Spring 2021

Theoretical Design of a 360 Degree Pendulum Ride

John William Elliott
jwe23@uakron.edu

John Elliott

Mechanical Projects: 2920:490:00

360 Degree Pendulum Ride

4/28/21

Contents

Introduction and Background

For this project, I will be designing a 360-degree pendulum ride based on the “Max Air” ride at Cedar Point. The pendulum ride is a good example of physics at work. It makes the rider feel like they are flying using gravity as the main driving force in motion. Pendulums start from rest and then go back and forth by making good use of gravity. Pendulums have 4 main forces: tangential forces due to gravity, perpendicular forces due to gravity, tensile forces in the string/arm, and downward forces due to gravity. These forces change as the ride moves in an arc due to the different angles. The object on the end that swings is known as the “bob.” The amount of time that it takes for the bob to make a full rotation is called the period (seconds). Air resistance works against the bob as it swings, but for the purposes of this project it will be ignored.

The ride at Cedar point called “Max Air” was used as the model for this project. The Max Air ride goes up to an angle of 120 degrees and reaches a height of 140 feet while only standing 84 feet when not running. It reaches speeds of 70 miles per hour as well. At the end of the pendulum arm at the bob, the riders sit in a circular area that twists and turns to give additional feelings of weightlessness. Supports go into the ground on either side to support the entirety of the ride (4 in total).

The main modification that I wanted to theoretically design was to make this ride go around 360 degrees. I say theoretical because the project is going to be highly simplified for the purposes of this report. There are several pendulum rides that go 360 degrees, but they are few and far between. The ride has many things to calculate from just hanging, let alone moving.

Many factors go into the construction of the pendulum rides, but I will be focusing on shear forces, torque, g forces on the riders, tensile forces, and the vector forces mentioned earlier associated with the ride. The velocities and angular accelerations will also be calculated. The ride will have two pendulums riding at the same time since the new design will have a smaller rectangular seating area bob rather than a circular one. The components of the ride were made in Solidworks as simple base models that represent the general shape and geometry. It will be assumed that the ride will be made of mostly steel. The tensile stresses that are calculated with the general weight of steel will specify which type of steel was selected.

Researching Real World Examples

Early research that I did involved looking for an example of a 360-degree ride in action. Two sources with two different videos briefly show how the 360-degree pendulum rides operate. The first one is from Beston Amusement Equipment (2018). It is a smaller pendulum ride than Max Air (see in Figure 1). It picks up speed and drives through the entire rotation with some of the pendulums arm sticking out on the top of the opposite side of the seating area. The second is a ride in Hong Kong called the Flash. The ride is much smaller than Max Air as well and has only one vertical support underneath it (see Figure 2). The support is to the side and attached via a shaft as to not get in the way of the ride's motion.

Figure 1: Benson Amusement Equipment Pendulum Ride

Figure 2: The Flash Pendulum Ride in Hong Kong

The Hong Kong ride gave me the idea to give the ride a central support leg to help distribute the downward forces and rotational moments so that the end legs and shaft do not bear the entire brunt of it. The components of the ride I designed include a middle shaft, two pendulum arms, two seating areas/bobs, four support legs on the ends, one middle support leg, two end shafts, and two support notches at the top for the legs.

Having a general idea of what the final model would look like, the dimensions of the ride were calculated. Initial hand drawings modeled after the Max Air ride were made (see appendix A: Figure 1). The model is the same height (84 ft) and rises to the elevation of 140 ft when it swings. The legs of the ride make a 45-degree angle with the ground at the top where the shaft

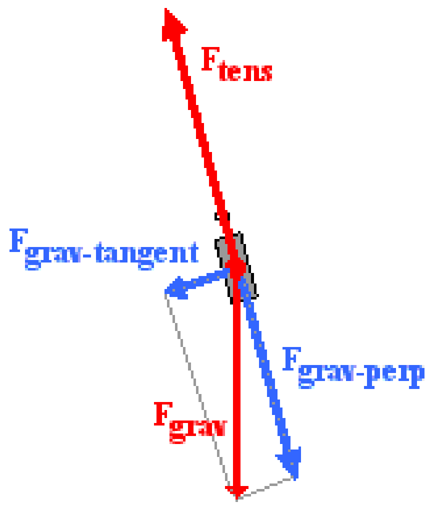
is, making two sides of the triangle 84 ft. This allowed me to use the trigonometry of the right triangle created to find the rough length of the side leg supports (the hypotenuse). The cosine formula gave a value of 118.79 ft. These values were converted into meters as well for force analysis.

Forces and Material Selection

The volume of the pendulum arm and the seating area were calculated since they will be most of the force bearing down on the shafts (see Appendix A: Figure 3). I made these components completely solid for simplicity. The pendulum arm is a rectangular arm measuring 8 ft by 8 ft by 80 ft for a volume of 5,120 cubic feet. The swing is another rectangular box measuring 30 ft by 20 ft by 5 ft minus the space it attaches with the arm (320 cubic feet) and is 2680 cubic feet. The weight was then calculated by multiplying the volumes by 489 lbs of steel per cubic foot (spaco.org, 2020) and then adding them together. The weights were then converted to kilograms. This was then multiplied by the acceleration due to gravity (9.82 m/s^2) to get the weights in Newtons for ease of future calculations. This is the most important force of gravity and was found to be -1.70 e +7 Newtons. Other forces for the outside legs were then calculated using shear, force, and moment diagrams and trigonometry (see Appendix A: Figure 5). The diagrams show the spacing that was chosen to allow enough clearance for the swings.

For a pendulum, the forces that matter (that lead to the tensile and shear forces) are the tangential force due to gravity, the force due to gravity, the perpendicular force due to gravity, and the tensile force in the “string” or the arm. A diagram of these forces can be found in Figure 3 below.

Figure 3: Diagram of Pendulum Forces



Equation set 1:

$\mathbf{F_{grav\text{-}tangent}}$ **(N) = cos(ϴ$_2$) * $\mathbf{F_{grav}}$**

$\mathbf{F_{grav\text{-}perp}}$ **(N) = cos(ϴ$_3$) * $\mathbf{F_{grav}}$**

$\mathbf{F_{tens}}$ **(N) = -$\mathbf{F_{grav\text{-}perp}}$**

The force due to gravity (F_{grav} = -1.7 e + 07) is always straight down, remains the same, and is equal to the weight of the arm and bob IF they are completely solid components. The weight of the arm and bob bears down as the maximum force on the shaft. The other forces are found from this force (see Appendix A: Figure 6). $F_{grav\text{-}tangent} = \cos(\Theta_2) * F_{grav}$ where ϴ2 is the angle between $F_{grav\text{-}tangent}$ and F_{grav}. The perpendicular force is found with $F_{grav\text{-}perp} = \cos(\Theta_3) * F_{grav}$ where Θ_3 is the same degree as the swinging arc ($\Theta_{1)}$ between F_{grav} and $F_{grav\text{-}perp}$. In a

spreadsheet, all these forces were calculated at many different angles up to 360 degrees for the full arc (see Appendix A: Figure 5). The tensile force is equal and opposite F_{perp}, so as F_{perp} changes $F_{tensile}$ changes.

This tensile force acts on a certain square area on the middle support shaft and turns into a shear force. This shear force is equal to $F_{tensile}$/(Area of shaft acted upon) in N/m^2 or Pascals. Since the shaft experiences rotational forces, the Torque on the shaft and the Torsional Shear Stress (see equation set 2) were found as well for several angles. A sample of these calculations is found in table 1, 2, and 3 below. The complete calculations can be found in Appendix A: Calculations in figures 7, 8, and 9.

Equation Set 2: Forces

Shear Force = $F_{grav\text{-}perp}$/Area

- **Area is area of shaft arm hangs from (m^2)**
- **Shear Force is in Newtons**

$T = L * F_{grav} * Sin(\Theta)$

- **T = torque (N*m)**
- **L = length of pendulum arm (m)**
- **Θ = Arc angle**

Torsional Shear Force (Pa) = (L* T)/J

- **L = length of pendulum arm (m)**
- **T = torque (N*m)**
- **J = polar moment of inertia (m^4)**

Table 1: Force Analysis on Pendulum

Angle	Tangential Force from Gravity (Newtons)	Force of Gravity (N)	Perpendicular Force from Gravity (N)
90	-1.04E-09	-1.70E+07	-1.70E+07
80	-2.95E+06	-1.70E+07	-1.67E+07
70	-5.81E+06	-1.70E+07	-1.60E+07
60	-8.50E+06	-1.70E+07	-1.47E+07
50	-1.09E+07	-1.70E+07	-1.30E+07
40	-1.30E+07	-1.70E+07	-1.09E+07
30	-1.47E+07	-1.70E+07	-8.50E+06
20	-1.60E+07	-1.70E+07	-5.81E+06
10	-1.67E+07	-1.70E+07	-2.95E+06
0	-1.70E+07	-1.70E+07	-1.04E-09
10	-1.67E+07	-1.70E+07	2.95E+06
20	-1.60E+07	-1.70E+07	5.81E+06
30	-1.47E+07	-1.70E+07	8.50E+06

Table 2: Shear Forces

Angle	Area on Shaft Affected (m^2) (1.83 m X 2.44 m)	Shear Force in N/m^2	Shear Force in MPa
0	4.46	3.81E+06	3.81E+00
10	4.46	3.75E+06	3.75E+00
20	4.46	3.58E+06	3.58E+00
30	4.46	3.30E+06	3.30E+00
40	4.46	2.92E+06	2.92E+00
50	4.46	2.45E+06	2.45E+00
60	4.46	1.91E+06	1.91E+00
70	4.46	1.30E+06	1.30E+00
80	4.46	6.62E+05	6.62E-01
90	4.46	2.33E-10	2.33E-16
100	4.46	-6.62E+05	-6.62E-01
110	4.46	-1.30E+06	-1.30E+00

Table 3: Torque and Torsional Shear Stress

Angle	Torque on shaft (N*m)	Torsional Shear Stress (Pa)
0	0.00E+00	0.00E+00
10	-6.39E+07	-1.26E+09
20	-1.26E+08	-2.48E+09
30	-1.84E+08	-3.62E+09
40	-2.36E+08	-4.65E+09
50	-2.82E+08	-5.54E+09
60	-3.19E+08	-6.27E+09
70	-3.46E+08	-6.80E+09
80	-3.62E+08	-7.13E+09
90	-3.68E+08	-7.24E+09

I used the maximum shear force to determine the material that could be used as the material for the ride. The torque and torsional shear stress should be used for future reference based upon the approved/standardized size of the ride components since the maximum values of these forces are based upon the diameter of the shaft. The maximum shear force that the ride experiences was found to be around 3.81 MPa converted from Pascals.

The general shear strength can be determined by multiplying the ultimate tensile strength by 60%. Most steels have an ultimate tensile strength well into 100s of MPa, so theoretically any steel can be selected for the ride. I decided to choose A36 Carbon Steel since most rides use carbon steel in their construction. According to Mott, Vavrek, and Wang in the Machine Elements in Mechanical Design Textbook (2018), it has an ultimate tensile strength of 400 MPa and a yield strength of 248 MPa. If the shear strength is 60 percent of 400 MPa, then the shear strength of the shaft would need to be at least 240 MPa. This is well above what the shaft is experiencing, so A36 carbon steel would work.

Velocity and Power

The values calculated for the motion of the pendulum include the velocity, the angular velocity, the acceleration, the power generated by the ride, and the g force values that are experienced by the riders. The values change with the different angles of the swinging arc. These formulas can be found in equation set number 3 below. Samples of the velocity, angular velocity, power, acceleration, and G force values can be found in Tables 4 and 5 below. The complete calculations can be found in Appendix A: Calculations in Figures 10 and 11.

Equation Set 3: Velocities and Power

$v^2 = 2gL\,(1-\cos\Theta)$

- **v = velocity (m/s)**
- **g = acceleration due to gravity (9.82 m/s^2)**
- **L = length of pendulum arm (m)**
- **Θ = pendulum arc angle**

$\alpha = v/L$

- **α = angular velocity (rad/s)**
- **v = velocity (m/s)**
- **L = length of pendulum arm minus suspended area above ground (m)**

P = T * α

- **P = power generated by ride (watts)**
- **T = torque on shaft (N * m)**
- **α = angular velocity (rad/s)**

$a = g * \sin\Theta + v^2/L$

- **a = angular acceleration (m/s^2)**
- **g = acceleration due to gravity (9.82 m/s^2)**
- **Θ = pendulum arc angle**
- **V = velocity (m/s)**
- **L = length of pendulum arm**

Table 4: Velocity, Angular velocity, and Power

Angle	Velocity (m/s)	Angular Velocity (rad s^-1)	Torque on shaft (N*m)	Power Generated Based on Torque and Angular Velocity (KW)
0	0	0	0.00E+00	0
10	2.763768932	0.127715755	-1.26E+09	160503.8496
20	5.506503914	0.254459515	-2.48E+09	629855.7951
30	8.207331076	0.379266686	-3.62E+09	1372414.98
40	10.84569549	0.501187407	-4.65E+09	2331515.979
50	13.40151762	0.61929379	-5.54E+09	3433376.584
60	15.8553461	0.732686973	-6.27E+09	4592190.025
70	18.18850583	0.840503966	-6.80E+09	5716054.128
80	20.38324004	0.941924216	-7.13E+09	6713332.701

Table 5: Acceleration and G values

Angle	Acceleration (m/s^2)	G Values from Acceleration
0	0	-0
10	2.003600836	-0.204032672
20	4.543074735	-0.462634902
30	7.54126107	-0.767949192
40	10.90706146	-1.110698723
50	14.53820778	-1.480469224
60	18.32436947	-1.866025404
70	22.15050592	-2.255652334
80	25.90036193	-2.637511398
90	29.46	-3
100	32.72126234	-3.332104108
110	35.58505715	-3.623732907
120	37.96436947	-3.866025404

The ride experiences a linear velocity and an angular velocity due to traveling in an arc. The linear velocity in an arc requires the use of gravity, the length of the pendulum arm, and the degrees of the arc because of potential and kinetic energy being converted into each other. Once the angular velocity was found, I found a relationship between torque and angular velocity where the torque is multiplied by the angular velocity to translate to power in KW. This power is the instantaneous power that the pendulum is generating, so it is not the power that the generators are required to produce to move it. It is, however, a good starting point in understanding what the power will add up to with the addition of generators and gravity propelling the ride once it gets in the air. The maximum velocity was found to be around 32 m/s or 70 mph. The maximum power generated by the ride instantaneously was around 8.2 million KW or 8200 MW.

The angular accelerations were calculated to find out what the g force values would be on the riders. G force is how many times an object is accelerating faster than the acceleration due to gravity. It is also a measure of how many times heavier you will feel when traveling at a certain acceleration or velocity. The g values can be negative or positive. Negative g values are considered downward toward the Earth. For example: if you experience 2 g's of force, you will feel twice as heavy. The acceleration is a combination of tangential acceleration and centripetal acceleration for the pendulum.

For smaller angles the centripetal acceleration matters more. At angles where the pendulum is facing the ground directly the force is mostly tangential and straight down. The tangential acceleration is equal to $g * \sin\Theta$ and the centripetal acceleration is the v^2/L. With these two accelerations combined, I divided each acceleration from different angles by 9.82 m/s^2. The maximum g force that a person on the ride will experience was -4.23 g's. Most people can withstand around 5 positive g's (Wikipedia, 2021). For negative g's people can withstand around 2 to 3 g's. This ride goes over that but since the pendulum will not expose them for more than a second to -4.23 g's, the ride should be relatively safe from people passing out. The addition of air resistance and the rider's mass would also reduce the acceleration and force on the rider.

Summary and Conclusions

The final assembly of the pendulum ride can be found at the end of this report in Appendix B in the Assembly drawings section along with detailed drawings in Appendix C. While it is modeled after the Cedar Point ride called Max Air, it varies in several ways. It does not only go up to 120 degrees, but it goes around completely in a 360-degree arc. It also has two pendulum arms that swing along with a central support that is absent from the Max Air ride. The general dimensions, such as the height and length of the legs, are very similar to Max Air. The actual sizes of the components, however, were not based on the measurements of Max Air but on motion clearances and observations of existing pendulum rides. The parts were also made proportional to each other as they were made in Solidworks.

Using free-body diagrams of pendulum forces, the four forces that affect the stresses on the shaft and the ride were the gravitational forces (perpendicular, tangential, gravity) and the tensile force opposite of the perpendicular forces. Once the force of the solid pendulum ride and the solid bob bearing down on the shaft were calculated, the shear, force, and moment diagrams created a picture of the ride and how spaced out the components would be. It also helped determine the maximum force bearing down on the shaft.

The force of the pendulum ride and the bob were used to calculate the perpendicular and tangential forces. The perpendicular forces were used to find the shear forces. The maximum shear force was used to select A36 carbon steel as the ride’s main material. Torque and torsional shear stress were calculated since it is a relevant force in the twisting of the shaft.

These values can be used in the future to specify a better or cheaper material based on the sizes selected for the components by different project designers.

The motion of the pendulum contains vital calculations that determine whether the riders will be comfortable or not. The ride reaches speeds of around 70 mph. The ride experiences angular velocities as well that give an indication on the power that the ride generates. The combination of angular velocity and torque on the shaft gives power values in KW that the ride generates in that instance. This is not an accurate way to choose generators since these power values are so big. They do, however, give an indication that most of the power and work done by the ride will be done when it moves. The total power that will be required at that instance will be a combination of generator electrical power and work done by the ride using gravity. Most of the generator power will be used to get the ride to move from rest. After that, gravity will provide free work and power.

The accelerations of the ride happen because of its arc and gravity. These changes in speeds change with the angle like the velocities do. Two accelerations are applicable: tangential and centripetal. From these accelerations, g values can be calculated since g values are multiples of the acceleration due to gravity. Humans can withstand up to +5 g's upward and -3 g's downward. The g values are mostly negative since the ride swings downward and reach a maximum of -4.23 g's. This is above the threshold that most people can withstand but since the ride will expose the riders to this force for less than a second or a second at most, the riders should be fine. Air resistance and the mass of the rider will also play a role in their comfort while in motion.

In the future electrical engineers, construction engineers, and other engineering fields will be needed to ensure the ride works. Air resistance will be considered to fully understand how fast the ride will be moving. The geometry of the ride will also need to be improved so that the ride is not a completely solid piece of steel to allow for sub-assemblies and electrical components to be manufactured in. Fasteners will need to be fitted to anchor the ride to the ground and to the other components. Maintenance access will need to be included as well to make sure the ride is operating correctly for as long as possible. Safety guidelines, seating accommodations that are up to code, and other materials that the components will need to be made of will need to be considered as well. These are just a few of the hundreds of things that will need to be worked on by many departments, organizations, and individuals. Many different types of engineers and other people working together will be needed to make this ride work safely and properly.

References

Bailey, Carlson, Podlogar, Zarske. (2007, July 17). *Lesson: The Science of Swinging.* Teach Engineering. Retrieved from https://www.teachengineering.org/lessons/view/cub_pend_lesson01

Boles, Cengel, Kanoglu. (2019). *Thermodynamics: An Engineering Approach.* McGraw Hill Education. (Pg. 21)

Convert meters per (second squared) to g-unit -Conversion of Measurement Units. (Accessed 2021, March 3rd). Convert units. Retrieved from https://www.convertunits.com/from/meters+per+(second+squared)/to/g-unit

Engineering ToolBox (2005). *Torsion of Shafts*. [online] Retrieved from https://www.engineeringtoolbox.com/torsion-shafts-d_947.html (Accessed 2021, February 7)

g-force. (2021, April 23) Wikipedia. Retrieved from https://en.wikipedia.org/wiki/G-force

How much does that piece of steel stock weigh? (2020, June 1). Spaco. Retrieved from https://spaco.org/Blacksmithing/SteelStockWeight.htm#:~:text=Fact%3A%20Most%20steel%20weighs%20about%20489%20pounds%20per%20cubic%20foot.

maXair (ride). (2020, May 30) Wikipedia. Retrieved from https://en.wikipedia.org/wiki/MaXair_(ride)

Mott, Vavrek, Wang. (2018). *Machine Elements in Mechanical Design.* Pearson. (Pg. 793)

Nice, K. (2021). *How Force, Power, Torque and Energy Work.* Ho Stuff Works. Retrieved from https://auto.howstuffworks.com/auto-parts/towing/towing-capacity/information/fpte7.htm

Pendrill and Modig. (2018, June 5). *Pendulum Rides, Rotations, and the Coriolis Effect.* IOP Science. Retrieved from https://iopscience.iop.org/article/10.1088/1361-6552/aac3cb

Pendulum Motion. (Accessed 2021, January 20). Physics Classroom. Retrieved from https://www.physicsclassroom.com/class/waves/Lesson-0/Pendulum-Motion

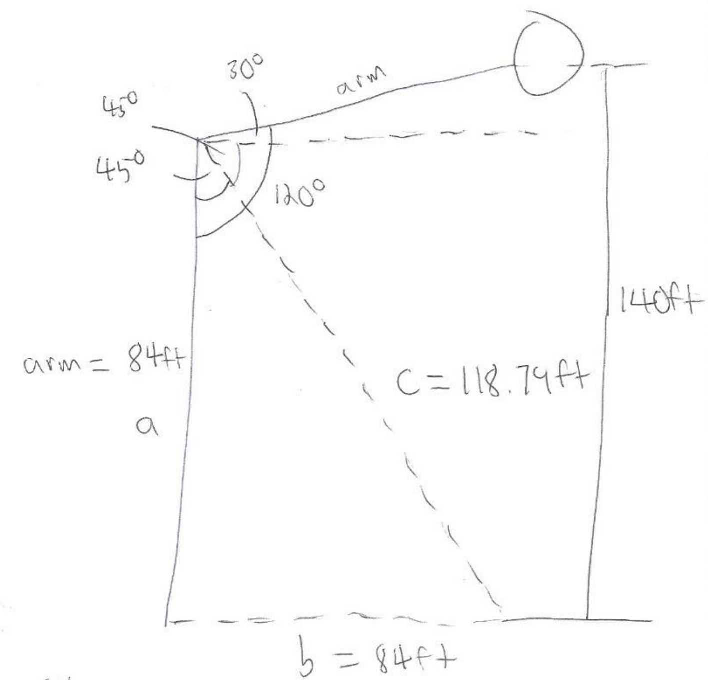
Pendulum Ride 360 Degree. (Accessed 2021, January 18). Pendulum Amusement Park Rides. Retrieved from https://pendulumamusementparkrides.com/pendulum-ride-360-degree/

Platenberg, K. (2016). *Engineering Graphics Essentials with AutoCAD 2016 Instruction*. SDC Publications.

Rotational Kinetic Energy. (2013). Lumen Learning. Retrieved from https://courses.lumenlearning.com/boundless-physics/chapter/rotational-kinetic-energy/#:~:text=The%20mechanical%20work%20applied%20during,%CF%84%CF%89%20P%20%3D%20%CF%84%20%CF%89%20.

Appendix A: Hand Calculations and Excel Calculations

Figure 1: Free Body Diagram of Pendulum Arm Dimensions



$$\cos(45°) = \frac{84}{C}$$

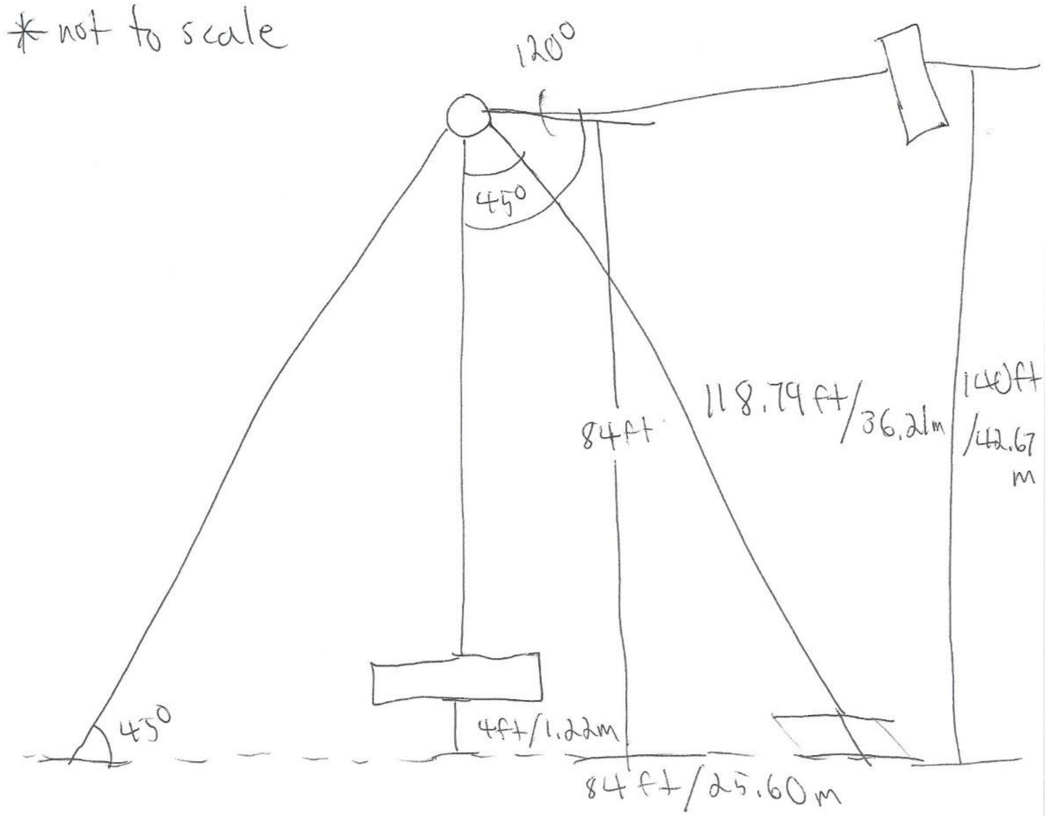
$$C(\cos(45°)) = 84$$

$$C = \frac{84\,ft}{\cos(45°)} = 118.79\,ft$$

$$\tan(45°) = \frac{84}{b}$$

$$b = 84\,ft$$

Figure 2: Free Body Diagram of Whole Ride and Important Equations



equations

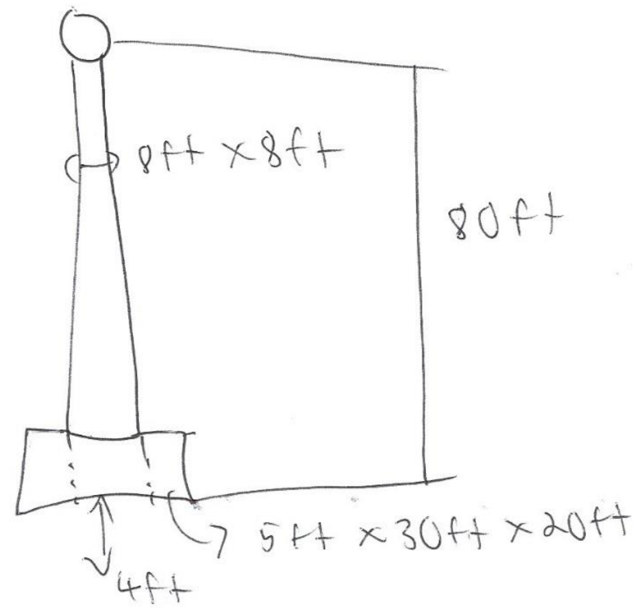
acceleration at max angle (θ_0): $a = g\sin\theta_0$

centripetal acceleration: v^2/L or $2g(\cos\theta - \cos\theta_0)$

speed: $v^2 = 2gL(1-\cos\theta_0)$

* other equations found later

Figure 3: Volume and Weight Calculations of Pendulum Arm and Bob



Volume arm shaft: 8ft · 8ft · 80ft = 5,120 ft^3

weight: 5,120 ft^3 · $\frac{489 lb}{ft^3}$ = 2,503,680 lbs

= 1,252 tons

Cross section of arm

volume swing: 5ft · 30ft · 20ft = 3,000 ft^3 − 320 ft^3

weight: 2,680 ft^3 · $\frac{489 lb}{ft^3}$ = 1,310,520 lbs

= 656 tons

Total: 1,908 tons

Figure 4: Force, Shear, and Moment Diagrams

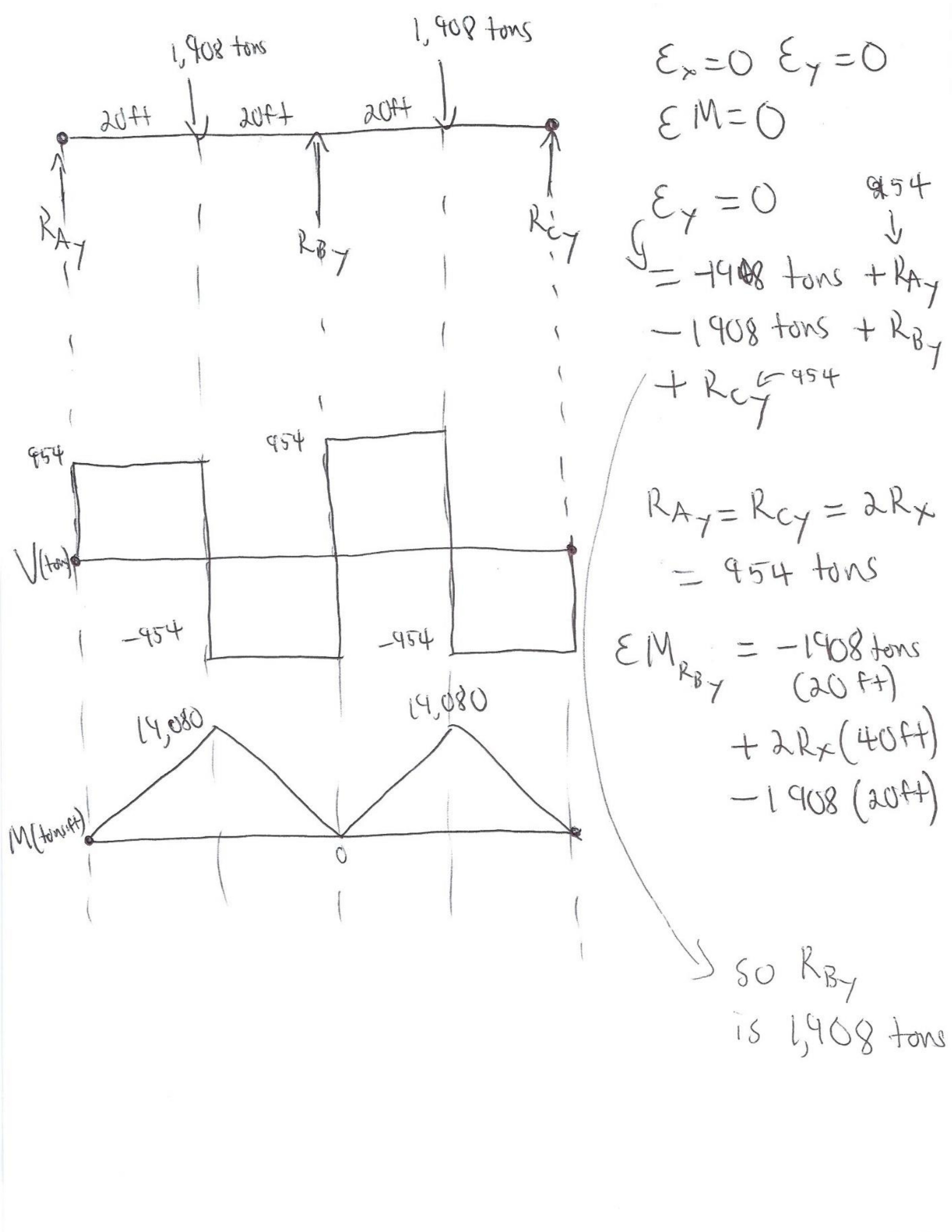
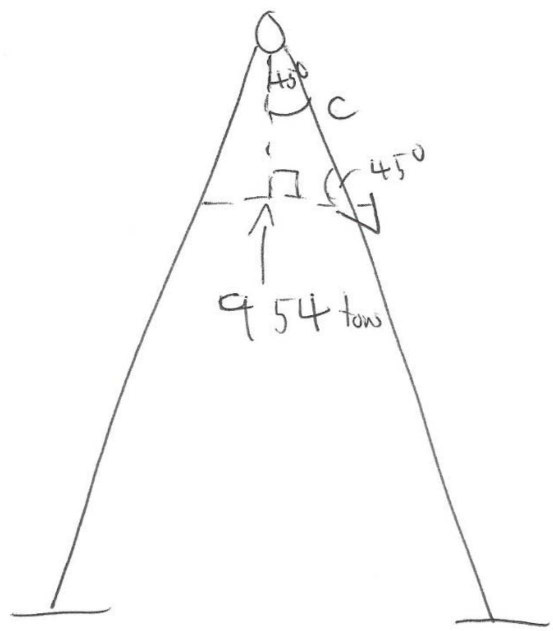


Figure 5: Free Body Diagram of Outside Leg Supports

Outside leg supports

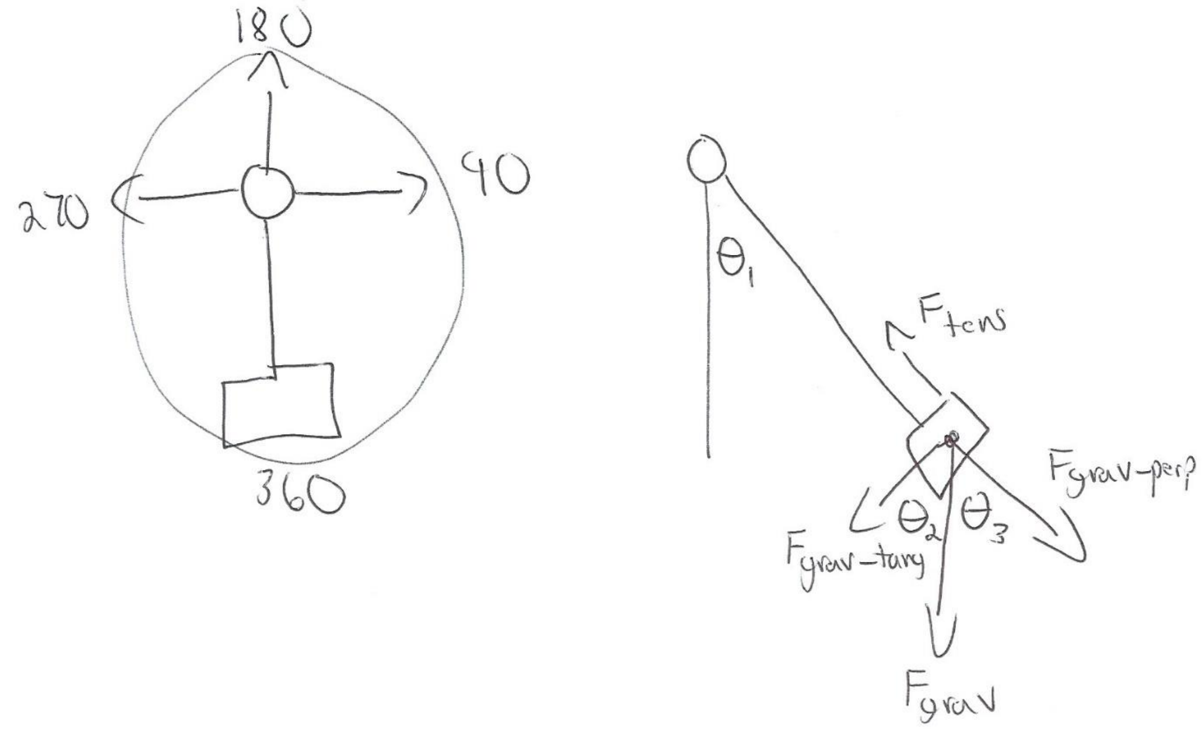


$$\cos(45^\circ) = \frac{954}{C}$$

$$C = \frac{954}{\cos(45)}$$

$$C = 1{,}349 \text{ tons}$$

Figure 6: Free Body Diagrams of Gravitational Forces



F_{grav} = weight of arm/swing $\cdot$ $(-9.82\ m/s^2)$
$(F = ma)$

$$F_{grav} = 1{,}908\ \text{tons} \cdot \frac{907.185\ \text{kg}}{\text{ton}} (-9.82\ m/s^2)$$

$$F_{grav} = -1.70e7\ N$$

$$F_{grav-tang} = \cos\theta_2 (F_{grav})$$

$$F_{grav-perp} = \cos\theta_3 (F_{grav})$$

Figure 7: Perpendicular Forces and Shear Forces

Perpendicular Force from Gravity (N)	Angle	Area on Shaft Affected (m^2)	Shear Force in N/m^2	Shear Force in Mpa	Stress due to gravity (N/m^2)
-1.70E+07	0	4.46	3.81E+06	3.81E+00	-3.80E+06
-1.67E+07	10	4.46	3.75E+06	3.75E+00	
-1.60E+07	20	4.46	3.58E+06	3.58E+00	Polar moment of inertia (m^4)
-1.47E+07	30	4.46	3.30E+06	3.30E+00	1.101042932
-1.30E+07	40	4.46	2.92E+06	2.92E+00	
-1.09E+07	50	4.46	2.45E+06	2.45E+00	
-8.50E+06	60	4.46	1.91E+06	1.91E+00	
-5.81E+06	70	4.46	1.30E+06	1.30E+00	
-2.95E+06	80	4.46	6.62E+05	6.62E-01	
-1.04E-09	90	4.46	2.33E-10	2.33E-16	
2.95E+06	100	4.46	-6.62E+05	-6.62E-01	
5.81E+06	110	4.46	-1.30E+06	-1.30E+00	
8.50E+06	120	4.46	-1.91E+06	-1.91E+00	
1.09E+07	130	4.46	-2.45E+06	-2.45E+00	
1.30E+07	140	4.46	-2.92E+06	-2.92E+00	
1.47E+07	150	4.46	-3.30E+06	-3.30E+00	
1.60E+07	160	4.46	-3.58E+06	-3.58E+00	
1.67E+07	170	4.46	-3.75E+06	-3.75E+00	
1.70E+07	180	4.46	-3.81E+06	-3.81E+00	
1.67E+07	190	4.46	-3.75E+06	-3.75E+00	
1.60E+07	200	4.46	-3.58E+06	-3.58E+00	
1.47E+07	210	4.46	-3.30E+06	-3.30E+00	
1.30E+07	220	4.46	-2.92E+06	-2.92E+00	
1.09E+07	230	4.46	-2.45E+06	-2.45E+00	
8.50E+06	240	4.46	-1.91E+06	-1.91E+00	
5.81E+06	250	4.46	-1.30E+06	-1.30E+00	
2.95E+06	260	4.46	-6.62E+05	-6.62E-01	
3.12E-09	270	4.46	-7.00E-10	-7.00E-16	
-2.95E+06	280	4.46	6.62E+05	6.62E-01	
-5.81E+06	290	4.46	1.30E+06	1.30E+00	
-8.50E+06	300	4.46	1.91E+06	1.91E+00	
-1.09E+07	310	4.46	2.45E+06	2.45E+00	
-1.30E+07	320	4.46	2.92E+06	2.92E+00	
-1.47E+07	330	4.46	3.30E+06	3.30E+00	
-1.60E+07	340	4.46	3.58E+06	3.58E+00	
-1.67E+07	350	4.46	3.75E+06	3.75E+00	
-1.70E+07	360	4.46	3.81E+06	3.81E+00	
		Max shear/tensile force	3.81E+06	3.81E+00	

Figure 8: Tangential Force

Angle	Tangential Force from Gravity (Newtons)	Force of Gravity (N)
90	-1.04E-09	-1.70E+07
80	-2.95E+06	-1.70E+07
70	-5.81E+06	-1.70E+07
60	-8.50E+06	-1.70E+07
50	-1.09E+07	-1.70E+07
40	-1.30E+07	-1.70E+07
30	-1.47E+07	-1.70E+07
20	-1.60E+07	-1.70E+07
10	-1.67E+07	-1.70E+07
0	-1.70E+07	-1.70E+07
10	-1.67E+07	-1.70E+07
20	-1.60E+07	-1.70E+07
30	-1.47E+07	-1.70E+07
40	-1.30E+07	-1.70E+07
50	-1.09E+07	-1.70E+07
60	-8.50E+06	-1.70E+07
70	-5.81E+06	-1.70E+07
80	-2.95E+06	-1.70E+07
90	-1.04E-09	-1.70E+07
100	2.95E+06	-1.70E+07
110	5.81E+06	-1.70E+07
120	8.50E+06	-1.70E+07
130	1.09E+07	-1.70E+07
140	1.30E+07	-1.70E+07
150	1.47E+07	-1.70E+07
160	1.60E+07	-1.70E+07
170	1.67E+07	-1.70E+07
180	1.70E+07	-1.70E+07
190	1.67E+07	-1.70E+07
200	1.60E+07	-1.70E+07
210	1.47E+07	-1.70E+07
220	1.30E+07	-1.70E+07
230	1.09E+07	-1.70E+07
240	8.50E+06	-1.70E+07
250	5.81E+06	-1.70E+07
260	2.95E+06	-1.70E+07
270	3.12E-09	-1.70E+07

Figure 9: Torque and Torsional Shear Stress

Angle	Torque on shaft (N*m)	Torsional Shear Stress (Pa)	Torsional Shear Stress (Mpa)
0	0.00E+00	0.00E+00	0.00E+00
10	-6.39E+07	-1.26E+09	-1.26E+03
20	-1.26E+08	-2.48E+09	-2.48E+03
30	-1.84E+08	-3.62E+09	-3.62E+03
40	-2.36E+08	-4.65E+09	-4.65E+03
50	-2.82E+08	-5.54E+09	-5.54E+03
60	-3.19E+08	-6.27E+09	-6.27E+03
70	-3.46E+08	-6.80E+09	-6.80E+03
80	-3.62E+08	-7.13E+09	-7.13E+03
90	-3.68E+08	-7.24E+09	-7.24E+03
100	-3.62E+08	-7.13E+09	-7.13E+03
110	-3.46E+08	-6.80E+09	-6.80E+03
120	-3.19E+08	-6.27E+09	-6.27E+03
130	-2.82E+08	-5.54E+09	-5.54E+03
140	-2.36E+08	-4.65E+09	-4.65E+03
150	-1.84E+08	-3.62E+09	-3.62E+03
160	-1.26E+08	-2.48E+09	-2.48E+03
170	-6.39E+07	-1.26E+09	-1.26E+03
180	-4.51E-08	-8.87E-07	-8.87E-13
190	6.39E+07	1.26E+09	1.26E+03
200	1.26E+08	2.48E+09	2.48E+03
210	1.84E+08	3.62E+09	3.62E+03
220	2.36E+08	4.65E+09	4.65E+03
230	2.82E+08	5.54E+09	5.54E+03
240	3.19E+08	6.27E+09	6.27E+03
250	3.46E+08	6.80E+09	6.80E+03
260	3.62E+08	7.13E+09	7.13E+03
270	3.68E+08	7.24E+09	7.24E+03
280	3.62E+08	7.13E+09	7.13E+03
290	3.46E+08	6.80E+09	6.80E+03
300	3.19E+08	6.27E+09	6.27E+03
310	2.82E+08	5.54E+09	5.54E+03
320	2.36E+08	4.65E+09	4.65E+03
330	1.84E+08	3.62E+09	3.62E+03
340	1.26E+08	2.48E+09	2.48E+03
350	6.39E+07	1.26E+09	1.26E+03
360	9.01E-08	1.77E-06	1.77E-12
Max Torque	3.68E+08		
Max Torsional Shear Stress	7.24E+09		

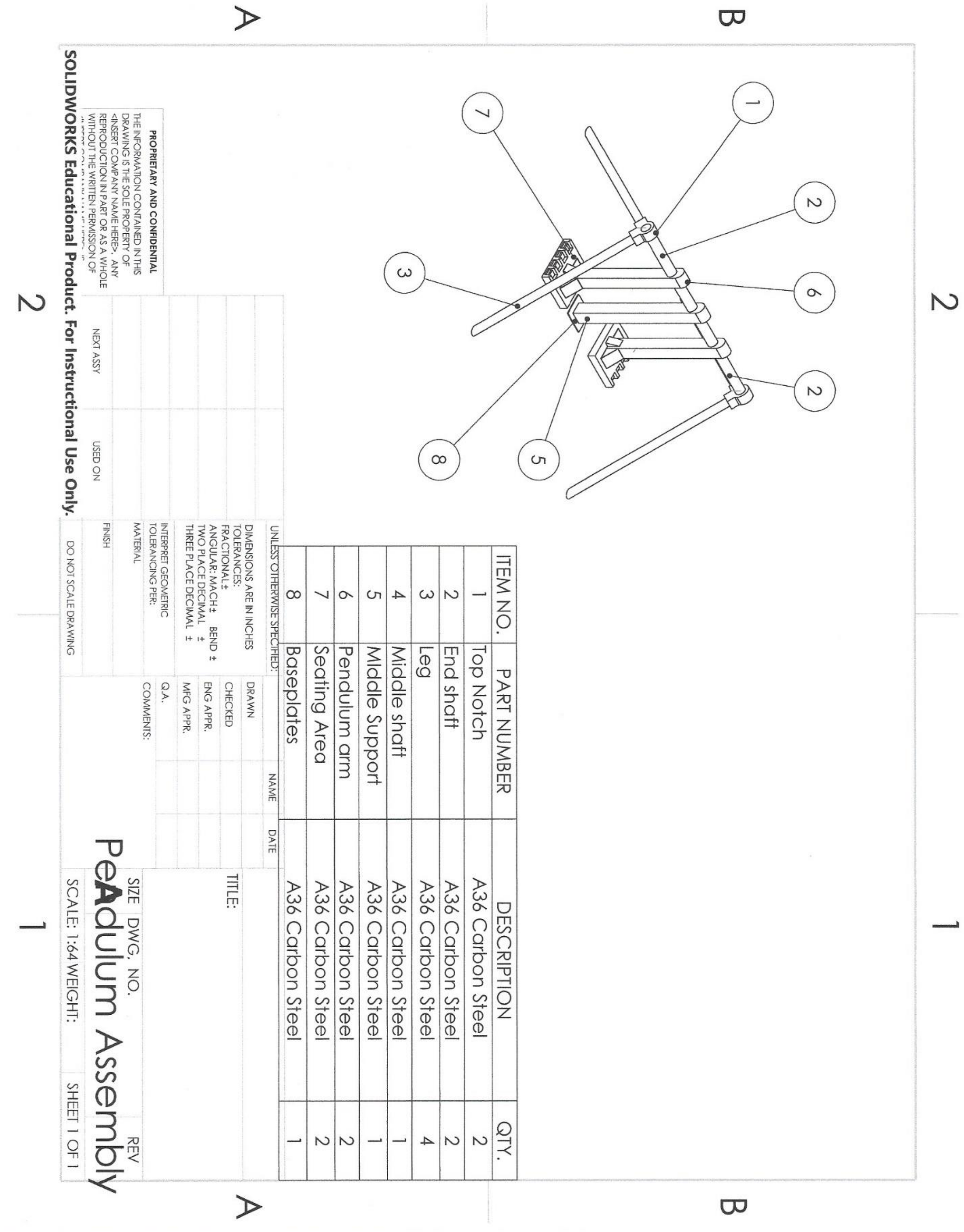
Figure 10: Velocities and Power

Angle	Velocity (m/s)	Angular Velocity (rad s^-1)	Torque on shaft (N*m)	Power Generated Based on Torque and Angular Velocity (KW)	Power in Megawatts
0	0	0	0.00E+00	0	0
10	2.763768932	0.127715755	-1.26E+09	160503.8496	160.5038496
20	5.506503914	0.254459515	-2.48E+09	629855.7951	629.8557951
30	8.207331076	0.379266686	-3.62E+09	1372414.98	1372.41498
40	10.84569549	0.501187407	-4.65E+09	2331515.979	2331.515979
50	13.40151762	0.61929379	-5.54E+09	3433376.584	3433.376584
60	15.8553461	0.732686973	-6.27E+09	4592190.025	4592.190025
70	18.18850583	0.840503966	-6.80E+09	5716054.128	5716.054128
80	20.38324004	0.941924216	-7.13E+09	6713332.701	6713.332701
90	22.42284549	1.036175855	-7.24E+09	7499014.909	7499.014909
100	24.29179955	1.122541569	-7.13E+09	8000638.365	8000.638365
110	25.97587834	1.200364064	-6.80E+09	8163371.309	8163.371309
120	27.46226502	1.269051064	-6.27E+09	7953906.442	7953.906442
130	28.73964728	1.328079819	-5.54E+09	7362899.844	7362.899844
140	29.79830346	1.377001084	-4.65E+09	6405787.506	6405.787506
150	30.63017657	1.41544254	-3.62E+09	5121922.435	5121.922435
160	31.22893554	1.443111624	-2.48E+09	3572089.72	3572.08972
170	31.59002345	1.459797756	-1.26E+09	1834567.396	1834.567396
180	31.7106922	1.465373947	-8.87E-07	1.2993E-09	1.2993E-12
190	31.59002345	1.459797756	1.26E+09	1834567.396	1834.567396
200	31.22893554	1.443111624	2.48E+09	3572089.72	3572.08972
210	30.63017657	1.41544254	3.62E+09	5121922.435	5121.922435
220	29.79830346	1.377001084	4.65E+09	6405787.506	6405.787506
230	28.73964728	1.328079819	5.54E+09	7362899.844	7362.899844
240	27.46226502	1.269051064	6.27E+09	7953906.442	7953.906442
250	25.97587834	1.200364064	6.80E+09	8163371.309	8163.371309
260	24.29179955	1.122541569	7.13E+09	8000638.365	8000.638365
270	22.42284549	1.036175855	7.24E+09	7499014.909	7499.014909
280	20.38324004	0.941924216	7.13E+09	6713332.701	6713.332701
290	18.18850583	0.840503966	6.80E+09	5716054.128	5716.054128
300	15.8553461	0.732686973	6.27E+09	4592190.025	4592.190025
310	13.40151762	0.61929379	5.54E+09	3433376.584	3433.376584
320	10.84569549	0.501187407	4.65E+09	2331515.979	2331.515979
330	8.207331076	0.379266686	3.62E+09	1372414.98	1372.41498
340	5.506503914	0.254459515	2.48E+09	629855.7951	629.8557951
350	2.763768932	0.127715755	1.26E+09	160503.8496	160.5038496
360	0	0	1.77E-06	0	0
	Max Velocity (m/s)		Max Power (KW)	8163371.309	
	31.7106922				

Figure 11: Acceleration and G Values

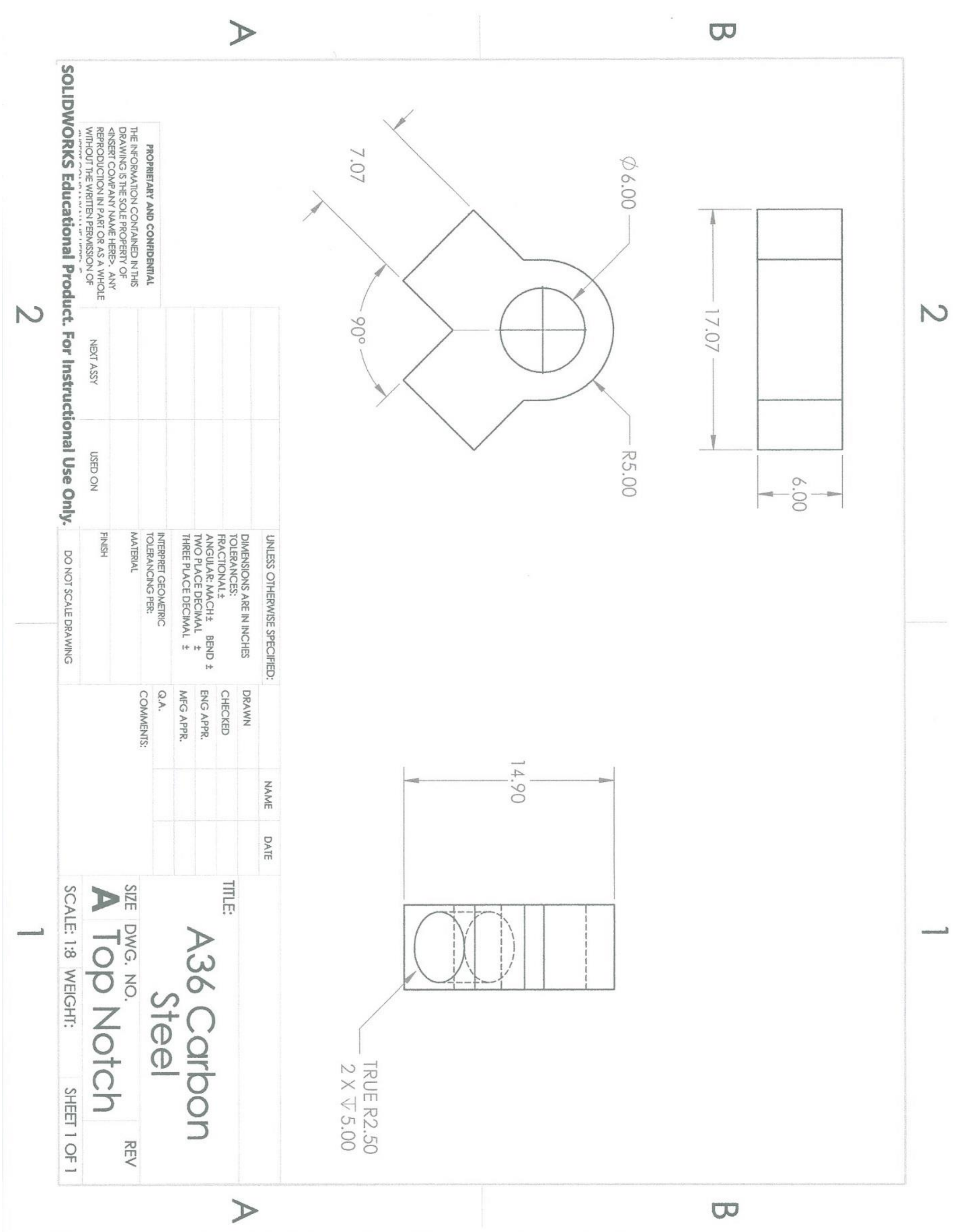
Angle	Acceleration (m/s^2)	G_Values From Acceleration
0	0	0
10	2.003600836	-0.204032672
20	4.543074735	-0.462634902
30	7.54126107	-0.767949192
40	10.90706146	-1.110698723
50	14.53820778	-1.480469224
60	18.32436947	-1.866025404
70	22.15050592	-2.255652334
80	25.90036193	-2.637511398
90	29.46	-3
100	32.72126234	-3.332104108
110	35.58505715	-3.623732907
120	37.96436947	-3.866025404
130	39.78690509	-4.051619662
140	40.99728719	-4.174876496
150	41.55873893	-4.232050808
160	41.45420088	-4.221405385
170	40.68684937	-4.143263684
180	39.28	-4
190	37.27639916	-3.795967328
200	34.73692526	-3.537365098
210	31.73873893	-3.232050808
220	28.37293854	-2.889301277
230	24.74179222	-2.519530776
240	20.95563053	-2.133974596
250	17.12949408	-1.744347666
260	13.37963807	-1.362488602
270	9.82	-1
280	6.558737656	-0.667895892
290	3.694942849	-0.376267093
300	1.315630535	-0.133974596
310	-0.506905086	0.051619662
320	-1.71728719	0.174876496
330	-2.27873893	0.232050808
340	-2.17420088	0.221405385
350	-1.406849374	0.143263684
360	-2.40619E-15	2.4503E-16
	Max Accelration (m/s^2)	Max G value
	41.55873893	4.232050808

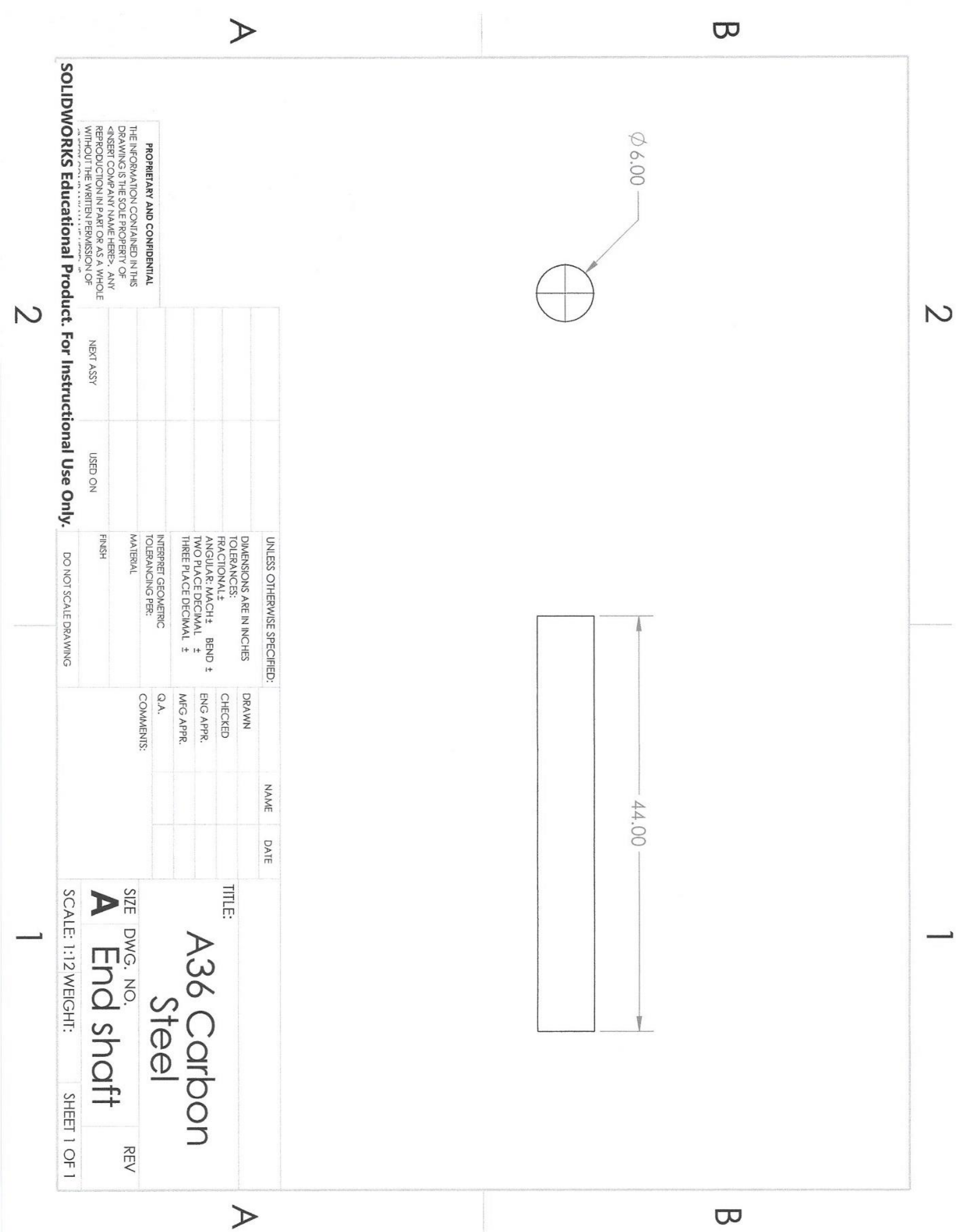
Appendix B: 360 Degree Pendulum Model Ride Assembly

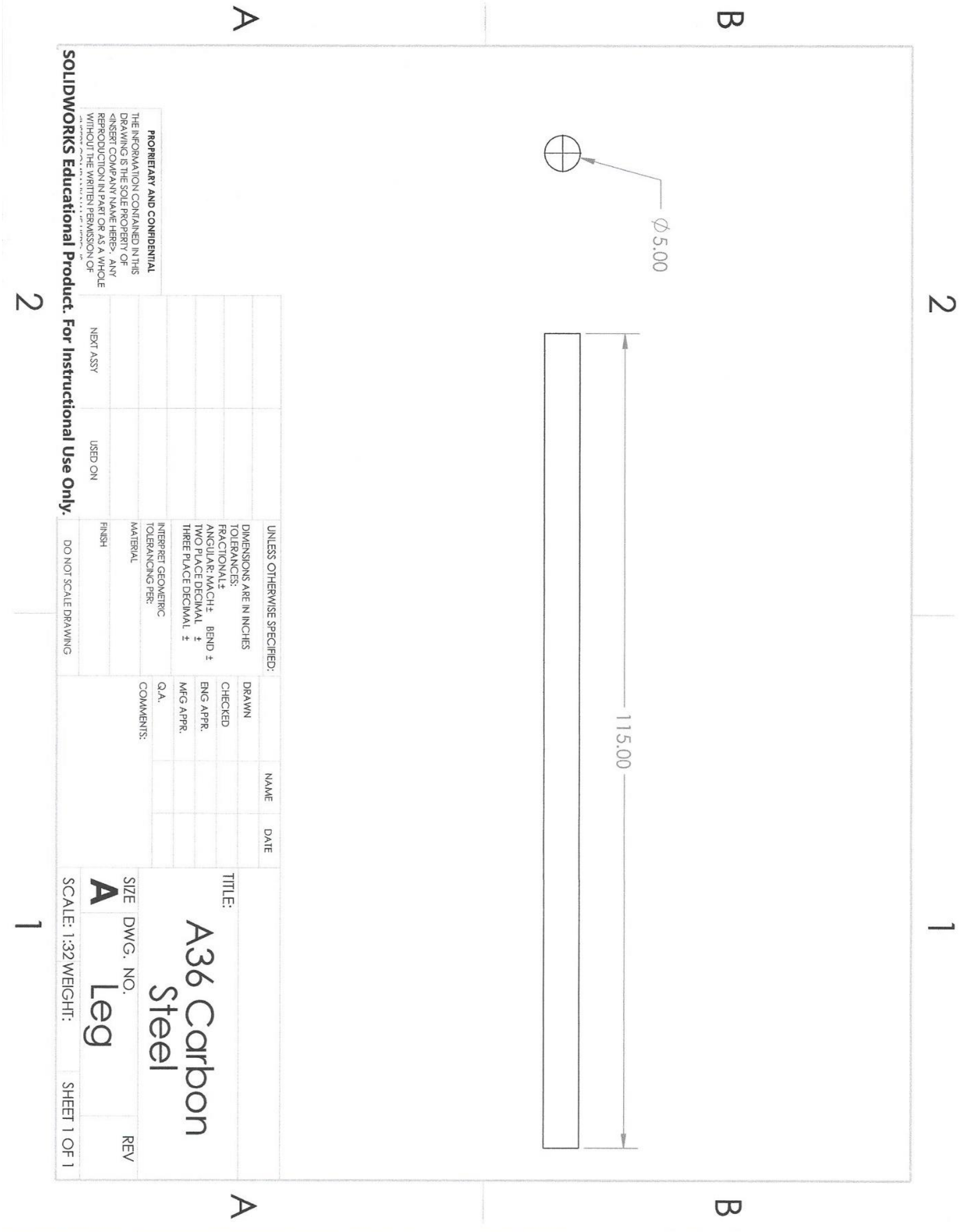


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Top Notch	A36 Carbon Steel	2
2	End shaft	A36 Carbon Steel	2
3	Leg	A36 Carbon Steel	4
4	Middle shaft	A36 Carbon Steel	1
5	Middle Support	A36 Carbon Steel	1
6	Pendulum arm	A36 Carbon Steel	2
7	Seating Area	A36 Carbon Steel	2
8	Baseplates	A36 Carbon Steel	1

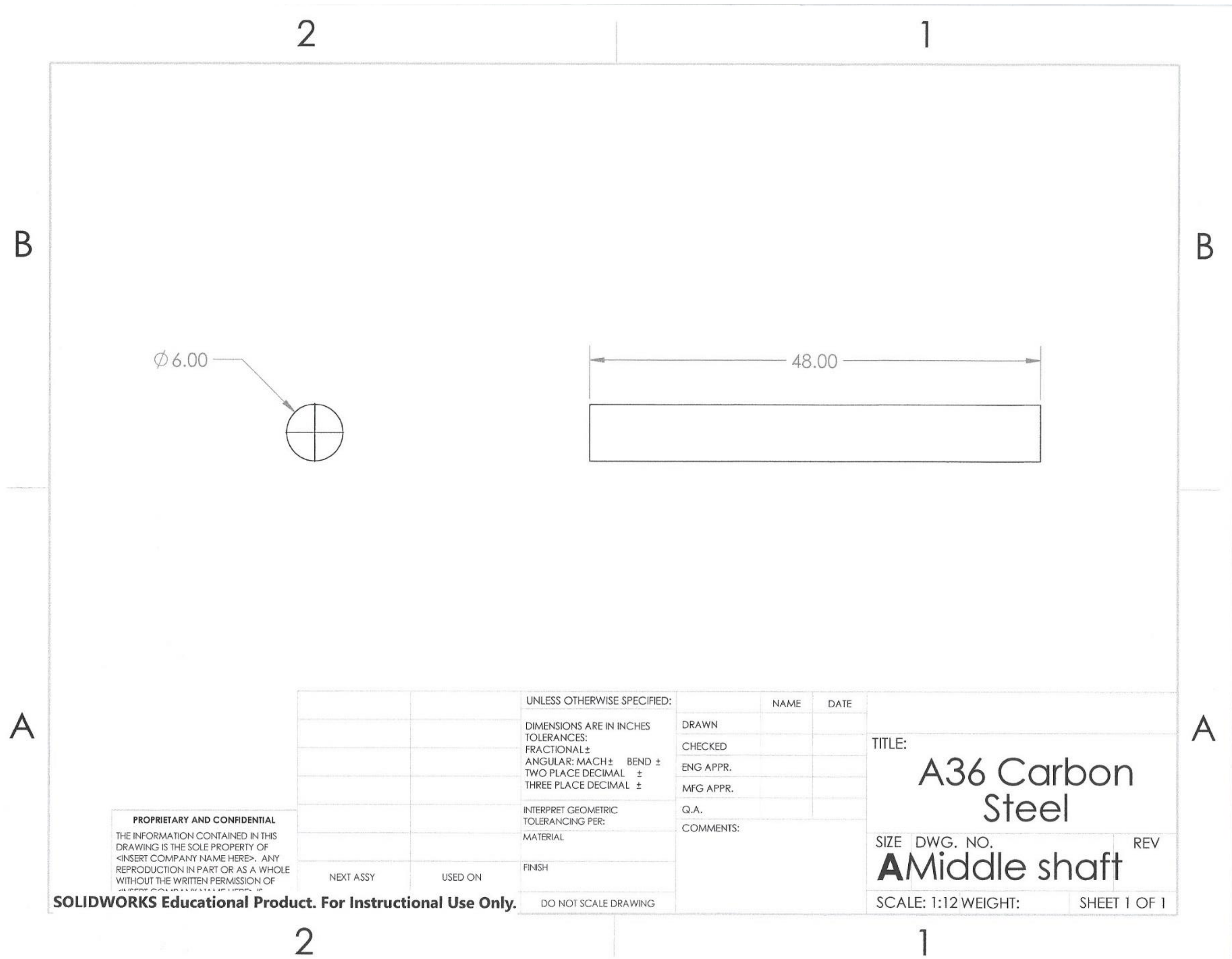
Appendix C: Detailed Part Drawings

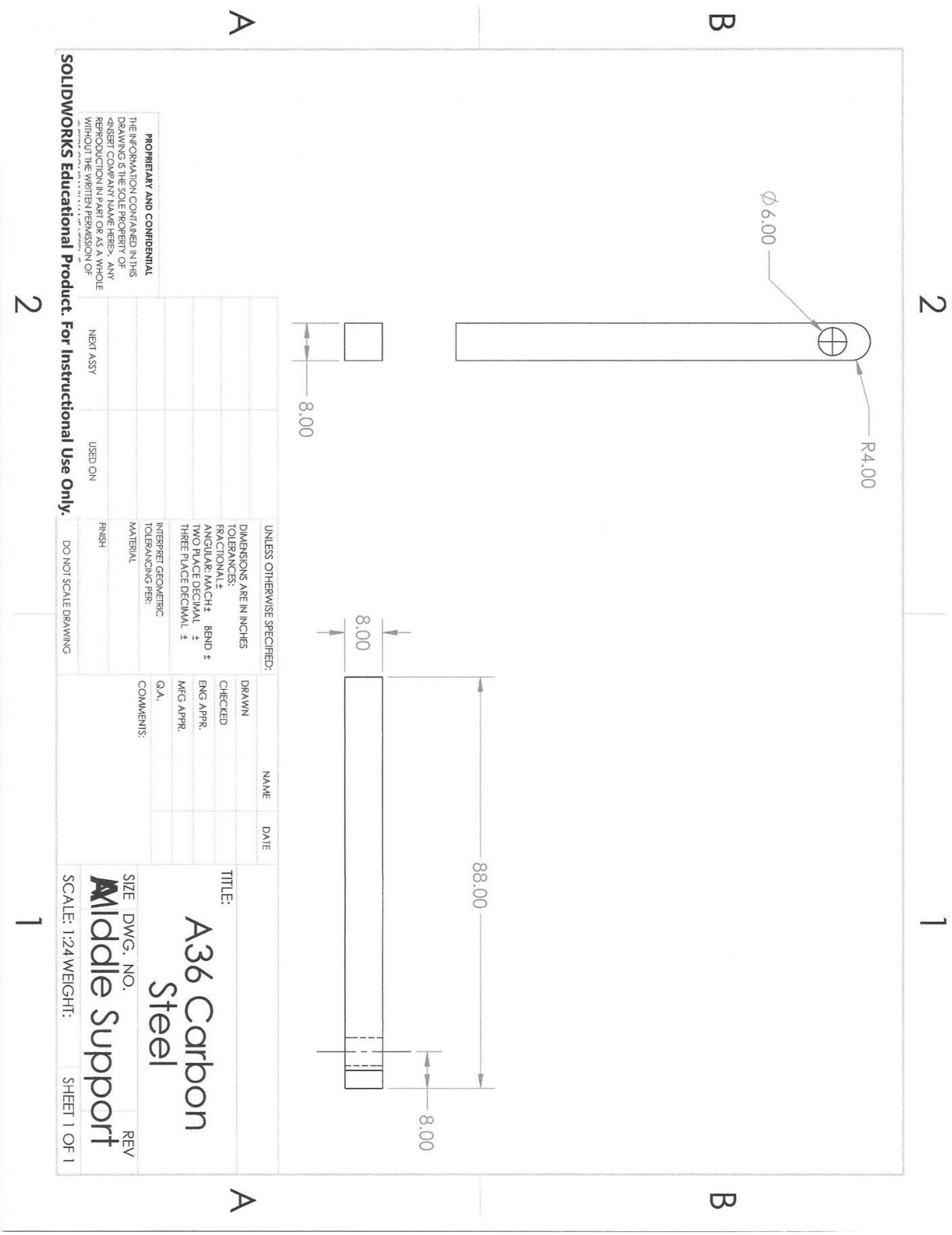



Ø6.00
44.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
A36 Carbon Steel
SIZE
A
DWG. NO.
End shaft
REV
SCALE: 1:12
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF
SOLIDWORKS Educational Product. For Instructional Use Only.

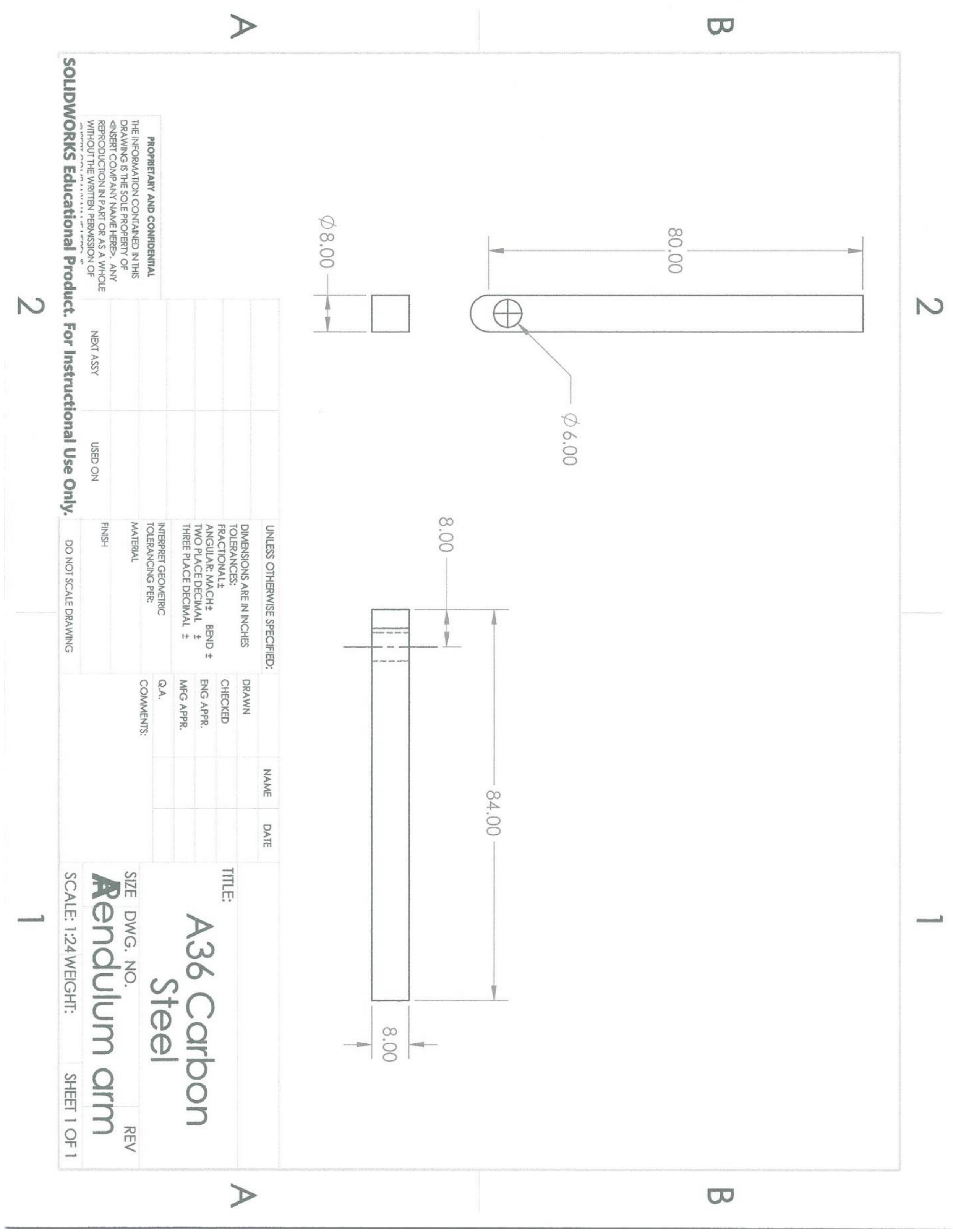


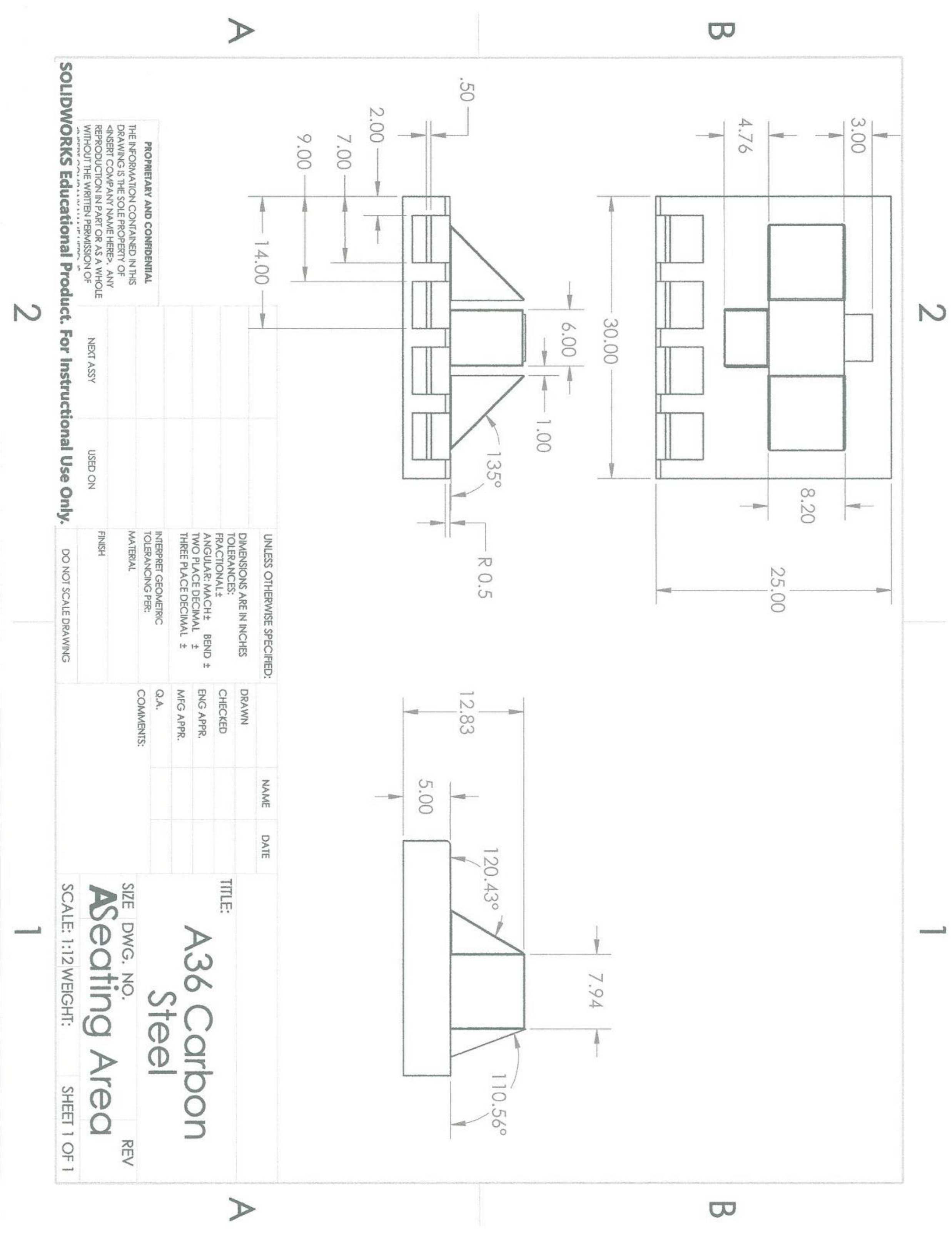
A
B
2
1
Ø5.00
115.00
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF
NEXT ASSY
USED ON
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
A36 Carbon Steel
SIZE
A
DWG. NO.
Leg
REV
SCALE: 1:32
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.


2
1
B
A
Ø6.00
48.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
A36 Carbon Steel
SIZE
DWG. NO.
REV
A
Middle shaft
SCALE: 1:12 WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF
SOLIDWORKS Educational Product. For Instructional Use Only.

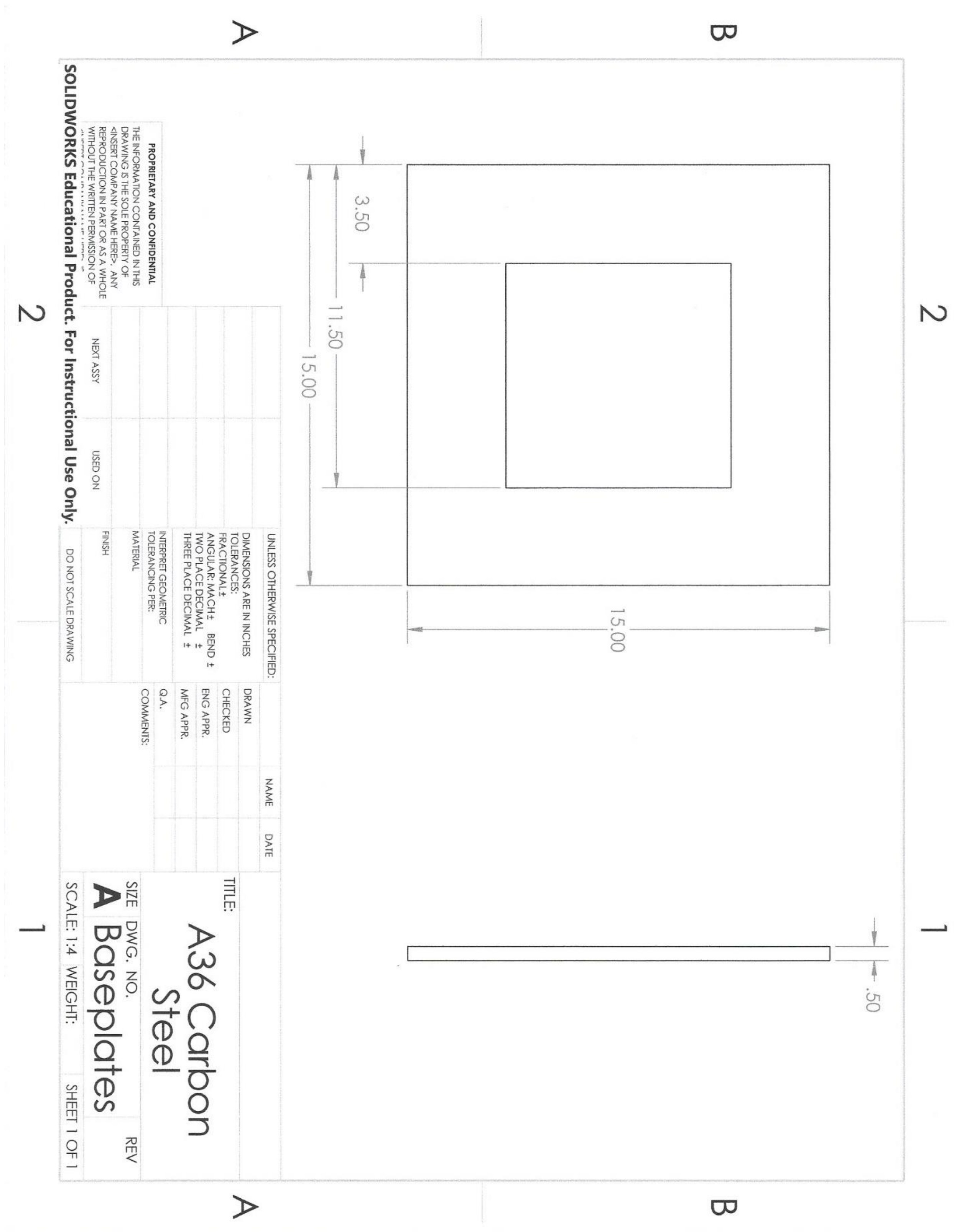


⌀6.00
R4.00
8.00
8.00
88.00
8.00
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF
NEXT ASSY
USED ON
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
A36 Carbon Steel
SIZE DWG. NO.
Middle Support
REV
SCALE: 1:24 WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.


80.00
Ø6.00
Ø8.00
8.00
84.00
8.00
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF
NEXT ASSY
USED ON
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
A36 Carbon Steel
SIZE
DWG. NO.
Pendulum arm
REV
SCALE: 1:24
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.



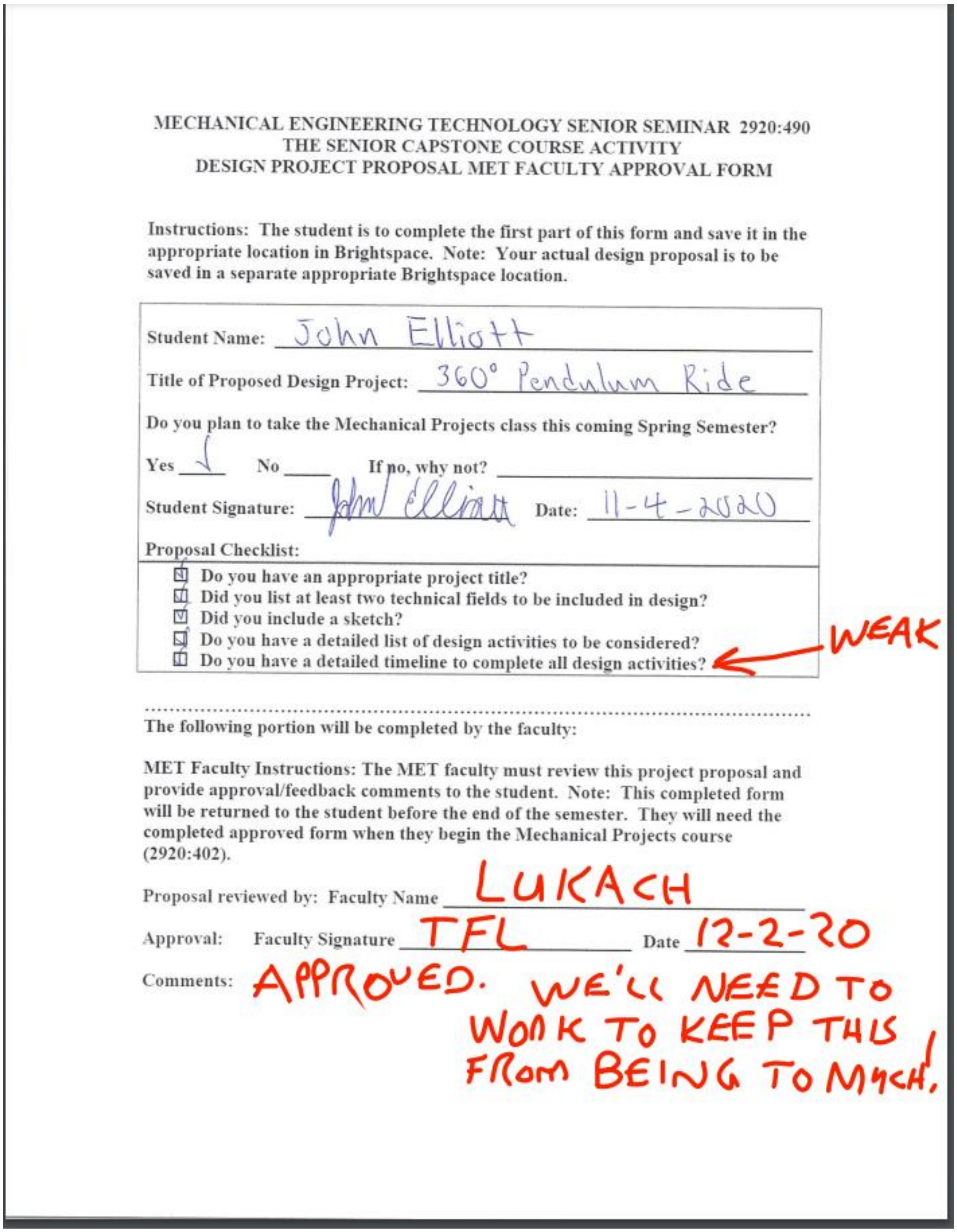
3.00
4.76
8.20
25.00
30.00
.50
2.00
7.00
9.00
14.00
6.00
1.00
135°
R 0.5
12.83
5.00
120.43°
7.94
110.56°
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF
NEXT ASSY
USED ON
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
A36 Carbon Steel
SIZE DWG. NO.
A Seating Area
REV
SCALE: 1:12 WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.



3.50
11.50
15.00
15.00
.50
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF
NEXT ASSY
USED ON
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
A36 Carbon Steel
SIZE
DWG. NO.
A
Baseplates
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.

Appendix D: Benchmark Assignments and Others

Figure 1: Project Approval Form



MECHANICAL ENGINEERING TECHNOLOGY SENIOR SEMINAR 2920:490
THE SENIOR CAPSTONE COURSE ACTIVITY
DESIGN PROJECT PROPOSAL MET FACULTY APPROVAL FORM

Instructions: The student is to complete the first part of this form and save it in the appropriate location in Brightspace. Note: Your actual design proposal is to be saved in a separate appropriate Brightspace location.

Student Name: John Elliott

Title of Proposed Design Project: 360° Pendulum Ride

Do you plan to take the Mechanical Projects class this coming Spring Semester?

Yes ✓ No ____ If no, why not? ____

Student Signature: John Elliott Date: 11-4-2020

Proposal Checklist:

- [x] Do you have an appropriate project title?
- [x] Did you list at least two technical fields to be included in design?
- [x] Did you include a sketch?
- [x] Do you have a detailed list of design activities to be considered?
- [x] Do you have a detailed timeline to complete all design activities? ← WEAK

The following portion will be completed by the faculty:

MET Faculty Instructions: The MET faculty must review this project proposal and provide approval/feedback comments to the student. Note: This completed form will be returned to the student before the end of the semester. They will need the completed approved form when they begin the Mechanical Projects course (2920:402).

Proposal reviewed by: Faculty Name LUKACH

Approval: Faculty Signature TFL Date 12-2-20

Comments: APPROVED. WE'LL NEED TO WORK TO KEEP THIS FROM BEING TO MUCH!

Figure 2: Revised Timeline

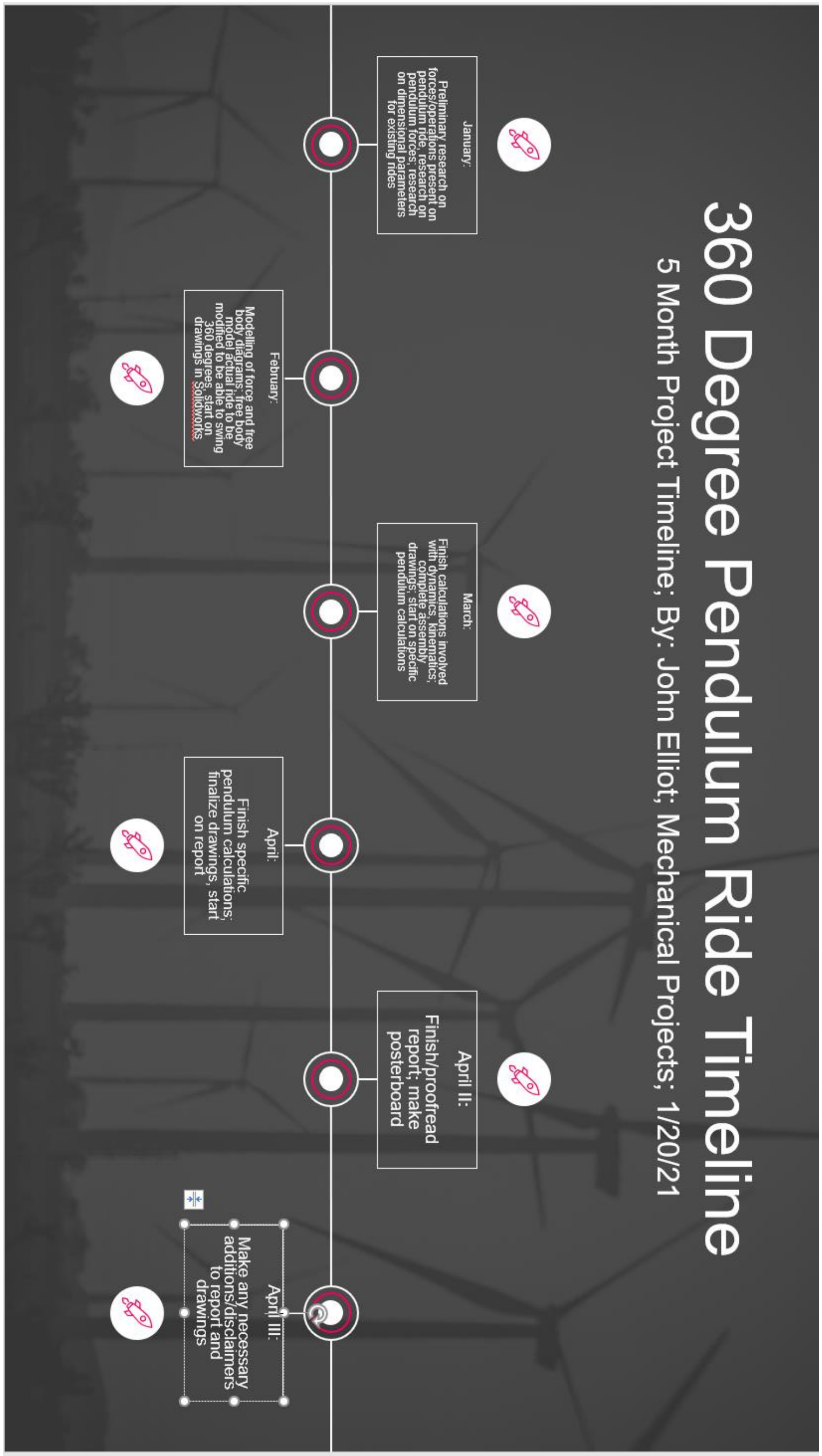


Figure 3: Progress Report 1

1/18/2021

360 Degree Pendulum Ride

Computer Software to be used: Free student edition of Solidworks

List of Tasks Accomplished so far:

1. Preliminary research on if there are pendulum rides that can go around in a 360-degree rotation. There are rides that can go in 360 degrees, and they tend to be smaller and rare. Most rides move in a 270-degree swing and are very large.
2. Drawings of what the supposed contraption will look like have been made. Since this will be a theoretical design of the entire ride, the design will be drawn and designed as a general guideline not as a finished product.
3. Some basic research as to how the pendulum ride functions. There are sources that show that the ride uses gravity to swing down but needs powerful electric generators to get it to swing from a resting position.
4. Some thoughts on how human comfort levels could be affected by the speed and feeling of weightlessness on the ride. This will come down to the speed and forces acting on the people on the ride, the air resistance, and the material that the ride is made from since the ride will be stiff.
5. Thoughts on how a small pendulum works to figure out which forces would be applicable since the ride is a very large and more complex version of this.

Figure 4: Progress Report 2

2/20/2021

Progress Report #2

Mechanical Projects

360 Degree Pendulum Ride

For this project, I have gone forward with several things. I have completed about 50% of the dimensional analysis of the pendulum ride. The parts of the pendulum ride include two swinging arms, five support legs, a central shaft, and the riding area. I have dimensioned the swinging arm based on internet data, the riding area based on rough sketches and pictures online, the length of the central shaft and the relative lengths of the outward support legs. I have written about 70% of the written report introduction and the background of the project. I explained the inspiration for the project as the pendulum ride called Max Air in Cedar point.

I have completed at least 30% of the material selection, since most of the ride will be made of steel. The specific kind of steel is to be determined since I am still in the process of figuring out the forces on the ride. I have completed about 20% of the calculations. I have performed statics calculations (loading diagram, shear force diagram, and moment diagram) on the swinging arms and the supports based upon the weight of the steel per cubic foot. I have completed 10% of the assembly drawings. I have done some preliminary drawings of the swinging arm and the seats on the ride in SolidWorks to make sure that the parts are able to fit and look decently

proportional. By the next progress report, I want to finalize the material selection, finalize the calculations, and complete at least 70% of the assembly drawings.

Figure 5: Progress Report 3

Mechanical Projects

Progress Report #3

360 Degree Pendulum Ride

John Elliott

3/21/21

Accomplishments made towards the Project

1. 90% of desired calculations including statics, dynamics, kinematics, strength of materials, and power requirements
2. 50% of material selection
3. 15% of completed components in Solidworks
4. 90% of completed detailed hand drawings for general dimensions
5. 85% of completed introduction and background
6. 10% of completed assembly models in Solidworks