and comfort. The rear wheels are protected by covering wheel wells for safety. To accommodate the child's growth, an insertable section extends the length of the supporting platform. To adjust the incline of the platform, a unique "spider-leg" wheel system is used. The caster wheels are attached to the base of the platform with a curved rod that simultaneously allows for stability, low height, but greater height adjustability. Disadvantages of this concept are its heavy weight, limited leg support, and "spider leg" manufacturing difficulty.

Concept B

Concept B is primarily concerned with comfort and adaptability of the crawler. The design features a "saddle"-type seat that cradles the child's waist but allows the legs to hang down on either side. The child is head in place with a three-point safety strap and a positioning hump that prevents the child from sliding off the back. This design is extendable both in platform length with a removable insert and leg containment length with extendable supports, accommodating Lincoln as he continues to grow. The rear wheels are caster wheels joined by an axle and protected by wheel wells for safety. The front Rifton wheels for this design are placed directly underneath the platform and offer adjustable resistance to challenge Lincoln as he gains strength. To support Lincoln's head and neck a padded support is used. This support is removable, with adjustable width and inclines for optimal comfort. The platform also inclines, through use of variable height shafts for the front wheels. The main weakness of this design is in the front wheels. They may not be able to provide adequate stability and space would be an issue in fitting them underneath the device.

Concept C

This concept was generated with safety and front wheel incline ability mainly featured. The overall shape is tapered in the front, allowing for maximum arm movement. This was used intending to make the crawling motion easier for Lincoln. A "saddle" design is used on the back portion to provide support for his legs, and a three-point adjustable safety strap is utilized to hold Lincoln in place on the crawler device. The rear wheels are housed on an axle and contained within a protective cover. They also feature locks and resistance to adapt to muscle growth. Another way to adapt to child growth is the length adjustability. The device will come with inserts that can be placed onto the board, making it longer. In order to keep the device on an incline to aid Lincoln in keeping his head up, a front wheel "fold-away" system will be used. This front wheel has two degrees of freedom, and its height can be adjusted by changing the track position of the connecting bar. Adjusting the bar to the far end of the track allows for the front wheel to fold all the way under the crawler, which makes for convenient storage capabilities. Lincoln's head will be supported with a head and chin support rest, which can be removed if desired. One disadvantage of this device is that the casing over the rear wheels will not allow for easy resistance or locking adjustments. The middle front wheel may result in an unstable device and could interfere with Lincoln's crawling motion.

Concept D

This concept has a rounded saddle-like body for Lincoln to center his body on. His legs will be in two grooved supports on either side of the device's body. These supports will be slightly lower than the rounded body to give a better crawling-like position and will have a curved shape to them. Lincoln's head will be supported with a masseuse-type head rest which will support him at his cheek bones and the two posts which make up the rest will be adjustable in width. In order to incline Lincoln to better support his head, the front top half of the rounded body will detach and hinge to create an inclined platform for Lincoln to lie upon. For safety reasons, a mesh barrier will be attached between the moveable platform and the bottom half of the device. There would also be a three point harness on the device to hold Lincoln onto it. From this moving platform, the head rest will incline upwards to better support his head. It would not be detachable. However, the inclined platform and head rest can return back to their initial positions for storage. It also has an adjustable length by having the front and back half of the device part where two inserts can be placed to make the device longer. The back wheels would be Rifton wheels which would have resistance and wheel locks. The front wheels would be smaller wheels, such as casters. There would also be some child-friendly attributes to the design, which would include a fin on the back of the device and shark teeth on the mesh barrier. Disadvantages of this concept are that it is heavy and the incline mechanism would be difficult to manufacture.

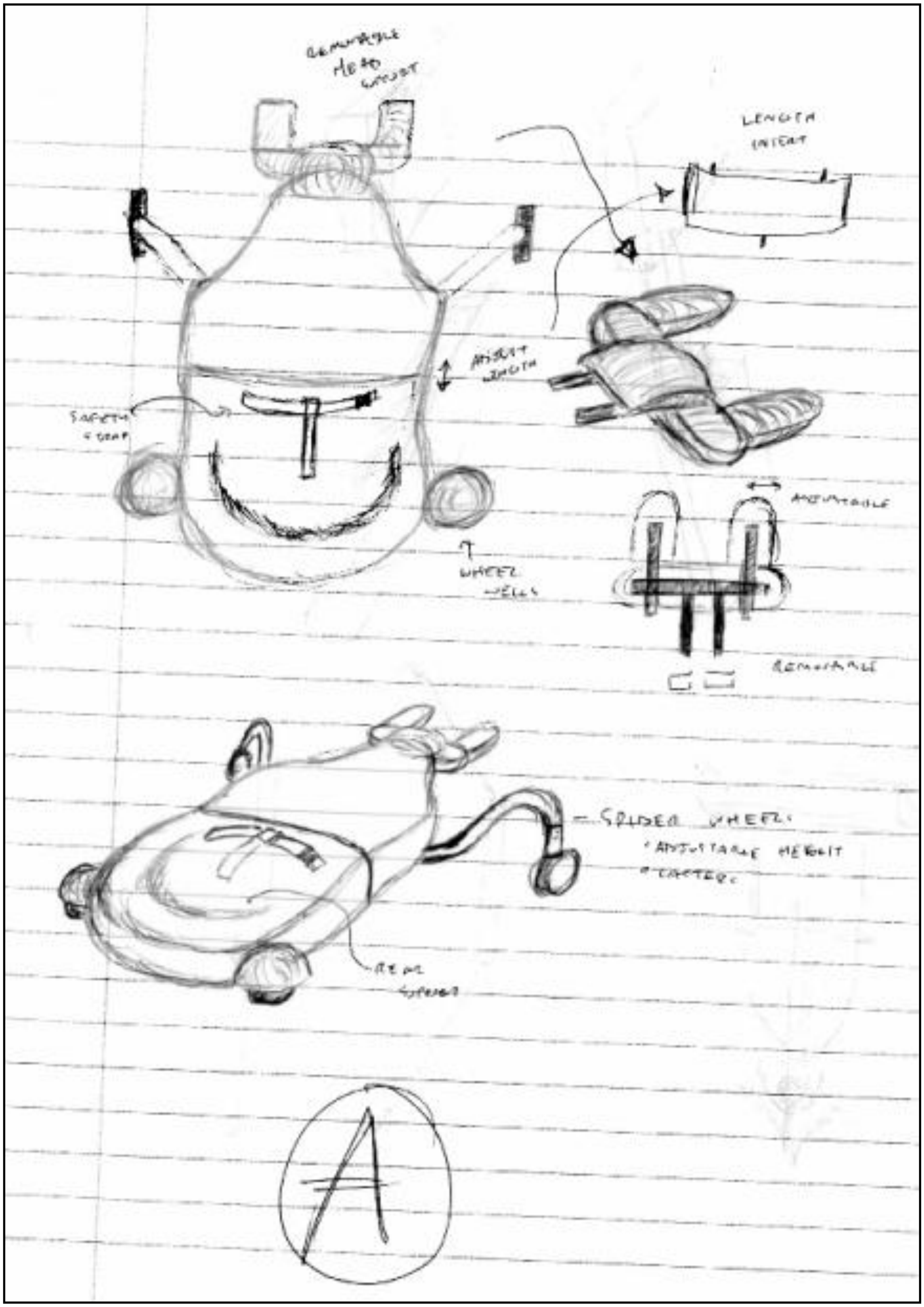
Concept E

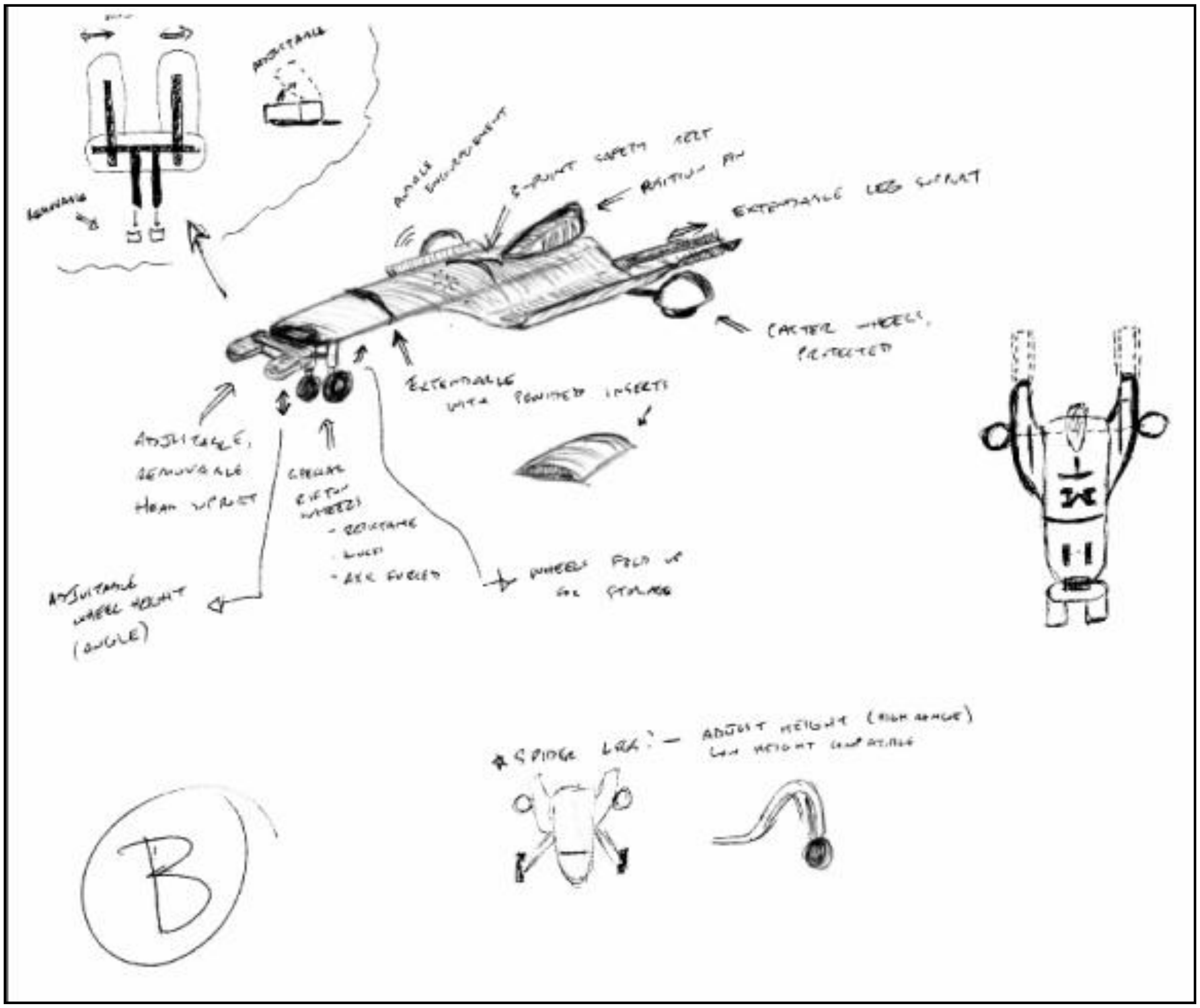
This concept has either a rounded saddle-like body or a flat body. It has a variable width with the device being thinner towards the headrest and it widens after the point in which Lincoln's waist would be lying on the device. There would be a diaper-like harness to keep Lincoln safe along with a seat type hump behind him. His legs would be supported to the side of his body a couple inches lower than the device's body. The head rest would be similar to a head rest one would find in a car with a padded U-shape along with a pillow like material at the bottom of the U. It would attach with two metal prongs, that would be covered for safety, which would be inserted into a device the helps the headrest rotate to different angles for comfort. The back wheels would be on one axle and would come from Rifton with variable resistance and wheel locks. Meanwhile, the front wheels would be on a special rod where it would have three smaller wheels, like casters, that would rotate on a hinge to ensure that they will be flat to the ground. The rod would also be hinged at a point near the bottom of the device to incline the entire platform at different predetermined angles. There would also be a slot in which a threaded screw would allow these rods to come out to the side of the device at different amounts to vary the balance Lincoln will need to use the device. Finally, the concept will also have an adjustable length with two inserts that would be placed at the thinner width section to make the device longer. One disadvantage of this device is that the casing over the rear wheels will not allow for easy resistance or locking adjustments. The incline adjustment hinge would be more difficult to manufacture than other incline options.

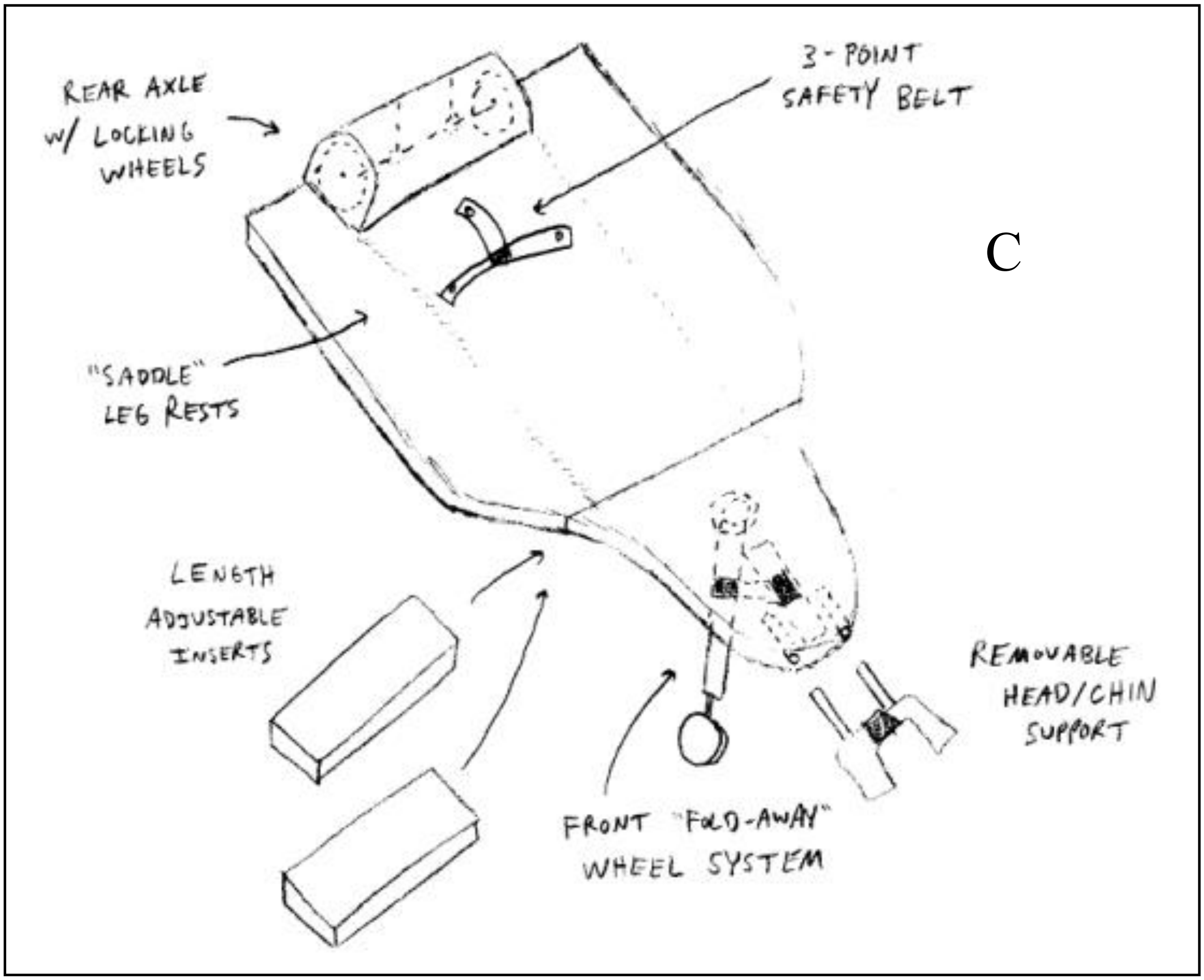
Concept F

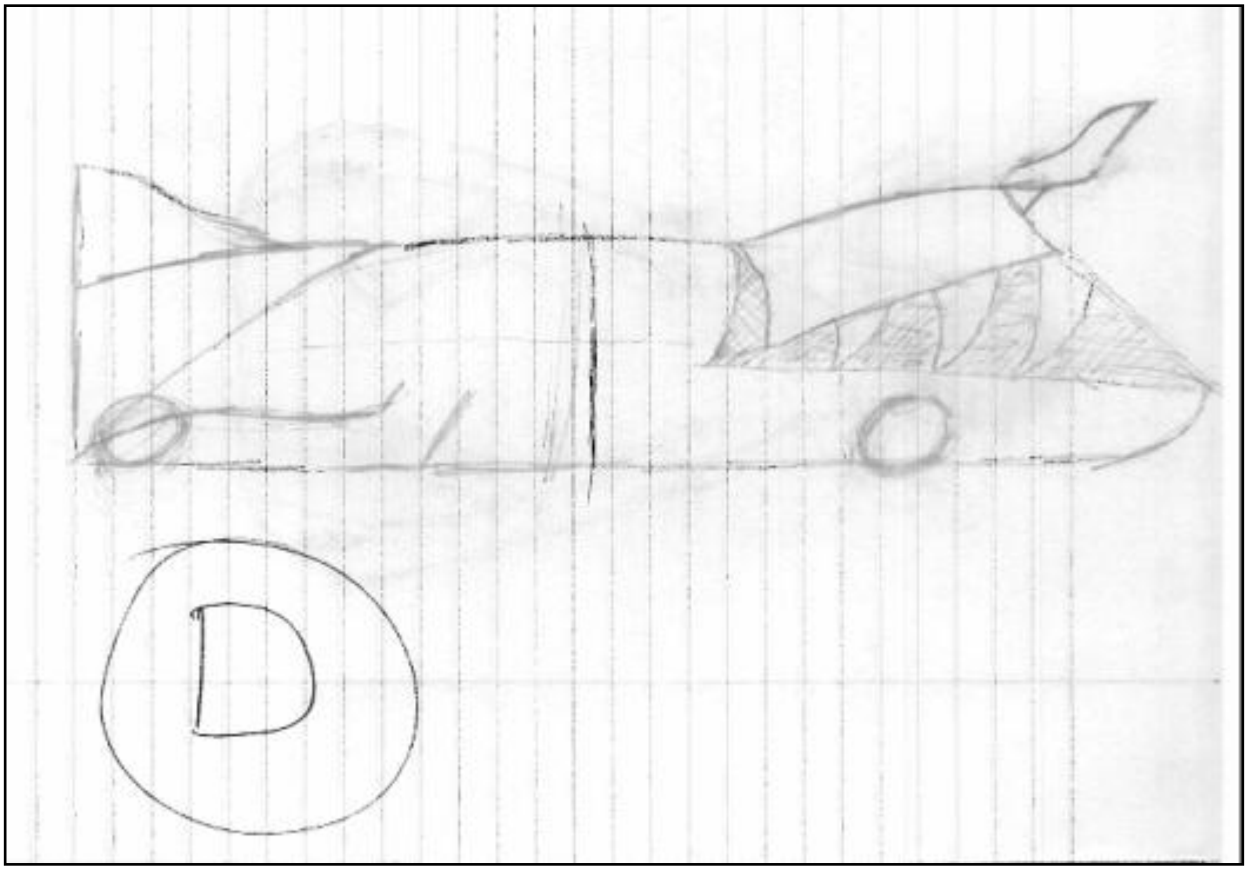
This concept addresses safety with its 3 point harness, wheel locks, and covers on the back wheels. The front wheels will have two degrees of freedom and will lie between Lincoln's arms. A telescoping mechanism will attach the front wheels to the platform, allowing for incline adjustability. The rear wheels will be on an axle to account for the inclining feature. The incline will begin at Lincoln's knees, so that only part of his body (from his knees to his head) will be inclined. This allows for a larger incline angle than if his whole body were to be inclined, while still being short enough in front so that Lincoln's hands can reach the ground. For head support, a pillow like cushion will be implemented. Weaknesses of this concept are the concern of the front wheels being too close to coming in contact with Lincoln's hands, and the pillow style headrest not being as adequate as the massage chair style one.

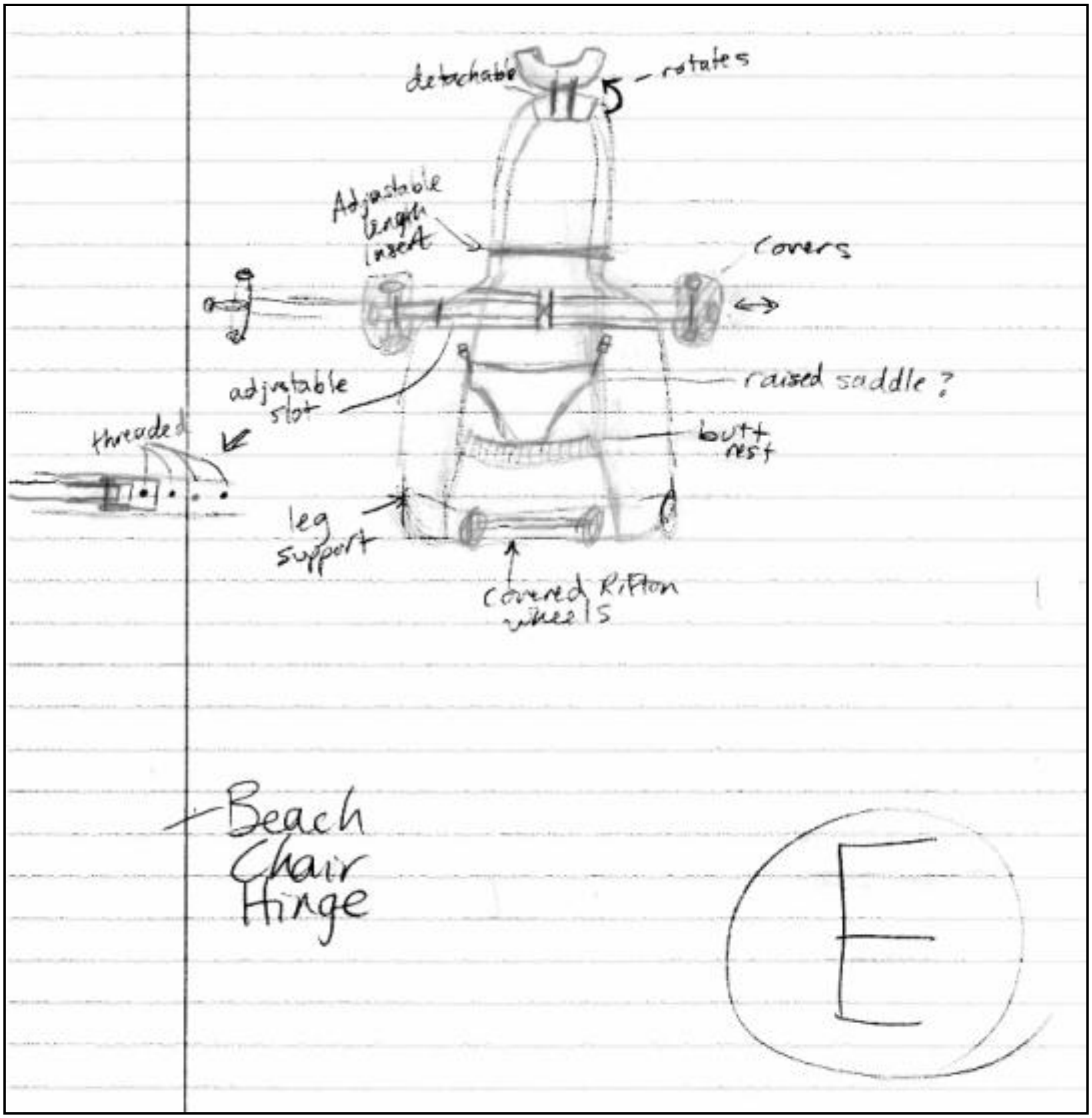
APPENDIX I – CONCEPT DESIGNS

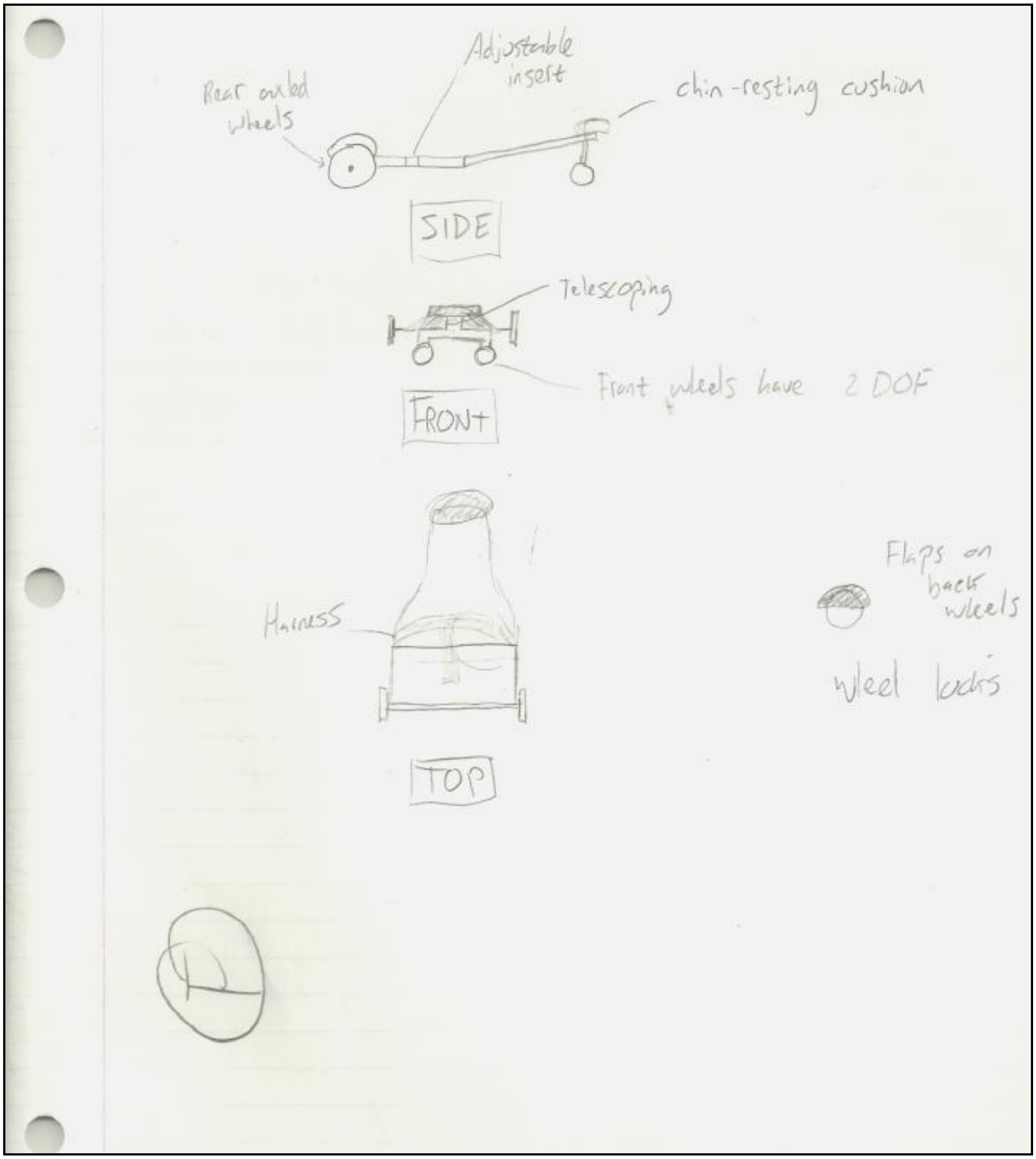


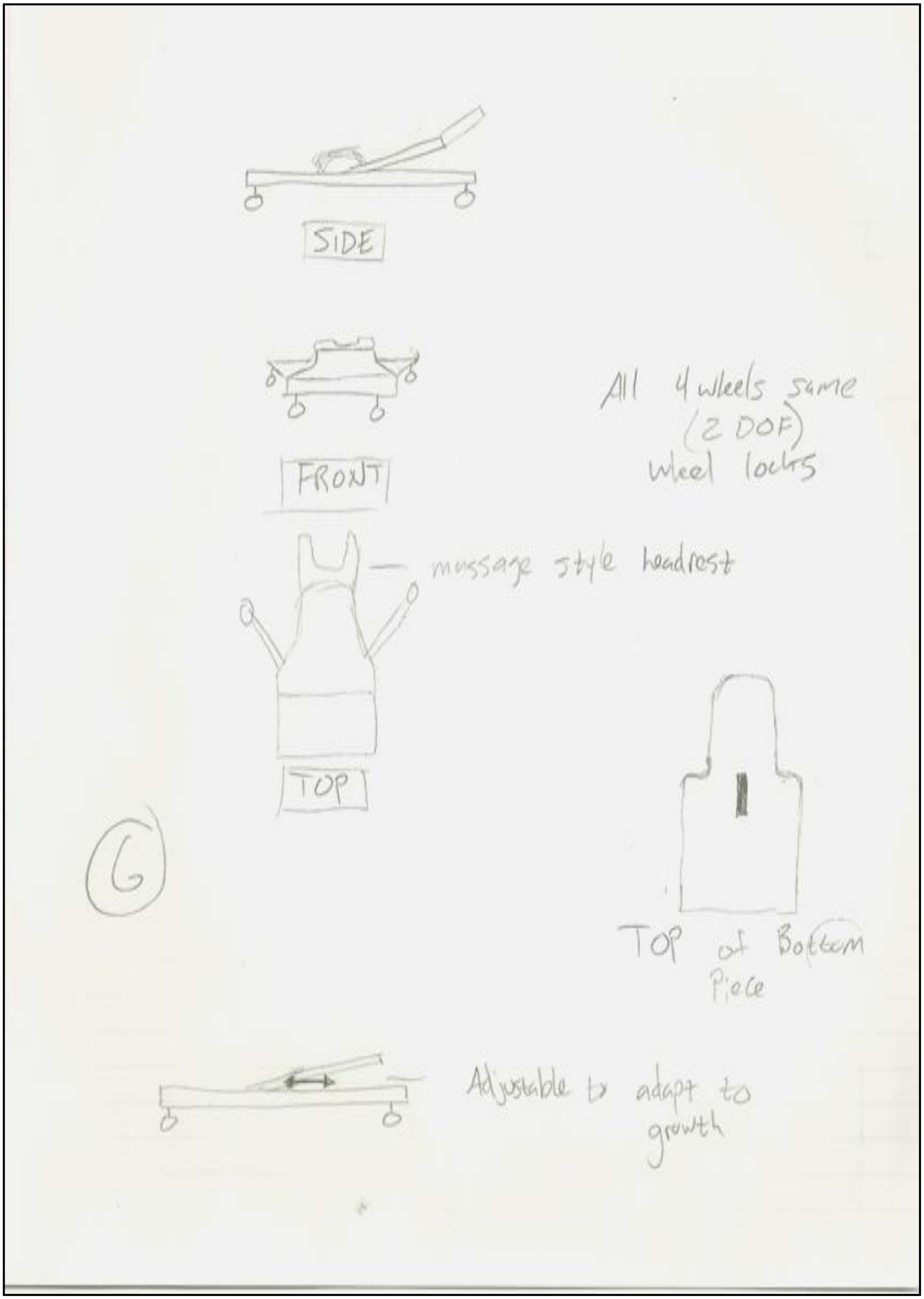

EXTENDABLE LEG SUPPORT
CASTER WHEELS, PROTECTED
EXTENDABLE WITH PADDED INSERTS
ADJUSTABLE, REMOVABLE HEAD SUPPORT
WHEELS FOLD UP FOR STORAGE
ADJUSTABLE WHEEL HEIGHT (ANGLE)
B


REAR AXLE
W/ LOCKING
WHEELS
3-POINT
SAFETY BELT
C
"SADDLE"
LEG RESTS
LENGTH
ADJUSTABLE
INSERTS
REMOVABLE
HEAD/CHIN
SUPPORT
FRONT "FOLD-AWAY"
WHEEL SYSTEM


D


detachable
rotates
Adjustable length insert
covers
adjustable slot
raised saddle ?
threaded
butt rest
leg support
covered Rifton wheels
Beach Chair Hinge
E

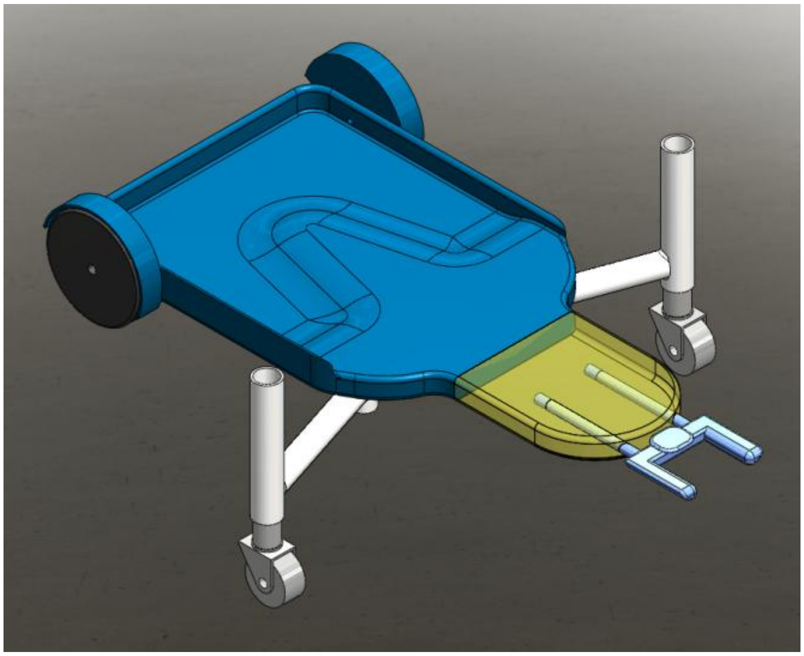

Adjustable insert
Rear axled wheels
chin-resting cushion
SIDE
Telescoping
Front wheels have 2 DOF
FRONT
Harness
Flaps on back wheels
wheel locks
TOP

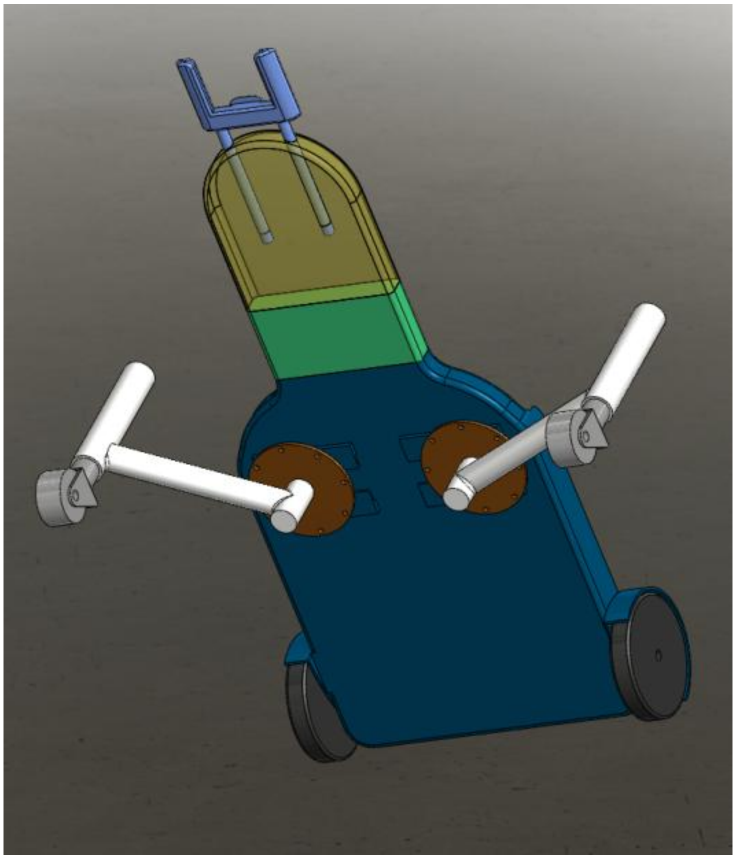


SIDE
FRONT
All 4 wheels same
(2 DOF)
wheel locks
massage style headrest
TOP
G
TOP of Bottom
Piece
Adjustable to adapt to
growth

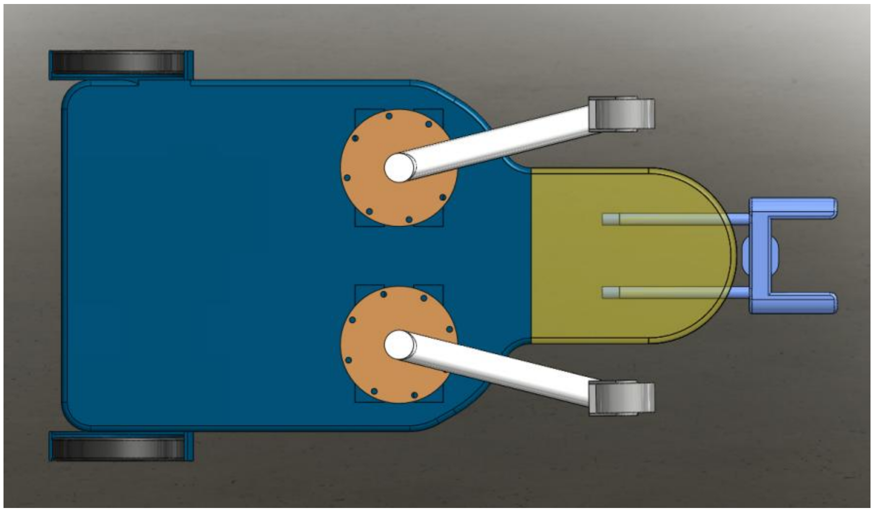
APPENDIX J – ALPHA DESIGN CAD DRAWINGS

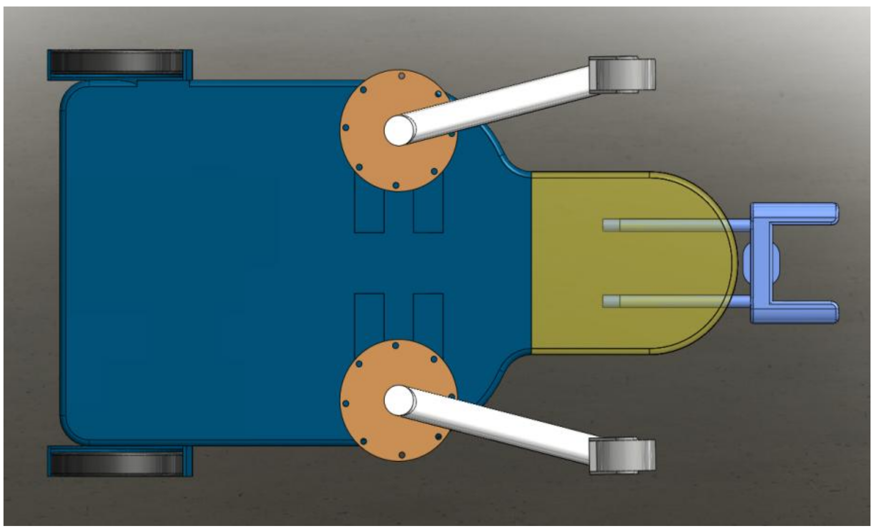
Isometric Views



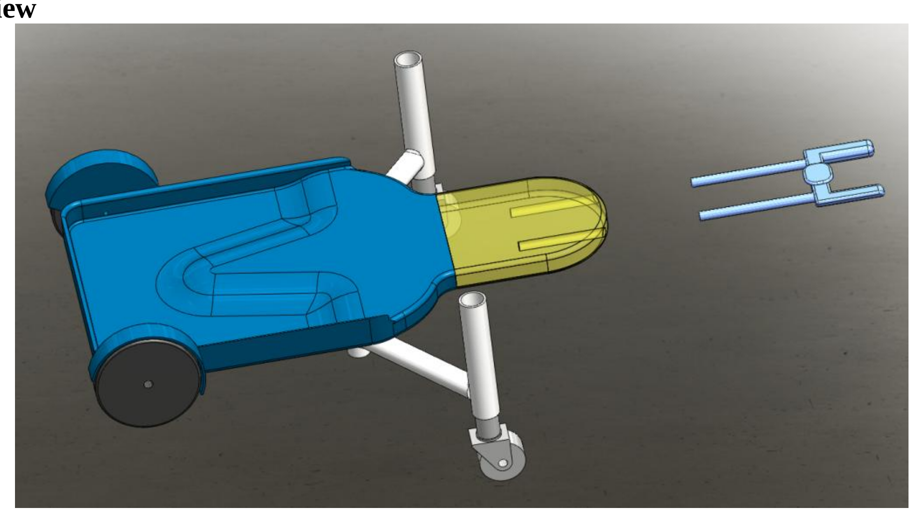


Wheel Views

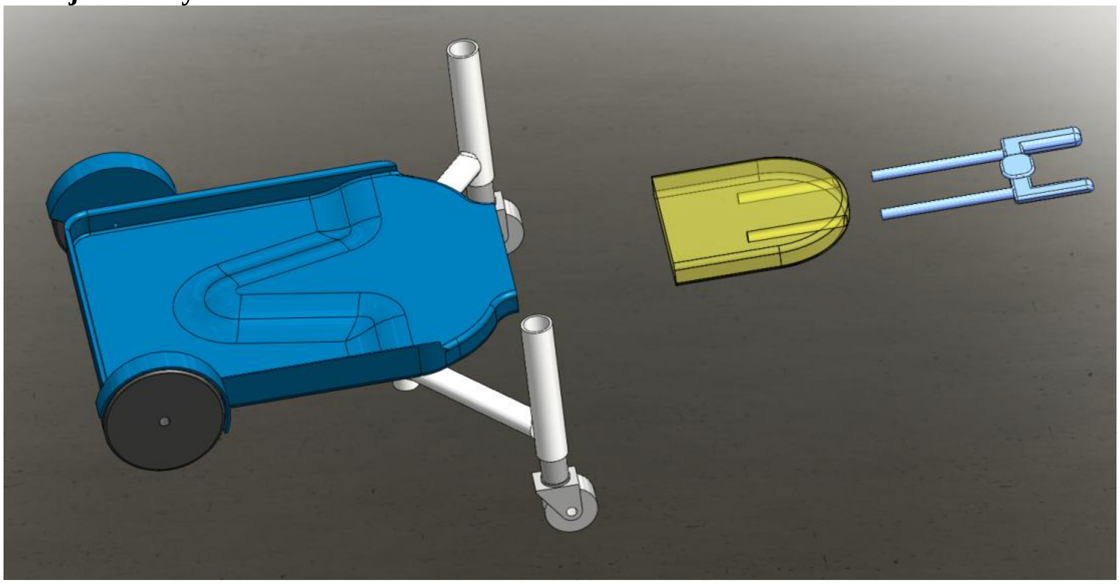


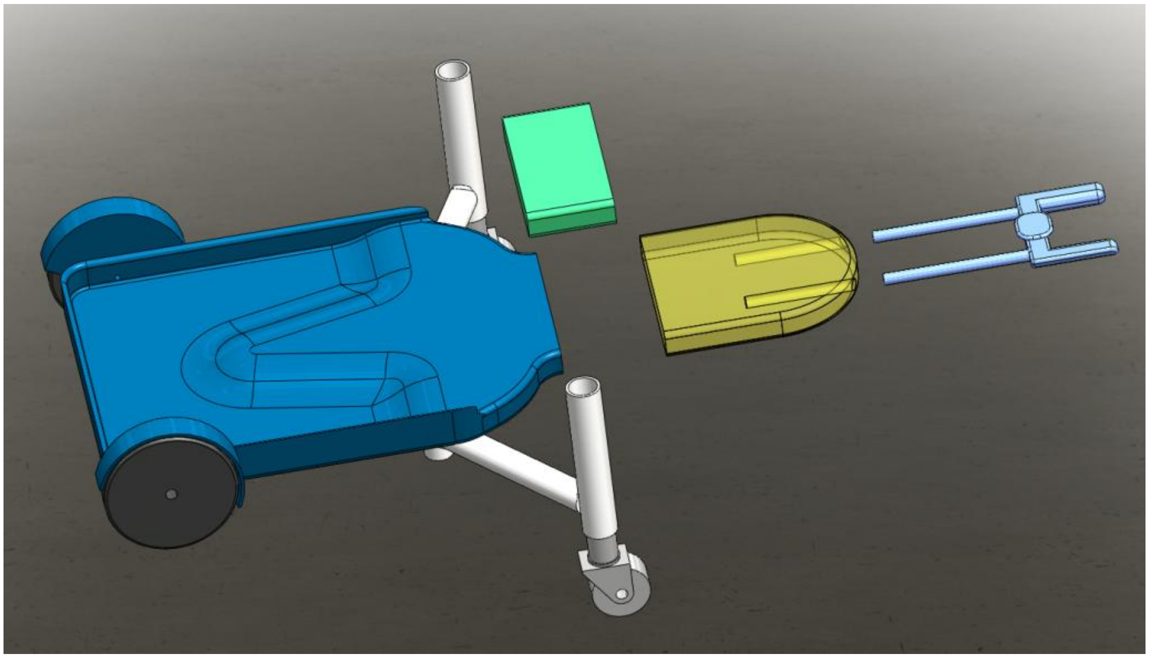


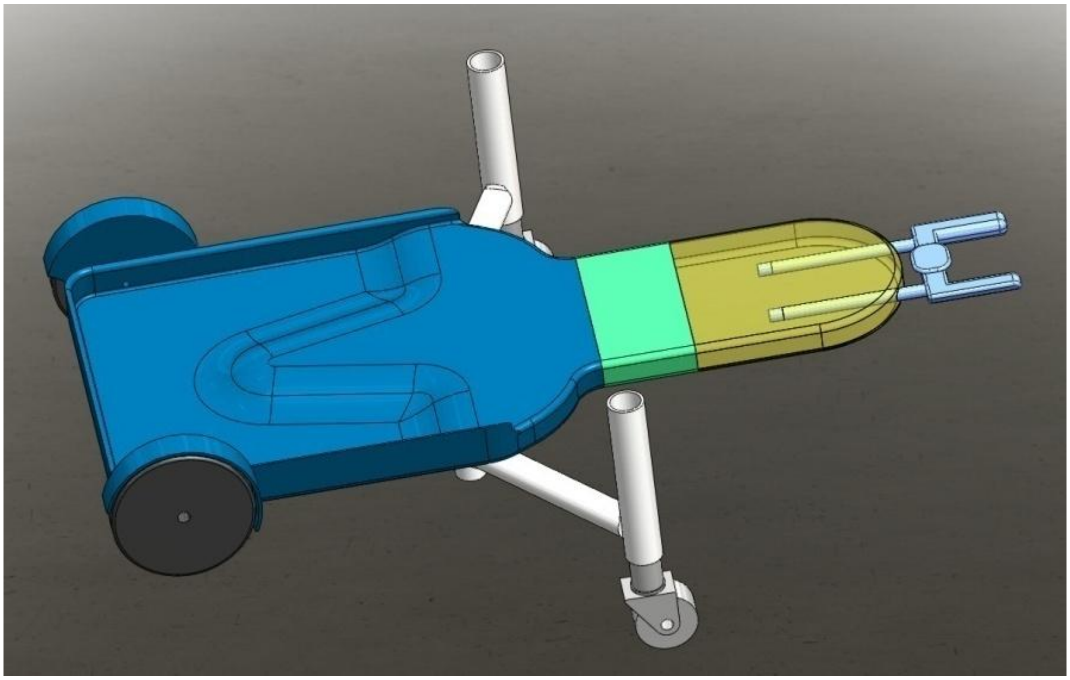
Head Rest View

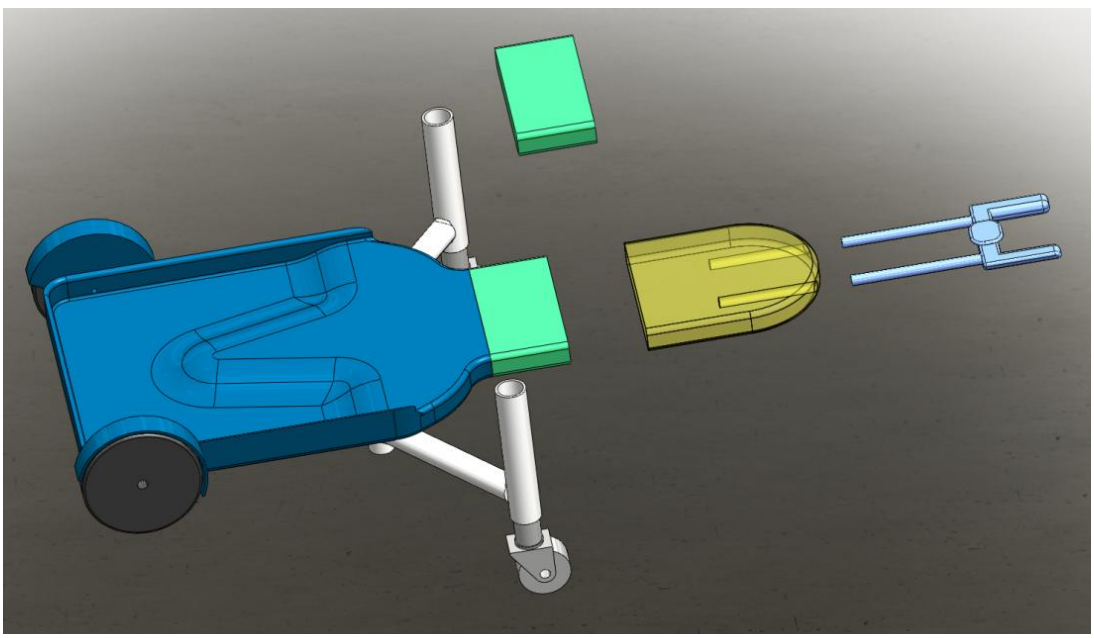


Length Adjustability Views

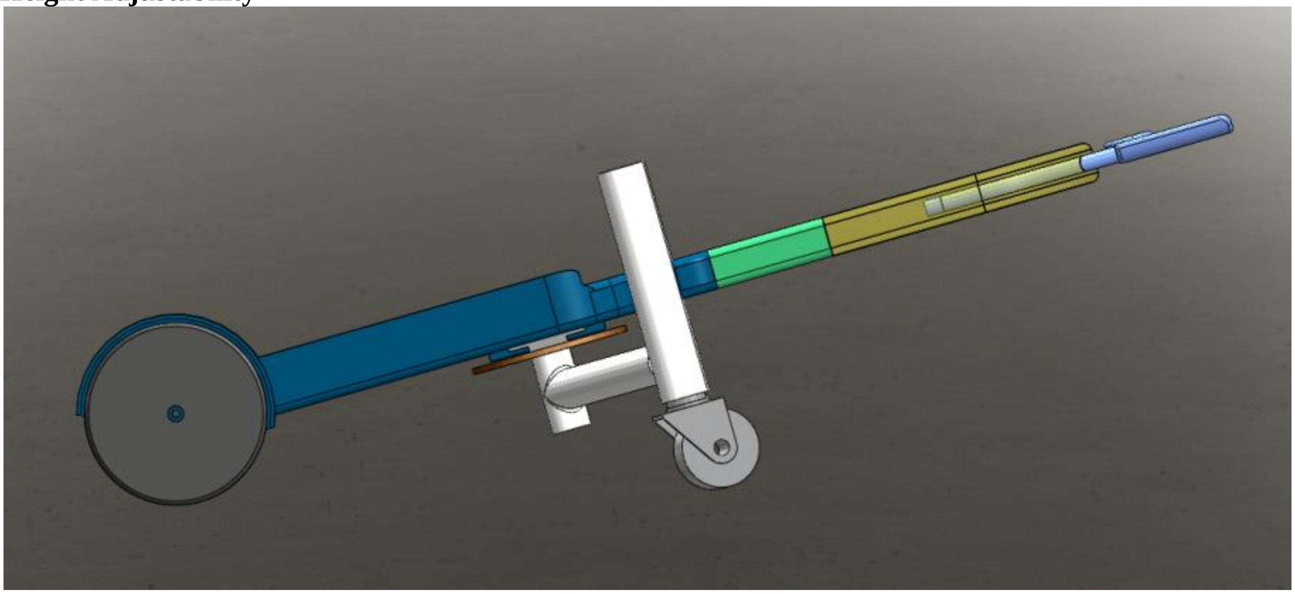


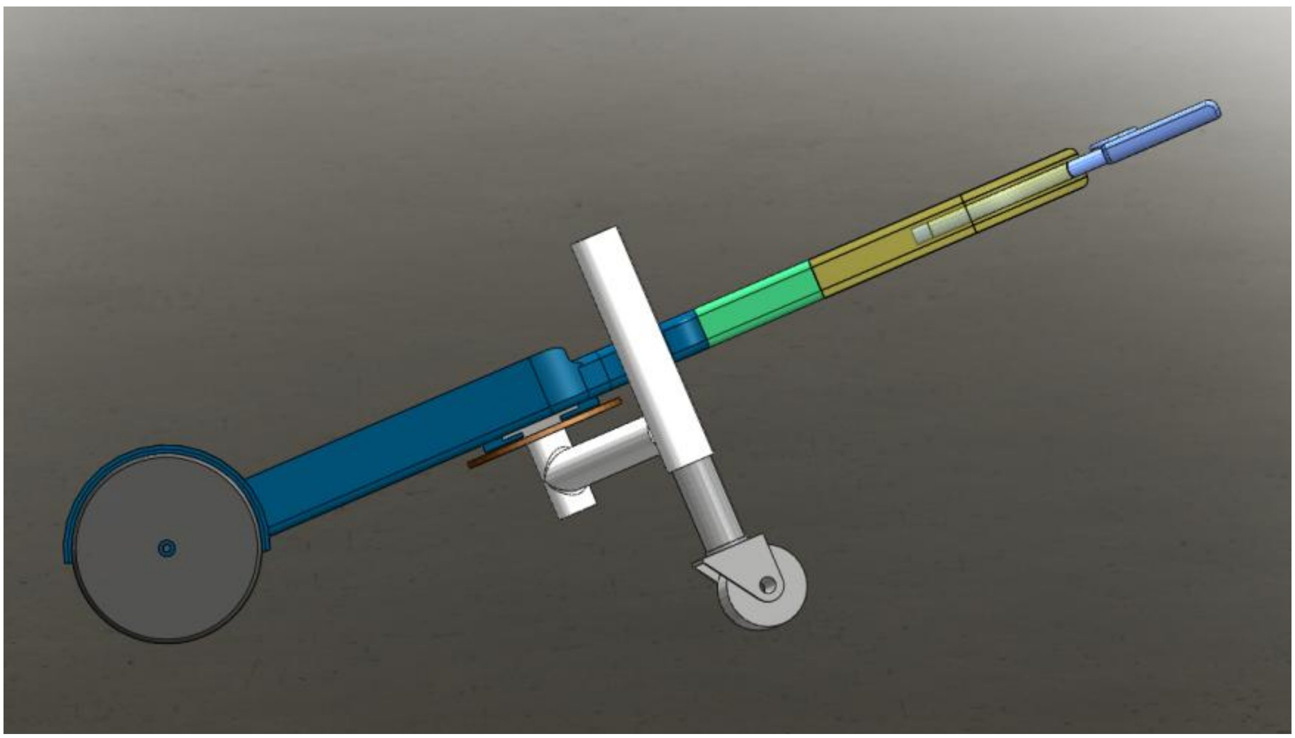






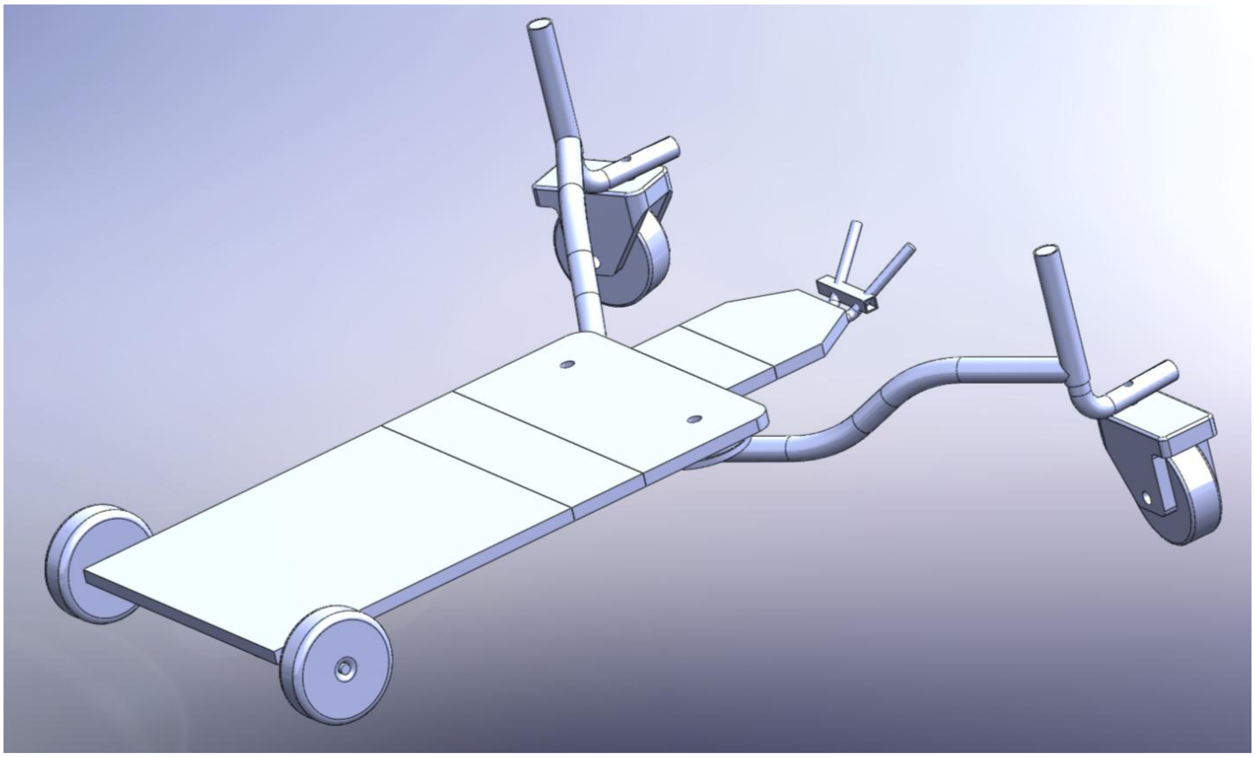
Height Adjustability

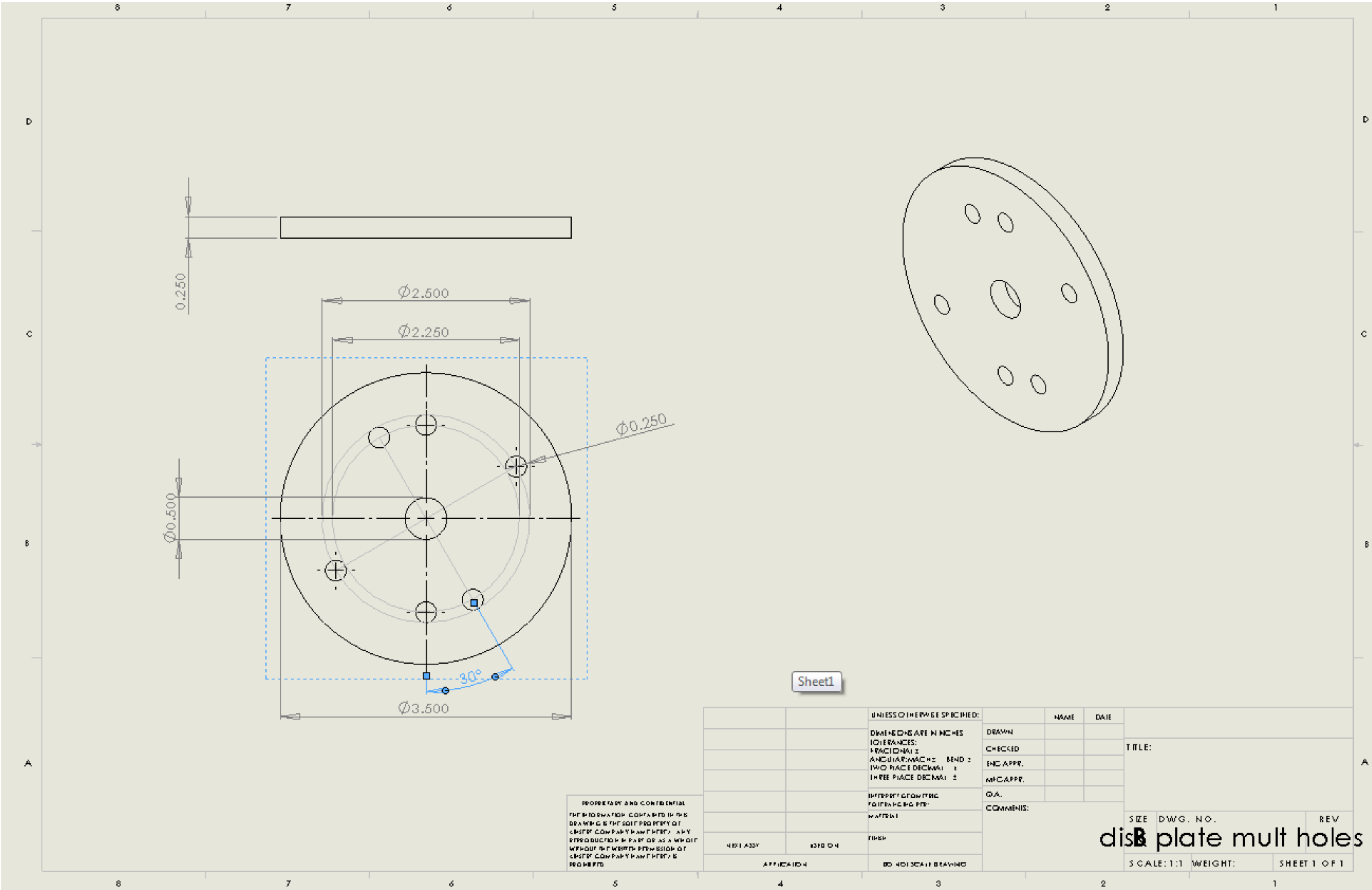




APPENDIX K – CAD DRAWINGS OF DESIGNED PARTS

The following pages show our CAD drawings for parts that we have manufactured. Dimensions that are unmarked have a tolerance of ±0.1 inch.





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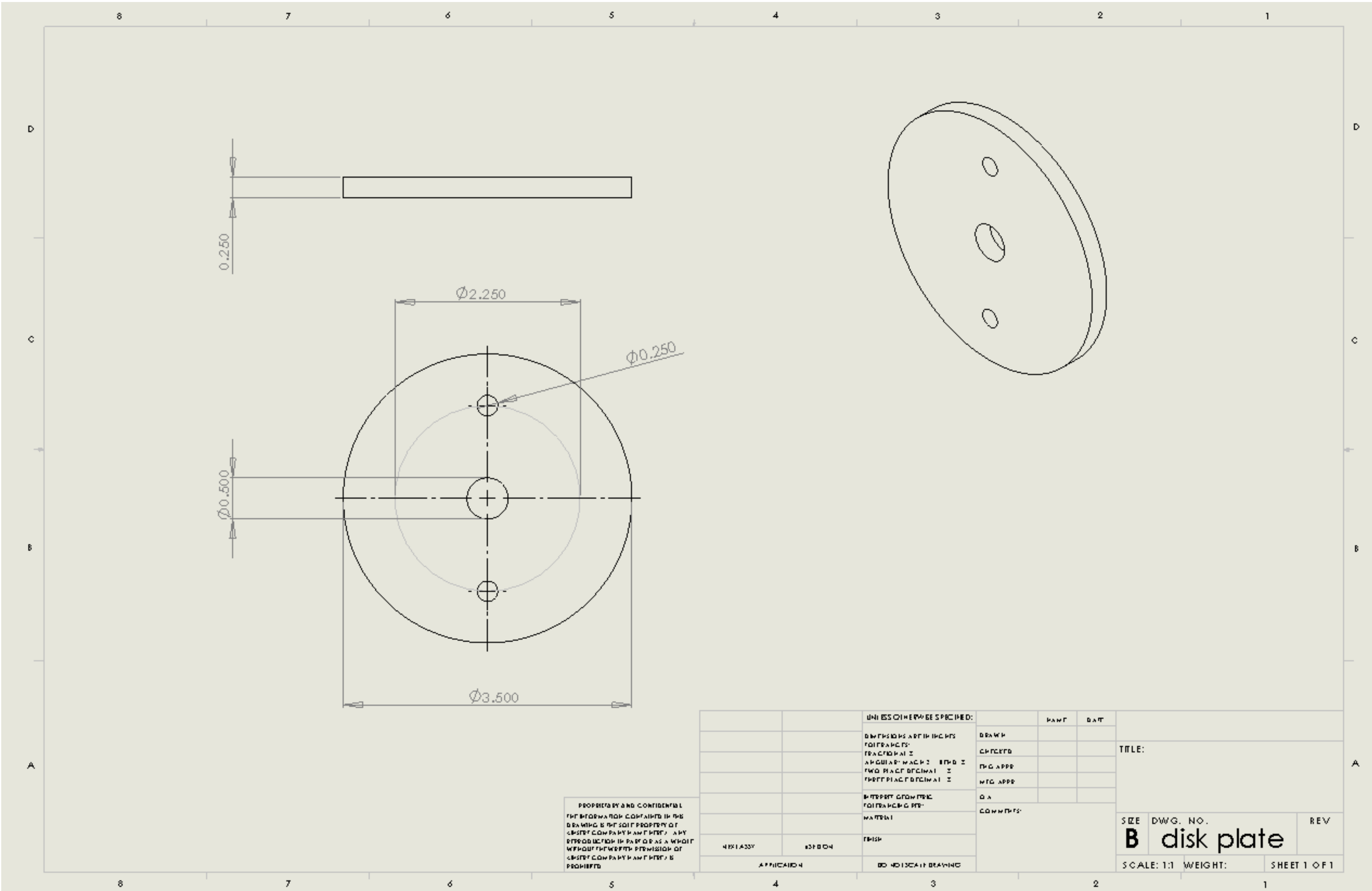
Ø2.500
Ø2.250
Ø0.250
Ø0.500
30°
Ø3.500
Sheet1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
B
disk plate mult holes
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL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DATE
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MFG APPR.
Q.A.
COMMENTS:
TITLE:
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B
DWG. NO.
disk plate
REV
SCALE: 1:1
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SHEET 1 OF 1
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USED ON
APPLICATION
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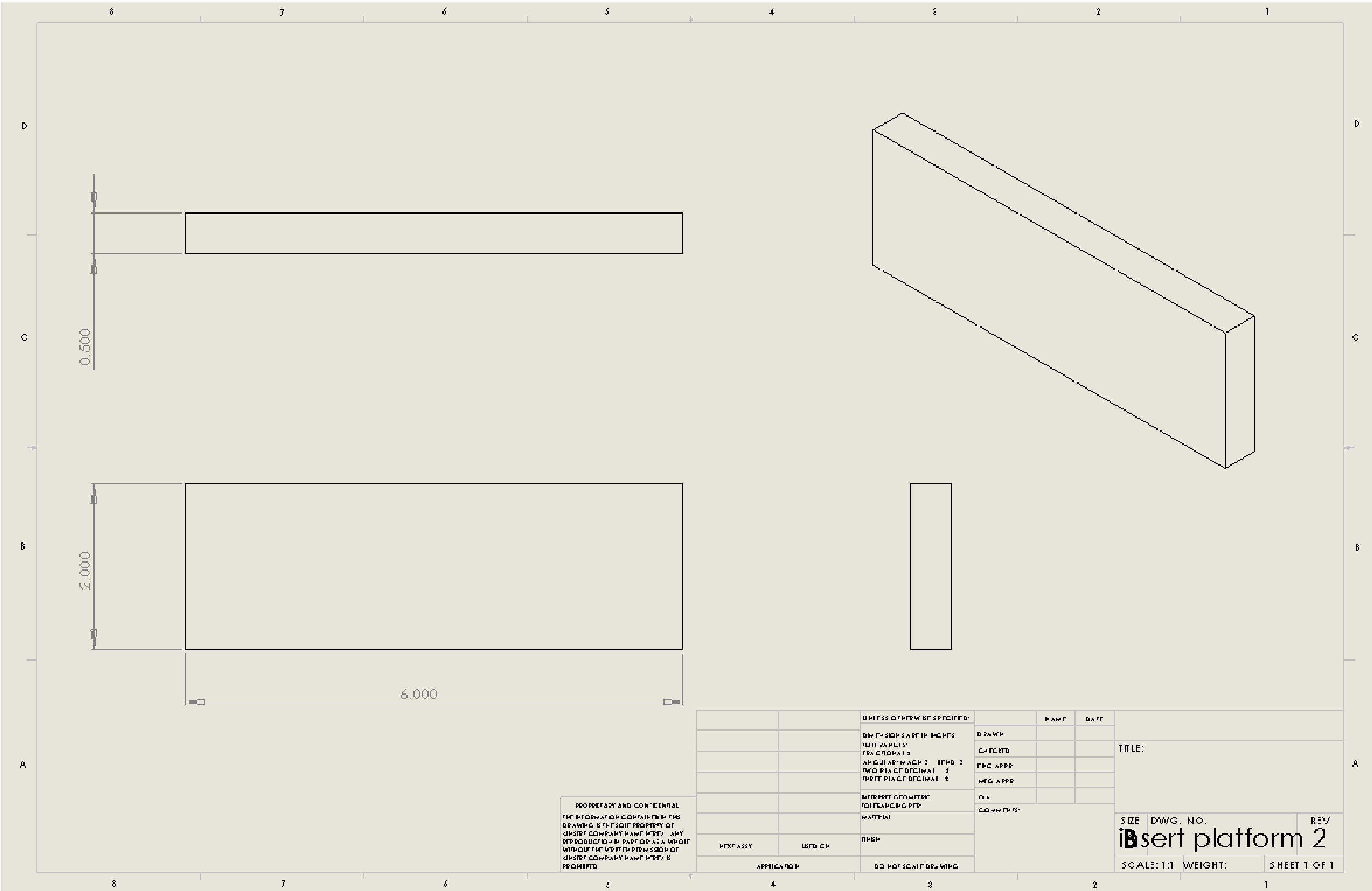
MATERIAL
FINISH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REV
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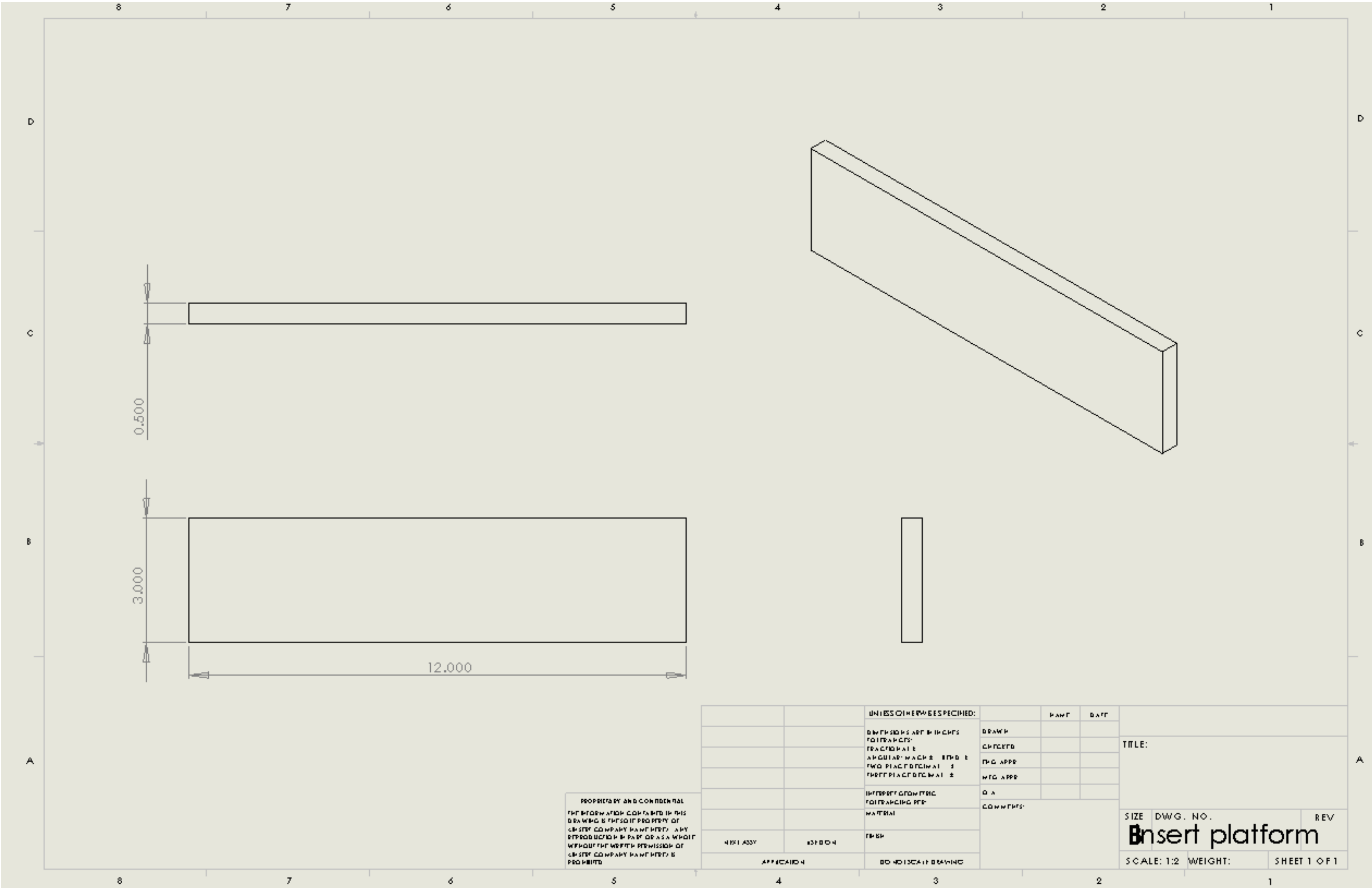
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3.000
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DATE
DRAWN
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
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MATERIAL
FINISH
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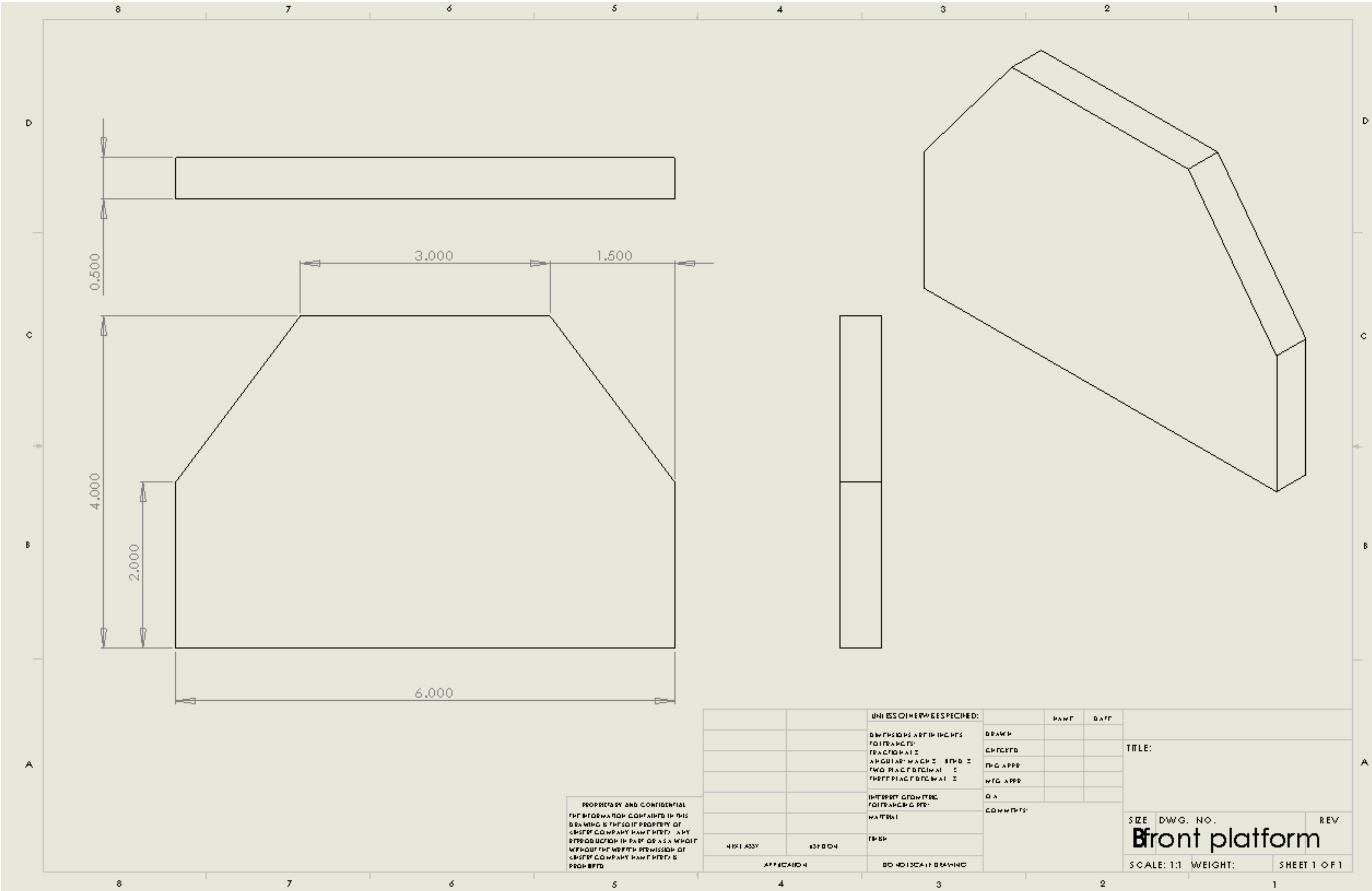
DWG. NO.
REV
Insert platform
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1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6.000
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
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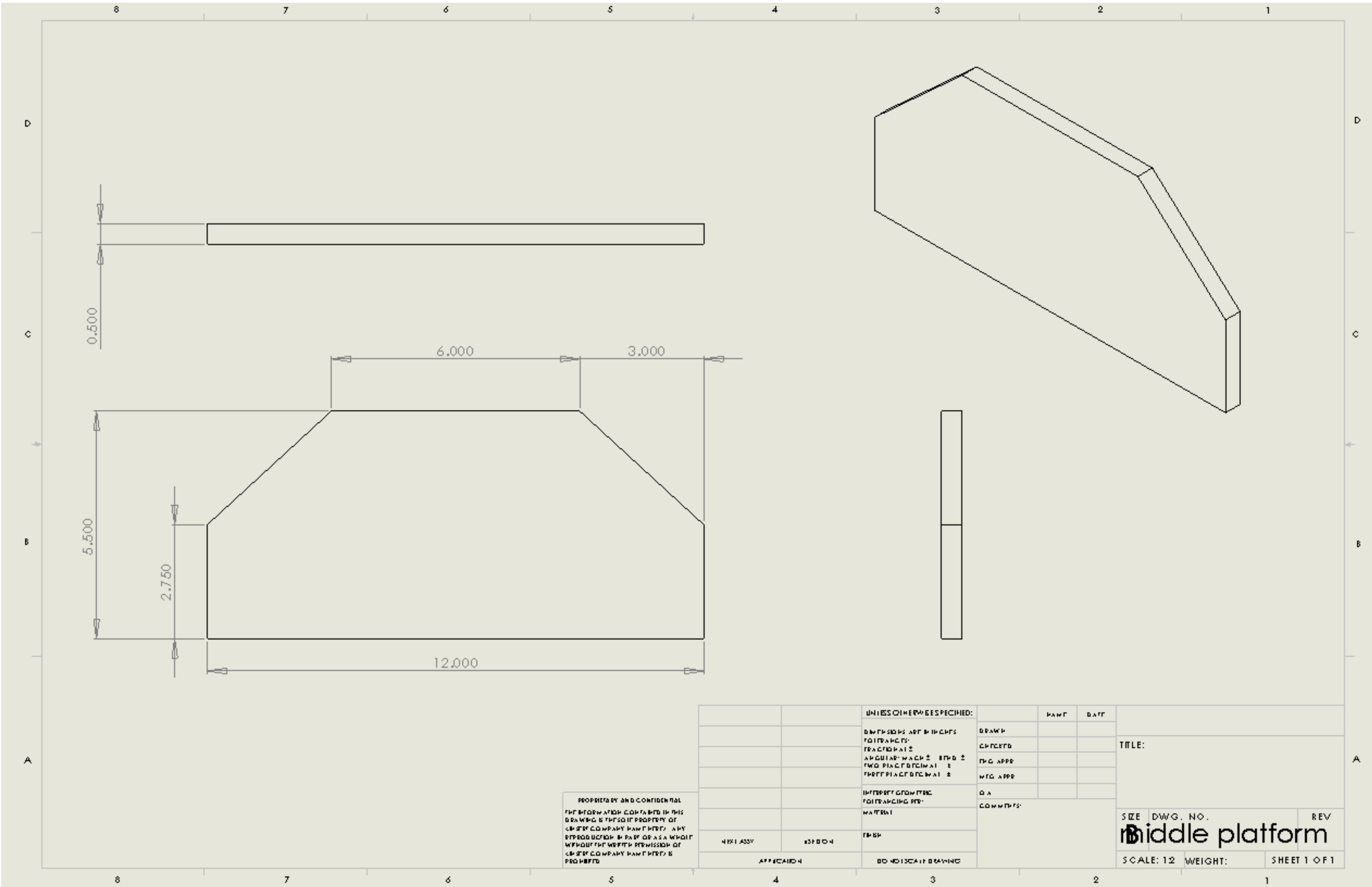
ENG APPR
MFG APPR
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
B
front platform
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING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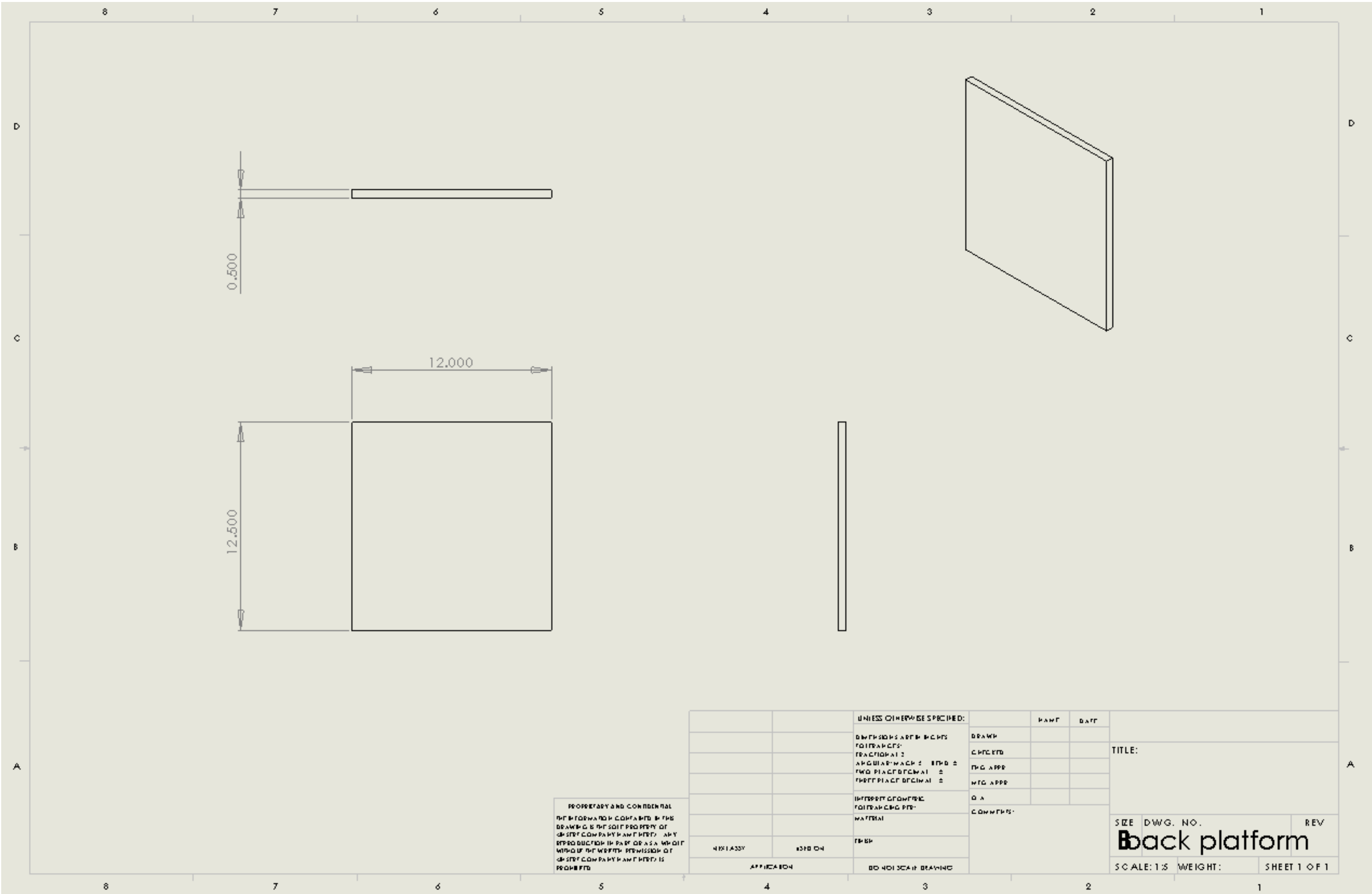
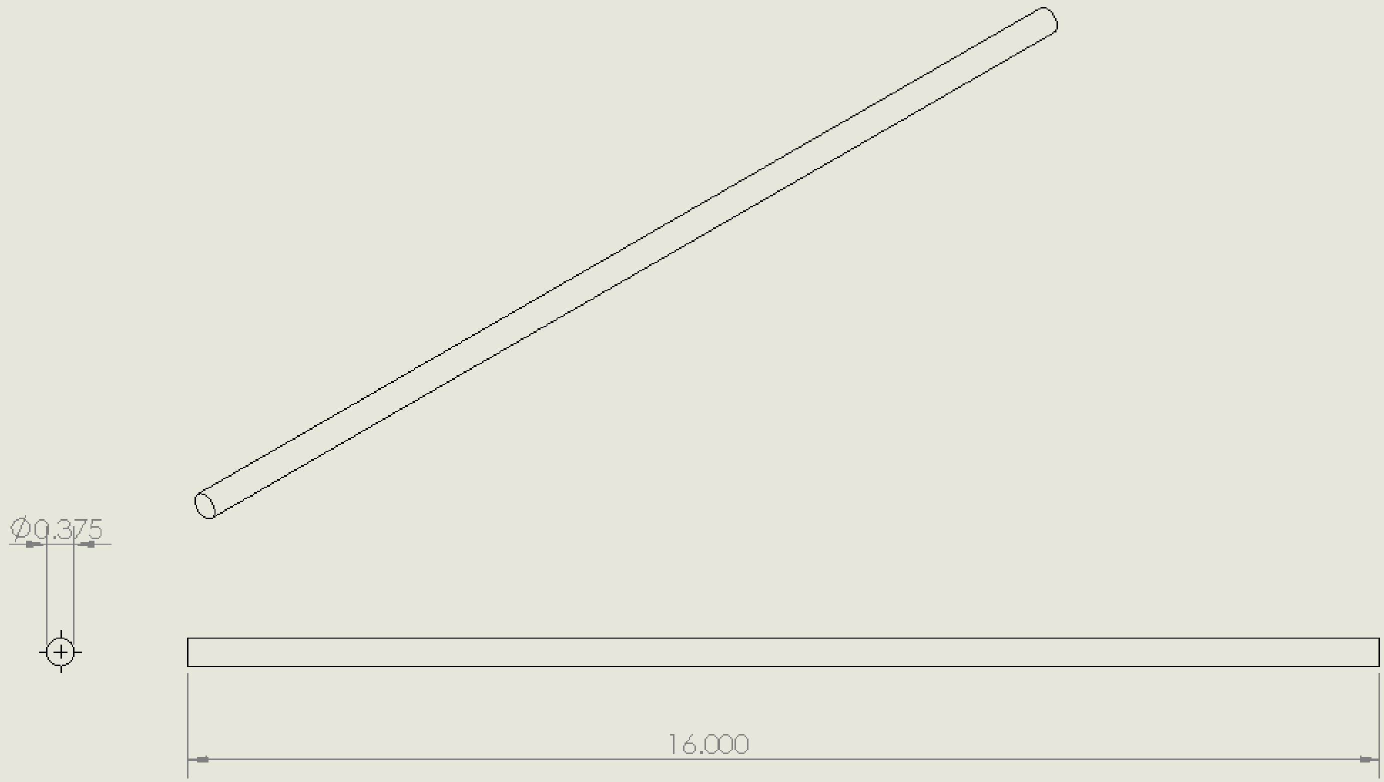
3.000
5.500
2.750
12.000
UNLESS OTHERWISE SPECIFIED:
TITLE:
SIZE
DWG. NO.
REV
B
middle platform
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


0.500
12.000
12.500
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
TITLE:
SIZE
DWG. NO.
REV
B
back platform
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1



NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

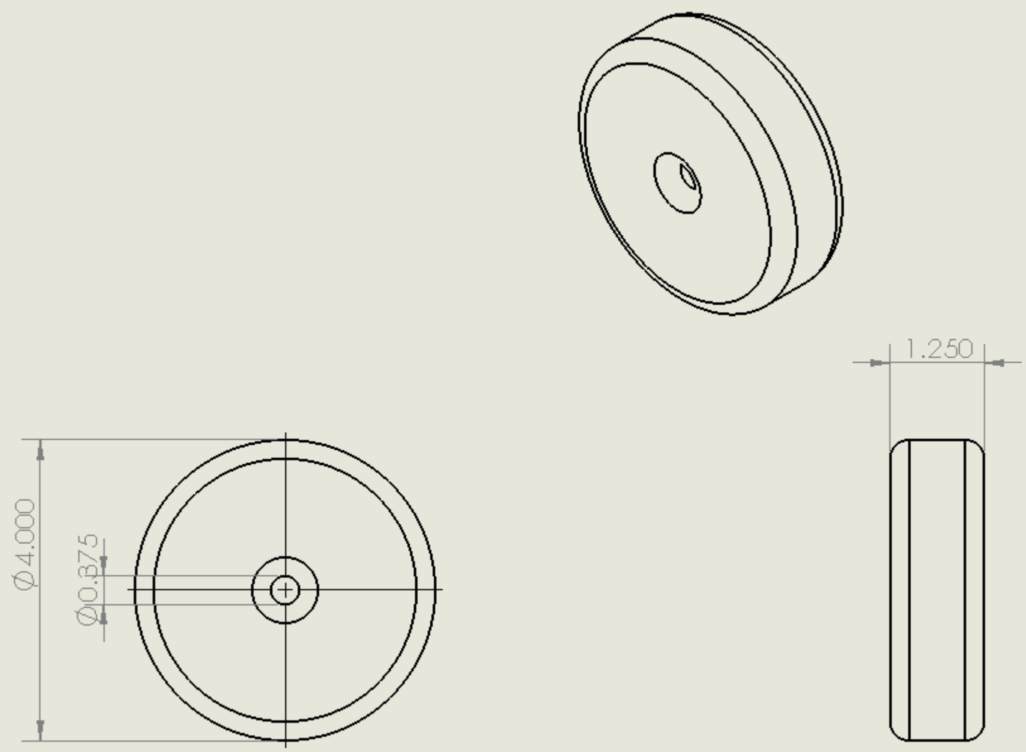
COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	axle	

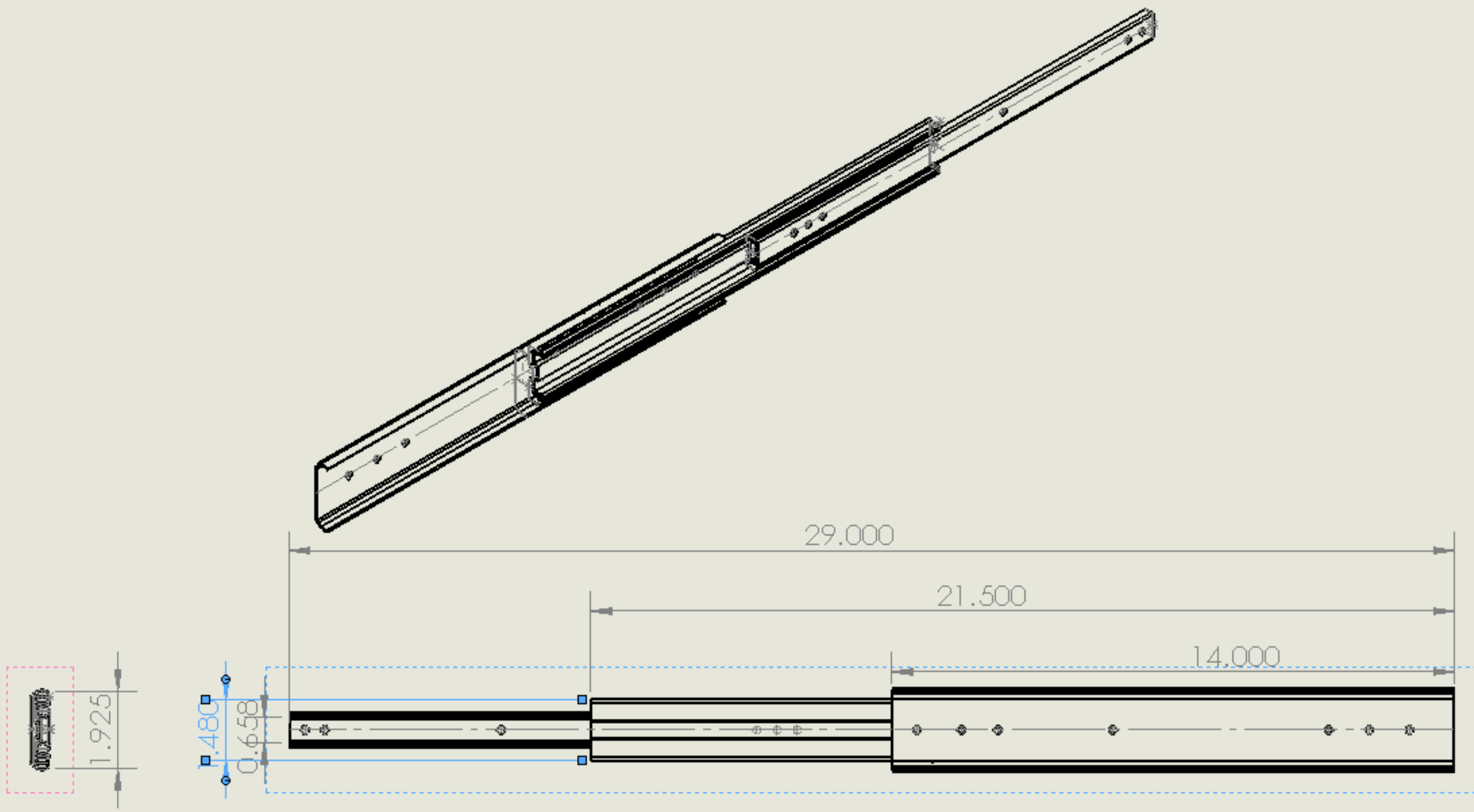
SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE:
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE DWG. NO. REV
NEXT ASSY	USED ON	FINISH				**A** back wheel
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

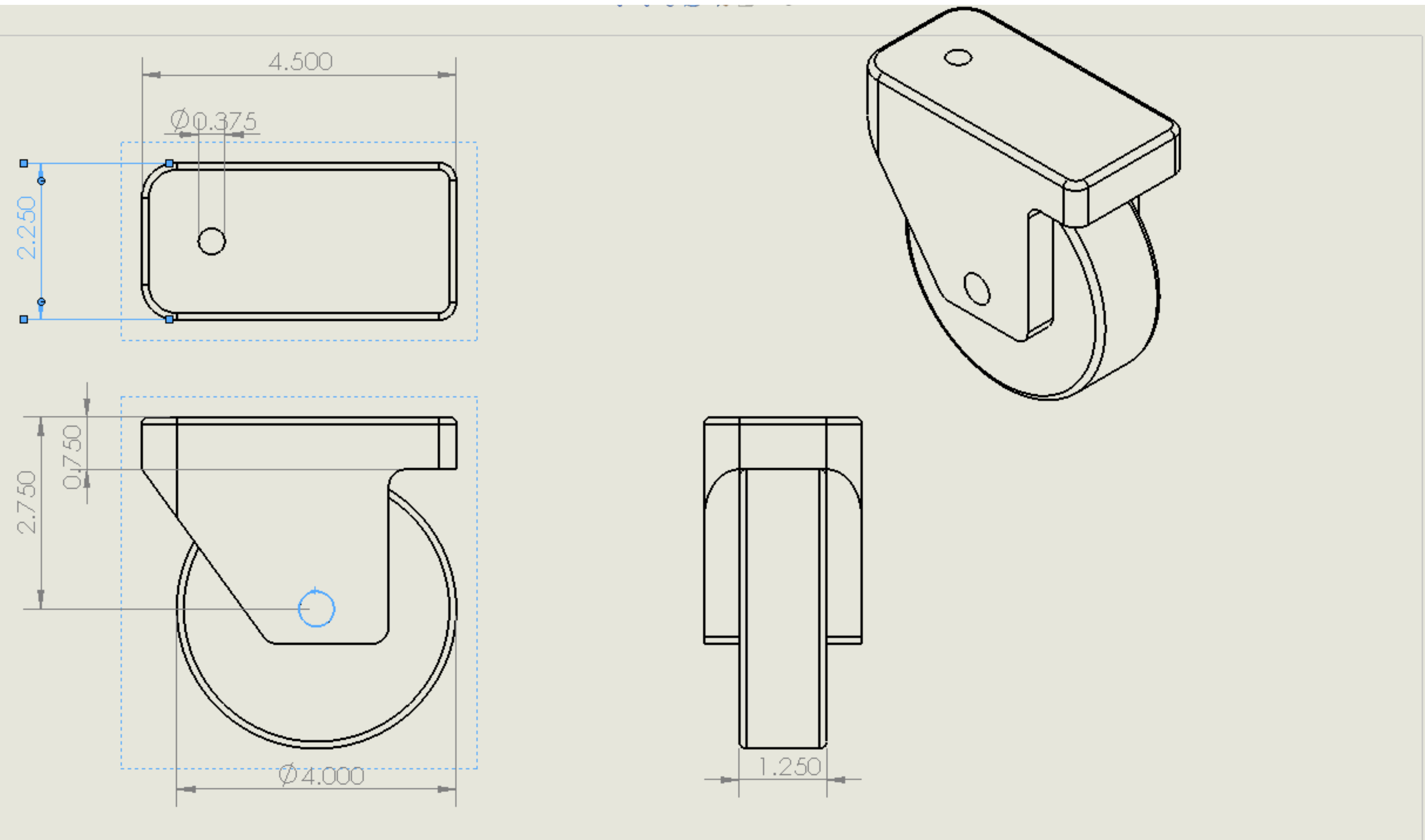
COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
	Adrawerslides	

SCALE: 1:8 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
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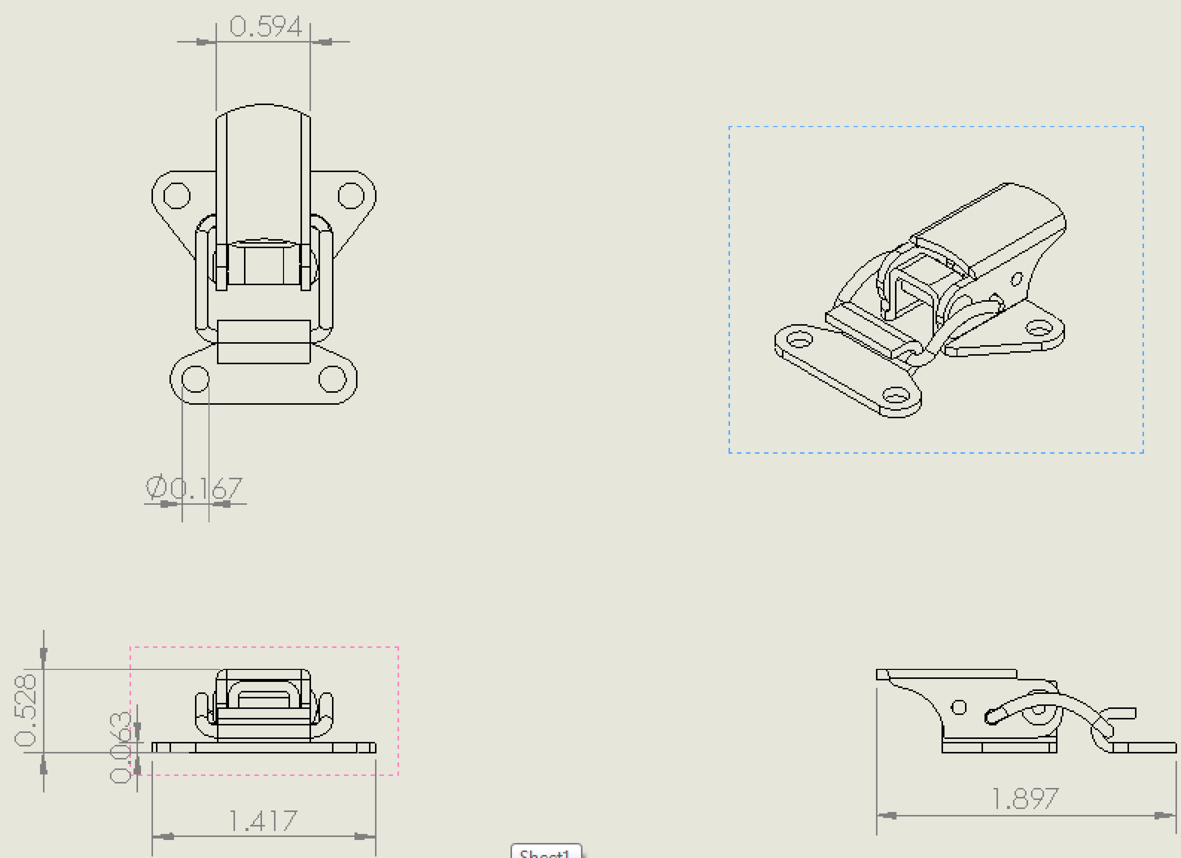
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE DWG. NO. REV front wheel asm
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



Sheet1

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

COMMENTS:

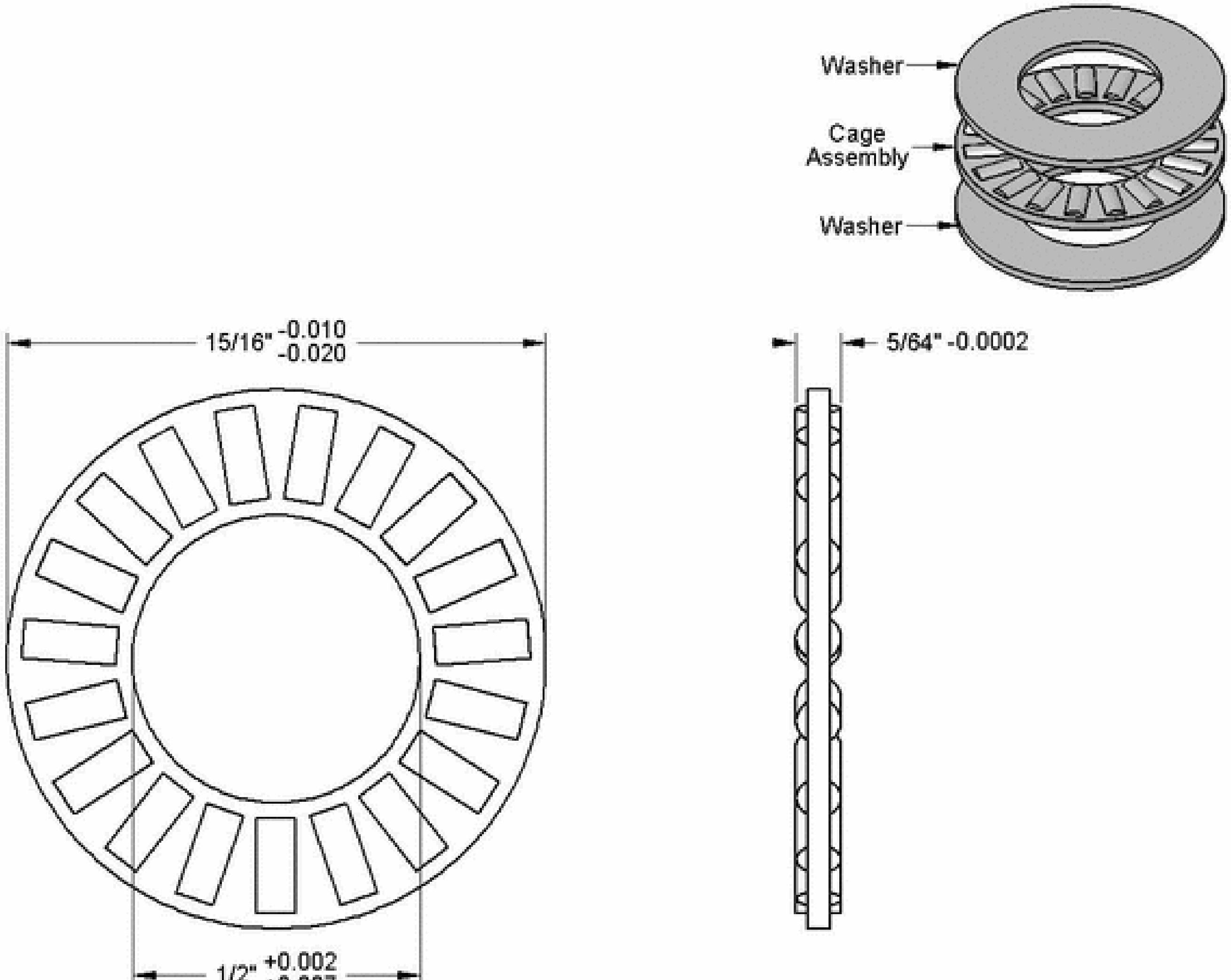
TITLE:

SIZE	DWG. NO.	REV
A	latch	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

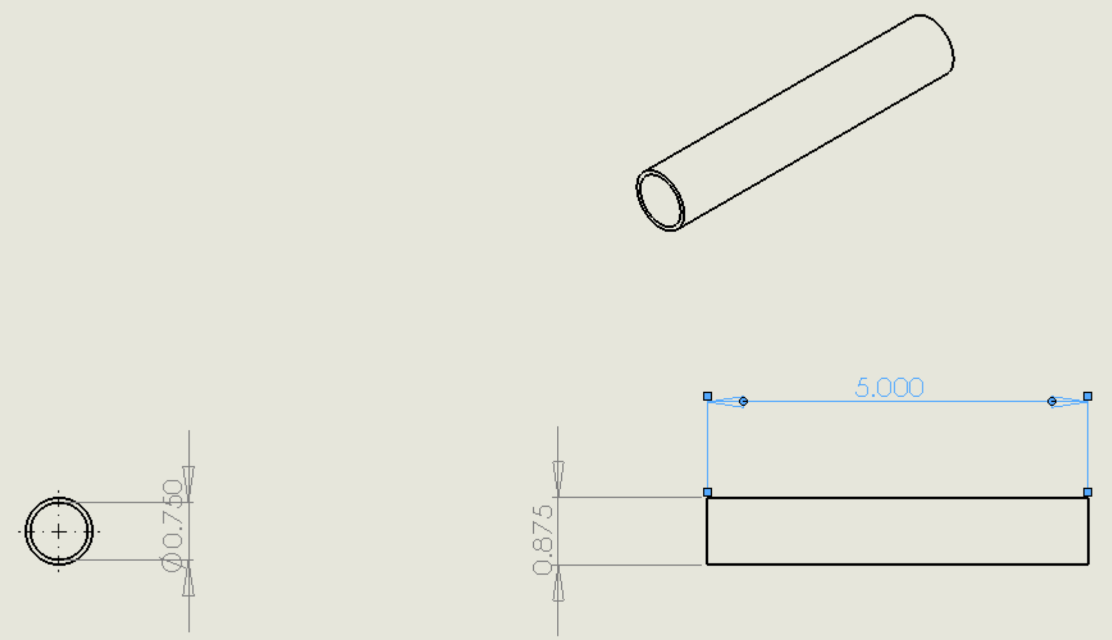
NEXT ASSY	USED ON
APPLICATION	

5 4 3 2 1



McMASTER-CARR	PART NUMBER	5909K31
http://www.mcmaster.com	Steel Cage Assembly for Needle-Roller Thrust Bearing	

Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.



UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

COMMENTS:

TITLE:

SIZE A DWG. NO. REV

OuterVerticle Telescop

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

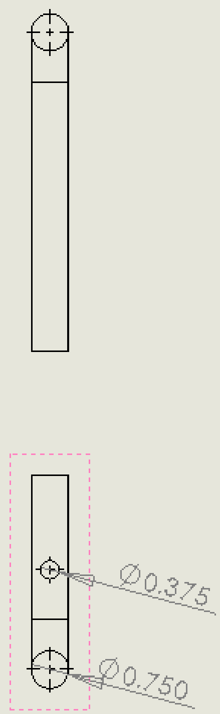
NEXT ASSY USED ON

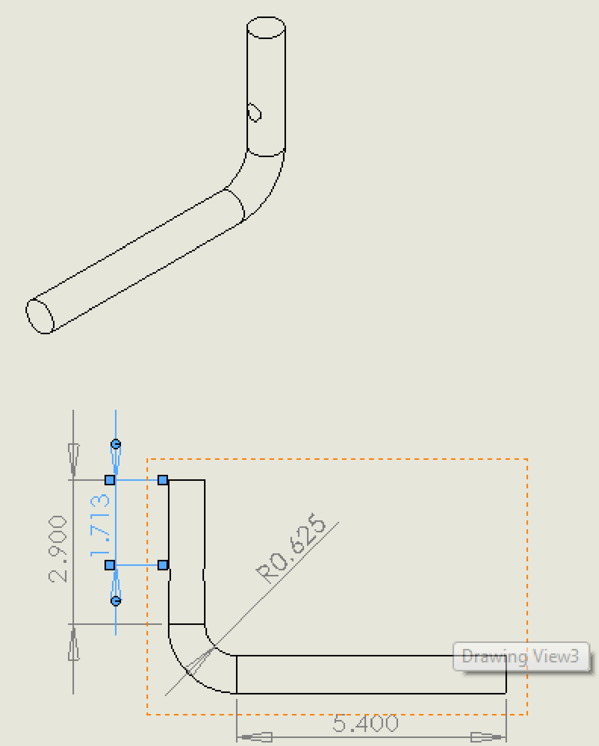
APPLICATION

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

5 4 3 2 1





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

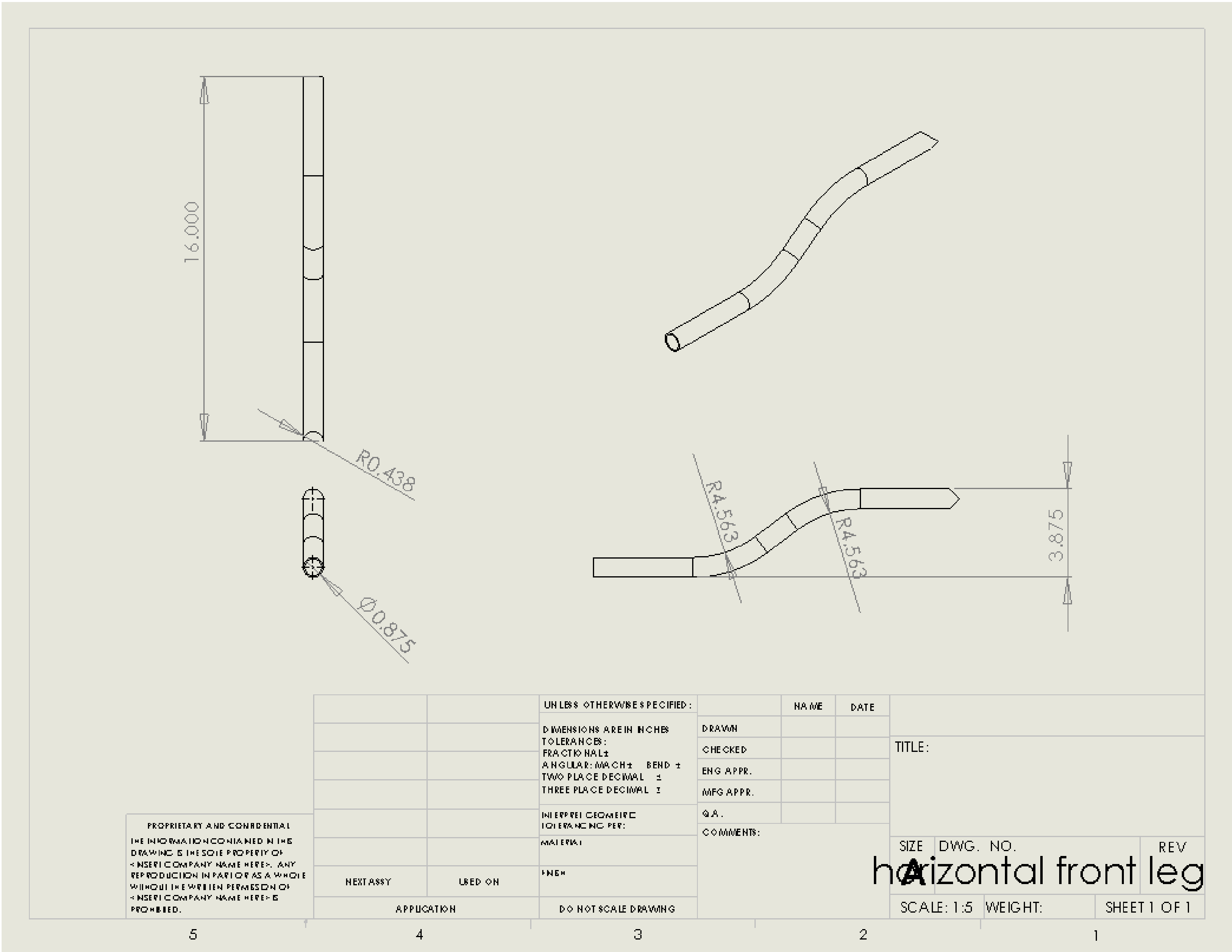
NEXT ASSY	USED ON
APPLICATION	

TITLE:

SIZE	DWG. NO.	REV
A	inside verticle shaft	

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



16.000
R0.438
Ø0.875
R4.563
R4.563
3.875
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
A
horizontal front leg
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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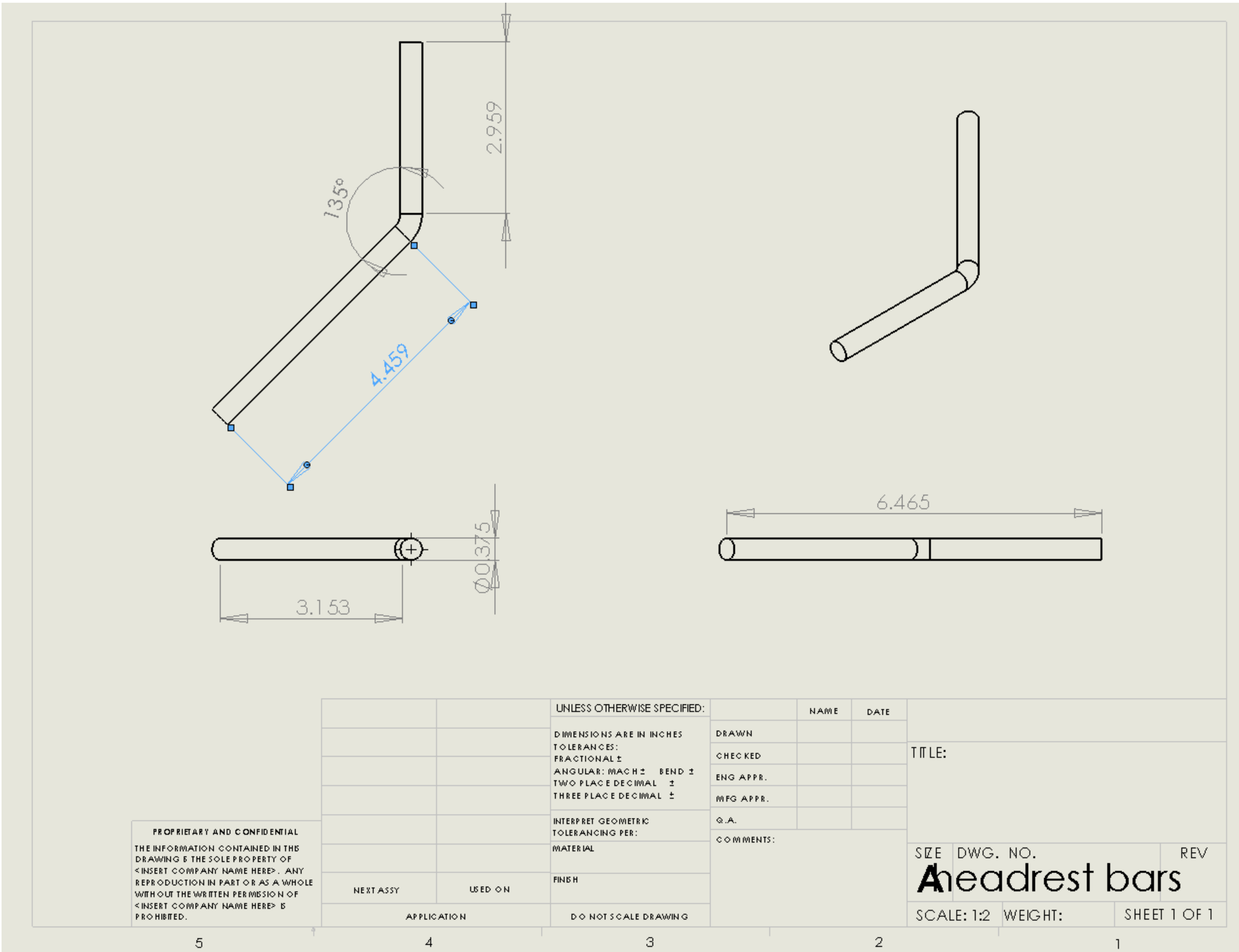
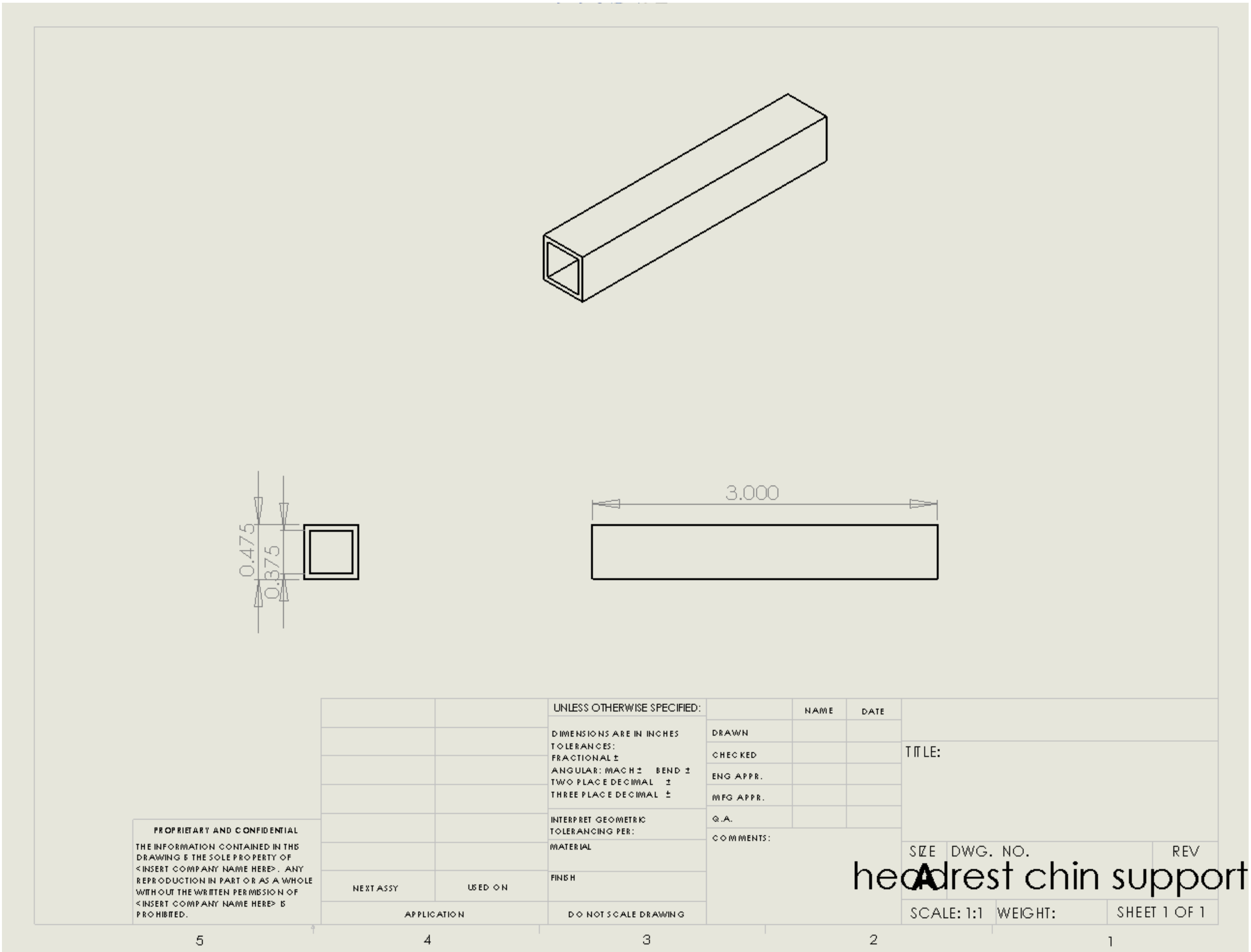
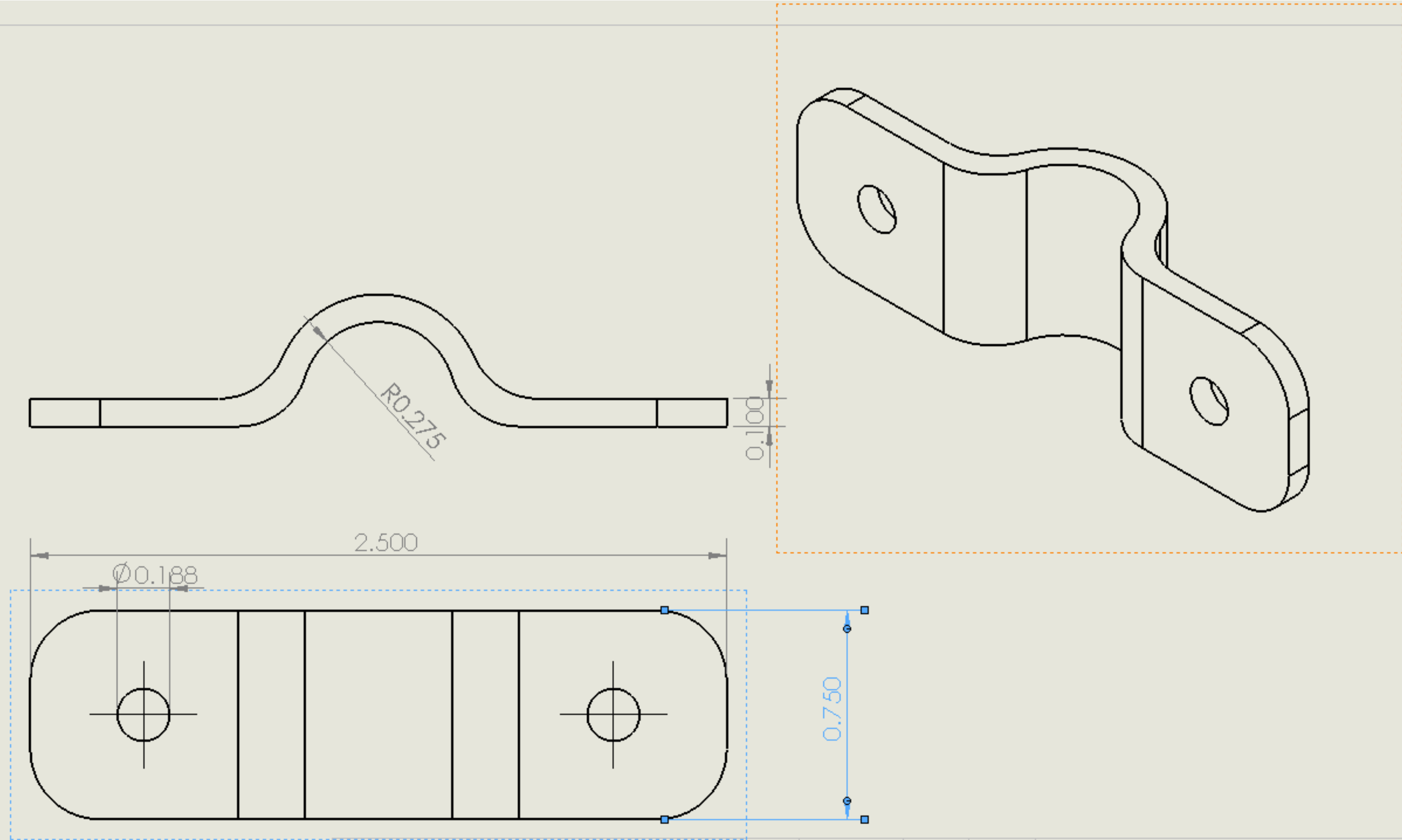
5
4
3
2
1


2.959
135°
4.459
3.153
Ø0.375
6.465
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
A headrest bars
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


3.000
0.475
0.375
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
A
headrest chin support
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
5
4
3
2
1



UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

COMMENTS:

TITLE:

SIZE A DWG. NO. mountbracket REV

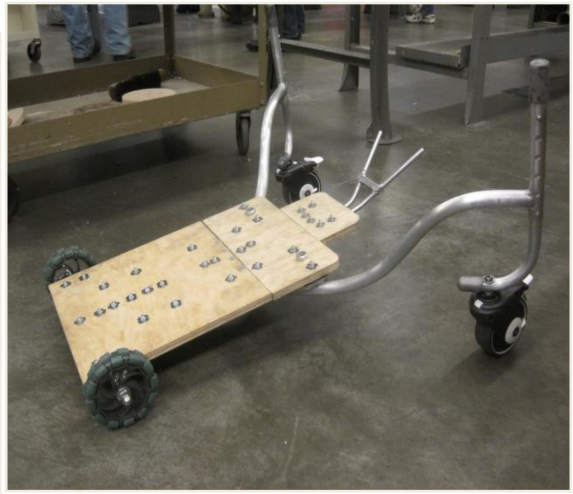
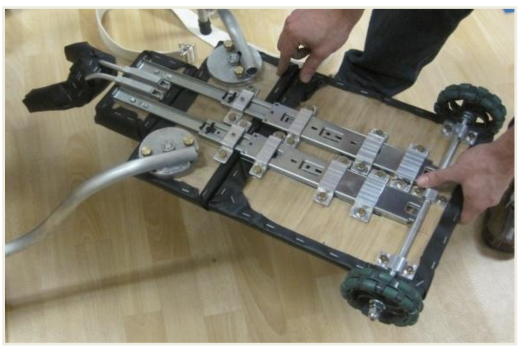
SCALE: 2:1 WEIGHT: SHEET 1 OF 1

NEXT ASSY USED ON

APPLICATION

5 4 3 2 1

APPENDIX L – PROJECT PHOTOGRAPHS







MICHIGAN

TEAM BIOGRAPHIES

Rachel Matson

Hometown: Troy, MI

Why Mechanical Engineering: My father is a mechanical engineer while my sister is a chemical engineer. When I was a junior in high school, I did very well in organic chemistry so I almost became a ChemE. However, I knew that I wouldn't be able to enjoy doing that as a career for the rest of my life. I also was involved in a robotics team in high school and so that solidified my interest in mechanical engineering.

Future Plans: I will be working full time for Procter & Gamble in the Fabric Care MPO organization in Cincinnati, OH. The products I will be working on are Tide, Downy, and Gain.

Interesting Facts: I have been in the Michigan Marching Band Flagline for the past four years and in the clarinet section of my high school marching band for four years. This year I am the Society of Women Engineers Social Chair and in high school, I was in a FIRST Robotics Team which competed nationally every year in a competition of building a robot in six weeks which was specifically designed for a new game every year.

Philip Minaudo

My name is Philip Minaudo and I am from Sterling Heights, Michigan. Growing up I was always interested in math and science, and I enjoyed building things and seeing how they worked. This interest, combined with the fact that my father is an automotive engineer, led to my pursuit of a degree in Mechanical Engineering. Here at the University of Michigan, I am part of the American Society of Mechanical Engineers, Tau Beta Pi Engineering Honor Society and the Michigan Italian-American Association. I am also a member of the Engineering Global Leadership Honors Program. After graduation this spring, I plan to complete a summer team project as part of the Tauber Institute for Global Operations, then continue on to earn my master's degree in Industrial and Operations Engineering here at Michigan. In my free time I enjoy baseball, hockey, snowboarding, golf, camping and other outdoor activities.

Alex Szypa

My name is Alex Szypa and I grew up in Sterling Heights, Michigan. I chose to go into engineering because I was always strong in math and science and thought engineering was right for me. I chose mechanical engineering because I really like the hands-on aspect of it. I am especially interested in manufacturing and am working towards a manufacturing systems concentration with my degree. I interned this past summer at General Dynamics Land Systems. I plan to get a job after I graduate and work toward getting an MBA while I am working. On my spare time, I enjoy playing and watching sports. I was even able to be an assistant coach of my old high school lacrosse team this past spring and summer.

Andrew Vella

I grew up in the downriver area, which is south of Detroit, Michigan. I graduated from Woodhaven high school in 2006. In high school I was a member of the National Honors Society, and a four year member of the soccer team. Also, I participated in track and field, tennis, and basketball. A nice accomplishment of mine was receiving the scholar-athlete award my senior year. This is only achieved by one individual from each high school in the state. I am an active member with the American Society of Mechanical Engineers at Michigan, where I am currently serving as the internal vice president. I decided to major in mechanical engineering simply because I'm interested in how things work. I have always enjoyed math and science courses, and I love to work with my hands. I get a great sense of accomplishment from solving problems and understanding mechanical systems and processes.

I will be graduating with my bachelors of science in mechanical engineering from the University of Michigan this spring. I have been searching for a full-time position in either design or manufacturing and hope to start once I graduate. I am currently working part-time at Heller Machine Tools, where I have interned the past two summers. Heller manufactures large scale commercial CNC machines, and I have been exposed primarily to the tooling operations that come with CNC machining. I want to find a job where I get the opportunity to contribute to the company while broadening my knowledge in the engineering field. I hope to attain my master's degree in the future in either mechanical engineering or business management.