California State University of Los Angeles

ME 2030_05

Dr. Bachman

Design Project

Team 4: Nixon Lopez & Erik Ho

10/20/20

Assignment	Team Member
Project: Experiment Analysis	Nixon Lopez
Project: Requirements	Saud Alreziza
Project: Gear Ratio	Erik Ho
Project: Concept Design	Nixon Lopez
Project: Decision Matrix and Predicted Time	Saud Alreziza
Project: CAD Model of Gearbox	Erik Ho
Project: Detailed Drawings	Nixon Lopez

1. Introduction

California is in a predicament of a new energy storage concept to pair any renewable power sources so that power can be provided when it is not produced. However, an engineering team discovered a new energy storage concept which was to move a large mass up to the top of a mountain to store the energy and to move the mass back down the mountain to recover the energy. An investment organization consulted with many companies including ours, to manufacture a scale model of this new energy storage concept to determine if it's viable. They requested manufacturing companies to design a system that can pull a 1 kg steel mass up a 0.5 m aluminum incline at 30 degrees using a Velleman MOT1N electric motor powered with a 3 Volt power supply.

Measurements of static and kinetic coefficient of friction

Introduction: Students are to determine the static and kinetic coefficient of friction for a mass of 1 kg that has a smooth side and a rough side at a given angle which the block begins to slide down the ramp. The smooth side of the mass started to slide at an angle of 24 degrees and the rough side at 21 degrees.

Materials: Ramp(50cm), Block(1 kg) with a tapped hole and 5 other sides with 0.25 inches straight holes.

Data:

	Static coefficient of friction (μ_s)	Kinetic coefficient of friction (μ_k)
Smooth	0.445	0.234
Rough	0.383	0.295

Data 1

Conclusion: Looking at the Data 1 above, we can see that the smooth static coefficient of friction is larger than the rough static coefficient of friction value. We can assume this because the frictional force acting in the x-direction is stronger on the rougher sides of the block than it is on the smoother sides. However, the values differ in terms of the kinetic coefficient values for both sides. The rougher side has a larger kinetic coefficient while the smoother side has a smaller one. With this in mind, the frictional force for the rougher side is larger due to an increase in acceleration in the x-direction as it slides down the ramp. According to engineersedge, the website states that the static coefficient of Aluminium is approximately 0.61. Comparing this with the value we got, we have sufficient information to determine the conceptual difference of the values.

<u>Measurement of Stall Torque</u>

Introduction: Our goal is to optimize a winch system. To do this, we need to determine how much weight will stop our model winch from rotating. This value is called the Stall Torque (Ts). Ts will let us solve for the motor's maximum output.

Materials: 1 Velleman MOT1N (motor), 1 String, 1 Scale, 1 Power supply, and 1 clamp.

Schematic:

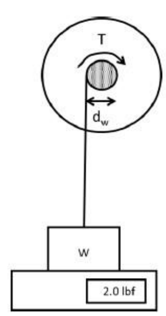


Figure 1: gray circle is the winch, larger circle is the motor, and scale reads 2.0

Torque Experimental	.005481 Nm (.004042 lbf*ft)
Torque Online	.005638 Nm (.004158 lbf*ft)
Power Max	2.0827 Nm/s
Percent Error	2.78%

DATA2

Conclusion: The Ts value which impedes the rotation of the winch experimentally is shown in row 1 of Data 2. See the Appendix A-1 for hand calculations. The value in row 2 was found from amazon's website[1].

<u>Measuring motor no-load speed:</u>

Introduction: In this experiment we analyze the data we were given to determine the no load speed of the motor. In order to make power calculations, we have to convert the units of angular velocity, which can be done by multiplying the RPM velocity by the constant.

Materials: A Piece of reflective tape, tachometer, power supply, and cylinder.

Calculation:

$$w_{rad/sec} = w_{rpm} \times \left(\frac{2\pi}{60}\right)$$

$$w_{rad/sec} = (14,524 \text{ rpm}) \times \left(\frac{2\pi}{60}\right)$$

$$= 1.52 \times 10^{3} \text{ rad/sec}$$

[1] Velleman MOT1N, *Amazon*, Velleman Inc, 2011, https://www.amazon.com/Velleman-MOT1N/dp/B00N399UHY

2. Requirements

Objects have the inherent ability to convert energy into different forms. There is a need to move from finite energy sources to renewable power as communities expand. By moving an object up and down a hill we may be able to discharge and store the object's gravitational energy. We modeled this concept with a 1 kg steel mass on a 50 cm aluminum incline, powered by a Velleman electric motor. Our design will travel up a gradient in less than 5 seconds with a constant velocity. Using common materials such as an aluminum rod, screws, nuts, and washers we can build a system which will accurately model a real system with the specific requirements shown below. The amount of energy that is generated and stored by this movement will accomplish the needs of our client. Together the system built and the report written will provide a comprehensive analysis of how this problem can be solved and later scaled to actual dimensions.

<table>
<tr><td colspan="5">Legend</td></tr>
<tr><td colspan="2">Yellow : Cost

Red : Power of Motor (P_{max})

Blue : Distance

Green : Gear Ratio

Magenta : Time</td><td>Highlighted texts : Important Variables

←

→

Colored texts : miscellaneous</td><td colspan="2">Red Berry : (I) Inspect

Cornflower Blue : (D) Design

Purple : (A) Analysis</td></tr>
<tr><td>I.D</td><td>Title</td><td>Requirements</td><td>Source of Requirement</td><td>Method of Verification
(I) Inspect
(D) Design
(A)Analysis</td></tr>
</table>

A.1	Material use	8” x 6” of 3/16” thick acrylic, 12 in of ⅜” Aluminum rod, <#10 Hardware	Client	D
A.2	manufacturing (Methods of Parts)	Parts must be be made using equipment in Makerspace	Self	D
B.1	Power of Motor (Watts)	2W < Pmax < 4W	Design Team	A
B.2	Gear Ratio (GR)	10 < GR < 20	Design Team	A
B.3	Distance Travel (meter)	.50m	Client	A
B.4	Time To Travel (seconds)	<5s	Client	A
B.5	Velocity (m/s)	1<V<2 m/s	Design Team	A
C.1	Price Budget	$15<Budget<$20	Client	D
C.2	Acrylic Sheet	Dimensions: 6” x 8” x 3/16” Cost: 6$	Client	D
C.3	Aluminum rod	Dimensions: 12 in of ⅜” Cost: 10$	Client	D
C.4	String	Dimensions: 2 meters Cost: 1$	Client	D
C.5	Screws, Nuts, and washers	Dimensions: 10-32 thread	Client	D

		Cost: 2$		

DATA3

3. Preliminary Analysis

A demonstration of an object being pulled up an incline provides critical information for the design process. Simplifying our object to a single point allows for proper investigation on the forces acting on it. This is known as a force body diagram (FBD) as shown in Figure 3. From the FBD, the weight and the friction between the surface is related to the tautness of the string pulling on the object. Cycling through the motion of the object, one finds the tautness of the string, which in turn gives the value of the resistive force on the body. This system is being operated by a single motor. The motor runs best at half it's spinning and twist value. Given the tautness of the string and the motors efficiency quantifies the type of gear size the system will need. This relative gear size is called Gear Ratio. With the motors specifications and the tautness we can determine the best Gear Ratio for this system. The velocity of the object is found by assuming the object is traveling at a constant velocity, which gives the total time traveled. One may accurately describe the movements of the object with a FBD, experimental data and Newton's second law.

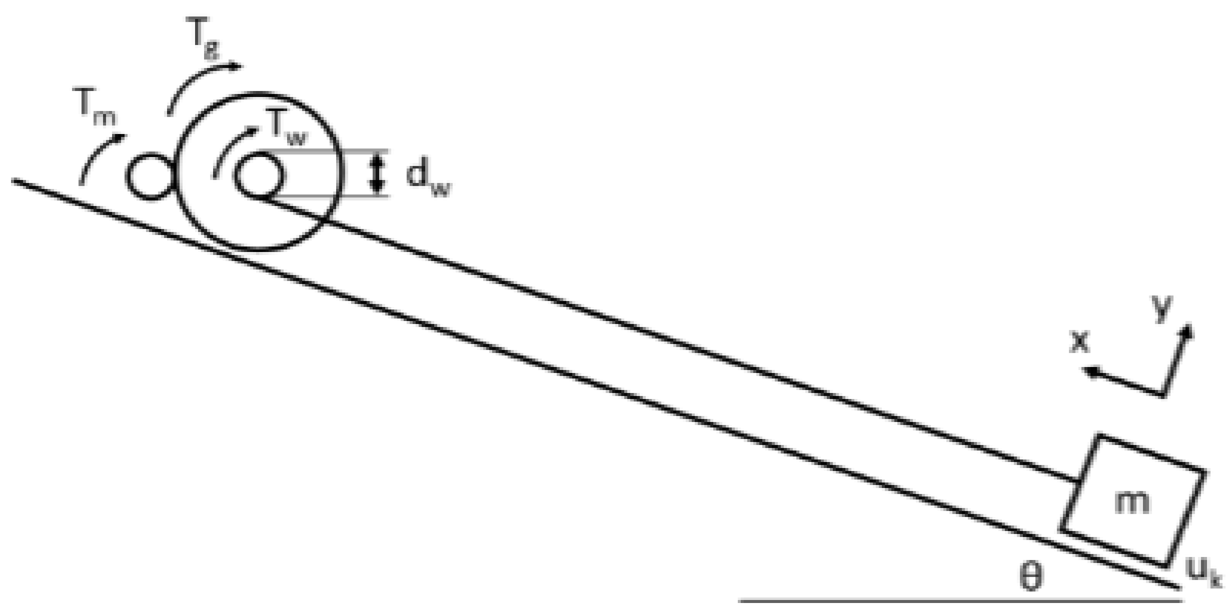


Figure 2: Diagram of the gearbox pulling the mass up the slope at an angle.

The purpose of this experimental project was to design a motor strong enough to pull up a mass of 1kg of a ramp (0.50m) at an angle of 30^o. To do this, we need to derive the Gear ratio from the torque of the motor, radius, and the stall torque of the motor. With the Gear ratio, we can optimize quantifications to perform better results of the motor, generating the full potential of the maximum power of the overall system. **Derivation of Gear Ratio is shown in Figure 3**

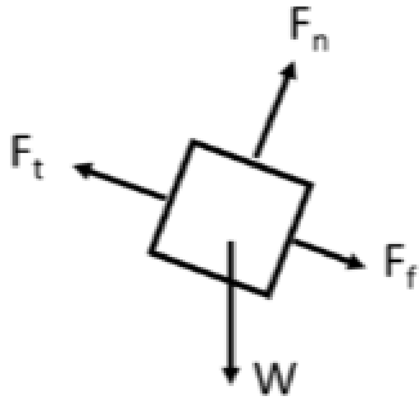


Figure 3: Free body diagram of forces acting on the mass

To determine the values of the Gear Ratio, we first need to calculate the force of the tension acting upon the mass through the string. By utilizing Newton's 2nd law which can be defined that all sums of the forces acting on the x and y axis are equal to zero. Noting this, we can determine the force of tension with respect to the x-axis by identifying the respective variables acting relative to the same axis.

$$\Sigma F_x = F_f - F_t - W_x = ma_x = 0$$

$$F_f = \mu_k * F_n \rightarrow \mu_k * mg\cos(\theta)$$

$$W_x = mg\sin(\theta)$$

$$\mu_k * mg\cos(\theta) - F_t - mg\sin(\theta) = 0$$

$$F_t = mg[\mu_k\cos(\theta) + \sin(\theta)]$$

The force of tension of the string acting on the mass of 1kg is calculated between the product and sum of the mass/gravity together with the kinetic coefficient of friction. We can assume that the smaller the coefficient of friction is, the bigger the force of the tension of the string. In addition, this also plays a significant factor in determining the Gear Ratio which then correlates with the power output and input of the motor.

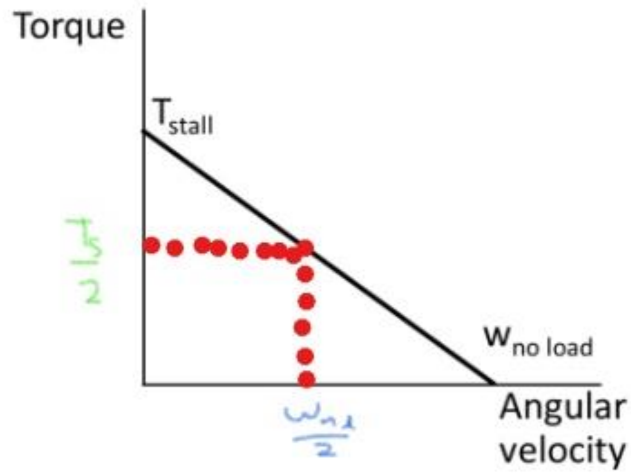


Figure 3: Torque Vs. Angular Velocity graph

The maximum power of the motor occurs at half the stall torque and angular velocity of the no load. Based on this, we can derive the Gear Ratio from the graph at half the stall torque. Assuming that the mass is in equilibrium while traveling up the ramp at an angle, we can solve for the force of tension of the string on the mass. **Refer to Figure 2** The key components for deriving the formula of the Gear Ratio are as follows: Torque of the motor, force of tension, and the radius of winch. These play an important factor in the motor specifications as a reference for our design as well as calculating the projected time at which the mass travels up the ramp. Because the strongest generated power occurs at half the stall torque, the torque of the motor is relative to half the stall torque.

$$GR = \frac{F_t R_w}{T_s} = \frac{F_t R_w}{(T_s/2)} = \frac{2F_t R_w}{T_s}$$

After obtaining the respective formula for determining the gear ratio, we can substitute our force of tension that we found earlier in figure 2. With this, we should get:

$$GR = \frac{2mg[\mu_k \cos(\theta)+\sin(\theta)]*r_w}{T_s}$$

Now that the GR ratio is found, we can determine the angular velocity of the output of the winch which then allows us to calculate the constant velocity of the mass traveling up the slope. The angular velocity of the input of the winch, however, is derived from where the motor is the strongest which is half the angular velocity of the no load. Finally, we can determine the time it takes for the mass to travel up the ramp with the velocity, change in time, and change in position of the mass from down to up the ramp.

$$GR = \frac{W_{in}}{W_{out}}$$

$$W_{out} = \frac{GR}{W_{in}}$$

$$V = W_{out} * r_w$$

$$\Delta T = \Delta x / V$$

Functions	Values
W_{nl}	1520 rad/s
m	1 (kg)
R_w	3/16in = 4.7625mm
T_s	5.5 (Nmm)
μ_k	0.295
Δx	500mm
θ	30°
GR	13
V	278.42mm/s
Δt	1.8s

4. Concept Designs

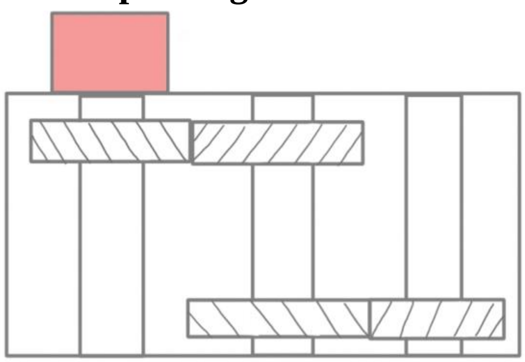


Figure4 : Sketch of a spur gear train design

Red: motor, Gray lines: gears, and hollow rectangle: axis

The spur gear is very versatile. The spur gear can be modified very easily on a budget. The gear is lightweight and can take a high load. The teeth of the gear can be cut at an angle to have a quieter meshing point.

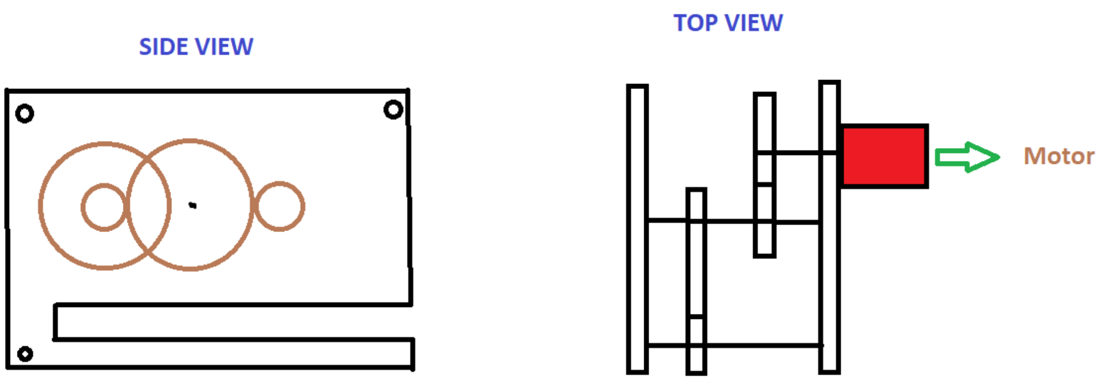


Figure: 5: Design of a helical spur gear

The plan with this design was to generate a high powered efficiency transmission towards the motor of the gearbox while spending a minimal amount of the budget (\$15<Budget<\$20). With the vastly produced rate of these types of gears, the gears can be made precisely to bring out its full potential during the duration of usages. In addition, all spur gears only produce radial forces with no relative to the axial forces. The cylindrical shape gear provides more proficient use when it is in series which allows for reduction of ratios. This is also known as a gear train.

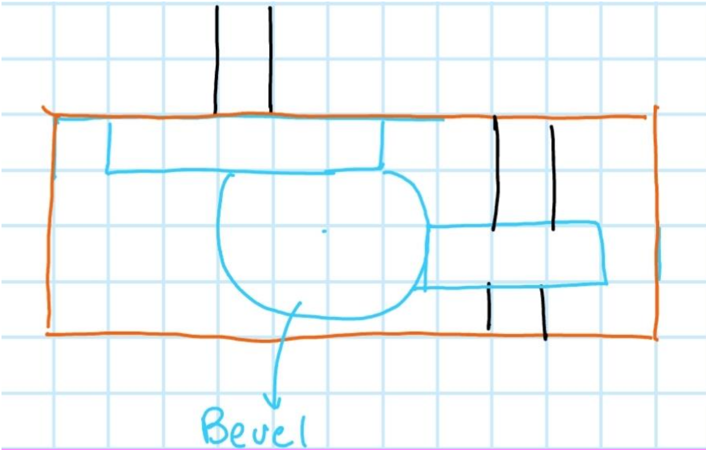


Figure 6: Design of a Bevel gear

The bevel although very simple it has the potential to increase the velocity of our winch system. This allows for the system to be modified at any time to adjust for fluctuating electricity needs. In addition, the bevel is a low maintenance gear since there are very few components.

5. Concept Review & Selection

Selection	Criteria weight	Spur	Spur Weighted	Helical Spur	Helical Spur Weighted	Bevel Spur	Bevel Spur Weighted
Cost	40%	4	1.6	4	1.6	4	1.6
Power	20%	5	1	4	0.8	4	0.8
Weight	5%	2	.1	2	.1	3	0.15
Efficiency	20%	3	.6	3	0.6	1	0.2
Durability	5%	3	.15	3	0.15	2	0.1
Friction	5%	2	.1	2	0.1	4	0.2
Material use	5%	2	.1	1	0.05	3	0.15

Total score			3.65		3.4		3.2
rank			1		2		3
Continue?			Yes		No		No

In comparison to the helical and bevel gear, the spur gear is cheap and achieves our desired goal to quickly and efficiently move an object up an incline. The gear transmits much of the power from the motor to the winch without losing much of its speed. The spur gear is compact, easily maintained and modified.

6. Detailed Drawings

Figure 7: Velleman MOT1N Electric Motor

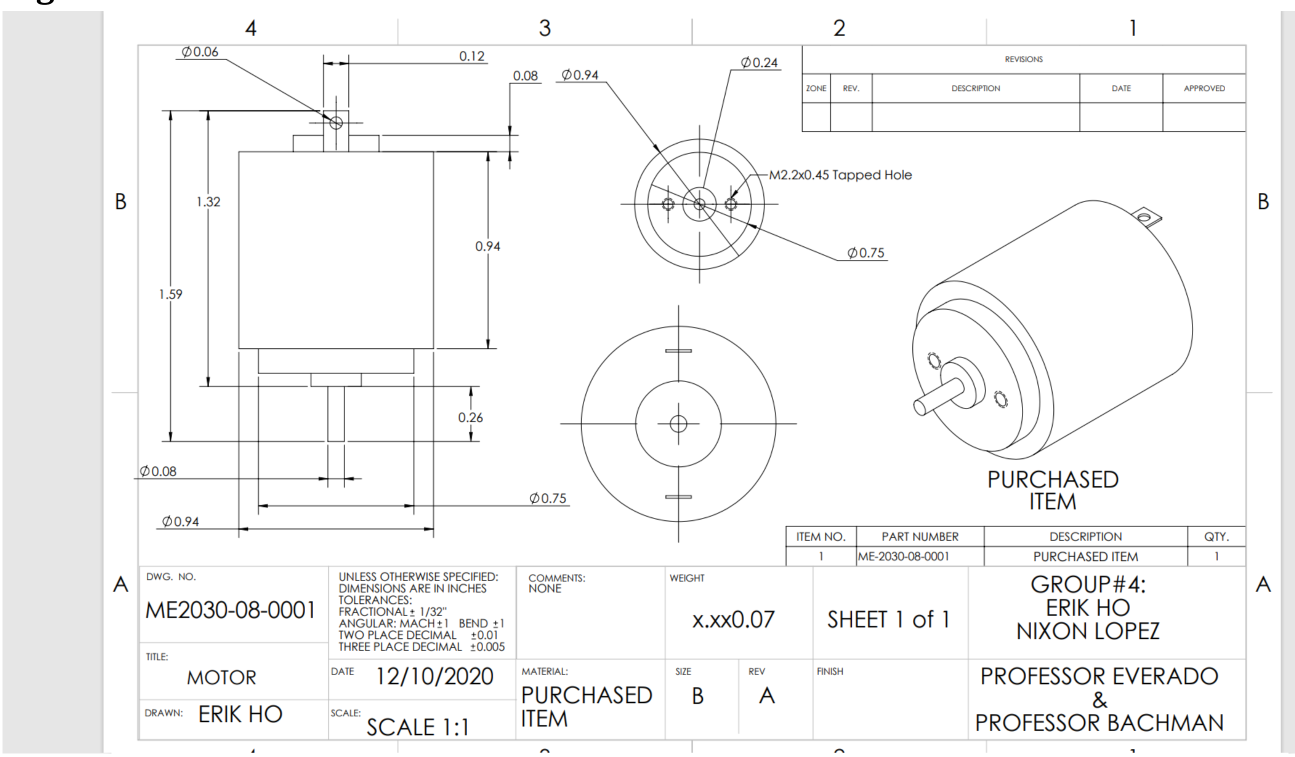


Figure 8: Shaft #1

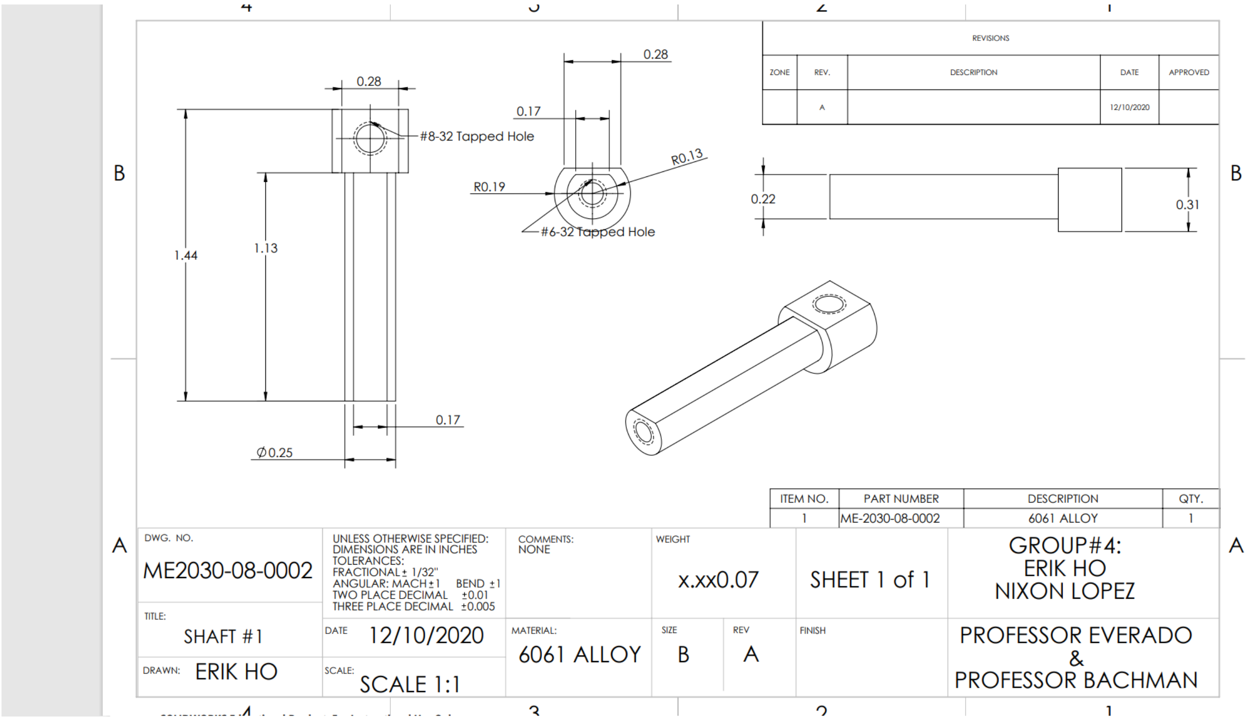


Figure 9 : Shaft #2

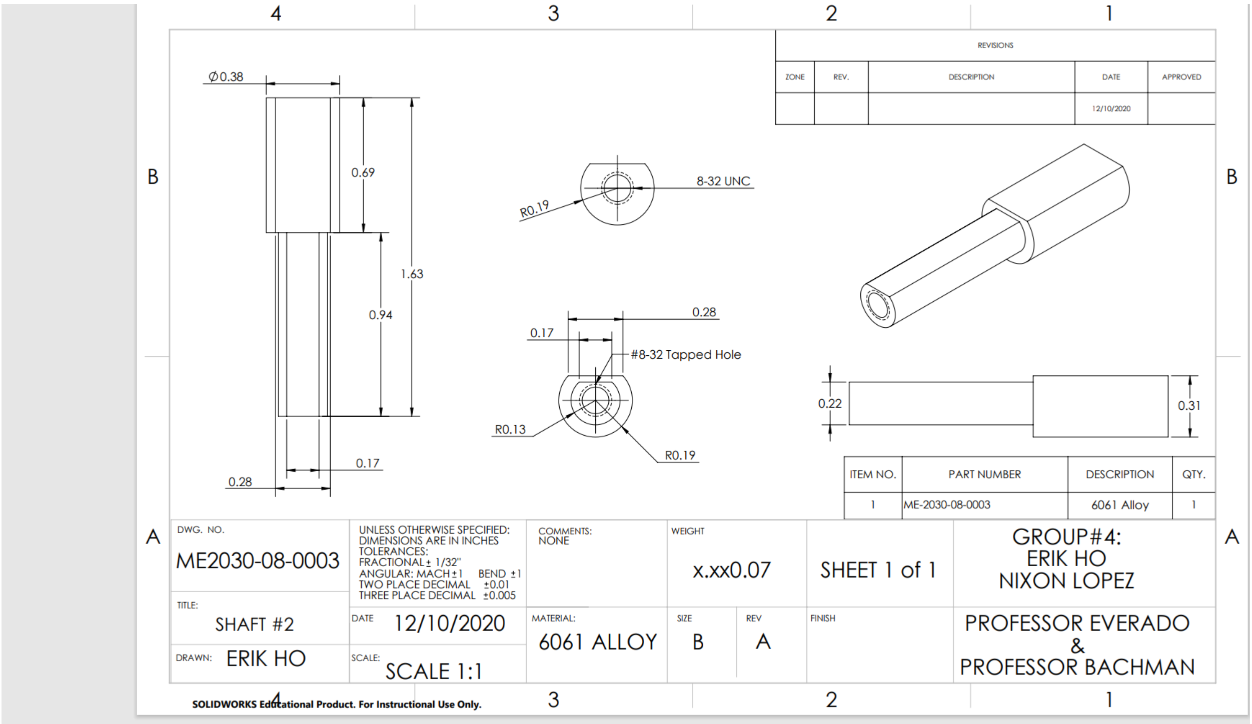


Figure 10: Shaft #3

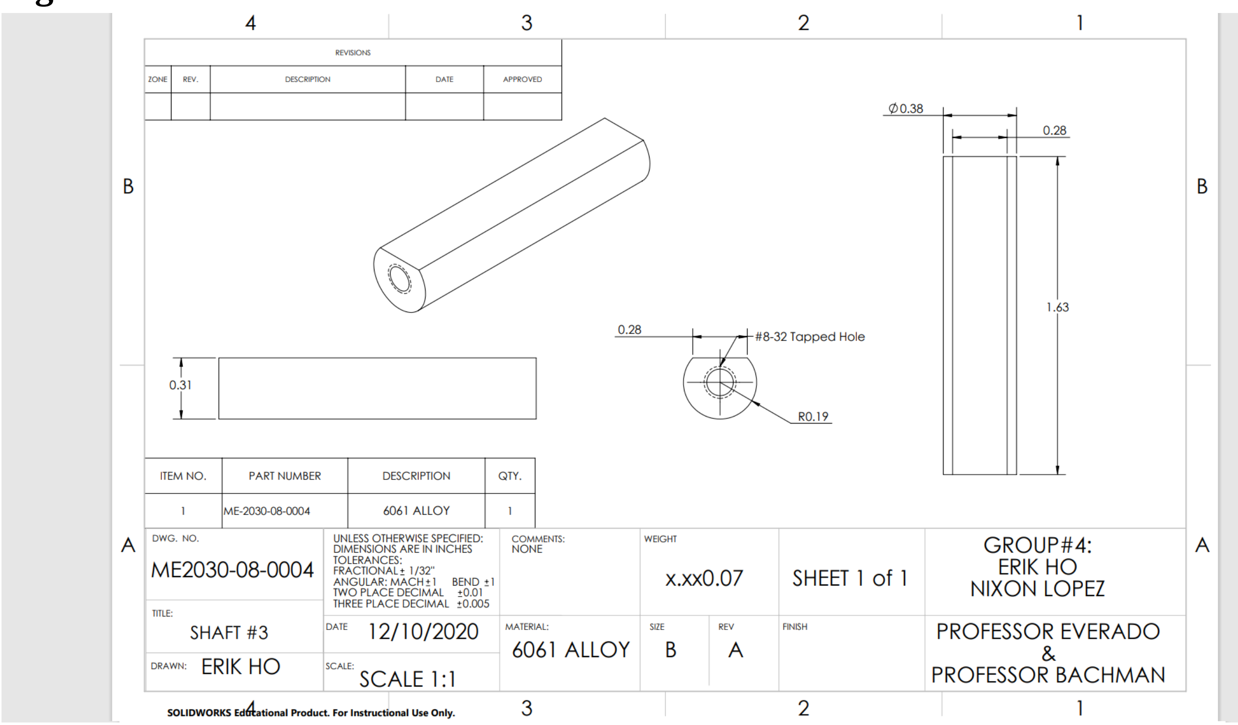


Figure 11: Small gear

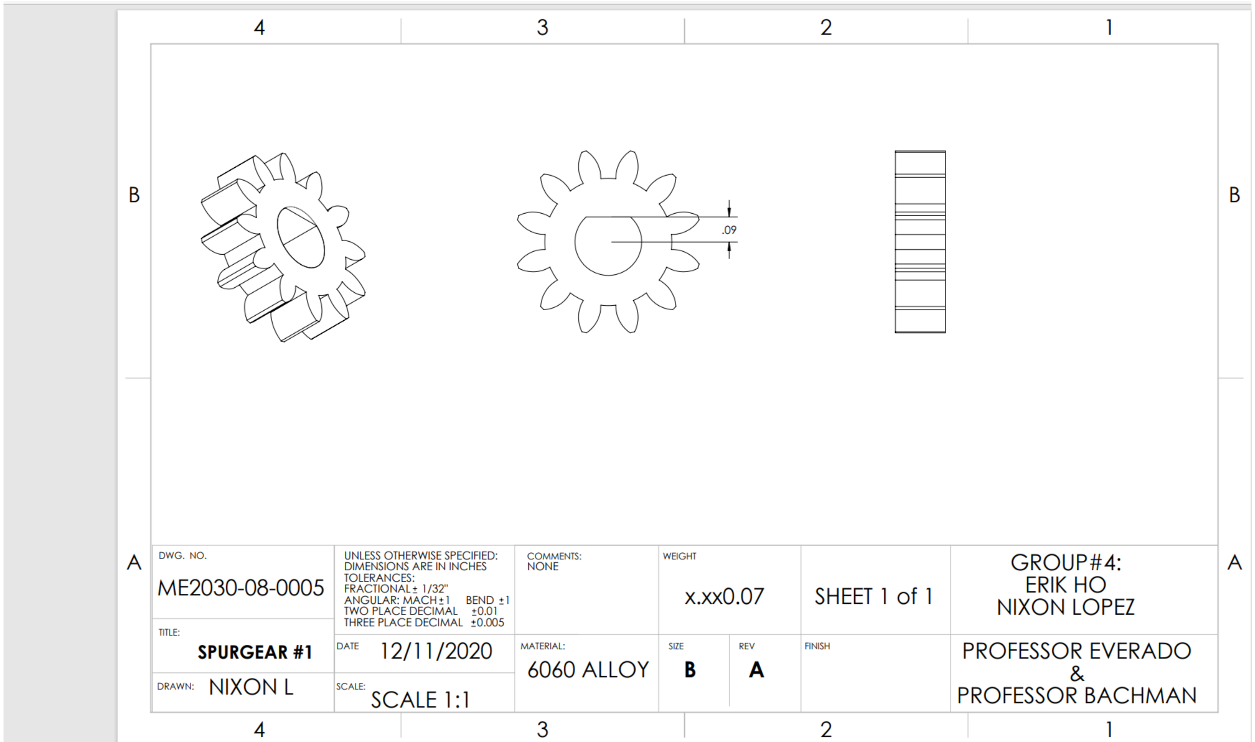


Figure 12: Big gear

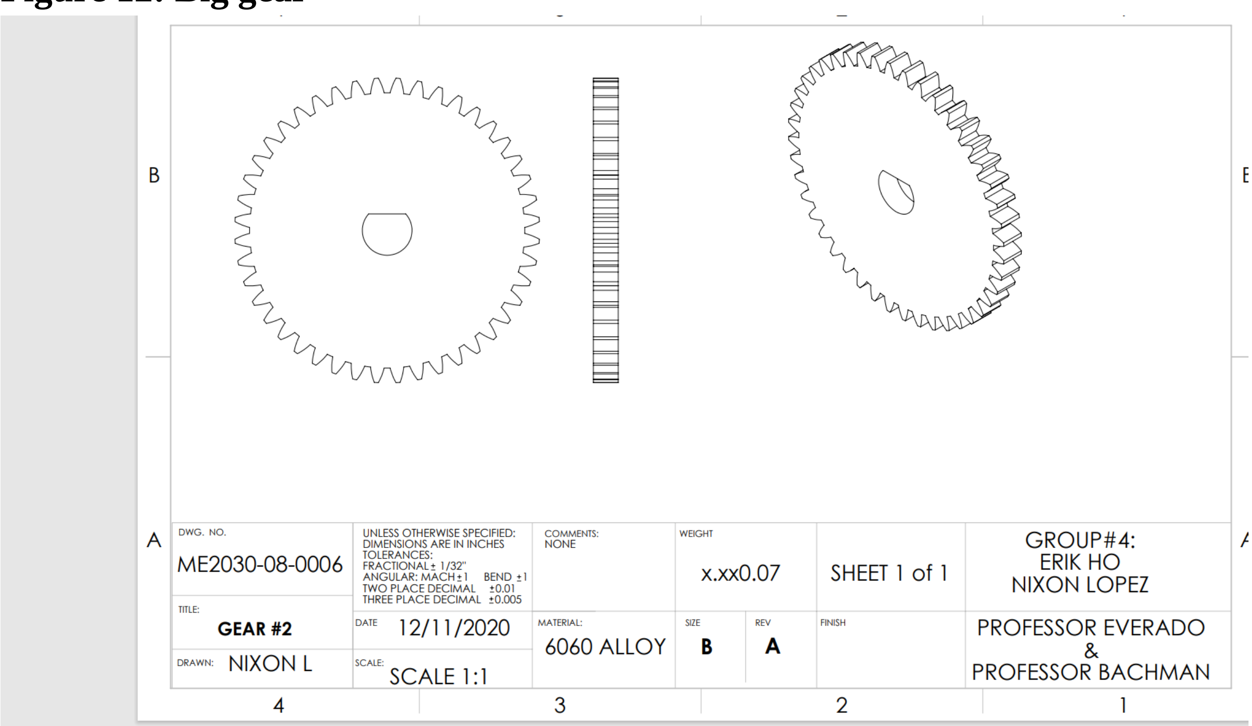


Figure 13: Our initial design before revision only consisted of getting the box, motor and shaft to align.

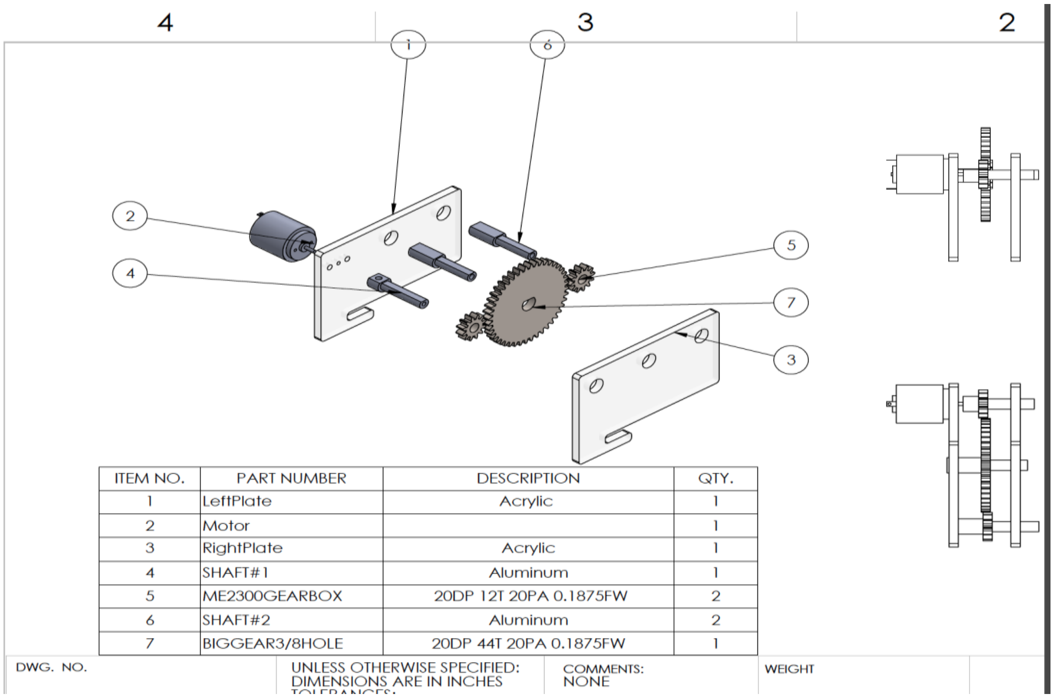


Figure 14: A top view of our finished compound spur gear box.

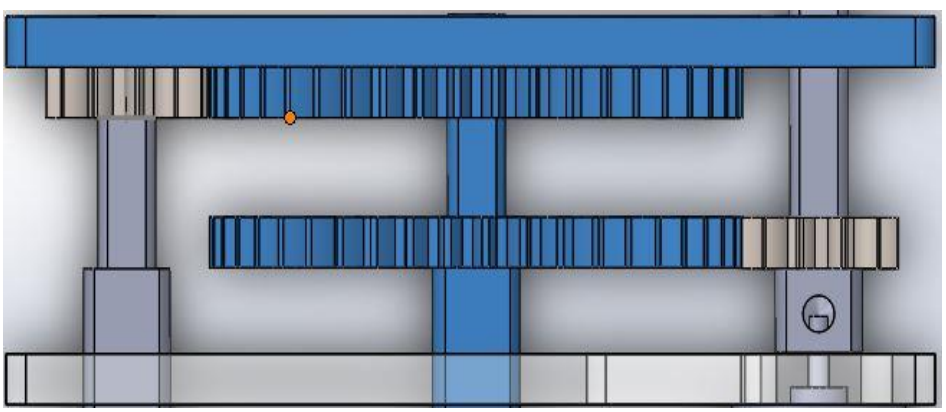
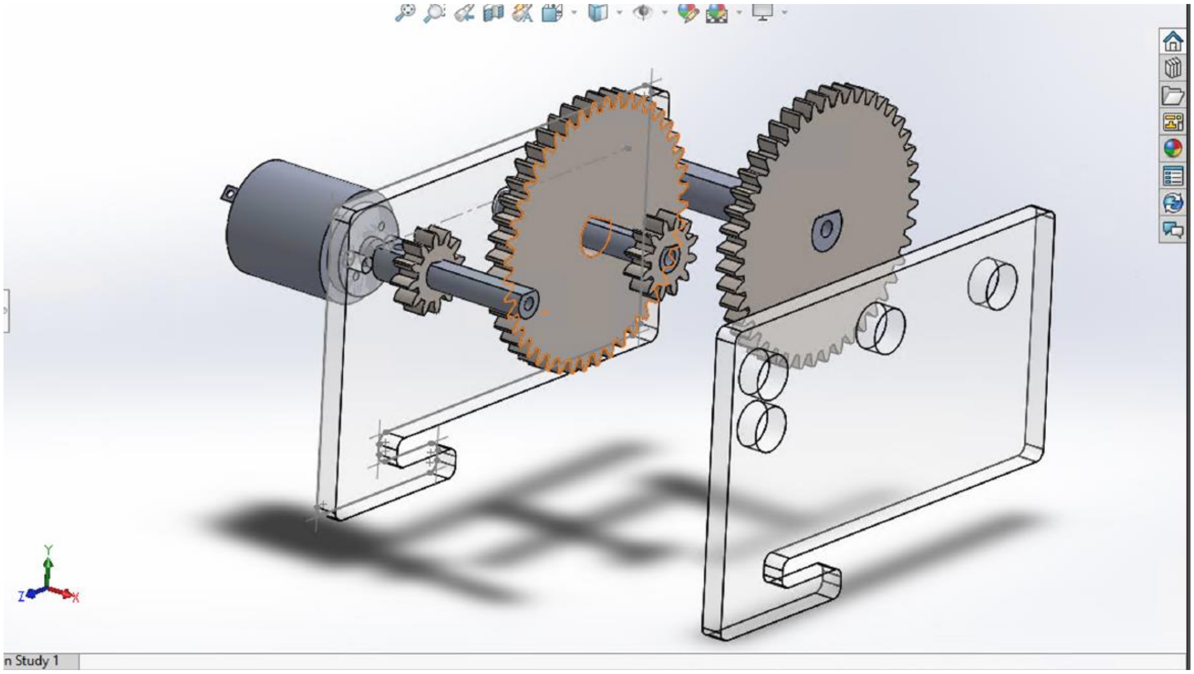
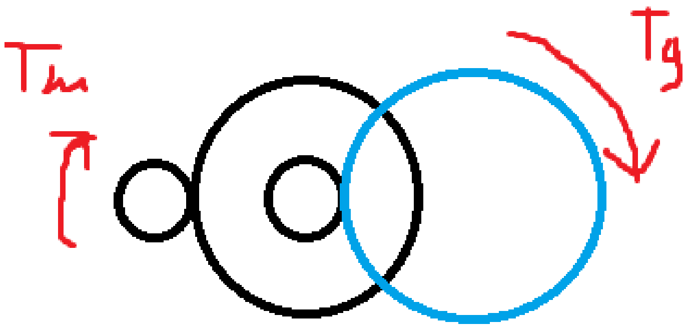


Figure 15: Isometric view of the final gear gearbox with four gears in total.



7. Stress Analysis

In order to calculate the stress, we needed to determine the gear that had the highest generated force acting upon it. The torque is increased as you go furthest from the motor and closer to the winch.



In our preliminary analysis, the gear tooth relative to the beam in bending with the force applied at the tip of the tooth is also where the torque of the motor is the stall torque.

$$F = \frac{T_s GR}{r_g}$$

$$\sigma = \frac{6FL}{wh^2}$$

$$n = \frac{S_y wh^2}{6FL}$$

Based on these formulas, the width is 0.1875 in, the height is 2.30 in, and the length is 2.30 in. Due to the stall torque being 5.5Nmm, we found the factor of safety being approximately 12. The yield strength was quantified to be about 78 MPa.

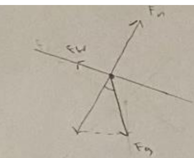
8. Testing

Although our team cannot physically test and tinker with our project we can take educated guesses on how to improve on the system. First, we would get a baseline of our system. This consists of multiple trail runs to get the average speed and time for the climb. Second is to have shafts and gears with different materials; such as aluminum, nickel, and bronze. These materials are either light or very sturdy. Our goal would be to interchange the components and see which orientation would improve on our baseline speed and time. Thirdly, would be the attachment of our rope onto the mass we're pulling up. One grapple would be bolting our rope to each hole, then reducing the bolting each time. This would cover the multiple orientations. Lastly would try different materials of rope. These short tests would improve on the overall speed and time.

9. Conclusion

Our goal was to climb a steep hill as fast as possible. Our design is effective in building up potential energy. Through our calculations Design Team 4 (D4) was able to estimate the time and velocity our pulley system would take to reach the peak. These are 1.8 seconds at 278mm/s. These specifications are all powered by our motor. The motor was analyzed as well. By plotting the Torque and Angular Velocity Graph of our motor, D4 is able to calculate the required dimensions for the gears in the system. These gears work in tandem with the motor to run at their best performance. Finally, D4 was ready to start putting the final design together. The chosen gear material and style were categorized weighted and then carefully eliminated until we were left with a simple spur gear. Through our process we feel confident that our design will be the quickest up the hill.

APPENDIX



$m = 1\,kg$

$\theta = 24^\circ \leftarrow$ smooth

$\theta = 21^\circ \leftarrow$ rough

$$\Sigma F_y = F_n - mg\cos\theta = 0$$

$$F_n = mg\cos\theta$$

$$\Sigma F_x = mg\sin\theta - \mu_s \cdot mg\cos\theta = 0$$

$$\mu_s = \frac{mg\sin\theta}{mg\cos\theta}$$

$$\mu_s = \frac{\sin\theta}{\cos\theta}$$

$$\mu_s = \tan\theta$$

$$\mu_s = \tan(24^\circ)$$

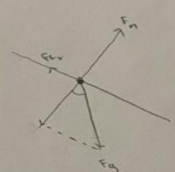
$$\mu_s = 0.445$$

$$\mu_s = \tan(21^\circ)$$

$$\mu_s = 0.383$$

$\mu_s = 0.445 \leftarrow$ smooth

$\mu_s = 0.383 \leftarrow$ rough



$g = 9.8\,m/s^2$

$m = 1\,kg$

$\Delta x = 50\,cm = 50 \times 10^{-2}\,m$

$\theta = 30^\circ$

$v_i = 0$

Smooth	Rough
0.51	0.66
0.63	0.78
0.73	0.56
0.55	0.63
0.51	0.58
AVG T: 0.586 s	0.646 s

$$\Delta x = \frac{1}{2}(v_f + v_i)t$$

$$(50 \times 10^{-2}) = \frac{1}{2}(v_f + 0)(0.586)$$

$$1 = 0.586 v_f$$

$$v_f = 1.706\,m/s$$

$$v_f = v_i + at$$

$$1.706 = 0 + a(0.586)$$

$$a = 2.912\,m/s^2$$

$$\Sigma F_y = F_n - mg\cos\theta = 0$$

$$F_n = mg\cos\theta$$

$$\Sigma F_x = mg\sin\theta - \mu_k \cdot mg\cos\theta = ma$$

$$\mu_k \cdot mg\cos\theta = mg\sin\theta - ma$$

$$\mu_k = \frac{mg\sin\theta - ma}{mg\cos\theta}$$

$$\mu_k = \frac{(1)(9.8)\sin(30^\circ) - (1)(2.912)}{(1)(9.8)\cos(30^\circ)}$$

$\mu_k = 0.234 \leftarrow$ smooth

$$(50 \times 10^{-2}) = \frac{1}{2}(v_f + 0)(0.646)$$

$$1 = 0.646 v_f$$

$$v_f = 1.547 \text{ m/s}$$

$$1.547 = 0 + a(0.646)$$

$$a = 2.346 \text{ m/s}^2$$

$$\mu_k = \frac{mg\sin\theta - ma}{mg\cos\theta}$$

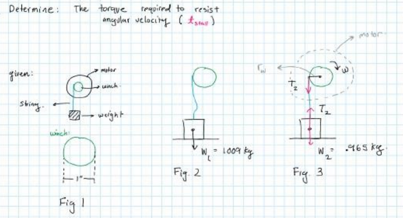
$$\mu_k = \frac{(1)(9.8)\sin(30) - (1)(2.346)}{(1)(9.8)\cos(30^\circ)}$$

$\mu_k = 0.245$ ← Rough

A-1

Determine: The torque required to resist angular velocity (τ_{stall})

given:



Conclusion: T_{stall} = .005481 N·m T_{stall} = .004042 lb.f·ft

$T_{online\ value}$ = .005638 N·m T_{online} = .004158 lb.f·ft

percent error: 2.78 %.

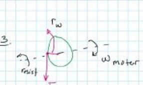
plan: 1. FBD on schematic
2. equate Forces
3. solve for T_{resist} (τ_{stall})

solve. 2 Fig. 3

$\Sigma F_y = 0$ only on the cube. (equilibrium)

$$T - W = 0$$
$$\Delta T - \Delta W = 0$$
$$\Delta T = \Delta W$$
$$T_2 - T_1 = W_2 - W_1$$
$$T_2 - 0 = ((-.965 \text{ kg}) - (-1.009 \text{ kg}))g$$
$$T_2 = (-.965 + 1.009 \text{ kg})\ 9.81 \text{ m/s}^2$$
$$T_2 = .044 \text{ kg}\ (9.81 \tfrac{m}{s^2})$$
$$\boxed{T_2 = .43164 \text{ N}}$$

solve 3.



note: $d_w = 1'' \times \frac{1 \text{ ft}}{12''} \times \frac{.3048 \text{ m}}{1 \text{ ft}} = .0254 \text{ m}$

$$T_{stall} = T_2 \cdot r_w = (.43164 \text{ N})(\frac{.0254}{2} \text{ m})$$

note: $\frac{d}{2}$ = radius

$$\boxed{T_{stall} = .005481 \text{ N·m}}$$

$$T_{stall} = .005481 \text{ N·m} \times \frac{.224809 \text{ lb.f}}{1 \text{ N}} \times \frac{3.28 \text{ ft}}{1 \text{ m}} = .004042 \text{ lb.f·ft}$$

Comparison Velleman NOT1N from amazon => T_{stall} = .005481 N·m

Velleman NOT1N from experiment => T_{stall} = .005638 Nm note: use a conversion calculator website

percent error => $\frac{\text{amazon} - \text{expirement}}{\text{amazon}} \times 100$

$$\left|\frac{(.005481 - .005638)\text{ Nm}}{(.005638)\text{ Nm}}\right| \times 100 = 2.78\ \%\ \text{error}$$

$r_w = 4.7625\ mm$ $\omega_{ne} = 1520\ rad/s$

$\mu_{k} = 0.245$ $d = 50\ cm = 500\ mm$

$\theta = 30^{0}$

$m = 1kg$

$$G_R = \frac{2mg\left[\mu_k \cos\theta + \sin\theta\right] \cdot r_w}{T_s}$$

$$\omega_{out} = \frac{\frac{\omega_{ne}}{2}}{G_R}$$

$$G_R = \frac{2(1)(9.8)\left[0.245 \cos 30 + \sin 30\right] \cdot 4.7625 \times 10^{-3}}{5.5}$$

$\omega_{out} = 58.465\ rad/s$

$\boxed{G_R = 12.8 \simeq 13}$

$v = \omega_{out} \cdot r_w$

$v = 58.461 \cdot 4.7625$

$\boxed{v = 278.342\ mm/s}$

$v = \frac{d}{t}$

$t = \frac{d}{v}$

$\boxed{t = \frac{500\ mm}{278.42\ mm/s} \simeq 1.8s}$