UNIVERSITY OF MICHIGAN

Stationary Bicycle Trainer

Final Report

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Executive Summary

Many of us take for granted the ease in which we can do and learn difficult physical activities, such as riding a bicycle. Sadly, there are many out there who are unable to learn as quickly. Many children suffer from disabilities that make the already difficult learning process of how to ride a bike even harder. In order to make it easier for them to learn to ride a bike and provide an ability to practice longer, we are developing an indoor bicycle trainer that is safe, affordable, and simulates all the requirements necessary to ride a bicycle more than any other indoor bicycle trainer.

In order to determine the best way to create this trainer, the group started by creating a survey that asked the physical therapists at Med-Rehab Milestones and the parents of the children who went there what they wanted most out of an indoor bicycle trainer. After this, the team started doing research on benchmark bicycle trainers, discovering their strengths and weaknesses. Using the data gathered, we were able to determine the customer requirements and the engineering specifications.

Next, the group started brainstorming, both in groups and individually to create numerous designs, some similar to benchmark products, some radically new. Five of these designs were then examined to determine the best ideas. From these designs we were able to develop the alpha design. We took the best parts from the best designs and combined them into one new design. Each of the individual systems was selected to complement each other and make sure that all disadvantages of one system were the advantages of another in the design. The resulting alpha design was considered the best option to fulfill the customer and design requirements.

Our final design has deviated slightly from the initial concept that our team demonstrated in the Alpha Design. Our final design now incorporates the idea of an inverted pendulum and adds the use of two gyroscopes. This addition will successfully simulate an on-road bicycle experience while also helping a new student to learn how to balance on a bicycle. Unfortunately, our final design that satisfies all important customer requirements is still over budget, so our team has produced a much cheaper prototype that will portray the most important aspects of our project and will demonstrate the function of a gyroscope and how it will help children learn to ride a bicycle indoors and in a stationary manner.

To determine the materials that would be required for our prototype and final design, we performed a static and dynamic analysis of all major components. Based on their function and stress requirements, our team utilized CES to determine the material required for all components of the prototype and final design.

As stated before, due to material cost and availability, a prototype has been made to demonstrate the engineering principles that our team is using in our final design. The prototype successfully validates some aspects of our design, but more testing is needed before we can validate our final design. Although more progress is needed, our team is optimistic that our design has opened doors to future endeavors in the stationary bicycle training field.

Introduction

"Life is like riding a bicycle. To keep your balance you must keep moving" -Albert Einstein [18]

Inside this quote is not just an analogy between life and bicycle riding, but holds an important scientific fact: in order to balance on your bicycle, you must keep the wheels moving, namely by moving forward. Balance is the most important aspect of riding a bicycle, and without balance, it would be a practice in futility. Children from an early age learn how to balance on a bicycle, but not all of them learn at the same pace. Some are naturals at riding a bicycle, and others need some practice. At one end of the spectrum are the children with Down syndrome, lower body deficiencies, and other significant disabilities. These children take the longest to learn. Most children can learn to balance on a bicycle within a summer, but these children take far longer, so much so that in order for them to retain their knowledge, they need to practice riding a bicycle during the fall and winter. These seasons aren't very welcoming to bicyclists, so an indoor bicycle trainer had to be constructed in order to allow children learning to ride a bicycle a chance to learn indoors in a safe environment when they couldn't ride outside

Perhaps you are wondering, "Why develop a bicycle trainer when there you can simply use a stationary bike like one found in a gym?" The answer is simple: riding stationary bikes and riding outdoor bikes are two almost completely different experiences. Riding a stationary bike won't teach you how to balance on a bike, mount a bike, or turn on a bike. A stationary bike only has an ability to simulate different resistances while riding a bike. Our major goal is to not only to create an indoor bicycle trainer, but to create an indoor bicycle trainer that teaches children how to ride while they use it.

If the design is a success, then it will open up a completely new chapter in indoor bicycle trainers. Most bicycle trainers available today are supplemental; they assume that the rider already knows how to ride a bicycle. Our trainer is designed with children in mind, namely children who are just learning to ride a bicycle. Our trainer does not assume the children know anything about riding a bicycle. Most bicycle trainers today only come with the ability to change the resistive pedaling force on the wheel; they are already balanced and do not have any focus on turning a bicycle. Our design will revolutionize this: it will include changing resistive pedaling forces on the wheels, assistance in balance for riders with less experience, and the ability to turn and therefore allow the rider to practice balancing and shifting their weight while turning. Since no other trainer is able to do all three of these important jobs, our design could become the most realistic bicycle simulator to date, and be used not only by novices, but by expert bicycle riders as well.

This project is sponsored by Med-Rehab Milestones. Med-Rehab Milestones is a rehabilitation clinic that specializes in helping children with disabilities function with their disabilities and find ways around them. Most of the activities at Med-Rehab are aimed to teach the necessary skills to participate in activities that most children their age are able to without any trouble. One such activity is riding a bicycle. Med-Rehab Milestones, as stated earlier, desires a bicycle trainer that can easily help train children with disabilities to ride a bicycle without exposing them to any danger. The purpose of the project revolves around this desire to create an indoor bicycle trainer that the children at Med-Rehab Milestones can use to learn to ride a bicycle. We hope that our current design fulfills all the wishes of Med-Rehab Milestones, and more.

Specifications

Based on our requirements, evaluations of competitive products and patents in the field of indoor, stationary bicycle trainers, and an analysis of normal outdoor bicycle functions, we have determined engineering targets for our design. The objective was to simulate all normal bicycle functions into our indoor stationary design therefore all engineering targets were determined to simulate all outdoor bicycle functions. All design targets for our final design and design specifications of current benchmarks can be found in our QFD (Appendix D). The following table demonstrates our key design targets along with the key design specifications of current benchmarks in the field.

Table 1: Key Design targets for our final design and key design specifications of current benchmarks.

Model/Patent	Max Yaw Angle from Vertical Position (Degrees)	Price ($)	Max Leaning Resistance (lbs)	Max Turning Deviation (Degrees)
Kurt Kinetic Rock and Roll Pro and Turntable Riser Ring	15	560	70	180
Kreitler Challenger 4.5 Bike Rollers	3	360	N/A	0
Bicycle Trainer Patent No. US 7326151 B2	15	N/A	70	120
Target	15	350	70	180

Quality Function Deployment (QFD)

Another component representing the top of the QFD is the correlation matrix that relates engineering specifications to other engineering specifications. Each engineering specification is compared to the other engineering specifications and is given a value of “9”, “3”, “1”, or “0”. “9” means that the correlation between the project requirement and engineering specification is strongly related, while “3” means that the correlation is somewhat related and “1” means that they are weakly related. “0” means that there is no relation at all. Our team evaluated each case and used our engineering intuition to determine the appropriate value.

The area that compares the different benchmarks to the project requirements is the benchmark competition on the right-most side of the QFD. Each benchmark product is evaluated with each project requirement is ranked “1” through “5”. A “5” means that the product satisfies the project requirement perfectly, while a “1” means that the product doesn’t satisfy the project requirement at all. Our team evaluated each case and used our engineering intuition to determine the appropriate value.

An additional component representing the bulk of the QFD diagram is the correlation matrix that relates all project requirements with engineering specifications. Each engineering specification is compared to every project requirement and is evaluated in a similar manner as the correlation matrix between the engineering specifications. Our team evaluated each case and used our engineering intuition to determine the appropriate value. For each engineering specification, the correlation values are averaged to determine the importance rating of the engineering specification. The engineering specification with the highest importance rating is determined to be the most important engineering specification.

If all design requirements are met, our design will imitate all outdoor functions while successfully developing a child's ability to ride a bicycle at a price cheaper than all other competitors.

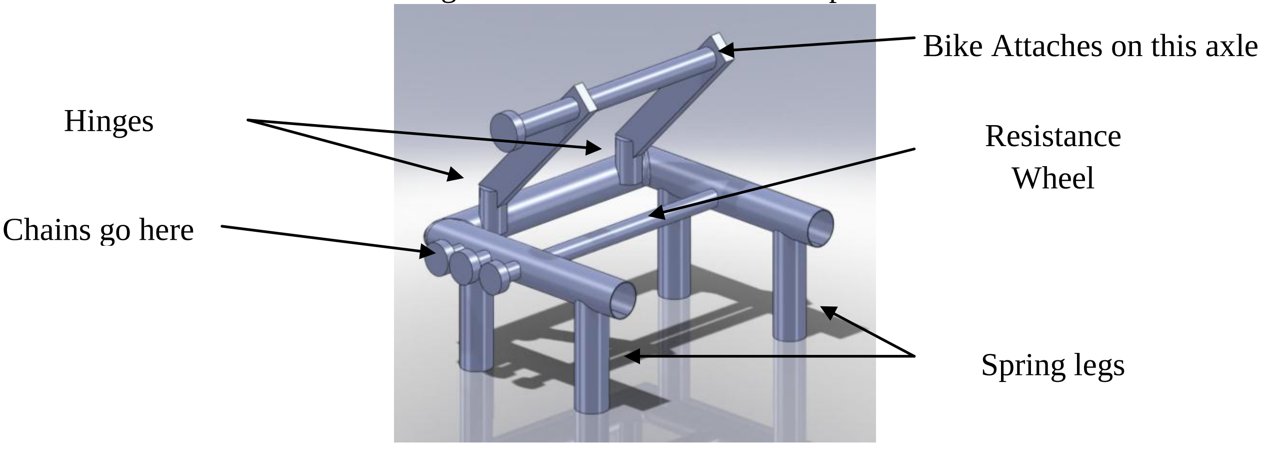
Concept Generation

The following section will describe, in detail, the five main concepts that our team have developed in order to come to our final design as well as the methods used to generate the designs.

Gear and Chain Concept

Our first design concept was a big departure from the Kurt Kinetic Rock and Roll Pro. The design has a rectangular frame with four legs for support instead of one solid base as seen with our competitors. These legs are composed of spring/damper columns that would allow the trainer to rock to each side with the motion of the bicycle. This design uses a set of chains and gears to allow for easier changes to the resistance that would simulate different terrains and hill pitches. By adding a chain and gear system, it would allow the user to change the riding resistance on the fly without having to discontinue use of the design. The chain and gear system is also completely mechanical; therefore, this design contains no electrical components. The gear and chain concept is shown below in Figure 1.

Figure 1: Gear and Chain Concept



On the other hand, this design would introduce many safety issues. We would have to determine the best way to situate all wires and gears so that the rider would not interfere with them and introduce a safety hazard. This design also would introduce many areas where someone can get injured. For example, a child could easily get their fingers caught within the gear and chain interface causing pinching or other injuries if the area was not covered and stored away safely. The type of lubrication would also be a considerable issue because if our design would be used indoors, we would want the lubrication used to not pose a threat to mark or stain anything inside. It would also have to be safe for children to be around as well.

When this concept was designed, the most important aspects it featured were balance and no electricity. In order to fulfill the no electricity requirement, the resistance wheel was attached to chains. These chains were attached to a 2-part gear train, and these gears were attached to more chains, which finally ended up connecting to a rod that was fixed on the wheel axle. The point of this was to make the resistance wheel turn using power generated from the rear bicycle wheel. This power would cause the chains and gears to rotate, which would rotate the resistance wheel. The most important aspect of this is that the gears would be able to be shifted similar to how a bicycle's speed shifter works. This would cause the resistance wheel to turn less and provide some resistance on the rear wheel.

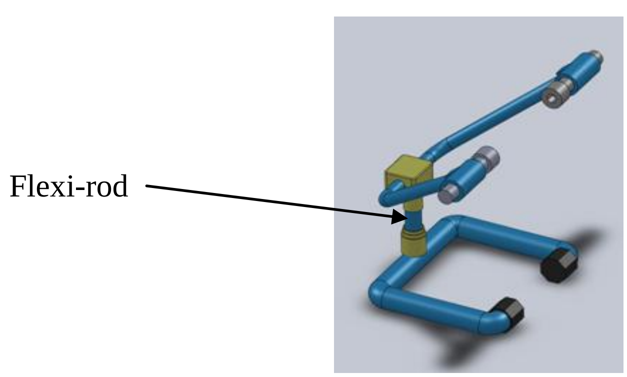
The balance part was perhaps the hardest part to design. Numerous ideas were created to allow for new ways to teach balance. In the end, the four spring-legged idea was inspired by the suspension in off-road vehicles and bicycles. The terrain in while off-road is far rougher and harder to traverse than the paved roads of cities, and the suspension used in off-road vehicles/bicycles allows for extra balance. Instead of using these suspension legs to stabilize the frame when the wheels are unstable, they would stabilize the wheel when the frame was unstable.

A functional decomposition diagram of the Gear and Chain Concept can be found in Appendix E.

Flexi-Rod Concept

Our third design is similar in nearly every aspect to the locking sleeve concept. The differences come in the method of applying the side-to-side motion. Instead of using a spring to exhibit the motion, we would use a flexible metal rod similar to that of eyeglasses that have modern flexible/memory metal frames. The rod would be made of a metal based material that would not need lubrication or replacement as often as the spring. It would require proper sealant around the location that it would be inserted as most fasteners (namely screws) would not hold and would likely tear free from the hole in which it was inserted. This design would also include the locking sleeve and dead man's switch to maintain the safety feature. The design also has all the advantages of the Locking Sleeve concept along with the disadvantages listed above. The Flexi-rod concept is shown in the Figure 2.

Figure 2: Flexi-rod concept

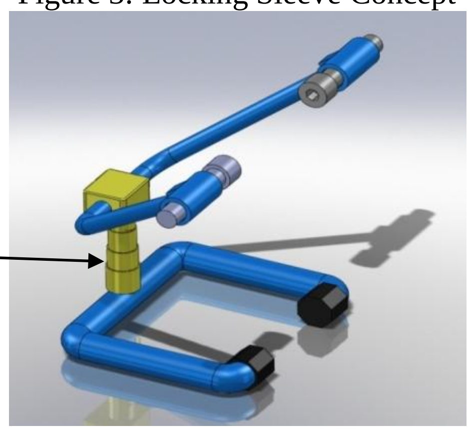


A functional decomposition diagram of the Flexi-Rod Concept can be found in Appendix E.

Locking Sleeve Concept

Our second design concept is very similar to the Kurt Kinetic Rock and Roll Pro except it introduces the idea of utilizing a locking sleeve to restrict the design from swaying from side to side when the apparatus is not in use by adding a dead man's switch in the form of a grip similar to a brake attached to a handlebar. Underneath the sleeve is a stiff spring, so that when the sleeve is up, the system will rock back and forth with the motion of the bicycle. The dead man's switch would stop the apparatus from swaying in the case that the switch is not activated. Once the switch is activated, the apparatus would continue to operate in its normal matter. The locking sleeve concept is shown below in Figure 3.

Figure 3: Locking Sleeve Concept



By adding a dead man's switch, it would allow a rider with no experience to mount/dismount their bicycle with ease without having the bike sway side-to-side. The bicycle would not be able to sway until the dead man's switch is triggered. In the event that no one is operating the apparatus, this would also prevent the concept from swaying, which would eliminate other safety issues that are introduced with moving parts, like pinching and so forth.

In the event that the dead man's switch is triggered to activate the locking sleeve when the rider does not intend so, safety hazards are introduced and injury is likely, in addition to improper operation of the concept. If the bicycle is locked unintentionally, the rider could potentially be thrown off the bicycle in an extreme case if they intended to lean to one side or the other. It would take much time and dedication to Figure the best place for such a switch where its use would be optimal.

A functional decomposition diagram of the Locking Sleeve Concept can be found in Appendix E.

Tilting Support Concept

A fourth design concept consisted of two U-shaped supports that allows the bicycle to sway side-to-side about the contact point of the back wheel using pins. The design consists of a base that allows for the U-shaped supports to move, lengthwise of the bicycle, either further from the point of contact of the back wheel or closer, dependent upon the size of the bicycle wheel. This device also consists of a side-to-side resistive unit that consists of a three-disk in-line system that utilizes the characteristics of elastic bands to provide a resistive force. The shaft about which the bicycle rotates will be attached to the center disk. The two outer disks will be attached to the center disk via elastic bands. So when the rider opts to turn, this unit will provide a yaw resistance to make sure that the bicycle does not tip over. To allow for adjustability in the yaw resistance, the rider will either have to separate the two outer disks further from the central disk to increase the resistance or move the outer disks closer to the central disk to decrease the yaw resistance. The tilting support concept is shown below in Figure 4 and Figure 5.

Figure 4: Isometric View of tilting support concept

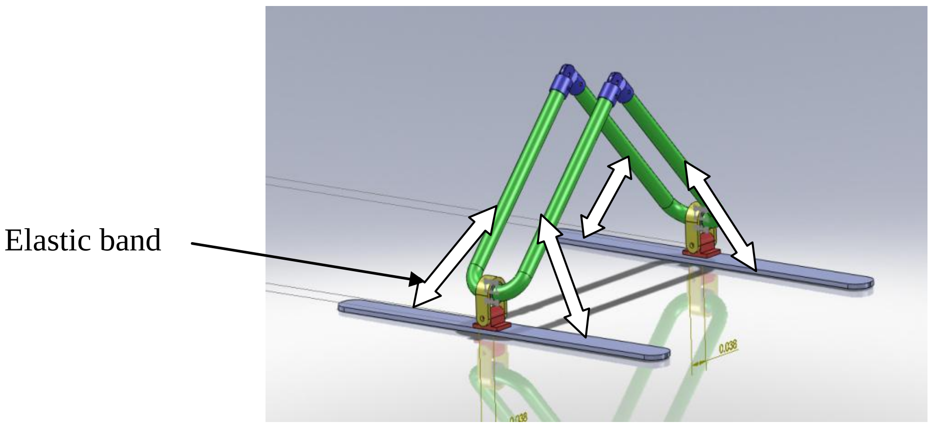
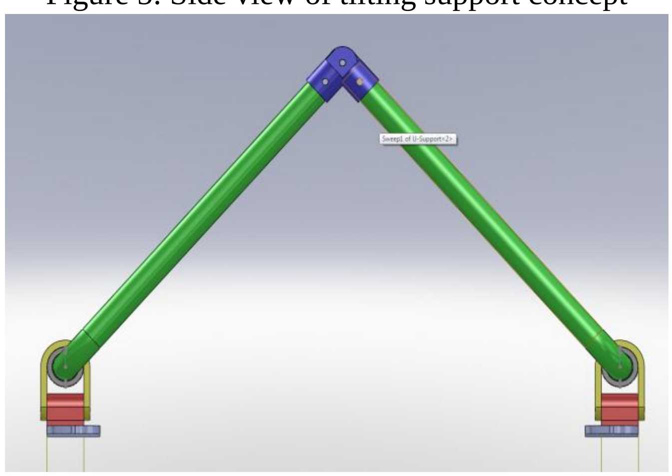


Figure 5: Side view of tilting support concept



This design is completely fresh in thought and allows for extremely easy adjustability. For example, instead of having to lift the bike to mount the bicycle into the design, the user would only have to adjust the U-support to the appropriate height of the bicycle's back wheel axel. Once the bicycle is attached to the design, the user would have to lock the U-supports into the appropriate slot for the size of the bicycle's wheel and the bicycle is ready for operation. The design also consists of an easily adjustable resistive yaw unit. Unlike the Kurt Kinetic Rock and Roll Pro, where the user has to obtain a screw driver to tighten the screws in its spinal design to adjust the yaw resistance, the user just simply has to twist the disks to preset locations to increase or decrease the resistance.

In addition to its adjustability, the folding U-supports make the design very easy to store. For storage, the U-supports simply would need to be detached from its base and folded. All components would thus be easily storable due to the relatively small volume that the design would envelope.

An issue still present with this design is that this design still does not accurately simulate turning the bicycle. Although balance is very clearly addressed with this model, if the rider were to turn, the rider would not feel if though they would be turning a bicycle if they were riding outdoors due to the fact that the front wheel is fixed and the movement of the bicycle cannot compensate for the impulse created by turning he bicycle.

A functional decomposition diagram of the Tilting Support Concept can be found in Appendix E.

Inverted Pendulum Concept

To address the issue of simulating turning, our fifth design involves an apparatus that treats the bicycle like an inverted pendulum. The back wheel would be attached to a base that allows the back wheel to rotate about the vertical axis through the contact point of the back wheel. The front wheel of the bicycle would be attached to another platform that works to make the total center of mass of the system to balance directly over the contact point of the bicycle. The back wheel base and front wheel apparatus would be attached by a telescoping tube to allow for adjustability in bicycle sizes. Since the normal operation of a bicycle outdoors operates similarly to an inverted pendulum, this design would most closely be able to simulate riding a bicycle indoors. The inverted pendulum concept is shown below in Figures 6 and 7.

Figure 6: Isometric view of Inverted Pendulum Concept

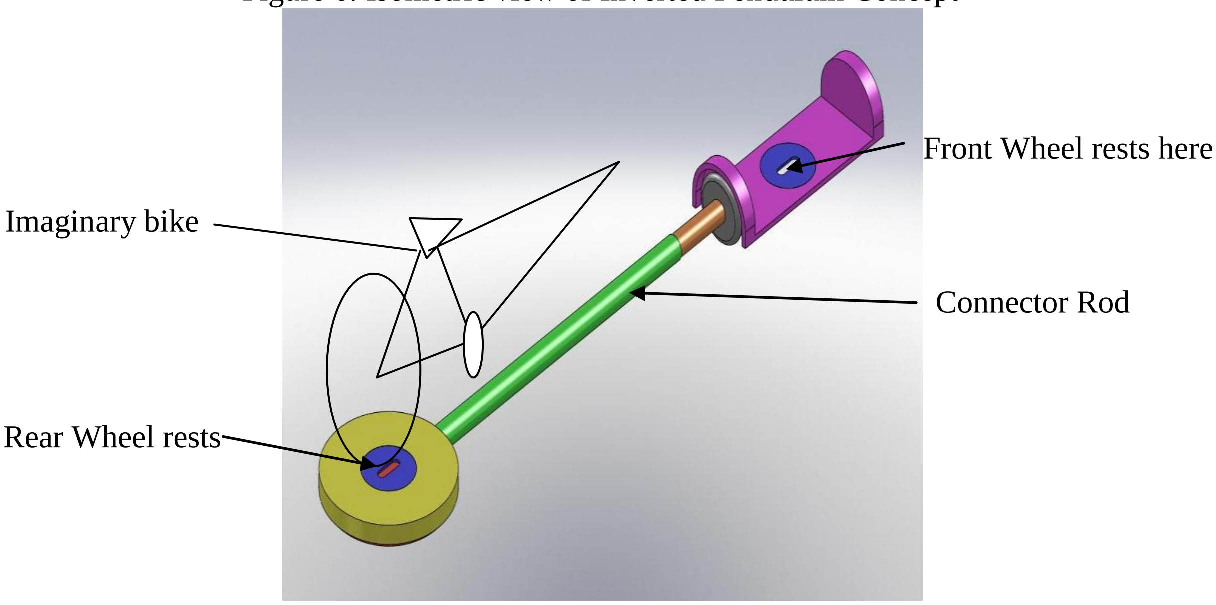
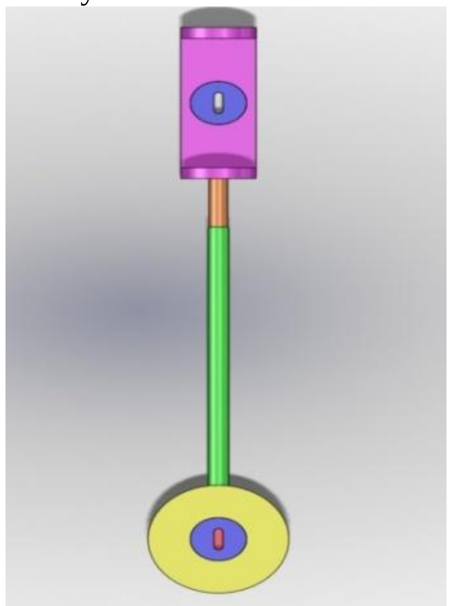


Figure 7: Birds eye view of Inverted Pendulum Concept



Although this design would be revolutionary, there are many other issues that would have to be addressed because of the nature of this design. First, because our design would most likely require a motor and data acquisition from a number of sensors, this design would require electricity. By having the front wheel attached to a moving apparatus, it is crucial to keep electrical wires clear of the front wheel apparatus to prevent a safety hazard. Other options would include batteries or rechargeable batteries, but this would add extra bulk and expenses. Another issue would be the bulky nature of this model compared to other designs. Due to the necessity of having the front wheel connected to the back wheel, this design will inevitably be larger than other designs. With the use of a telescoping tube that connects the front wheel apparatus to the back wheel base, the storable volume will be minimal compared to the operational volume.

Other issues that would have to be addressed would be the way to attach the wheels to the apparatus. The front wheel will have to be able to rotate about the vertical axis through the contact point of the tire to the apparatus as well as yaw. This makes attaching the front wheel to the apparatus very difficult and challenging. In addition, this design consists of many moving parts, which introduces safety hazards. Many measures would have to be taken to reduce the safety hazards to a minimal.

A functional decomposition diagram of the Inverted Pendulum Concept can be found in Appendix E.

Concept Selection

The following section will describe in detail the methods used to generate our alpha design as well as a detailed description of our alpha design.

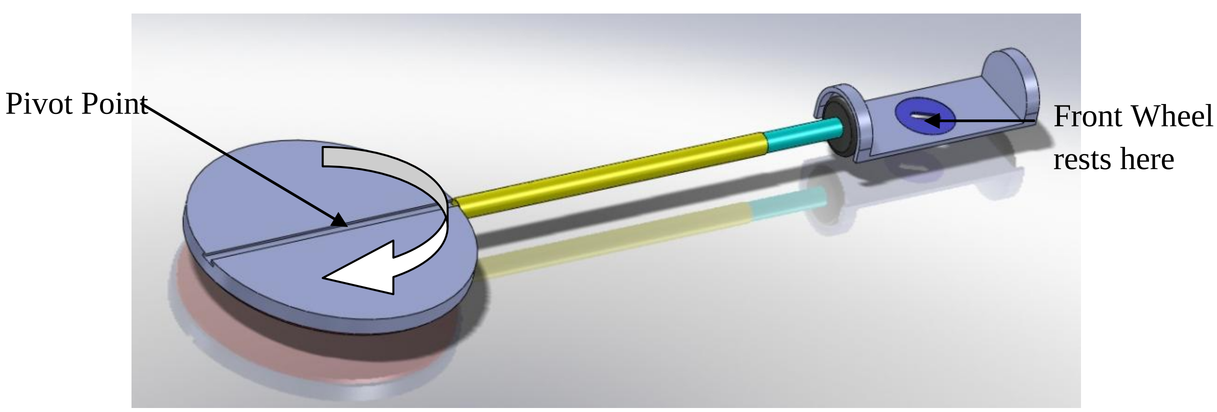
Process

To determine our alpha design, our team evaluated the five best designs together using a Pugh Chart, which can be located in Appendix F. Each concept that was generated was evaluated with each of the customer requirements. If the concept satisfied a specific customer requirement, then the concept was given a "+" for that requirement, otherwise the concept was given a "-". Then, after evaluating the performance of each concept with the relative importance of the customer requirement, which was determined using the QFD, our team collaborated to design a concept that would serve as a hybrid between all designs. This hybrid design, also known as the alpha design, was then evaluated similarly to all previous designs to make sure that all important customer requirements are satisfied.

The Alpha Design

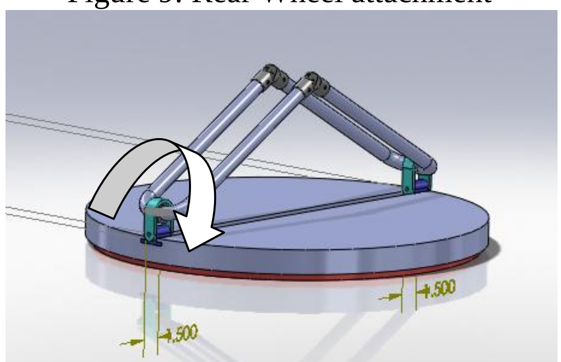
During our initial design phase, we held many brainstorming sessions. During these sessions each member came up with as many ideas as possible that could be used to meet our engineering specifications and customer requirements as given in our QFD chart. Our alpha design is an amalgam of the best parts of the many individual ideas we came up with during our brainstorming sessions as determined by our engineering logic and the Pugh chart we created. During our brainstorming session, new problems were encountered, such as how to accurately simulate turning of the bicycle by simulating the forward momentum that provides a straightening force upon the rider while turning. In order to simulate this we took elements from the inverted pendulum system described in the concept generation section. This design treats the bicycle itself as an inverted pendulum and uses a motorized control system to keep the bicycle upright. The back wheel of the bicycle attaches to a circular base on thrust bearings that allow it to rotate freely. The front wheel of the bicycle attaches to a motorized platform that will rotate about the pivot point of the rear wheel. The wheel is placed on a smaller rotating disk so as to allow the front wheel to be turned while on the motorized platform This design simulates not only the turning of a bike, but also the momentum that comes from riding a bike while turning that keeps the rider upright. The pendulum section of the alpha design is shown in Figure 8 below.

Figure 8: Pendulum section



The next section is the attachment between the rear wheel and the rotating base of the pendulum design that attaches to the front wheel. This design incorporates many elements from the tilting support concept and encourages proper balance on the bicycle. This section consists of two U-shaped supports that are attached to the rear wheel at the axle. The supports are able to fold, allowing for use of many different bicycle sizes. The bottoms of these supports are attached to pins that are aligned with the bicycle, allowing it to fall to either side naturally. This system is also attached to a resistive unit that prohibits the side to side falling motion in order to supplement balancing. This resistive unit is designed so it can be variable, allowing for greater, or less resisting force to motion and is described above in the concept generation section. This section will also take elements from the locking sleeve concept by adding a dead man's switch, locking the system from movement when it is released. It will act in two manners, one will drop the locking sleeve over the leaning pins and one will lock the front wheels in place, preventing it from swinging around. Figure 9 below demonstrates this section of the concept.

Figure 9: Rear Wheel attachment



The final part of this system deals with the resistive force to pedaling. The system is designed to create variable resistive forces to pedaling to simulate different biking inclines and to strengthen the bicycler. This design consists of a cylinder that is placed against the rear wheel. As the rear wheel turns the cylinder will resist the motion. The cylinder will be placed on an axis that is attached to an electric motor that will provide electro-magnetic force that will resist motion. Other designs are also under review in the event that this system is not feasible. These systems will utilize fluid resistance, similar to current market products. This resistive unit and the rear wheel attachment is designed so it can be removed from the pendulum and used separately if electricity or space is a concern to the operator. Figure 10 and Figure 11 below demonstrates the complete alpha design concept.

Figure 10: Alpha Design Isometric View

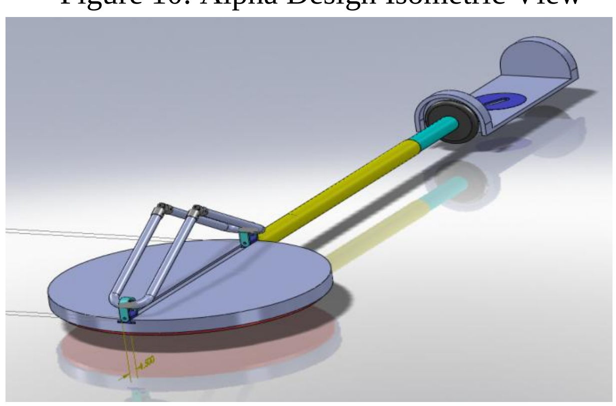
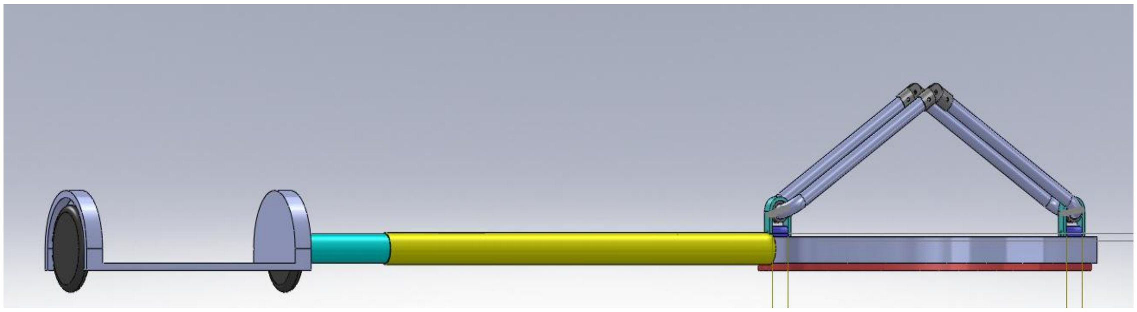


Figure 11: Alpha Design side View



This concept has a few problems associated with it as well however. The mechatronics required to make this a viable design are very complicated and most likely very expensive as well. Placing a motor, and the different actuators and sensors as well as a power supply within the front wheel base will be difficult to manage while still keeping the system non-bulky. The overall system, will fail on some customer requirements such as space considerations as well as portability. The overall system will be bulky and the moving parts could be dangerous to be around.

In an ideal world, this would be a great system. However, the time to manufacture a full working prototype would be enormous and the cost of such a system could well be out of the 400 dollar budget given us.

However, from the use of our Pugh chart, and all considerations in accurately simulating an outdoor bike riding experience, this is the only design that accomplishes the most important aspects of this project. This alpha design will imitate the real world feel of an outdoor bicycling experience and help teach how to balance and turn. It accomplishes this by rotating the entire bicycle about an axis in order to simulate the experience of forward momentum while turning a bicycle. It teaches the child balance by having variable resistive forces attached to the rear wheel area in order to supplement and build balance, and finally it utilizes a resistance to pedaling that will help strengthen the rider and provide a realistic riding experience.

Concept Description

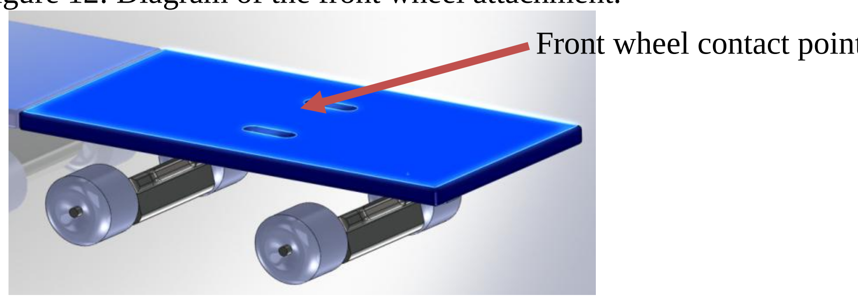
Our final design is a culmination of a long design process and many designs and ideas were developed to solve the individual design requirements given to us by Med-Rehab Milestones. However, because no single design fully solved all the design requirements, multiple designs and ideas were combined to create our final design. Pieces of the best designs and ideas were selected and carefully placed together to create a new unique design that would completely simulate riding a bicycle. Then taking this alpha design, improvements were made and engineering intuition was used to reshape it into the current final design.

Front Wheel

Our final design consists of a bicycle, of any size, and provided by the user, attached to two parts. The front wheel of the bicycle rests on a small, motorized, wheeled platform. The front wheel will be secured to the platform by two straps that are threaded between the spokes and attached to the platform. This front wheel attachment is designed to remain flat as the bicycle leans so that as the bicycle leans to either direction, the trail will cause a torque on the front wheel to turn it toward the direction of the lean, requiring the rider to apply a torque in the opposite direction to control it. This simulates the effect of turning on the front wheel of a bicycle and forces the rider to react in the same way.

In addition, the front wheel will operate similar to an inverted pendulum. It will contain an electrical system that utilizes an optical encoder, a labView program, and a motor to achieve such a result. The front platform's operation will thus provide a corrective force the will work to center the center of mass of the rider directly over the contact points of the wheel. Figure 12 below show how the front wheel attaches to the bicycle.

Figure 12: Diagram of the front wheel attachment.



Back Wheel

The rear wheel of the bicycle is attached to the inside of the rear frame. The hub nuts of the rear wheel are grasped and supported by two rods on both sides to support the bike. These two rods are inserted within the mounting assembly and can be retracted and extended by turning a knob on the outside of the mounting assembly.

Two gyro wheels with a pulley attached to each will be rotating on the same axis as the rods grasping the rear wheel of the bicycle. The pulley will be attached by a series of bolts. There will be one gyro wheel on each side of the rear wheel. The gyro wheels will rotate freely on the rod with the use of needle bearings. Electric energy from a motor will be transmitted to the gyro wheels in rotational energy by use of a belt and pulley system. The motor will be attached to the back of the U-Support and coupled to the belt system using a shaft that attaches the belt from the motor shaft to the belts attached to the pulleys. Figures 13 and 14 below show the diagrams of the mounting assembly.

Figure 13: Diagram of the mounting assembly without gyro wheels

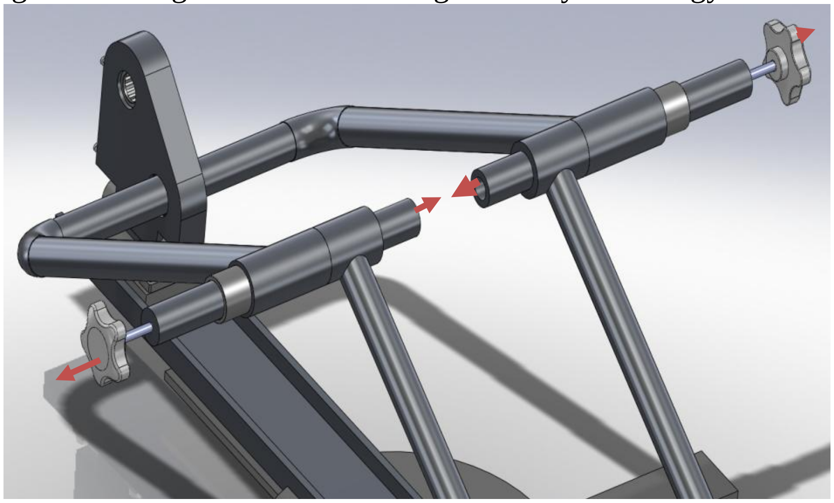
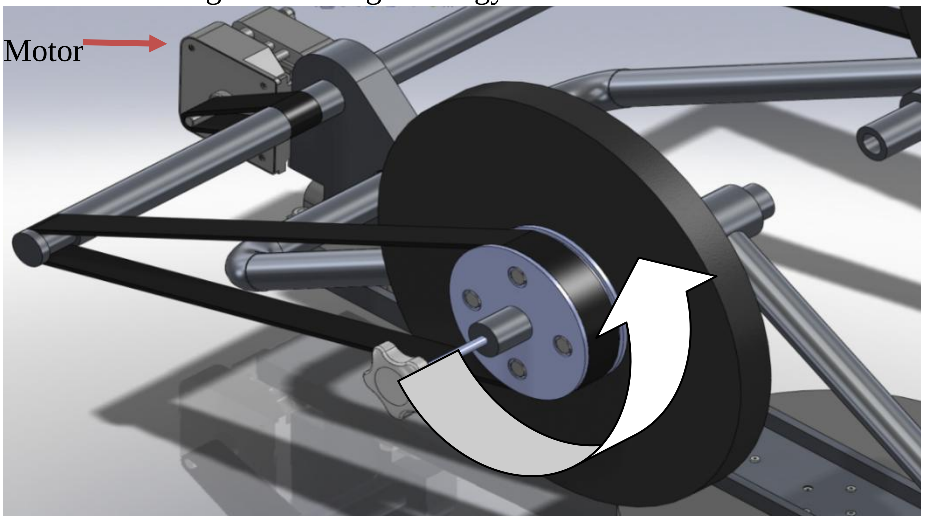
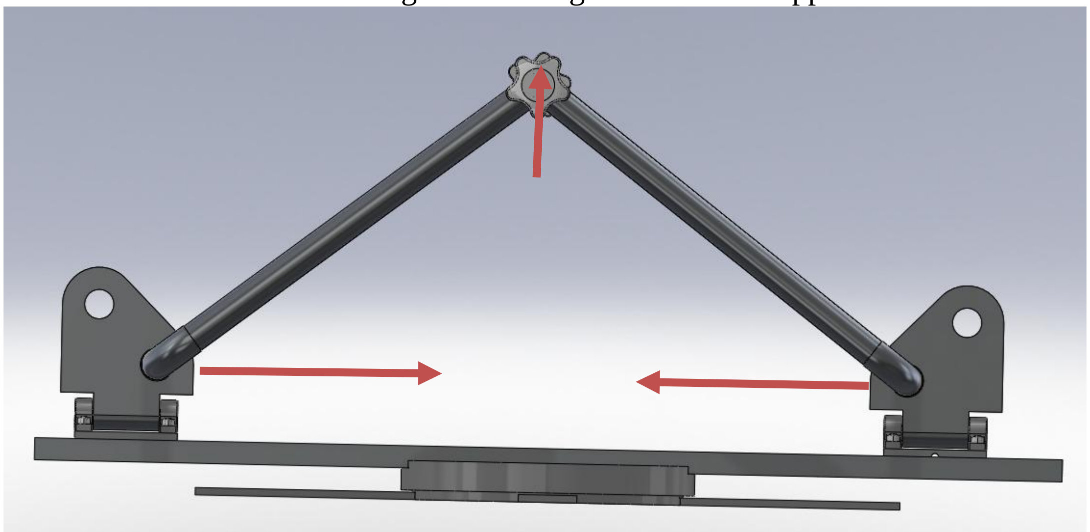


Figure 14: Diagram of gyro wheels and belt



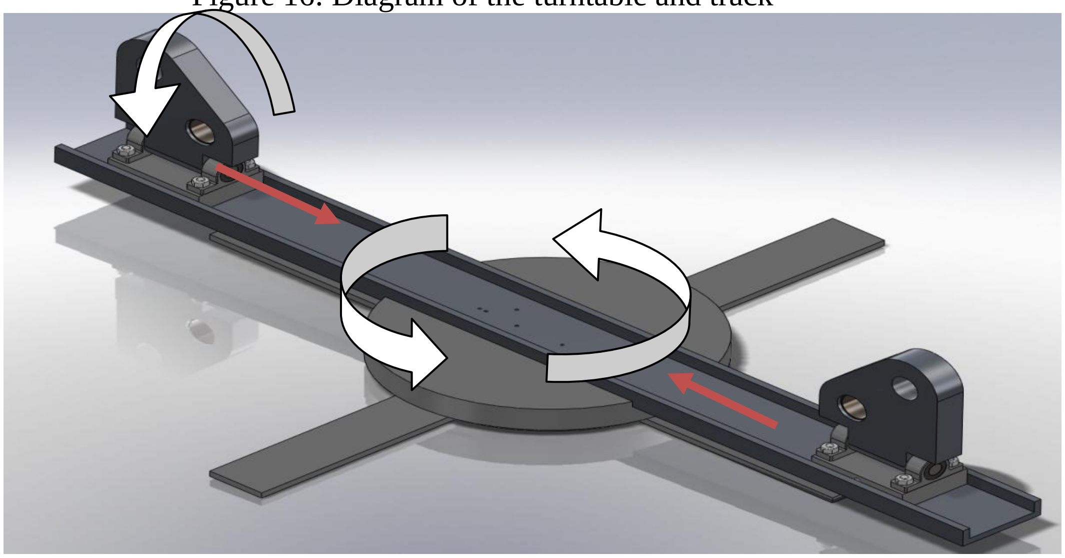
The mounting assembly and rear wheel is supported by two U-shaped supports. These supports are then attached to a joint that allows for the bicycle to lean. The joints are allowed to lean with the use of mounted bearings and shafts in which the joints set upon. The bearings are attached to high-density polyethylene blocks called a sliders that easily slide. The sliders are permitted to move closer or further from the center of the assembly to allow for variable bicycle sizes. To keep the blocks from sliding while in operation, pins with predetermined holes for various bicycle sizes will be able to lock the sliders in place. Figure 15 below shows the U-supports and how they can scissor to accommodate for various bicycle sizes.

Figure 15: Diagram of the U-Supports



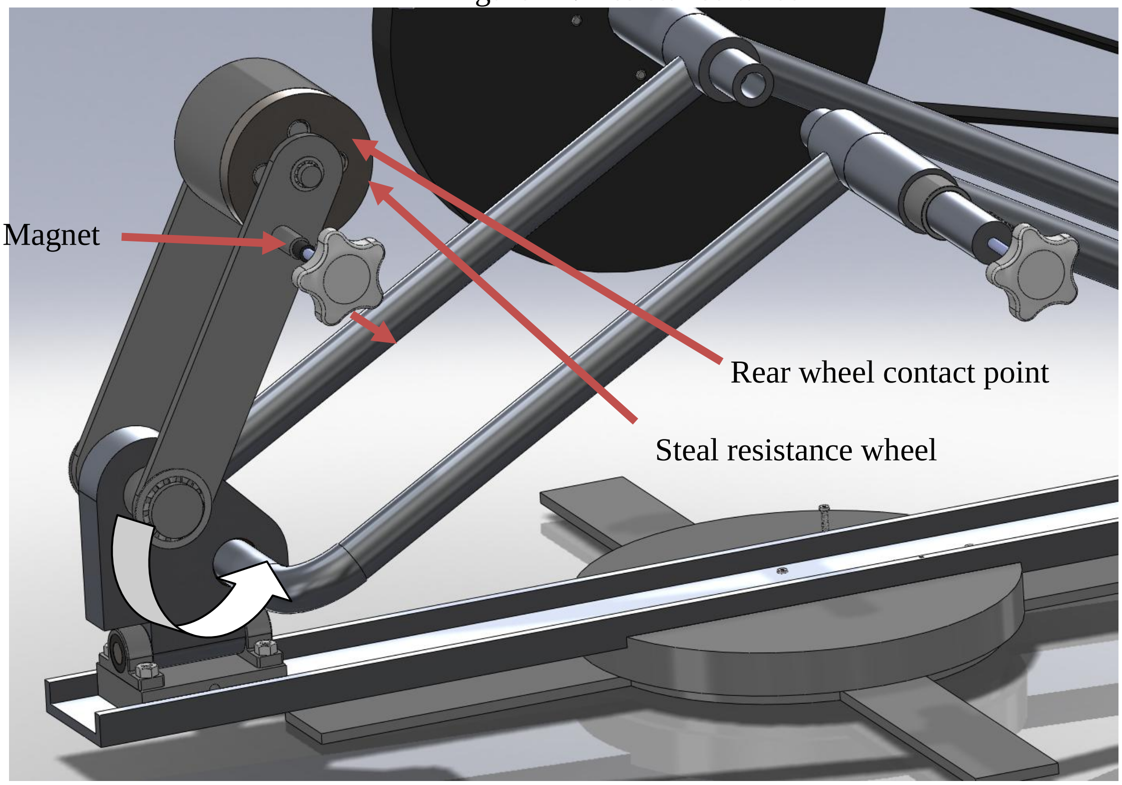
The sliders are on an aluminum track that is attached to a circular plastic plate via bolts. The circular plate lies on a torsion bearing to allow it to rotate like a turntable. This allows the entire system to rotate about the contact point of the rear wheel and the "ground". Figure 16 below shows the turntable and track for the sliders and how they rotate.

Figure 16: Diagram of the turntable and track



The rear wheel will also be pressed against a resistance wheel. This resistance wheel will use a magnetic eddy current and act as an eddy brake. As the rear wheel spins, the friction between the plastic contact point and the rear wheel will rotate the plastic contact point wheel. The plastic contact point is bolted to a steel plate that rotates the steel plate at the same speed as the plastic contact point. A very strong magnet will be applied by rotating a knob. To increase the resistance the user will need to move the magnet closer and the user will need to move the magnet further to decrease the resistance. As the magnet comes close to the steel plate, the spinning of the disk will affect the magnetic field and eddy currents will cause a resistance to further change to the magnetic field, causing a resistive drag on the spinning of the resistance wheel. Figure 17 below shows the resistance wheel.

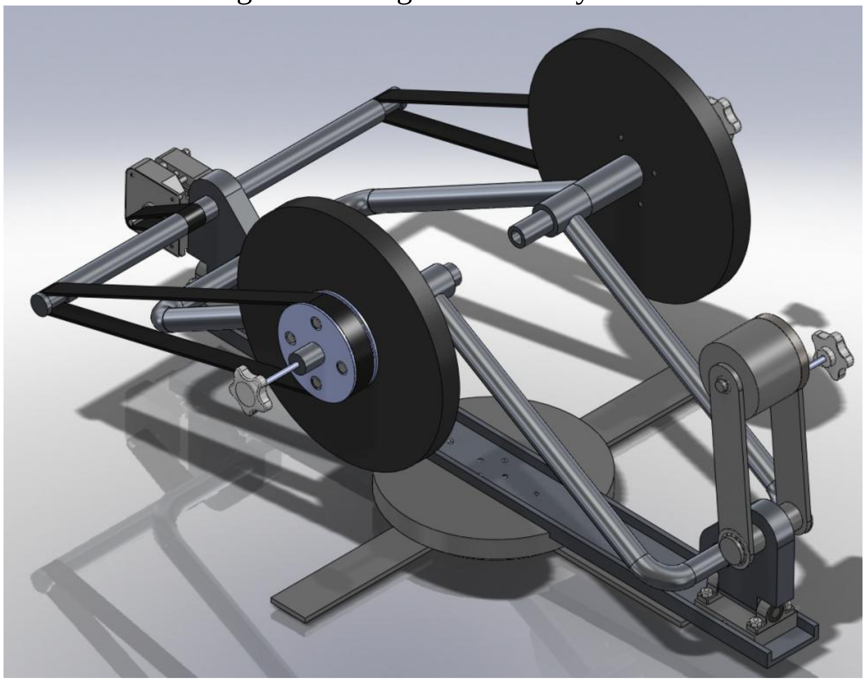
Figure 17: Resistance wheel



The application of the gyroscopes will allow the user to vary the leaning resistive by utilizing physics principles that primarily focus on the Conservation of Angular Momentum. When a torque is applied to a gyroscope, there will be a resistive force to the change in orientation dependent upon the rate of change of the angle change and angular speed of the gyro wheels. At faster angular speeds, the gyro wheels will provide a larger leaning resistance, while at lower speeds, the gyro wheels will provide a smaller leaning resistance for more advance riders.

To accommodate for turning, if the rider were to lean, the combination of precession and the inverted pendulum function of the front platform will cause the entire system to very closely simulate the turning of an on-road bicycle. Precession is a phenomenon experienced with gyroscopes where if you tilt an upright gyroscope to either side, it will resist the tilting and rotate in the direction it is being tilted much like the operation of a bicycle. This resistance can be varied for different skill levels of rider, based on how fast the gyro wheel is spinning. Figure 18 below shows a diagram of the complete rear wheel assembly.

Figure 18: Diagram of rear system



This system should fully mimic riding a bicycle outdoors by providing a resistive force to pedaling, providing a leaning resistive force, simulating turning the bike and providing forces to the bike and rider that would be prevalent in actual riding. A Bill of Materials for all parts for the assembly and manufacturing of the final design are located in Appendix A.

Parameter Analysis

Since the beginning of the design process, our design has undergone several changes to its functionality to introduce a gyroscope to provide the user of our system to be more stable while the system is in use. This is an improvement from our Alpha design because it provides a real-time response to our system. When the user or the environment provides a stimulus to the system it responds instantaneously. In the following subsections, we will present information that explains why we believe that a gyroscope provides the best method of simulating balance and turning a bicycle. We will also produce information on how it aids in teaching balance.

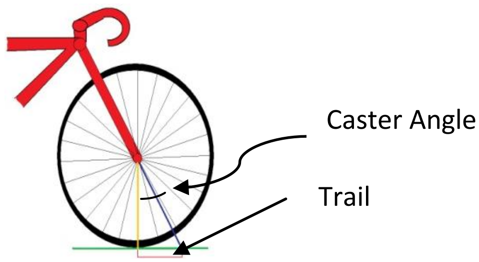
Theory behind our design

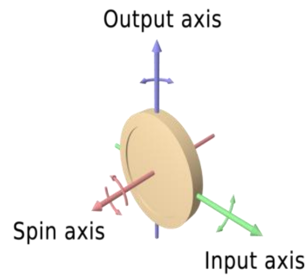
The following section will explain in detail, the equations and principles used to come about the logistics of our design.

Simulating Balance (Gyroscope provides a side-to-side resistive force aiding in the balance of the bicycle): Our design relies on using the precession and conservation of angular momentum of a gyroscope to mimic the trail/caster effect of a bicycle. Trail can be thought of as the extent to which the front wheel of a bicycle follows its steering axis. This can be shown in Figure 19.

Figure 19: Trail and Caster angle of a bicycle

Figure 20: Rotation about the axes of a Gyroscope





The trail of a bicycle makes it easier to ride because it links the lean angle of the frame with the turning angle of the fork. Leaning the bike causes the fork to turn in that direction, because the frame is lower after the fork has turned. Trail effect causes sideways force on the front tire to produce a torque about the steering axis also known as the output axis. This tends to lower the center of gravity of the bicycle. Also shown in Figure 19, the steering axis angle, also called caster angle, is the angle that the steering axis makes with the horizontal or vertical, depending on convention. The steering axis is the axis about which the steering mechanism (fork, handlebars, front wheel, etc.) pivots. The tendency of a castor (wheel) to align itself with the direction of travel is based upon the center of thrust being offset from the axle of the wheel.

We believe that a gyroscope will provide a side-to-side resistive force aiding in the balance of the bicycle. Based on the Conservation of Angular Momentum, an object spinning will remain spinning unless a force disturbs it. The amount of angular momentum of an object has always remains constant. The angular momentum is measured by the mass, its velocity, and its position from the axis of rotation. The product of these three quantities (mass *m*, velocity *v*, radius *r*) must remain constant. Gyroscopic action is the characteristic trait of a spinning disc to resist certain changes in motion. As the wheels rotate they will begin to stabilize the bike and do their part to keep the bike from toppling over.

Gyroscopic action is the force that keeps a spinning top from falling. From the information above it is easy to see that increases in angular speed, radius, and mass will increase the angular momentum and will make the resistive force greater to provide more stability. Also because the gyroscope would be connected directly to our system it would provide an instantaneous force resisting the rider from falling off.

Simulating Turning (Precession of a gyroscope simulates turning): Precession is a change in the orientation of the rotation axis of a rotating body. Torque-induced precession (gyroscopic precession) is the phenomenon in which the axis of a spinning object (e.g. a part of a gyroscope) "wobbles" when a torque is applied to it. This phenomenon is commonly seen in a spinning toy top, but all rotating objects can undergo precession. If the speed of the rotation and the magnitude of the torque are constant the axis will describe a cone, its movement at any instant being at right angles to the direction of the torque. In the case of a toy top, if the axis is not vertical, the force of gravity tending to tip it over applies the torque. In theory, this behavior will cause the bike while on the trainer to stay upright while in operation.

Gyroscopic precession means that if a gyroscope is tipped, the gyroscope will try to reorient to the spin axis of the rotor in the same direction. If released in this orientation, the gyroscope will precess in the direction that it is on a tilt because of the torque exerted by gravity on the gyroscope.

For our project, if the rider leans to the right, then the gyroscope will turn the bicycle to the right, similar to the normal operation of a bicycle.

Simulating Pedaling against Variable Force (Eddy currents to apply a resistive force on the rear bike wheel for varying road conditions): For our system, we chose to use plastic for our resistance wheel. It eliminates the need of a bearing for the interior diameter of the resistance wheel because ultra high molecular weight polyethylene exerts very little friction. Due to this fact, we plan to coat/treat the contact surface to increase friction to decrease the chance of slippage when in operation. We would like score the surface or apply a friction tape around it, both are cost effective ways of applying friction to our system given our budget. A ferric steel plate is attached to one end of the plastic wheel. A powerful magnet will then be placed in a mount near the steel plate that can be brought closer or further to the steel wheel. We chose the steel plate because its magnetic properties when rotating and near a magnetic field will produce an eddy current resistance. We can vary the amount of force applied by a magnet closer to provide more resistance and further away to provide a smaller resistance.

Equations of Motion for a gyroscope: The fundamental equation describing the behavior of a gyroscope is:

$$\tau = \frac{dL}{dt} = \frac{d(I\omega)}{dt} = I\alpha \qquad \text{Eq. 1}$$

The vectors τ and L are, respectively, the torque on the gyroscope and its angular momentum, the scalar I is its moment of inertia, the vector ω is its angular velocity, and the vector α is its angular acceleration.

We arrive at this equation due to the fact that a torque applied perpendicular to the axis of rotation, and perpendicular to the angular momentum, results in a rotation about an axis perpendicular to both the torque and the angular momentum. As discussed earlier, this is precession. The velocity of the angular velocity of precession ω_P is given by the cross product:

$$\tau = \omega_P \; X \; L \qquad \text{Eq. 2}$$

Under a constant torque, we notice the gyroscope's speed of precession ω_P is inversely proportional to the magnitude of its angular momentum:

$$\tau = \omega_P \; X \; L \cdot \sin(\theta) \qquad \text{Eq. 3}$$

Where θ is the angle between the vectors ω_P and L. Consequently, the gyroscope's spin slows down its angular momentum and decreases so the rate of precession increases. This continues until the device is unable to rotate fast enough to support its own weight, when it stops precessing and falls off its support, mostly because friction or drag against precession cause another precession that goes to cause the fall. If this was implemented in our system we would notice that at relatively low speeds, the bike would tend to be less stable.

We can calculate the maximum angular speed of a gyro for the given geometry and material of the flywheel that we chose, based on the maximum tilting force observed by the user. The following proof was used to verify this. Let *M*=moment, *I*=moment of inertia of the flywheel about its axis of spin, F_T=tilting force, *m*=mass of flywheel, *r*=radius of flywheel, *R*=length of the flywheel's axle (distance to the flywheel's pivot point), ω_P=rate (angular velocity in radians per second) of precession, ω_f =spin (angular velocity in radians per second) of the flywheel, *g*=acceleration due to gravity. Then:

$$M = \mathrm{I} \cdot \omega_p \cdot \omega_f \qquad \text{Eq. 4}$$

$$R\ X\ F = \mathrm{I} \cdot \omega_p \cdot \omega_f \qquad \text{Eq. 5}$$

$$F = \frac{\mathrm{I} \cdot \omega_p \cdot \omega_f}{\mathrm{R}} \qquad \text{Eq. 6}$$

$$I = \frac{m \cdot r^2}{2}, \text{for a solid flywheel} \qquad \text{Eq. 7}$$

$$I = m \cdot r^2, \text{for a flywheel shaped ring} \qquad \text{Eq. 8}$$

Kg, m, s, N, rad, rad/s (converted from RPM) are the units of measure in these equations.

Material Selection: In an effort to choose the best materials to support the loads that our rear frame would experience, we created a simple model to characterize the stresses and load our system. The model itself focuses on the rear wheel system, as it is responsible of most of the stabilizing forces to be exhibited by our system when in use.

For the weight of user and bike, we determined from our research that the distribution of weight for a bicycle and its user is represented as two-thirds on the rear wheel and one-third front wheel. All loads and forces are represented as equivalent "nodal" loads for simplicity. With these assumptions accounted for, we performed a static forces analysis to find the reactions forces at the ends of our shaft and the moment areas of inertia to find our resulting moment and max bending stress, which was 42060 psi. Using this we were able to choose a material for the gyroscope shaft. We choose steel for the gyroscope shaft, giving this component a safety factor of 2.13. We deemed this the most crucial area to for deciding the materials that we would for our system as the greatest loads will be applied at this location.

All calculations and Figures regarding our model can be found in the Appendix E.

Riding a bicycle seems so basic, but through our research we have discovered the physics behind it is very involved. We want to make sure that the product that we design and produce is as safe as possible for its user, so the formulation of our design is very thorough. At this stage of the design phase, we have found that there is an extensive amount of calculations that are required solving for the forces that are attributed to bicycles dynamics. We feel that it is very necessary to go in depth to prove the validity of our project. We believe that our proposed method for this design is plausible and is backed the accredited research on bicycle/motorcycle physics, dynamics, and stability. The most important equations that we found involved the principles of Conservation of Angular Momentum, trail/caster effect, and precession.

It is with full confidence that we believe and feel that our research and analysis supports our plan to move forward and produce a physical model. The analysis and models that we have produced suggest that this model is very plausible. We do however, realize that more research is required to produce a design and final product that performs as we predict. We are in contact with Professor Perkins and his doctoral student Stephen Cain for assistance with better understanding the physics of bicycle stability and gyroscopes, and the results are promising. In order to get a thorough analysis for the system we would need significantly more time to produce the design that we are presenting. We, however, have decided to move forward with a scaled down, more simplified version of our current design. This means that we will produce a design that does not meet all of our customer requirements. Our scaled down version is no longer adjustable for various bike sizes. This removes a great deal of complexity, weight, and cost to our design. After meeting our sponsor, this change has been approved as the age range of patients that she works with is 7-12 years old and the height range for the children she works with for bicycles is 45-55 inches. This is a plus for us because the bike for children of this age range is the same.

Table 1: Bicycle size chart

Wheel Size	10" and 12"	16"	20"
Age	1.5 - 5 years	4 - 8 years	6 - 12 years
Height	26" - 38"	34" - 48"	48" - 60"

[17]

The dimensions for key parts of the prototype are based on the dimensions of the bicycle for a child ranging from 8-12 years old. Therefore, the primary dimensioned components are the U-supports to user load and gyro wheel, size of the gyro shaft changing diameters, front wheel platform, and the strap to hold the front wheel. The primary shape for all parts was to add functionality, aesthetics, as well as safety, thus all edges are rounded and smooth. The turntable top/turntable bottom/turntable were chosen to be round disk shapes because it safer having the round edges, especially being this system is meant to be used with children. The materials that we chose were based on loads that calculated that the system would undertake, then using CES software selected the material to use for each component. The supplier our mechanical/structural components were McMaster-Carr and Grainger. Our key electrical components (motor and power supply) were purchased using www.allelectronics.com.

The information mentioned above supports the engineering judgments/decisions that we made in proceeding with each phase of the project from Design Review 3 through project delivery at the Design Expo. Upon testing the system without a bike attached, we found that system behaves as expected. However, when the bike is attached, it is obvious that the gyro wheel was unable to produce the force required to keep the bike upright for long periods. Moreover, we recognize that we do need to make additional calculations concerning the gyroscopic force, precession, etc. We focus our efforts on this area of the design because the Conservation of Angular momentum calls for a larger radius for gyro wheel to increase the inertia providing a greater stabilizing force, or force resistive to leaning.

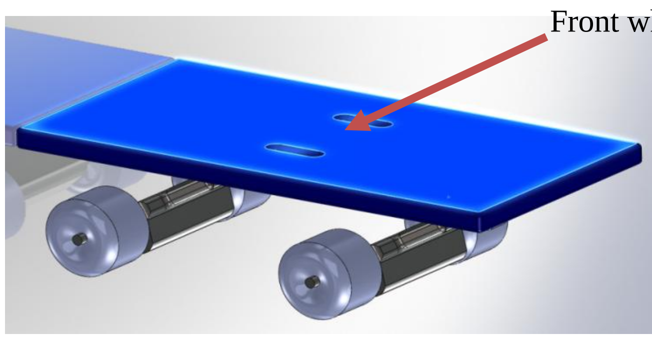
We used CES software, as an aid in selecting materials as well as materials. With this tool, we were able to increase the options of materials that we would use. It was also used to acquire information about the processes to use for mass production of our system. SimaPro software was an excellent resource to have to allow us the ability understand the impact our choices of materials that we use for a given component. It allowed us to determine which material choice has a bigger impact on the environment within each of the EcoIndicator99 damage classifications. We are able to arrive at a conclusion of what damage meta-categories ("human health", "ecotoxicity", and "resources") were most likely to be significant based on the EcoIndicator99 point system. In creating a safety report our team was fortunate to identify possible issues that could arise while handling the materials and components during time in the shop, during the assembly process, and during operation by a consumer. This was very helpful in avoiding key problems like handling one of the U-supports after it have recently welded to a slider joint.

Final Design

The prototype deviates slightly from the final design mentioned earlier. In order to prove that the concept will work, the prototype will not be scaled down and will fit a functioning bicycle. It will be a full size bicycle trainer, but it will be slightly different. During the design expo, the bicycle trainer will have a bicycle attached to it to demonstrate how it works and that the theories behind it are sound.

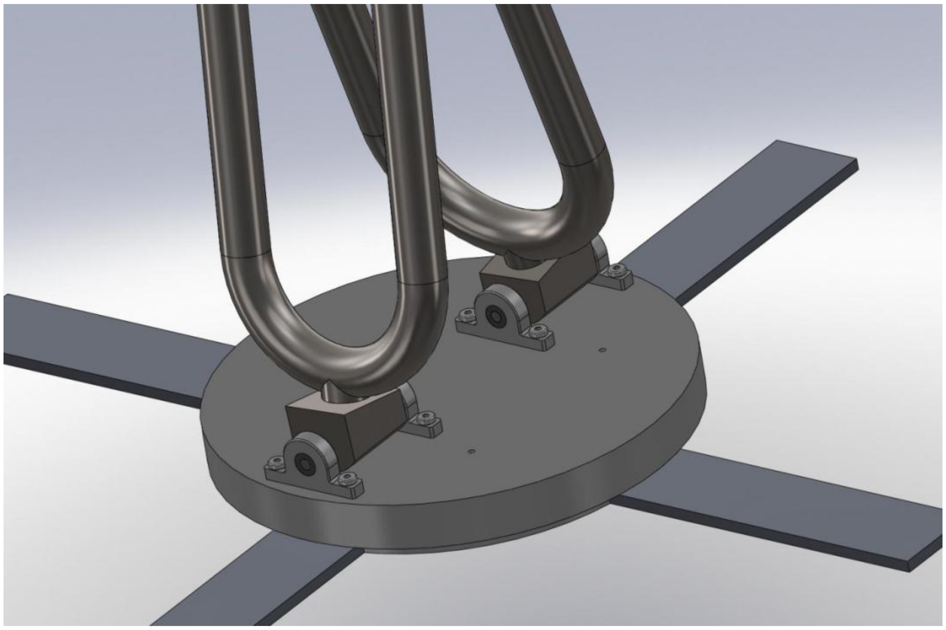
The front wheel design will be slightly different from that of the front wheel final design. The front tire will rest on a platform that has been converted from a skateboard. In addition, it will not contain any electrical components due to cost constraints. Therefore our prototype design will not be able to simulate turning or balance because it will not contain a restorative force that will work to center the rider's center of mass directly over the bicycle wheels. There will be two holes on either side of the wheel with straps coming out of them. These straps will be threaded between the spokes and attached to the platform. These straps will not damage the spokes. Figure 21 below shows the basic design of the front platform.

Figure 21: Diagram of prototype front assembly



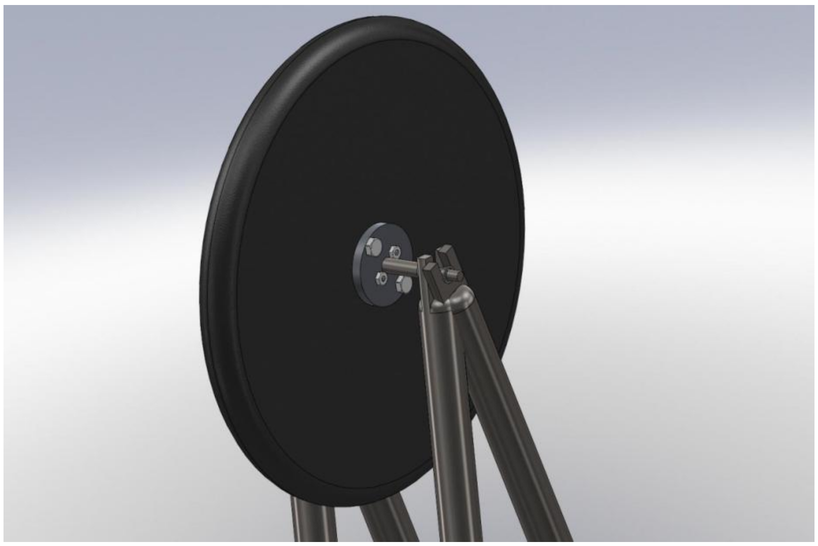
Instead of the originally planned U-Support beams, there will be two bicycle forks in its place. These will be longitudinally and lattitudinally static compared to the turntable base; they will be attached to mountings that are hinged on mounted bearings, so they can still rotate from side to side. These bearings are attached directly to the turntable top, so there will be no sliders or track due to cost constraints. Figure 22 below shows the turntable top, bearings and forks.

Figure 22: Diagram of prototype base



Also due to cost constraints, the rear wheel will be detached from the bicycle, and be replaced by a single gyro wheel. When the rider shifts their weight to turn, the entire system will lean. The presence of the gyro wheel will allow a rider to experience a leaning resistance. Figure 23 below shows the bike mounting and gyroscopic axle and wheel.

Figure 23: Mounting assembly of prototype



In addition, we have to eliminate the use of a multiple output power supply due to cost constraints. Without the multiple output power supply, we will not be able to vary the angular speed of the power supply so the rider will not be able to experience variations in leaning resistance by changing the angular speed of the gyro wheel.

As well, also due to cost constraints, there will be no resistance wheel. With the cost of materials, there was no place in the budget for the sliders, track, real U-Beam supports, multiple output power supply, inverted pendulum system, or eddy current resistance wheel. With luck, if the prototype proves how sound our theory is, someone will be able to manufacture a prototype on a bigger budget, and therefore be able to make a model closer to the original design. Figure 24 below shows the full prototype system.

Figure 24: Full prototype

The only thing that our design will be able to validate for our final design will be the fact that changing the speed of the motor will vary the leaning resistance. To validate, we will analyze the differences in force applied to the system when the motor is off and when the motor is on.

All engineering drawings can be located in Appendix G.

Fabrication Plan

The following section will provide a detailed fabrication plan for the prototype described in the previous section. This section will include all necessary materials complete the design and manufacturing process that is required to complete our design.

Prototype

Due to money constraints, the prototype model will not look a lot like the final design. Numerous design changes were made in order to save time and money. However, all of these changes only affect the secondary functions of the trainer, such as allowing for numerous bicycle sizes, and do not affect the primary functions, such as balance.

The prototype is divided into several parts: front wheel platform, rear wheel base, rear wheel frame, and the gyro wheel. Each piece was fabricated individually and will be constructed out of multiple pieces, some requiring certain procedures in order to put them together.

Before fabrication could begin, all of the components had to be ordered. This included polyethylene and aluminum stock, which will took up the majority of the cost, as well as screws, nuts, bolts, bearings, and steel stock. The polyethylene was used to make the outer shell of the turntable base, while the aluminum was used to create the legs that give the base stability and the steal was used for the u-support legs.

Manufacturing process

The first part is the front wheel platform. It uses parts from a skateboard as the front wheel platform. The design and bottom wheel placement on the skateboard is already very similar to the final design of the front wheel platform. The skateboard is cut down to a manageable platform size and then the wheels reinstalled to this new platform. After this, several slots are drilled into it to allow for the strap that will be used to secure the front bicycle wheel to the front platform.

The second part fabricated was the rear wheel base. First, one piece of polyethylene stock is taken and machined down to a flat plate. A turntable is placed in this hollow area and secured with screws. Next, another piece of polyethylene stock is machined into a hallow circle. This is placed on top of the turntable. Next, the aluminum stock is machined into four long rectangles and secured to the bottom of the polyethylene base to form stabilizing legs. Finally, two sets of sleeve bearings are secured to the top of the turntable.

The third part is the U-support beams that make up the rear wheel frame. This starts as two blocks of steel stock, which are machined into two rod holders. These rod holders are machined to fit between the mounted bearings attached to the turntable top and freely rotate along the axis. The rod holders also have holes drilled into the top to allow for the U-support beams. The U-support beams were originally to be made out of welded cylindrical stock, but due to price constraints, they will be made out of two steal bicycle forks.

The fourth part is the axle between the two forks. A piece of steel rod is lathed down in steps to have at ¼” diameter ends and 1” diameter middle. This rod will act as the axle for the gyro wheel and be placed between 4 ball bearings attached to the ends of the bike forks.

The fifth part is the gyro wheel. A solid 25 lb iron weight was purchased. 2 holes are drilled around the center axis in the weight. Then, two circular aluminum plates machined from extra stock and about 2” in diameter with a ½” center hole are bolted to the outsides of the gyro wheel locking the axle rod in place. Then two more bolts will be placed through the outside aluminum plates and the steel rod axle to create a linkage between the gyro wheel and the axle. As the axle rotates, the gyro wheel will rotate.

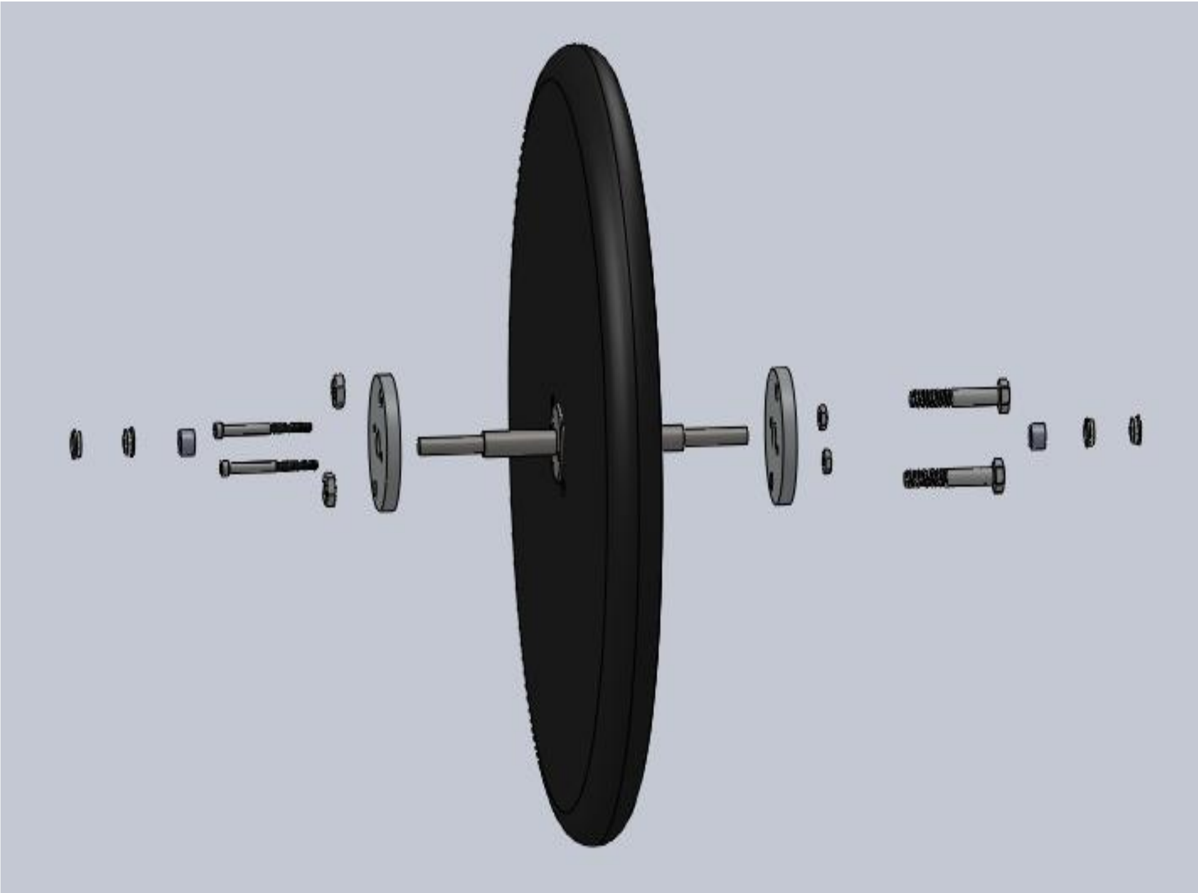
The sixth part is the motor mount and the power supply. A small electric scooter 24v motor is purchased along with a 24v ac to dc linear switching power supply. The motor mount is made from using excess aluminum from the aluminum legs. A small 2x2 plate is drilled in coordination with the screw holes on the motor face. Then a 3x1 inch plate is welded at a right angle to the front plate. Then two 1x1.5 inch plates are welded at a right angle to the sides of the long strip. Slots are drilled into these legs and used to slide over extrusions of the u-support legs. These are screwed onto the u-supports and the motor is attached to the front plate. A belt is then run from the belt gear to the belt gear attached to the axle.

A complete process plan chart that details all of the machining for this prototype can be located in Appendix H. Machine drawings of all parts to be machined can be found in Appendix G.

Assembly

1. Place gyro shaft inside gyro wheel.
2. Slide gyro plates onto gyro shaft and line up holes with holes drilled into the gyro wheel.
3. Slide 2 bolts into inner diameter holes on gyro plates and attach nuts.
4. Slide 2 bolts into outer diameter holes on gyro plate and attach nuts.
5. Slide 1 nylon spacer onto each side of gyro shaft.
6. Slide 2 bearings onto each side of gyro shaft, flanged sides pointing to the inside.

Figure 25: Exploded view of axle assembly

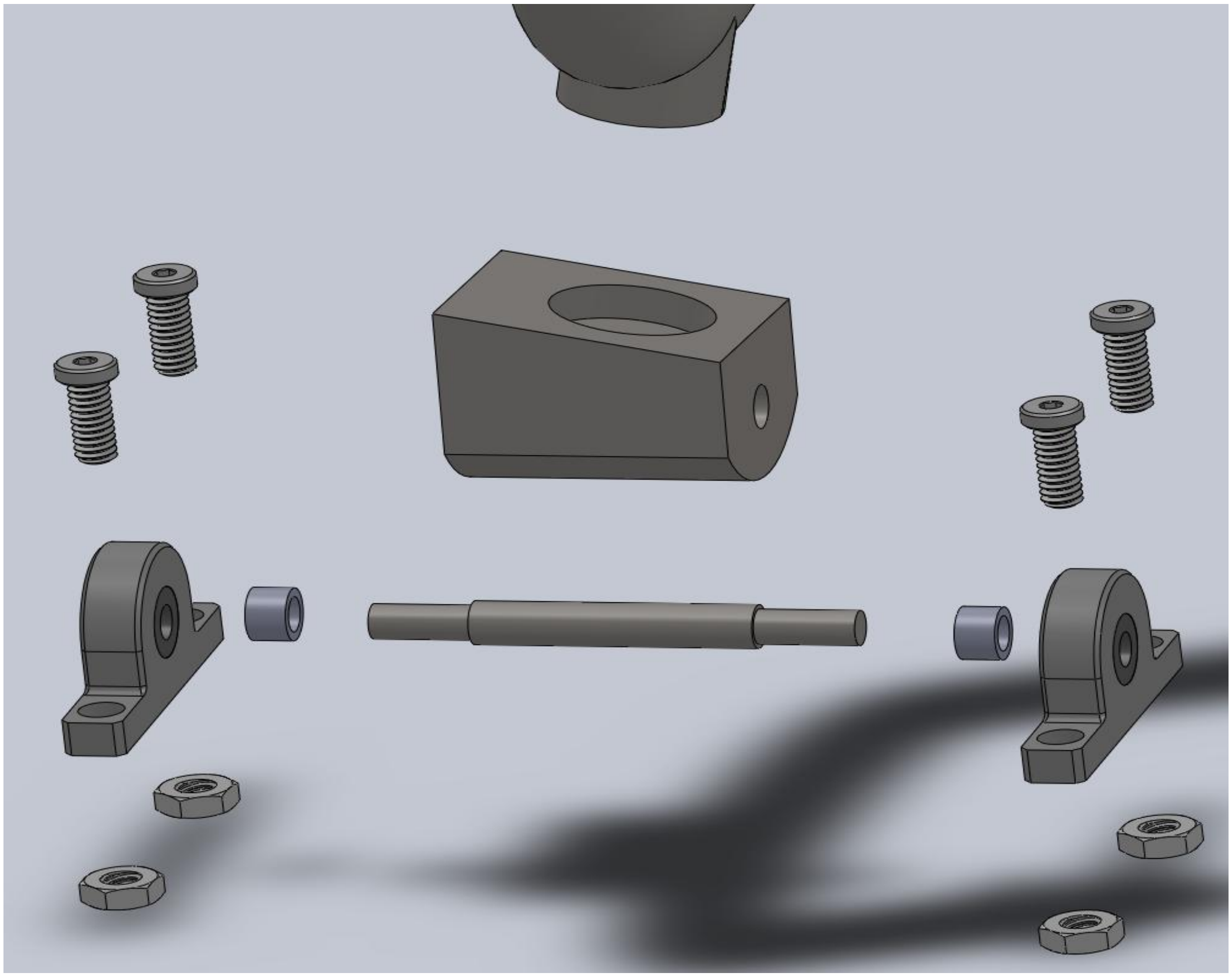


7. Slide slider shaft 1 into joint 1.
8. Place 1 nylon spacer on each side of the slider shaft.
9. Place 1 slider bearing onto each side of the slider shaft.

Repeat steps 7 through 10

10. Slide slider shaft 2 into joint 2.
11. Place 1 nylon spacer on each side of the slider shaft.
12. Place 1 slider bearing onto each side of the slider shaft.
13. Put two bolts into each slider bearing.
14. Put two bolts into each slider bearing.

Figure 26: Exploded view of slider joint assembly

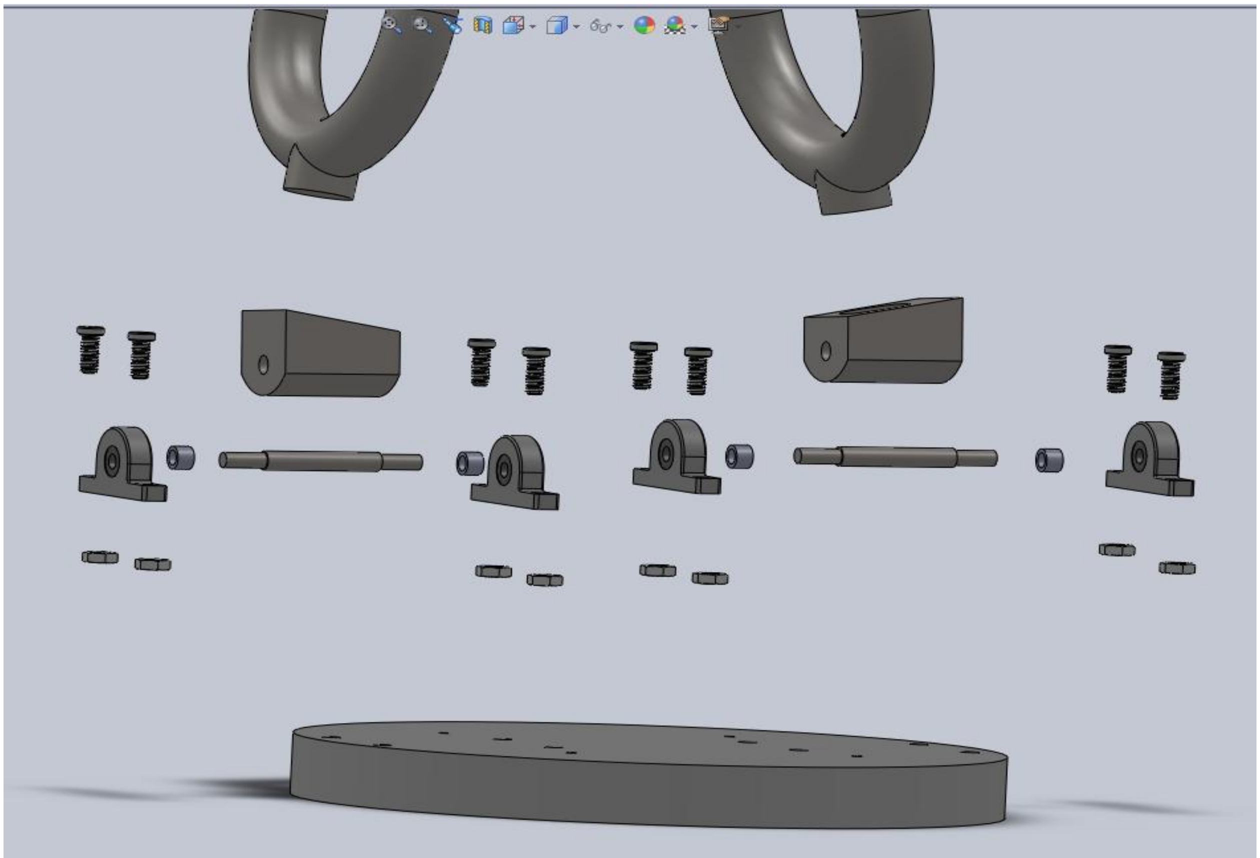


15. Line up slider bearings with turntable top holes.
16. Place slider joint bolts through holes and attach nuts.

Repeat steps 15 and 16 for the other u-support and slider joint assembly

17. Line up slider bearings with turntable top holes.
18. Place slider joint bolts through holes and attach nuts.

Figure 27: Exploded view of turntable top and slider assembly

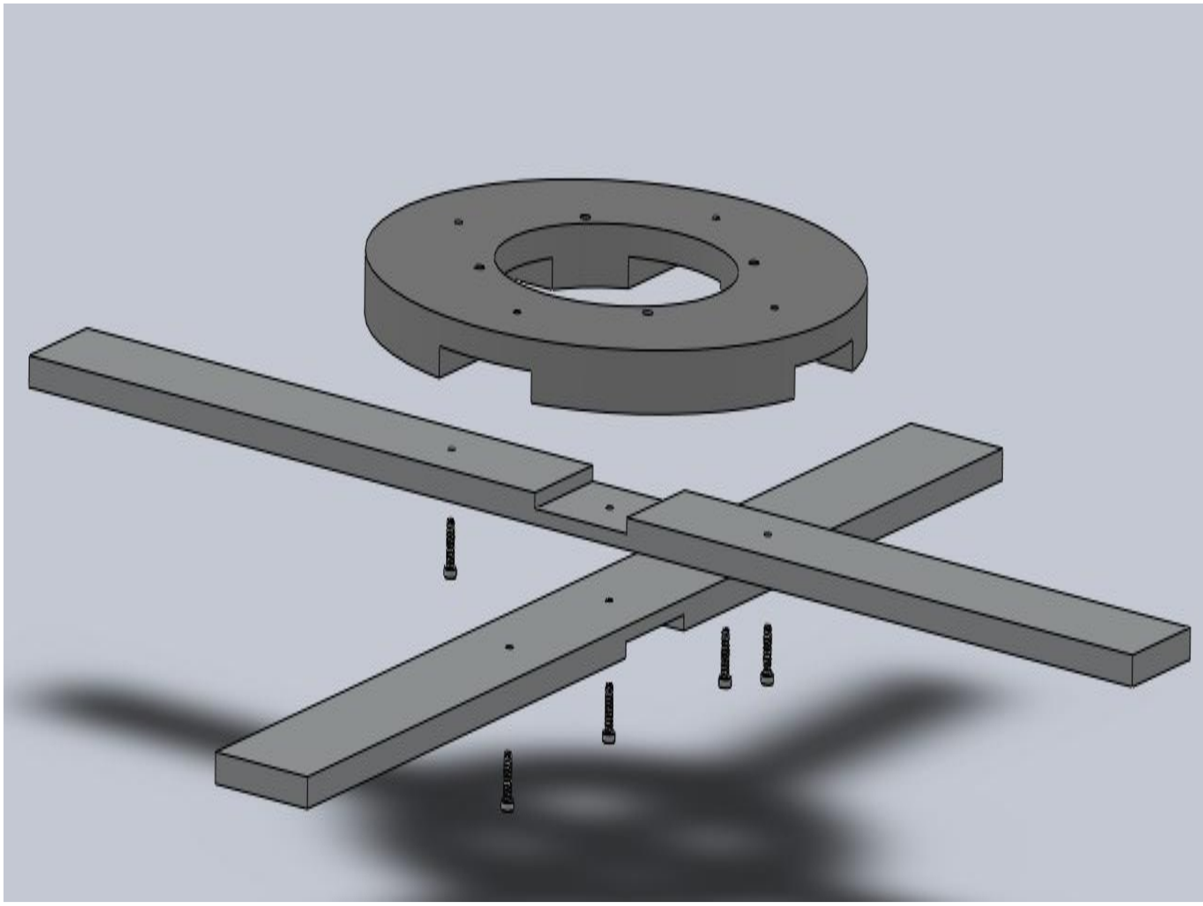


19. Place leg 1 on top of leg 2, lining up the two milled sections so that the top and bottom of each leg are on the same planes.
20. Put 1 bolt through middle hole to hold the legs and attach nut.
21. Put turntable base on the legs, lining the legs up so that they fit into the slots on the turntable base.
22. Place bolt through the leg hole and through the turntable base. Attach nut.

Repeat step 22, 3 more times for each leg bolt hole in turntable base

23. Place bolt through the leg hole and through the turntable base. Attach nut.
24. Place bolt through the leg hole and through the turntable base. Attach nut.
25. Place bolt through the leg hole and through the turntable base. Attach nut.

Figure 28: Exploded view of turntable base and leg assembly



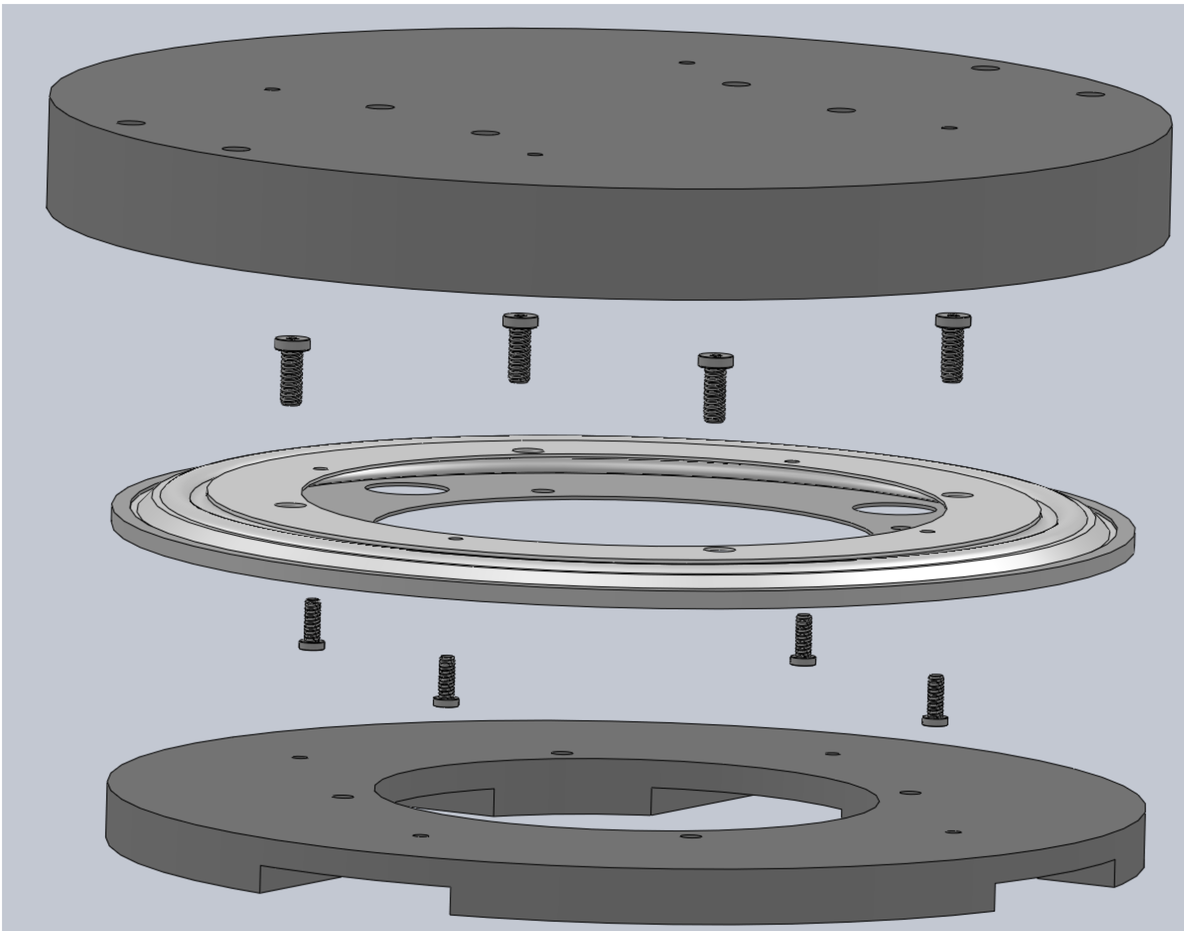
26. Place 4 bolts through top of turntable bearing.
27. Line up with holes on turntable top and push bolts through. Attach nuts.
28. Place turntable top onto the turntable base.
29. Using a hole predrilled into the turntable top, rotate the top until it aligns with a hole in the turntable bearing and turntable base.
30. Place a bolt through this hole and attach nut.

Repeat steps 29 and 30 3 more times for each hole in the turntable base for the bearing attachment.

31. Using a hole predrilled into the turntable top, rotate the top until it aligns with a hole in the turntable bearing and turntable base.
32. Place a bolt through this hole and attach nut.
33. Using a hole predrilled into the turntable top, rotate the top until it aligns with a hole in the turntable bearing and turntable base.
34. Place a bolt through this hole and attach nut.

35. Using a hole predrilled into the turntable top, rotate the top until it aligns with a hole in the turntable bearing and turntable base.
36. Place a bolt through this hole and attach nut.

Figure 29: Exploded view of turntable top and base

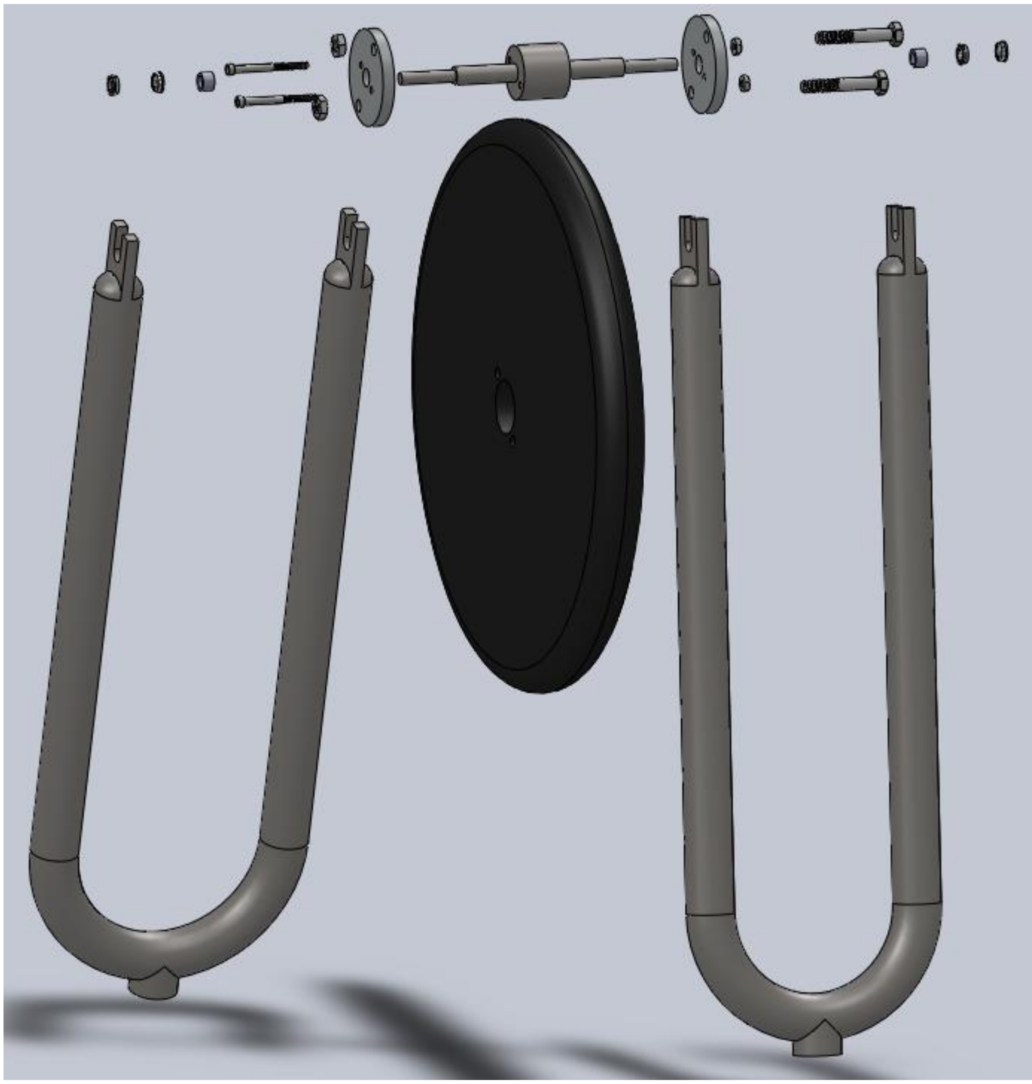


37. Align top of inner u-support with inner bearings on the gyro shaft assembly.
38. Place U-support tip holes over bearings carefully.

Repeat steps 37 and 38 for larger u-support

39. Align top of outer u-support with outer bearings on the gyro shaft assembly.
40. Gently pry apart the u-support legs and place U-support tip holes over bearings carefully.

Figure 30: Exploded view of u-support and gyro shaft assembly.



41. Place motor onto motor mount.
42. Line motor up face holes with holes in face plate of mount and screw in face screws.
43. Slide motor mount over u-support extrusions and place holding screws into each extrusion with washers on each side of mount legs.
44. Attach belt gear to gyro shaft.
45. Attach belt to gyro shaft belt gear and motor belt gear.
46. Push down motor and mount until belt is taut, then screw in extrusion screws to hold mount down.
47. Attach green wire of motor to ground on power supply.
48. Attach black wire to live voltage output.
49. Attach white wire to neutral voltage output.
50. Place power supply between u-support legs on side and screw down onto turntable top.
51. Plug in power supply.

Mass Production of Final Design

In the event that we would need to produce our product in mass, we would require new machines that would produce our components in a more timely and cost effective manner. For the high-density polyethylene components, we would need an injection-molding machine. Due to the unique design of the gyro wheels, the gyro wheels would be required to undergo a sand casting process. We would order the aluminum in bulk and would use an industrial size band saw to cut the aluminum components to length. To form the steel components, we would need an industrial steel-forging machine that would form the steel into the desired shape and size. With the use of the mentioned machines, we would greatly increase the production time to the point where we would be able to keep up with the demand for the product.

Validation Results

In order to validate the theories behind the trainer, during the design expo, we used a prototype connected to a small bicycle. However, before we ever made it to the design in the expo, we first needed to test, in a safe environment, that our bicycle trainer will not only fulfill all of the design specifications given to us by Med-Rehab Milestones, but that it is completely safe, while in operation and while not in operation.

The first testing for the prototype was done by using specially designed computer programs. This is done by developing a complete model of the prototype in SolidWorks and importing this model into different test environments such as HyperMesh and Adams to test the stresses on all the components. The results found using these programs was that the individual components, when subjected to the combined load of a child and bicycle would not buckle or break. We used a safety factor of 2 in HyperMesh. We then confirmed these results by doing hand calculations, which can be located in appendix E. With the hand calculations we found the materials being used could handle the stresses on the parts with a safety factor of 20.

The next round of tests was done on the actual completed prototype. The purpose of this testing was to evaluate the performance of our design and to ensure that it properly simulated changing resistances, and the centripetal force while turning by precessing about its base. In order to do this we set up experiments, both with a bike attached and without.

The non manual tests were held first in order to ensure the safety of our team members. These tests included functionality tests and safety tests. First we tested that the motor ran while connected to the power supply, and that the power supply allowed the motor to rotate at different speeds. The motor did not initially work when we plugged in the power supply. We were worried that the power supply was faulty, and talked with John Baker on what we could do. He could not figure out the problem either and supplied us with an additional lower voltage power supply. Embarrassingly, later that night we realized that we had the power supply on the European volt setting. Fixing this, the motor indeed did work. However, the power supply, which was a linear switching power supply, and from what the specs said, lead us to believe it switched from 12 to 24 volts, did not do this. It only switched about a range of 22 to 24 volts. Therefore the motor and power supply did not give us an ability to significantly change the speed of the motor.

We then attached the motor to the full prototype assembly in order to test its functionality and safety. We first ran the motor attached to the gyro while we held the system upright in order to test that the motor would indeed rotate the heavy 25lbs of the gyro wheel. The motor successfully was able to rotate the wheel, spinning up to its maximum speed over the course of about a minute. We then tested the stability support of the gyro wheel. We ran the motor, initially holding the system upright, and then let the system go in order to see if the spinning gyro held the system upright. The gyro did indeed hold the system up when running at its maximum speed. Next we tested the leaning resistance of the spinning gyro system. We started the motor once more, while keeping a hold of the u-supports. Then we forcefully tilted the system back and forth. There was a definite and noticeable difficulty when trying to tip the system side to side.
Finally, we tested the precession capability of the gyro system. We did this by once again running the motor while holding the system upright. Then we let go, allowing the gyro to support the weight of itself and keep itself stable. Next we pressed against the side of the u-supports to simulate a lean. The system first resisted movement, but then precessed around the base. The system would then become unstable and eventually fall over because the overall system did not provide a force to push the system back upright. In order to correct this problem, we attached springs that crossed inwards and attached the u-supports to the base. This helped provide a correcting force to the system.

After validating that the system worked when not attached to a bicycle, we then moved towards testing the system with a bicycle attached. These tests were used solely to decide whether the effects found while not attached to the bike were strong enough to be noticeable while a bike was attached. We first ran the motor and tested whether or not it provided a significant side to side resistance. Unfortunately, what we found is that, yes, you can feel a resistance to side to side motion, however, it was not strong enough to be significant in helping keep ones balance while on the bike. We next tested whether or not the gyro would be able to keep the bicycle upright. Unfortunately the gyroscopic effects were not strong enough to keep the bike upright without a rider. Finally we decided to test whether the gyroscopic effect were strong enough to cause the bike to precess about the base. Again, the results showed that our small gyro wheel was not powerful enough to cause the bike to precess around when tipped.

Overall our prototype did indeed validate that, a spinning gyro wheel can be used to self stabilize. The gyro did provide a slight side to side resistance when attached to the bicycle, and a strong one when not attached to the bicycle. When not attached to the bike, the gyro did indeed precess about the base and was able to keep itself upright. The prototype did not however validate that when attached to a bike it would help stabilize and keep the bike upright, nor would it rotate the bike and rider around the base. We do not think this is a definite invalidation however. Because the gyro was able to hold itself upright and work when not attached to the bike, we believe that further testing is needed with a larger wheel with the majority of its mass situated around the outside diameter. The force a gyroscope provides is proportional to its mass and its radius squared. So a significant increase in radius of the gyro wheel will exponentially increase the effectiveness of the gyro wheel.

Discussion

In retrospect, there are a couple of design changes that our team would include for our final design. At first, our team was hoping that our final design was to be produced and showcased at the Design Expo. Unfortunately, due to cost, that was not the case. Since our team was planning on building the final design, we built the design in our CAD model with parts that are easily machined and/or purchased off of McMaster Car. For instance, instead of include an extremely massive cast iron wheel for the gyro wheel, we would look to make a custom made wheel that would focus a significant amount of mass towards the outer diameter. As demonstrated earlier, the angular momentum depends on the radius of the gyro wheel to the power of two.

Another design change that we would like to make is eliminating all plastic material. The wear properties are not very promising and the overall strength of the material does not compare to materials such as aluminum or steel. Like I stated previously, our plan was to use high-density polyethylene primarily due to the cost. The only part that would remain plastic would be the part of the resistance unit that comes in contact with the back wheel of the tire.

We would also produce custom U-Supports that would look similar to that of a bicycle fork. In addition, we would consider is utilizing a telescoping feature involving the U-Supports rather using a slider track to accommodate for variable bicycle sizes. Both design changes would significantly save on space and size by reducing the space taken both lengthwise of the slider track and widthwise.

In order to provide a more responsive feedback system for variable pedaling forces, our team would also consider utilizing an electrical resistance system that will allow us to easily create a program that will more accurately simulate an on-road experience. With the mentioned design changes, our team is confident that a redesign with our reconsiderations would make this product very marketable and potentially successful as a consumer product.

Upon reconsideration of the prototype that we built, I am confident when I say that I would not consider any major design changes. Based on the money that we had to produce our project, the only thing that we could remotely prototype was the simulation of balance. With that being said, the only reconsideration would be to possibly search more intently for a weighted wheel that may be heavier and focuses its mass towards the outer diameter of the wheel.

Recommendations

It is our recommendation to our sponsor that they pursue this project in the upcoming semesters to come. With a larger budget, this project has the potential of being a success and a competitive commercial product.

On a design-based level, it is our recommendation to our sponsor to look into the possibility of custom made gyro wheels that would be appropriate to our design. With the correct size gyro wheels with the mass primarily located near the rim of the wheel, the motor will not need to rotate as fast. In addition a much larger diameter gyro wheel will be able to provide much more force upon the rider. With the reduced speed associated with the spinning of the larger gyro wheel, stability issues that came up with the smaller and heavy gyro wheel rotating at extremely fast speeds should be mitigated and controllable.

In addition to a larger gyro wheel, a stronger motor will be needed in order to power it. Also, with the new size gyro wheel, the motor will need to be placed further away. This brings up concerns of a longer belt driving the gyro wheel, which would need a covering for safety concerns.

Another additional recommendation is a power supply that can provide multiple voltage inputs from 3v to the maximum of 24v would be ideal in allowing the control of the speed of the gyro wheel.

Another addition that would be beneficial would be the addition of strong springs attached to the sides of the u-supports and anchored by the turntable top on each side. This would be used to provide a correcting force to help bring the bike and rider back to the correct vertical position. For this addition, the turntable top would also need to be strengthened. This strengthening could be done by changing the material of the turntable top from polyethylene to aluminum.

With a much larger budget, this project has the possibility of being a successful product.

Conclusion

Children with weakness in their lower body often have difficulties learning to ride a bicycle. It takes them extended practice to learn the skills for bicycle riding. To help children learn to ride a bicycle, our team has been tasked to construct a stationary bicycle trainer that would mimic the skills/challenges involved in riding a bicycle, including balance, shifting weight to turn, pedaling against variable force, etc., while remaining stationary indoors and preventing the child from completely falling off.

To solve the problem, our team has designed a product that utilizes the function of a gyroscope and inverted pendulum system to simulate an on-road bicycle riding experience. Unfortunately, with a limited budget, our team was not able to create a product that successfully addresses all issues described earlier. In order to validate that our final design would work, our team designed a prototype that focuses on the gyroscopic effects of the design, while leaving out other functions of our final design.

After our team successfully designed and produced our prototype, we were able to successfully demonstrate that changing the speed of the gyroscopic wheel can increase or decrease the leaning resistance of the bicycle. By increasing the speed, the user will experience an increase in leaning resistance and a decrease in speed will experience a decrease in leaning resistance. As well, our team successfully demonstrated that precession of a gyroscope in the manner that we hoped to apply it to the bike closely simulates turning an on-road bicycle. We hope that our results will inspire future research and funding in the subject of stationary bicycle riders and provide hope to all children that everybody can ride a bicycle.

Acknowledgements

The most important person we would like to acknowledge is Kirsten Klompstra. She was the person who spearheaded this entire project. She told us exactly what she was looking for, always answered our questions, and was with us during some of the most important parts of the design of our bicycle trainer. We would also like to thank the numerous parents and staff at Med-Rehab Milestones who sadly shall remain nameless due to the anonymity of the survey. Without them, we would never have known what the most important customer aspects of the bicycle trainer were, and therefore would never have been able to design the bicycle trainer properly. Finally, we want to thank Professor Wineman. He was an excellent man who met with us frequently and was always on call should we ever need him.

Information Sources

To develop a solution to their problem, we first needed to evaluate current products and patents. Determining the strengths and weaknesses helped us obtain a set of target engineering specifications that gave us an idea as to what our design should include. The following section will provide an evaluation of current products and patents.

To gather information about our project, we first conducted some background research. An article given to us by Med-Rehab Milestones describes a camp in which children with Down syndrome are taught how to ride a bicycle [1]. Another website by Velovision, gave us insight to special needs bicycling [2].

The next step was to research into current benchmark products. The best product, in our opinion, was made by Kurt Kinetic. The Kurt Kinetic Rock and Roll Pro and Turntable Riser Ring set was determined to be the best, and was the primary study for the design. This design utilizes a set of metal discs separated by rubber inserts, similar to a spinal cord nicknamed a "spinal system". This spinal system provides the model with a side-to-side resistive that increases with increased displacement, much like a spring to simulate an on the road bicycle experience for professional riders [3].

Another model designed to imitate a bicycle experience was the Kreitler Challenger 4.5 Rollers. This model is the most accurate simulation to an outdoor bicycle experience. It allows a user to balance with no help. A downfall of the product is that the design does not allow for the user to turn and it is very hard to mount. But the most important downfall is that you must know how to ride a bicycle before operating the product [4].

To make sure that any of our design ideas did not infringe on any previous designs, our team conducted a search of related patents. The first of these designs is US Patent 7326151, which is a large bike trainer that is meant to attach to the rear wheel axle and have the front wheel removed. This design is important because it was designed to train the rider to balance the bike, because unlike other designs where only the back wheel is attached to a trainer, the entire bike is placed on the trainer. This design, however, was ultimately discarded due to the size of the trainer [5].

The next design, US Patent Application 20090075785, is a basic bike trainer design that attaches to the rear wheel axle. This design was interesting because, unlike the designs by Kurt Kinetic, this design did not utilize the spinal spring component to provide a spring force in order to simulate balance, but had a simple point of rotation where the axle connector arms meet the balancing legs. Much like the Kreitler design, the user must know how to ride a bicycle before they are able to operate this device [6].

The design US Patent 5656001 included a novel concept to simulate varying forces of resistance using eddy currents. This design has an electric motor connected to the resistance wheel, allowing for resistances to be changed not only while the biker was riding the bike, but could also be done automatically without any assistance, allowing the biker to experience increasing or decreasing resistance as time passed [7].

Another design, US Patent 7470220, was completely unique. Unlike all other designs, this trainer was attached solely to the bike, and not only did not require to be balanced on the floor. It attaches to the neck of the seat and the resistive unit rests on the top of the rear wheel. As the rider picks up speed, the resistance unit will provide a resistance. It is extremely small and took up virtually no room. This design was ignored due to the fact that it wasn't designed with anything to keep the bike stationary [8].

The final design, US Patent 6736761, operates similar to ordinary stationary bicycle trainers in that it doesn't allow the rider to sway from side to side. However, what's unique about this design is that it features a moveable switch that could be used to switch between five different settings of resistance. The only disadvantage to this particular design's resistance changing wheel was that in order to change the resistance while the rider was still on the bike, they would require some assistance from another person [9].

The focus here was on using system dynamics (Right hand plane poles and zeros) to evaluate stabilization and steering of a rider. Although most of the system control elements of this source are not considered for the prototype that we are presenting in this report, we were provided with information that would be helpful if we decided to continue with our previous model which would be fairly controls based. As mentioned earlier, this source provided us with valuable information on momentum balances for the frame and rider as well as a momentum balance for the front fork to illustrate the effect of trail. This is discussed later in the parameter analysis section [10].

This is article helped to support our theory of using a gyroscope as a stabilizing force for our trainer. The author here performs several experiments to "disprove" the myth that "the gyroscopic action plays very little part in the riding of a bicycle at normally low speeds." We found valuable information regarding self-centering and steering geometry and its importance to riding a bike. Also, we take from this article several of his theories on how a bicycle behaves:

When a bicycle leans, the point of contact of the front tire moves to one side of the plane of the wheel, creating a frictional torque twisting the wheel into the lean and stabilizing the bicycle by centrifugal action. The contact point of the bicycle's front tire is ahead of the steering axis. Turning the front wheel therefore moves the contact point with the turn, and the rider uses this effect when he finds himself leaning, to move his baseline back underneath his center of gravity. The contact point of the bicycle's tire is behind the steering axis. As a result, when the bicycle leans a torque is developed that turns the front wheel [11].

Similar to other sources, we are provided a working mathematical model of a bicycle. The Whipple bicycle model was selected as an appropriate model here. This model is made up of four rigid bodies (frame/rider, fork/handlebar and wheels) connected to each other by frictionless revolute joints. The wheels contact the ground under pure rolling and no sideslip conditions. The model used in this article is used with physical parameters algorithm to evaluate the dependency of several key design parameters (trail, wheelbase, front wheel diameter, and head tube angle) on the user stability of a bicycle. We find here that increased idealized moment of inertia of the front wheel adds stability at low speeds [12].

The most important source that we found was most likely a PDF that was about a virtual bicycle simulator built in the CIM Institute in Shanghai, China. This simulator used numerous sensors, motors, pistons, and other mechatronics components to read what the rider was doing and create a response in the system that would be extremely accurate, as well as change the display that the rider saw. This is similar to what we wanted to do, but much more advanced mechanics applications as well as with a far bigger budget. However, this report had numerous equations that we used in used in our calculations to determine what materials to use, as well how to determine the speed of the gyros, angles of turning, and almost everything else related to how our trainer would simulate riding a bicycle [13].

This next source talked mostly about how the dynamics regarding a bicycle differ depending on the bike's current speed, such as how turning, breaking, and vibrations in the bicycle differed from one speed to another. There were also examples of how the dynamics were affected not only by the current speed of the bicycle, but also by how they were affected by the current acceleration (or deceleration) and the incline of the bicycle as well as how using different kinds of tires and material for the frame affect the dynamics of the bicycle. It was an excellent source for information on how different speeds can affect how well bicycles turn, and gave us several equations that would relate the amount of resistance on the rear wheel to the speed of the gyro wheels, and how to make them work together to make a more realistic ride [14].

This source's focus here is turned away from the stability of a normal bicycle, but what happens when a bicycle is uncontrolled (i.e. the handlebars are not gripped). It provided a lot of information regarding how a bicycle balances, where the centers of mass are on each component of the bicycle, and the inertia of the bicycle in different areas. Simply put, it explains how a bicycle works in terms of mathematics. However, it also goes an extra step further by noting what happens when your ride a bicycle hands free, and how it changes all the calculations previously mentioned, as well as debunk several myths regarding how a bicycle works [15].

This final resource explains how a motorcycle is stabilized, or to be more specific, how it is not stabilized. It is stated that due to the fact that counter steering is required in order to turn the motorcycle, the motorcycle is a giant gyroscope, and therefore makes it laterally unstable. It provides a lot of insight into how motorcycles, and by extension, bicycles turn in the real world and helped us determine what the new balancing method for our final design should be [16].

After an evaluation of current patents and products on the market, our team developed a good understanding of what many customers are looking for. In doing so, we were able to evaluate many of the problems that occurred with each product to determine challenging areas that we may come across in the design process of creating the best product possible.

Diagrams and pictures of the various patents and products can be located in Appendix H.

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Appendix A: Bill of Materials

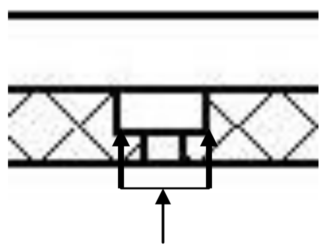
	Item	Quantity	Source	Catalog Number	Cost	Contact	Item #
Turntable Assembly							
	0.25 x 2 x 36 Aluminum Sheets	2	McMaster-Carr	8975k713	$24.44	mcmaster.com	1
	0.5 x 12 x 12 HDPE Block	1	McMaster-Carr	8769K71	$12.76	mcmaster.com	2
	9.12 D Turntable Bearing	1	McMaster-Carr	1544T2	$10.25	mcmaster.com	3
	1.5 x 12 x 12 HDPE Block	1	McMaster-Carr	85705K62	$42.83	mcmaster.com	4
U-Support Assembly							
	0.25 D Sleeve Bearings	4	McMaster-Carr	5912K100	$37.64	mcmaster.com	5
	Bike Forks	2	scrap	XXXXXX	$39.98	N/A	6
	0.3125 D x 12 Steel Rod	1	McMaster-Carr	88565K38	$10.90	mcmaster.com	7
	1.5 x 1.75 x 12 Steel Block	1	McMaster-Carr	8910K875	$36.19	mcmaster.com	8
	Springs	1	Home Depot	30699275816	$1.04	homedepot.com	9
Mounting Assembly							
	11.75 D x 1 25lb cast iron weight	1	Play it again Sports	XXXXXX	$24.75	playitagainsports.com	10
	1.125 D x 12 Steel Rod	1	McMaster-Carr	90075K251	$9.32	mcmaster.com	11
	0.375 OD x 0.25 ID x 0.25 Ball Bearings	4	McMaster-Carr	57155K336	$28.00	mcmaster.com	12
Screws, Bolts, Nuts, and Spacers							
	6-32 x 0.375 Screws	1	McMaster-Carr	92220A142	$8.04	mcmaster.com	13
	10-24 x 0.5 Screws	1	McMaster-Carr	92220A163	$7.54	mcmaster.com	14
	0.25-20 x 0.625 Screws	1	McMaster-Carr	93615A412	$6.80	mcmaster.com	15
	0.375 OD x 0.25 ID x 0.25 Spacer	2	McMaster-Carr	6389K352	$4.34	mcmaster.com	16
	0.25 - 20 Nuts	1	McMaster-Carr	90494a029	$1.13	mcmaster.com	17
	6-32 x 1.625 Bolts	1	McMaster-Carr	91251A875	$6.75	mcmaster.com	18
	0.25 - 20 x 1.625 Bolts	1	McMaster-Carr	92198A547	$6.29	mcmaster.com	19
	six-32 Nuts	1	McMaster-Carr	90480A007	$1.09	mcmaster.com	20
	Wite Connector Nut	1	Grainger	4FA26	$7.20	grainger.com	21
Front Assembly							
	Skate Board	1	Play it again Sports	XXXXXX	$29.99	playitagainsports.com	22
	1 x 12 Hook & Loop Velcro	1	McMaster-Carr	3955T71	$2.62	mcmaster.com	23
Mechatronics							
	24VDC 6.5A 150W Power Supply	1	All Electronics	PS-24150	$26.95	allelectronics.com	24
	24VDC 135W Motor w/ belt gear	1	All Electronics	DCM-130	$15.00	allelectronics.com	25
	3 Ft Powersupply Cord	1	Grainger	1FD85	$3.15	grainger.com	26
	XI Gearbelt Pulley	1	Grainger	2L518	$13.98	grainger.com	27
	100 Teeth, 20 In, XL Gearbelt	1	Grainger	1DHG3	$3.37	grainger.com	28
	XI Gearbelt Pulley	1	Grainger	2L526	$25.78	grainger.com	29
Bicycle							
	20" Bicycle	1	Personal Ad	N/A	$30.00		30
Drill Bit							
	2.78" Drill Bit	1	McMaster-Carr	3096A339	7.49		31
Total					$485.61		

Appendix B: Description of Engineering Changes since Design Review 3

The only significant issue that our team encountered during the production stage of the prototype was that many times the lengths of the bolts were not sufficient. In those cases, we acted in two different ways. When the length of the screw was considered important, we were forced to counter-bore slightly deeper than expected. When the length of the bolt was considered unimportant, we saved time by using a bolt that was slightly longer than the bolt that was intended to be used.

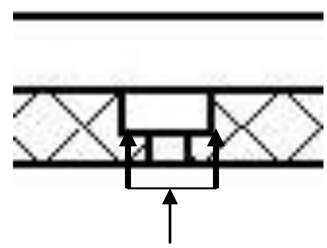
Engineering Change Notice

WAS:



.6 inch diameter countersink hole

IS:



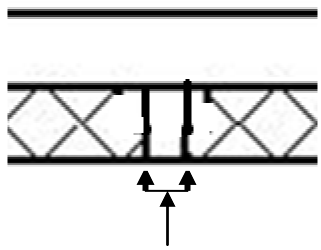
.75 inch diameter countersink hole

Notes:

Needed to increase the size of all 8 of the countersink holes on the turntable top from .6 inches to .74 inches in order to allow bolt heads to properly fit.

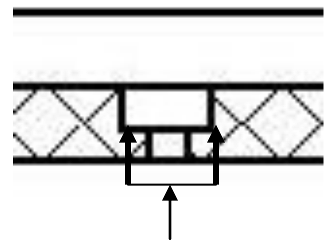
EALS Innovation	
Project Bicycle Trainer	
Ref. Drw. Turntable Top	
Stephen Woolverton	4/4/2010
LaDante Riley	4/4/2010

WAS:



No countersink hole

IS:



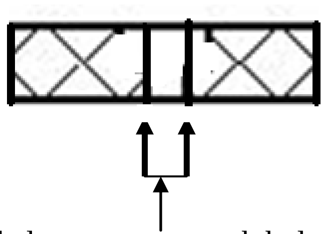
.5 inch diameter countersink hole

Notes:

Needed to create 8 countersink holes on the turntable base for each bolt hole in order to allow bolt heads to properly fit.

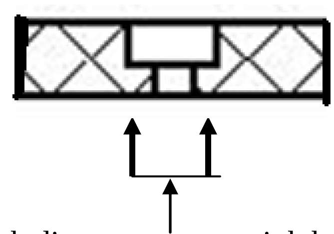
EALS Innovation	
Project Bicycle Trainer	
Ref Drawing Turntable Bottom	
Stephen Woolverton	4/4/2010
LaDante Riley	4/4/2010

WAS:



Threaded non-countersunk hole

IS:



.5 inch diameter countersink hole

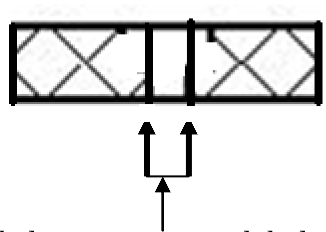
Notes:

Needed to create 3 countersink holes on the top leg for each bolt hole in order to allow bolt heads to properly fit and prevent the need to thread the holes.

	EALS Innovation	
	Project Bicycle Trainer	
	Ref Drawing Top Leg	
RGD	Stephen Woolverton	4/4/2010
	LaDante Riley	4/4/2010

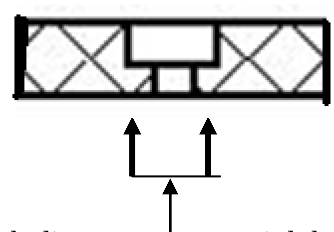
Engineering Change Notice

WAS:



Threaded non-countersunk hole

IS:



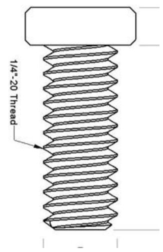
.5 inch diameter countersink hole

Notes:

Needed to create 3 countersink holes on the top leg for each bolt hole in order to allow bolt heads to properly fit and prevent the need to thread the holes.

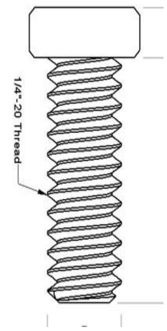
EALS Innovation	
Project Bicycle Trainer	
Ref Drawing Bottom Leg	
Stephen Woolverton	4/4/2010
LaDante Riley	4/4/2010

WAS:



.25 x 5/8 1/4-20 thread cap screw

IS:



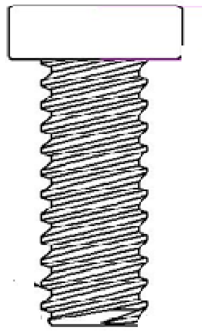
.25 x .75   1/4-20 thread cap screw

Notes:

Needed to increase the length of the previous screw so as to fit through the turntable top and the turntable bearing with the addition of a nut on the end.

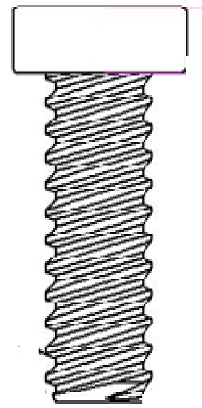
EALS Innovation	
Project Bicycle Trainer	
Ref Drawing Part 93615A412	
Stephen Woolverton	4/4/2010
LaDante Riley	4/4/2010

WAS:



.19 x 1/2 10-24 thread cap screw

IS:



.19 x 3/4 10-24 thread cap screw

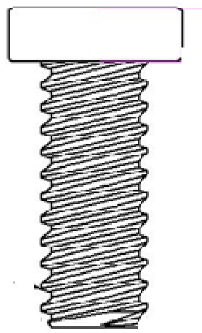
Notes:

Needed to increase the length of the previous screw from ½ inch to ¾ inches so as to fit through the turntable bottom and legs with the addition of a nut on the end.

EALS Innovation	
Project Bicycle Trainer	
Ref Drawing Part 92220A163	
Stephen Woolverton	4/4/2010
LaDante Riley	4/4/2010

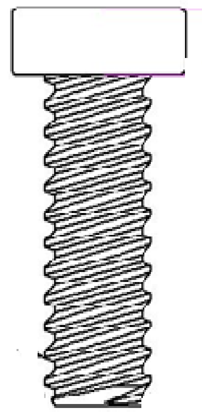
Engineering Change Notice

WAS:



.138 x 3/8 10-24 thread cap

IS:



.138 x .75 10-24 thread cap screw

Notes:

Needed to increase the length of the previous screw from 3/8 inches to .75 inches so as to fit through the turntable bottom and legs with the addition of a nut on the end.

EALS Innovation	
Project Bicycle Trainer	
Ref Drawing Part 92220A142	
Stephen Woolverton	4/4/2010
LaDante Riley	4/4/2010

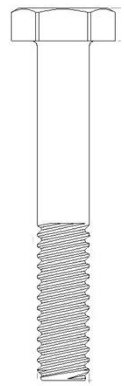
RGD

Engineering Change Notice

WAS:

.25 x 1in

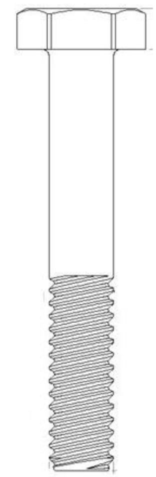
5/8 1/4-20 thread cap screw



IS:

. .25 x 2in

1/4-20 thread cap screw



Notes:

Needed to increase the length of the previous screw from 1 5/8 inches to 2 inches in order to penetrate fully through the gyro wheel and gyro plates and attach to a nut.

EALS Innovation	
Project Bicycle Trainer	
Ref Drawing Part 92198A547	
Stephen Woolverton	4/4/2010
LaDante Riley	4/4/2010

WAS:

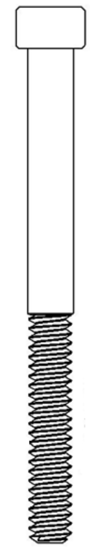
.138 x 1 5/8 in

5/8 0-24 thread cap screw

IS:

. 138 x 2in

1/4-20 thread cap screw



Notes:

Needed to increase the length of the previous screw from 1 5/8 inches to 2 inches in order to penetrate fully through the gyro wheel and gyro plates and attach to a nut.

EALS Innovation	
Project Bicycle Trainer	
Ref Drawing Part 91251A875	
Stephen Woolverton	4/4/2010
LaDante Riley	4/4/2010

RGD

Appendix C: Design Analysis Assignment from Lecture

Material Selection Assignment (Functional Performance)

U-supports: They support the weight of the bike, its user, gyro wheel, and shaft. Its purpose other than supporting weight the bike, the user, and gyro wheel's components is to act as a stable mount when in use. The user will experience movement in all directions so it is like necessary that it have a "base" that is makes them feel as safe as possible. The supports are themselves constrained from all movement except for rotation about the central axis of the slider shaft. Gyro shaft: This component is attached to the gyro wheel, by two contacting plates, to translate the rotational energy from the motor to the gyro wheel. It is constrained by the bicycle forks on one side and a bolt and nut on the other. As mentioned, it is attached to the gyro shaft by two contacting plates on each side of the gyro wheel.

Turntable top: Attached to each the turntable bottom via the rotating turntable and the U-support legs via the stationary journal bearing and slider shafts, this component allows for the rear end of the bicycle to rotate about the vertical axis to simulate turn while riding a bicycle. A detailed picture of this can be found in the Appendix G.

Table C.1: Stiffness-limited design at minimum mass (cost, energy, environmental impact*)

Component	Function	Objective	Constraint	Index
U-supports	Column	Support a load	Buckling Load	$M=\frac{\sigma_f}{\rho}$, $M=\frac{E}{C_m \rho}^{1/2}$
Gyro shaft	Shaft	Provide rotation	Torque	$M=\frac{\tau^{2/3}}{\rho}$
Turntable top	Beam	Support a load	Load	$M=\frac{E^{1/2}}{\rho}$

To aid in validating our material selection, we used a lecture from the University of Illinois on material indices. The primary slides can be found in our Appendix J.

Using CES software, we found the best material to choose for the bicycle forks to be: Low Carbon Steel, Aluminum nitride, Cast iron, gray, Magnesium (wrought) alloys, and cast Al-alloys. For the gyro shaft, we found that the best materials were: Low Carbon Steel, Aluminum nitride, Cast iron, gray, Magnesium (wrought) alloys, and cast Al-alloys. Low carbon was shown to have high compressive strength. It was also labeled as the cheapest of all structural metals for reinforcement by the CES software. Aluminum nitride is a good heat conductor mostly used for high powered electronics. Cast iron was said to machine easily (*Dependent on the composition of the object) and damp vibrations well, yet it is relatively brittle and has low tensile strength. Magnesium is very light weight, but is very hard to form at room temperature. Cast Aluminum alloys are corrosion resistant, but few alloys have tensile strengths above 350 MPa.

Having machined a 25lb cast iron weight for our gyro wheel, we found that this material machines easily if using a carbide tip drill/mill bit. Carbide tool are much more expensive than standard high speed cutting tools.

For the turntable top our top five choices for materials were aluminum 3015, aluminum 6061, polyethylene (high density, high molecular weight), polypropylene, and polyvinylchloride (PVC).

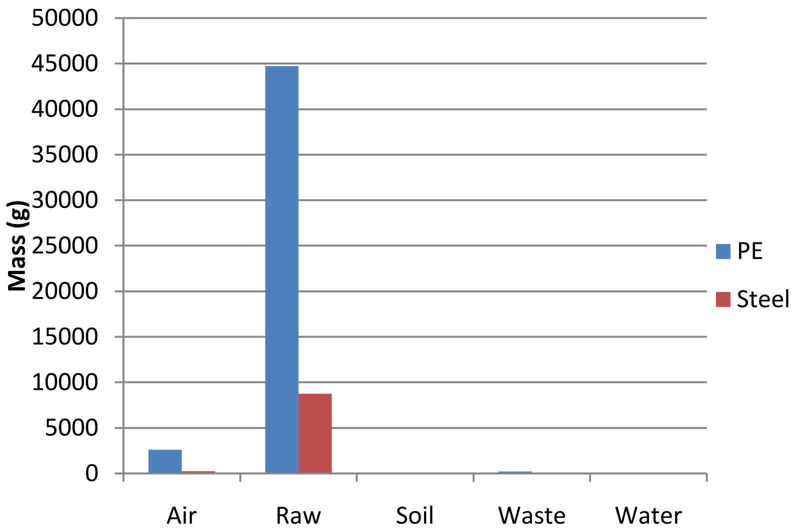
Ultimately, we choose to use steel for each component. Low carbon steel is chosen for the bicycle forks because it is required that the forks be welded to the slider joints to maximum strength at the connection. Low carbon steel was also chosen for the gyro shaft because unlike our second option cast iron is very machinable. Of the all the metals chosen low carbon steel had the highest range for fracture toughness thus be less likely to fail due, although, our design is able loads up to twice that allowed. However, safety being our greatest concern, we felt that it was important to account for Murphy's Law.

Nickel would be an optimal material to use; however, this material is very expensive. We chose polyethylene (high density, high molecular weight) for the turntable price being the biggest factor. Knowing that this component would be primarily under compression, it is reasonable to assume that the strength of the material would not be an issue, thus we focused on being cost effective. Given our budget, we chose polyethylene (high density, high molecular weight) because it was both cost effective and strong enough to support the loads that it would experience.

Material Selection Assignment (Environmental Performance)

The largest mass consumption of materials comes from Polyethylene as raw materials. Polyethylene is also the highest contributor for air emissions and (solid) waste, whereas in water the emissions are relatively the same. Also, emissions in the soil can be considered negligible as values of 0g for polyethylene and 0.019378g for steel. In summary, the contributions to the air are proportional to the mass of each component. However, we notice a difference in the amount of air emissions produced by the construction steel as well as raw material and solid waste, yet there is a drop in soil waste and water emissions. Again, we attribute this to the type of steel that is being used for this.

Figure C.2.1: Construction Steel Total Mass Comparison



	PE	Steel
Air	2603.451	236.5767
Raw	44740.61	8732.037
Soil	0	0
Waste	204.4618	2.447049
Water	3.491208	0.172501

Figure C.2.2: Construction Steel Characterization

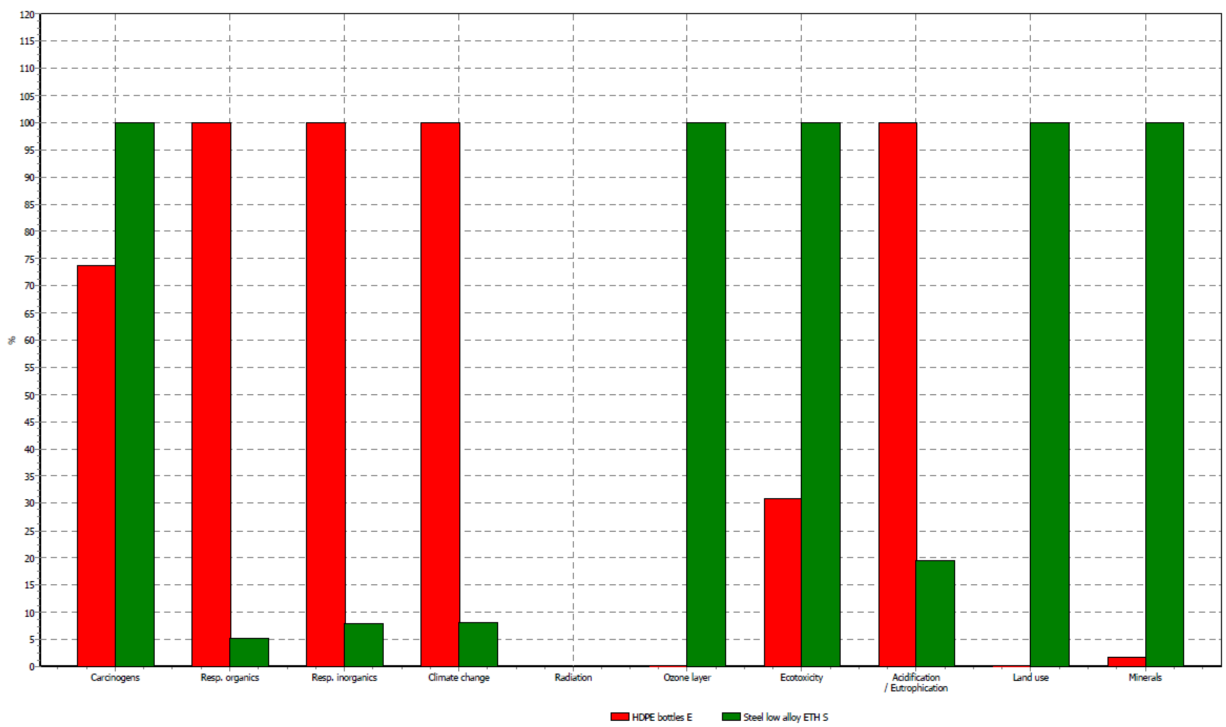


Figure C.2.3: Construction Steel Damage Assessment

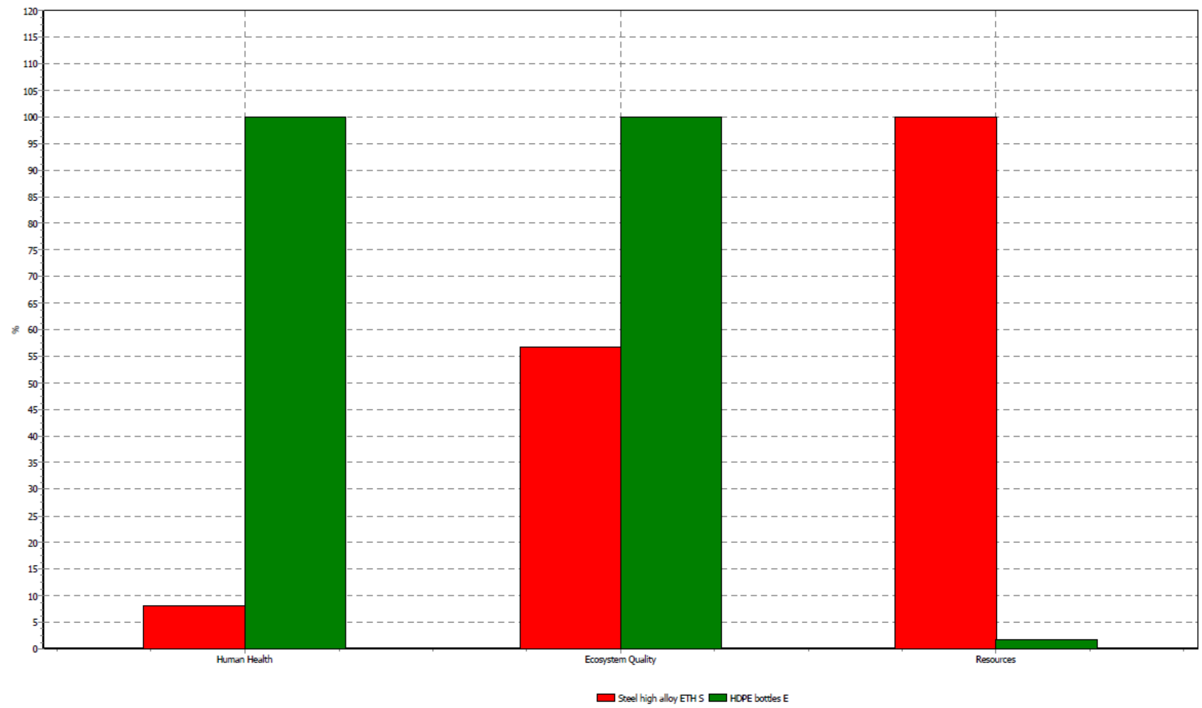


Figure C.2.4: Construction Steel Normalization

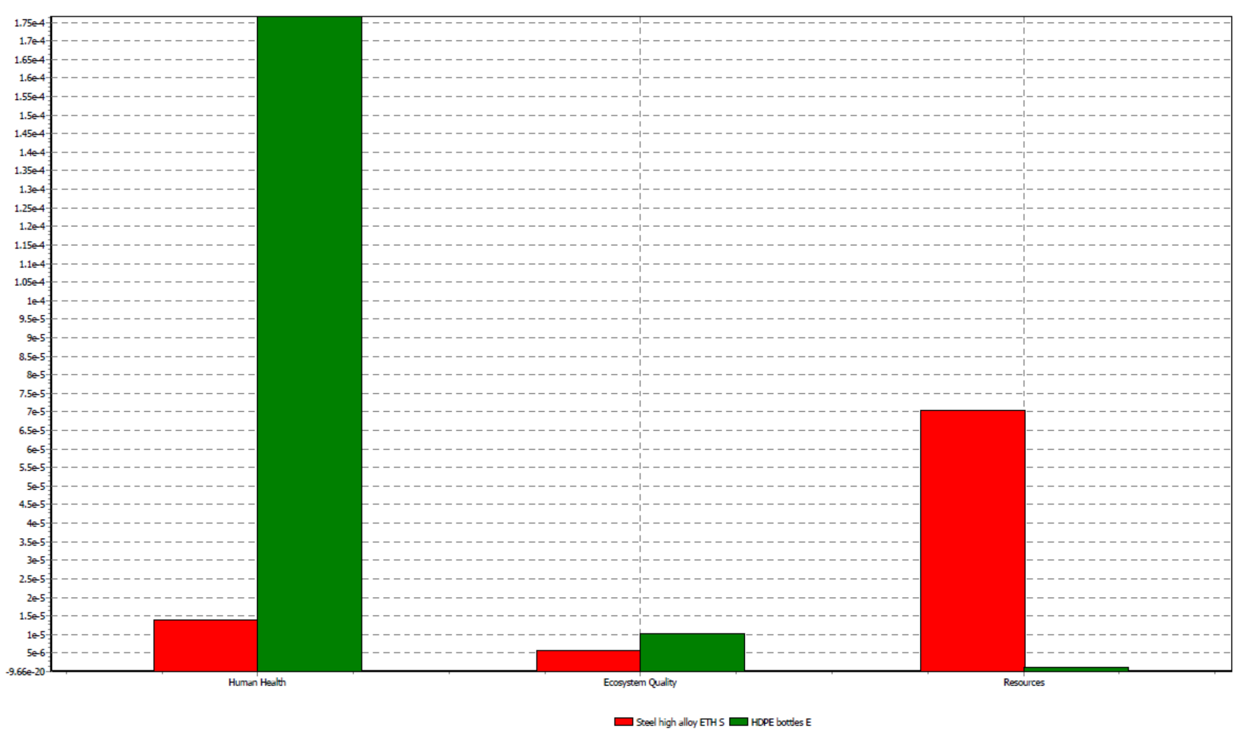
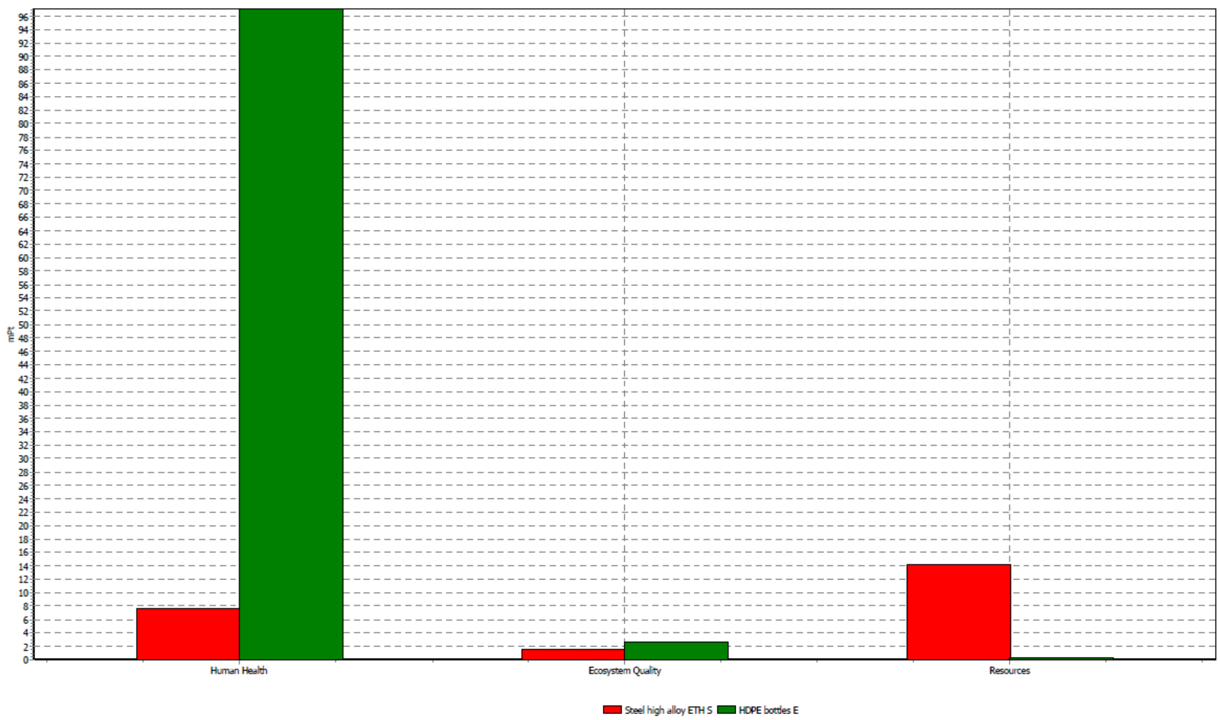


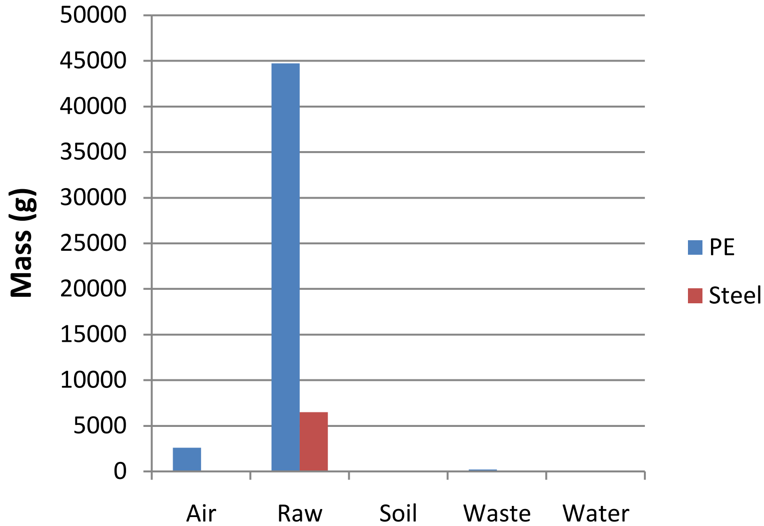
Figure C.2.5: Construction Steel Single Score

Figure C.2.6: Construction Steel Weighting



The largest mass consumption of materials comes from Polyethylene as raw materials. Polyethylene is also the highest contributor for air emissions and (solid) waste, whereas in water emissions are relatively the same. Also, emissions in the soil can be considered negligible as values of 0g for polyethylene and 0.019378g for steel. In summary, the contributions to the air are proportional to the mass of each component whereas the additional water emissions from steel can be accounted for by the additional minerals that are contained in this type of steel.

Figure C.2.7: Standard Steel Total Mass Comparison



	PE	Steel
Air	2603.451	15.39909
Raw	44740.61	6484.481
Soil	0	0.019378
Waste	204.4618	0
Water	3.491208	9.734125

Figure C.2.8: Standard Steel Characterization

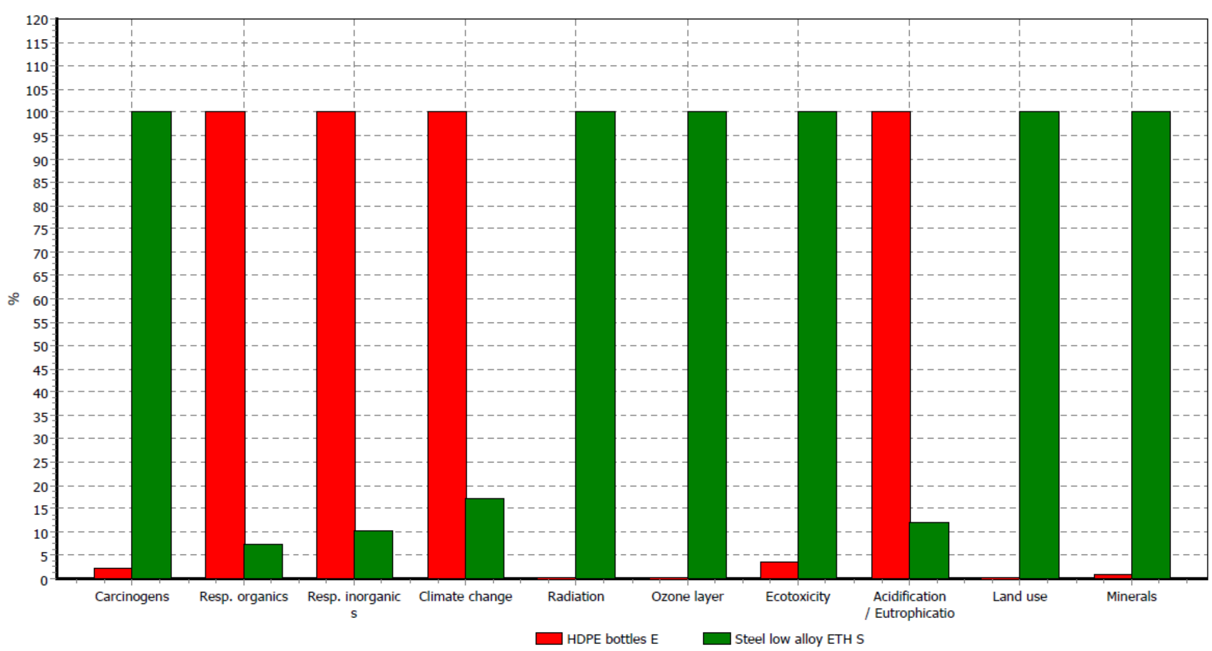


Figure C.2.7: Standard Steel Damage Assessment

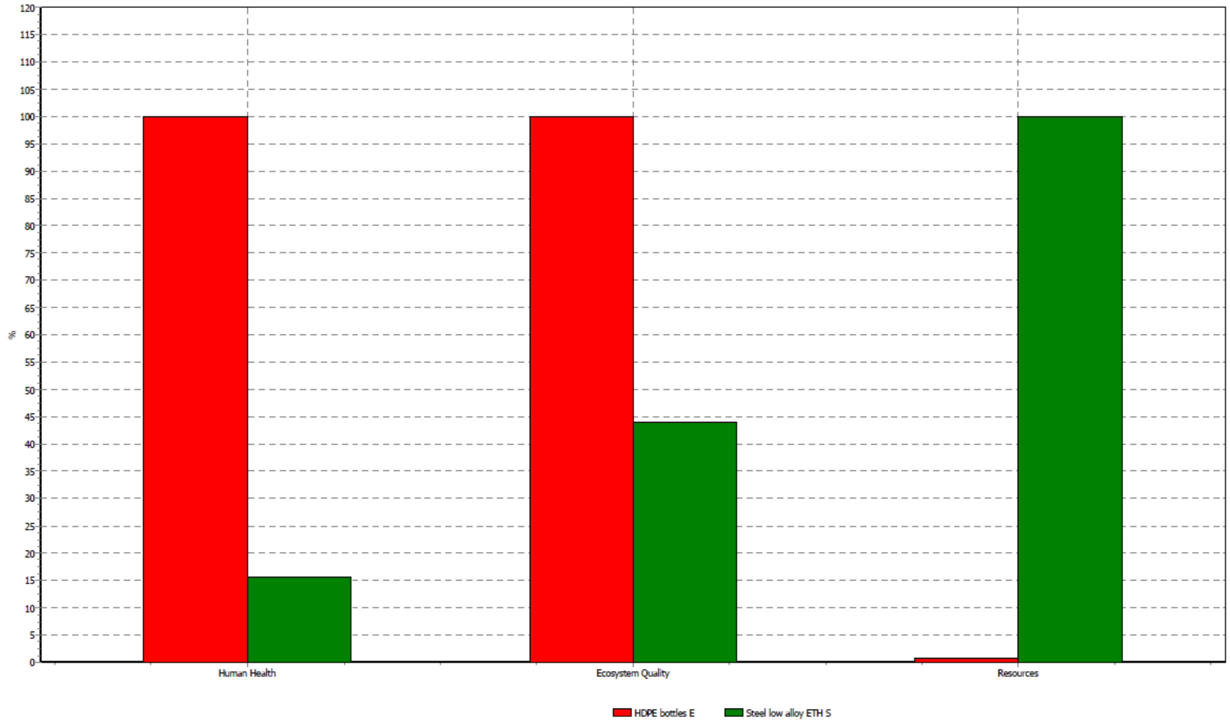


Figure C.2.7: Standard Steel Normalization

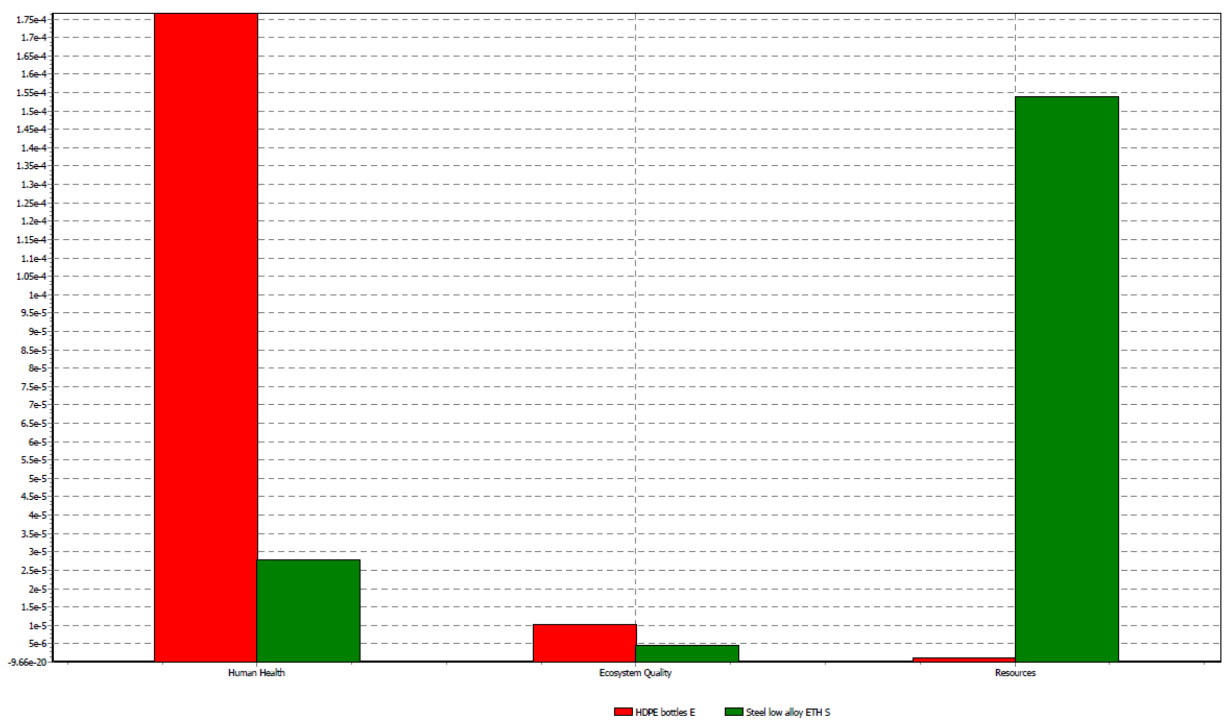
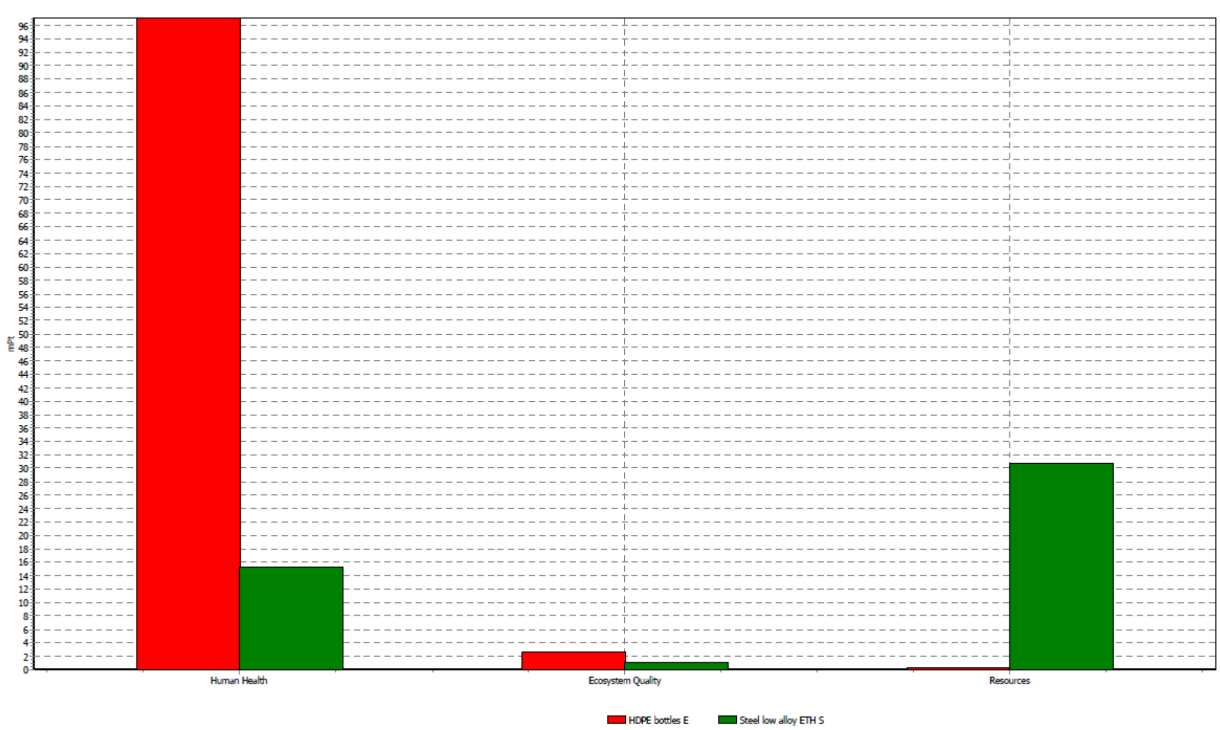


Figure C.2.7: Standard Steel Single Score

Figure C.2.7: Standard Steel Weighting

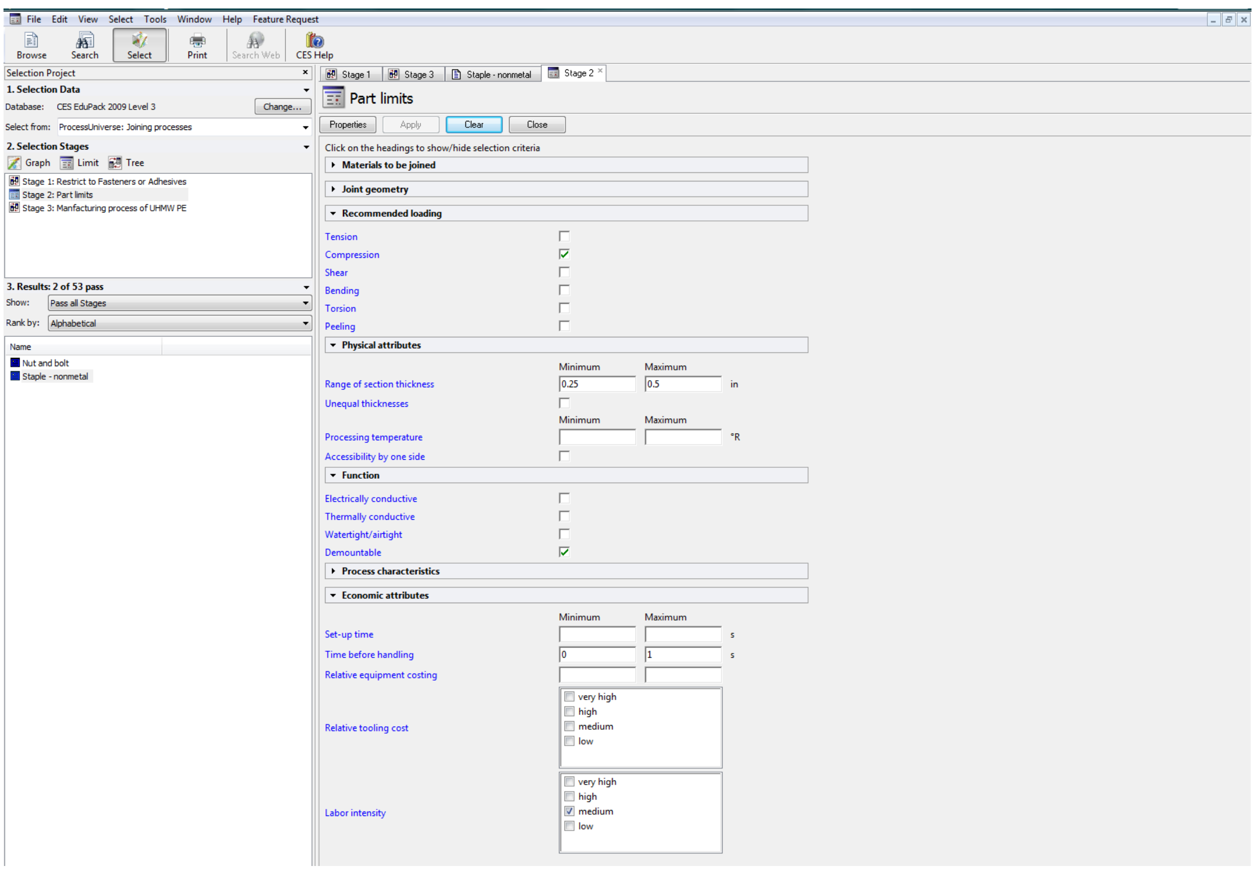


Manufacturing Process Selection Assignment

UHMW PE

We can see that there are 2 options for joining PE to another material: nut and bolt and staple-nonmetal. The best of these options is joining by nut and bolt. It has a minimal environmental impact. It is most effective means to join any type of two materials of any thickenss together. Stapling for non-metal is a effective for joining dissimilar material. It can handle most any load type. However, this method of joining was turned down as the section thickness that it could handle had an upward bound too close to the thickness on the components that would be joined. Deciced that this would be unsafe to use, we arrive at joining by nut and bolt to be the best method for PE to other materials.

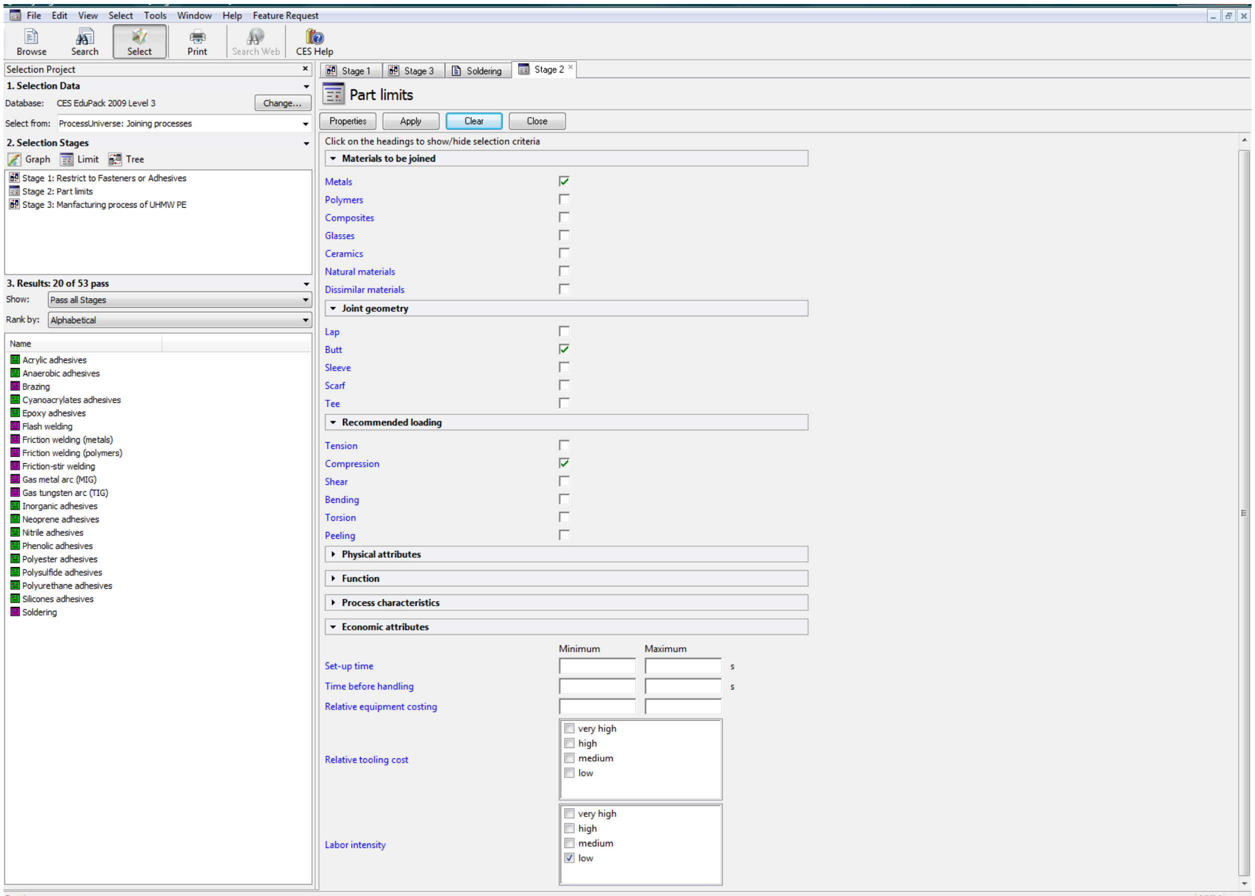
Figure C.3.1: UHMW PE Manufacturing Options



Low carbon/Low alloy steel

Using CES, we find that there are 20 methods that would be suitable for handling the task of joining steel to steel. We eliminated the adhesives that are listed due to cost, safety hazards with handling, and availibility. We eliminated soldering and brazing because we did not believe that the the bond would be as strong as the other methods listed. Flash and friction welding was were ignored because the equipment perform either operation is not available on campus. Also, it would take additional training to be able to use either process. Ultimately, either MIG or TIG welding can be used because both handle the same material and cost the same. Both are easily available on campus.

Figure C.3.2: Low Carbon/Low Alloy Steel Manufacturing Options



The final design of our product is marketed at a wide range of users. It can be used with the everyday biker just looking for exercise to the athlete training for a race. The trainer however is specially designed to teach children to ride bicycles. This is for both regular children, but mainly aimed at children with disabilities. This wide range of user's means there will be many different markets in which our product will be sold. It could be sold in catalogues for sports equipment, special biking stores and specifically sold to rehabilitation and therapeutic clinics. It can be marketed to adults, parents and physical therapists.

Statistically, .5 percent of the population considers themselves an avid bike rider. With an optimistic assumption of 1 percent of these people deciding to buy our trainer, that is 15,000 units. 30 percent or more of the population owns a bicycle. Assuming .01 percent of these people purchase our bicycle trainer, that is another 9,000 units sold. 1 of every 1000 children born has Down syndrome. 4 million children are born every year, which comes out to 4000 children born every year with Down syndrome. An optimistic assumption of 10 percent of parents then buys a bicycle trainer. That is another 400 units every year. 1 percent of children born also have a moderate disability. Assuming of these, not including the children born with Down syndrome, 1% of these parents then buy our trainer. That is 400 units per year. Finally, there are over 1000 physical therapy clinics throughout the country. Assuming each of these purchases one of these devices for their clinics use, that is 1000 units. The estimated lifetime of one of these bicycle trainers is about 5 years. Therefore, with an optimistic outlook, over the course of 5 years, there will be 29,000 bicycle trainers bought.

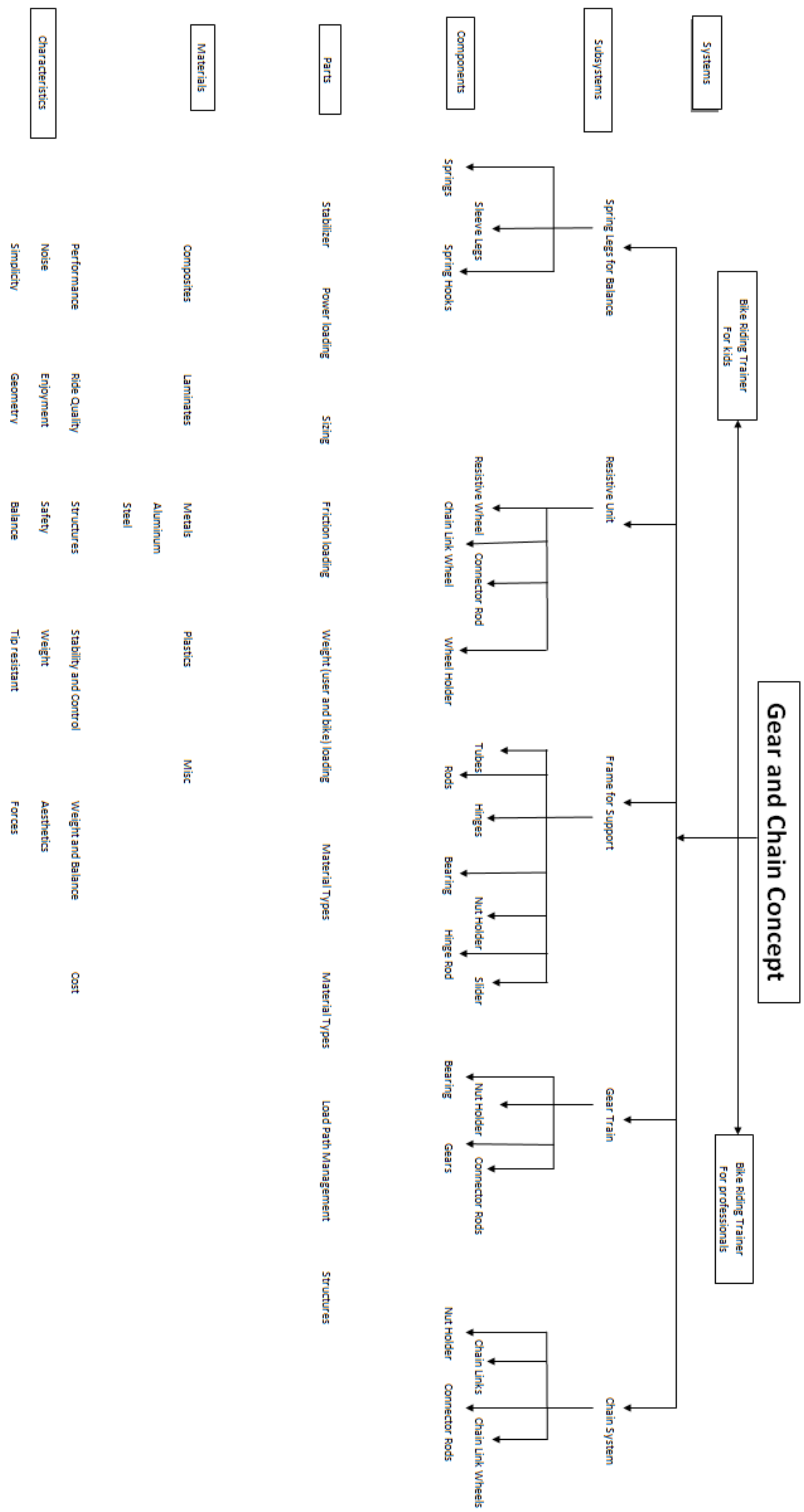
Appendix D: Quality Function Deployment Diagram

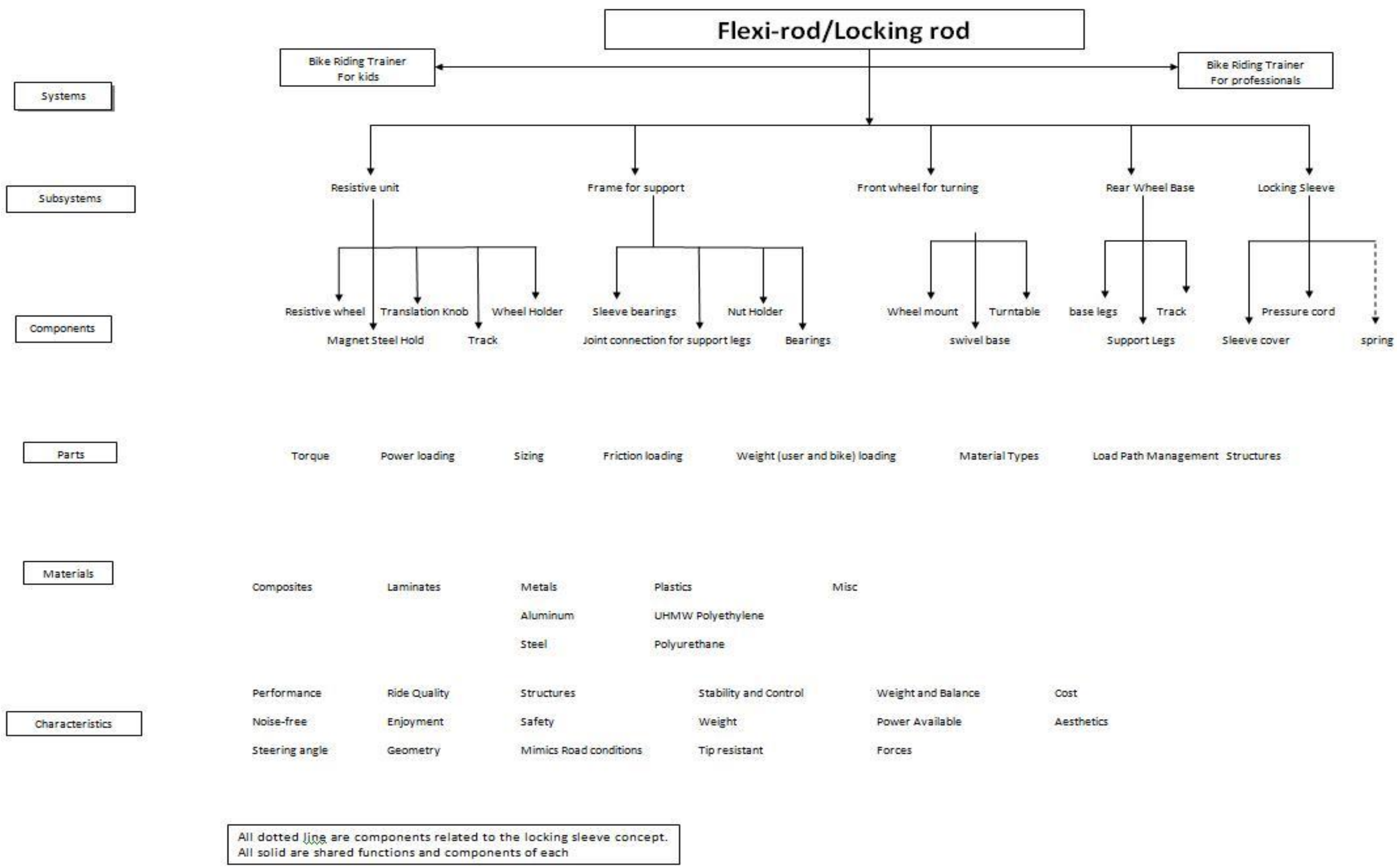
Project:	Stationary bike riding trainer
Date:	1/21/2010

	Max User Weight	Bike Size Range	Size of the Trainer	Weight of Trainer	Max Rear Wheel Resistive Force	Max Side-to-Side Spring Force	Max Turning Deviation	Max Yaw Angle from Vertical Postion	Price
Max User Weight	XXX								
Bike Size Range	9	XXX							
Size of the Trainer	3	9	XXX						
Weight of Trainer	3	3	9	XXX					
Max Rear Wheel Resistive Force	0	1	3	1	XXX				
Max Side-to-Side Spring Force	9	3	9	3	3	XXX			
Max Turning Deviation	0	9	1	0	0	9	XXX		
Max Yaw Angle from Vertical Postion	9	9	9	1	3	9	9	XXX	
Price	1	1	9	3	9	9	3	9	XXX

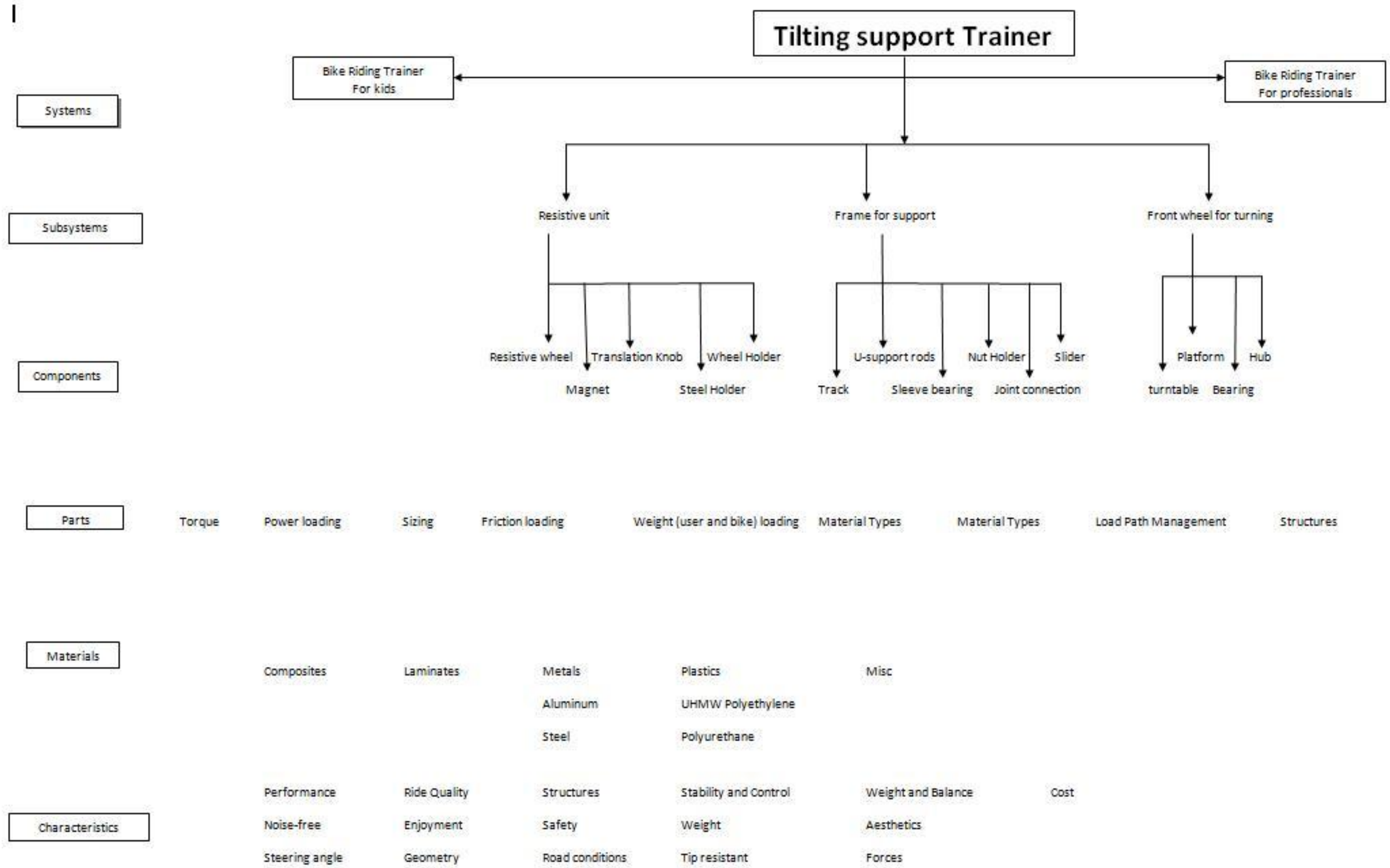
	Project Requirements	Physical Therapist	Personal Use	Max User Weight	Bike Size Range	Size of the Trainer	Weight of Trainer	Max Rear Wheel Resistive Force	Max Side-to-Side Spring Force	Max Turning Deviation	Max Yaw Angle from Vertical Postion	Price	Kurt Kinetic Rock and Roll Pro and Turntable Riser Ring	Kreitler Challenger 4.5 Bike Rollers	Bicycle Trainer Patent No. US 7326151 B2
1	Simulates varying Inclines	10	8	1	0	0	1	9	0	0	1	3	3	1	1
2	Variety of uses	6	12	3	9	1	0	0	3	9	3	1	1	3	1
3	Adjustable for different bike sizes	5	11	3	9	3	1	3	9	9	3	3	3	5	1
4	Doesn't take up much space in operation	3	3	0	0	9	1	0	3	3	3	1	3	3	1
5	Aesthetically pleasing	12	10	0	0	3	0	0	3	3	3	3	4	3	1
6	Simulates turning a bike	1	1	3	3	1	1	9	9	9	9	9	4	1	3
7	Product life	11	6	3	0	1	0	0	3	1	3	3	4	4	2
8	Ease of installment/uninstallment	7	9	0	3	0	0	1	1	3	9	3	3	4	1
9	Lightweight	9	7	3	0	9	9	3	1	1	9	3	3	4	1
10	Low cost	8	4	0	0	3	3	3	3	3	3	9	2	3	1
11	Ease of storage	4	5	0	1	9	3	1	3	3	3	3	2	3	1
12	Safety	2	2	9	3	3	3	1	9	3	9	9	4	3	1
13	Non-Electrical	13	13	0	0	0	0	3	3	0	3	3	5	5	5
			Total	1.9	2.2	3.2	1.7	2.5	3.8	3.6	4.7	4.1			
			Importance Rating	8	7	5	9	6	3	4	1	2			
			Measurement Unit	lbs	inches	ft^3	lbs	lbs	lbs	degrees	degrees	$			
	Kurt Kinetic Rock and Roll Pro and Turntable Riser Ring			any	16 to 29	6	30	15	70	180	15	560			
	Kreitler Challenger 4.5 Bike Rollers			any	12 to 29	3.75	25	0	N/A	0	3	360			
	Bicycle Trainer Patent No. US 7326151 B2			any	28	32	60	0	70	120	15	N/A			
	Target			any	12 to 28	6	25	35	70	180	15	350			

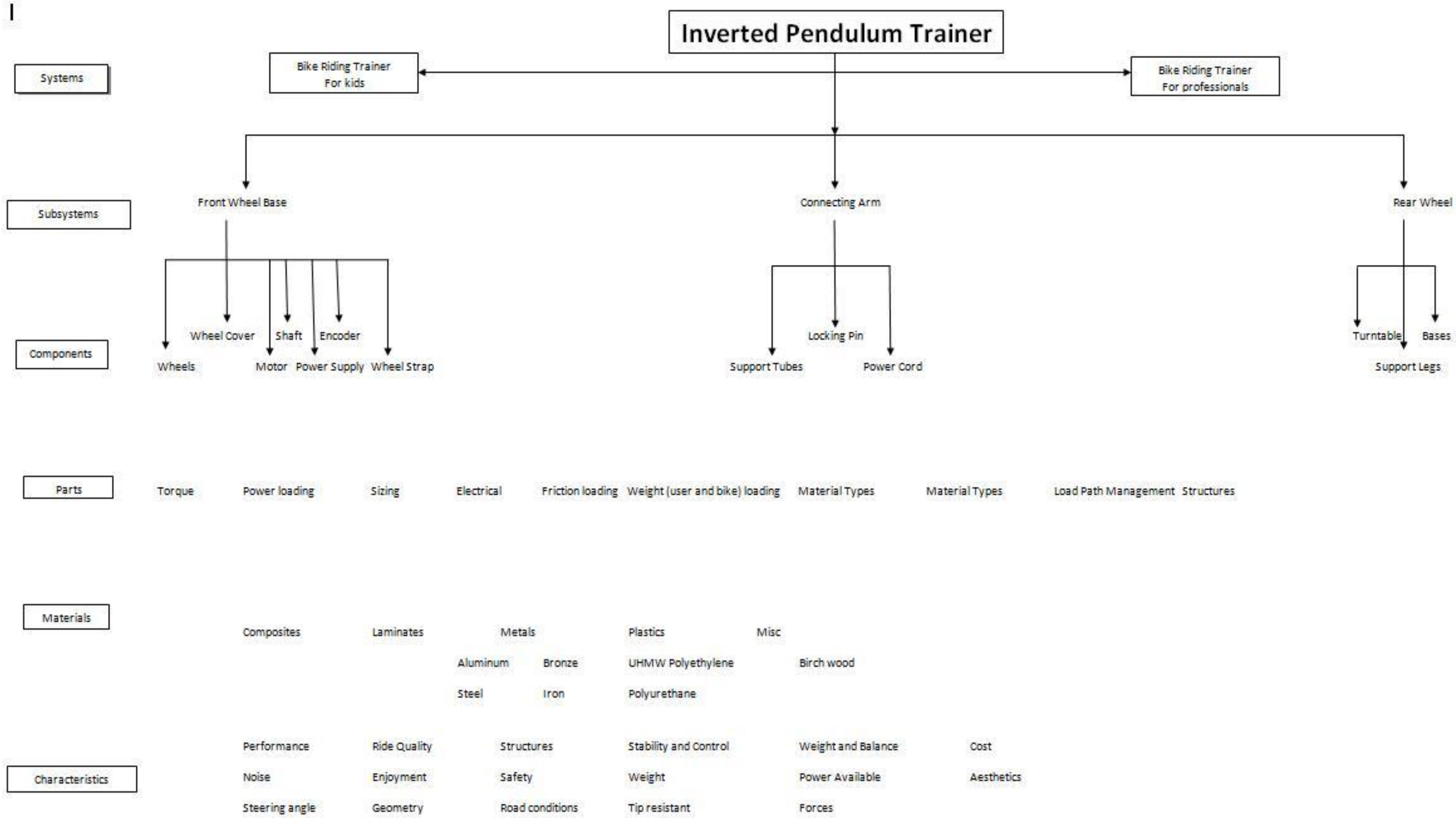
Appendix E: Functional Decomposition Diagrams

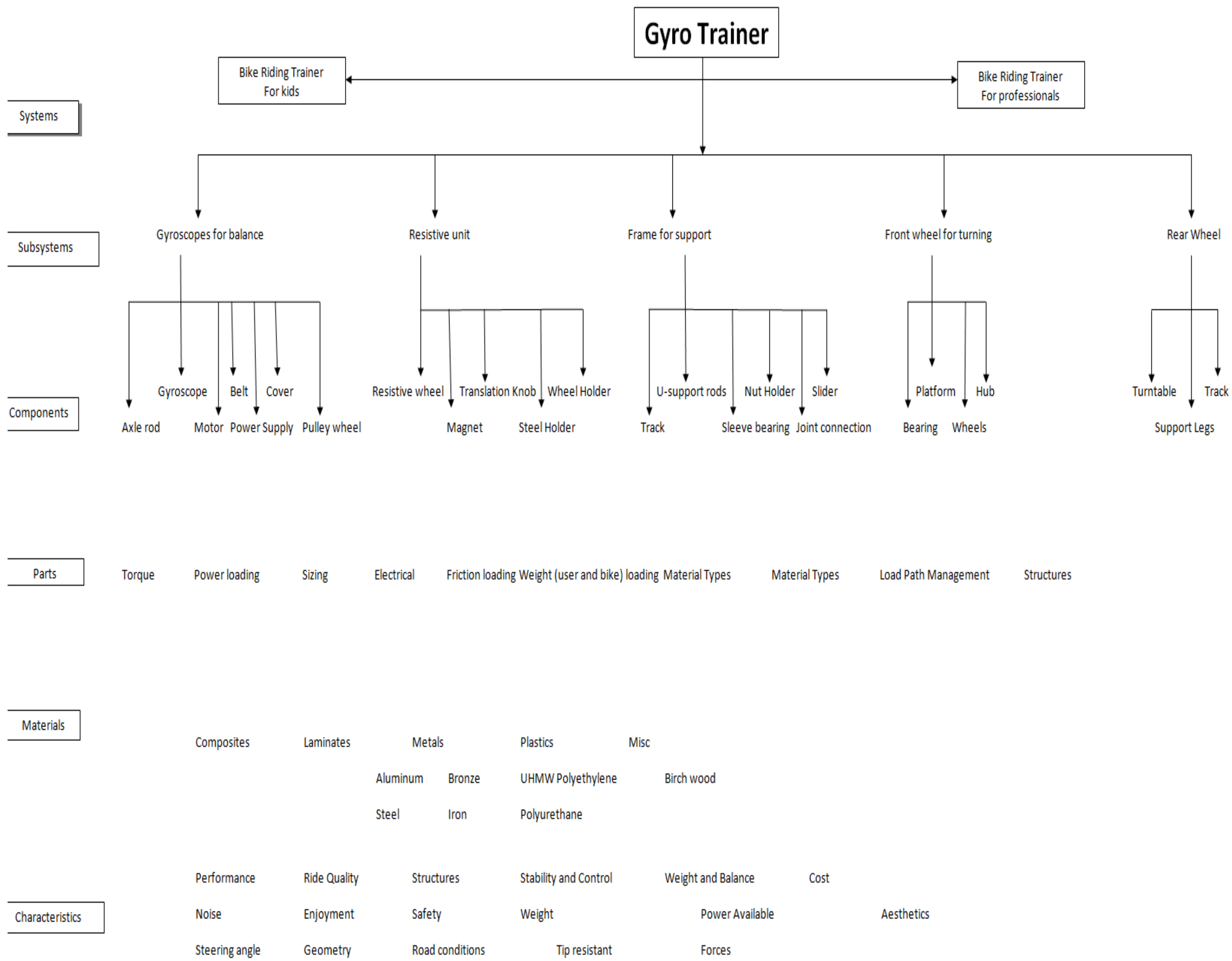




Flexi-rod/Locking rod
Systems
Subsystems
Components
Parts
Materials
Characteristics
Bike Riding Trainer For kids
Bike Riding Trainer For professionals
Resistive unit
Frame for support
Front wheel for turning
Rear Wheel Base
Locking Sleeve
Resistive wheel
Translation Knob
Wheel Holder
Magnet Steel Hold
Track
Sleeve bearings
Nut Holder
Joint connection for support legs
Bearings
Wheel mount
Turntable
swivel base
base legs
Track
Support Legs
Pressure cord
Sleeve cover
spring
Torque
Power loading
Sizing
Friction loading
Weight (user and bike) loading
Material Types
Load Path Management
Structures
Composites
Laminates
Metals
Aluminum
Steel
Plastics
UHMW Polyethylene
Polyurethane
Misc
Performance
Noise-free
Steering angle
Ride Quality
Enjoyment
Geometry
Structures
Safety
Mimics Road conditions
Stability and Control
Weight
Tip resistant
Weight and Balance
Power Available
Forces
Cost
Aesthetics
All dotted line are components related to the locking sleeve concept.
All solid are shared functions and components of each


Tilting support Trainer
Bike Riding Trainer For kids
Bike Riding Trainer For professionals
Systems
Subsystems
Resistive unit
Frame for support
Front wheel for turning
Components
Resistive wheel
Magnet
Translation Knob
Steel Holder
Wheel Holder
Track
U-support rods
Sleeve bearing
Nut Holder
Joint connection
Slider
turntable
Platform
Bearing
Hub
Parts
Torque
Power loading
Sizing
Friction loading
Weight (user and bike) loading
Material Types
Material Types
Load Path Management
Structures
Materials
Composites
Laminates
Metals
Aluminum
Steel
Plastics
UHMW Polyethylene
Polyurethane
Misc
Characteristics
Performance
Noise-free
Steering angle
Ride Quality
Enjoyment
Geometry
Structures
Safety
Road conditions
Stability and Control
Weight
Tip resistant
Weight and Balance
Aesthetics
Forces
Cost


Inverted Pendulum Trainer
Systems
Bike Riding Trainer For kids
Bike Riding Trainer For professionals
Subsystems
Front Wheel Base
Connecting Arm
Rear Wheel
Components
Wheels
Wheel Cover
Shaft
Encoder
Motor
Power Supply
Wheel Strap
Support Tubes
Locking Pin
Power Cord
Turntable
Bases
Support Legs
Parts
Torque
Power loading
Sizing
Electrical
Friction loading
Weight (user and bike) loading
Material Types
Material Types
Load Path Management
Structures
Materials
Composites
Laminates
Metals
Aluminum
Bronze
Steel
Iron
Plastics
UHMW Polyethylene
Polyurethane
Misc
Birch wood
Characteristics
Performance
Noise
Steering angle
Ride Quality
Enjoyment
Geometry
Structures
Safety
Road conditions
Stability and Control
Weight
Tip resistant
Weight and Balance
Power Available
Forces
Cost
Aesthetics

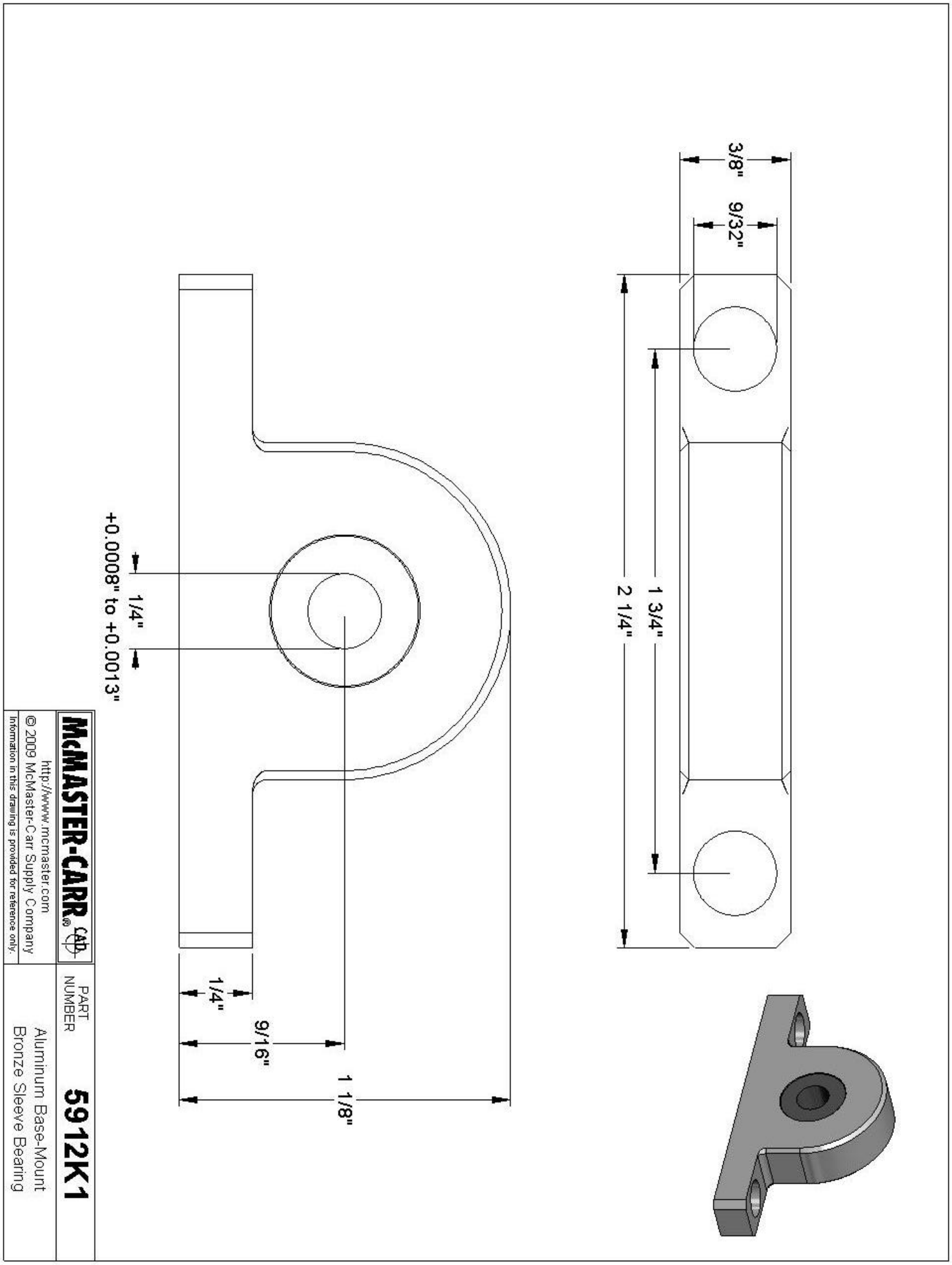


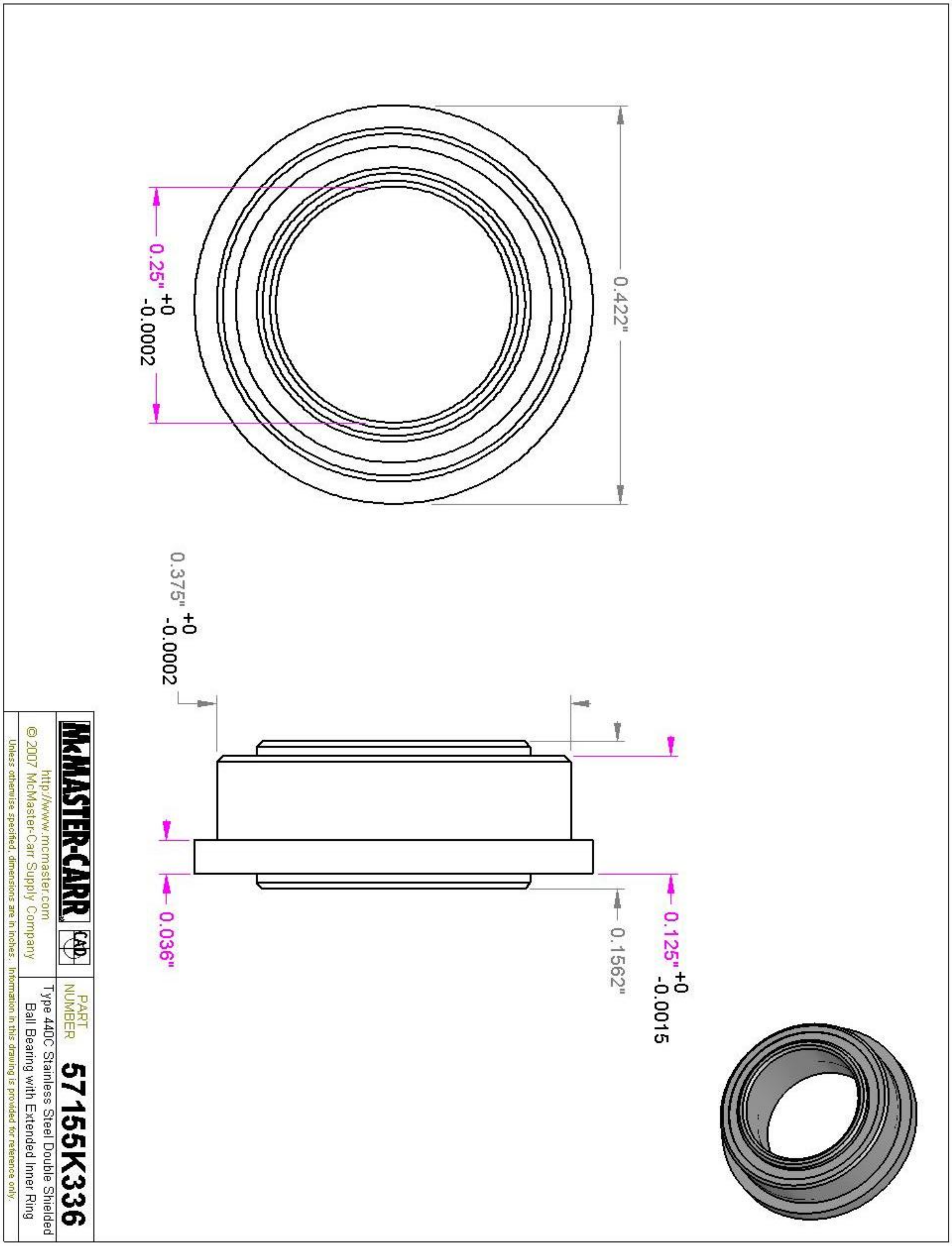
Gyro Trainer
Bike Riding Trainer For kids
Bike Riding Trainer For professionals
Systems
Subsystems
Gyroscopes for balance
Resistive unit
Frame for support
Front wheel for turning
Rear Wheel
Components
Gyroscope
Belt
Cover
Axle rod
Motor
Power Supply
Pulley wheel
Resistive wheel
Translation Knob
Wheel Holder
Magnet
Steel Holder
U-support rods
Nut Holder
Slider
Track
Sleeve bearing
Joint connection
Platform
Hub
Bearing
Wheels
Turntable
Track
Support Legs
Parts
Torque
Power loading
Sizing
Electrical
Friction loading
Weight (user and bike) loading
Material Types
Material Types
Load Path Management
Structures
Materials
Composites
Laminates
Metals
Plastics
Misc
Aluminum
Bronze
UHMW Polyethylene
Birch wood
Steel
Iron
Polyurethane
Characteristics
Performance
Ride Quality
Structures
Stability and Control
Weight and Balance
Cost
Noise
Enjoyment
Safety
Weight
Power Available
Aesthetics
Steering angle
Geometry
Road conditions
Tip resistant
Forces

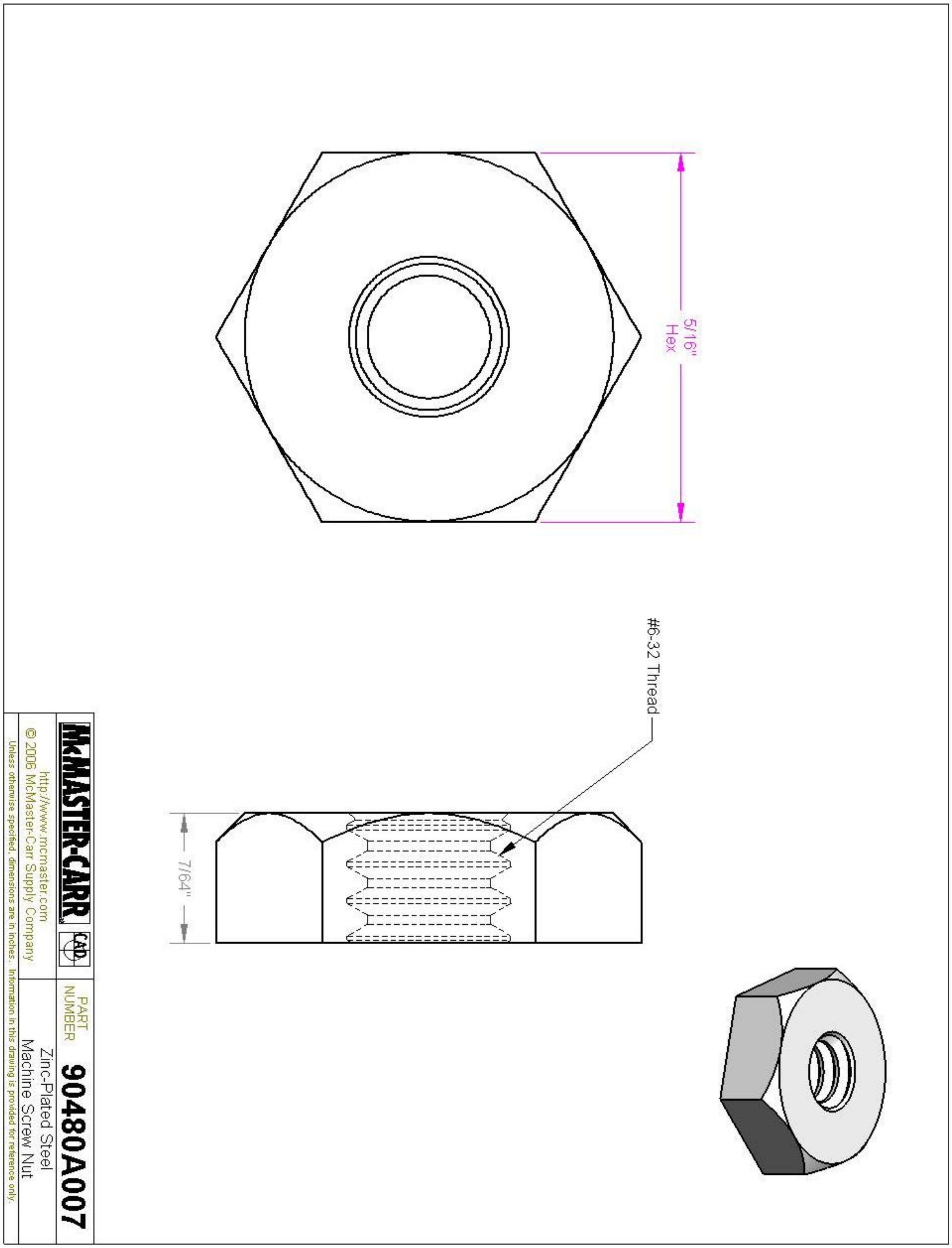
Appendix F: Pugh Chart

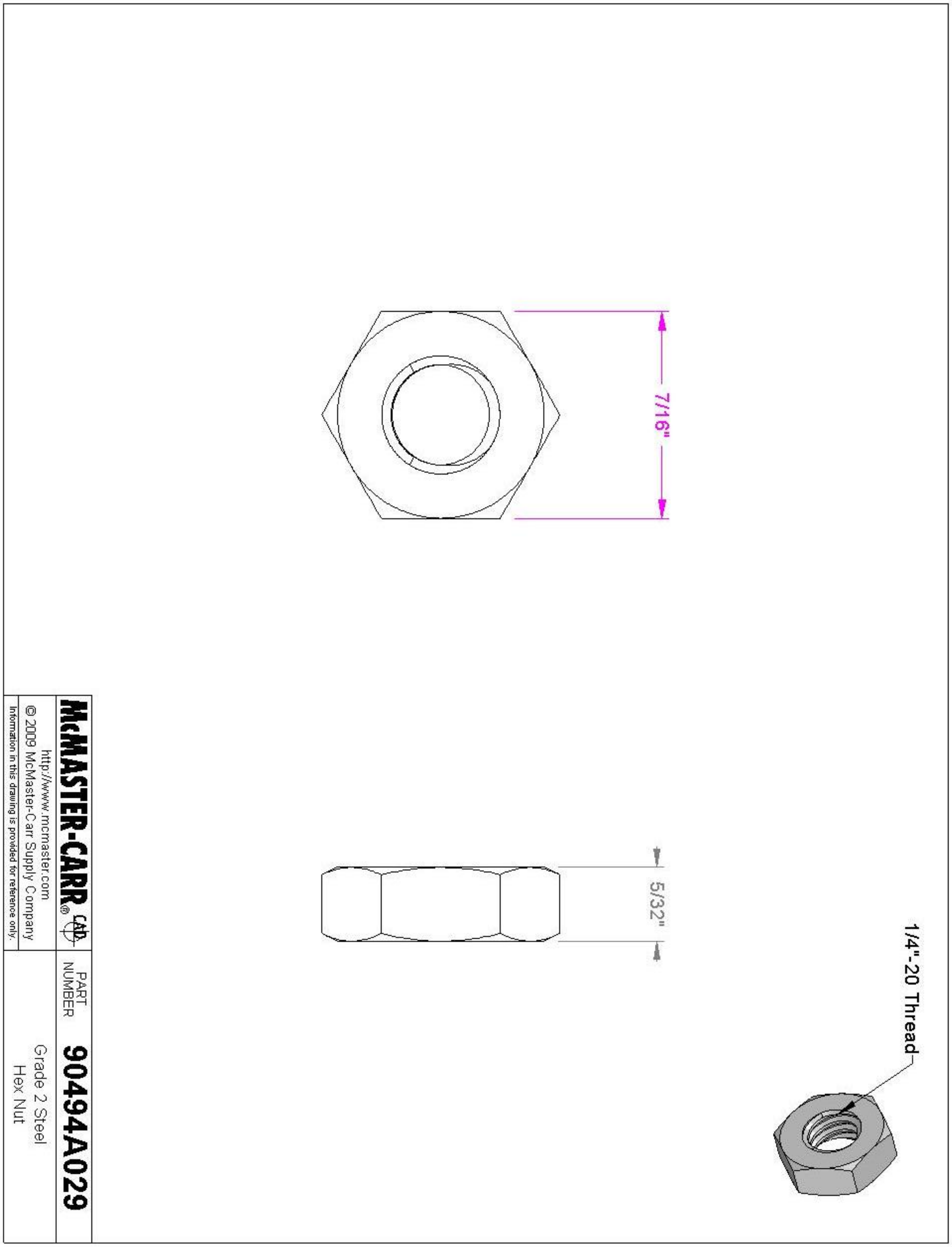
	Gear and Chain	Locking Sleeve	Tilting Support	Inverted Pendulum	Alpha Design	Physical Therapist	Personal Use
Simulates varying Inclines	+	+	+	+	+	10	8
Variety of uses	+	+	+	+	+	6	12
Adjustable for different bike sizes	+	+	+	+	+	5	11
Doesn't take up much space in operation	+	+	+	-	-	3	3
Aesthetically pleasing	+	+	+	+	+	12	10
Simulates turning a bike	-	-	-	-	+	1	1
Product life	+	+	+	+	+	11	6
Ease of installment/uninstallment	+	+	+	-	+	7	9
Lightweight	+	+	+	-	-	9	7
Low cost	+	+	+	-	-	8	4
Ease of storage	-	-	+	-	+	4	5
Safety	-	+	-	-	+	2	2
Non-Electrical	+	+	+	-	-	13	13

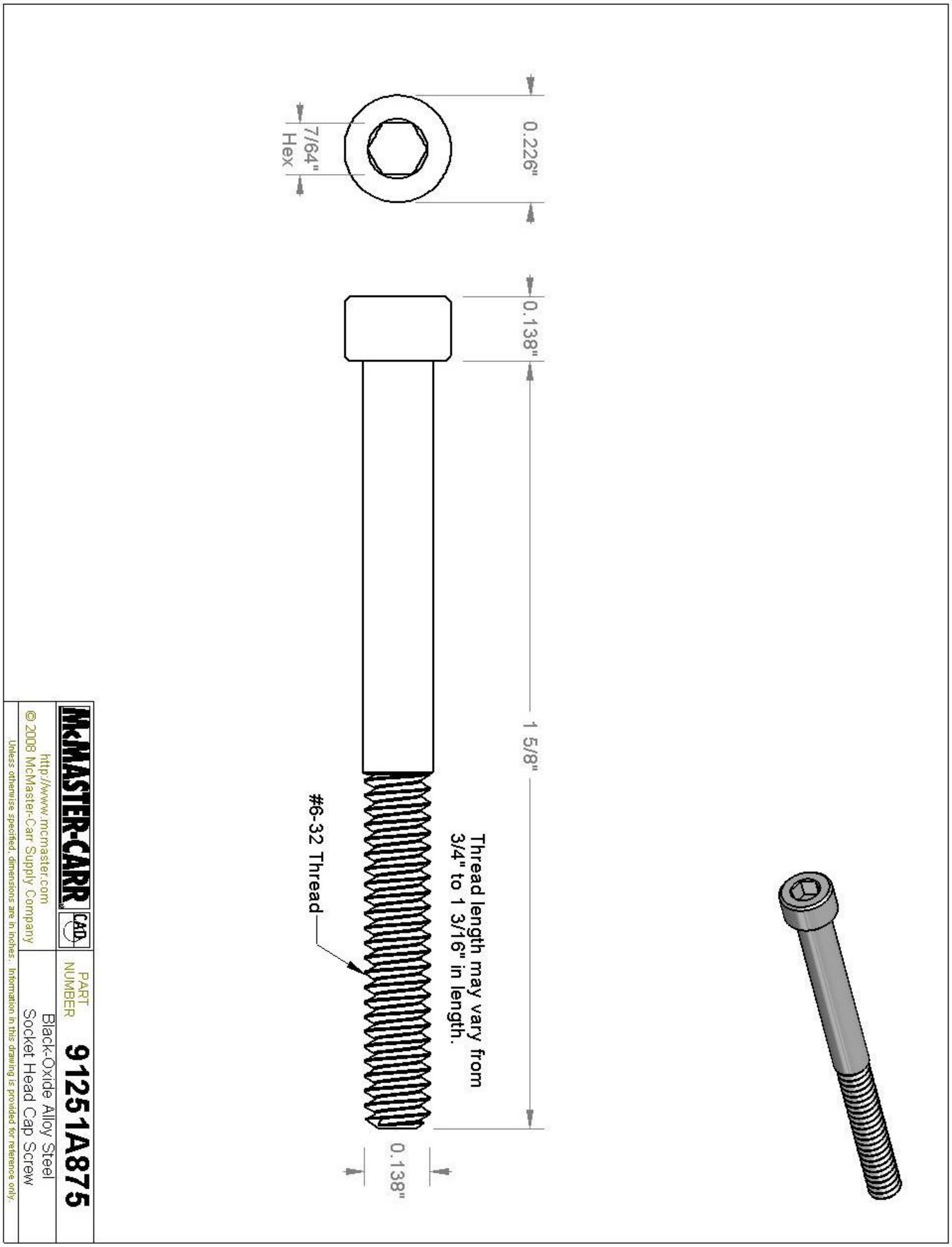
Appendix G: Engineering Drawings




0.422"
0.25" +0 -0.0002
0.375" +0 -0.0002
0.036"
0.1562"
0.125" +0 -0.0015
McMASTER-CARR
http://www.mcmaster.com
© 2007 McMaster-Carr Supply Company
PART NUMBER 57155K336
Type 440C Stainless Steel Double Shielded Ball Bearing with Extended Inner Ring
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.


5/16"
Hex
#6-32 Thread
7/64"
McMASTER-CARR
http://www.mcmaster.com
© 2006 McMaster-Carr Supply Company
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.
PART NUMBER
90480A007
Zinc-Plated Steel
Machine Screw Nut


7/16"
5/32"
1/4"-20 Thread
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2009 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
90494A029
Grade 2 Steel
Hex Nut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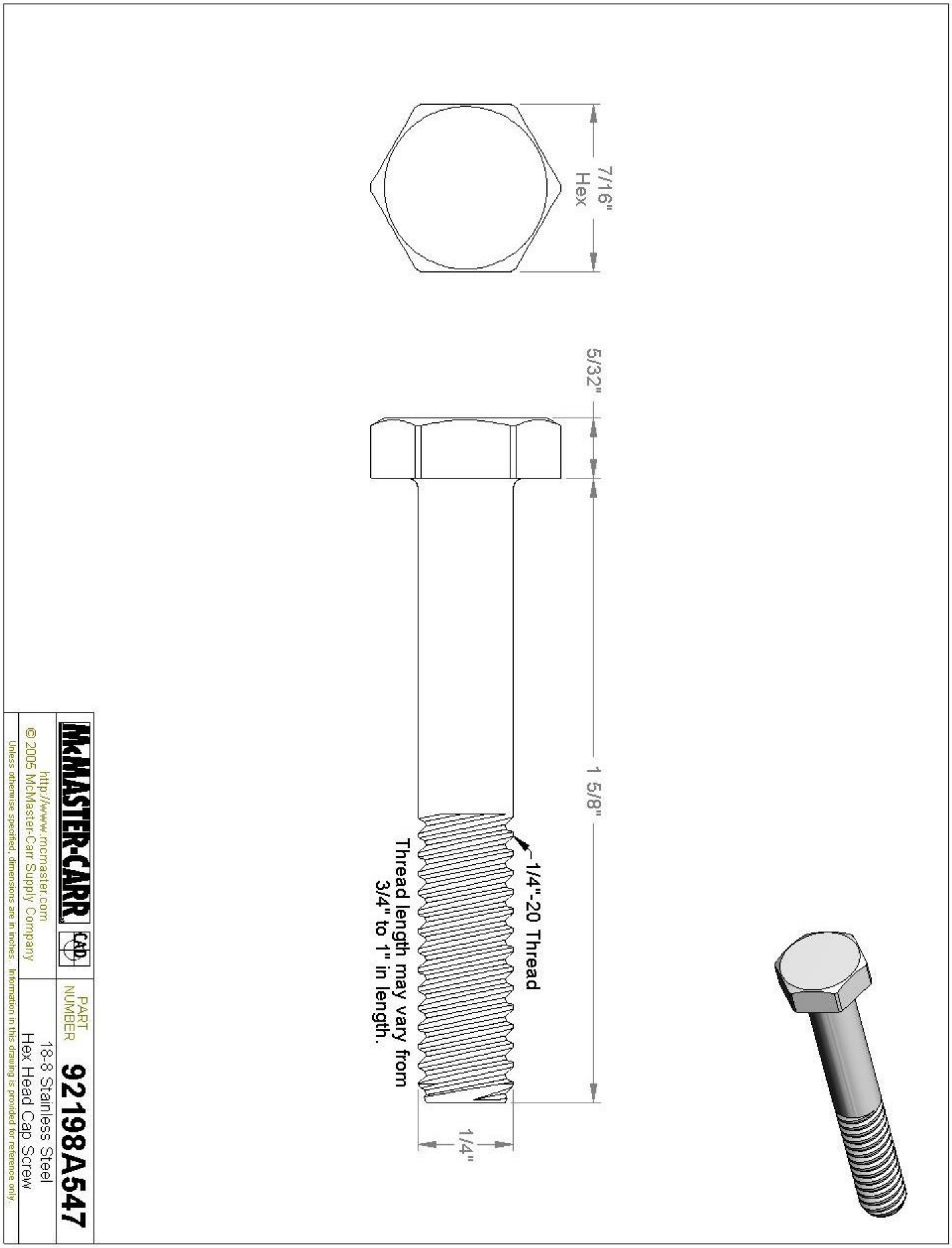
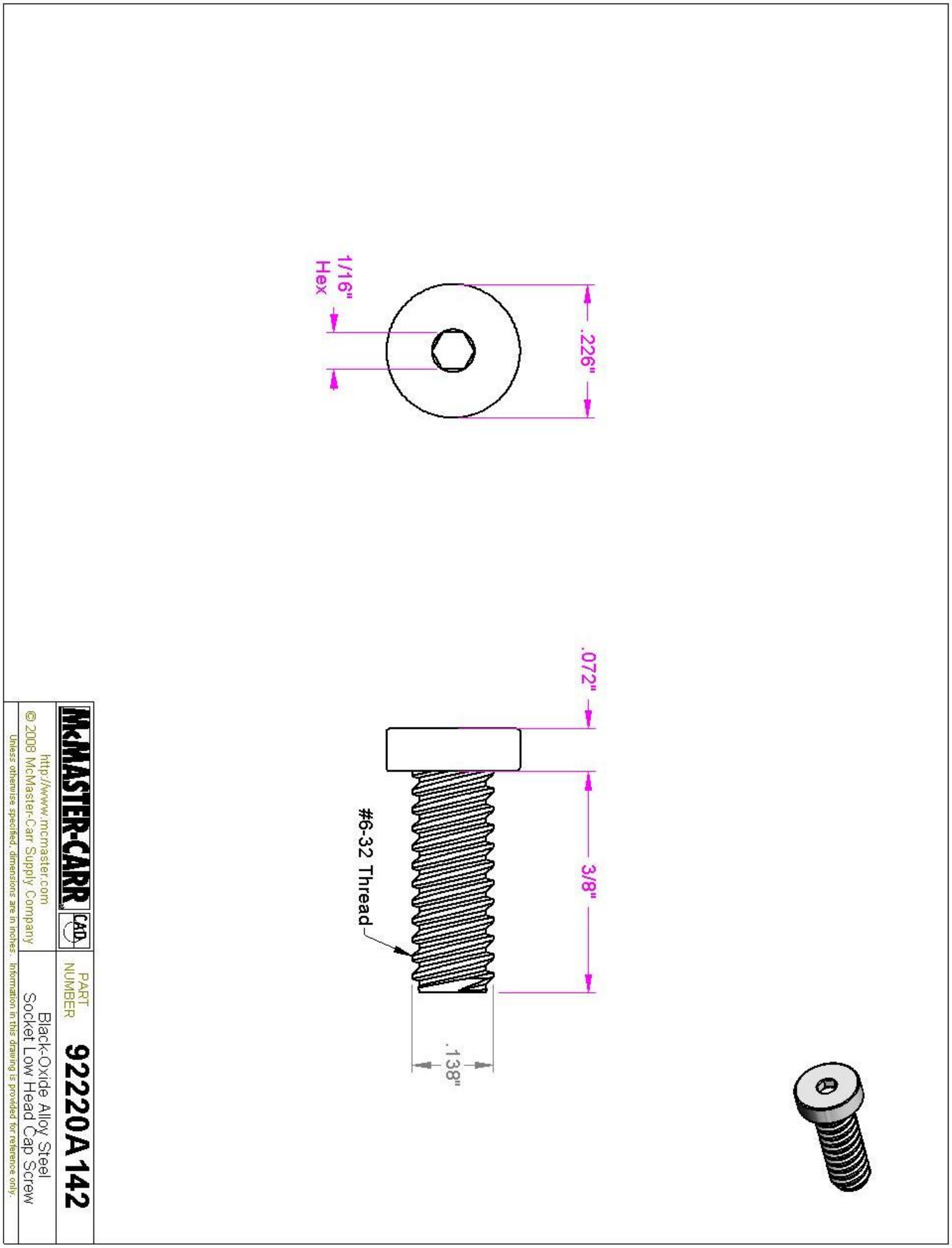
7/64"
Hex
0.138"
1 5/8"
Thread length may vary from
3/4" to 1 3/16" in length.
#6-32 Thread
0.138"
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2008 McMaster-Carr Supply Company
PART
NUMBER
91251A875
Black-Oxide Alloy Steel
Socket Head Cap Screw
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.


7/16"
Hex
5/32"
1 5/8"
1/4"-20 Thread
Thread length may vary from
3/4" to 1" in length.
1/4"
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2005 McMaster-Carr Supply Company
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.
PART
NUMBER
92198A547
18-8 Stainless Steel
Hex Head Cap Screw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Hex
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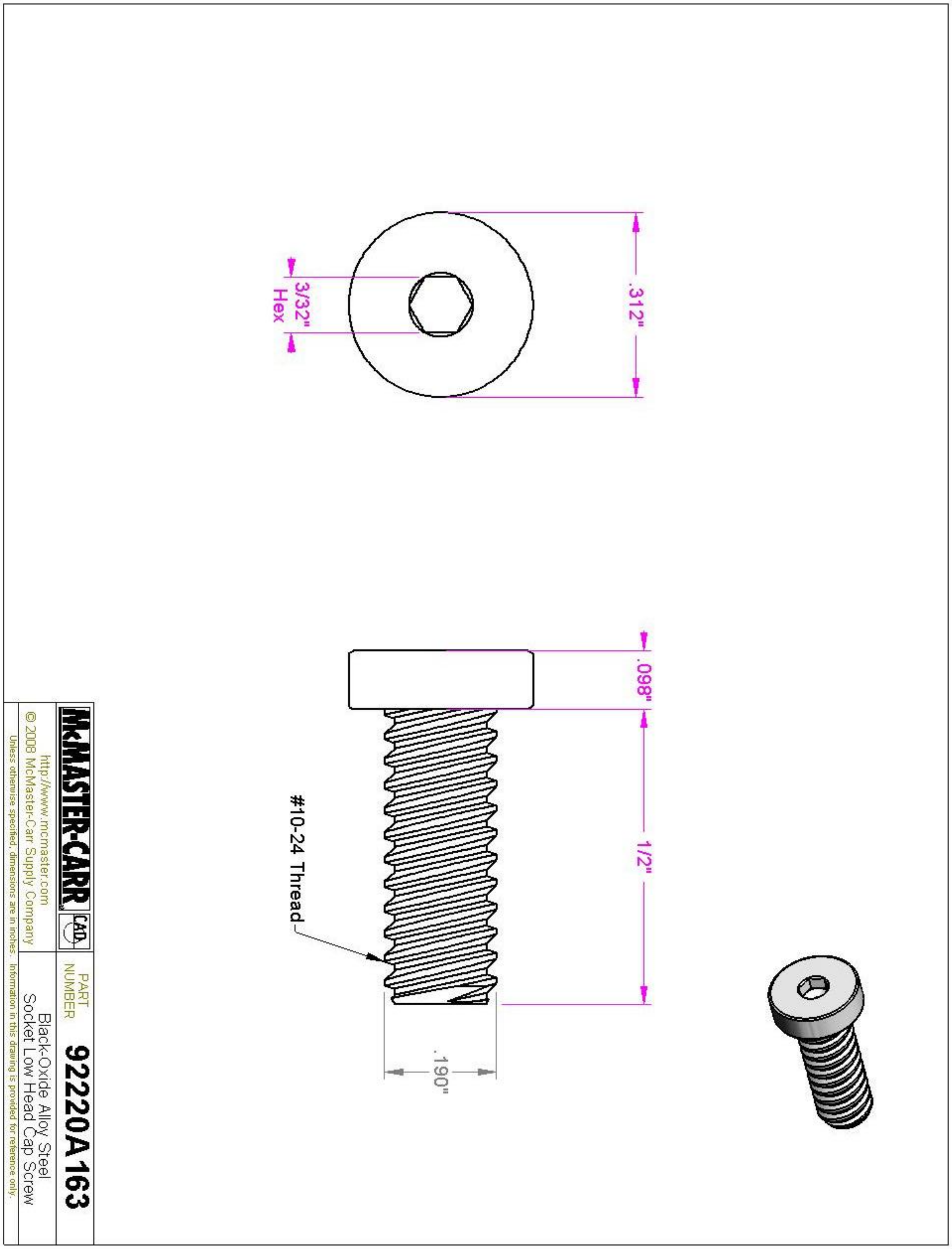
.072"
3/8"
#6-32 Thread
.138"
McMASTER-CARR
PART NUMBER
92220A142
http://www.mcmaster.com
© 2008 McMaster-Carr Supply Company
Black-Oxide Alloy Steel
Socket Low Head Cap Screw
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.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Hex
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.098"
1/2"
#10-24 Thread
.190"
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2008 McMaster-Carr Supply Company
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.
PART NUMBER
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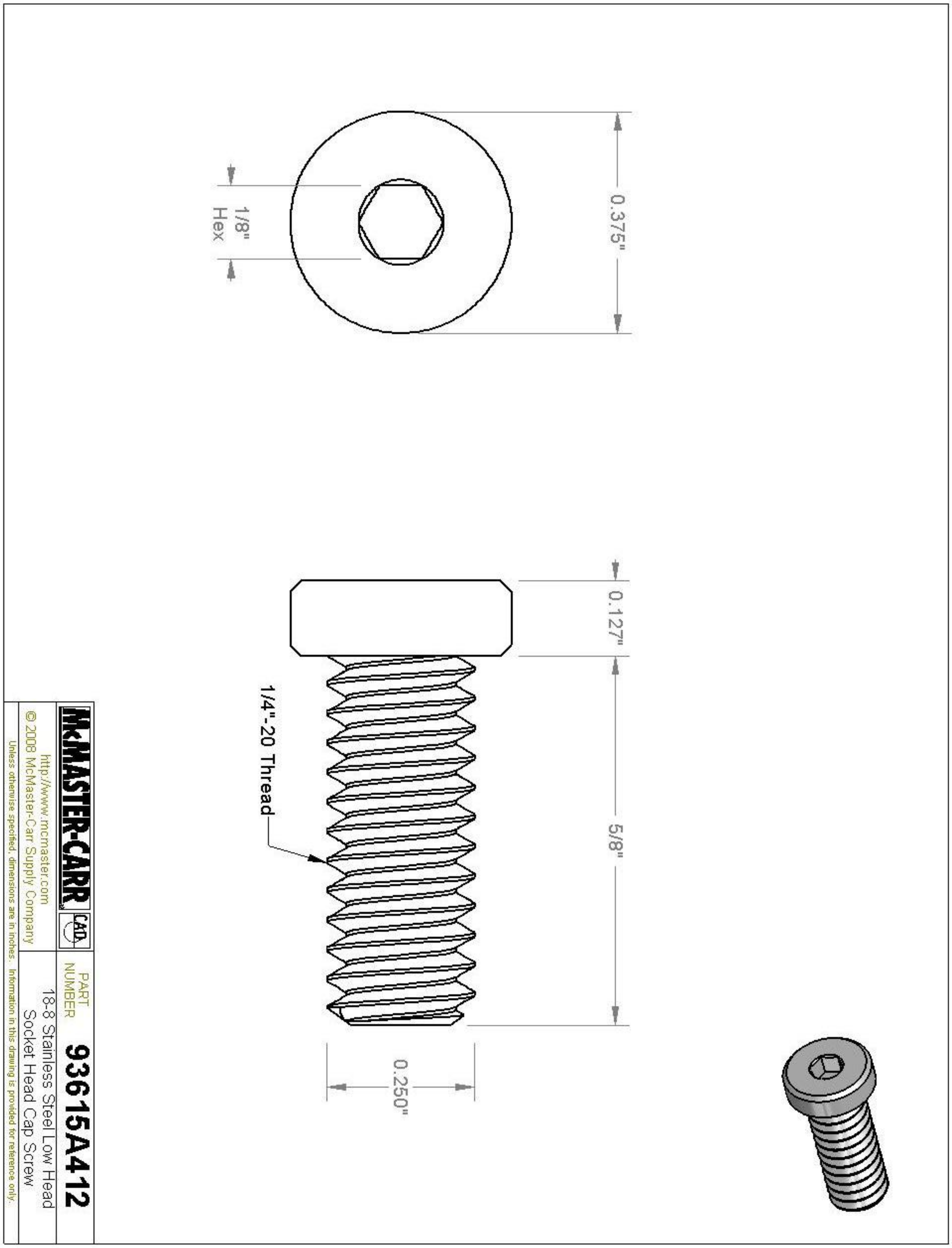
Black-Oxide Alloy Steel
Socket Low Head Cap Screw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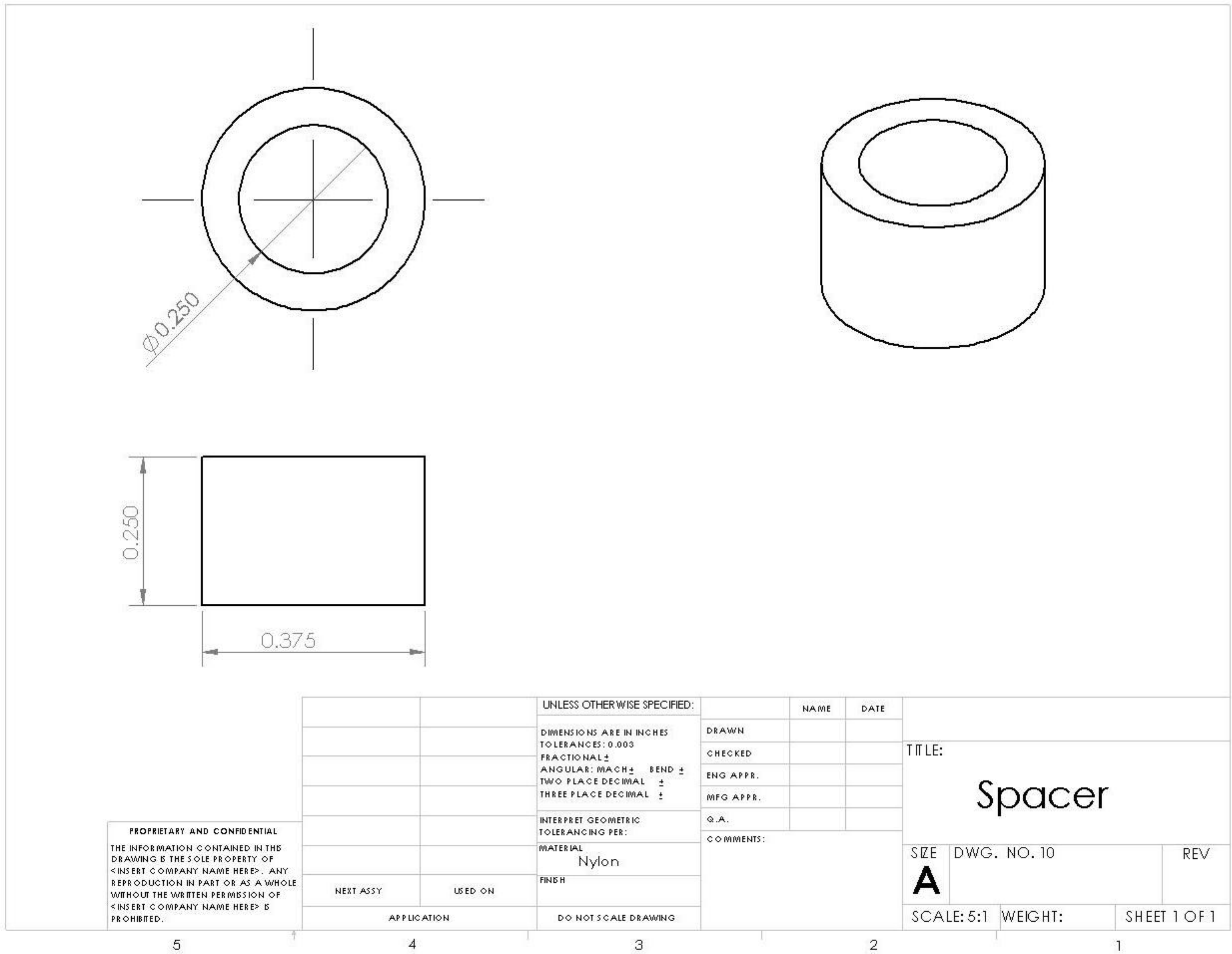
Hex
0.127"
5/8"
1/4"-20 Thread
0.250"
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2008 McMaster-Carr Supply Company
PART NUMBER
93615A412
18-8 Stainless Steel Low Head Socket Head Cap Screw
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.



Ø0.250
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NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: 0.003
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Nylon
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Spacer
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SHEET 1 OF 1
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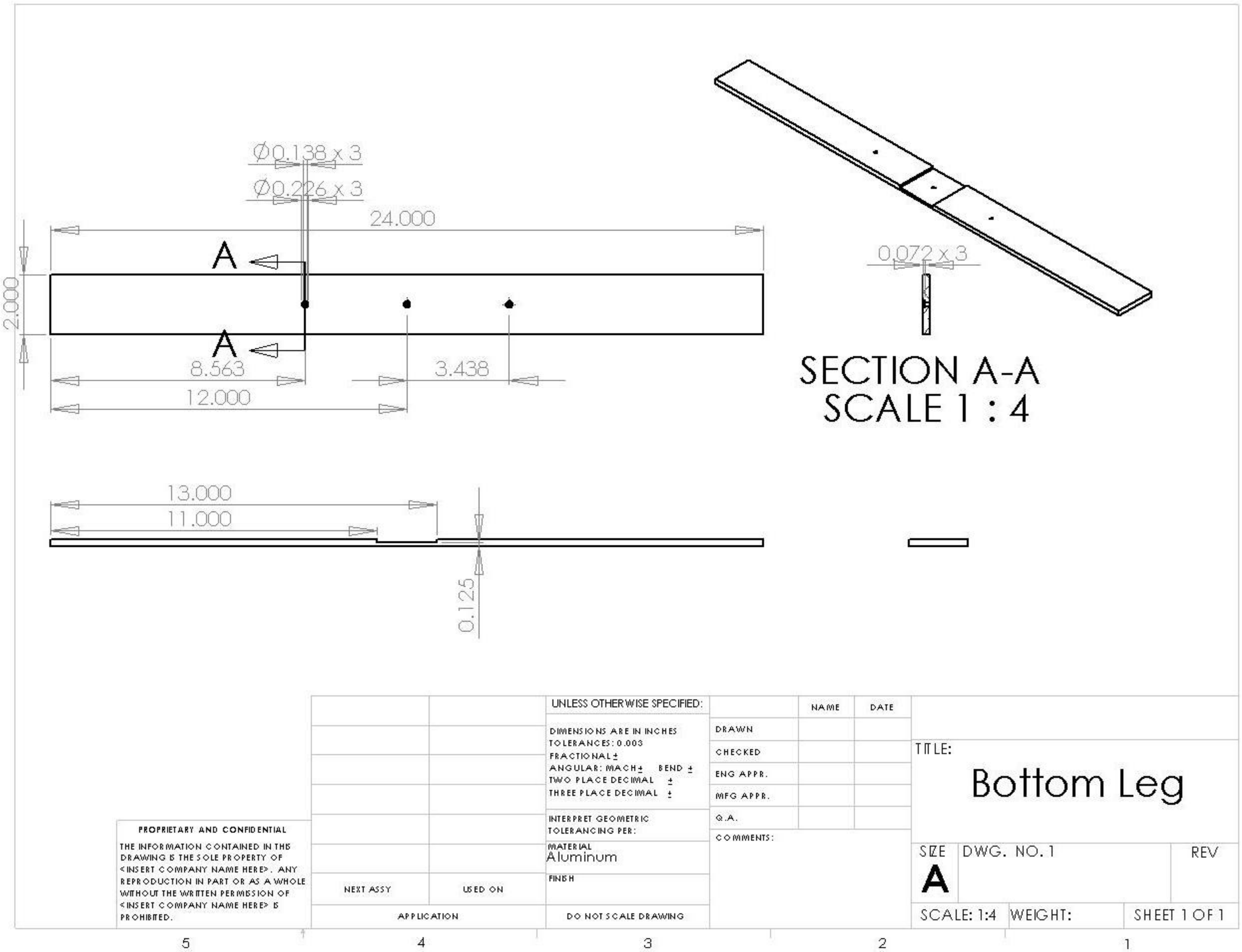
4
3
2
1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SECTION A-A
SCALE 1 : 4
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13.000
11.000
0.125
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APPLICATION
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DIMENSIONS ARE IN INCHES
TOLERANCES: 0.003
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Bottom Leg
SIZE
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DWG. NO. 1
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
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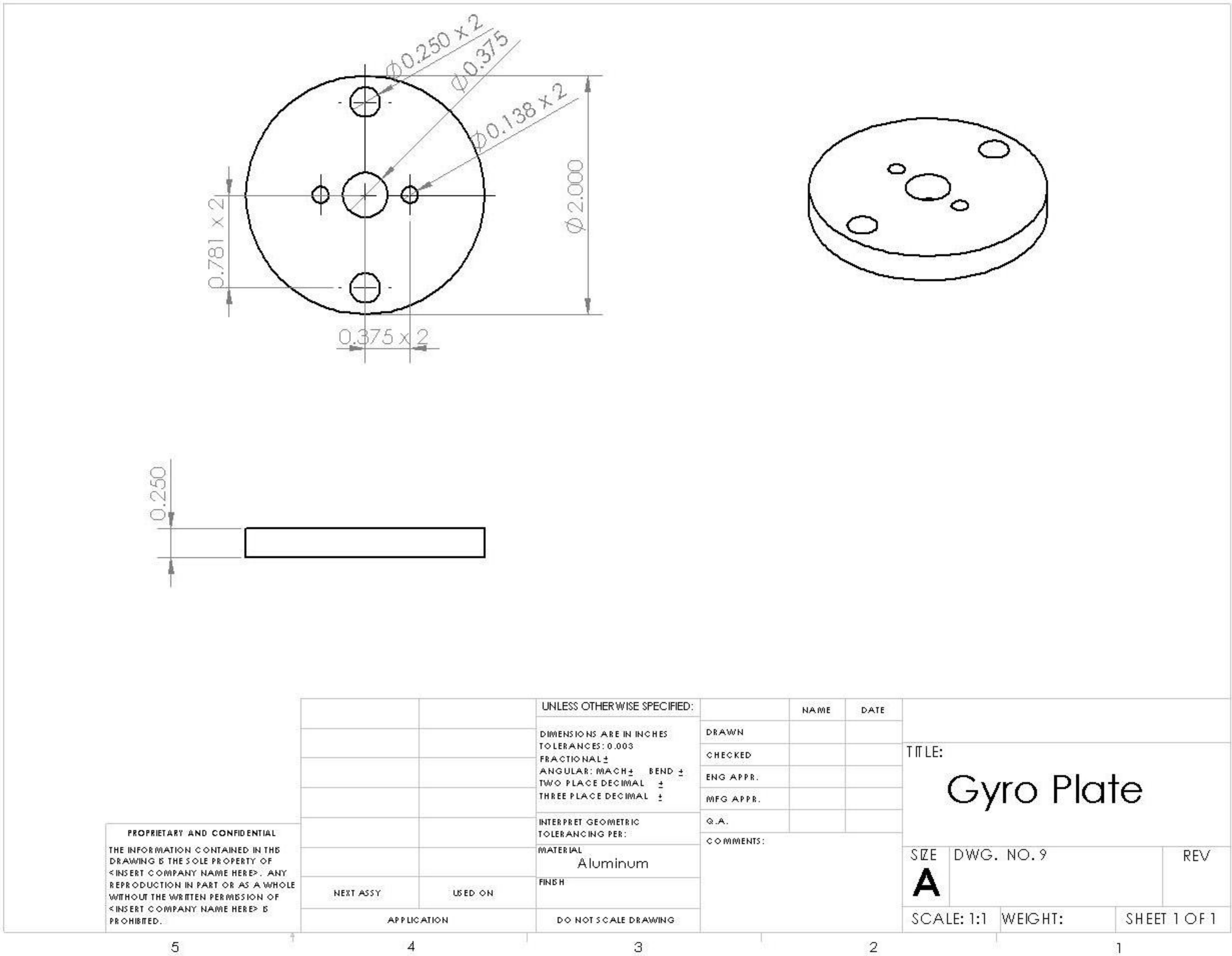
1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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Gyro Plate
SIZE
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DWG. NO. 9
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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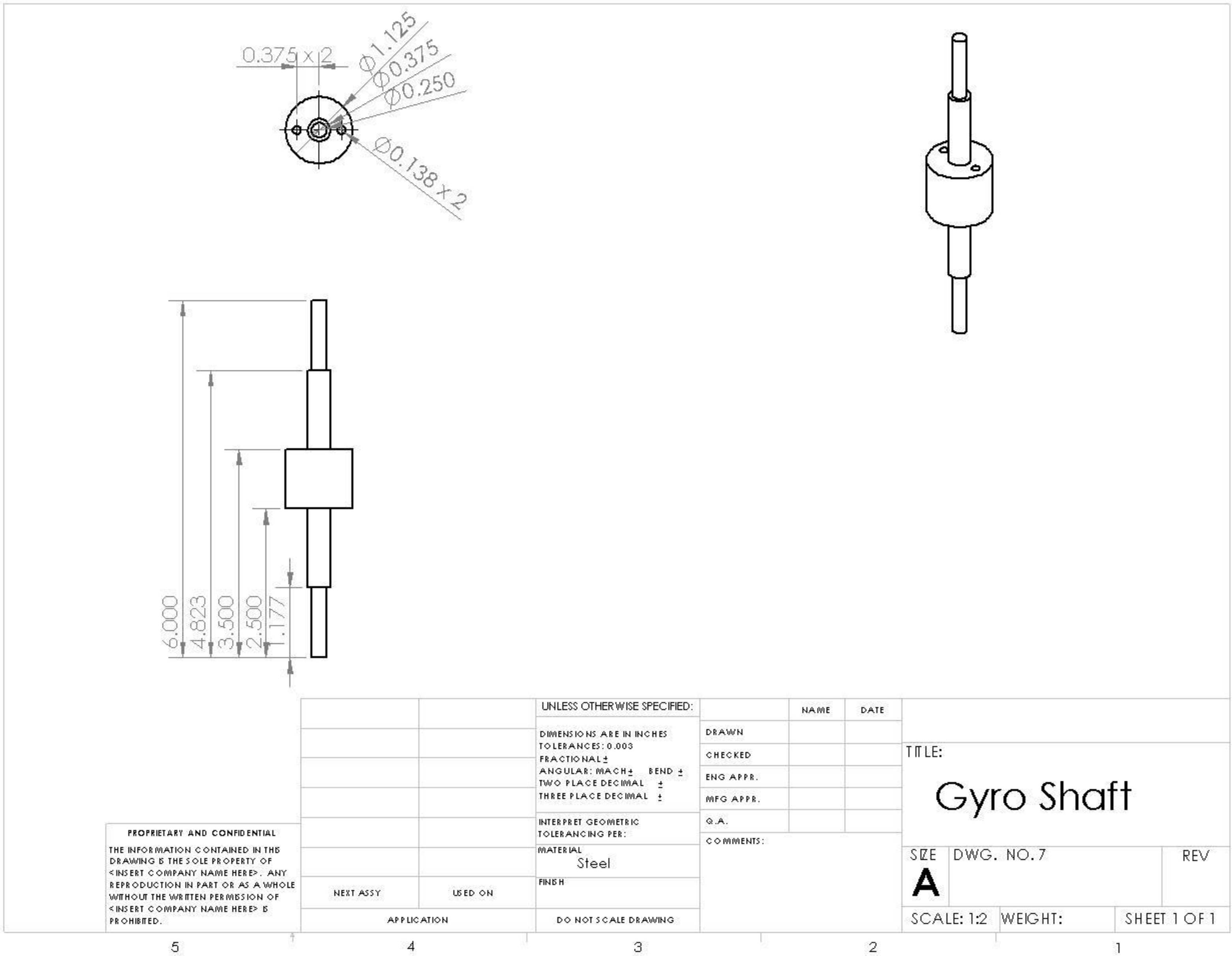
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Ø0.138 x 2
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DIMENSIONS ARE IN INCHES
TOLERANCES: 0.003
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Gyro Shaft
SIZE
A
DWG. NO.7
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
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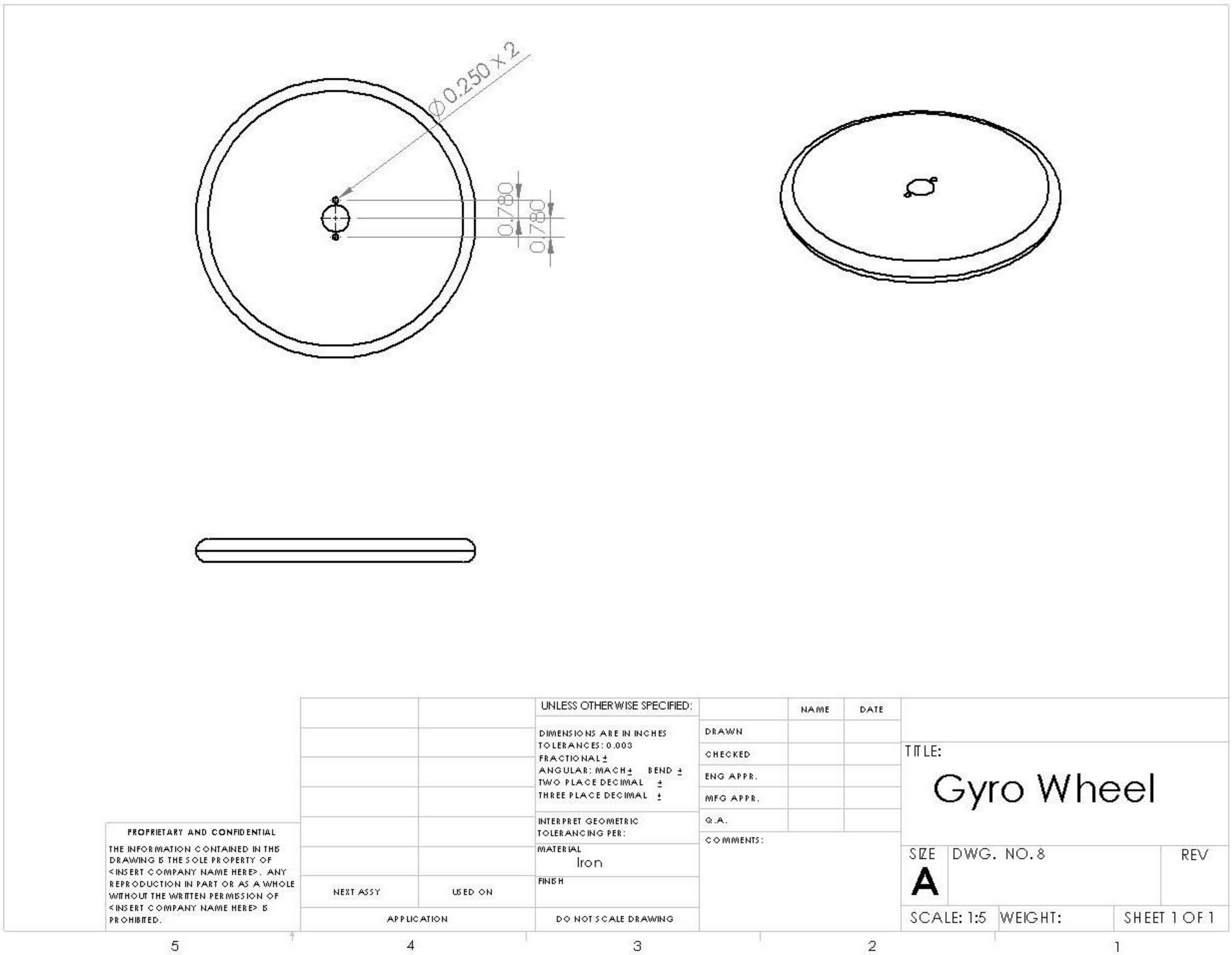
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0.780
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FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
Iron
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Gyro Wheel
SIZE
A
DWG. NO. 8
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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5
4
3
2
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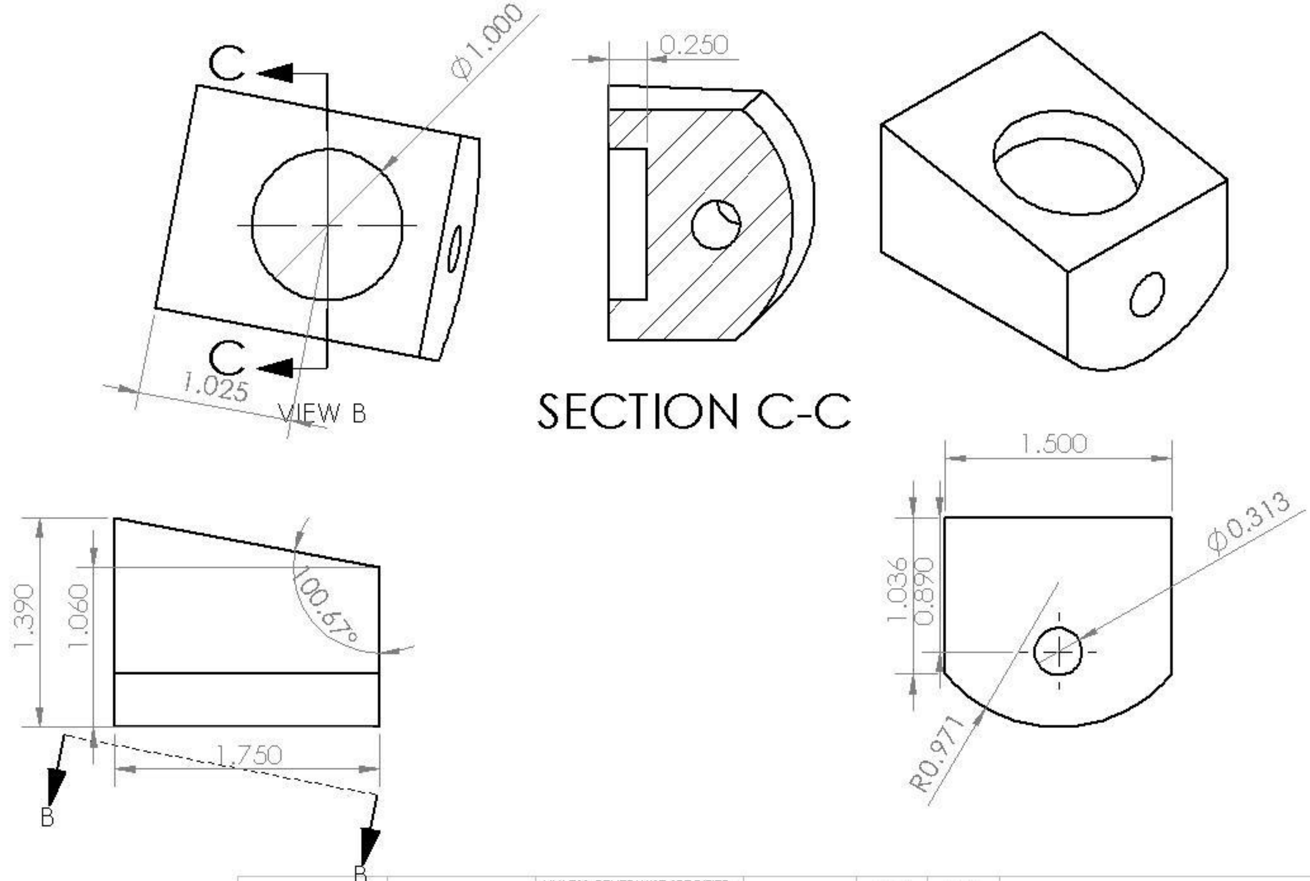

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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Steel

FINISH

DO NOT SCALE DRAWING

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

TITLE: Joint

SIZE A | DWG. NO. 6 | REV

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

NEXT ASSY | USED ON

APPLICATION

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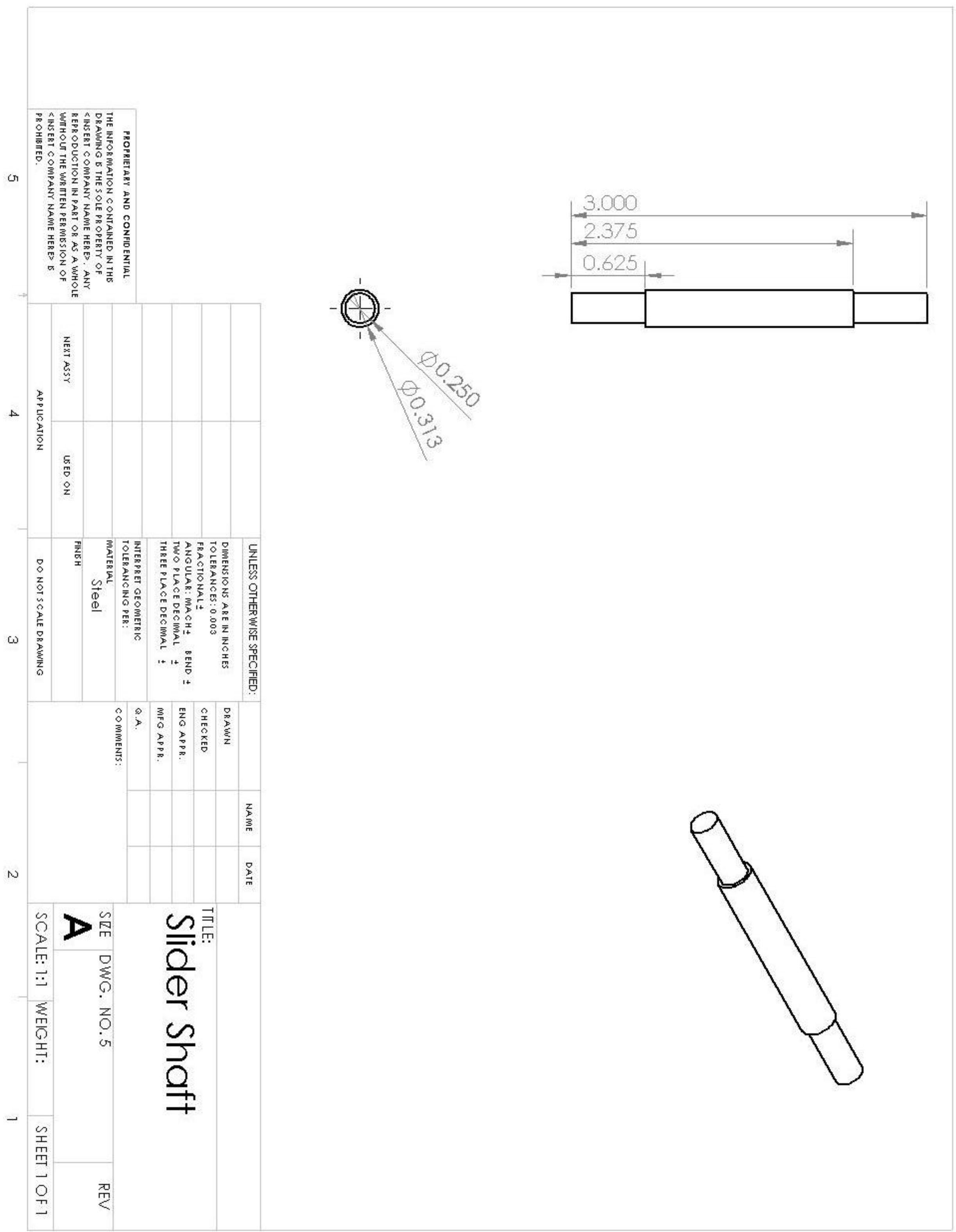
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APPLICATION
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: 0.003
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Steel
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
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DWG. NO. 5
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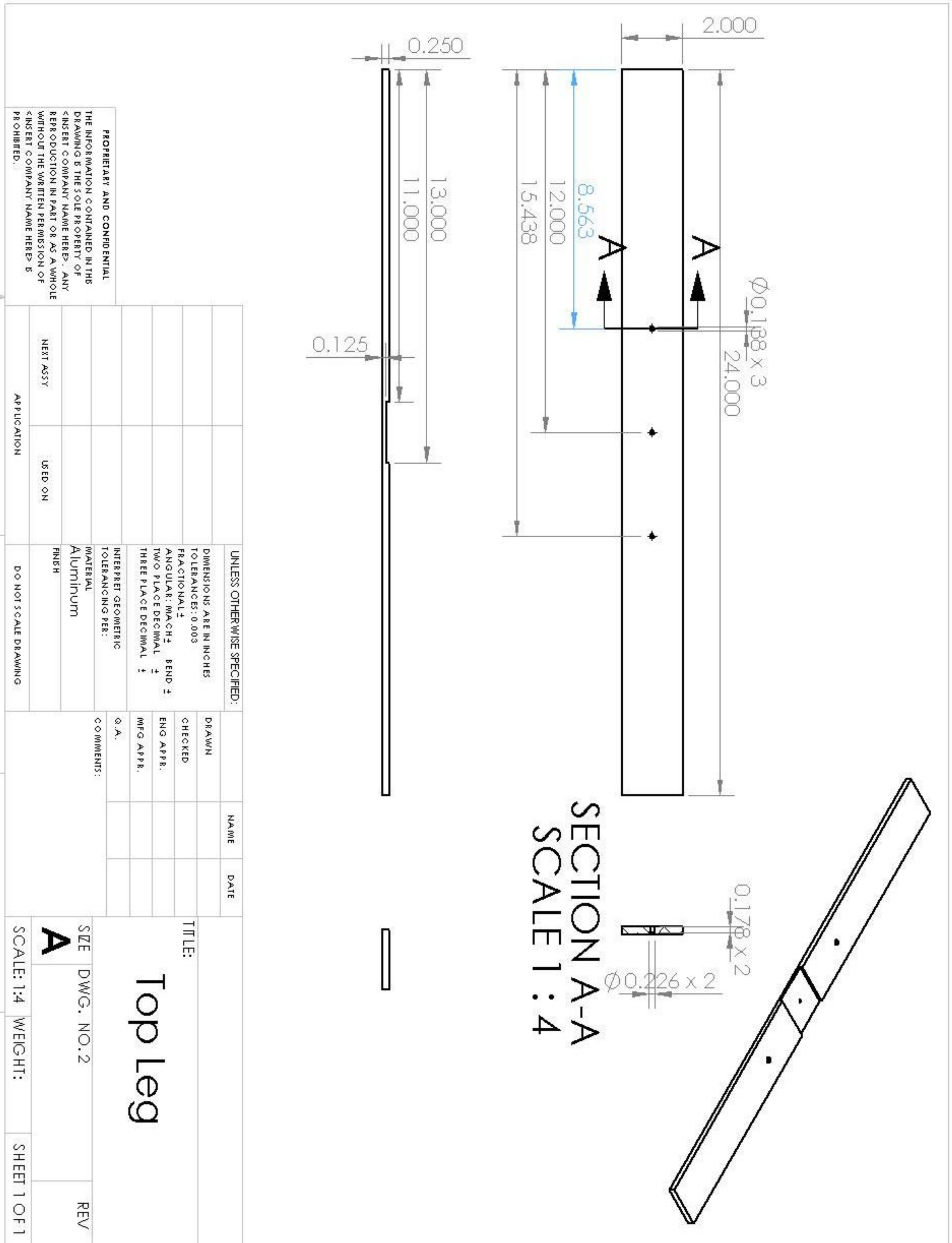
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SECTION A-A
SCALE 1 : 4
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Ø0.226 x 2
PROPRIETARY AND CONFIDENTIAL
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NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: 0.003
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
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SIZE
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DWG. NO. 2
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
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4
3
2
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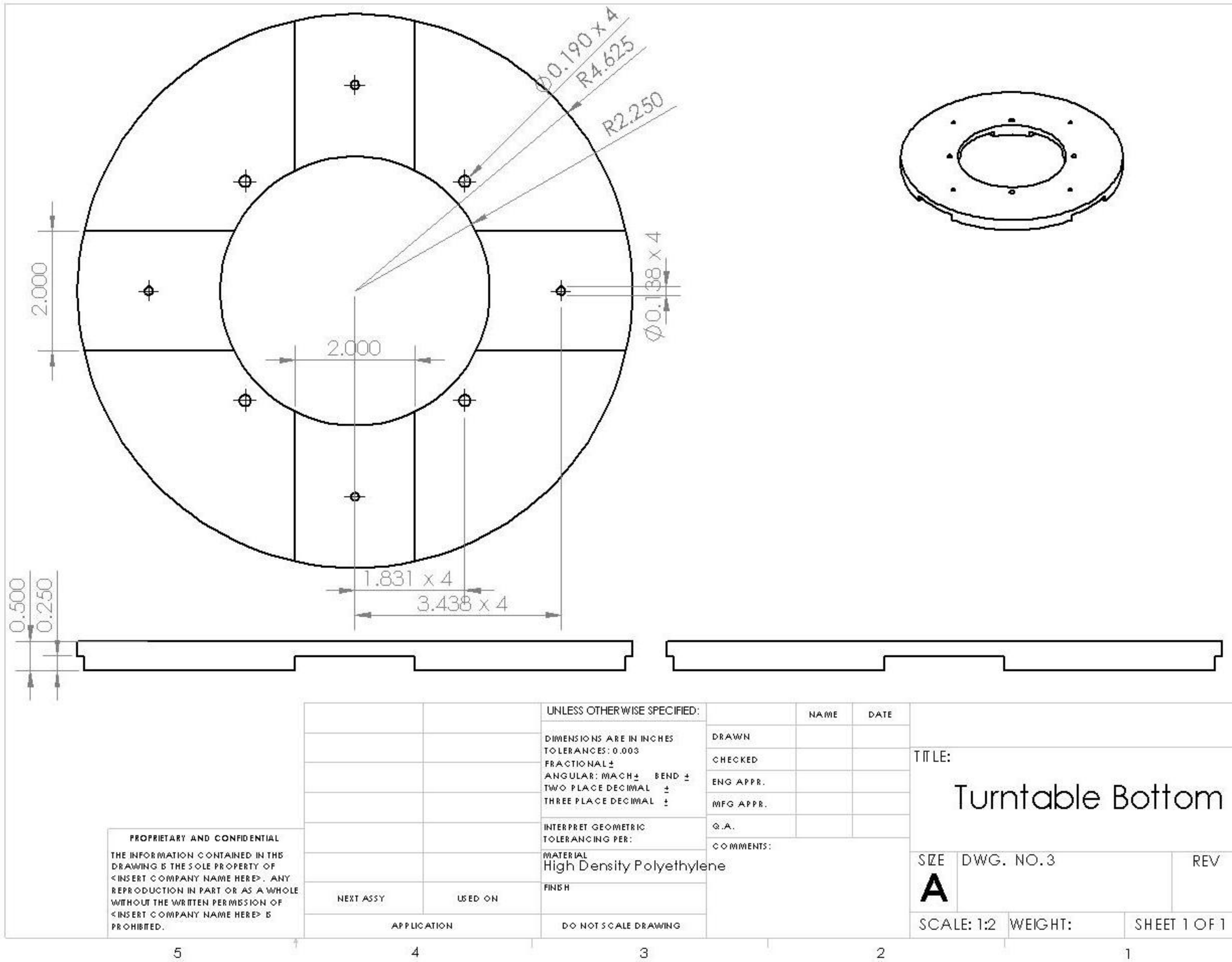
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2.000
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1.831 x 4
3.438 x 4
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0.250
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: 0.003
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
High Density Polyethylene
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Turntable Bottom
SIZE
A
DWG. NO.3
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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NEXT ASSY
USED ON
APPLICATION
5
4
3
2
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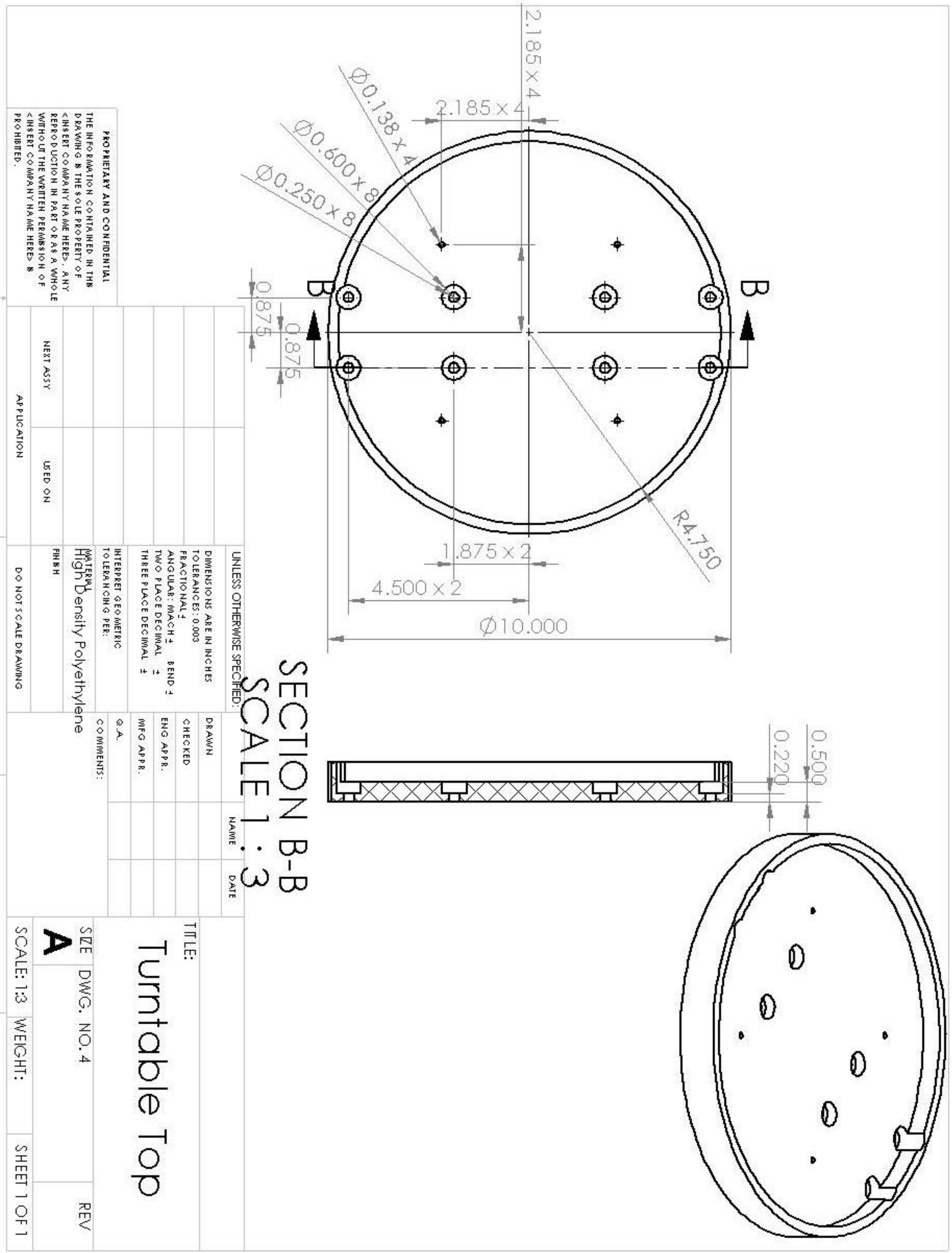

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Ø0.250 x 8
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0.875
B
B
R4.750
1.875 x 2
4.500 x 2
Ø10.000
SECTION B-B
SCALE 1 : 3
0.500
0.220
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NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: 0.003
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
High Density Polyethylene
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Turntable Top
SIZE
A
DWG. NO. 4
REV
SCALE: 1:3
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

Appendix H: Manufacturing Process Plan

Operation Number	Part	Description	Machine / Device	Tool/Activity	Fixture	Parameters
1	Turntable	Order all related materials	-	-	-	2" x 36" x 1/4" aluminum stock, 12” x 12” x ½” Polyethylene, 9.12” round Turntable, 12” x 12” x 1-1/2” Polyethylene stock
2	Mounting	Order all related materials	-	-	-	Mounted bearings, Polyethylene stock
3	U-support	Order all related materials	-	-	-	26” Mountain Bike Forks w/o steel pivot, aluminum stock
4	Motor-gyro	Order all related materials	-	-	-	D/C motor, 25 lb weight, Belt
5	Front Platform	Order all related materials	-	-	-	Skateboard, Holders
6	Screws/bolts, nuts	Order all related materials	-	-	-	6-32 Thread 3/8” Screw, 6-32 Thread ½” Screw, ¼”-20 Thread 1-1/4” Screw
7	Front Platform	Cut Edges	Band Saw		-	6” x 7.5” x 0.25”
8	Front Platform	Drill holes	Drill Press	37 drill bit	Vice	0.0971
9	Turntable Top	Cut to Circle	Water jet	-	-	10.25” Diameter
10	Turntable Bottom	Cut to Circle	Water Jet	-	-	9.5” Outer Diameter 4.75” Inner Diameter
11	Gyro Plate	Cut to Circle	Water Jet	-	-	2.25” Outer Diameter 0.5” Inner Diameter
12	Gyro Plate 2	Cut to Circle	Water Jet	-	-	2.25” Outer Diameter 0.5” Inner Diameter
13	Turntable Top	Mill to Specification	Mill	Face Mill 200 ft/min 2 in/min	Vice	10” Diameter

14	Turntable Top	Mill To Specification	Mill	End Mill 200 ft/min 2 in/min	Vice	9.5” Diameter x 0.5” Thickness
15	Turntable Top	Counter bore	Mill	Borer 200 ft/min 2 in/min	Vice	0.6” Diameter x 0.22” deep
16	Turntable Top	Drill Holes	Drill Press	7 Drill Bit 36 Drill Bit	Vice	0.1887” Diameter 0.0997” Diameter
17	Turntable Top	Tap Holes	Tap	-	-	1/4-20 Thread 6-32 Thread
18	Turntable Bottom	Mill to Specification	Mill	Face Mill 200 ft/min 2 in/min	Vice	9.25” Outer Diameter
19	Turntable Bottom	Mill to Specification	Mill	End Mill 200 ft/min 2 in/min	Vice	4.5” Inner Diameter 2” Channels
20	Turntable Bottom	Drill Holes	Drill Press	36 Drill Bit 21 Drill Bit	Vice	0.0997” Diameter 0.1517” Diameter
21	Turntable Bottom	Tap Holes	Tap	-	-	6-32 Thread 10-32 Thread
22	Gyro Plate	Mill to Specification	Mill	Face Mill 165 ft/min	Vice	2” Outer Diameter
23	Gyro Plate 2	Mill to Specification	Mill	Face Mill 165 ft/min	Vice	2” Outer Diameter
24	Gyro Plate	Drill Holes	Drill Press	27 Drill Bit F Drill Bit W Drill Bit	Vice	0.144” Diameter 0.257” Diameter 0.386” Diameter
25	Gyro Plate 2	Drill Holes	Drill Press	27 Drill Bit F Drill Bit W Drill Bit	Vice	0.144” Diameter 0.257” Diameter 0.386” Diameter

26	Bottom Leg	Cut to Specification	Band Saw	-	-	24.5” Length
27	Top Leg	Cut to Specification	Band Saw	-	-	24.5” Length
28	Bottom Leg	Mill to Specification	Mill	Face Mill 165 ft/min	Vice	24” Length 2” Channel x 0.125” thick
29	Top Leg	Mill to Specification	Mill	Face Mill 165 ft/min	Vice	24” Length 2” Channel x 0.125” thick
30	Bottom Leg	Counter Bore	Mill	Borer 165 ft/min	Vice	0.226” Diameter x 0.072” deep
31	Top Leg	Counter Bore	Mill	Borer 165 ft/min	Vice	0.226” Diameter x 0.072” deep
32	Bottom Leg	Drill Holes	Drill Press	36 Drill Bit	Vice	0.0997” Diameter
33	Top Leg	Drill Holes	Drill Press	36 Drill Bit	Vice	0.0997” Diameter
34	Bottom Leg	Tap Holes	Tap	-	-	6-32 Thread
35	Top Leg	Tap Holes	Tap	-	-	6-32 Thread
36	Joint	Cut to Specification	Band Saw	-	-	1.5” x 1.75” x 1.5”
37	Joint 2	Cut to Specification	Band Saw	-	-	1.5” x 1.75” x 1.5”
38	Joint	Mill to Specification	Mill	Face Mill 100 ft/min	Vice	1.39” x 1.75” x 1.5” with 100.67 degree angle
39	Joint 2	Mill to Specification	Mill	Face Mill 100 ft/min	Vice	1.39” x 1.75” x 1.5” with 100.67 degree angle
40	Joint	Counter Bore	Mill	Borer 100 ft/min	Vice	1” Diameter x 0.25” deep
41	Joint 2	Counter Bore	Mill	Borer 100 ft/min	Vice	1” Diameter x 0.25” deep
42	Joint	Mill to Specification	Mill	Face Mill 100 ft/min	Vice	0.971” radius fillet

43	Joint 2	Mill to Specification	Mill	Face Mill 100 ft/min	Vice	0.971” radius fillet
44	Joint	Drill Holes	Drill Press	P Drill Bit	Vice	0.323” Diameter
45	Joint 2	Drill Holes	Drill Press	P Drill Bit	Vice	0.323” Diameter
46	Gyro Wheel	Drill Holes	Drill Press	F Drill Bit	Vice	0.257” Diameter
47	Fork	Cut to Specification	Band Saw	-	-	0.5” Length
48	Fork 2	Cut to Specification	Band Saw	-	-	0.5” Length
49	Slider Shaft	Cut to Specification	Band Saw	-	-	3.5” Length
50	Slider Shaft 2	Cut to Specification	Band Saw	-	-	3.5” Length
51	Slider Shaft	Lathe to Specification	Lathe	Facer 60 ft/min	Chuck	3” Length
52	Slider Shaft 2	Lathe to Specification	Lathe	Facer 60 ft/min	Chuck	3” Length
53	Slider Shaft	Lathe to Specification	Lathe	Turning Tool 60 ft/min	Chuck	0.25” Diameters
54	Slider Shaft 2	Lathe to Specification	Lathe	Turning Tool 60 ft/min	Chuck	0.25” Diameters
55	Gyro Shaft	Cut to Specification	Band Saw	-	-	6.5” Length
56	Gyro Shaft	Drill Holes	Drill Press	27 Drill Bit	Vice	0.144” Diameter
57	Gyro Shaft	Lathe to Specification	Lathe	Facer 60 ft/min	Chuck	6” Diameter
58	Gyro Shaft	Lathe to Specification	Lathe	Turning Tool 60 ft/min	Chuck	0.25” Diameters 0.375” Diameters

Appendix I: Benchmark Products

Figure A.1: Kurt Kinetic Rock and Roll Trainer

Figure A.2: Kreitler Challenger 4.5 Rollers

Figure A.3: US Patent 7326151

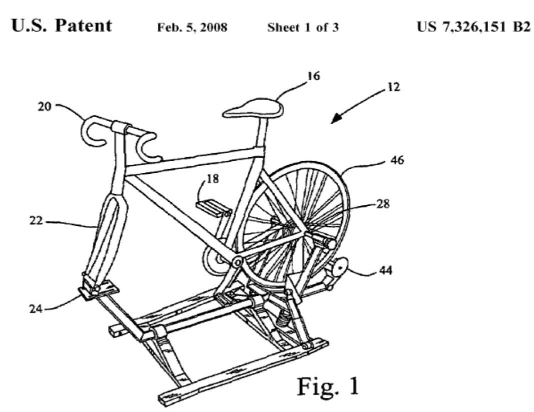

Figure A.4: US Patent 5656001

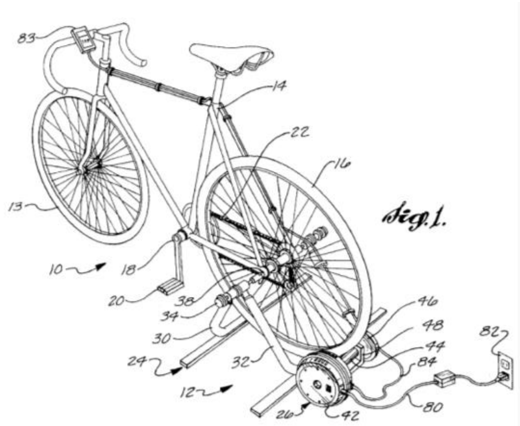

Figure A.5: US Patent 6736761

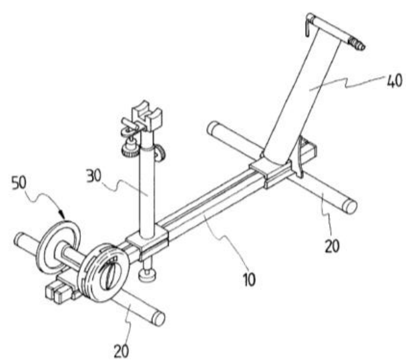

FIG. 1 PRIOR ART

Appendix J: Material Indices

Example 1: Material Index for a Light, Strong, Tie-Rod

A Tie-rod is common mechanical component.

Functional needs: F, L, σ_f

- Tie-rod must carry tensile force, F.
- NO failure. Stress must be less than σ_f. (f=YS, UTS)
- L is usually fixed by design, can vary *Area A*.
- While strong, need to be lightweight, or low mass.

-Strength relation:

$$\frac{F}{A} \leq \frac{\sigma_f}{S}$$

- Mass of rod:

$$m = \rho L A$$

- Eliminate the "free" design parameter, A:

$$m \geq (FS)(L)\left(\frac{\rho}{\sigma_f}\right)$$

minimize for small m

Or Maximize Materials Index:
For light, strong, tie-rod

$$M = \frac{\sigma_f}{\rho}$$

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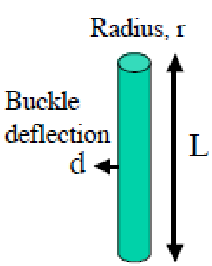
Example 5: Material Index for a Cheap, Stiff Support Column

(From Ashby "Materials Selection in Mechanical Design")



A slender column of fixed intial length *L* uses less material than a fat one; but must not be so slender than it buckles under load F.

- No buckling relation:

$$F \leq F_{crit} = \frac{N\pi^2 EI}{L^2}$$

Load less than *Euler Load*.
N given by end constraint on column.

- Cost objective:

$$C = mC_m = AL\rho C_m$$

C_m is the cost/kg of (usually processed) material.

- Eliminate the "free" design parameter, A:

$$C \geq \left(\frac{4}{n\pi}\right)^{1/2}\left(\frac{F}{L^2}\right)^{1/2} L^3 \left(\frac{C_m \rho}{E^{1/2}}\right)$$

specified by application

minimize for small m

Maximize → Cheap, Stiff Beam

$$\left(\frac{E^{1/2}}{C_m \rho}\right)$$

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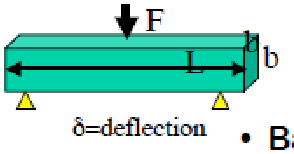
Example 3: Material Index for a Light, Stiff Beam in Deflection



Bending is common mode of loading, e.g., golf clubs, wing spars, floor joists.

- Bar with initial length L must not deflect by more than δ under force F.
  - Stiffness relation:
  $$\frac{F}{\delta} \geq \frac{C_1 E\mathbf{I}}{L^3} = \frac{C_1 E}{L^3}\left(\frac{b^4}{12}\right) = \frac{C_1 E}{L^3}\left(\frac{A^2}{12}\right)$$
  - Mass of bar:
  $$m = b^2 L\rho = AL\rho$$
- Eliminate the "free" design parameter, A:

specified by application → $\left(\frac{12S}{C_1 L}\right)^{1/2}$

$$m \geq \left(\frac{12S}{C_1 L}\right)^{1/2} (L^3) \left(\frac{\rho}{E^{1/2}}\right)$$

minimize for small m → $\left(\frac{\rho}{E^{1/2}}\right)$

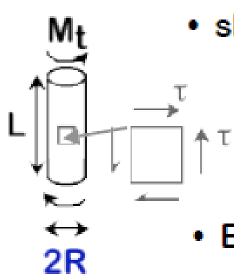
Maximize → Light, Stiff Beam

$$M = \frac{E^{1/2}}{\rho}$$

If only beam height can change (not A), then M= ($E^{1/3}/\rho$) (Car door) $I \propto b^3 w$

If only beam width can change (not A), then M= (E/ρ)

Example 4: Torsionally stressed shaft (Callister Chpt. 6)



- shaft must carry moment, M_t, with length L.

Mass plus Twisting Moment, M_t: $\tau = 2M_t/\pi R^3$

  - Strength relation:
  $$\frac{\tau_f}{S} = \frac{2M_t}{\pi R^3}$$
  - Mass of bar:
  $$m = \rho\pi R^2 L$$
- Eliminate the "free" design parameter, R:

$$m = \left(2\sqrt{\pi}\ SM_t\right)^{2/3} L\ \frac{\rho}{\tau_f^{2/3}}$$

specified by application → $\left(2\sqrt{\pi}\ SM_t\right)^{2/3} L$

minimize for small M → $\frac{\rho}{\tau_f^{2/3}}$

- Maximize the Material's Index: (strong, light torsion members)

$$M = \frac{\tau_f^{2/3}}{\rho}$$

"Materials Selection and Design: Design & Selection: Materials Indices." *Materials Selection and Design*. Ed. D D. Johnson. University of Illinois at Urbana-Champaign, 2004. Web. 19 Apr. 2010. <http://web.mse.uiuc.edu/courses/mse406/Handouts/chX_selection.pdf