Amusement Park Ride

A Major Qualifying Project (MQP) Report
Submitted to the Faculty of the
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the
Degree of Bachelor of Science in Mechanical Engineering

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Abstract

Mechanical systems have often been used for amusement park rides. Whether it is a roller coaster of as simple as a teeter-totter, each device is composed of mechanical systems to create an enjoyable ride. The intention of this Major Qualifying Project was to design, test, and manufacture an eye catching, human-powered, kinematic amusement ride. The motion of this ride incorporates coupler curves. This device is intended for fundraising events; therefore it is designed for easy assembly and disassembly, and for compact storage. To increase effective portability and reduce energy consumption, the device was designed to be human powered. The design was done with modeling using SolidWorks and Creo CAD software, interpreting the results of material cost benefit analysis, custom part machining, and stress calculations.

Executive Summary

Charitable organizations receive large donations every year from Greek organizations and their fundraising. In the year 2012 the top twenty-two Greek organizations donated a combined amount of 5,585,934 dollars to charity. At Worcester Polytechnic Institute, the local Greek organizations donated a combine amount of 63,762 dollars to charity. Raising money effectively through enjoyable interactive events on campus is a large part of how these organizations are capable of raising money. [U.S. fraternity ranking 2012]

The goal of this Major Qualifying Project was to design, test, and manufacture an eye catching, human-powered, kinematic amusement ride to raise money for charity. Research was initially done to determine the key aspects of a successful philanthropy event. These characteristics were refined into three key components; the event must catch the eye of passersby, the event must have minimal running and operating cost, and the donors should have incentive to donate. These characteristics were compiled and preliminary designs of an amusement ride were drawn up.

Coupler curves were researched to create a one of a kind ride that would satisfy all of the categories. A series of different curves were compared and a figure eight curve was chosen as the most enjoyable path for the rider. Once the final curve was established, models were designed in SolidWorks and design iterations were performed to create a functioning model. A series of analyses were performed using SolidWorks simulation to ensure the safety of the rider along with the ride. These analyses were checked with an analysis of a static situation to ensure the proper design constraints were in place in the computer model.

The model went through a series of further iterations until the stress analysis was within an acceptable range with the ideal materials chosen. A small-scale prototype was constructed as a proof of concept and to flush out any further design problems the model might have. These design concerns were noted and further iteration was performed on the model to create the final design. The final design was constructed to scale however machining issues limited the ride to a proof of concept model. Following the construction of the full scale model, a survey was conducted to determine the level of interest on the ride. The results of the survey were very promising, 87% of participants said they would like to ride and 80% of the participants said they would be open to donating one to two dollars to charity for the opportunity to ride

1. Introduction

The goal of this Major Qualifying Project is to create an eye catching human-powered amusement park ride that any student can ride, which can be used by an organization to raise money for a charity. Normally philanthropy events hosted by Greek organizations that use rides prevent donators from participating in the event due to liabilities they encounter. However, by creating a ride that is tested to follow all safety practices this can be changed. To measure the effectiveness of participation in donation research was conducted on several events done at Worcester Polytechnic Institute by Greek organizations; the breakdown can be seen in Figure 1. [Perlow, E]

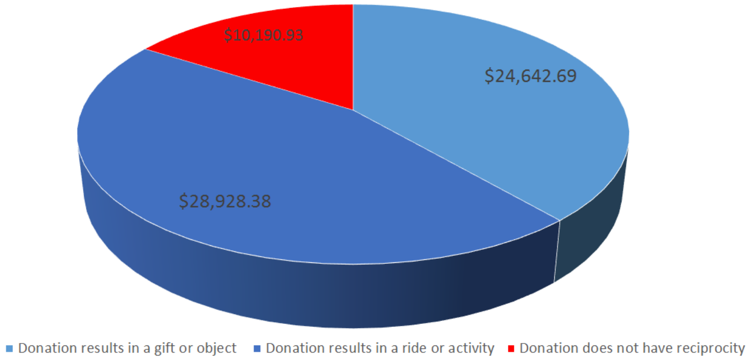

Figure 1: Money Raised for Charity from Greek Organizations from Active and Non Active Events

Figure 1 shows the total amount of money raised by Greek organizations for charity from the year 2014. The blue regions show money that was raised through events where donors receive something for their donation. This general trend from events shows that philanthropy events are more successful at raising money for charity when they offered reciprocity for donations, such that the donors were active. There are two kinds of philanthropy events that offered something in return for donations, one that offered an object and one that provided a ride or activity. This research showed that events where students are able to experience a ride or activity from their donation would raise more money in comparison to those where donors receive an object.

Based on the research, the group decided to create an amusement park ride for Greek organizations to use for events to raise money for charities. This amusement park ride will follow Massachusetts State regulation for a standard amusement park ride. This ride will also not constrict the organization on the location placement of the ride, therefore it will not rely on electricity, rather be human-powered. This project will focus on the research and construction of a human-powered amusement park ride, which will be constructed and temporarily placed on the Worcester Polytechnic Institute Quadrangle that would raise money for charitable organizations.

2. Background

2.1 Safety Standards

In order for an amusement ride to be considered safe according to ASTM it must pass a patron restraint and containment analysis, patron clearance envelope analysis, and a failure analysis.

2.2 Patron Restraint and Containment

In order to keep the rider safe, anything that the rider might come into contact with must be smooth in order to prevent and cuts, scrapes, or splinters. The amount of force required to lock and unlock rider-powered restraints cannot exceed 18 lbs[1].

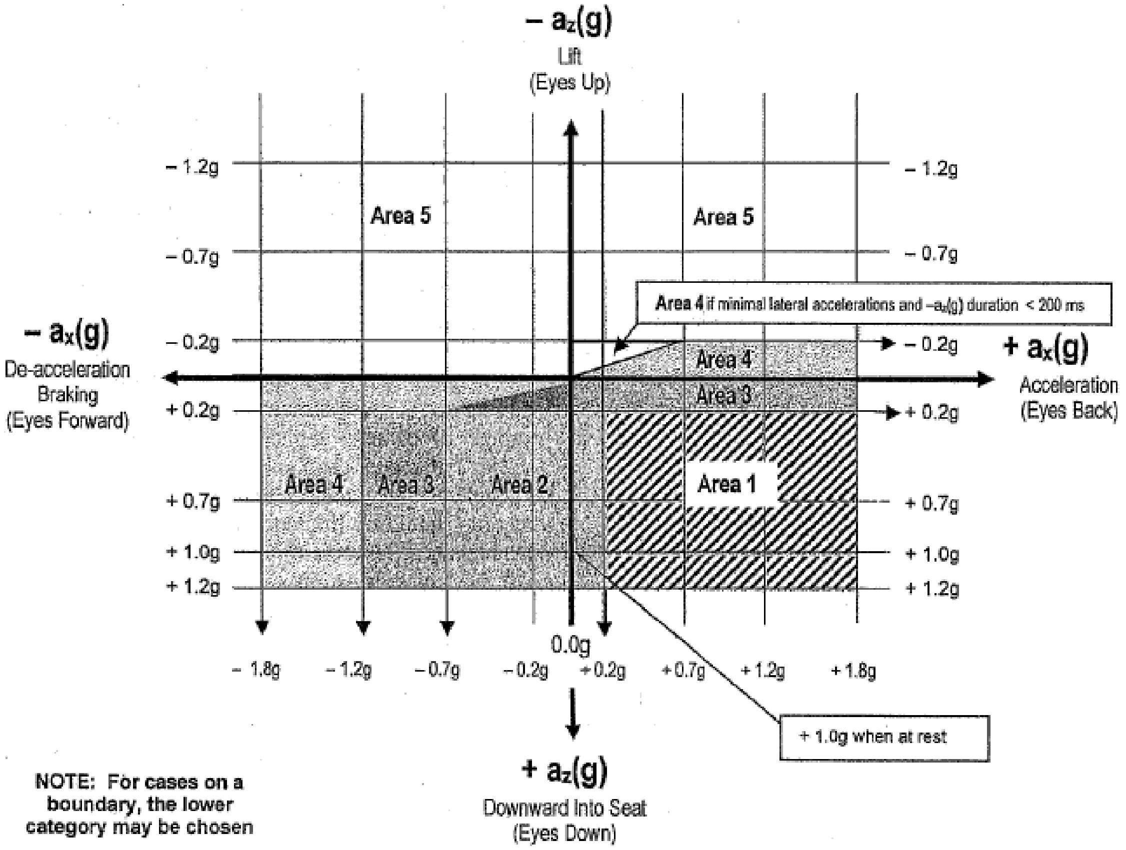

Figure 2: Different Restraints Required for Various Accelerations for A Patron Moving Up, Down, Forward, and Backward

Figure 2 shows a graph of the different types of restraints required for the given accelerations a rider will exhibit in the up, down, forward, and backward directions. If a ride falls

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[1] International, A. (2006). Standard Practice for Design of Amusement Rides and Devices. ASTM.

into Area 1, no restraint required for the patron because the patron is exhibiting enough acceleration, which does not put them in harm. Area 2 requires latching restraint because of the increased acceleration experienced by the rider. The latching restraint for area 2 can restraint more than one person and can be locked by either the patron or the operator. The final latching position may also be variable or fixed in relation to the rider. The rider or operator can unlatch it and the latch may be activated manually or automatically. Area 3 requires a latching restraint on the rider, for instance a bar with multiple latching positions where different sized patrons can use to keep their body held down. Area 4 requires a locking restraint for each rider. Each rider is required to have his or her own constraint and the final latching position must be variable. The latch should automatically lock but may be unlocked manually only by the operator. The restraint can be open and closed automatically or manually and redundancies shall be provided for locking function[2].

In Area 5, a locking restraint for each rider is required, meaning that it is the same as area 4, except an external method of detecting failure is required and when failure is detected, it must bring the ride to a top and if no failure is detected can start the ride[3]. Also two forms of restraints are required (shoulder and lap or a failsafe restraint) is required. Restraints shall also be designed to with stand the full force of an average person intentionally or unintentionally trying to break it[4].

2.3 Patron Clearance Envelope

The purpose of the clearance envelope is to reduce the possibility the rider will come into contact with anything other than their seat in order to decrease likelihood of injury. Measurements should be taken to ensure harmful object and surfaces (sharp corners and splinters) that the rider can come into contact with cannot injure the rider. When designing the clearance envelope a model rider should be the size of the 95th percentile male, adult, or child plus 3 in. depending on the target audience illustrated in the Figure 3[5].

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[2] Ibid
[3] Ibid
[4] Ibid
[5] Ibid

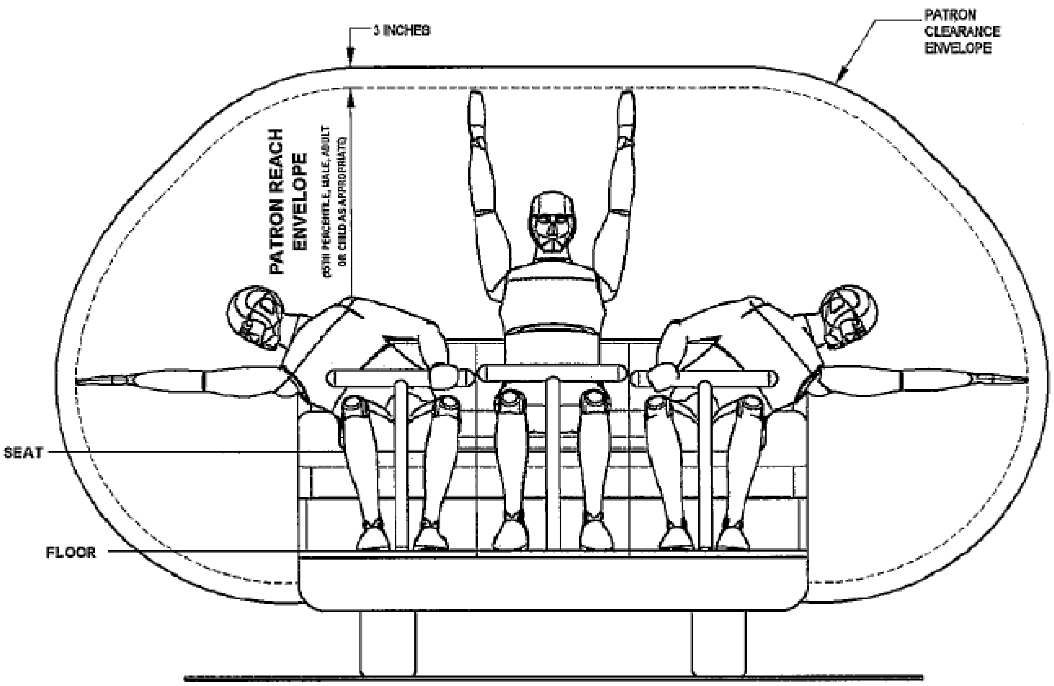

Figure 3: Maximum Clearance Envelope

2.4 Acceleration limits

All acceleration limits were calculated using a 48 in. person and are measured in G. The following figure shows the base acceleration limits in the Y-Z plane.

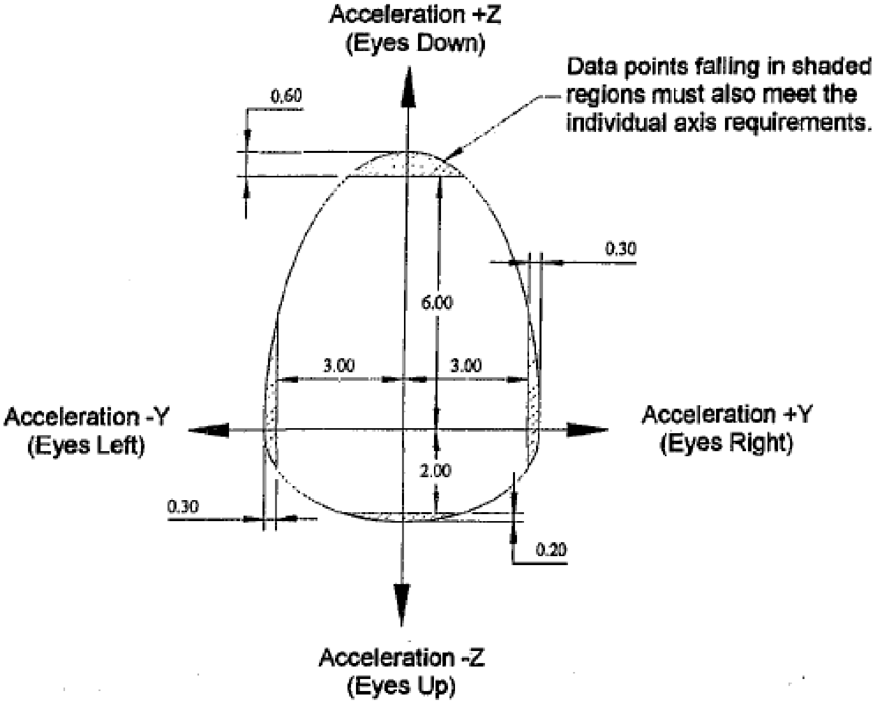

Figure 4: Maximum Allowable Acceleration Going Either Left or Right

Figure 4 shows that the maximum allowable acceleration going either left or right is 3G, the maximum going up is 6G, and down is 2G. If the acceleration from peak to peak is less than 200 ms, than the limit is reduced by 50%[6].

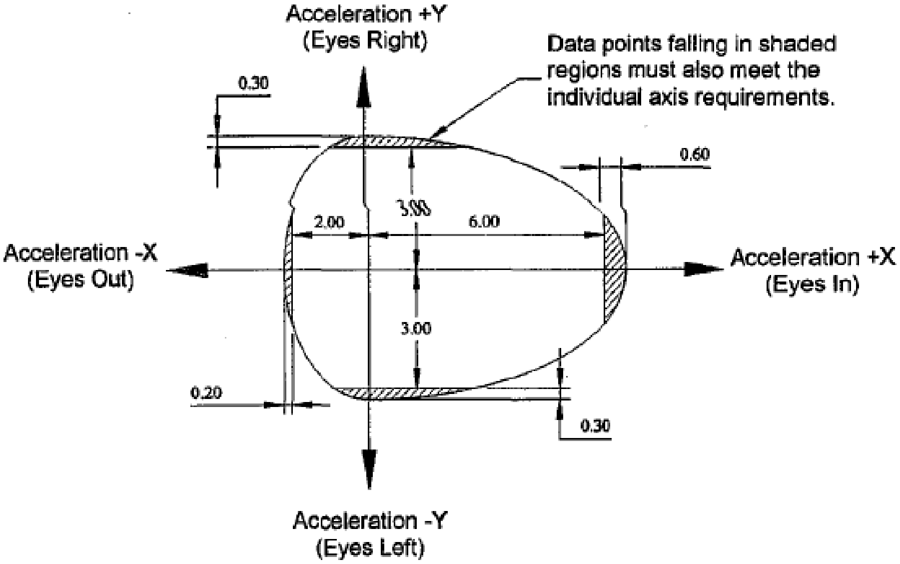

Figure 5: Maximum Acceleration Limit Moving Along The Y Plane

Figure 5 shows that the maximum acceleration limit moving along the Y plane is 3G, moving forward along the X plane is 6G, and moving backward along the X plane is 2G[7].

2.5 Fatigue Analysis

2.5.1 Operational Hours Criteria

The primary structures should be designed using calculation and analysis based on a 35,000 operational hour criteria for primary parts of the structure (excluding bolts, washers etc.). The loading and unloading of rider can account for a maximum of 50% of this criterion. The operational hours that will be used for analysis can be determined using the following equations[8].

$$General\ Reduction\ for\ \frac{load}{unload}\ time = \frac{Total\ \frac{load}{unload}\ time\ per\ ride}{Total\ \frac{load}{unload}\ time\ per\ ride + Time\ per\ ride}$$

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[6] Ibid

[7] Ibid

[8] Ibid

$$Operational\ Hours = 35000 * 1.00 - General\ Reduction\ for\ \frac{load}{unload}\ time$$

2.5.2 Loads

For the purpose of design and analysis, patron weight shall be 170 lbs. for adults and 90 lbs. for children. The amusement ride shall also be designed to hold a person weighing 300lbs, or the heaviest person that can fir it the designed seat. Other loads to be considered in analysis include permanent loads (do not vary with time), variable loads (vary with time), dynamic loads (loads encountered during operation), nonoperational loads (loads when ride is being assembled/dissembled and repaired), and environmental loads which include wind. Ride must be designed to operate in a maximum of 34 mph winds[9].

2.5.3 Analysis

A structural analysis must be done to determine if the stresses and strain will cause failure. A deflection analysis must also be done in order to ensure the deformation will not impair the motion of the ride. An Impact factor of 1.2 or higher shall be applied to all dynamic parts. A safety factor of 2.0 or higher should be applied to all anti-rollback devices. A vibration factor of 1.2 or higher shall be applied to dynamic loads[10]. Vibration factors should be applied to supports, ground pressure, settling, and stability. Also high cycle fatigue analysis must be done and the method depends on the material. In order to ensure the amusement ride has satisfactory strength, either the Load and Resistance Factor Design (LFRD) or the Allowable Stress Design (ASD) must be used[11].

For ASD the following loads must be considered:

D: Permanent Load
L: Variable Load
H: Load due to weight and pressure of soil/ water in soil
R: Load due to rainwater/ice

Lr: Roof Load
W: Wind Load

S: Snow Load
F: Loads due to fluids
T: Loads due to self straining forces from differential settlements of foundation and restrained dimensional changes due to

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[9] Ibid
[10] Ibid
[11] Ibid

temperature, moisture, shrinkage, creep and
similar effects.

The following load combinations shall be investigated for ASD

D

$D + L + F + H + T + (Lr\ or\ S\ or\ R)$

$D + (W\ or\ E)$

$D + L + (Lr\ or\ S\ or\ R) + (W\ or\ E)$

For LFRD the following combinations must be considered:

$1.4D$

$1.2(D + F + T) + 1.33 * (L) + 1.6(H) + .5(Lr\ or\ S\ or\ R)$

$1.2D + 1.6(Lr\ or\ S\ or\ R) + (0.5L\ or\ 0.8W)$

$1.2D + 1.3W + 0.5L + O.5(Lr\ or\ S\ or\ R)$

$1.2D + 1.0E + 0.5L + 0.2S$

$0.9 \pm (1.0E\ or\ 1.3W)$[12]

The ride also has to be design to be stable in worst-case scenarios such as high wind and unbalanced loading. There must also be a method to visually verify the stability of ride for acceptable settlement and level. The materials used must in accordance with ASTM F 1159. Only metal and metal alloys with industry recognized physical properties may be used. Timber structures shall be designed in accordance with USDA -72 or National Design Standard (NDS) for ASD design or ASCE. Bored holes in the wood shall be relieved from local stresses by load spreading plates or other recognized method[13].

Permanent loads include:

- Weight of equipment
- Conduits and Piping
- Ballast
- Cladding
- hard and soft decoration
- Cables
- Water (nonponding)
- Operational loads include
- High Cycle
- Drive/ actuation forces
- Moving loads
- Braking Forces

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[12] Ibid

[13] Ibid

- Operational dynamics / vibration
- Kinematic induced loads
- Hydrostatic / dynamic
- Unbalanced loads
- Misalignment (rotating shafts)
- Aerodynamic
- Movement of decorations
- Patron restraint (inertial and direct)
- Low Cycle
- Emergency evacuation
- Runway condition
- Large adult patrons
- Fuel Consumption
- Collision with emergency stops
- Shock due to failure
- High or Low Cycle
- Reverse operation
- Emergency stops
- Anti-rollback
- Possible failure modes producing loads on secondary structure (that is, safety cables and links, etc.)
- Loads generated by special testing requirements (for example, increased weight, velocity, or acceleration during cycle testing).
- Patron load/unload forces

2.5.4 Mechanical Systems and Components

Chains and related accessories shall be produce in compliance with ANSI and European Standards. Chains in the load path that do not pass around sprockets or wheels must have a safety factor of at least 5 and ones that do must have a safety factor of at least 6. Safety factor is defined as the ultimate tensile strength of the chain divided by the mass steady state tension. There must also be a method to measure wear and the maximum allowable change in pitch length as well as cleaning and lubrication details[14].

2.5.5 Anti-Rollback Devices

Anti-rollback devices prevent undesirable movement in the opposite direction but are not required if movement in the reverse direction will not result in injury[15].

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[14] Ibid

[15] Ibid

2.5.6 Machine Guards

Measures must be taken to ensure patrons and operators do not come into unwanted contact with chains, gears, and other similar moving machinery[16].

2.5.7 Fencing and Guard Rails

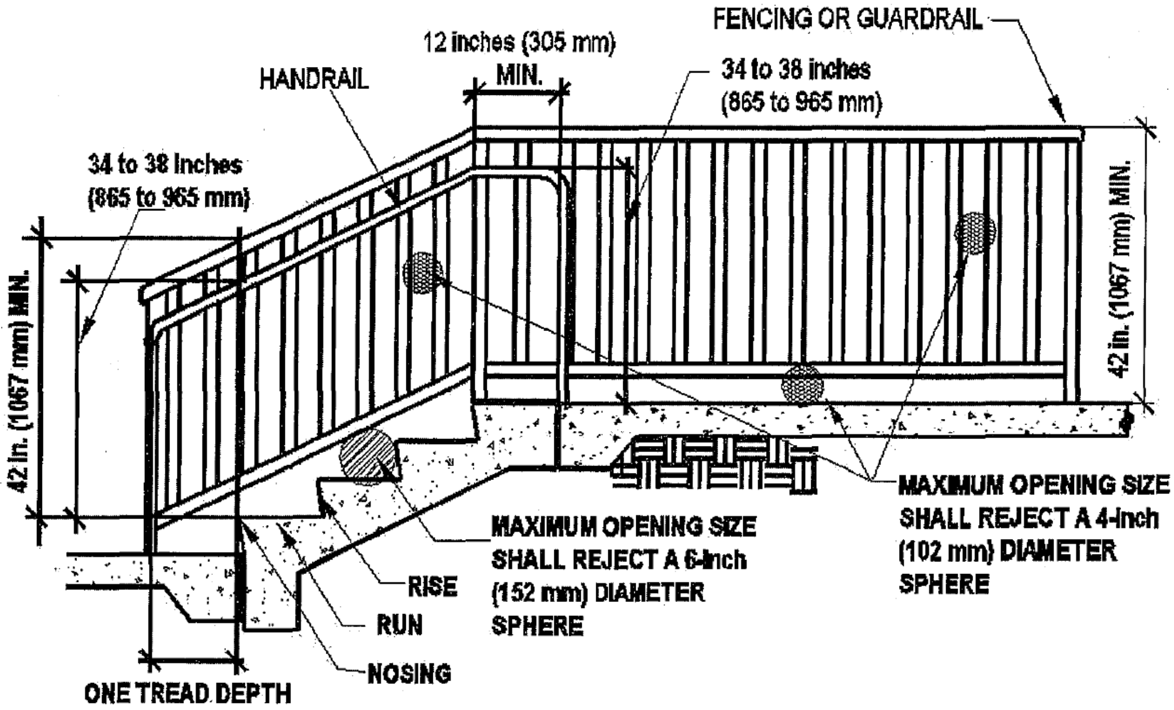

Figure 6: Fencing and Guard Rails Before Entering The Ride

Fencing must be at least 42 in. above where the patrons are standing and constructed so that a 4 in. diameter sphere cannot fit through any openings. A triangular opening shall not allow a 6 in. diameter ball to pass through[17].

The guardrails shall support 50 plf (pound per lineal foot) in any direction. They should also be able to hold at least 200 lbs. in any direction at any point[18]. Gates shall follow the same guidelines as above. They should also be designed so that when opened they cannot interfere with the ride[19].

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[16] Ibid
[17] Ibid
[18] Ibid
[19] Ibid

2.5.8 Welding

Welding procedures must be in accordance with American National Standards Institute/American Welding Society (ANSI/AWS)[20].

2.6 Coupler Curves

Since the human body can only withstand so much acceleration the acceleration of points on the coupler curve must be calculated. The equations below show the calculations needed to measure the acceleration of a specific point in a coupler curve:

However in order to save time, acceleration calculations can by various analysis programs. By using the analysis tool of Creo changing accelerations over a long period of time can easily be graphed.

A coupler curve is a complex motion, which a joint follows that has a high degree of path motions. Coupler curves are created with four or more linkages. Wunderlich created an expression to calculate the highest degree, which is possible for the coupler curve to make with the number of links.

$$m = 2 * 3^{\left(\left(\frac{n}{2}\right)-1\right)}$$

Where n is the number of links and m is the highest degree possible for the coupler curve.[21]

2.6.1 Cusps and Crunodes

A cusp is a sharp point on a curve, where at that point, the instantaneous velocity and acceleration is zero. Anything attached to the linkage that follows a cusp path stops at the sharp point, then accelerates on a different path. A crunode is a double point that occurs where the coupler crosses itself that creates multiple loops.

2.6.2 Geared 5-Bar Coupler Curves

Five-bar coupler curves are more complicated than the four-bar linkages. The link ration, gear ration as well as the phase angle between the gears are additional independent design variables. This allows the coupler curve to have more curves and cusps within it. In 1875, Reuleaux looked at variations of five bar mechanisms like a sewing machine. After, Tao and

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[20] Ibid

[21] Norton, R. (2011). *Design of Machinery* (5th Edition ed.): McGraw-Hill Science/Engineering/Math.

Hall observed symmetrical geared 5-bar linkages for the gear rations as well as the phase angles. From there, Freudenstein and Primrose derived equations for the coupler curves that are generated by a joint between two floating links and derived the general properties of a coupler curve for any geared five-bar mechanisms.

It was found that it was not necessary for the gear ratio needed to be constant when applying it to each mechanism. However, non-circular gears or the drag link four bar equivalent can be used to couple geared links which therefore allow displacement and velocity to vary over the coupler point that is obtained with a constant ratio.[22]

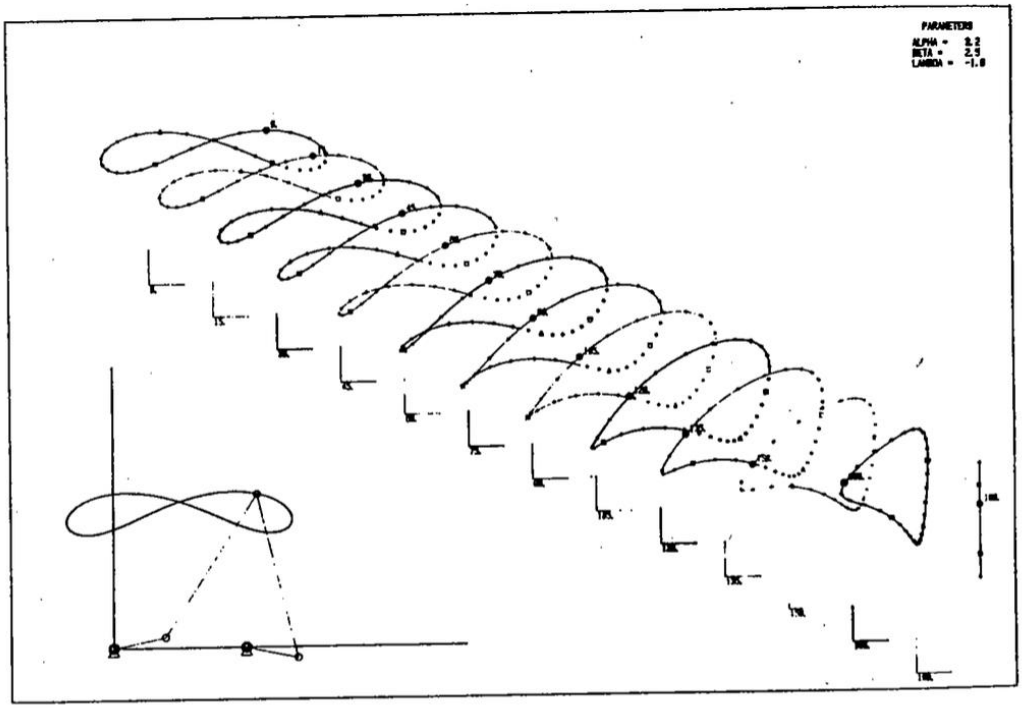

Figure 7: Zhang Atlass Drawing of a Simple Five-Bar Geared Mechanism

Zhang, Norton, and Hammund (ZNH) created atlas drawings of geared 5-bar mechanisms. They show typical curves for linkages that limit the symmetrical geometry. Another factor that is considered is that the pin connecting the two couplers is taken as a tracer point. In the right hand corner of the drawing, there is a box which represents the ratios of each link and the direction which the gears turn.

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[22] Ibid

2.6.3 Acceleration Calculations

Since the human body can only withstand so much acceleration the acceleration of points on the coupler curve must be calculated.

However in order to save time, acceleration calculations can be analyzed by various programs. Software such as SolidWorks and Creo Parametric are capable of taking measurements and analysis of any moving parts modeled within a system. By using the analysis tools involved with these programs, changing accelerations over a set period of time can easily be graphed.

With this graph it is easy to tell if the maximum acceleration provided by the coupler curve is within the safety standards for the human body. As outlined in the safety standards section the minimum acceleration in any direction that could cause an issue with the rider is a 2G acceleration downwards.

3. Detailed Description of the Project

After a thorough investigation of mechanical systems was conducted, this information was then used to create design specifications and goals. Once these were created, they then served as guidelines to develop the amusement park ride. Analyses of several coupler curve designs were conducted. Once a coupler curve was chosen, an initial linkage analysis was conducted and placed into a program called “Linkages” in a 2-D analysis. The linkage sizes were then put into SolidWorks to create multiple designs for the ride. Based on these options, a design matrix was formed and the designs were compared. After settling on a design, a simple prototype was made out of Legos. A stress analysis was conducted on each part of the amusement park ride using Mathcad for calculations. The amusement park ride was then built and then tested to make sure the accelerations and G-force on the ride was in a safe measure.

3.1 Design Goals

Amusement park rides are designed for human entertainment. The first amusement parks began when local breweries offered an inexpensive way for families to relax with concerts, beer and food. Rides as simple as a racetrack with carts were built on Coney Island for wealthy families to ride with their children. The next ride followed the simplest coupler curve, a circle, was then built called a Ferris wheel. This ride gained thousands of riders and was the main attraction of Coney Island. Coney Island offered a lot of rides that were intended for a month use. Those were to be put up in a set number amount of hours, and to be placed in a set square area. After looking into different rides, three goals were constructed. The goals of this project were making it human powered, having it being easy to assemble, and make it eye-catching.

The first goal of the project was to make this ride human powered. The location for this ride is to be put up on the quadrangle as a fundraiser. After analyzing the quadrangle, there are a limited number of outlets, which limits the amount of space where the ride can be placed. In order to maximize the places where the ride can be put up, the ride cannot rely on electricity as a limiting factor.

The second goal of the project was to have it easily assembled. This rides intension is to only be used for a set number of days, therefore, this ride must be able to be easily assembled. This allows the group who intends to use it to use it for small amounts of time.

The third goal is to design it to be eye catching to the public. This ride is intended for a group to be able to raise money for a charity. Amusement park rides must look good to be able to have a lot of people ride it, however if it does not look pleasing to the eye, or enjoyable, no one would ride it.

3.2 Design Specifications

In order to meet these goals, design specifications were made.

3.2.1 Functional

1. Device must occupy a stationary space that should not exceed a 10ft by 10ft space when it is assembled.
2. Acceleration the rider experiences must be within the range of the NASA study. A typical human can bear about 5 g (49 m/s^2), therefore the ride will not exceed over 5 g on the vertical axis, and 12 g (118 m/s^2) on the horizontal axis.[23]
3. Device must be storable in a 10 cubic meter room. This is to be able to save space when in storage.
4. Device must be able to function in 32-100^{O}F, rain exceeding 50 mL/hr and winds exceeding 50mph.
5. Device should not substantially degrade over 1 year of storage.

3.2.2 Rider

1. Maximum weight allowed on the ride is 250lbs. The average weight of an adult human being living in the United States is around 178lbs (80.7 kg)[24]. Having a standard deviation of around 70lbs creates a wide range of individuals to ride this ride.
2. Rider must be taller than 4’10” and shorter than 6’5”. This ride is designed to have a safety bar and a seat belt to ensure the rider is safely secured inside the seat.
3. Rider must follow the rules and regulations written by the team.

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[23] Human Tolerance Of Vertical Axis G Force. (n.d.). Retrieved April 29, 2015, from http://www.gforces.net/insight-human-tolerance-vertical-axis.html

[24] Walpole et al.: The weight of nations: an estimation of adult human biomass. BMC Public Health 2012 12:439

3.2.3 Operator

1. Operator must be at least 4’10”. The seat on the bike that is used to power the device will be adjustable, however the minimum height is 4’10”.
2. Operator must be wearing closed toed shoes to prevent injury from biking.

3.2.4 Other

1. Device must be able to be cleaned with a commercial grade power washer.
2. Material cost of the apparatus must be less than $640

3.3 Methodology

Once the design specifications and goals were established, the following procedure was followed to complete the amusement park ride. The following method was used: pick out a coupler curve path for the rider to follow, create the linkages in different programs to simulate the movement, design models for the ride, analyze each design, conduct a stress analysis on the final design, build the ride, test with non-human and human test subjects, and address the results and conclusions.

Utilizing the design specifications and goals, several general coupler curves were chosen for a path. Once the coupler curve was chosen, the link sizes were then analyzed and placed into a program called “Linkages” to analyze the length of the links and the path which the rider follows. After the length of the links was set, they were then designed in SolidWorks and assembled into a model. Each design was then compared to each other and a final design was chosen. Once the final model was completed on the computer, a stress analysis of the model was conducted using MathCad. Then, a physical model was made out of Legos. After looking at the model once more and finalizing all of the details, a physical model was then built and assembled.

After the assembly was completed, tests and analysis were conducted on the ride. The first “rider” was composed of home gym weights to make sure the average weight could withstand the ride. Once the gym weights passed, a human subject was utilized at a slow rate. After, multiple humans were able to sit on the ride and test it. A survey would be handed to each patron after they tested the ride to see if they enjoyed their experience. After the testing is completed, a manual will be written up to show the user how to assemble and disassemble the ride in the shortest time possible. An analysis on the ride will be conducted after the testing was completed to determine whether the ride was successful or not.

3.4 Coupler Curve Path

Once the design goals and specifications were completed, a coupler curve path must be decided on before designing the ride. There were four general curves that were observed which looked exciting and thrilling. The following parts of the curve will be analyzed: Number of cusps and crunodes, link ratio (Link 1: Link 2: Link 3: Link 4: Link 5), gear ratio, direction of gears spinning, and the phase angle (angle between Link 1 and Link 5). For every diagram, Link 1 will be set at a 0^{O} angle for observation, and the angle between link 1 and link 2 as well as link 1 and link 4 will be set at a 0^{O} angle.

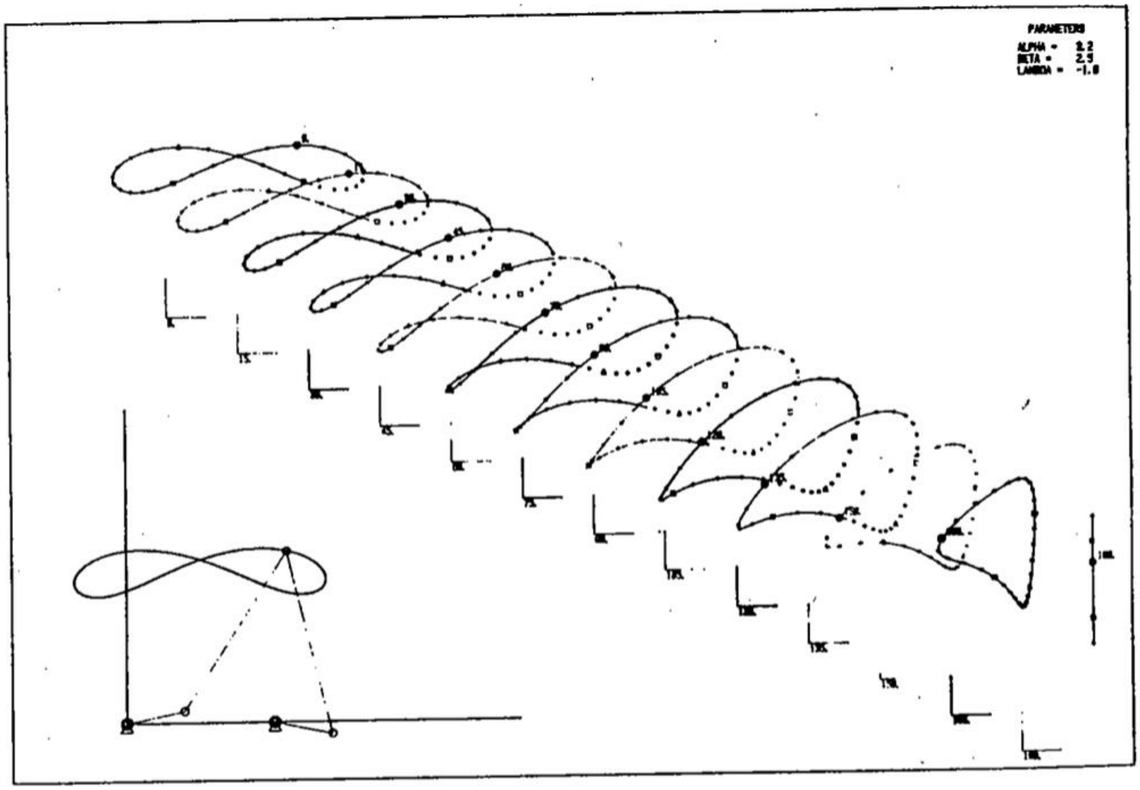

Figure 8: Coupler Curve #1[25]

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[25] Norton, R. (2011). *Design of Machinery* (5th Edition ed.): McGraw-Hill Science/Engineering/Math.

1. Number of Cusps and Crunode: 0 Cusps, 1 Crunode
2. Link Ratio: 2.5:1:3.2:1:3.2:1
3. Gear Ratio: 1:1
4. Direction of Gears Spinning: Opposing
5. Phase Angle: 10^{O}

This design allows for a figure-8 motion of the rider with horizontal and vertical direction changes. The rider will be following a smooth path without any sudden velocity change.

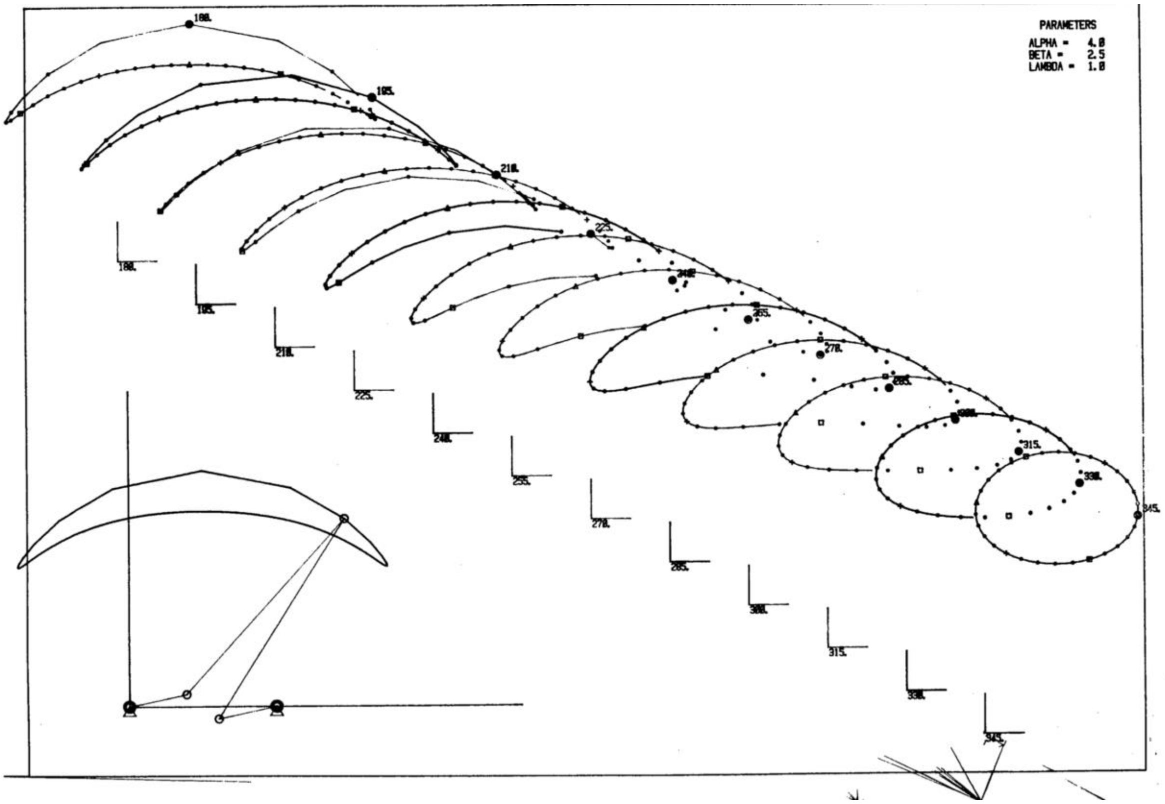

Figure 9: Coupler Curve #2[26]

1. Number of Cusps and/or Crunode: 2 Cusps, 1 Crunode
2. Link Ratio: 2.5:1:4:4:1
3. Gear Ratio: 1:1
4. Direction of Gears Spinning: Same Direction
5. Phase Angle: 180^{O}

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[26] Norton, R. (2011). *Design of Machinery* (5th Edition ed.): McGraw-Hill Science/Engineering/Math.

This design requires the change in velocity and fast jerking motion for the rider. This will make an uncomfortable ride, produce motion sickness, and possible brain damage.

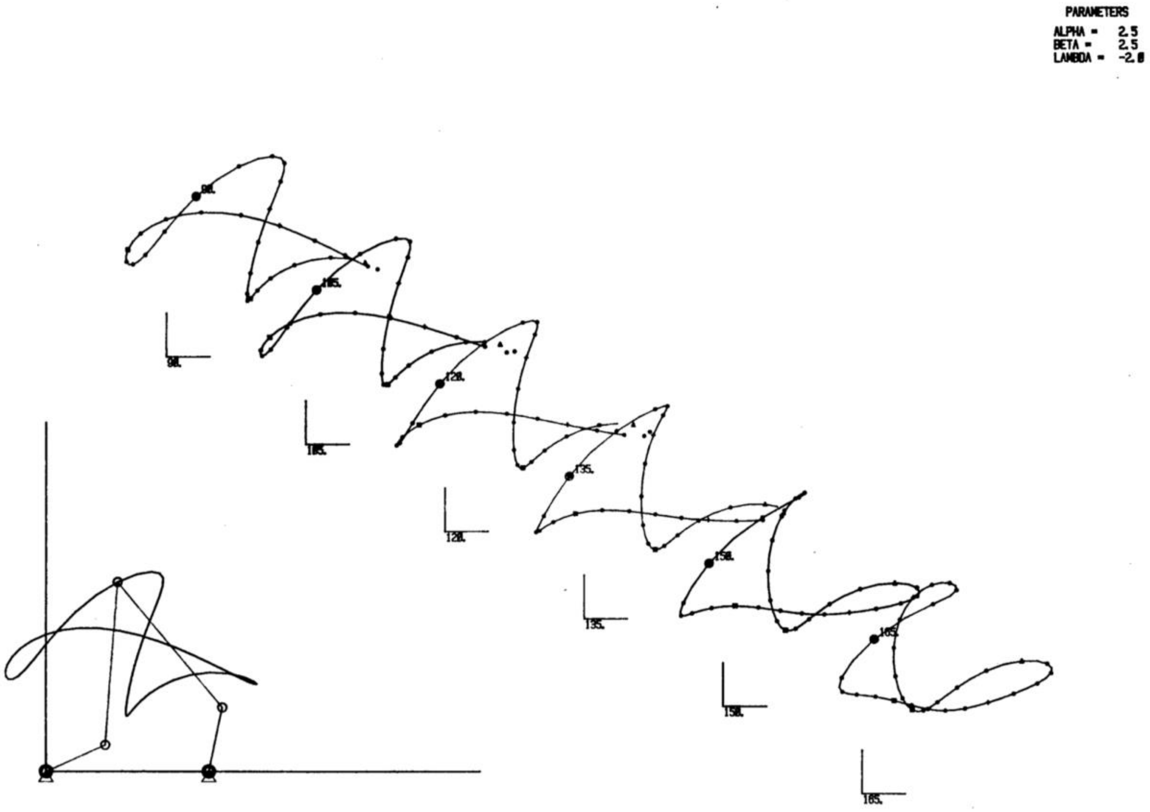

Figure 10: Coupler Curve #3[27]

1. Number of Cusps and Crunode: 1 Cusps, 3 Crunode
2. Link Ratio: 2.5:1:2.5:2.5:1
3. Gear Ratio: 2:1
4. Direction of Gears Spinning: Same Direction
5. Phase Angle: 90

This design has one cusp, which will require a large change in velocity, a stop in the rider's motion, as well as three crunodes. One of the crunodes is considered as a cusp, because it

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[27] Norton, R. (2011). *Design of Machinery* (5th Edition ed.): McGraw-Hill Science/Engineering/Math.

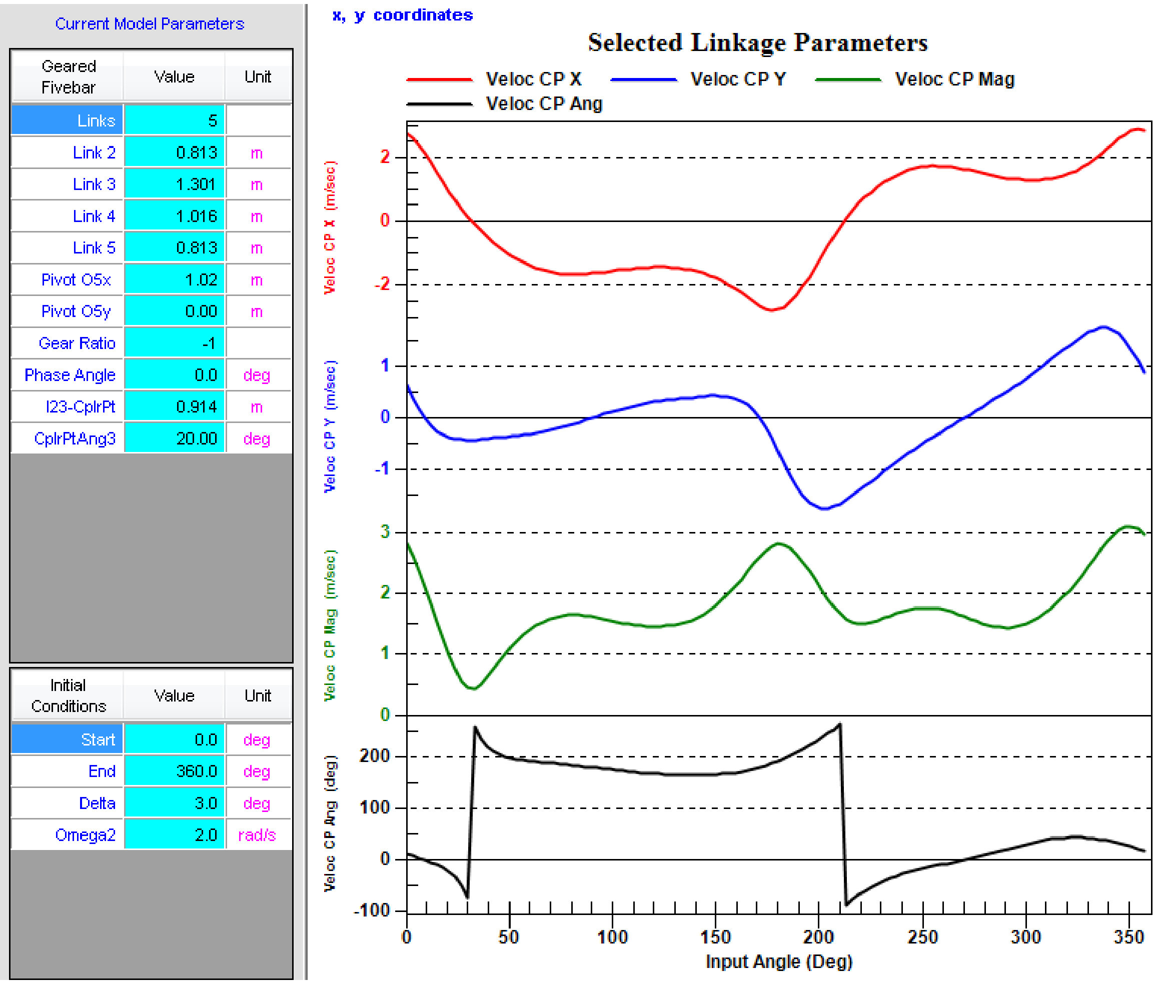
is small, and will result in a sudden large change of velocity. Despite its variance and excitement factor, this curve will produce an uncomfortable and possibly dangerous ride.

After analyzing each coupler curve, the curve, which will be used, is the first one discussed, the figure-8. This curve has one crunode, and follows a smooth path for the rider. The rider will experience vertical and horizontal g-forces, however with the correct amount of velocity, the rider will experience g-forces in the safe ranges stated in the previous section.

3.4 Linkage Analysis

Once the link ratio was found, the numbers from the Zhang Atlas drawing were inputted into “Linkages”, the gear ratio as well as the link sizes can be analyzed. This program allowed for the phase angle to vary, as well as the angle between link 3 and the coupler point.

After settling on an angle and final link sizes, a velocity and acceleration at the coupler point was assessed. The following graphs show the velocity and acceleration at each point. The degree angle is the angle of link 2 relative to the x-axis.

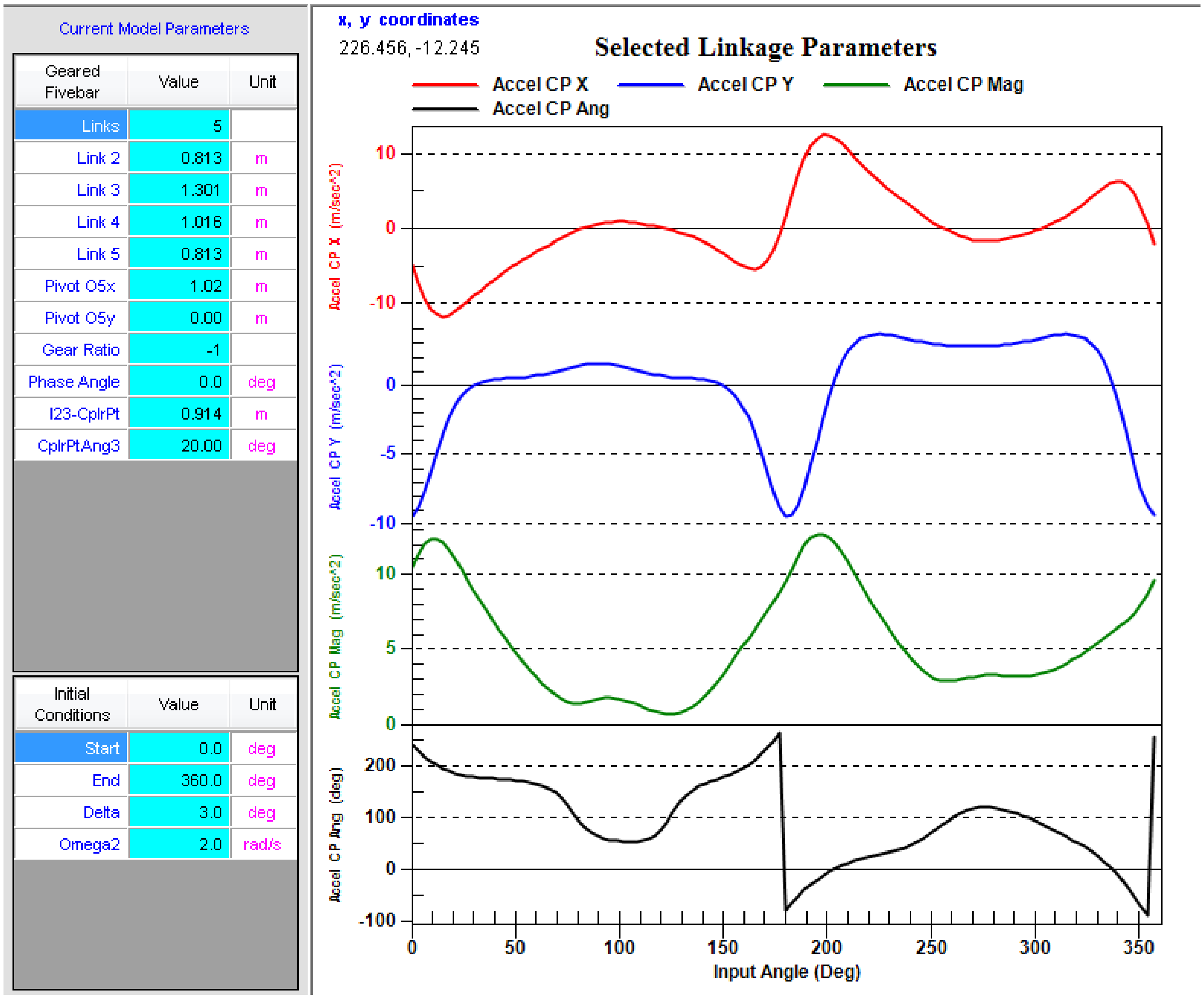


Current Model Parameters

Geared Fivebar	Value	Unit
Links	5	
Link 2	0.813	m
Link 3	1.301	m
Link 4	1.016	m
Link 5	0.813	m
Pivot O5x	1.02	m
Pivot O5y	0.00	m
Gear Ratio	-1	
Phase Angle	0.0	deg
I23-CplrPt	0.914	m
CplrPtAng3	20.00	deg

Initial Conditions	Value	Unit
Start	0.0	deg
End	360.0	deg
Delta	3.0	deg
Omega2	2.0	rad/s

Figure 11: Velocity vs. Phase Angle of a Geared 5-Bar


Current Model Parameters

Geared Fivebar	Value	Unit
Links	5	
Link 2	0.813	m
Link 3	1.301	m
Link 4	1.016	m
Link 5	0.813	m
Pivot O5x	1.02	m
Pivot O5y	0.00	m
Gear Ratio	-1	
Phase Angle	0.0	deg
I23-CplrPt	0.914	m
CplrPtAng3	20.00	deg

Initial Conditions	Value	Unit
Start	0.0	deg
End	360.0	deg
Delta	3.0	deg
Omega2	2.0	rad/s

x, y coordinates
226.456,-12.245

Figure 12: Acceleration vs. Phase Angle of a Geared 5-Bar

The graph showed the maximum acceleration, which the rider will experience, will be 12.7 m/s^2, which is under the maximum acceleration stated in the design specifications (49-118m/s^2). The “Linkages” provided a visual example, as well as a way to calculate velocity and acceleration at the coupler point. After analyzing the initial linkage design in two dimensions, the next step is to create the full model in SolidWorks.

3.5 Design Analysis

3.5.1 Design 1

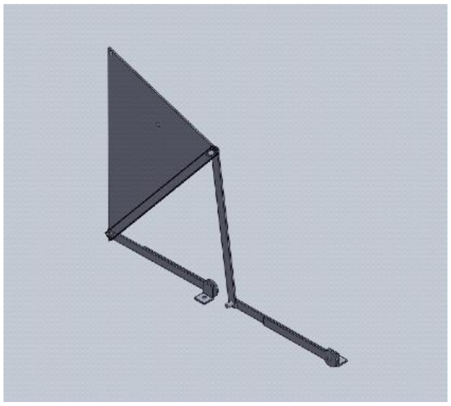


Figure 13: Design 1

The first design was a proof of concept based off of our coupler curve, which was developed in linkages. This design ignored a lot of safety concerns and had no base for it was intended to evaluate the coupler curve.

3.5.2 Design 2

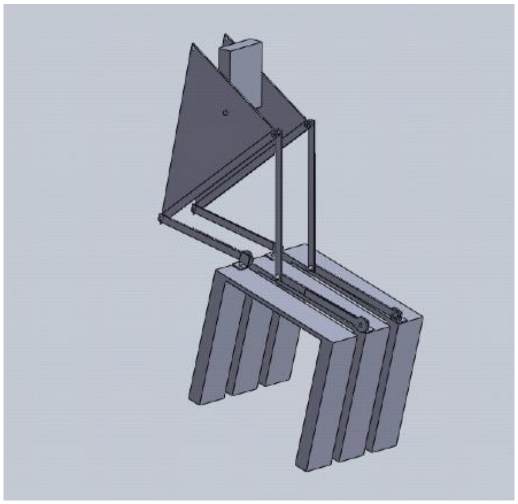


Figure 14: Design 2

The second design included a base and we added a chair to display where the attachment of the chair would be located. However, the middle base proved to interfere with this design. This problem occurred due to the connection points between the links of the machine and the base. These connection points resided on both sides of our design. This can be seen in design 1 and by the addition of the middle base portion in design 2.

3.5.3 Design 3

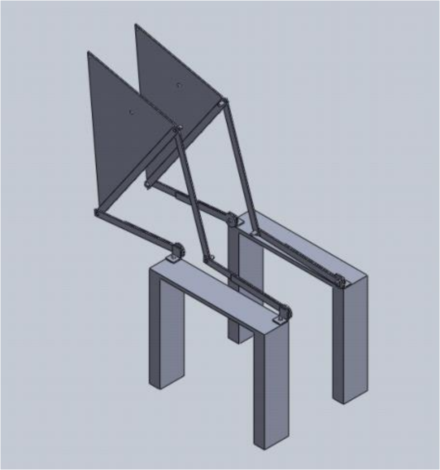


Figure 15: Design 3

After further review, it was determined that the middle base section can be removed from the design. This elimination reduced the overall size and cost of the mechanism and it resolved the interference problem from design 2 however it lead to a stress problem. By having both of the supports on the same side of the mechanism each set of links were falling in on themselves, only supported by the connection pieces.

3.5.4 Design 4

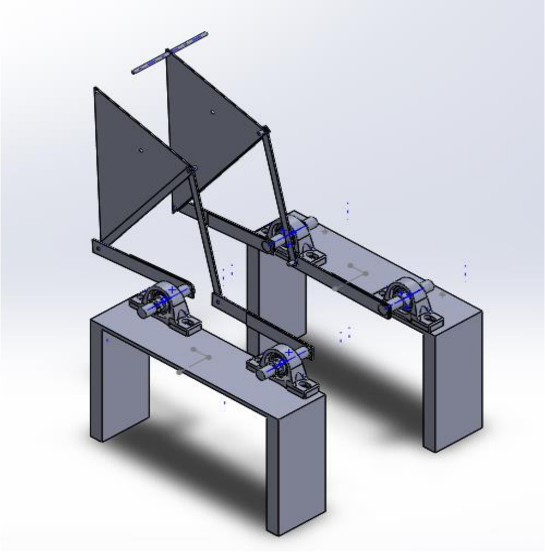


Figure 16: Design 4

Next, roller bearings were chosen based on the static and dynamic analysis from design 3. We chose roller bearings for their versatility and because they do not need to be lubricated as often as some other types.

3.5.5 Design 5

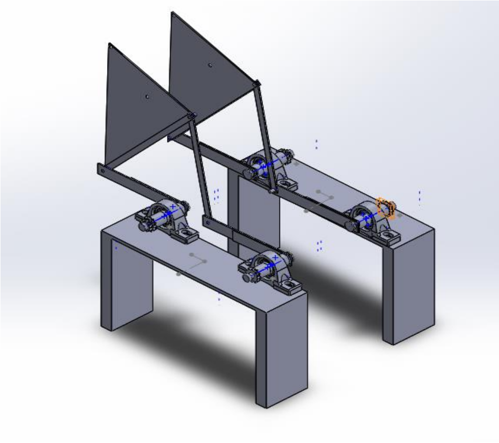


Figure 17: Design 5

The fifth design added a gear train to the mechanism to reduce the power needed to operate the mechanism. In order to transmit power from the bicycle to the links a gear ratio was chosen and attached to the bearings. In order for the ride to follow the chosen coupler curve, the links on the same side base had to be moving in opposite directions therefore, the two gears were added to each shaft. This would allow for a chain to be attached to the gears from one shaft to the other which cause the links to rotate in opposite directions.

3.5.6 Design 6

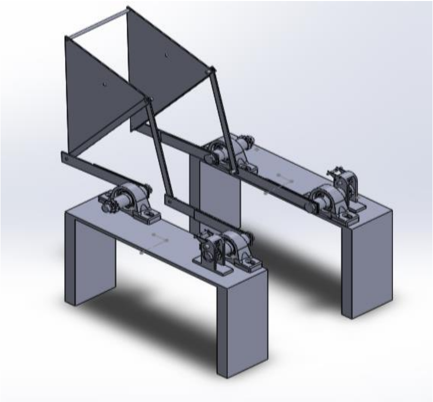
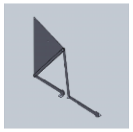
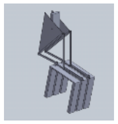
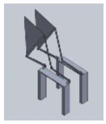


Figure 18: Design 6

Finally a chain tensor was added to ensure the chains would remain tight as an added safety precaution. Along with the chain tensor bushings were evaluated instead of bearings because they were less expensive than bearings. The following design matrix demonstrates numerically each of the designs and concluded to the final design.

Table 1: Design Matrix

		 Design 1		 Design 2		 Design 3		 Design 4		 Design 5		 Design 6	
Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Stress Analysis	15.00%	0	0	5	0.75	4	0.6	8	1.2	7	1.05	8	1.2
Amount of Energy it takes to Run	15.00%	9	1.35	3	0.45	3	0.45	3	0.45	6	0.9	9	1.35
Assembly Difficulty	10.00%	8	0.8	8	0.8	8	0.8	6	0.6	6	0.6	6	0.6
Material Cost	10.00%	10	1	4	0.4	5	0.5	4	0.4	6	0.6	5	0.5
Weight	25.00%	10	2.5	5	1.25	7	1.75	4	1	5	1.25	4	1
Safety	25.00%	0	0	2	0.5	4	1	7	1.75	8	2	9	2.25
Total	100.00%	37.00	**5.65**	27.00	**4.15**	31.00	**5.10**	32.00	**5.40**	38.00	**6.40**	41.00	**6.90**

From Table 1, Design 8 was calculated to be the best based on the factors outlined above.

3.6 SolidWorks Modeling

3.6.1 Part and Assembly Modeling

In SolidWorks, each individual piece of the ride assembly was separately modeled. Design and dimensions for pieces such as the link lengths and base were determined by the team through calculations based on the needs of the ride. More complex pieces such as the bearings and their housings were drawn using schematics as provided by the product supplier. Following this, assemblies were created with the individual parts. An assembly for the base was designed as well as a final assembly containing the entire ride including the base, 5-bar linkage, and seating. The final SolidWorks design is shown in Figure 19

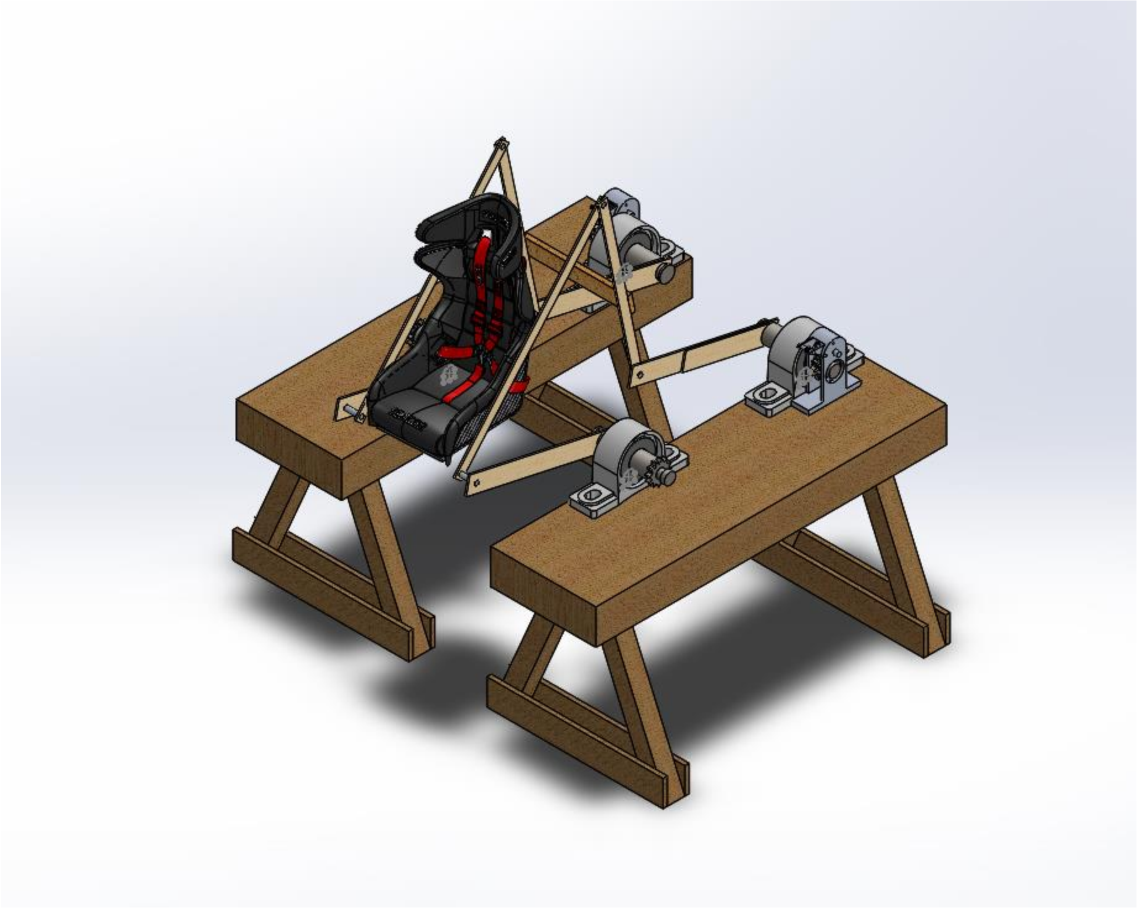


Figure 19: Final SolidWorks Assembly

An entire model of the assembly of the amusement ride served several purposes, one of which is the ride design. The model showed that the entire ride verified that the dimensioned used for each individual part will properly mesh and result in the desired end product. Lengths and widths can be checked to confirm the ride will be able to physically exist without overlap problems.

3.6.2 Finite Element Analysis

Once the assemblies were constructed a stress analysis was conducted on the ride model. In order to perform a finite element analysis SolidWorks Simulation was used to measure the effects of external forces upon the assembly. Given the student version of SolidWorks that was provided for the team's use as well as the power of the available computers a static analysis was done in lieu of a dynamic analysis. Static analysis were performed at several positions and the largest magnitude of stress was used for the overall results.

The bottom end of the base supports were set as fixed geometry in order to link them to the ground. This creates a frame of reference with which to move the rest of the linkage around.

The connections between each link and the pin connecting it to other links were set as a pin joint to allow 350 rotation of motion. The exception to this is the joints connecting the bearings to links 2 and 5 which were set as rigid so that any motion rotating the axel would translate to the links.

By assigning material properties the proper stress amounts and weight of the ride could be determined. Wood was used for the base, links, and chair while steel rods were used for the pins connecting the links. Bearings connecting the links to the base were also initially calculated using steel.

Finally in order to simulate the added weight of a person on the ride an external load of 200 lbs. was applied to the seat portion of the chair model. This ensures that the ride will not undergo any exorbitant amounts of stress while a person is riding compared to the ride on its own.

To further ensure that the ride would be properly constructed, a safety factor of 2 was used to make certain that the weight required to break the device would be twice that of the ideal load. A visual representation of the Von Misses stress analysis performed on the ride is shown in the following Figure 18.

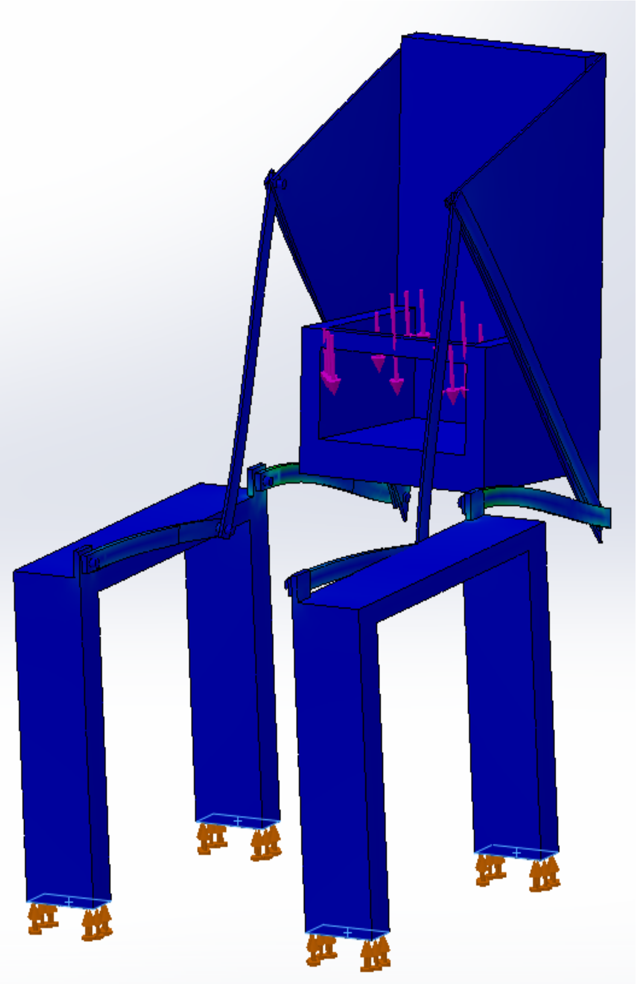


Figure 20: Von Misses Stress Diagram

In Figure 20, as in most Von Misses stress diagrams, the amount of stress in an object is represented by its color. A solid blue indicates little to no stress and as the color gets ‘warmer’, moving from green to yellow to red, the amount of stress becomes larger. As Figure 20 demonstrates the majority of apparent stress is located within links 2 and 5 given the current configuration of the 5-bar linkage. Figure 21 shows an additional view of the stress analysis highlighting the stresses found in the ride.

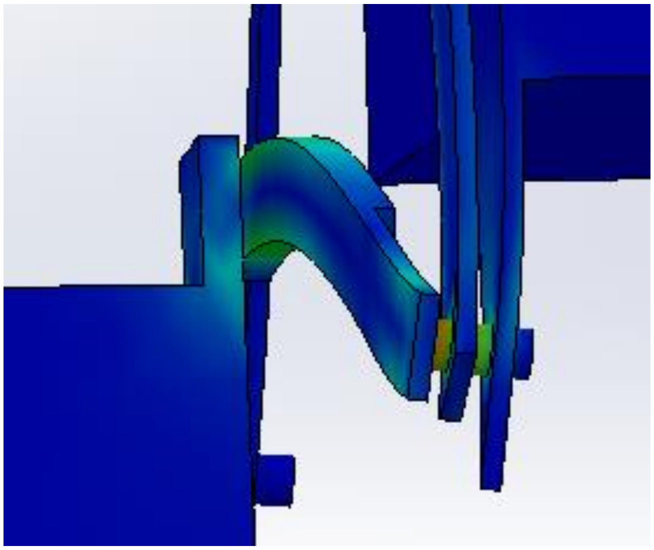


Figure 21: Close View of Link Stress Analysis

From Figure 20 several conclusions were drawn. First, as Figure 21 also shows, the links that are most prone to stress and therefore breaking are the two links attached directly to the base, aka links 2 and 5. This view also shows the large amount of stress in the connectors between the links. These pins contain very large stresses and need to be designed for very large loads in mind.

3.7 Stress Analysis

A stress analysis was done to evaluate the total force acting on the axle in a static situation. This was further evaluated to ensure that the SolidWorks simulation was functioning accordingly. The following steps were taken when calculating the stress on the axles when contacting the bearings.

The total weight of each link was determined from the density of the material and the volume of the total links. This weight was determined to be sixty-one pounds. The link weight was added to the maximum weight allowed for the rider along with all of the connection components resulting in a maximum weight of three hundred and thirty pounds. This weight was converted into a force of 1.481*10^3 N. From here the effected are of the axle was determined to be .024m^2. Using this data we found that the overall stress experienced on the central axis by the maximum rider to be 6.094* 10^4 Pa. The hand calculations done in Mathcad can be seen in Appendix B: Stress Analysis Mathcad File.

3.8 Prototype

After the model was completed in SolidWorks a prototype was created as a proof of concept model. The prototype followed the designed path within a small tolerance. The variance from the modeled oath to the path the prototype followed was due to the material choice for the prototype. The entire prototype was created out of Legos. Legos were chosen for the versatility of the material. The model consisted of both Lego blocks and Lego Technic pieces seen in Figure 22. The overall working prototype can be seen in Figure 23. Both axles of the prototype needed to be constrained; this was accomplished with human input, compared to with chains like designed. This was decided due to the lack of chains that functioned with the gears used in the prototype.

Figure 22: Relaxed View of Prototype

Figure 23: Upright Position of the Ride

The prototype was used to evaluate certain design concerns regarding the base and the housings supporting the bearings attached to the links. The base was further designed to deal with cyclic load experienced from the rotating links.

3.9 Building

Once the prototype was built, the materials were bought, and a full-scale model was created using wood as the main construction material. This model was built utilizing multiple personal power tools to create crisp cuts and precise measurements. The ability of the power tools required the group to utilize creative ways to fasten each part together.

The team decided to utilize pressure-treated oak to create the full-scale model. Oak can withstand the maximum weight load of the links and bearings with the housings, without failing. Also, wood can be machined easily using hand tools. The base platform was made out of 2”x6” beams which were attached together by screws and nails. Once the base was made, the legs were manufactured based on the SolidWorks model and made out of 4”x4”. Then holes were drilled into the legs and the base to create an attachment mechanism. The legs, shown in Figure 24, were then bolted onto the bottom of the bases, which created a platform for the links to attach onto, shown in Figure 25.

Figure 24: Leg Assembly

Figure 25: Full Base Assembly

Next, the links were created to match the exact length calculated by the Linkages program. To attach the links together, the team drilled holes through each link, then added within each hole, a PVC pipe to prevent friction and allow easy movement between the link and the bolt. A bolt was put through each link and allowed the links to move with respect to one another using washers and nuts.

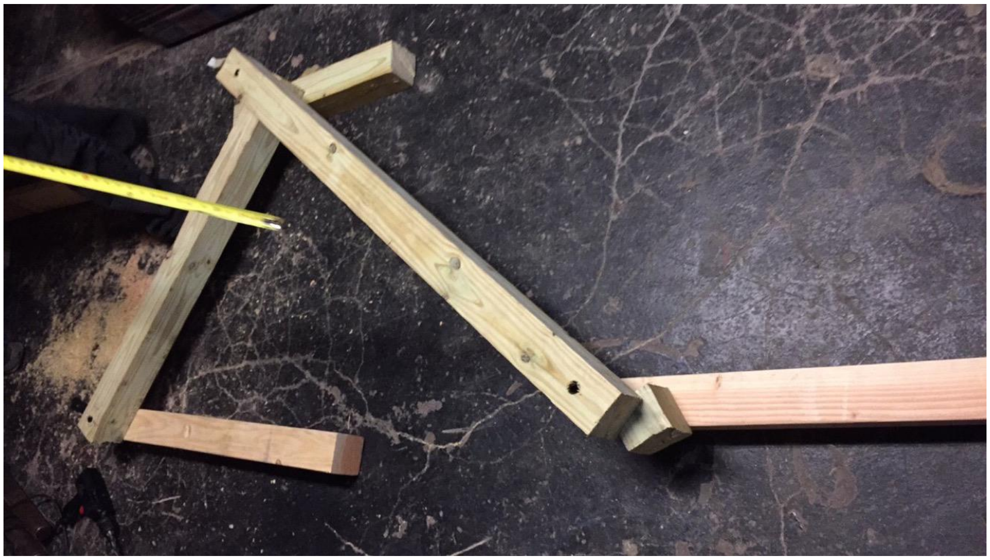


Figure 26: Linkage Assembly

Once the final linkage was assembled, bearings were created and attached. Due to complications machining the housing mechanisms for the designed bushings, a steel pipe, and a block of wood with a PVC pipe put in the center was used to create a through bearing. Gears were attached on after the through bearings along with the chain.

After the through bearings were assembled, the linkages were put on the base; half of the ride was complete due to time constriction. A detailed bill of materials is located in Appendix B.

4. Results

After the full-sized physical model was half constructed, the group tested the base to evaluate the weight displacement on the base. The bearing housing was created to withstand over 400lbs of force directly applied to the bearings while it is in motion. Once the bearing housing and the links were attached to the base, the group then released the full system and allowed the base structure and the bolts to take over. The base withstood the weight of the linkage system as well as the bearings attached to it, allowing the ride to be able to stand up on its own.

In order to power the ride, a standard mountain bike was chosen. This allowed for multiple different people to ride the bike, as well as a way for users to interchange the bike for a different one depending on who is riding at the time. Once the power mechanism was chosen, gears and chains were chosen based off of the bike. This allowed the ride to be powered by a gear ratio with respect to a mid-gear setting on the bike, which allowed the operator to have a less difficult biking experience especially starting and stopping the ride. The gears found were based on the pitch similar to that of bike’s gears. This allowed for the chains to be used universally across the ride. The chains chosen were from a company called “Fastenal” which provided chains that are a single row, roller type chain with a pin diameter of .1567 and an ultimate tensile strength of 3125 lbs. This chain allows the ride to be used with any weight that is applied to it as well as on the ride up to 400lbs.

4.1 Survey Results

After the ride was completed a small survey was conducted among various students at Worcester Polytechnic Institute. The survey included qualitative and quantitative questions that regarded the overall ride and the interest level of the person taking the survey. The majority of the survey group was individuals who are active members in Greek life. This offset the results because those who are active members in Greek life are more likely to participate in other Greek organization’s events. This was taken into account when the expected money raised from the ride was calculated.

Overall 87% of the surveyed group were interested in the ride and would like to ride it. They were asked a series of questions about how much they would be willing to donate in order to ride the ride. 79% of people would be willing to donate one to two dollars in order to ride the amusement ride. 26% of people would be willing to donate three to five dollars only 5% were willing to pay six to ten dollars. This survey concluded that as the admission price increased, the interest level of riders decreased.

Once the survey was collected, a projected fundraiser total was calculated if an organization was to use the ride with different rates. A range of one to two dollars would raise 1,674 dollars, three to five dollars would raise 540 dollars, and five to ten dollars would raise 108 dollars. The results proved the overall success of the design as an eye-catching ride which would raise money for charity.

5. Discussion

5.1 Design Modifications

In order to facilitate the construction of the amusement ride several design modifications were made. The reasoning behind these changes and their resulting effects are discussed in the section as follows.

In order to house the 2 inch-diameter bushings a steel bearing housing is needed. While the team planned on manufacturing one, a makeshift wooden bearing housing had to be used instead due to limitations in both budget and the machining capabilities of the labs available for use. While the wooden bearing casings would not be ideal for use over a long period of time, as intended by the use of the ride, the served their purpose in supporting the weight while testing was being done.

Additionally the team originally intended to use a solid steel weightlifting bar as the axle by which the links would be rotated. However cutting the 7ft Olympic sized steel bar down to size with the available machinery proved problematic. Due to this the idea was scrapped and 1ft sections of metal piping were used instead. This eliminated the need for cutting at the cost of some strength. Despite this deficit the structural integrity of the axles were not significantly affected. This allowed for a successful adaptation in material. This swap also provided the benefit of allowing the purchase of pipe endcaps to be used to prevent any z-plane movement of the pipe laterally along the hole.

In an unforeseen error the triangle leg design of the base extended too far laterally and created an interference error in the moving linkage. Figure 27 below shows a side view of the triangle base supports colliding with link 2 attached to the bearing axle. The red area represents the points of overlap that prevents full 360-degree motion.

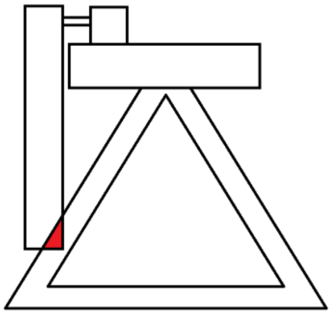


Figure 27: Interference between the base and link 2

To solve this issue both links 5 and 2 where shortened to allow the ability of full rotation. Both links were shortened to the same length in order to preserve a similar coupler curve design that is dependent on the symmetry between these links. Since only a minor change in length was needed the output coupler curve was not changed and the planned ride path remained safe with minimal changes in acceleration.

6. Conclusion

This project allowed the group members to design and study an amusement park ride, which was human powered and utilized a 5-bar linkage system. During the prototype design, all of the adjustments were made for the full-sized model, however during the construction of the full sized model, errors were made from purchasing the parts required to fully construct the model. Further analysis of the model once half of it was built allowed the group to look into different ways to make the ride more enjoyable and easier to construct.

7. Recommendations

Based on the results gathered from the design, building, and testing of the amusement ride several recommendations can be made for future designs. These suggestions are made with the teams' experience in mind and as such they provide insight on potential issues that can be repaired.

In order to improve the effectiveness of the human rider and to decrease the complexity of building it is highly recommended that four-bar designs are strongly considered when re-evaluating desired coupler curves. While the range of motion is much simpler and not quite as exciting for the rider as a 5-bar linkage, the complexity of gearing two links together in opposite directions, given the low budget as well as the materials used proved to be unnecessarily large. Since the ride is meant to be constructed for informal fundraising events a four-bar linkage is likely eye-catching enough for this purpose so a complex five-bar linkage is not necessarily needed.

While the base design that was used proved structurally sound, there was a slight margin of error that allowed for movement in the top of the base. This was due to the two-connection support between the base top and the base legs. In order to prevent this in future designs it is important to reevaluate the base and to develop a four-connection support. This will reduce any tilting and help ensure that the base is the unmoving support it was intended to be.

The amount of torque required to power the ride is large and as such to lift the heavy wooden links and occupying rider a large quantity of power is needed. Considerations into adding additional bike stations with which to deliver power to the system would reduce the stress on any individual rider significantly. Using a two or three person tandem bike can provide much more power to the system while allowing more leniencies in the physical condition of the people powering the ride. This allows the amusement ride to be used by a much larger pool of potential philanthropic organizations.

Wood materials were used since they were the cheapest material available for the desired strength to weight ratio. In future designs it would be important to look into other materials for various sections of the ride. Hard plastic links can be considered, as they would prove to be much lighter than the 4x4 wooden beams. Further testing to confirm that the plastic is strong enough to hold the required weight would have to be done.

Additionally if the ride was to be constructed for actual use metal bearing housings are a necessity and need to be constructed or purchased to preserve structural integrity over the lifetime of the ride. It is recommended that more of the allocated into these casings.

Instead of regular PVC piping between the links and the axles holding them together, oil lubricant impregnated piping can be used to reduce friction between the link connections. This will allow for a smoother motion and less frictional forces resisting the movement of the links allowing for an easier time delivering power to the system.

While many safety considerations were taken into account additional measures can be taken. Instead of a simple seatbelt strap to secure the rider a four-point parachute strap harness can be used to more securely hold the rider to the chair. This allows for a greater level of safety and further prevents the rider from being thrown from the ride.

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Appendix A: Bill of Materials and Budget Breakdown

Bill of Materials

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base		2
2	beam 1		4
3	Beam 3		2
4	Beam 4		2
5	pin 1		6
6	beam 2		4
7	Triangle		2
8	ball bearing		4
9	bearing shaft		4
10	bearing cap		4
11	bearing cap2		4
12	bearing compound gear		2
13	bearing shaft gear		2
14	tensor support		2
15	tensor triangle		2
16	tensor triangle 2		2
17	tensor lower shaft		2
18	tensor shaft		2
19	actual tensor gear		2
20	tensor lower compound gear		2
21	cross pin		1
22	tensor shaft cap		4
23	Tensor lower shaft cap		2

Budget Breakdown

Starting funds	Budget	Actual	Difference
Money allocated per student	160.00	160.00	-
Students	4.00	4.00	-
Total	**640.00**	**640.00**	**-**

Base	Budget	Actual	Difference
2X Material 16x64x36			-
Machining/Adjustments			-
			-
	0.00	**0.00**	**-**

Beams	Budget	Actual	Difference
2X Beam 1 34X4x.4	10.00		10.00
Beam 1 Machining			-
2X Beam 2 20X4x.4			-
Beam 2 Machining			-
2X Beam 3 51.2x2x.4			-
Beam 3 Machining			-
2X Beam 4 40x2x.4			-
Beam 4 Machining			-
	10.00	**0.00**	**10.00**

Bearings	Budget	Actual	Difference
Ball Bearing-4 Plain Open for 3/4" Shaft Diameter, 1-3/4" OD, 9/16" Wide	44.12		44.12
Bearing Housing - need to build			-
Bearing cap			-
	44.12	**0.00**	**44.12**

Gears	Budget	Actual	Difference
Bearing Shaft Gear	50.00		50.00
Bearing Compound Gear	80.00		80.00
Actual Tensor Gear	30.00		30.00
Tensor Lower Compound Gear	80.00		80.00
	240.00	**0.00**	**240.00**

Pins	Budget	Actual	Difference
Pin1			-
Cross pin			-
	0.00	**0.00**	**-**

Triangle	Budget	Actual	Difference
Triangle			-
Triangle machining			-
	0.00	**0.00**	**-**

Shafts	Budget	Actual	Difference
Bearing Shaft			-
Tensor Lower Shaft			-
Tensor Shaft			-
	0.00	**0.00**	**-**

Chain	Budget	Actual	Difference
2 X Chain 1 - 8.5 ft	179.35		179.35
Chain 2 -12.5ft	131.88		131.88
	311.23	**0.00**	**311.23**

BUDGET SUMMARY	Budget	Actual	Difference
Total Income	**640.00**	**640.00**	
Total Expenses	**605.35**	**0.00**	
NET	**34.66**	**640.00**	

Appendix B: Stress Analysis Mathcad File

Shaft analysis assuming the shaft is made of aluminum 1100

$L := .1016\,m$ $\quad a := .00889\,m$ $\quad b := .08255\,m$ $\quad c\_1 := .09271\,m$ $\quad M_h := 1.539\,kg$ $\quad E := 69\,GPa$

$I := 1.80 \cdot 10^{-8}\,m^4$

$D_1 := .0127\,m$ $\quad D_2 := .0254\,m$ $\quad D_3 := .0127\,m$ $\quad \rho := 750\,\frac{kg}{m^3}$ $\quad P := 1\,kW$

$x := 10\,rpm$

$\gamma := \rho \cdot g = 7.355 \times 10^3 \cdot \frac{N}{m^3}$ $\quad T := \frac{P}{x} = 954.93\,N \cdot m$ $\quad F := M_h \cdot g = 15.092\,N$

$w_1 := \pi \left(\frac{D_1}{2}\right)^2 \cdot \gamma = 0.932\,\frac{N}{m}$ $\quad w_2 := \pi \left(\frac{D_2}{2}\right)^2 \cdot \gamma = 3.727\,\frac{N}{m}$

$w_3 := \pi \left(\frac{D_3}{2}\right)^2 \cdot \gamma = 0.932\,\frac{N}{m}$

$$R_1 := \frac{\frac{w_1}{2} \cdot L^2 - \frac{w_1}{2} \cdot (L - a)^2 + \frac{w_2}{2} \cdot (L - a)^2 - \frac{w_2}{2} \cdot (L - b)^2 + \frac{w_3}{2} \cdot (L - b)^2 + F \cdot (c\_1)}{(L - a)} = 15.268\,N$$

$x := 0 \cdot in, 0.001 \cdot L .. L$ $\quad S(x, z) := \text{if}(x \ge z, 1, 0)$

$q(x) := -w_1 \cdot S(x, 0 \cdot m) + w_1 \cdot S(x, a) - w_2 \cdot S(x, a) + w_2 \cdot S(x, b) - w_3 \cdot S(x, b)$

$$V(x) := w_1 \cdot S(x, 0 \cdot m) \cdot x + w_1 \cdot S(x,a) \cdot (x - a) + R_1 \cdot S(x,a) - w_2 \cdot S(x,a) \cdot (x - a) + w_2 \cdot S(x,b) \cdot (x - b) - w_3 \cdot S(x,b) \cdot (x - b) - F \cdot S(x, c\_1)$$

$$V_{max} := -V(c\_1 - .0001m) = -15.149N$$

$$M(x) := -F \cdot S(x, c\_1) \cdot (x - c\_1) - -\frac{w_1}{2} \cdot S(x, 0 \cdot m) \cdot x^2 + \frac{w_1}{2} \cdot S(x,a) \cdot (x - a)^2 + R_1 \cdot S(x,a) \cdot (x - a) - \frac{w_2}{2} \cdot S(x,a) \cdot (x - a)^2 + \frac{w_2}{2} \cdot S(x,b) \cdot (x - b)^2 - \frac{w_3}{2} \cdot S(x,b) \cdot (x - b)^2$$

$$M_{max} := -M(c\_1 - .0001m) = -1.273 N \cdot m$$

$$c := \frac{D_1}{2} = 6.35 \times 10^{-3} m \qquad I := \pi \cdot \frac{D_1^{\,4}}{64} = 1.277 \times 10^{-9} m^4 \qquad J := \frac{\pi \cdot D_1^{\,4}}{32} = 2.554 \times 10^{-9} m^4$$

$$\sigma_x := \frac{M_{max} \cdot c}{I} = -6.328MPa \qquad \sigma_z := 0Pa \qquad \tau_{xz} := \frac{T \cdot \frac{D_1}{2}}{J} = 2.374 \times 10^3 \cdot MPa$$

$$\sigma_{a1} := \frac{(\sigma_x + \sigma_z)}{2} + \sqrt{\left[\frac{(\sigma_x - \sigma_z)}{2}\right]^2 + \tau_{xz}^{\,2}} = 2.371 \times 10^3 \cdot MPa$$

$$C_3 := \frac{w_1}{6} \cdot a^3 + \frac{F}{2} \cdot a^2 = 5.965 \times 10^{-4} \cdot N \cdot m^2$$

$$C_4 := \frac{w_1}{24} \cdot a^4 + \frac{F}{6} \cdot a^3 - C_3 \cdot a = -3.535 \times 10^{-6} \cdot N \cdot m^3$$

$$\sigma_{a3} := \frac{(\sigma_x + \sigma_z)}{2} - \left[\left(\frac{\sigma_x - \sigma_z}{2}\right)^2 + \tau_{xz}{}^2\right]^{\frac{1}{2}} = -2.377\times 10^3 \cdot \mathrm{MPa}$$

$$\tau_{a13} := \frac{(\sigma_{a1} - \sigma_{a3})}{2} = 2.374\times 10^3 \cdot \mathrm{MPa}$$

$$A := \pi \frac{D_1{}^2}{4} = 1.267\times 10^{-4}\,\mathrm{m}^2$$

$$\tau_t := \frac{(4V_{max})}{3\cdot A} = -0.159\mathrm{MPa}$$

$\sigma_x := 0\mathrm{Pa}$ $\quad$ $\sigma_y := 0\mathrm{Pa}$ $\quad$ $\tau_{max} := \tau_t + \tau_{xz} = 2.374\times 10^3 \cdot \mathrm{MPa}$

$$\sigma_{b1} := \frac{(\sigma_x + \sigma_y)}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{max}{}^2} = 2.374\times 10^3 \cdot \mathrm{MPa}$$

$$\sigma_{b3} := \frac{(\sigma_x + \sigma_y)}{2} - \left[\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{max}{}^2\right]^{\frac{1}{2}} = -2.374\times 10^3 \cdot \mathrm{MPa}$$

$$\tau_{b13} := \frac{(\sigma_{b1} - \sigma_{b3})}{2} = 2.374\times 10^3 \cdot \mathrm{MPa}$$

Beam weight assuming Oak with a density of .75 $\rho := 750 \frac{kg}{m^3}$

Beam 1- our file uses two beams of the same length refeered to as beam 1

$L\_1 := .2159m$

$H\_1 := .0254m$

$W\_1 := .0508m$

$V\_1 := (L\_1)\cdot(H\_1)\cdot(W\_1) = 2.786\times 10^{-4}\cdot m^3$

$W\_1 := V\_1\cdot\rho = 0.209kg$

Beam 2

In our file our beam 2 can be replaced with spacers

Beam 3

$L\_3 := .32512m$

$H\_3 := .0508m$

$W\_3 := .0508m$

$V\_3 := (L\_3)\cdot(H\_3)\cdot(W\_3) = 8.39\times 10^{-4}\cdot m^3$

$W\_3 := V\_3\cdot\rho = 0.629kg$

Beam 4

$L\_4 := .254m$

$H\_4 := .0508m$

$W\_4 := .0508m$

$V\_4 := (L\_4)\cdot(H\_4)\cdot(W\_4) = 6.555\times 10^{-4}\cdot m^3$

$W\_4 := V\_4\cdot\rho = 0.492kg$

$W\_Beams\_total := 2\cdot(W\_1) + (W\_3) + (W\_4) = 1.539kg$

Appendix C: Survey

Survey for Amusement Ride

Question 1- Are you male for female (Please circle)

Question 2- Are you currently a member of a fraternity or sorority?

Question 3- After viewing the model and the ride itself would you be interested in riding this amusement ride? (Please circle)

Yes No

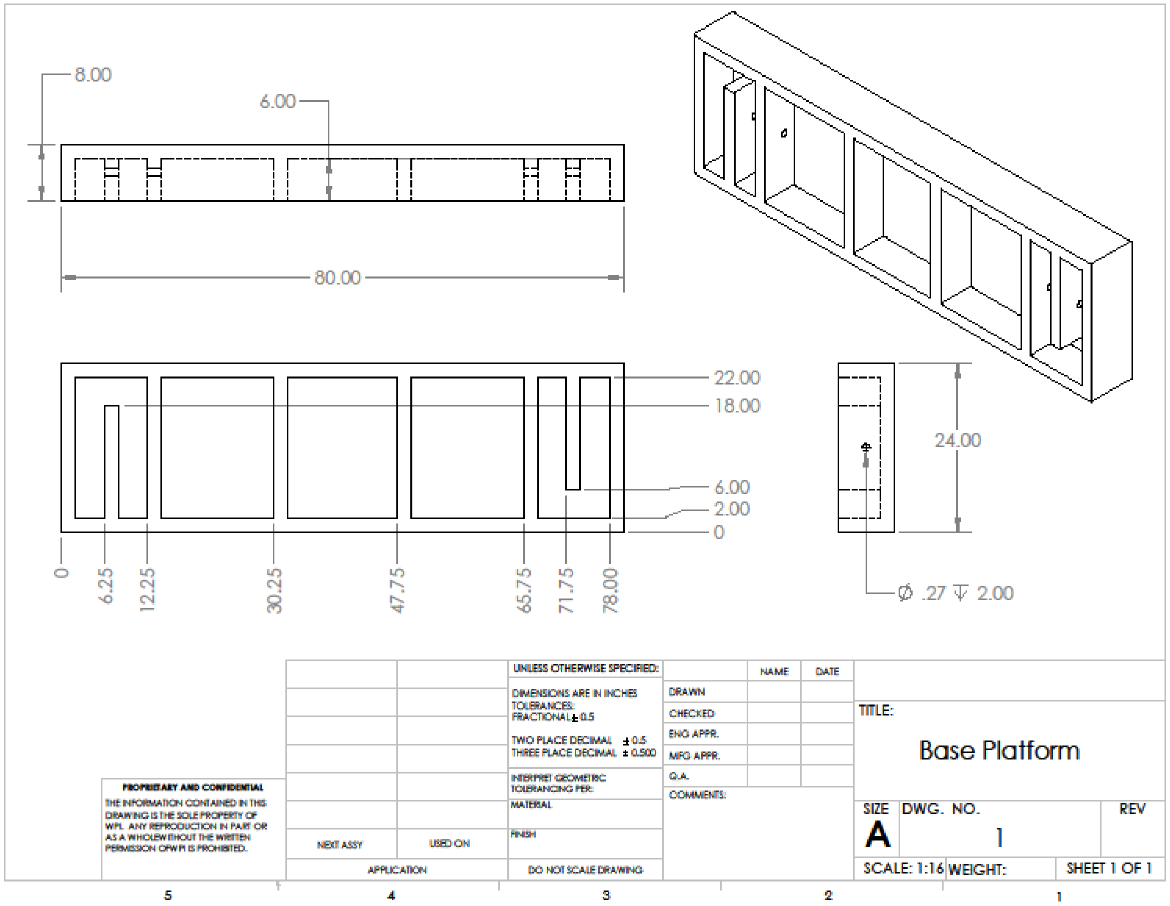
Question 4- Please circle the amount you would be willing to donate towards charity in order to ride.

\$1-\$2 \$3-\$5 \$6-\$10

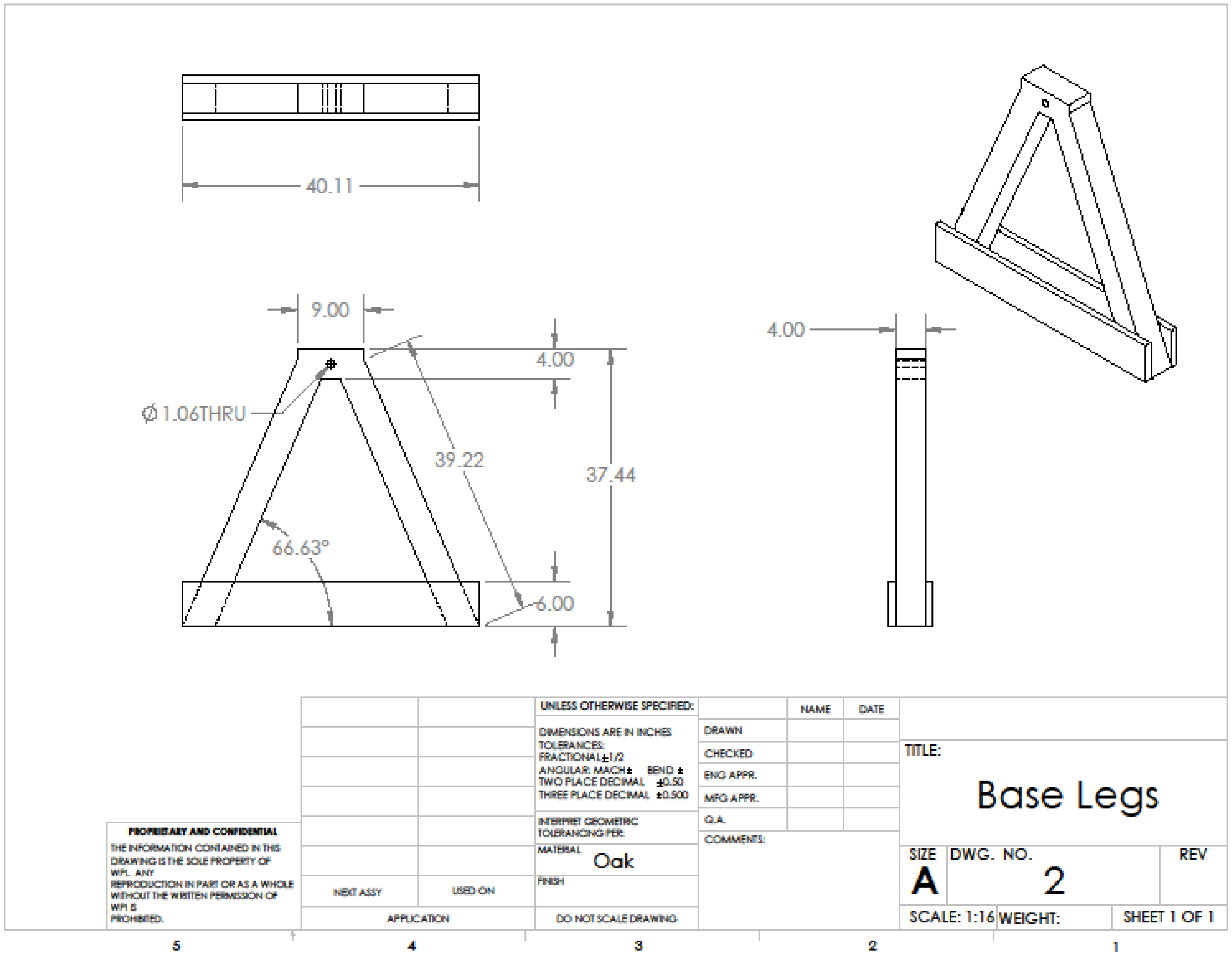
Question 5- Please list any comments about the ride or suggestions for improvement.

Appendix D: Part Drawings

Base



Legs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9.00
4.00
Ø 1.06THRU
39.22
37.44
66.63°
6.00
4.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/2
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.50
THREE PLACE DECIMAL ±0.500
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Oak
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Base Legs
SIZE
A
DWG. NO.
2
REV
SCALE: 1:16
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF WPI. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF WPI IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
5
4
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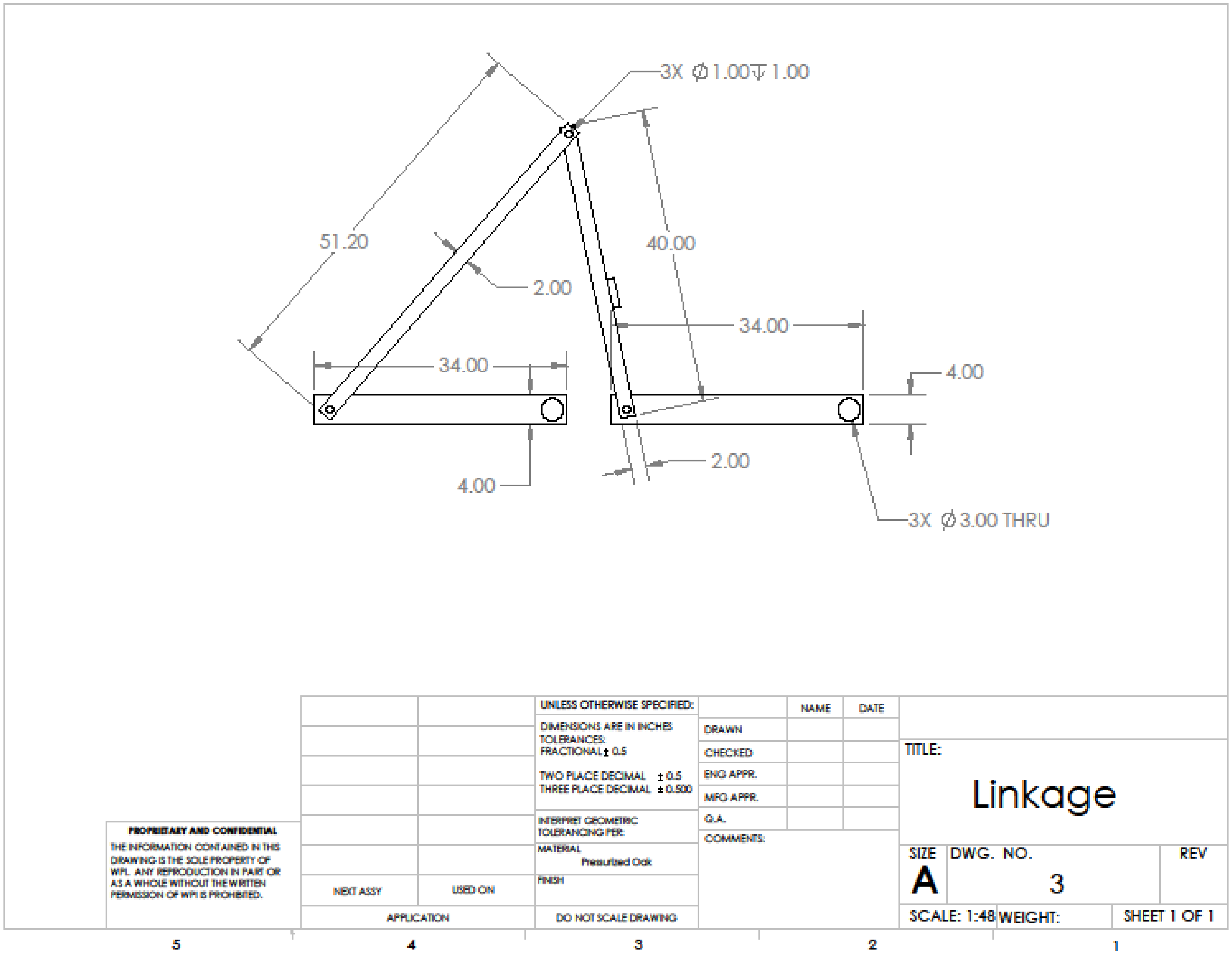
1

Linkage


3X ⌀1.00 ↧ 1.00
51.20
2.00
40.00
34.00
34.00
4.00
4.00
2.00
3X ⌀3.00 THRU
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 0.5
TWO PLACE DECIMAL ± 0.5
THREE PLACE DECIMAL ± 0.500
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Pressurized Oak
FINISH
DO NOT SCALE DRAWING
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Q.A.
COMMENTS:
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Linkage
SIZE
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SCALE: 1:48
WEIGHT:
SHEET 1 OF 1
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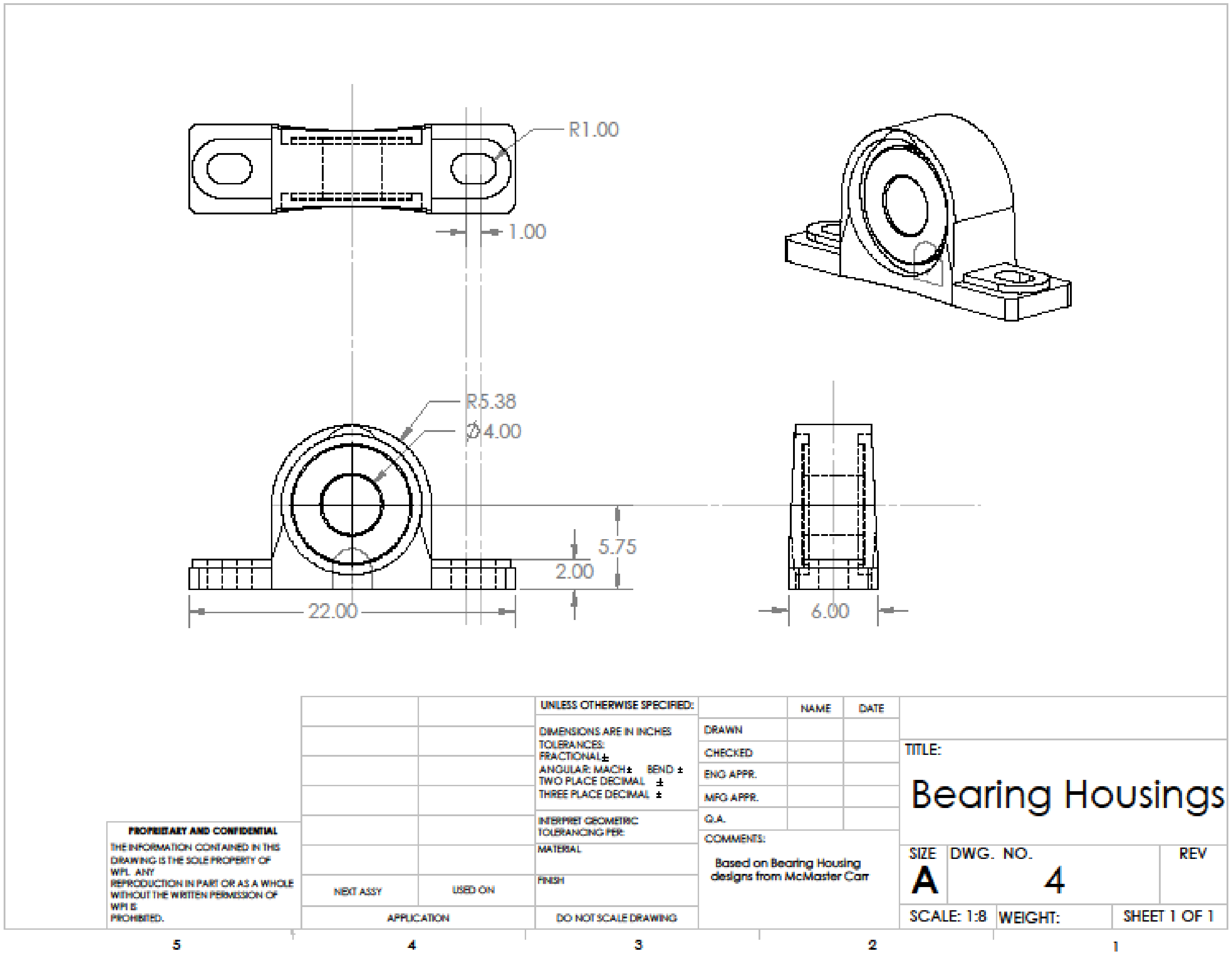
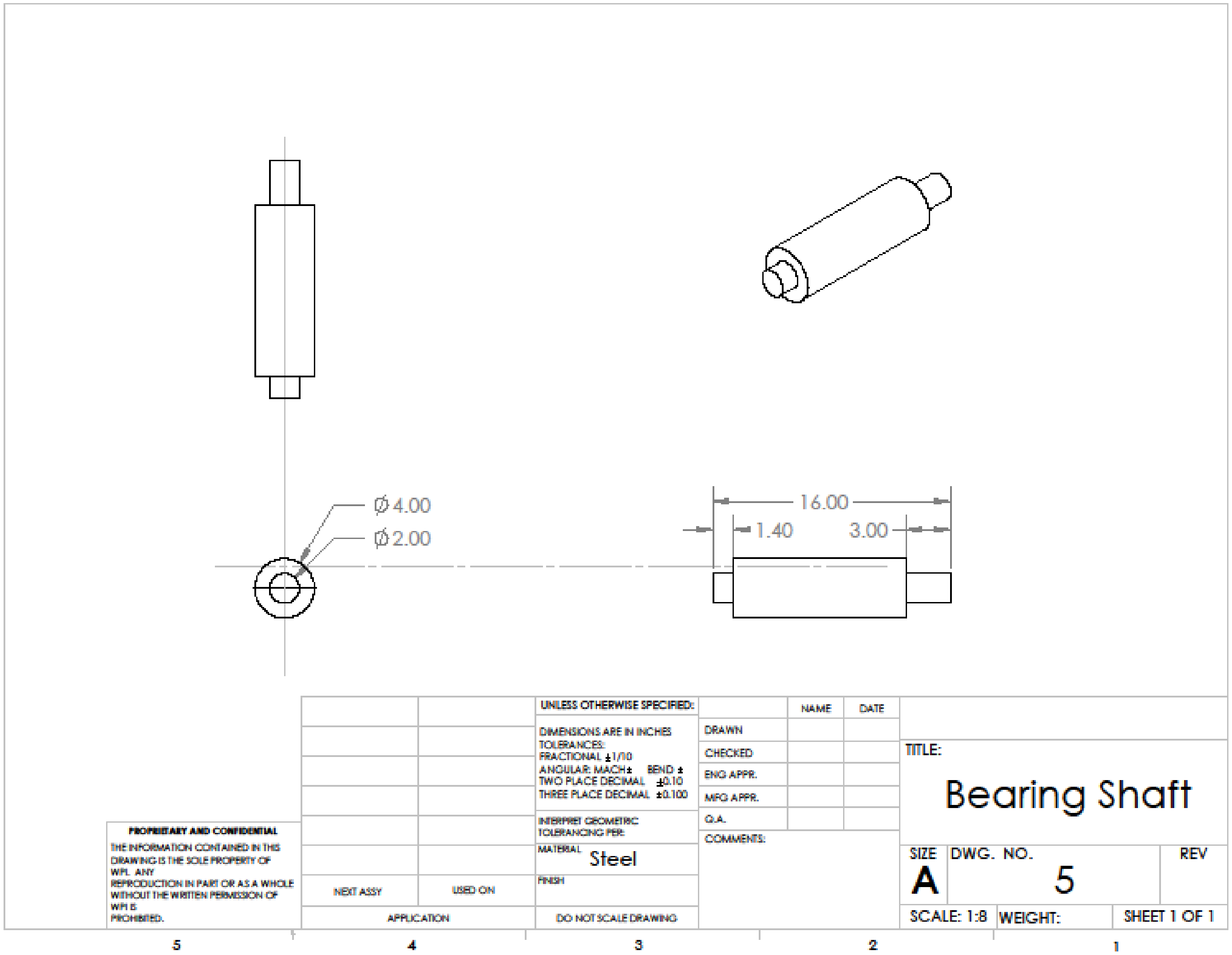
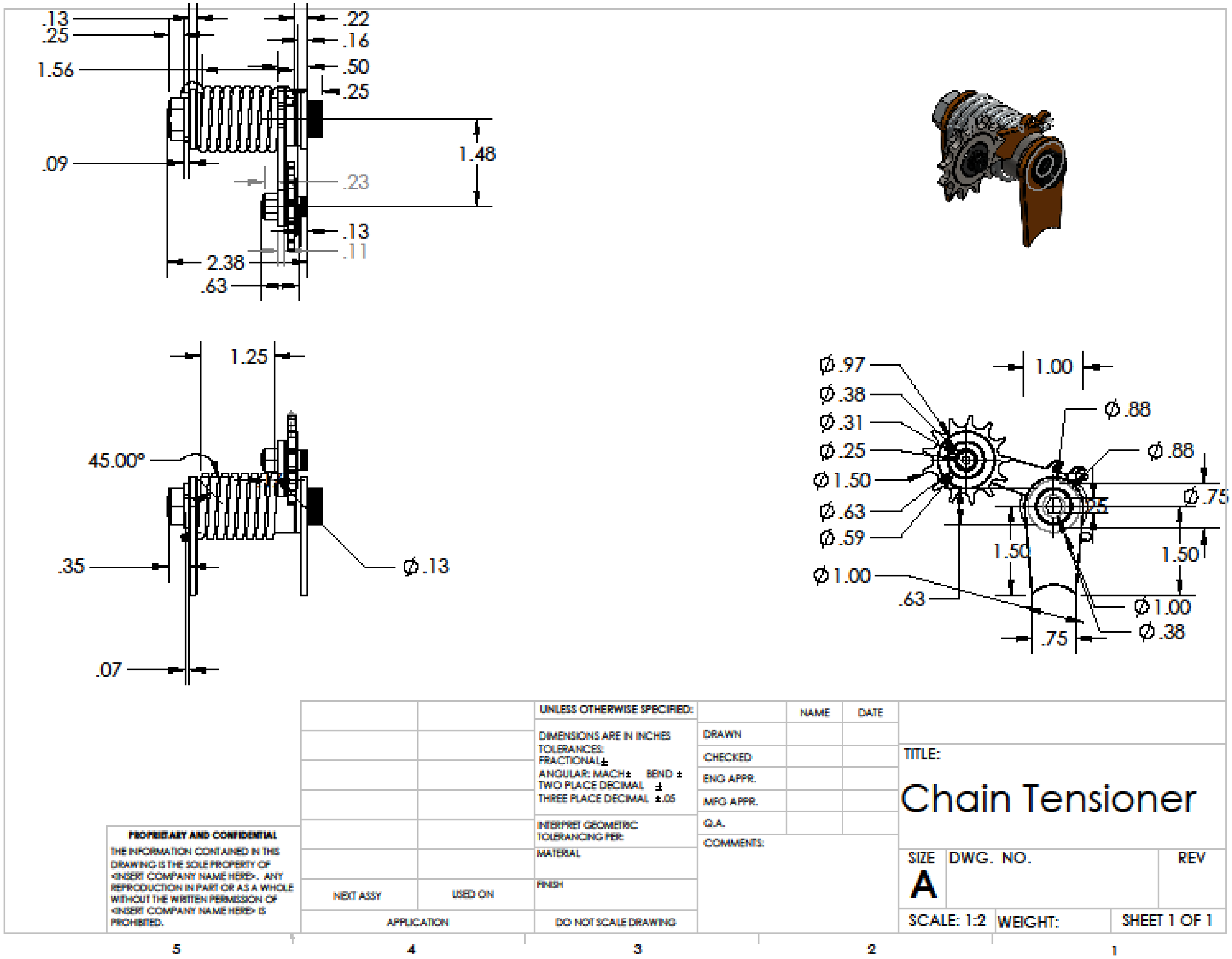
Bearing Housing



Bearing Shaft



Tensor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.25
1.56
.09
.22
.16
.50
.25
1.48
.23
.13
.11
2.38
.63
1.25
45.00°
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.07
Ø.13
Ø.97
Ø.38
Ø.31
Ø.25
Ø1.50
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Ø.59
Ø1.00
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±.05
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
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DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Chain Tensioner
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
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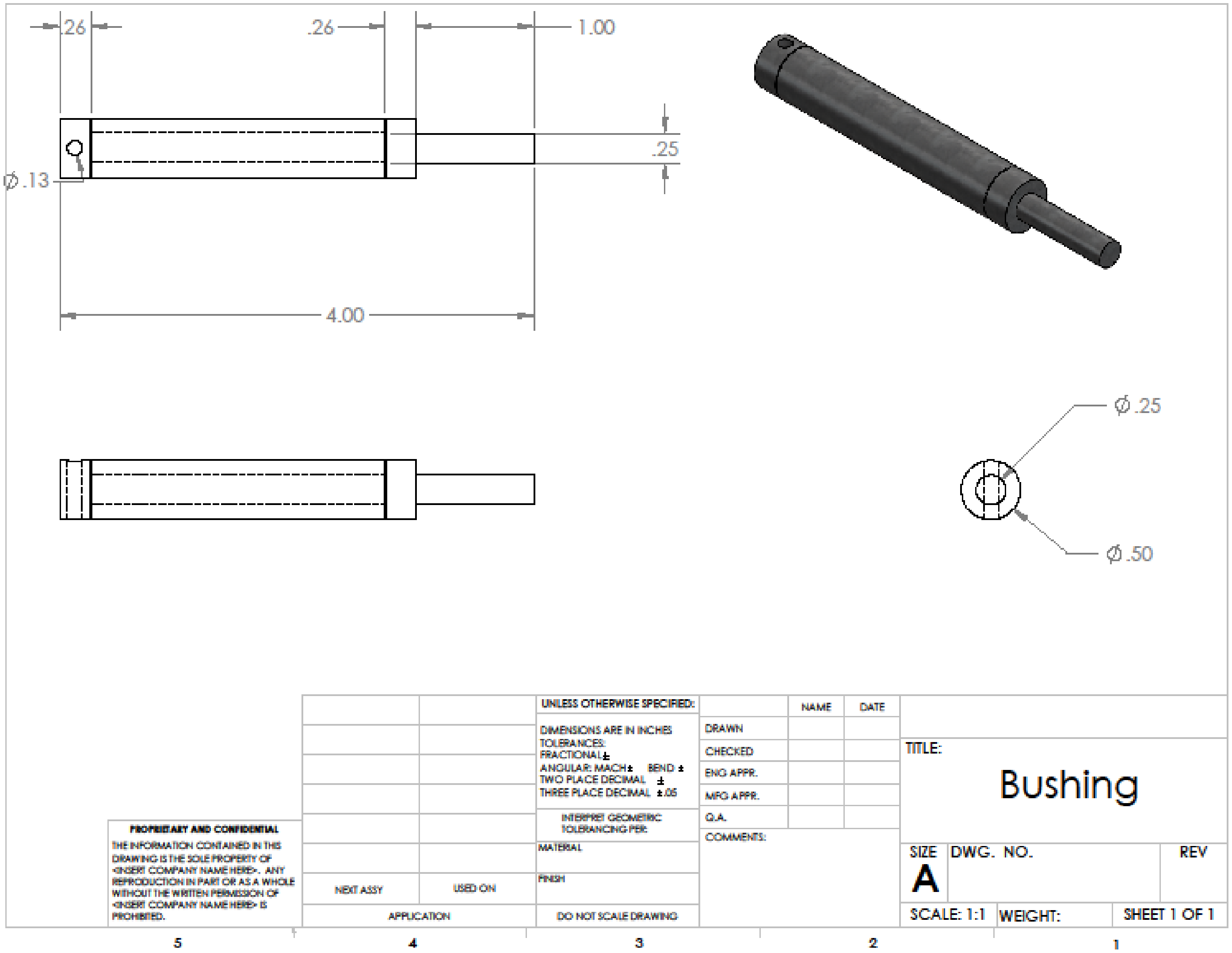
Bushings


.26
.26
1.00
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⌀.13
4.00
⌀.25
⌀.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±.05
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Bushing
SIZE
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DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
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NEXT ASSY
USED ON
APPLICATION
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