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EV Clutch System

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ELECTRIC VEHICLE CLUTCH PROJECT

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Contents

Abstract

This project's goal was to add a clutch system to an electrical vehicle at Central Washington University. The project's second goal was to have the clutch system improve the electrical vehicle's fuel economy for Electrathon events. Electrathon uses an equivalent mpg formula to determine an electrical vehicle's "fuel economy." Based on the amount of energy in kilo-Watt hours in a gallon of gas, Electrathon assumes each car uses 0.026 gallons of "gas" in the hour long race and the mpg value given to an electrical vehicle is based on the distance the vehicle travels in the race. Analyzes and problem solving showed that only a lightweight clutch system was going to effectively increase the fuel economy of the small electrical vehicle.

A one-way clutch was purchased. Then a hub was manufactured, and the clutch was pressed into the middle of the hub, then screws held the clutch system up against a sprocket on the driven shaft. This clutch system allowed the electric motor to drive the vehicle forward. When power is no longer being delivered from the motor, the clutch system allows the vehicle to "coast" forward. This idea of covering more distance with the same amount of input energy is what makes the addition of a one-way clutch system so useful.

The clutch system proved to add as much as 5 mpg (6% increase) to the electrical vehicle's fuel economy. In a full speed test, the vehicle coasted 48 more feet on average when the clutch system was equipped.

Keywords: <clutch> <bearing>

1: INTRODUCTION

1a: Description:

Without a clutch, the electric vehicle has no system or device to make power transmission between the engine and drive system possible. Engineering in this case can help to make sure the clutch system is efficient, reliable, and safe with design and analysis.

1b: Motivation:

This project is a subproject for the Electric Vehicle (EV) club. The EV club has lost ground in recent years and making progress on the vehicles, including the clutch and other devices could help the EV club get funding to continue as an entity.

1c: Function Statement:

A device is needed to control the transmission of power from the motor to the drive system.

1d: Requirements:

1. The clutch system must not wear out before one million cycles or before five years of service (whatever comes first).
2. The clutch must have a high enough torque rating to handle a motor that runs at 2800 rpm and has a power rating of 3 hp.
3. Improve the efficiency score of the electric vehicle by 1 mpg or more.

1e: Engineering Merit:

This project gives those involved the opportunity to decipher which kind of clutch system to use with a certain kind of vehicle in interest. The project can allow those involved to design a new clutch system. Cars are anticipated to be around for a while and continual improvement in fuel efficiency, safety, and performance of cars is much needed; this project allows for the opportunity to improve the vehicle. The project also allows those involved to gain experience in choosing optimal designs.

Green sheet problem calculations and analysis are needed to successfully complete the project. The analyses help determine aspects such as torque, wear, power, inertia, acceleration, deflection and other quantifiable values. The engineer will get more practice at determining if the design will work with the green sheet analyses.

1f: Scope of Effort:

The goal is to successfully mount the clutch system in the electric vehicle to allow forward motion and allow the vehicle to coast (wheels spin freely) when the clutch is disengaged. The electric vehicle has no reverse gear, so the clutch will intentionally be designed to help with forward motion only.

1g: Success Criteria:

When all of the requirements have been met reliably, then the project is a success.

2: Design and Analysis

a. Approach: Proposed Solution

A 0.75 inch Inner Diameter or appropriately sized clutch roller bearing will be ordered. The clutch bearing will be installed to allow forward motion. The installed clutch bearing will allow for coasting, but will lock if the electric vehicle goes in reverse. The clutch bearing will make pulling the electric vehicle in reverse more difficult because the clutch won't allow the wheels to roll in reverse.

b. Design Description (pic, sketch, rendering)

Appendix B 1-7 describes the geometry, sizing, and tolerances of the clutch bearing.

c. Benchmark

The clutch bearing needs to allow for coasting like clutches do on a higher end bicycles.

d. Performance Predictions

The MPG gain from the last Electrathon event to the next event will be over 1 MPG. The bearing will last over 5 years.

e. Description of Analyses

A title description in the appendix where each analysis is resides in the appendix titles. Each analysis is described in two sections below.

f. Scope of Testing & Evaluation

The main test this project is concerned with is the MPG rating the electric vehicle gets at the next Electrathon event. This project also cares about the clutch bearing lasting more than 5 years.

g. Analyses (Design Issue, Calculated Parameters & Best Practices)

The first analysis for this project was to solve for the minimum torque capacity needed by the clutch to run with the electric vehicle motor, which can run at 2800 (rpm) and has a power of 3 (hp). Based on the calculations and analysis, a clutch with at least a torque capacity of 111 (lb * in) is needed to run with the motor. This analysis helps the engineers decide what kind of clutches will work and this analysis also helps engineers keep the budget lower; for example, if one buys a clutch with a very high torque capacity for the situation, much more money may be spent when a cheaper clutch would suffice to move the small electric vehicle forward.

The second analysis for this project was to solve for the torque capacity needed from the clutch to accelerate the vehicle from rest to full speed in 3.5 seconds. The torque needed from the clutch calculated out to be about 415 (lb * ft), which is a high value for the scenario. This kind of acceleration will not be achieved and it’s time to think about changing the acceleration requirement. Perhaps this calculation will be repeated with the acceleration reaching half speed in 5 seconds.

Figure A 1-3 is the analysis to see what power rating the clutch needs to run with the 3 hp electric motor on the EV. This analysis uses the torque value (T) from Figure A 1-1 along with the motor speed (n) to figure out the power. With the T and the n values known it was simple to solve the equation to conclude that the clutch needs to have a 4.5 (hp) rating or higher for this scenario.

Figure A 1-4 is similar to the previous analysis except the torque used was the torque value from Figure A 1-2. The motor speed is still the same (2800 rpm). The needed power came out to be about 220 (hp), which is much too high of a value for a feasible clutch. A 220 hp clutch would cause the project to be well over budget.

In figure A 1-5, the main goal was to solve for the allowable shear force the shaft could handle for operational use. The allowable shear force was calculated as 16,000 (psi) with a safety factor of 3. The allowable shear force is 16,000 (psi) if the material SAE 1144 OQT 1000 steel is used for the shaft.

In figure A 1-6, the analysis solves for the required diameter size needed by the shaft to handle the 16,000 (psi) allowable shear force from the analysis in figure A 1-5. The material chosen for the analysis was SAE 1144 OQT 1000 steel. The diameter size came out to be 2.5 inches, which seems large. A material with a higher estimated actual endurance limit is needed to drive the required diameter size down. If it is found out that the actual shear force will be much less than 16,000 (psi), then the allowable shear stress can be lowered, which will drive down the required diameter of the shaft as well.

The analysis in figure A 1-7 solves for the moment of inertia of the shaft connected to the clutch. The moment of inertia lets the engineer know how much force is needed to change the speed of the shaft. The moment of inertia was calculated to be 62.7 (lb * in^3). From figure A 1-1 the torque rating needs to be at least 101 (lb * in), so the clutch will have enough torque to overcome the inertia of the shaft.

The frictional power was solved for in the analysis of figure A 1-8. The frictional power of the clutch needs to produce at least 4.9 (hp), which isn’t too far away from the 4.5 (hp) required power rating solution in figure A 1-3.

In figure A 1-9 the analysis is used to see if the one million cycle requirement for the bearing can be met. The design life came out to be 1.26 x 10^8 cycles which is well above the one million cycle goal. The one million cycle requirement seems achievable. To calculate the problem, it was assumed from Table 14-4 in Mechanical Elements of Mechanical Design, that the electric vehicle would last for 1500 operational hours (Mott, 575). The motor speed used was 1400 (rpm) which is half the motor speed.

The design load of the bearing was solved for in figure A 1-10. The design load helps the engineer warn the customers of possible loading issues like placing three people on the small electric vehicle. The design load came out to be 480 (lbs) and with a +/- 10% off due to the design life cycle uncertainty. Using the low limit of the tolerance, the load should never exceed 430 (lbs) on the bearings. A good follow up analysis would be to solve for how much weight can be at the driver location in the car before the bearings experience a load beyond the 430 (lb) design load.

With a simple free body diagram shown in figure A 1-11, it was determined that the expected load on the bearings and shaft will be under the design load and the max allowable weight of a driver is about 480 (lbs). The bearings and shaft can be expected to last longer than the million cycles determined in the requirements.

The main goal of the analysis in figure A 1-12 was to calculate the effective MPG loss due to the weight of a heavy and a light clutch. The heavy clutch was expected to cause around a 3 (mpg) loss, while the light clutch was about a 0.5 (mpg) loss. The heavy clutch has too much fuel efficiency to be worth having on the electric vehicle, so the design is now changed to a light clutch, perhaps a one-way clutch, for the project. Drawing 1 thru 6 are for the first design. Drawing 7 will be the first part for the new design.

h. Device: Parts, Shapes & Conformation

The 16 needle rollers are cylinders and the rest of the clutch bearing is a hollow cylinder with a quarter inch wall thickness, inner diameter of 0.75 inches, and a face width of 0.625 inches.

i. Device Assembly & Attachments

The clutch bearing is manufactured and shipped fully assembled. The one way needle rollers come assembled inside the clutch.

j. Tolerances, kinematics, Ergonomics, etc.

The tolerance for the 0.75 Inner Diameter of design 2's clutch bearing is (-0.0005) as it will be press fitted onto a 0.75 inch shaft. The one inch outer diameter on the clutch bearing has a tolerance of (-0.001) in case the bearing is placed in a housing. The 0.625 inch face width of the clutch bearing has a tolerance of (-0.01).

k. Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operation Limits

The first operation limit is the driver and ballast cannot weigh more than 430 (lbs). Another operation limit is only one person max is allowed in/on the vehicle to ensure the integrity of the vehicle's structure and the safety of those interacting with the vehicle.

3: Methods & Construction

a. Methods

There are four subassemblies that will eventually need to be mated together in order for the entire clutch assembly to be functional. The cover plate, pressure pate, and diaphragm spring will be the first subassembly needed to be ordered. Following, a cushioning plate, hub flange, splined hub, and spring hub are the next parts that need to be ordered to construct the second subassembly. The first and second subassemblies can then be mated together.

The next order will construct the third subassembly and the parts included are plate washer, friction facing, cushion spring, hub damping spring, and four damper springs. Twelve facing rivets, four cushioning rivets, two washer brackets, and a flywheel are the parts that will need to be ordered to construct the fourth and final subassembly. The third and fourth subassembly can now be mated together. To finish the whole clutch assembly, one simply mates the first and second constructed subassemblies with the third and fourth constructed subassemblies.

Now that the clutch is assembled, the project engineer will consult with an experienced engineer to determine if a mounting bracket is needed to put the clutch on the electric vehicle. The mounting bracket would be created using a CAD/CAM sheet metal process and Ted Bramble will be consulted during this process. After the clutch is assembled, installation of the clutch on the electric vehicle will be implemented. It is expected that the installation process will last up to 6 hours. The clutch needs to be installed in a way that the clutch is strongly fixed; the clutch must stay in place and not detach from its’ position on the electric vehicle frame. The clutch cannot detach even in a crash because projectiles are not safe and the electric vehicle club would be disqualified if the clutch came off during a race.

Design 2 has a different method approach. Only a couple of parts need to be ordered with the second design. Design 1 has been discontinued due to its' heavy structure. Once the clutch bearing is on site, the clutch can be slip fitted onto the driving shaft. The clutch bearing must be correctly oriented when installed, allowing forward motion.

The second part will be a designed and manufactured hub that will be welded to the sprocket and will have a FN1 force fit with the clutch bearing.

b. Construction

i. Description:

The clutch bearing will be shipped as an assembly and will be able to be slip fitted onto the driving shaft on the electric vehicle. The hub will be press fitted around the clutch bearing and then the hub will be welded to the sprocket.

The driving shaft and shaft components must be disassembled to put the clutch bearing in an appropriate position on the shaft. The shaft was able to get disassembled to the point until there was just the collars left on the shaft. A manual press was used to remove the collar where the clutch bearing would be placed. The clutch bearing slid onto the driving shaft easily.

A hub that press fits around the clutch bearing will prevent the clutch bearing from rotating and will allow the clutch to do what the design intended. A manual press will be used to perform the press fit between the hub and the clutch bearing. The hub will be welded to the sprocket to prevent the hub and clutch bearing from rotating with the shaft. Welding may be bypassed if six quarter inch threaded screws are used to fasten the hub and sprocket together.

ii. Manufacturing Issues

All the needle rollers need to be assembled in a way that all the needle rollers are rolling the same way. McMaster-Carr has plenty of experience making clutch bearing and the first part shipped should work.

The hub was initially designed to be manufactured using just CNC mill operations. It was advised in the machine shop that the hub mainly be manufactured with the use of a manual lathe. As the outer diameter was being reduced on the manual lathe, it became apparent that the stainless steel material for the stock was too tough for manual machines. Among other issues, the manual machines' main issue was the lack of lubrication.

The stock for the hub was then transferred to an automated lathe machine where the outer diameter was reduced, faced, and then the center bore hole was cut. The bolt circle holes were created using a CAD/CAM CNC mill program. After that operation the hub was fully manufacturing. The clutch bearing was pressed into the hub with appropriate orientation to allow forward motion of the electrical vehicle. The six threaded screws locked the hub and clutch bearing into place against the sprocket.

The sprocket and hub bolt circle holes had to gradually be drilled larger and larger until the clutch no longer was binding the shaft. The clutch now allows the shaft to freely spin and the screws for the hub can be tightened by hand.

iii. Drawing Tree & ID's

Design 1

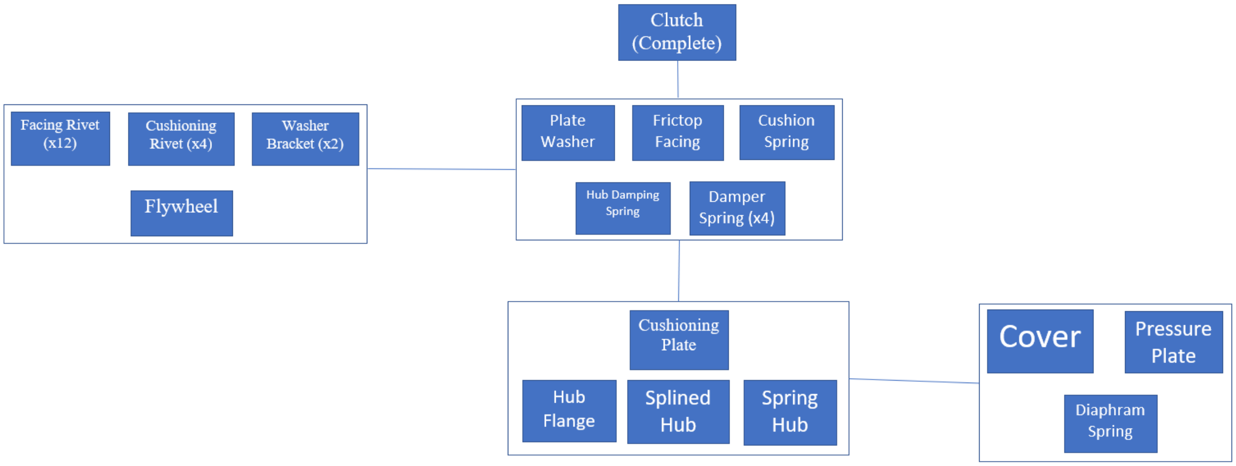

Figure 3a: This is the drawing tree for the whole clutch assembly.

iv. Parts list and labels

Item ID	**Item Description**	**Item Source**
2489K13	Single Row Clutch Bearing	McMaster Carr
89325K65	2.25in Dia. QD Hub	McMaster Carr
92200A351	#10-32 thread screws (x6)	McMaster Carr

v. Discussion of assembly, sub-assemblies, parts & drawings

The other parts associated with the clutch that parts 1 through 6 belong to will not be completed. It was after part 6 of clutch 1 was completed that the project geared towards a lighter one-way clutch. Part 7 is the clutch bearing with 16 needle rollers that all need to roll the same direction. The second design is expected to increase the fuel efficiency of the car and the second design is much cheaper at just $33.50 as opposed to $490 for the clutch associated with design one.

4: Testing Method

a. Introduction (What will be tested)

The torque rating will be provided by the manufacturer. The torque rating will be tested using an acceleration test. The life cycle for the bearings would need instrumentation and a lot of time to know how many revolutions the bearings survived before failing. The design life of the bearings is expected to be much more than a million cycles assuming the electric vehicle will top out around 1500 hours of use in its' life running at the median rotational speed of 1400 (rpm).

The vehicle's MPG rating will be tested and if the MPG rating is one MPG more than the best fuel efficiency the electric vehicle has ever had, then the fuel efficiency improvement requirement will have been met.

The coasting distance with the clutch assembled will be compared to the coasting distance without the clutch assembled.

b. Method/Approach (How it be tested)

To test to see if the clutch accelerates the vehicle as fast as expected, some assumptions need to be made. The top speed of the car must be captured with a device that can measure the speed of the car. At top speed, it will be assumed the motor is running at 2800 (rpm) (the motor's top speed). At half the mph speed, it will be assumed the motor is running at 1400 (rpm). A stopwatch should be used to measure how many seconds it took the electric vehicle to get to half speed. The experiment data will be compared to the analysis for how long it'll take the clutch to get the motor speed to 1400 (rpm) based off the manufacturer's product torque rating for the clutch.

The electric vehicle's fuel efficiency will be tested at an Electrathon event. The fuel efficiency score will be given after 60 minutes of racing and the goal is to have the next Electrathon score beat the best efficiency score the vehicle has ever had by at least one MPG.

Ideally there will be trial runs before the Electrathon event. To test if the clutch bearing improves the MPG of the electric vehicle, the EV will be taken to a track and driven until the battery runs out. The first run will have the clutch assembly on the EV, then the clutch will be taken off for the next run. If the EV travels further with the clutch bearing, than without the clutch it will prove that the clutch bearing improves the MPG of the EV. Track surface conditions, weather, and temperature will be noted for both runs.

The first iteration of a coasting test procedure was very flawed. The energy that goes into each 10 yard push is too inconsistent and the results may not be at all accurate. Setting a starting point on a hill (Mint Valley hill would be ideal) and lining the front of the car up with the starting line would result in a consistent amount of energy for the coasting test, assuming one just lets go of the car and does not push at all. Chalking off where the front of the car stops rolling gives a good way to record stopping points for measurements at the end. Remember to use one color for trials with the clutch attached and a different color of chalk for trials without the clutch. The coasting test would be safe if brakes were assembled onto the vehicle, but brakes have yet to been constructed. Knowing there is no brakes on the car, have as many people needed to warn others ahead in the coasting path. Also, don't place the vehicle high up on the hill. Try to reach somewhere around 10 mph maximum speed, otherwise too much speed would cause a very long coasting path and that would open up more chances for a harmful event to happen because the vehicle will not be able to stop.

c. Test Procedure description

Attaining Acceleration Time:

1. Start the timer after a 3-2-1 countdown.
2. Stop the timer when the car reaches half speed.
3. Record the timer time in seconds.
4. Repeat
5. Use the average time from step 3 to solve for the experimental torque using a process similar to the one used in figure A 1-3.

Clutch's Affect on MPG:

1. Race the EV with clutch until battery is drained. Record distance and time for run.
2. Race the EV w/o clutch until battery is drained. Record distance and time for run.
3. Compare distance traveled with clutch vs. w/o clutch.

Coasting Test:

1. Set tire pressure to 50 psi on all three tires.
2. Referencing the middle of the back wheel, push the EV for 10 yards.
3. Wait for the EV to completely stop rolling.

4. Measure to the center of the back wheel to attain the coasting distance.
5. Record the coasting distance for the trial.
6. Complete three trials with the clutch attached and without the clutch attached.
7. Compare results

**the same person must push the EV every trial.

Improved Coasting Test on Hill:

*Use same person to steer car every time (same weight).

*Use a straight line path to minimize steering and side loads.

*Bring an allen wrench for attaching/removing the clutch system.

1. Mark a starting point on the hill and set all the tires pressure to 50 psi.
2. Line up the front of the car even with the starting point.
3. Let go of the car (don't push) and let the vehicle coast until it stops without the aid of braking.
4. Mark off where the front of the vehicle stops coasting. Use one color for clutch trials and use a different color for trials without the clutch.
5. Repeat steps 2-4 until three or more trials are completed with the clutch on and clutch off.

d. Deliverables (Summary of data produced in testing compared to prediction)

The data needs to include tabulated results of the time it took the vehicle to accelerate to half speed. A comparison report of experimental torque vs manufacturer torque rating needs to be represented with a bar graph.

In a table, report the next Electrathon efficiency score compared to the best efficiency score the vehicle has previously had. Also, tabulate MPG with clutch vs. w/o clutch. Tabulate the coasting distance with and without the clutch attached as well.

With regards to the coasting test, the coasting distance needs to be tabulated for each trial. Three trials or more are needed with the clutch attached and without the clutch attached. To remove the need for a very long measuring tape, the shortest coasting distance can be considered the “zero foot” mark. This test is essentially testing to see if the vehicle consistently coasts significantly further with the clutch attached compared to when no clutch is assembled at all. The “zero foot” mark (shortest coasting distance) is predicted to happen with a no clutch trial.

5: Budget

a. Discuss part suppliers, substantive costs and sequence or buying issues

It would be very dire to make sure the dimensions are correct and precise if all the parts are bought separately. Otherwise, if the sizes don’t all fit with one another, then the clutch assembly wouldn’t be able to be completed and more parts would have to be ordered. It would be best to find a clutch that has all of the components used in the drawings.

The making of a mounting bracket would come after the clutch is delivered. The decision to use a mounting bracket has not been confirmed yet; that decision will come when the full clutch assembly is in the project engineer’s hands. The raw material for the bracket will be decided after consulting with Ted Bramble and a sheet metal bending process using CAD/CAM will occur to create the bracket if needed.

As of February 13th, the parts for the second design include the clutch bearing, the quick disconnect hub, and the six #10-32 threaded screws. All material for the three parts was ordered from McMaster-Carr. All orders arrived in a timely manner and the parts were able to be completed on time. Before taxes and shipping, the three parts total cost equals $94.56. The tax was $9.31 for all three parts and the shipping cost was $11.33. The total cost to just get the material for all the parts was **$115.20**.

$211.00 was spent on a new internet connection due to an unexpected relocation of the office, if you will. Out of pocket costs due to logistical changes from the pandemic were cut significantly because travel to and from the university is restricted until at least the end of May. The true out of pocket savings comes from not having to spend money on gas to get to the testing site and then back to the university. In a real-world sense, money was saved on the resources and hourly work pay that would have been needed for testing. Assuming gas was $3 per gallon if no pandemic happened and the truck got 10 mpg while towing the electrical vehicle, then the coasting test would cost $130.20 for a roundtrip of gas. The funds are in place for the coasting test and that is the only test that may reasonable have a chance to be completed before this project is delivered on June 9th.

b. Labor Outsourcing Rates & costs

The project engineer will be used for much of the required man hours for the project. The project engineer is expected to spend around 125 hours on the project at a rate of $25 per hour (**$3125**). It is estimated the project engineer will need to spend about one tenth of the time (12.5 hours) consulting with a more experienced engineer costing $42 per hour (**$525**).

Ted Bramble will need to be hired if the mounting bracket is to be made and he is expected to spend three hours max on the project. His wage is $35 per hour ($105).

Ted Bramble's services were used to make the quick disconnect hub. 2.8 hours of his time was needed to make the part, so he would be paid for 3 hours total; **$105**.

c. Labor

The installation process of the clutch (and maybe mounting bracket) is expected to take 6 hours or less. The installation process would require paying two installers at $19 per hour each ($228).

The installation process for the hub and clutch bearing took 1.5 hours to get all the screws in. It took another 1.5 hours to properly reassemble the electric vehicle.

d. Estimated Total Project Cost

Design 1

Total parts cost = **$489.69**

Total project cost for company = $**4,683.69**

Design 2

Total parts cost = **$115.20**

Total professor time cost = **$630.00**

Project engineer cost = **$3125.00**

Total project cost for company = **$4081.20**

e. Funding Sources

All potential funding sources for the EV clutch project:

1. EV Club 2. CWU Services and Activities ***3. Financial Aid**
4. Go Fund Me account

*Most, if not all the funding for costs that actually came out of pocket were covered with financial aid.

6: Schedule

a. High Level Gantt Chart

Following is the condensed version of the Gantt chart created for this project:

b. Specific Tasks and Assigned Times

The bulk of the time spent creating the proposal will be spent on writing the proposal, making drawings for the parts, and the analyses. Each process is expected to last 18 hours, 20 hours, and 9 hours respectively. The report needs to be completed in 10 months and no later than June 9th. Writing of the proposal started on September 25th. It would be best to start the drawings and analyzes as soon as possible, but this project did not start these tasks until the fifth week (October 21st).

The function statement and requirements were first initialized by the end of the first week. The requirements are needed at the beginning stages of creating a proposal to help define the scope of the project. A first draft of the introduction section of the proposal was created by the end of the second week. In the third week a website was created to begin to share the project progress online. An outreach summary should be completed by the end of the third week.

Analyses should begin in week 4 or earlier. If analyses are started in week 4, then only two analyses per week need to be completed. Creation of drawings should begin in week 5, but starting sooner will make it easier to create all the drawings needed by week 10. A rough draft of methods and construction should be created by the end of week 5.

Two analyses and one more drawing need to be completed in week 6. A parts list and budget are scheduled to begin work on and completed in week 6. In week 7, two more analyses and one more drawing need to be completed. The creation of a project schedule with a Gantt chart needs to be done by the end of week 7. A safety risk form needs to be created in week 7 as well.

Week 8 is the time when the project's testing methods and resources need to be declared. Week 8 also calls for at least two more analyses and one more drawing. Week 9 is the time when the website needs to be updated to show the progress of the project. The web page mission needs to be published on the project website by November 22nd. Specialized software and videos need to be declared in this week along with project discussion, declaration of project management resources, and a conclusion of the proposal and project. By the end of week 9 all analyses and drawing should be completed. Week 10 is short and during these two days the presentation methods need to be resolved before presenting the potential project.

The final submission of the proposal happens at the end of week 10. Week 11 is just for presenting the potential project.

Using design 2 to move forward with the project would call for the engineer to order the clutch bearing by the end of the first week in the winter quarter, so installation can begin in the 3rd week. The proper assembly for the clutch device was completed on time and the clutch assembly was fixed on the “complete assembly” due date by drilling bigger holes in the bolt circle holes on the hub. After those holes were drilled, the clutch allowed the shaft to freely spin and the clutch no longer binds to the shaft.

The coasting test was planned to undergo enough trials for data on the weekend before May 5th. Revisions were made in the middle of April, changing the coasting test from a push test to a test that allows the vehicle to fall or coast from a specific height on a hill. When the test was originally formed and planned out, there was no pandemic in sight, so the student was confident he would be a main resource for completing the tests and getting results. However, in April the plan was to have a lab technician complete the tests and get results. There are 35 other students in the class and the coasting test was planned to take 9 hours in round trip travel alone, plus two hours to do the testing. Resources were thin given the unusual circumstances. The test was also unsafe because there are no brakes on the vehicle. This project planned a braking system in early March and planned on placing a simple bicycle-like braking system onto the vehicles two front tires by April 17th, so the tests could be safe.

During the week of SOURCE (May 18th – May 24th) the project student will plan to be online to answer comments and questions every day from 1pm-2pm. If there are no more questions to answer in that time frame, then the project student will look at the other engineering student presentations.

Project status reports will continue to be submitted every Monday morning with the last status report submitted on June 8th. The website is intended to be finished on May 20th, but small edits to the website are expected to continue until this project is dead. The budget is expected to be completed on May 22nd citing what has come out of pocket and the expected cost from the labor and consulting among other things that would cost a company in the real world. The report will be absolutely final on June 9th with clean up, the jump drive, and the report uploaded to a scholarly website on June 9th as well. A promotion video will be completed for the engineering student on June 9th as well if the student does not have a job locked up yet.

c. Allocate task dates, sequence and estimate duration

At this time of the project the design has moved away from a flywheel clutch to a lighter weight clutch that allows coasting. The first task now is to hone in on a new design. Dimensions of the vehicle need to be sorted out to help get the dimensions for the design (this can be done before the new design is chosen). There's an appropriate clutch bearing that can be ordered from McMaster-Carr. If the project calls for a titanium clutch bearing, the drawing for the new design could be created, then the part could be ordered and cut at a shop like emachineshop. After the clutch is shipped, the clutch can be installed onto the electric vehicle. Testing will then begin after the clutch is installed. The light weight clutch may take 1.5 hours to install compared to the 6 hour estimated installation time for the first clutch design.

In the second of three quarters, it became evident a quick disconnect hub would need to be manufactured to house the clutch bearing and lock the clutch bearing into place on the shaft. Stock material came in on February 3rd and manufacturing began on February 4th. The hub is expected to be fully manufactured and ready for assembly on the afternoon of February 7th. A CAD/CAM operation for a CNC mill was created in order to make the hub. Mr. Bramble suggested that the center hole and pocket be turned on a manual lathe to limit the supervision needed. After about an hour on the manual lathe, it became evident that the stainless-steel stock material was going to be too much for the manual lathe to handle.

The pocket and center hole operations were transferred to an automated lathe where supervision was needed. To create the six bolt circle holes (1.75 inch bolt circle) and to complete the part, a CAD/CAM drilling operation will be used on a CNC mill.

The manufacturing process was expected to take 2.8 hours. The accumulated operation time so far is 4.1 hours and the six bolt circle holes still need to be drilled on the CNC Mill. The good news is that the installation process is only expected to take 6 minutes; whereas, the installation process for the first design was expected to take upwards to 6 hours.

d. Specified Deliverables & Milestones

The proposal will be the first deliverable in the project. After the proposal is approved, the clutch bearing will be ordered and assembled. The clutch bearing will then be installed on the designated shaft of the electric vehicle. Testing can then be done and if testing goes well, then the clutch bearing will stay on for the Electrathon event.

e. Estimated Total Project Time

The project is estimated to take the project engineer 127 hours. With others needing to be hired, the total man hours for this project is expected to be around 144 hours.

7: Project Management

a. Human Resources

The engineer of the project is the most involved human resource in this project. Other human resources are mentors who facilitate and aid with the project.

b. Physical Resources

Torchmate table, CAD/CAM sheet metal bending process, press fit mechanism, and other tools.

c. Soft Resources

Solidworks 2019, Solidworks demo: https://youtu.be/azITzOcZ6-g, McMaster-Carr

d. Financial Resources

The main funding source is projected to be CWU Student Services and Activities through the CWU EV Club. The project engineer will fund the rest of the project alone or will try to acquire additional funding from other sources.

8: Discussion

a. Design Evolution / Performance Creep

In week 8, the project engineer agreed with engineer Pringle that a lighter one-way clutch should be used to achieve the EV Club stakeholders' goal. That goal is to be as fuel efficient as possible. The project engineer researched one-way clutches and decided that a clutch bearing would be the best fit for the design. The car will be able to coast with the one-way clutch bearing when the gas pedal is depressed and the clutch will counteract the winding down of the electric motor, which slows the car down; fuel efficiency will be increased as a result.

As of January 30th, the clutch bearing has been placed on the driving shaft. The clutch bearing was believed to have a press fit relation with the shaft, but the fit was a slip fit after all; at this point those involved with the project realized a hub was required to be manufactured. The clutch bearing will have a press fit relation with the manufactured hub. The dimensional tolerances for the hub hole diameter and clutch bearing outer diameter is documented in Appendix B 1-9 and Appendix B 1-7, respectively.

The CAD/CAM process code to manufacture the hub was completed on January 29th and the stock that will be operated on to create the hub is scheduled to arrive in house on January 31st. The project ran into an issue with the hub face width being too large. The one-inch hub face width pushes other shaft components out and the block holding the bearing (not the clutch bearing) covers the hole where a cotter pin needs to be placed. To resolve this issue, one extra operation is now needed to remove roughly 5/16 of an inch off the hub's face width. The said operation will be done on a manual mill. The hub will still be wide enough to house the clutch bearing.

The face reduction for the hub was planned to be completed on a manual mill, but as some manual operations were being completed on the lathe (the machine shop suggested that manual machine operations be used in leu of the planned CAD/CAM CNC operations) it became apparent that the 316 stainless-steel stock for the hub was too tough for the manual machines to handle. The main issue is that the manual machines (lathe and mill) did not have machine delivered coolant and speeds and feeds needed to be precise.

An automated lathe was used to reduce the outer diameter, reduce the face, and bore the center hole where the clutch was pressed into. A CAD/CAM program on a CNC mill drilled the six bolt circle holes where the screws hold the clutch and hub in place on the shaft and up against the sprocket.

b. Project Risk Analysis

If one person is trying to pull the 300-pound vehicle in reverse, the wheels won't turn because the clutch bearing will lock and one may become injured exerting his or her body while trying to drag the 300-pound vehicle. It would be best for multiple people to lift the back end up (where the clutch is) and then the vehicle's front wheel will be able to roll in reverse.

Make sure the electric vehicle is properly supported by blocks before assembling or disassembling components, especially if the wheels are to come off.

For the coasting test on the hill, having no brakes is by far the greatest safety concern. To minimize the risk, the coasting distance should be limited to about 200 feet. Start from the bottom of the hill and progressively let go of the electric vehicle from higher positions until the coasting distance is about 200 feet. What needs to be avoided is releasing the vehicle from high up on the hill, which would result in a long coasting distance. Without brakes, the longer the coasting distance the more dangerous the test becomes.

c. Successful

The project will be successful if the MPG rating is higher than it has ever been for the catmobile. The project can also be defined as successful if it is proven that the clutch yields a higher MPG compared to when the vehicle doesn’t have the clutch attached.

Successful results from the coasting test would show that the clutch allows 10 or more feet of coasting compared trials without the clutch attached to the vehicle. If the vehicle coasts further without the clutch attached, then it’ll be assumed the clutch assembly is not constructed well enough. Drilling bigger bolt circle holes in the hub and sanding out the hub center hole to loosen the press fit between the clutch will be addressed first. Then a retest would be done to see if the results change.

d. Project Documentation

The clutch bearing is showcased in the assembly drawing in Appendix B 1-7. The analysis indicating the clutch bearing will be successful is documented in Appendix A 1-1.

An analysis was completed mainly using conservation of energy principles to calculate the coasting distance. The starting point was considered to be 3 meters in elevation up on the hill. Using conservation of energy, the velocity of the vehicle at the bottom of the hill was solved for. A reasonable deceleration value had to be assumed to calculate the coasting distance and the hill is assumed to transition into level ground. A slightly lower deceleration value was assumed for when the clutch was on the vehicle to get the clutch coasting distance. The "anticipated" results are only as good as the assumptions put into this analysis. If resources become available and open to this project, then physical testing will be completed and those results will drive this project.

e. Next Phase

The next phase is to construct and put the clutch bearing on the wheel shaft of the electric vehicle. Improvements may be implemented for a better performing bearing. For example, a titanium bearing, although much more expensive, can be used to get higher torque rating with less weight than stainless steel.

As of May 1st, testing results have not been compiled and received. Hopefully results will be available by May 5th to keep the project on track. There are limited resources (i.e. people and students) available to help complete testing due to "stay at home" recommendations set by the government.

9: Conclusion

a. Complete Design Readiness

The second design has been selected as the design to accomplish the project. The resources are available to construct the clutch bearing onto the electric vehicle. The 0.75 inch ID clutch bearing from McMaster-Carr fits the 0.75 inch diameter shaft on the drive system. The same clutch bearing has a high enough torque rating per the analysis in Appendix A 1-1. There is enough room (more than 5/8 inch) on the shaft to accommodate the clutch bearing.

b. Important Analyses

The analysis in Appendix A 1-1 is important because the analysis lets the designer know what the minimum torque rating the clutch must have. The clutch bearing is rated for 17 (ft*lbs) of torque, which is more than the 8.5 (ft*lbs) minimum torque rating the clutch is required to have. If the torque rating was below the minimum torque rating, then a stronger material like titanium would have to be used.

The analysis in Appendix A 1-11 is important because the analysis gives the design engineers an idea on what weight limit should be accessed to ensure the clutch bearing and shaft last over the required one million cycles.

c. Predicted Performance vs. Actual Performance

The predicted MPG gain is expected to be over 1 MPG at the next Electrathon race. The requirement is to get at least a 1 MPG gain. Any other possible modifications that could increase the gas mileage will be noted, but the clutch bearing is the only modification planned to improve the MPG as of now.

The clutch bearing is expected to last more than one million cycles. If the clutch bearing fails within the next five years, then the requirement for sure would not be met.

The anticipated results based off the analysis from the testing report using conservation of energy principles were not able to be compared with real testing data due to resources being limited and restricted due to the pandemic. Unfortunately, the analysis document was lost because the binder was mistakenly misplaced or thrown away during spring cleaning; the project engineer would have not lost the analysis document if he was able to stay at his own place on campus, most likely. The testing method section explains how the anticipated results were formulated and analyzed. The clutch shows to considerable coast further (48 feet further) than when the vehicle does not have the clutch assembled and is released from a height of 3 meters up on the hill.

10: Acknowledgements

There is much appreciation for Charles Pringle, Dr. Craig Johnson, Ted Bramble, Dr. Choi, and other members of the ETSC program from Central Washington University. This project would not have gained much ground without these members' support. A special thanks to the assigned advisor, Charles Pringle, for his advice and mentorship that helped improve the project.

Thank you to those who created the Solidworks tutorial #253 video, especially because it saved the project a lot of time in creating the drawings. The project engineer is grateful for the design experience and the strengthening of Solidworks skills from the learning in the video.

Last best not least, Ted Bramble did an excellent job at showing the project design engineer improved methods compared to the ones presented to him for constructing the clutch system.

11: References

Mott, Robert L., Machine Elements in Mechanical Design, 6th edition, Prentice Hall, 2018.

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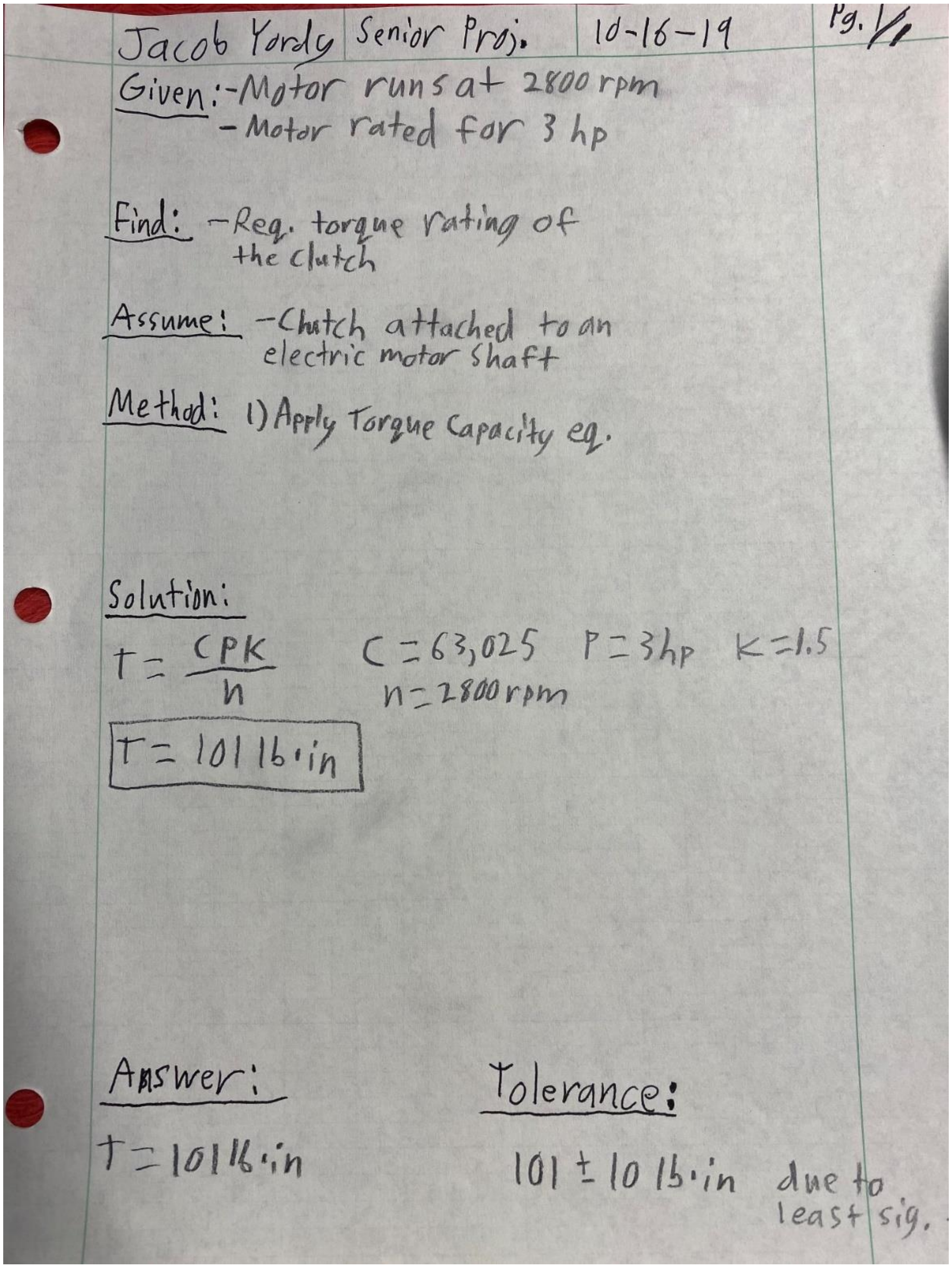
"Solidworks Tutorial #253 : Clutch (Complete)." *YouTube*, Solidworks Tutorial, 8 Dec. 2016, https://youtu.be/azITzOcZ6-g

Pringle, Charles. Personal interview. November, 2019.

Appendix A 1-1: Torque w/motor



Jacob Yordy | Senior Proj. | 10-16-19 | Pg. 1/1

Given: -Motor runs at 2800 rpm
-Motor rated for 3 hp

Find: -Req. torque rating of the clutch

Assume: -Clutch attached to an electric motor shaft

Method: 1) Apply Torque Capacity eq.

Solution:

$$T = \frac{CPK}{n} \qquad C = 63{,}025 \quad P = 3\,hp \quad K = 1.5$$
$$n = 2800\,rpm$$

$$\boxed{T = 101\ lb \cdot in}$$

Answer:

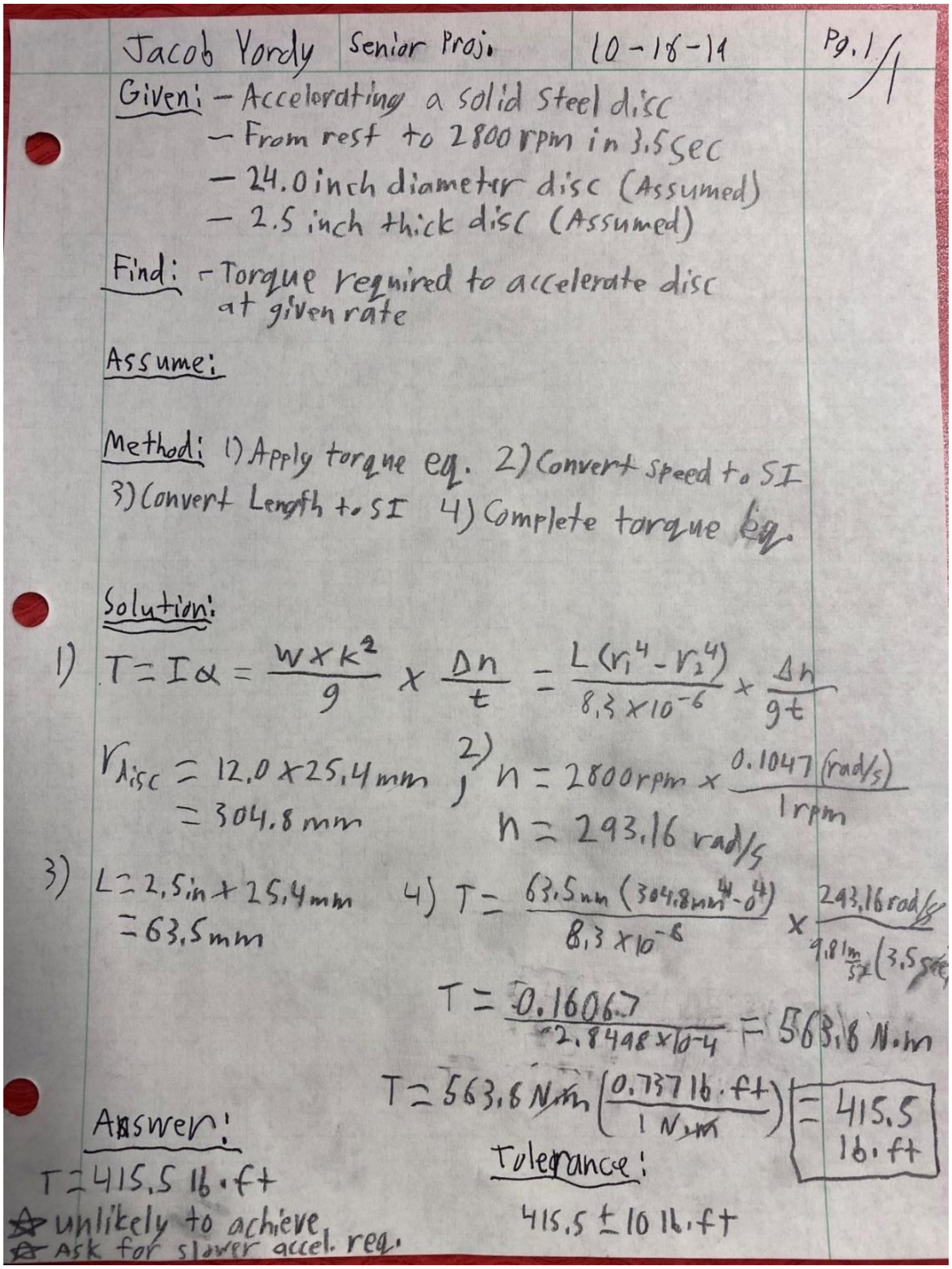
$T = 101\ lb \cdot in$

Tolerance:

101 ± 10 lb·in due to least sig.

Figure A 1-1: Torque needed in the clutch to handle a 3 hp engine running at 2800 rpm.

Appendix A 1-2: Torque for Acceleration



Jacob Yordy | Senior Proj. | 10-18-19 | Pg. 1/1

Given: – Accelerating a solid steel disc
– From rest to 2800 rpm in 3.5 sec
– 24.0 inch diameter disc (Assumed)
– 2.5 inch thick disc (Assumed)

Find: – Torque required to accelerate disc at given rate

Assume:

Method: 1) Apply torque eq. 2) Convert speed to SI 3) Convert Length to SI 4) Complete torque eq.

Solution:

1) $T = I\alpha = \frac{W \times k^2}{g} \times \frac{\Delta n}{t} = \frac{L(r_1^4 - r_2^4)}{8.3 \times 10^{-6}} \times \frac{\Delta n}{gt}$

$r_{disc} = 12.0 \times 25.4\,mm$
$= 304.8\,mm$

2) $n = 2800\,rpm \times \frac{0.1047\,(rad/s)}{1\,rpm}$
$n = 293.16\,rad/s$

3) $L = 2.5\,in \times 25.4\,mm$
$= 63.5\,mm$

4) $T = \frac{63.5\,mm\,(304.8\,mm^4 - 0^4)}{8.3 \times 10^{-6}} \times \frac{243.16\,rad/s}{9.81\frac{m}{s^2}(3.5\,sec}$

$T = \frac{0.16067}{2.8448 \times 10^{-4}} = 563.8\,N \cdot m$

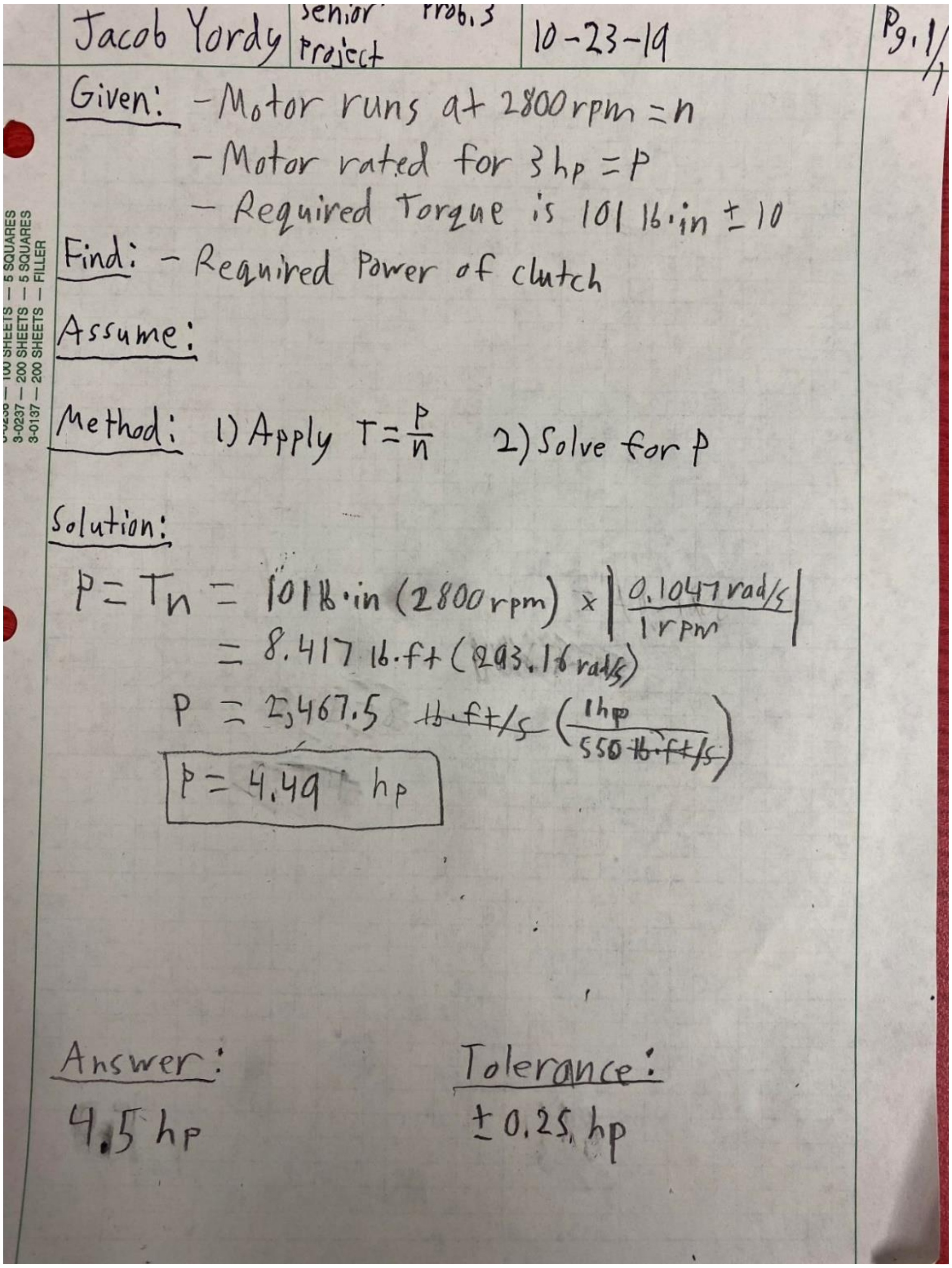
$T = 563.6\,N{\cdot}m \left(\frac{0.737\,lb \cdot ft}{1\,N{\cdot}m}\right) = \boxed{415.5\,lb \cdot ft}$

Answer:
T = 415.5 lb·ft
☆ unlikely to achieve
☆ Ask for slower accel. req.

Tolerance:
415.5 ± 10 lb·ft

Figure A 1-2: Torque needed in the clutch to accelerate the vehicle from rest to 2800 rpm in 3.5 seconds.

Appendix A 1-3: Power w/motor



Jacob Yordy | Senior Project | Prob. 3 | 10-23-19 | Pg. 1/1

Given:
- Motor runs at 2800 rpm = n
- Motor rated for 3 hp = P
- Required Torque is 101 lb·in ± 10

Find:
- Required Power of clutch

Assume:

Method: 1) Apply $T = \frac{P}{n}$ 2) Solve for P

Solution:

$$P = Tn = 101\,\text{lb·in}\,(2800\,\text{rpm}) \times \left|\frac{0.1047\,\text{rad/s}}{1\,\text{rpm}}\right|$$

$$= 8.417\,\text{lb·ft}\,(293.16\,\text{rad/s})$$

$$P = 2{,}467.5\,\cancel{\text{lb·ft/s}}\left(\frac{1\,\text{hp}}{550\,\cancel{\text{lb·ft/s}}}\right)$$

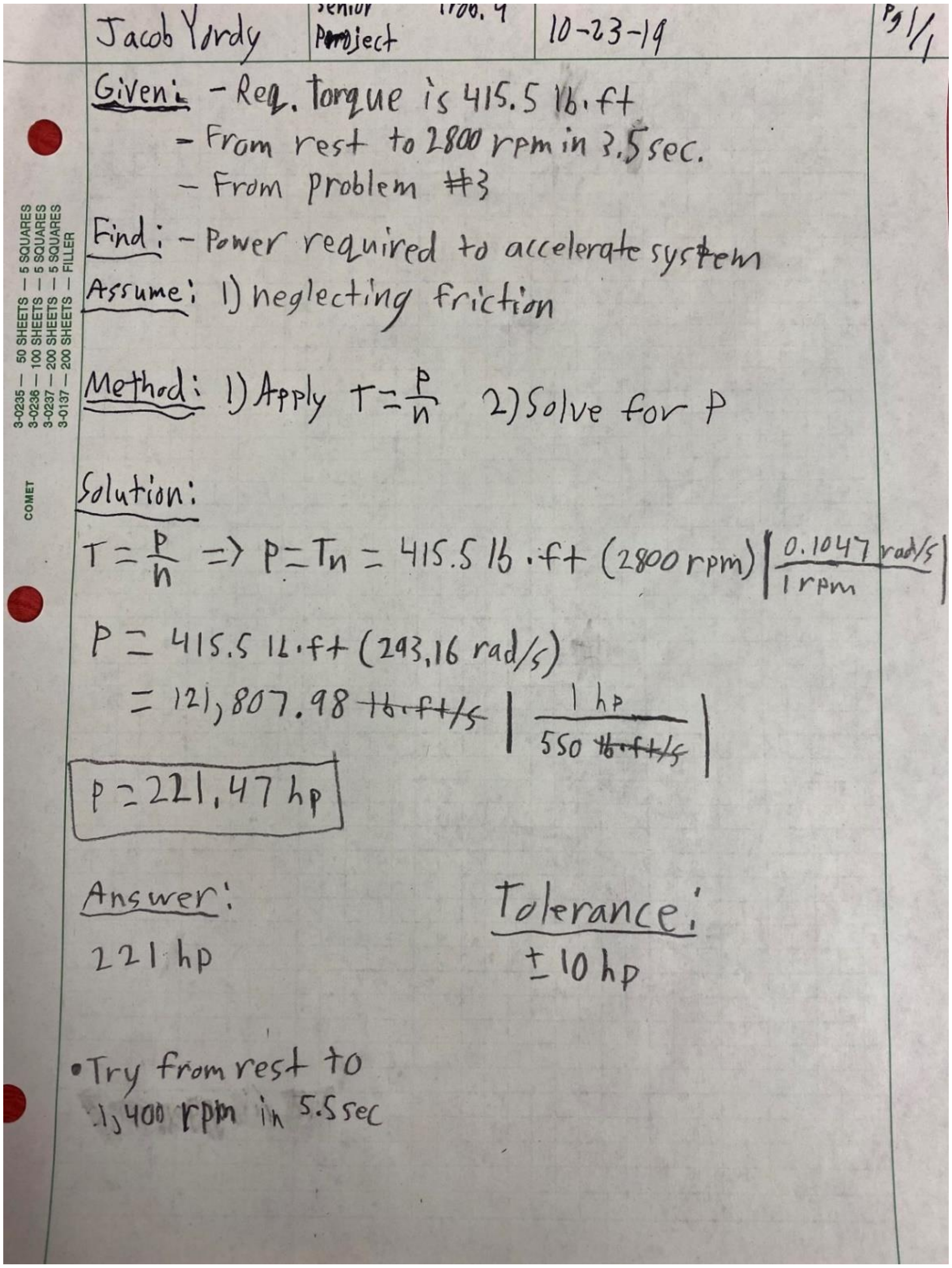
$$\boxed{P = 4.49\,\text{hp}}$$

Answer:
4.5 hp

Tolerance:
± 0.25 hp

Figure A 1-3: The power needed by the clutch to run with the 3 hp electric motor is shown in this analysis. The clutch will need to be more powerful than the motor by a factor of 1.5 or more.

Appendix A 1-4: Power for Acceleration



Jacob Yordy | Senior Project | Prob. 4 | 10-23-19 | Pg 1/1

Given: - Req. torque is 415.5 lb·ft
- From rest to 2800 rpm in 3.5 sec.
- From problem #3

Find: - Power required to accelerate system

Assume: 1) neglecting friction

Method: 1) Apply $T = \frac{P}{n}$ 2) Solve for P

Solution:

$$T = \frac{P}{n} \Rightarrow P = Tn = 415.5 \text{ lb} \cdot \text{ft} \, (2800 \text{ rpm}) \left| \frac{0.1047 \text{ rad/s}}{1 \text{ rpm}} \right|$$

$$P = 415.5 \text{ lb} \cdot \text{ft} \, (293.16 \text{ rad/s})$$

$$= 121{,}807.98 \, \cancel{\text{lb} \cdot \text{ft/s}} \left| \frac{1 \text{ hp}}{550 \, \cancel{\text{lb} \cdot \text{ft/s}}} \right|$$

$$\boxed{P = 221.47 \text{ hp}}$$

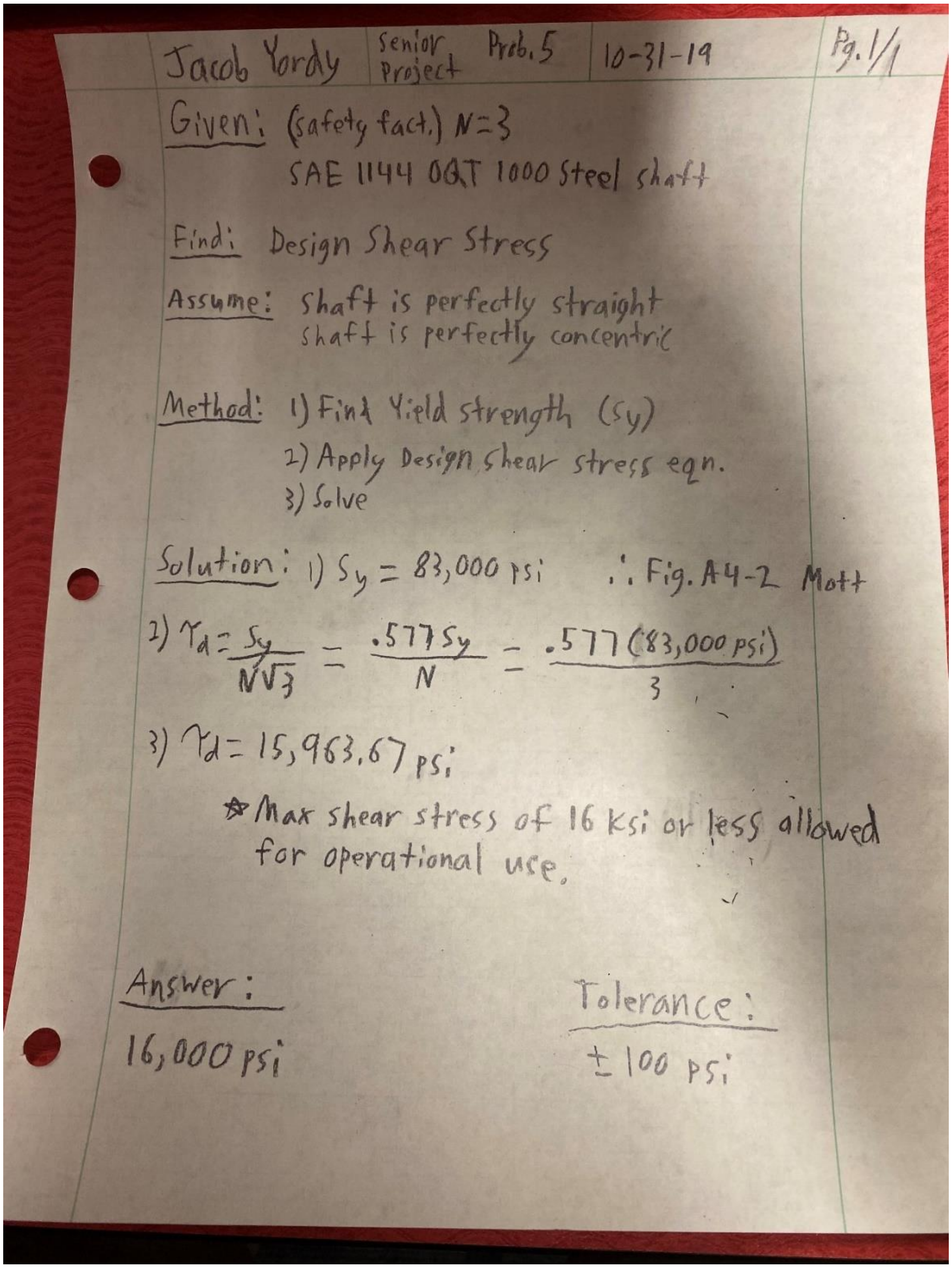
Answer:
221 hp

Tolerance:
± 10 hp

- Try from rest to 1,400 rpm in 5.5 sec

Figure A 1-4: 221 hp of power is needed from the clutch to accelerate the EV to full speed in 3.5 seconds. This project does not have the budget to attain a clutch with this much power.

Appendix A 1-5: Design Shear Stress



Jacob Yordy | Senior Project | Prob. 5 | 10-31-19 | Pg. 1/1

Given: (safety fact.) $N = 3$

SAE 1144 OQT 1000 Steel shaft

Find: Design Shear Stress

Assume: Shaft is perfectly straight

shaft is perfectly concentric

Method: 1) Find Yield strength (S_y)

2) Apply Design shear stress eqn.

3) Solve

Solution: 1) $S_y = 83{,}000$ psi ∴ Fig. A4-2 Mott

2) $$\tau_d = \frac{S_y}{N\sqrt{3}} = \frac{.577 S_y}{N} = \frac{.577(83{,}000 \text{ psi})}{3}$$

3) $\tau_d = 15{,}963.67$ psi

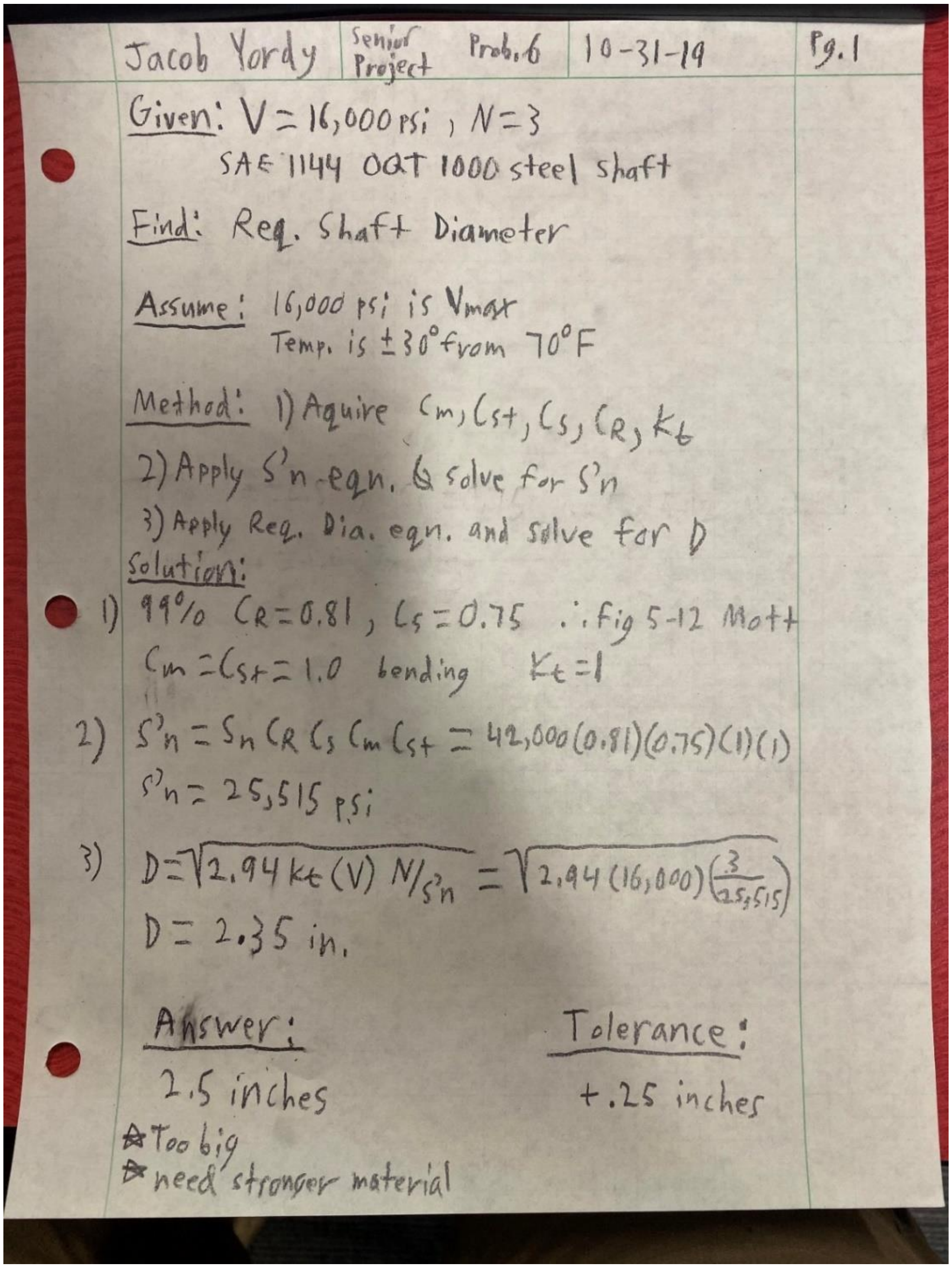
★ Max shear stress of 16 ksi or less allowed for operational use.

Answer: 16,000 psi

Tolerance: ± 100 psi

Figure A 1-5: Using a design factor of 3, 16 ksi is the maximum operational shear stress that is allowed with confidence that the shaft will hold up over time. The allowed shear stress will be different if the shaft is not made of SAE 1144 OQT 1000 Steel.

Appendix A 1-6: Shaft Diameter



Jacob Yordy | Senior Project | Prob. 6 | 10-31-19 | Pg. 1

Given: $V = 16{,}000$ psi ; $N = 3$

SAE 1144 OQT 1000 steel shaft

Find: Req. Shaft Diameter

Assume: 16,000 psi is V_{max}

Temp. is ±30° from 70°F

Method: 1) Aquire $C_m, C_{st}, C_s, C_R, k_t$

2) Apply S'_n eqn. & solve for S'_n

3) Apply Req. Dia. eqn. and solve for D

Solution:

1) 99% $C_R = 0.81$, $C_s = 0.75$ ∴ Fig 5-12 Mott

$C_m = C_{st} = 1.0$ bending $K_t = 1$

2) $S'_n = S_n C_R C_s C_m C_{st} = 42{,}000(0.81)(0.75)(1)(1)$

$S'_n = 25{,}515$ psi

3) $D = \sqrt{2.94 k_t (V) N/S'_n} = \sqrt{2.94(16{,}000)\left(\frac{3}{25{,}515}\right)}$

$D = 2.35$ in.

Answer: 2.5 inches

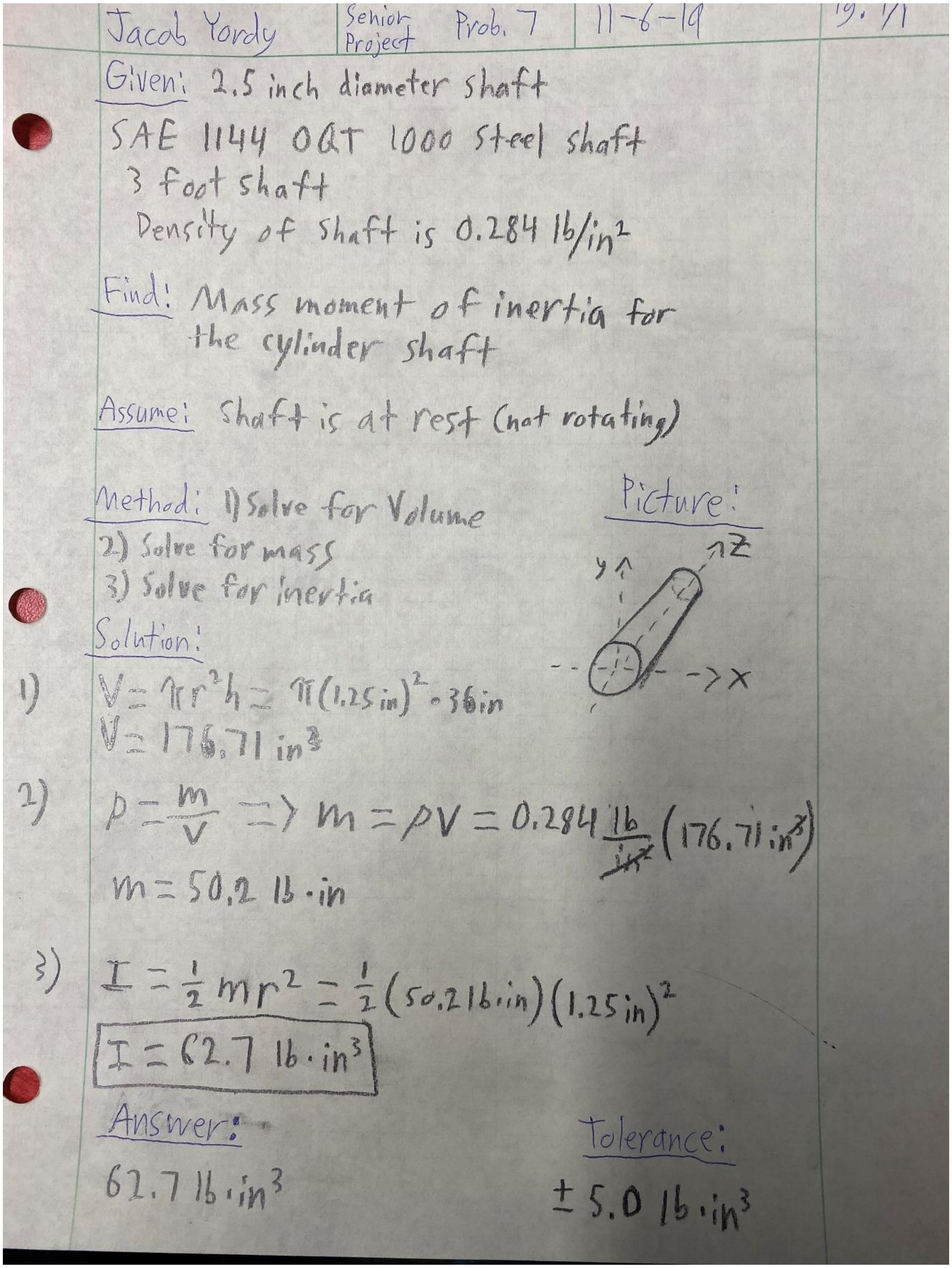
Tolerance: +.25 inches

☆ Too big

☆ need stronger material

Figure A 1-6: This problem solves for the minimum required diameter size for the shaft in conjunction with the clutch. 2.5 inch is not a feasible diameter and a material with a higher estimated endurance limit is needed to drive the required diameter size down.

Appendix A 1-7: Shaft Inertia



Jacob Yordy | Senior Project | Prob. 7 | 11-6-19 | 19. 1/1

Given: 2.5 inch diameter shaft

SAE 1144 OQT 1000 Steel shaft

3 foot shaft

Density of Shaft is 0.284 lb/in²

Find: Mass moment of inertia for the cylinder shaft

Assume: Shaft is at rest (not rotating)

Method: 1) Solve for Volume

2) Solve for mass

3) Solve for inertia

Picture:

Solution:

1) $V = \pi r^2 h = \pi (1.25\,in)^2 \cdot 36\,in$

$V = 176.71\,in^3$

2) $\rho = \frac{m}{V} \Rightarrow m = \rho V = 0.284\,\frac{lb}{\cancel{in^2}}(176.71\,in^{\cancel{3}})$

$m = 50.2\ lb \cdot in$

3) $I = \frac{1}{2} m r^2 = \frac{1}{2}(50.2\,lb \cdot in)(1.25\,in)^2$

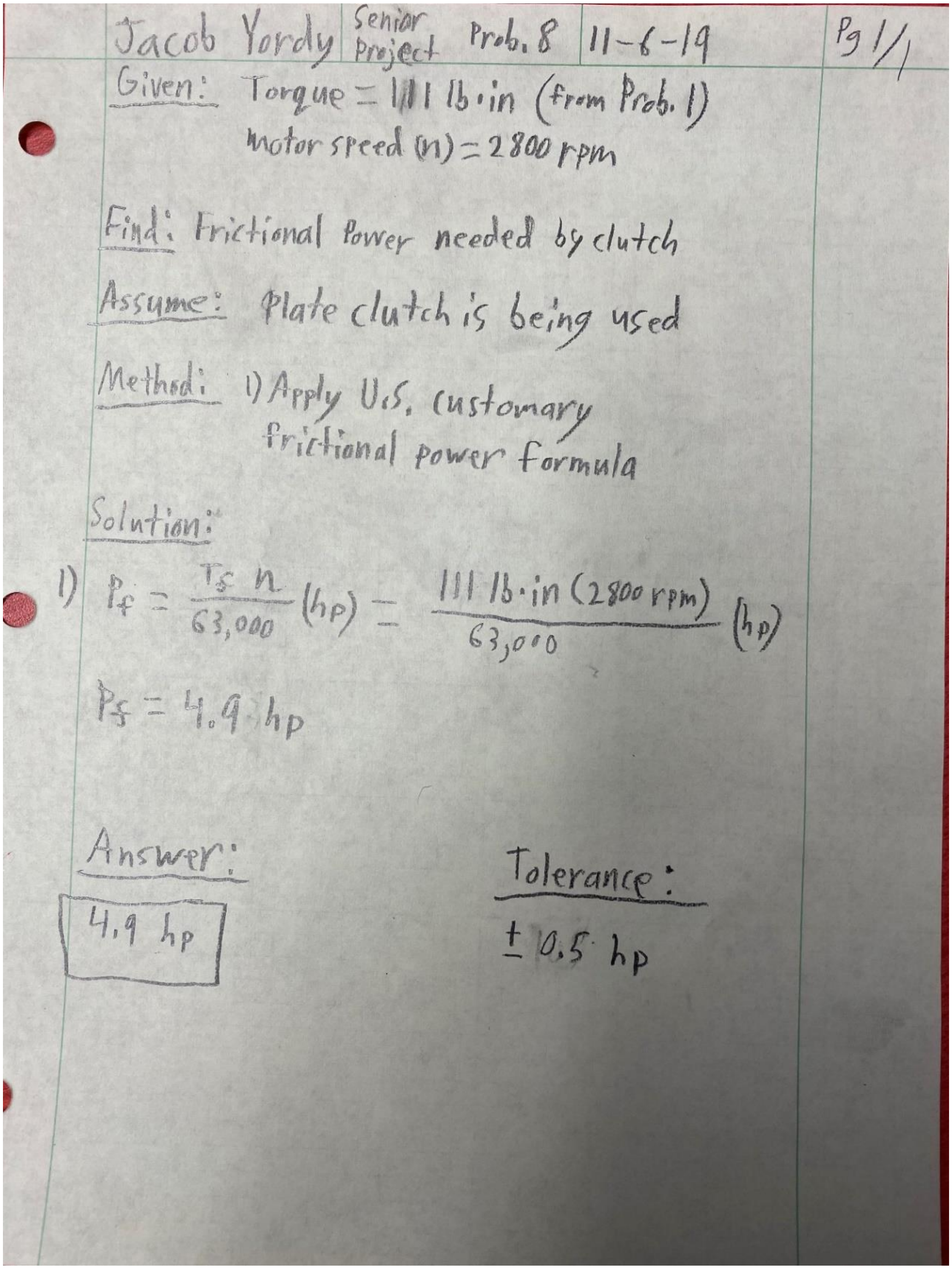
$\boxed{I = 62.7\ lb \cdot in^3}$

Answer: 62.7 lb·in³

Tolerance: ± 5.0 lb·in³

Figure A 1-7: This is the inertia it takes to change the velocity of the driving shaft.

Appendix A 1-8: Frictional Power



Jacob Yordy | Senior Project | Prob. 8 | 11-6-19 | Pg 1/1

Given: Torque = 111 lb·in (from Prob. 1)
motor speed (n) = 2800 rpm

Find: Frictional Power needed by clutch

Assume: Plate clutch is being used

Method: 1) Apply U.S. customary frictional power formula

Solution:

1) $$P_f = \frac{T_s n}{63,000}(hp) = \frac{111 \text{ lb}\cdot\text{in}(2800 \text{ rpm})}{63,000}(hp)$$

$$P_f = 4.9 \text{ hp}$$

Answer:

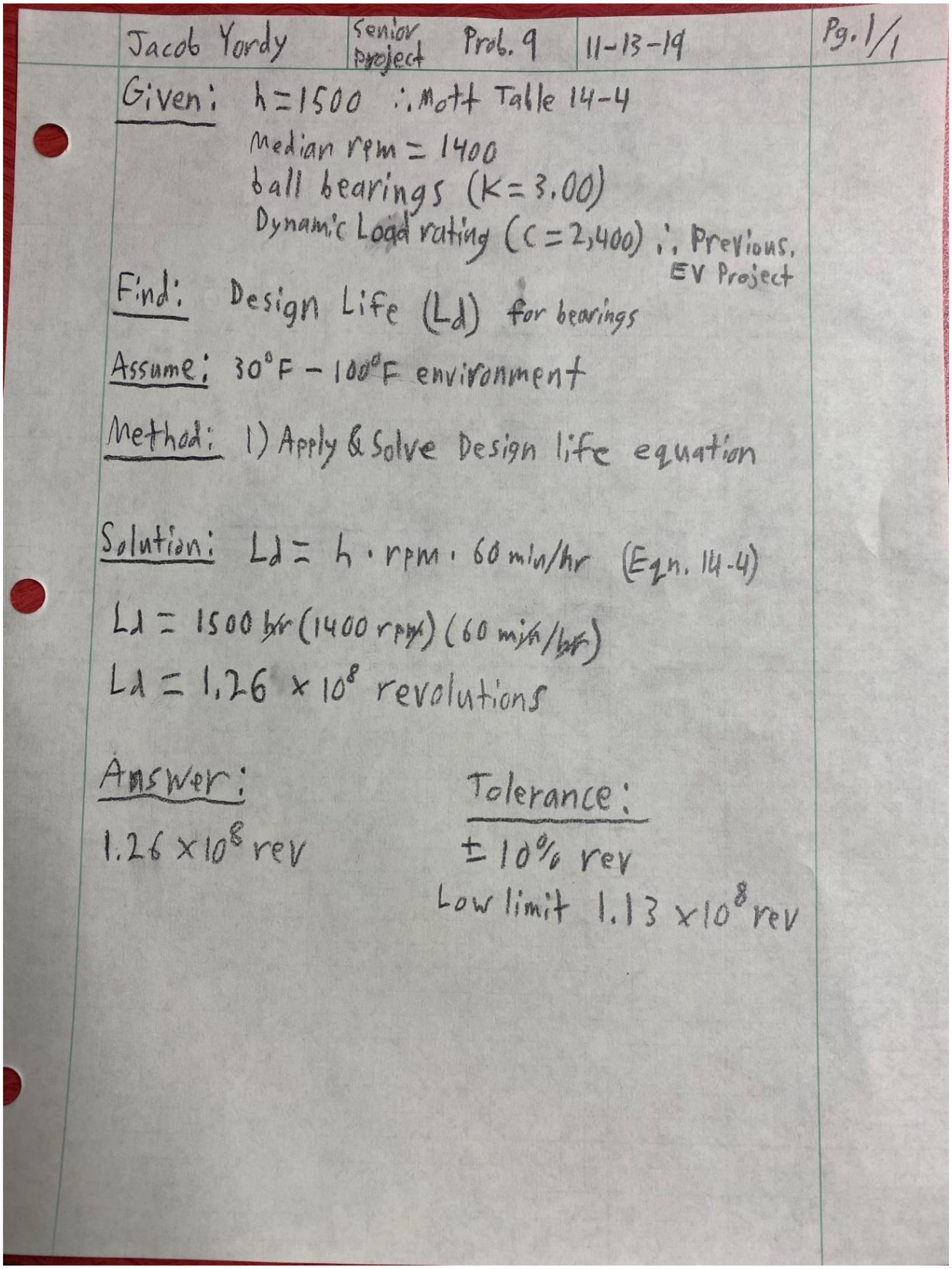
$\boxed{4.9 \text{ hp}}$

Tolerance:

± 0.5 hp

Figure A 1-8: The frictional force needed in the system for a plate clutch.

Appendix A 1-9: Design Life



Jacob Yordy | Senior Project | Prob. 9 | 11-13-19 | Pg. 1/1

Given: h = 1500 ∴ Mott Table 14-4
Median rpm = 1400
ball bearings (K = 3.00)
Dynamic Load rating (C = 2,400) ∴ Previous, EV Project

Find: Design Life (L_d) for bearings

Assume: 30°F – 100°F environment

Method: 1) Apply & Solve Design life equation

Solution: $L_d = h \cdot rpm \cdot 60\ min/hr$ (Eqn. 14-4)

$L_d = 1500\ \cancel{hr}\ (1400\ r\cancel{pm})\ (60\ \cancel{m}in/\cancel{hr})$

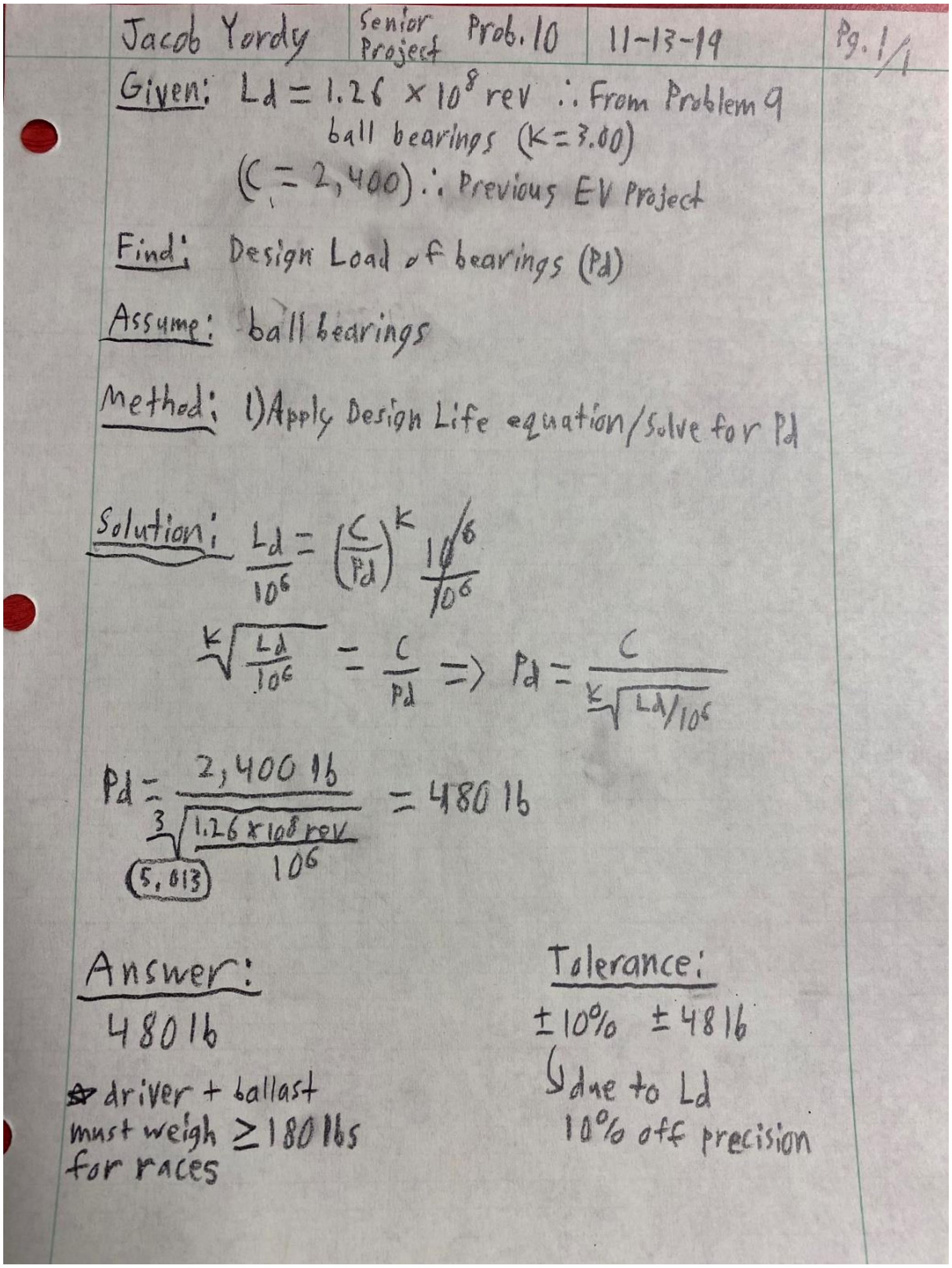
$L_d = 1.26 \times 10^8$ revolutions

Answer:
1.26×10^8 rev

Tolerance:
±10% rev
Low limit 1.13×10^8 rev

Figure A 1-9: This calculation helps the designer know how many turns (revolutions) the bearings will go through before failing.

Appendix A 1-10: Design Load



Jacob Yordy | Senior Project | Prob. 10 | 11-13-19 | Pg. 1/1

Given: $L_d = 1.26 \times 10^8$ rev ∴ From Problem 9
ball bearings $(K = 3.00)$
$(C = 2,400)$ ∴ Previous EV Project

Find: Design Load of bearings (Pd)

Assume: ball bearings

Method: 1) Apply Design Life equation/Solve for Pd

Solution: $\frac{L_d}{10^6} = \left(\frac{C}{P_d}\right)^K \frac{\cancel{10^6}}{\cancel{10^6}}$

$$\sqrt[K]{\frac{L_d}{10^6}} = \frac{C}{P_d} \Rightarrow P_d = \frac{C}{\sqrt[K]{L_d/10^6}}$$

$$P_d = \frac{2,400 \text{ lb}}{\sqrt[3]{\frac{1.26 \times 10^8 \text{ rev}}{10^6}}} = 480 \text{ lb}$$

$\boxed{5,013}$

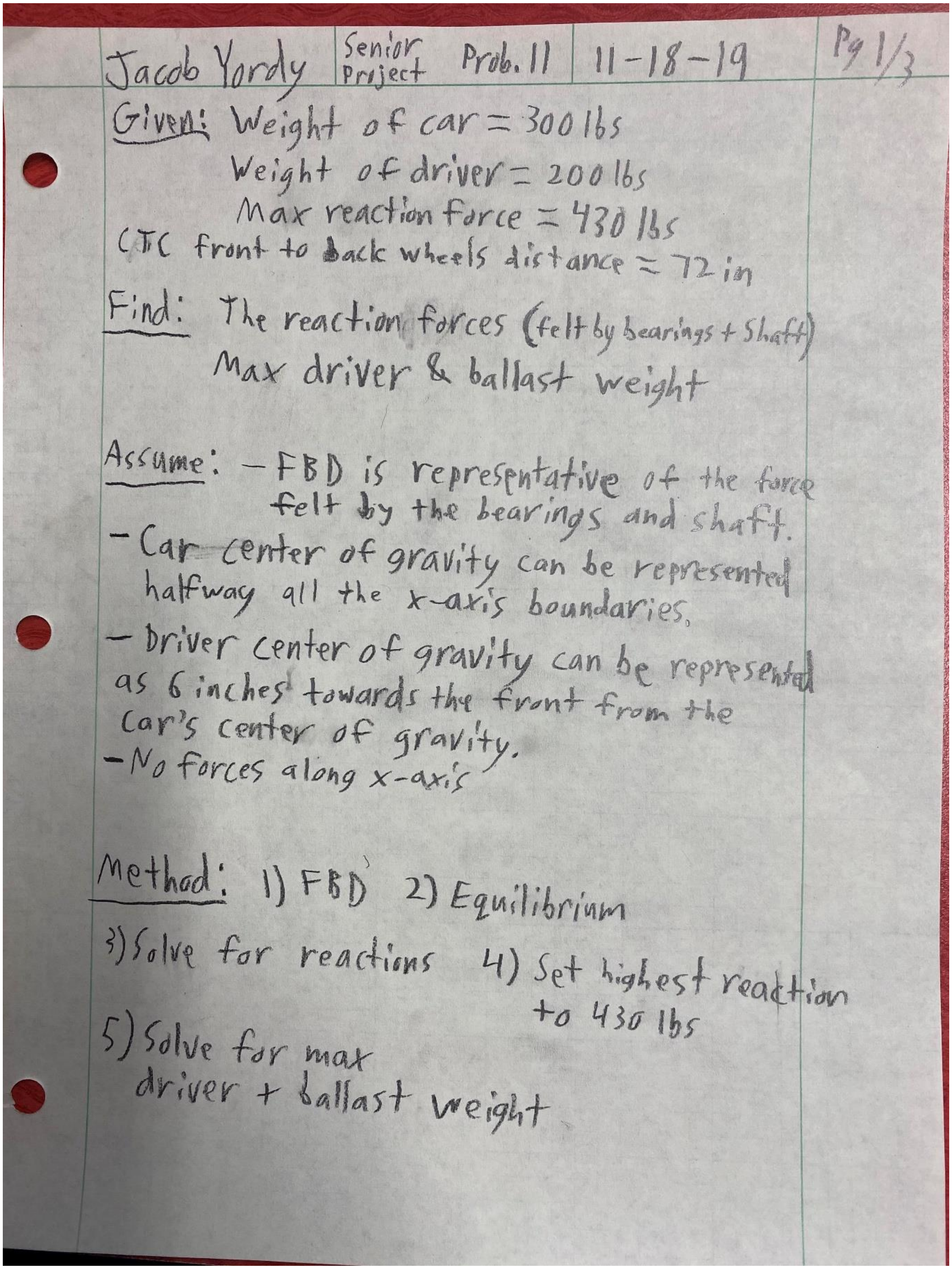
Answer:
480 lb

Tolerance:
±10% ±48 lb
↳ due to Ld
10% off precision

☆ driver + ballast must weigh ≥ 180 lbs for races

Figure A 1-10: This calculation helps the designer know how much weight or load amount the bearings can continually handle during operation in order for the bearings to last the full design life.

Appendix A 1-11: Reactions & Max Driver Weight



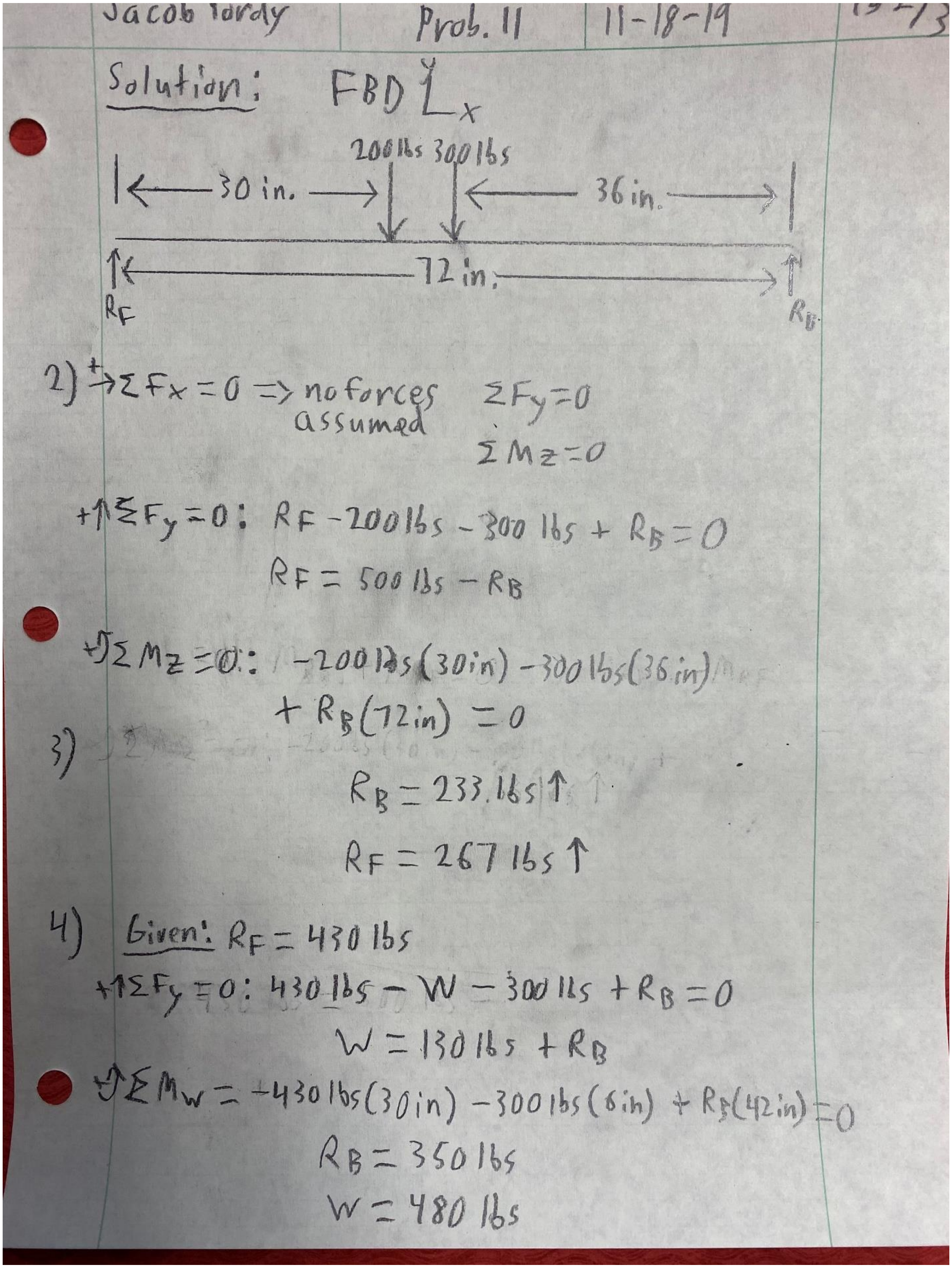
Jacob Yordy | Senior Project | Prob. 11 | 11-18-19 | Pg 1/3

Given: Weight of car = 300 lbs
Weight of driver = 200 lbs
Max reaction force = 430 lbs
CTC front to back wheels distance = 72 in

Find: The reaction forces (felt by bearings + Shaft)
Max driver & ballast weight

Assume: - FBD is representative of the force felt by the bearings and shaft.
- Car center of gravity can be represented halfway all the x-axis boundaries.
- Driver center of gravity can be represented as 6 inches towards the front from the car's center of gravity.
- No forces along x-axis

Method: 1) FBD 2) Equilibrium
3) Solve for reactions 4) Set highest reaction to 430 lbs
5) Solve for max driver + ballast weight



Jacob Tordy | Prob. 11 | 11-18-19

Solution: FBD $\overset{y}{\llcorner}_{x}$

2) $\overset{+}{\rightarrow}\Sigma F_x = 0 \Rightarrow$ no forces assumed $\quad \Sigma F_y = 0$

$\Sigma M_z = 0$

$+\uparrow \Sigma F_y = 0$: $R_F - 200\text{ lbs} - 300\text{ lbs} + R_B = 0$

$R_F = 500\text{ lbs} - R_B$

$\circlearrowleft^{+} \Sigma M_z = 0$: $-200\text{ lbs}(30\text{in}) - 300\text{ lbs}(36\text{ in})$

$+ R_B(72\text{in}) = 0$

3)

$R_B = 233\text{ lbs}\uparrow$

$R_F = 267\text{ lbs}\uparrow$

4) **Given:** $R_F = 430\text{ lbs}$

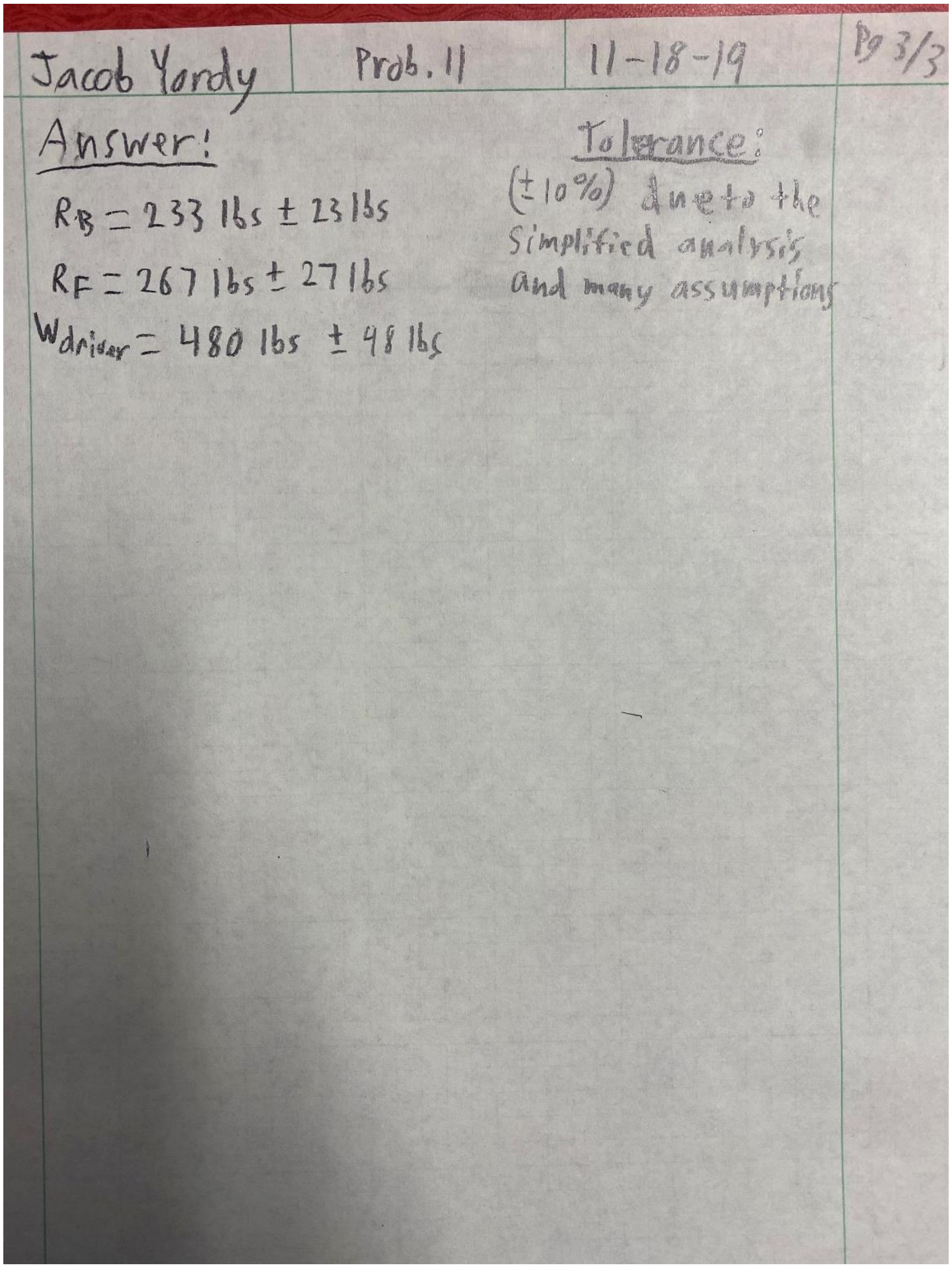
$+\uparrow \Sigma F_y = 0$: $430\text{ lbs} - W - 300\text{ lbs} + R_B = 0$

$W = 130\text{ lbs} + R_B$

$\circlearrowleft^{+} \Sigma M_W = -430\text{ lbs}(30\text{in}) - 300\text{ lbs}(6\text{in}) + R_B(42\text{in}) = 0$

$R_B = 350\text{ lbs}$

$W = 480\text{ lbs}$



Jacob Yordy | Prob. 11 | 11-18-19 | Pg 3/3

Answer:

$R_B = 233$ lbs ± 23 lbs

$R_F = 267$ lbs ± 27 lbs

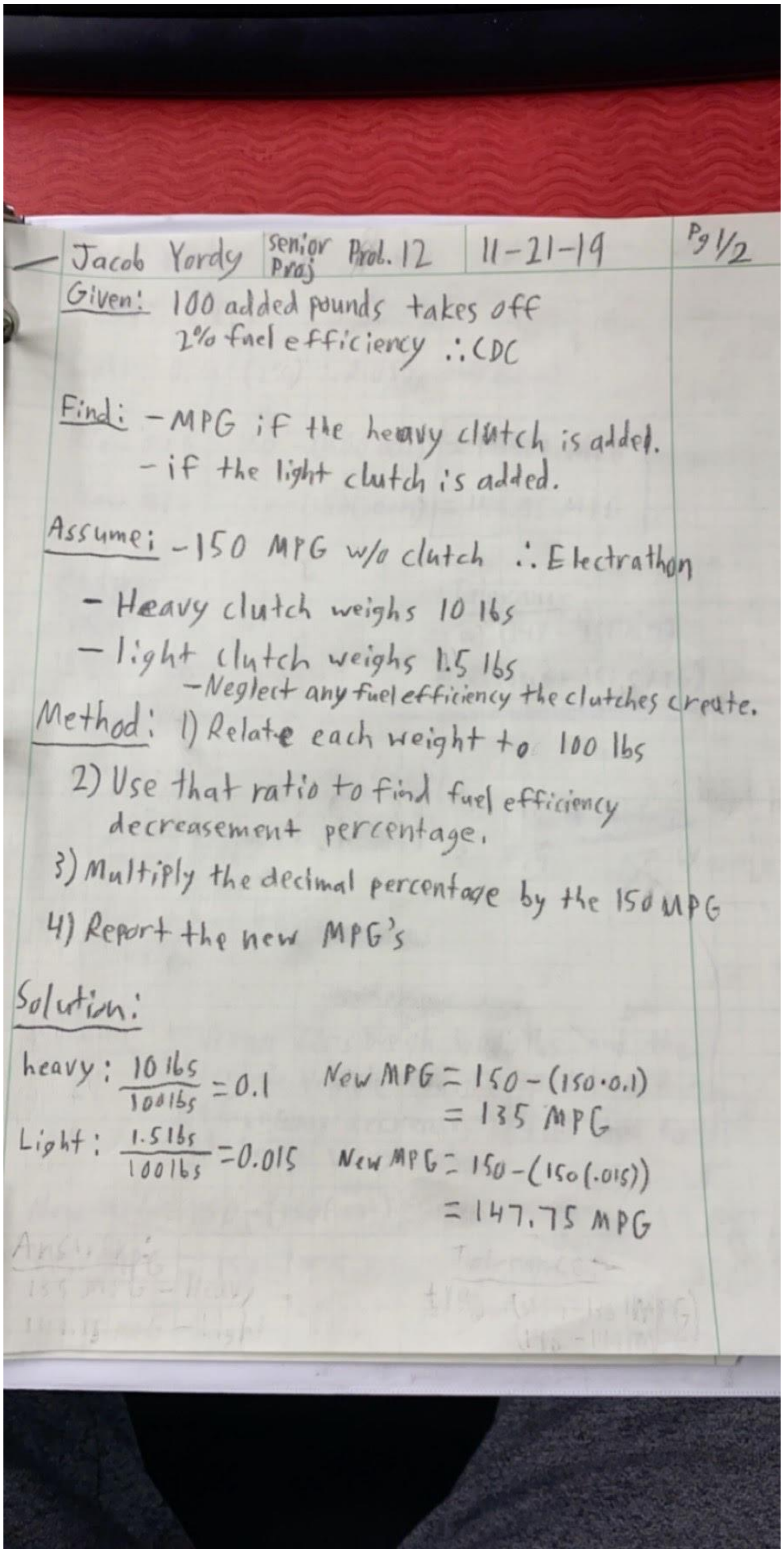
$W_{driver} = 480$ lbs ± 48 lbs

Tolerance:

(±10%) due to the Simplified analysis and many assumptions

Figure A 1-11c: The reaction forces are well below the design load and the maximum weight of the driver is high enough for one person to be bearing weight on the vehicle.

Appendix A 1-12: Effective MPG Loss



Jacob Yordy | Senior Proj | Prob. 12 | 11-21-19 | Pg 1/2

Given: 100 added pounds takes off 2% fuel efficiency ∴ CDC

Find: - MPG if the heavy clutch is added.
- if the light clutch is added.

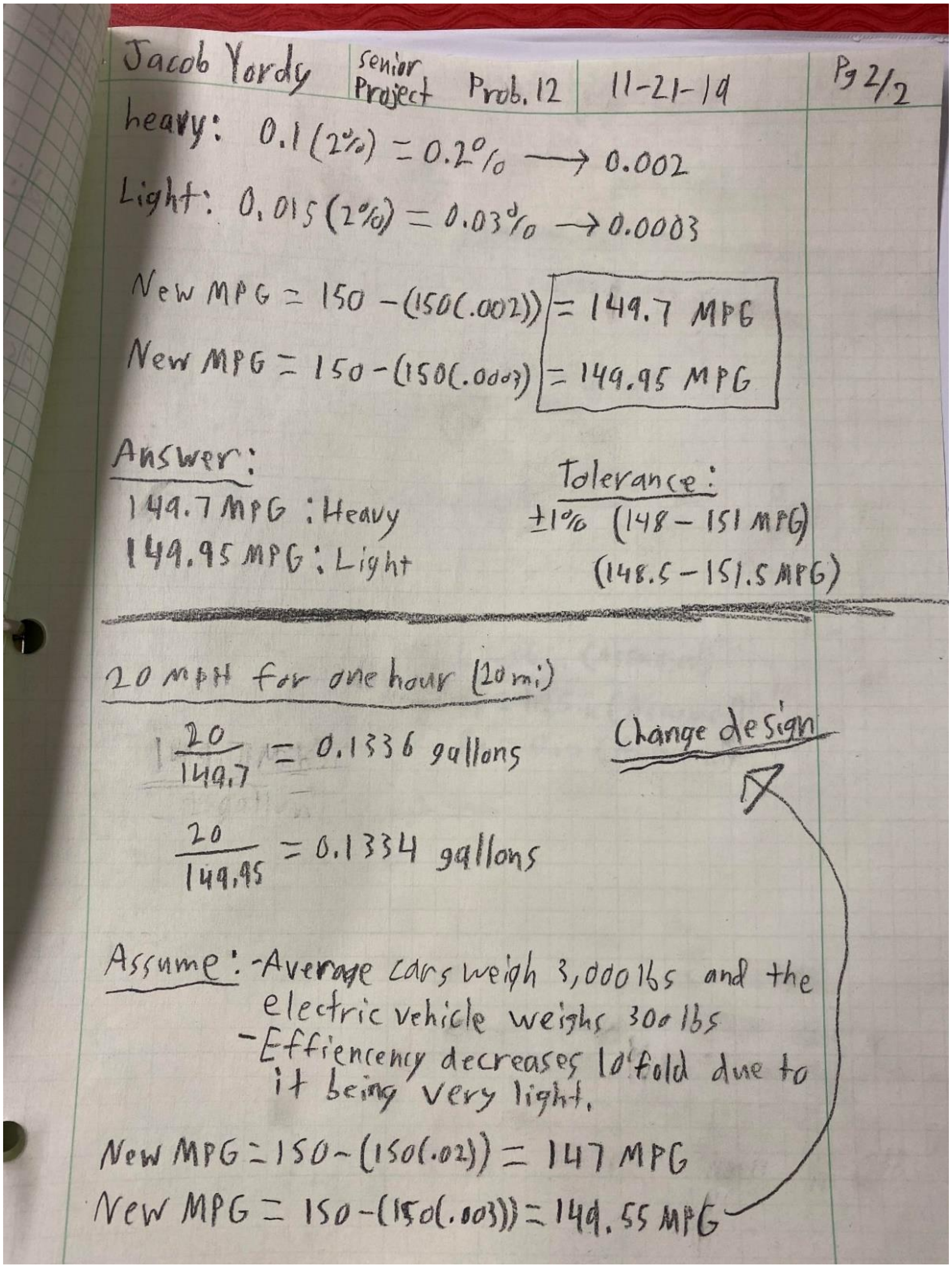
Assume: - 150 MPG w/o clutch ∴ Electrathon
- Heavy clutch weighs 10 lbs
- light clutch weighs 1.5 lbs
- Neglect any fuel efficiency the clutches create.

Method: 1) Relate each weight to 100 lbs
2) Use that ratio to find fuel efficiency decreasement percentage.
3) Multiply the decimal percentage by the 150 MPG
4) Report the new MPG's

Solution:

heavy: $\frac{10\text{ lbs}}{100\text{ lbs}} = 0.1$ New MPG $= 150 - (150 \cdot 0.1)$
$= 135$ MPG

Light: $\frac{1.5\text{ lbs}}{100\text{ lbs}} = 0.015$ New MPG $= 150 - (150(.015))$
$= 147.75$ MPG



Jacob Yordy | Senior Project | Prob. 12 | 11-21-19 | Pg 2/2

heavy: $0.1(2\%) = 0.2\% \rightarrow 0.002$

Light: $0.015(2\%) = 0.03\% \rightarrow 0.0003$

New MPG $= 150 - (150(.002)) \boxed{= 149.7 \text{ MPG}}$

New MPG $= 150 - (150(.0003)) \boxed{= 149.95 \text{ MPG}}$

Answer:

149.7 MPG : Heavy

149.95 MPG : Light

Tolerance:

±1% (148 − 151 MPG)

(148.5 − 151.5 MPG)

20 mpH for one hour (20 mi)

$\frac{20}{149.7} = 0.1336$ gallons

$\frac{20}{149.95} = 0.1334$ gallons

Change design

Assume: -Average cars weigh 3,000 lbs and the electric vehicle weighs 300 lbs
-Effiencency decreases 10 fold due to it being very light.

New MPG $= 150 - (150(.02)) = 147$ MPG

New MPG $= 150 - (150(.003)) = 149.55$ MPG

Figure A 1-12: A lot of assumptions were made but even the problem is still representative. The design must change to a lightweight clutch to not harm the CWU EV club’s chance at winning an Electrathon event.

Appendix B 1-1

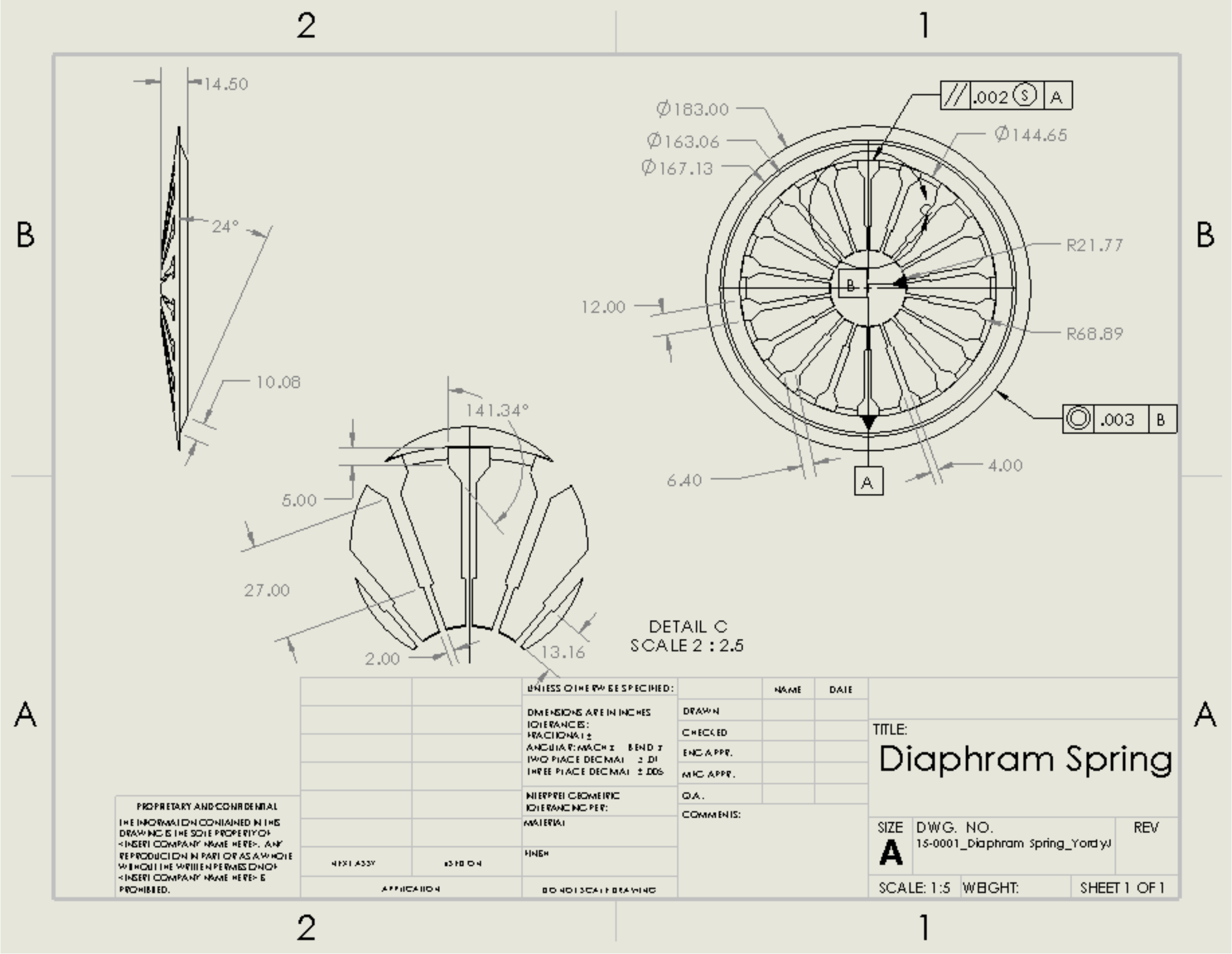


Figure B 1-1: This is the drawing and dimensions associated with the diaphragm spring. This was the first part created for the clutch and the part was made following the demo is this video: https://youtu.be/azITzOcZ6-g

Appendix B 1-2

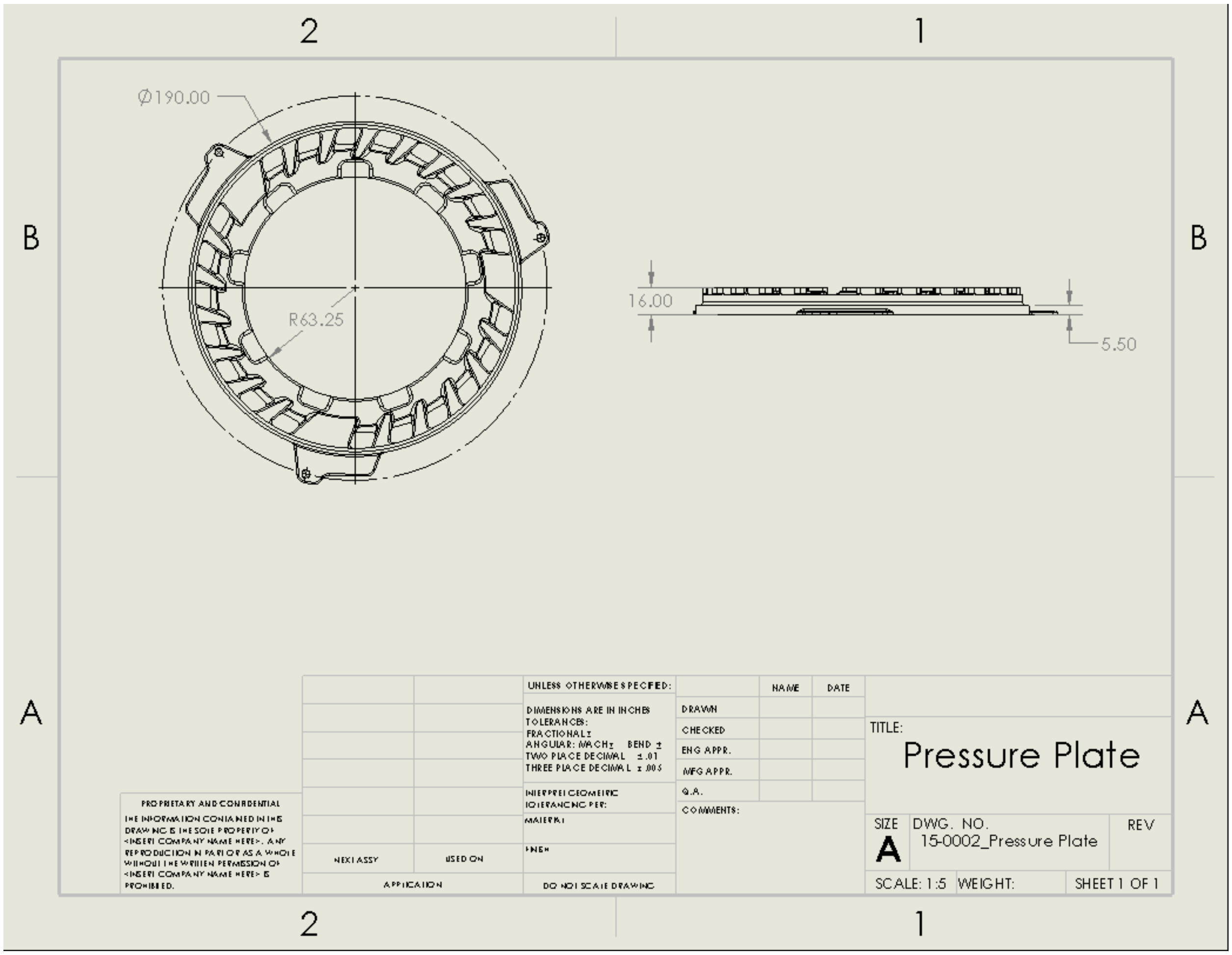


Figure B 1-2: This is the drawing and some dimensions related to the pressure plate. This was the 2nd part made in order to make the clutch assembly. The part was made following the demo in the following video from about [9:00 to 30:00 min]: https://youtu.be/azITzOcZ6-g

Appendix B 1-3

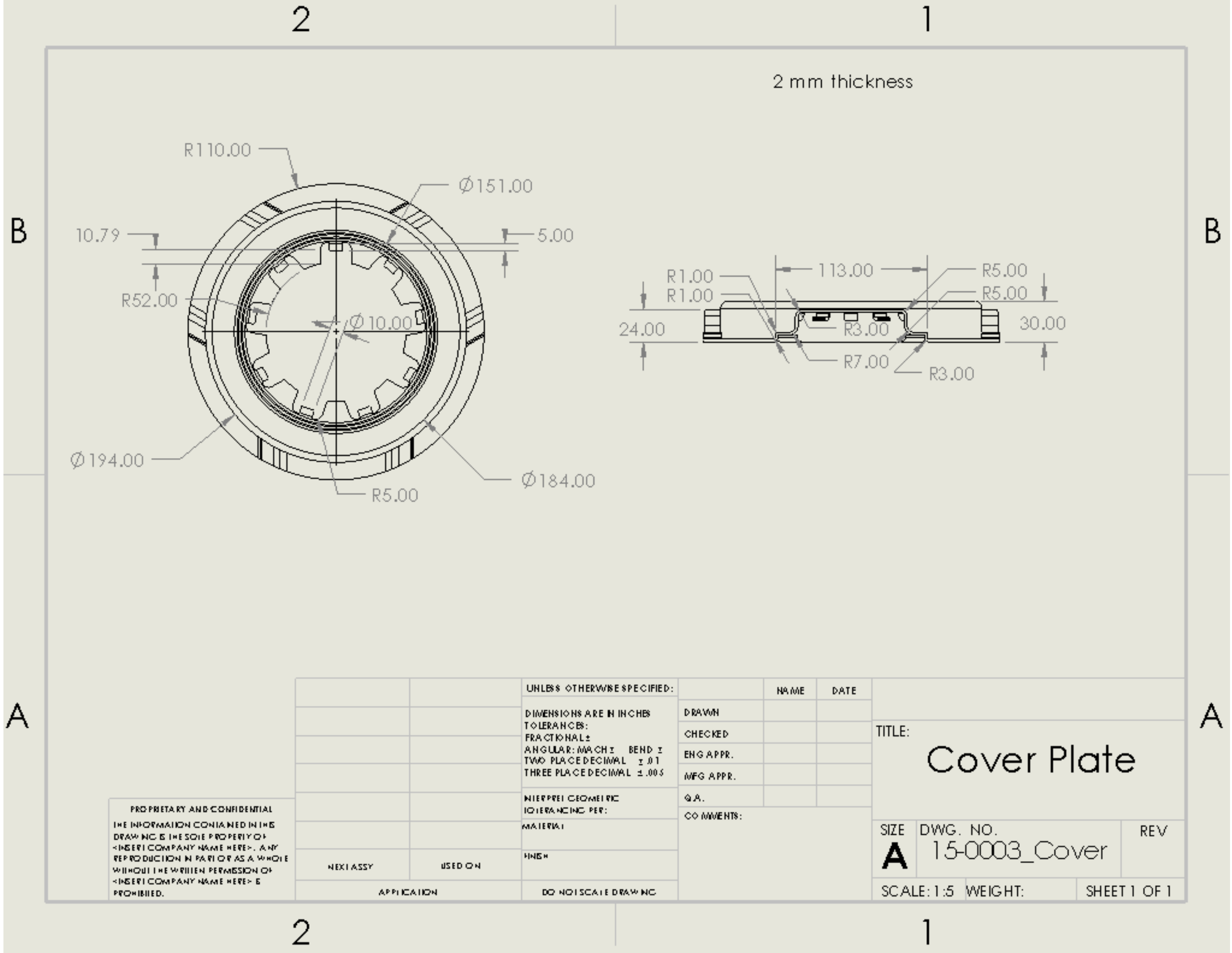


Figure B 1-3: Above is the dimensional layout for the cover plate. This is the third part made for the clutch. The part was made by following the demo in the link [30:00-45:00]: https://youtu.be/azITzOcZ6-g

Appendix B 1-4

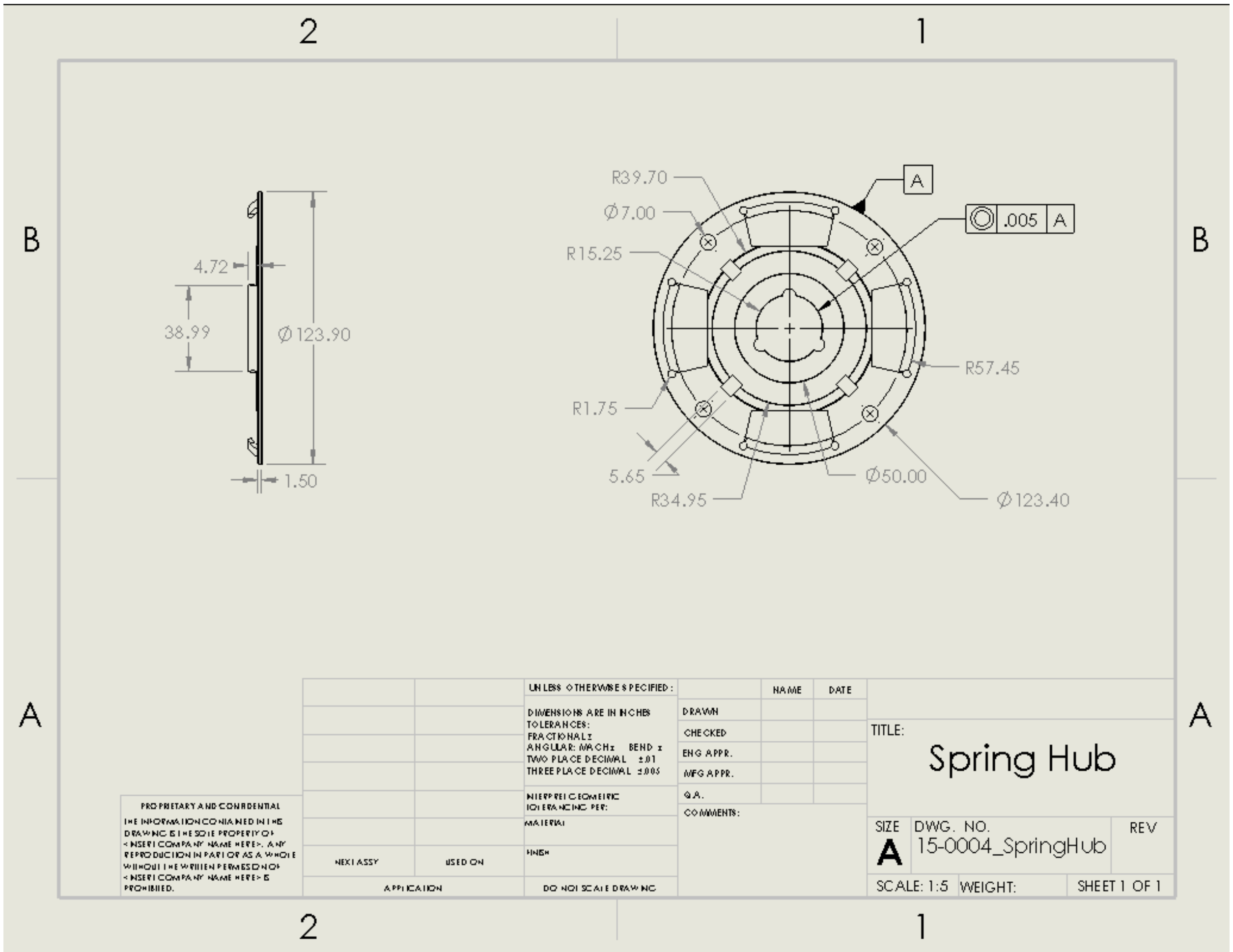


Figure B 1-4: Above is the dimensional drawing for the spring hub which is the fourth part to be made for the clutch. During minutes [50:00 – 1:05:00] the demo for creating the spring hub can be found. https://youtu.be/azITzOcZ6-g

Appendix B 1-5

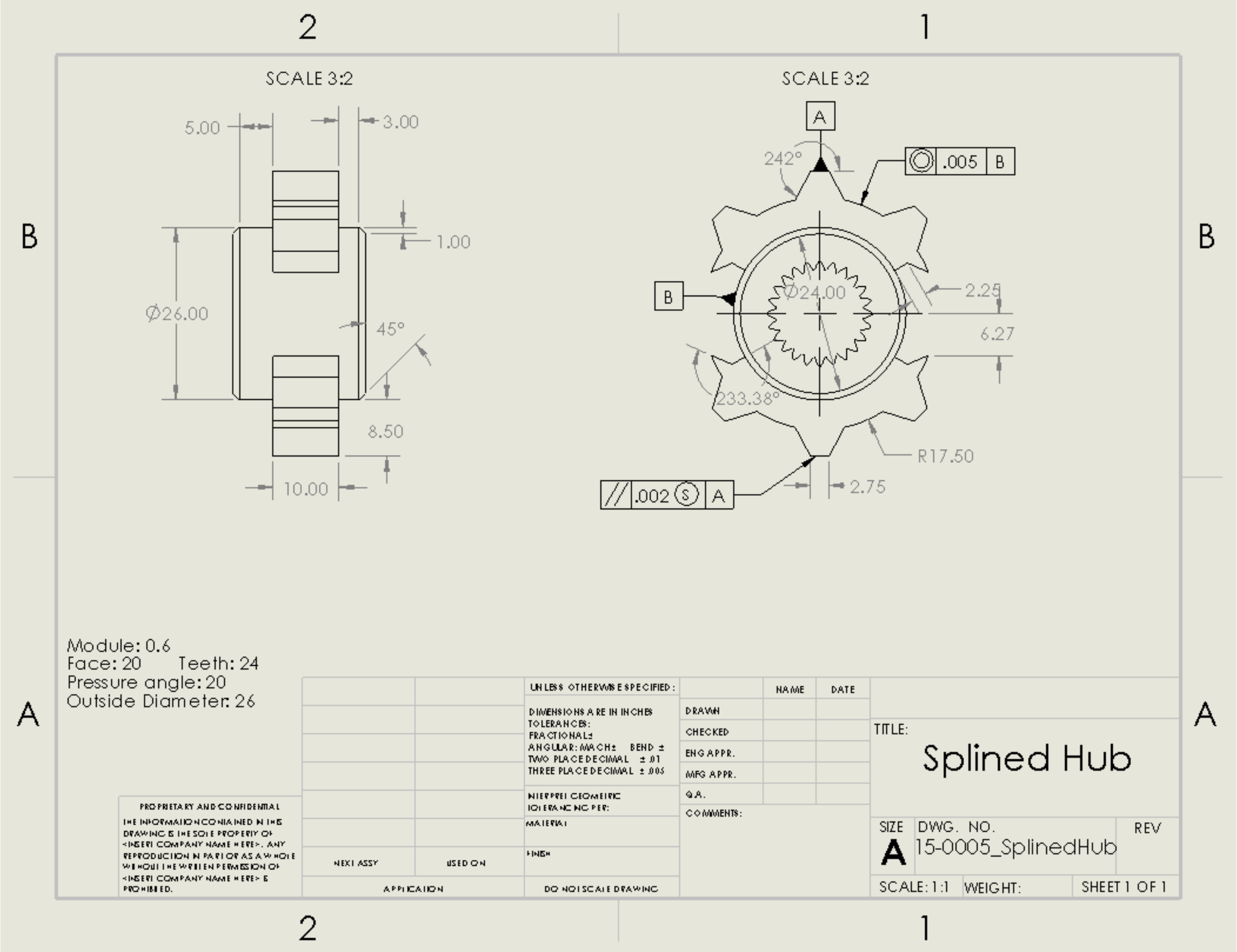


Figure B 1-5: The splined hub is the fifth part to make for the clutch assembly. One can make the part by following along with the demo using the techniques used in minutes [1:05:00 – 1:13:00]: https://youtu.be/azITzOcZ6-g

Appendix B 1-6

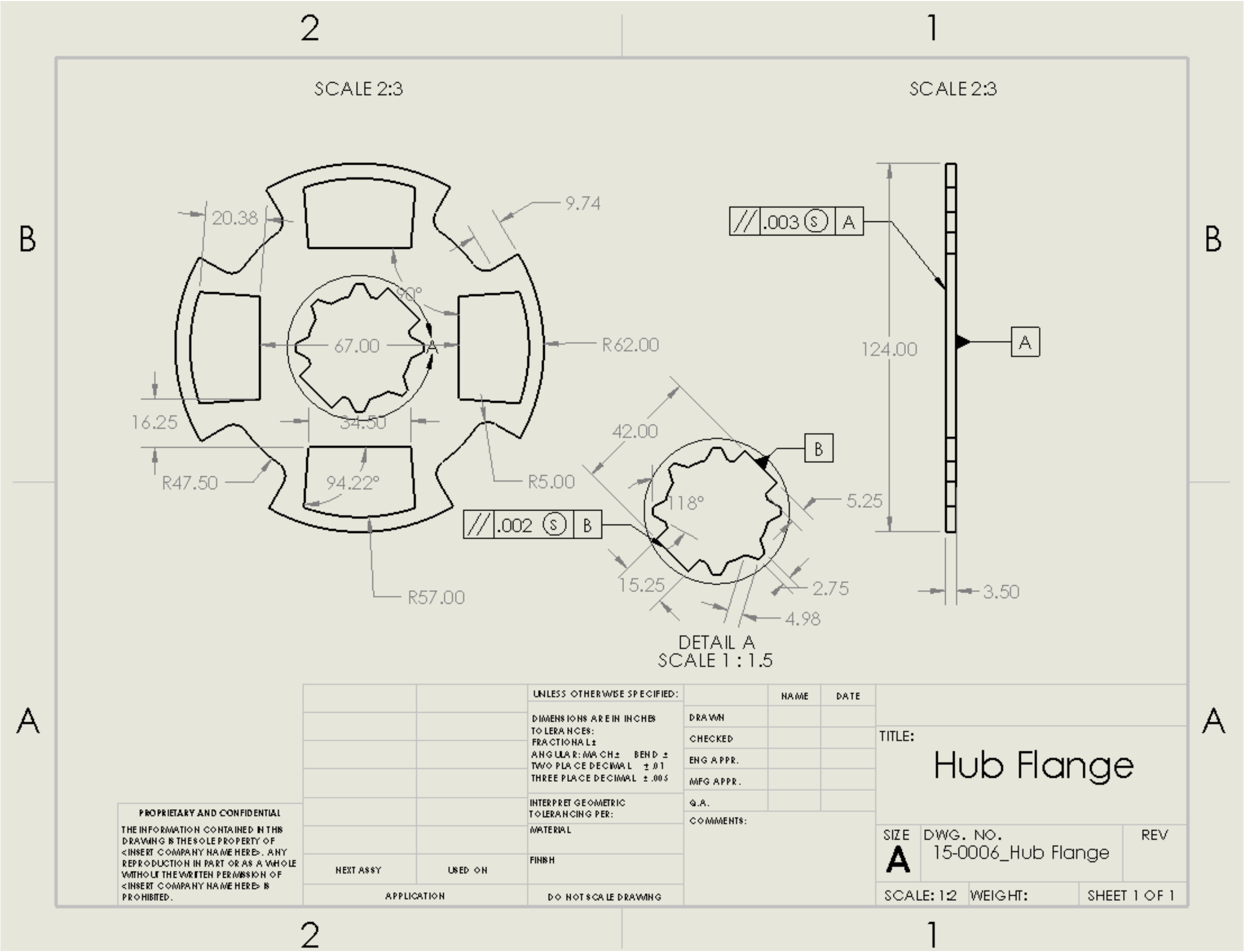


Figure B 1-6: These are the main geometric and dimensional tolerances for the hub flange. This is the 6th part to make following the video [1:13:00 – 1:18:00]: https://youtu.be/azITzOcZ6-g

Appendix B 1-7

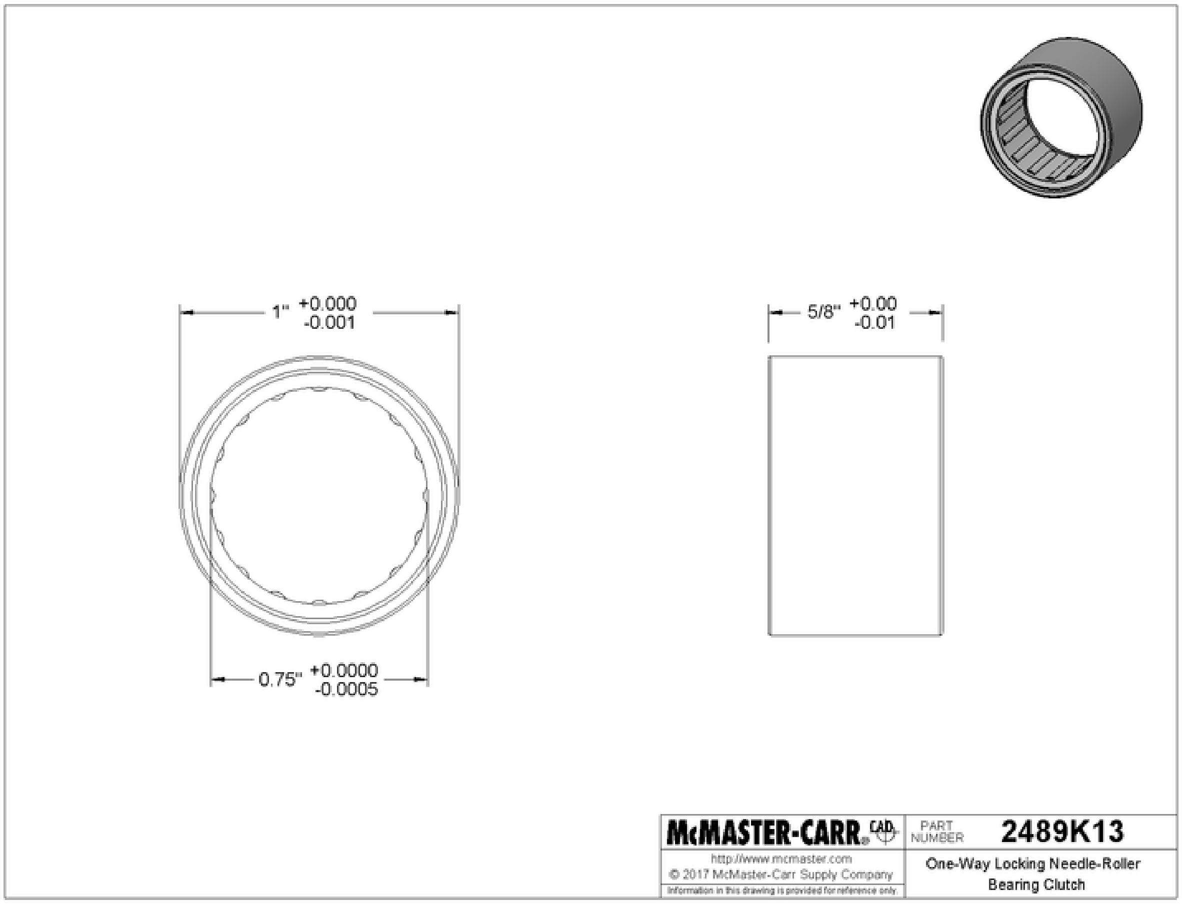
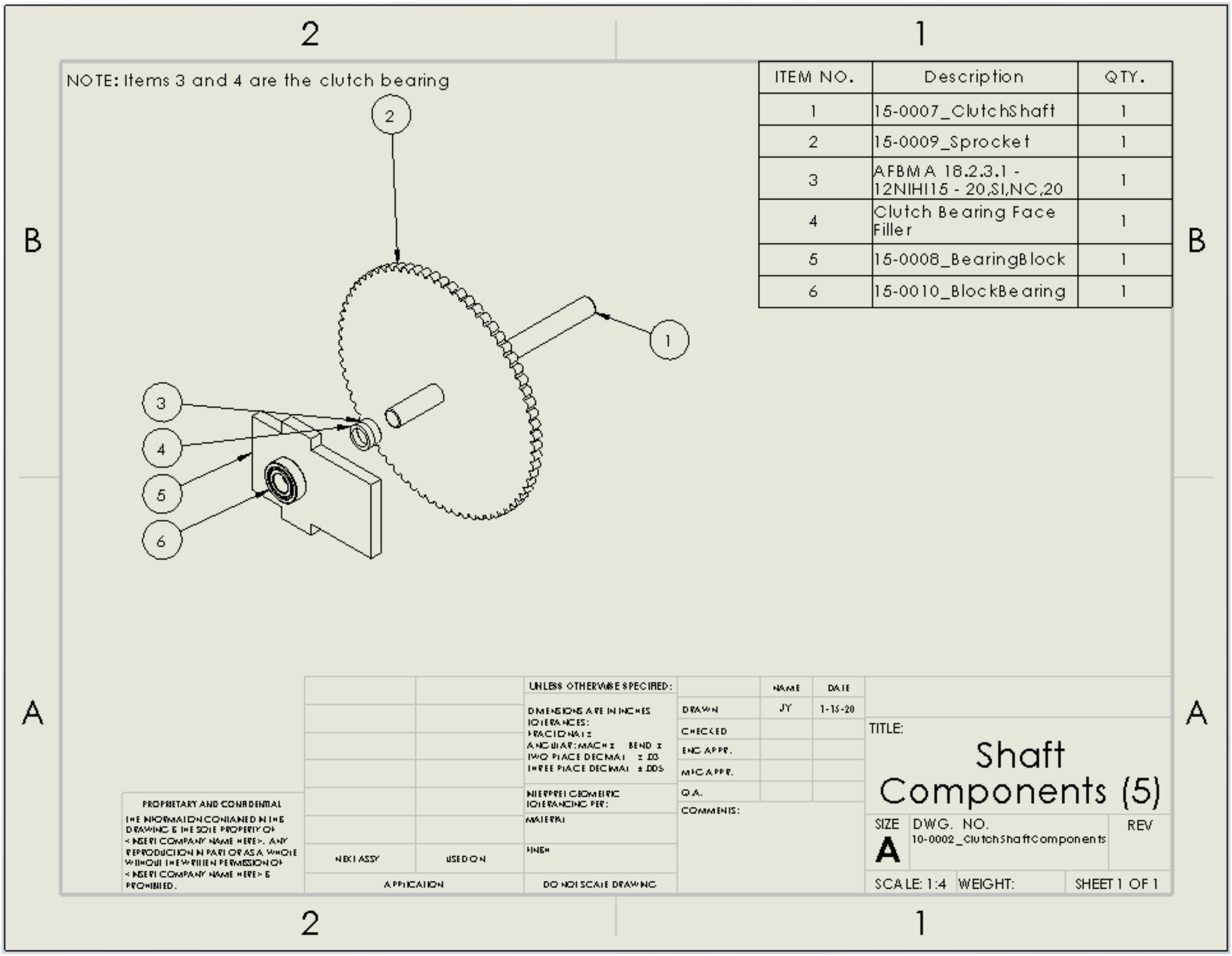


Figure B 1-7: This is a drawing from McMaster-Carr and this is the only part needed to accomplish the project. The torque rating for the clutch bearing is high enough by Appendix A 1-1 standards.

Appendix B 1-8



NOTE: Items 3 and 4 are the clutch bearing

ITEM NO.	Description	QTY.
1	15-0007_ClutchShaft	1
2	15-0009_Sprocket	1
3	AFBMA 18.2.3.1 - 12NIH115 - 20,SI,NC,20	1
4	Clutch Bearing Face Filler	1
5	15-0008_BearingBlock	1
6	15-0010_BlockBearing	1

DRAWN JY 1-15-20

TITLE: Shaft Components (5)

SIZE A

DWG. NO. 10-0002_ClutchShaftComponents

SCALE: 1:4

SHEET 1 OF 1

Appendix B 1-8: The drawing shows all the components on the shaft that the student has to disassemble to place the clutch bearing right up against the sprocket.

Appendix B 1-9

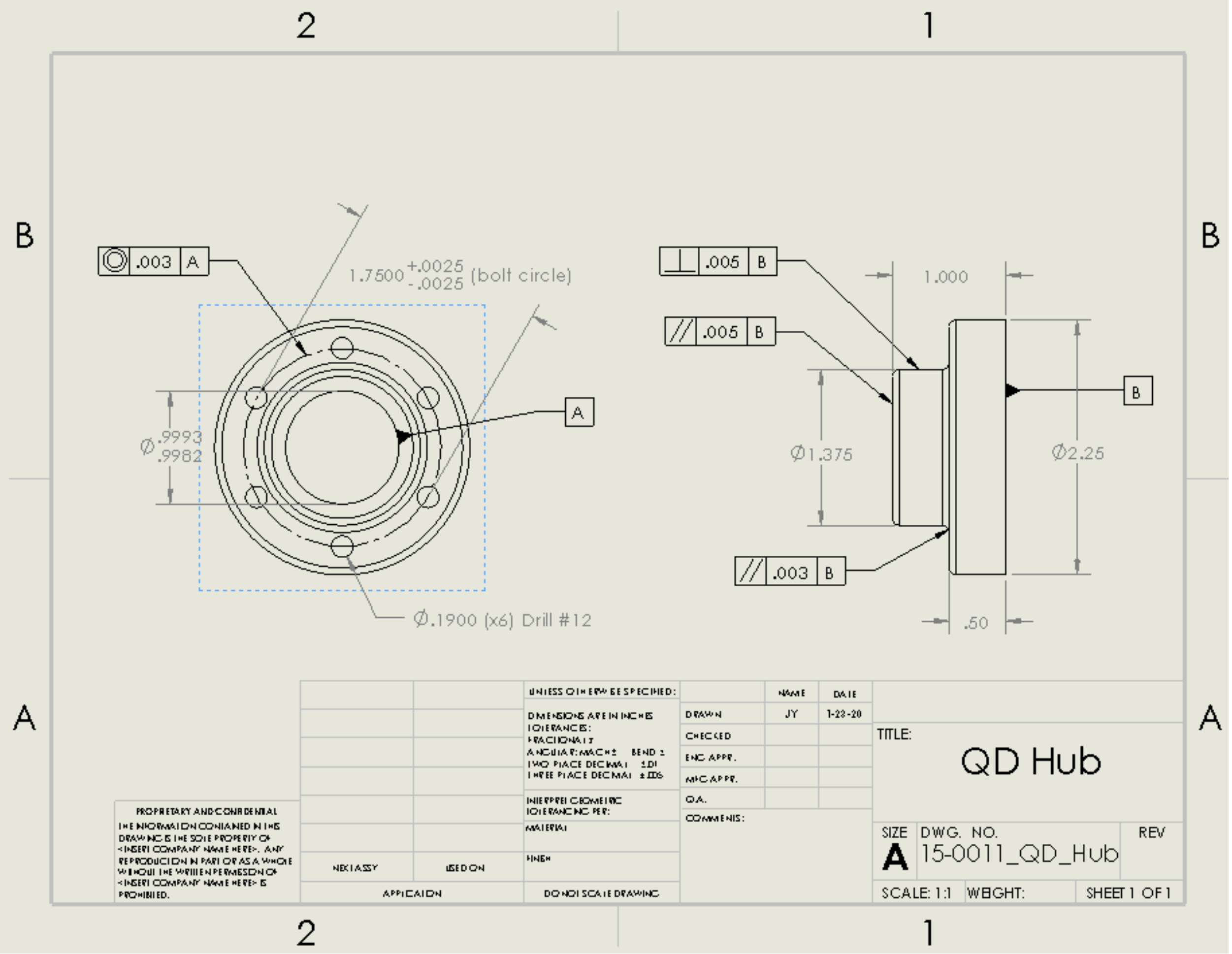


Figure B 1-9: This hub will be manufactured if a hub with the appropriate dimensions cannot be found online.

Appendix B 1-10

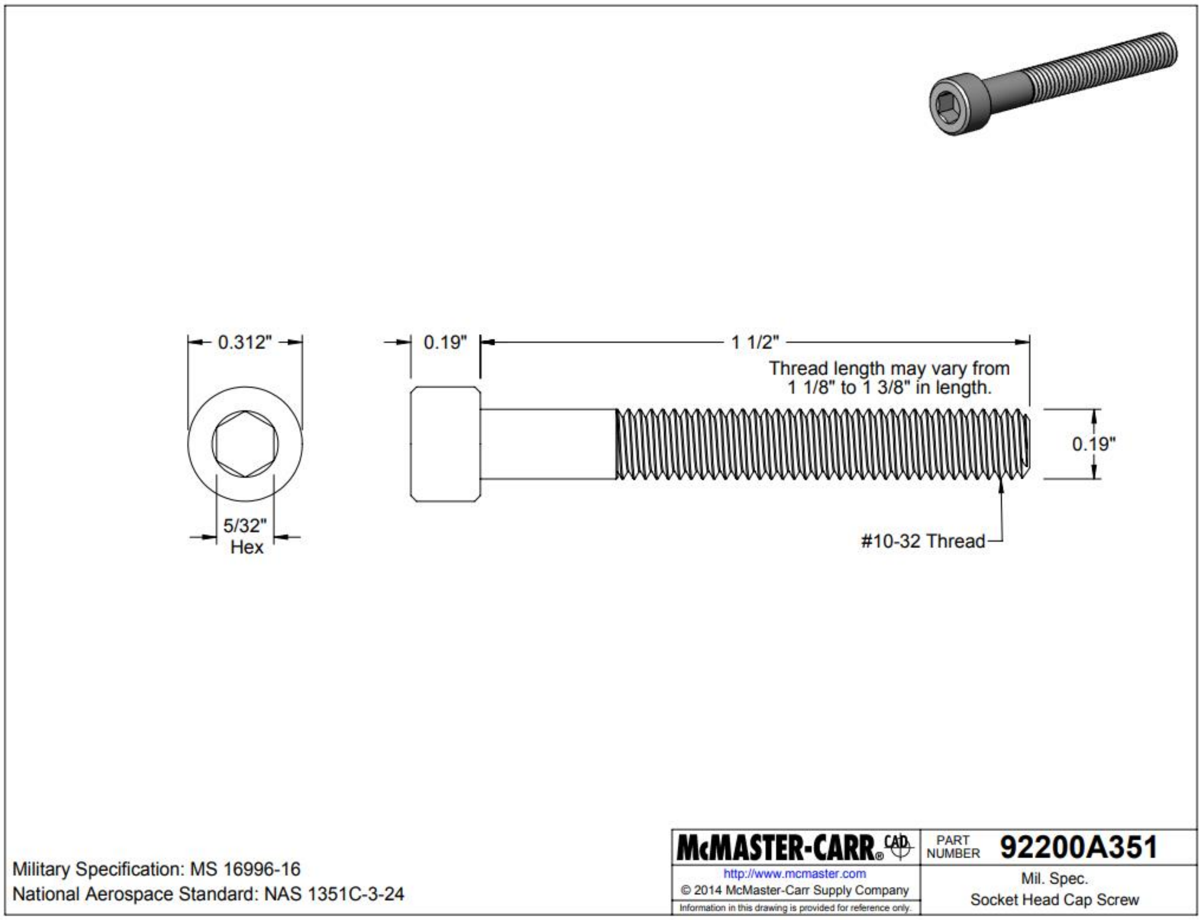


Figure B 1-10: Six of these screws will be used to lock the hub and clutch bearing into place up against the sprocket.

Appendix B 1-11

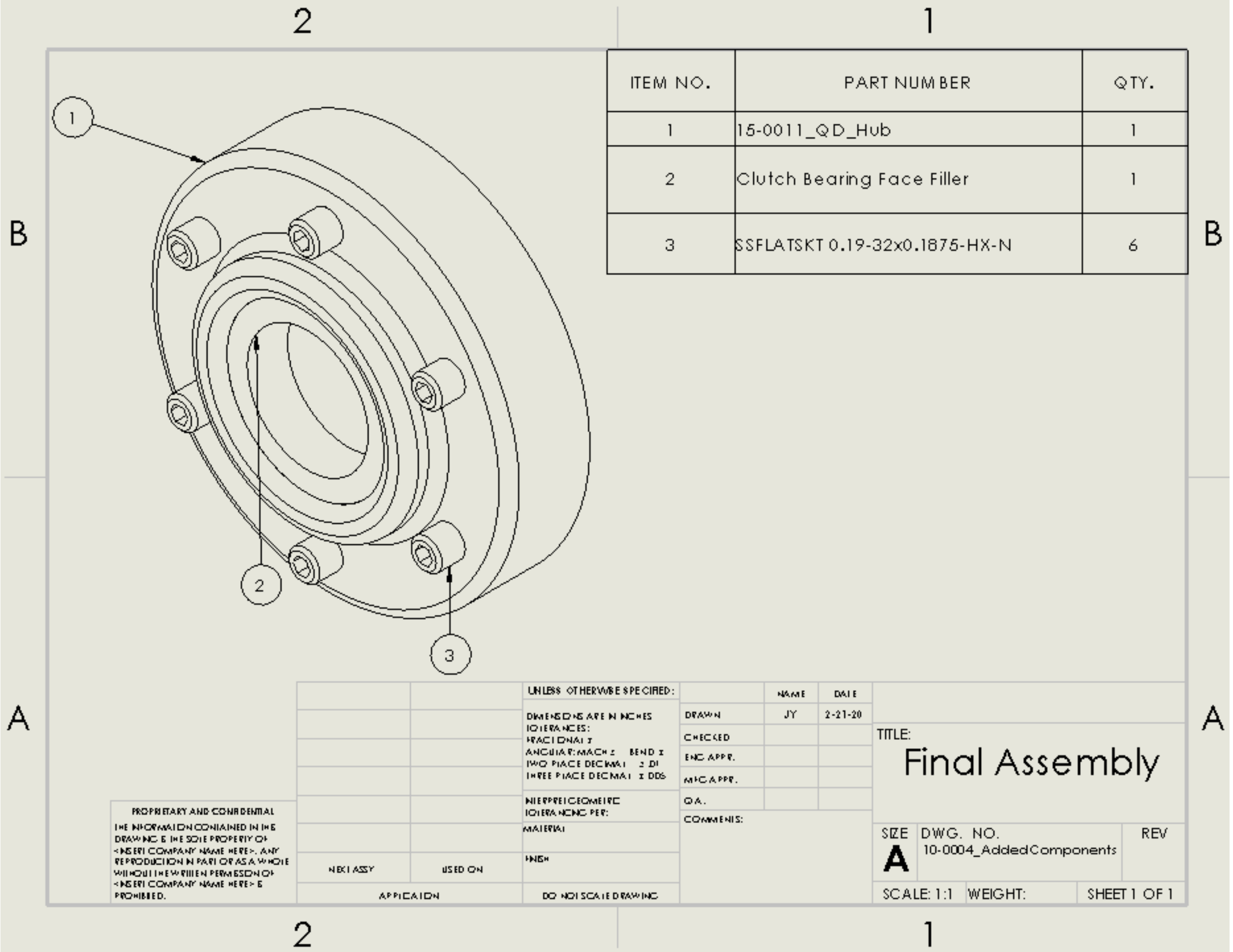


Figure B 1-11: The assembly above includes all of the components this project added to the electrical vehicle.

Appendix C – Parts List

Design 1

Item ID	**Item Description**	**Item Source**
1	Diaphram Spring	mfg
2	Pressure Plate	mfg

3	Cover	mfg
4	Spring Hub	mfg
5	Splined Hub	mfg
6	Hub Flange	mfg
7	Cushioning Plate	mfg
8	Damper Spring	mfg
9	Hub Damping Spring	mfg
10	Cushion Spring	mfg
11	Friction Facing	mfg
12	Plate Washer	mfg
13	Flywheel	mfg
14	Washer Bracket	mfg
15	Cushioning Rivet	mfg
16	Facing Rivet	mfg
17	Mounting Bracket	mfg/machined

Figure C 1-1: Full parts list for clutch assembly.

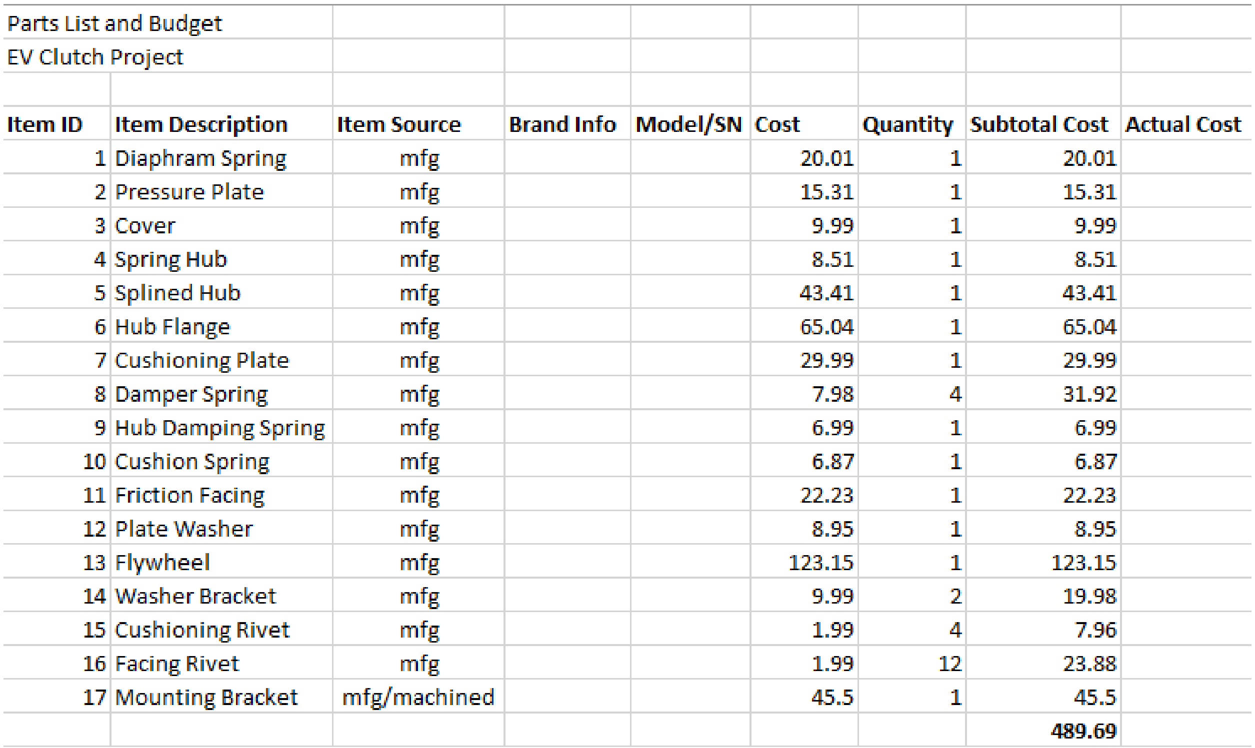
Design 2

Item ID	**Item Description**	**Item Source**
2489K13	Single Row Clutch Bearing	McMaster Carr
89325K65	2.25in Dia. Steel bar stock	McMaster Carr
92200A351	#10-32 thread screws (x6)	McMaster Carr

Figure C 1-2: The first part needed for the second design has a 0.75 inch ID. 17 (ft*lbs) torque rating and a price of $33.50. The stock needed to manufacture the hub is 316 stainless steel at a price of $53.40 for 6 inches. The last parts are the screws that will hold the assembly together at a price of $7.66 per 10 pack.

Appendix D – Budget

Design 1 Budget



Parts List and Budget
EV Clutch Project

Item ID	Item Description	Item Source	Brand Info	Model/SN	Cost	Quantity	Subtotal Cost	Actual Cost
1	Diaphram Spring	mfg			20.01	1	20.01	
2	Pressure Plate	mfg			15.31	1	15.31	
3	Cover	mfg			9.99	1	9.99	
4	Spring Hub	mfg			8.51	1	8.51	
5	Splined Hub	mfg			43.41	1	43.41	
6	Hub Flange	mfg			65.04	1	65.04	
7	Cushioning Plate	mfg			29.99	1	29.99	
8	Damper Spring	mfg			7.98	4	31.92	
9	Hub Damping Spring	mfg			6.99	1	6.99	
10	Cushion Spring	mfg			6.87	1	6.87	
11	Friction Facing	mfg			22.23	1	22.23	
12	Plate Washer	mfg			8.95	1	8.95	
13	Flywheel	mfg			123.15	1	123.15	
14	Washer Bracket	mfg			9.99	2	19.98	
15	Cushioning Rivet	mfg			1.99	4	7.96	
16	Facing Rivet	mfg			1.99	12	23.88	
17	Mounting Bracket	mfg/machined			45.5	1	45.5	
							489.69	

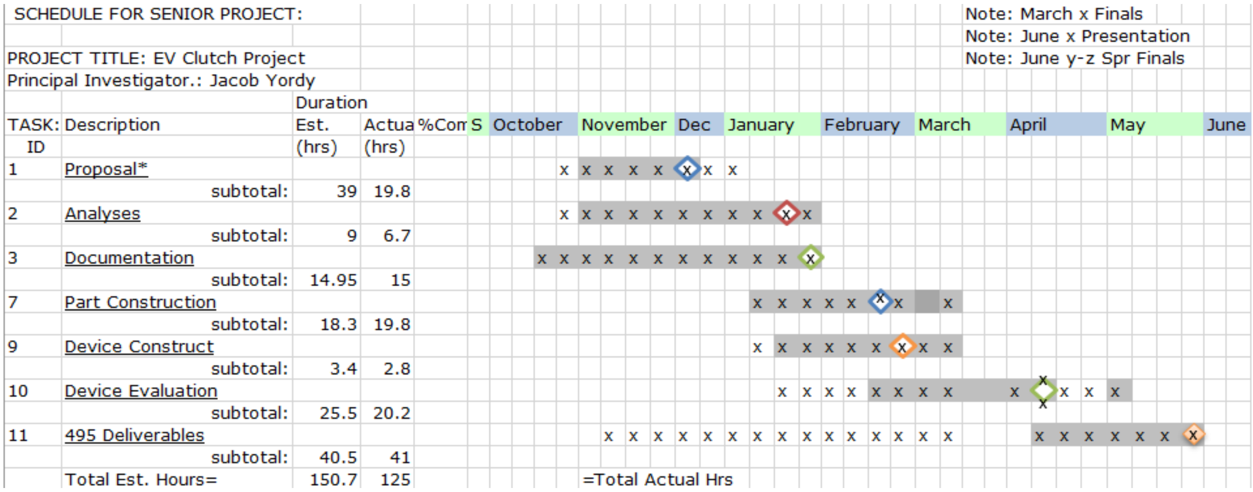
Figure D 1-1: Here are all of the parts and related quoted expenses for the project.

Design 2 Budget

Part	**Price**
0.75 inch ID clutch bearing	**$33.50**
2.25 inch Dia. Steel bar stock (6in long)	**$53.40**
#10-32 threaded screws (10 pack)	**$7.66**
	$94.56 total

Including the $211.00 for internet needed in the spring quarter, the project spent a total of **$305.56** out of pocket.

Appendix E – Schedule



SCHEDULE FOR SENIOR PROJECT:

PROJECT TITLE: EV Clutch Project
Principal Investigator.: Jacob Yordy

Note: March x Finals
Note: June x Presentation
Note: June y-z Spr Finals

TASK: ID	Description	Duration Est. (hrs)	Actua (hrs)	%Con
1	Proposal*			
	subtotal:	39	19.8	
2	Analyses			
	subtotal:	9	6.7	
3	Documentation			
	subtotal:	14.95	15	
7	Part Construction			
	subtotal:	18.3	19.8	
9	Device Construct			
	subtotal:	3.4	2.8	
10	Device Evaluation			
	subtotal:	25.5	20.2	
11	495 Deliverables			
	subtotal:	40.5	41	
	Total Est. Hours=	150.7	125	

Figure E 1-1: The overall outline of the Gantt Chart for the project.

Appendix G – Testing Report

EV Clutch Project Test Report

Introduction

The main requirement that will be tested is the fuel/power efficiency of the electric vehicle. The torque rating was given by the manufacturer and the torque rating was about twice as much as needed. The torque rating requirement is known to be met. The endurance of the clutch bearing will be informally tested. The electric vehicle is not used often, so the shaft should not rotate fully for over a million cycles within 5 years of service. If the clutch fails before March 1st, 2025 then the endurance requirement of the clutch will be deemed unachieved.

With the hill coasting test, the coasting distance is what will be measured and recorded for data. The expectation is the coasting distance will be longer when the clutch is attached to the vehicle. The fully charged battery test will measure the distance (in laps) when the clutch is attached to the vehicle compared to when the clutch is removed. The expectation is that the vehicle will travel further (more laps) on a fully charged battery when the clutch is attached.

Data can simply be recorded on an excel spreadsheet or paper for the coasting test. Bring two different colored chalk sticks to mark off where the front end of the vehicle stops. One color of chalk is for clutch trials and the other color is for no clutch trials. Make sure to have a measuring tape at least 200 feet in length. The shortest coasting mark (chalked off) can be considered the “zero-foot mark”. The rest of the chalk marks can be measured from the zero-foot mark; this will reduce the length of measuring tape needed. The data of interest will be the difference in coasting distances. The zero-foot mark is expected to be associated with a no clutch trial. Data can simply be recorded on excel or be handwritten for the fully charged battery test. Record the number of laps and associated distance traveled after the vehicle runs out of battery. The driver should drive as if he or she were racing.

Methods

Resources needed for the hill coasting test are the catmobile, an allen-wrench, two crescent wrenches, two 4x4 wood blocks, a hammer, a truck and a trailer. Two humans will be needed. One person will always need to be the driver and one person must hold up the car at the starting position before releasing the vehicle. Two different colors of chalk will be needed, as well as a long measuring tape (i.e. 200 feet). Excel will be needed to record the coasting distances. The same resources are needed, except the fully charged battery tests will need a track and an outlet for charging the battery.

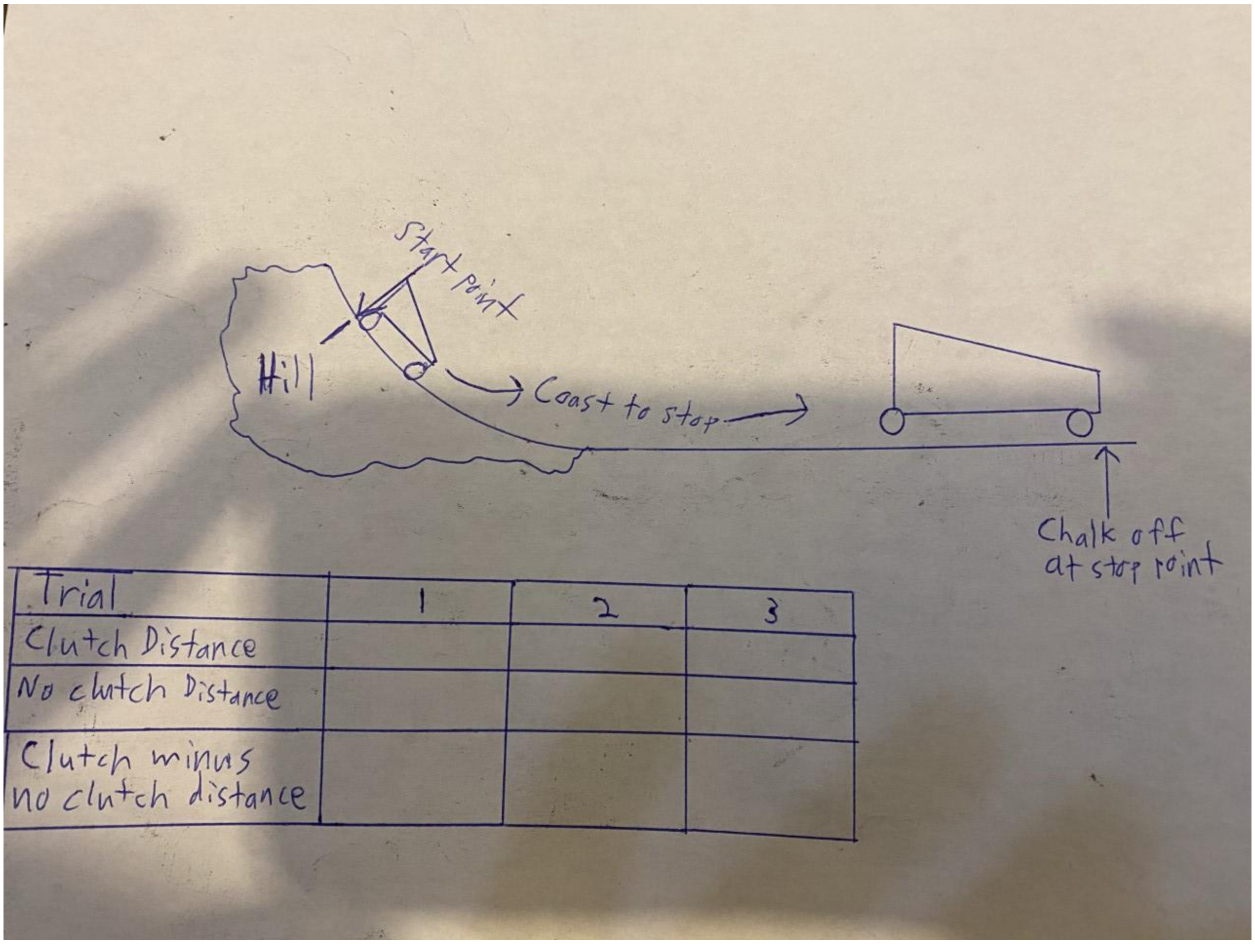
It should be noted that there are no brakes on the electric vehicle as of May 5th and the earliest anticipated date for having brakes would be June 1st, 2020. Having brakes would make these tests incredibly safer, especially the coasting tests. Depending on how tight the turns are on the track, brakes may not necessarily be needed if the driver is alone on the track. To reduce safety risks in the coasting test, start releasing the vehicle from the bottom of the hill and keep moving the starting point a foot higher on the hill until the vehicle coasts about 200 feet. What needs to be avoided is starting high up on the hill allowing the vehicle to coast well beyond 200 feet. A lot can go wrong with extended coasting distances, especially when brakes are not there to stop the vehicle. Once brakes are applied, higher speed coasting tests can be exercised as brakes could stop the car if needed.

Considering the thickness of the chalk and eye balling where the front of the vehicle is when coasting stops, one measurement to the next may be as far off as +/- 2 inches in the coasting test. If the temperature is within 10 degrees and the surface is dry each trial, then the distance can be off by +/- 1 lap in the fully charged battery tests depending on how consistent the driver is with his or her speed and approach on turns between trials. Tables and bar graphs will be used to represent the data in both tests.

Test Procedures

Hill Coasting Test

Overview



Trial	1	2	3
Clutch Distance			
No clutch Distance			
Clutch minus no clutch distance			

Duration

The coasting test was planned to be exercised and completed on May 5th, 2020. It was expected to take 3 hours to complete all the trials and the clutch assembly process is included too. Round trip travel time is expected to be 8.5 hours.

Place

The location (pictured on the next page) is at the corner of Pacific Way and 38th Ave in Longview, Washington. The blue line represents the intended straight-line coasting path.

Resources Needed

1. Two people (One always the driver)
2. Catmobile with clutch assembly
3. Allen wrench
4. Two crescent wrenches
5. Two 4x4 wood blocks
6. Long measuring tape (200 feet or more)
7. A hammer
8. Two 4x4 wood blocks
9. Chalk sticks (two different colors)
10. Trailer and Truck

Step-by-Step Procedure

*Use same person to steer car every time (same weight).

*Use a straight line path to minimize steering and side loads.

1. Mark a starting point on the hill and set all the tires pressure to 50 psi.
2. Line up the front of the car even with the starting point.
3. Let go of the car (don’t push) and let the vehicle coast until it stops without the aid of braking.
4. Mark off where the front of the vehicle stops coasting. Use one color for clutch trials and use a different color for trials without the clutch.
5. Repeat steps 2-4 until three or more trials are completed with the clutch on and clutch off.

Risk and Safety Concerns

Having no brakes causes almost all, if not all the safety concerns. Look ahead where the vehicle will be coasting to make sure no pedestrians or bicyclists are in the way. Also, consider the second paragraph under the Methods section in this document when beginning the test.

Discussion

Without brakes, the longer the coasting distance the more dangerous the test becomes. Until brakes are applied the coasting tests are limited to short distance and low speed. As brought up by a colleague, getting the vehicle up to full speed then allowing it to coast could show practical results. Of course, to coast from full speed it would be ideal to have brakes because they might be especially needed at high speed. The hill coasting test is consistent enough to give results that can be reflected on. As said earlier, start from the bottom of the hill. If high enough on the hill when released, the vehicle could reach speeds beyond what the vehicle could reach from running at full power on level ground (a.k.a. max speed). To avoid that, it must be emphasized that the vehicle starts being released from the bottom. The vehicle can be moved up the hill one foot in elevation at a time until the vehicle coasts for about 200 feet.

Fully Charged Battery Distance Test

Overview

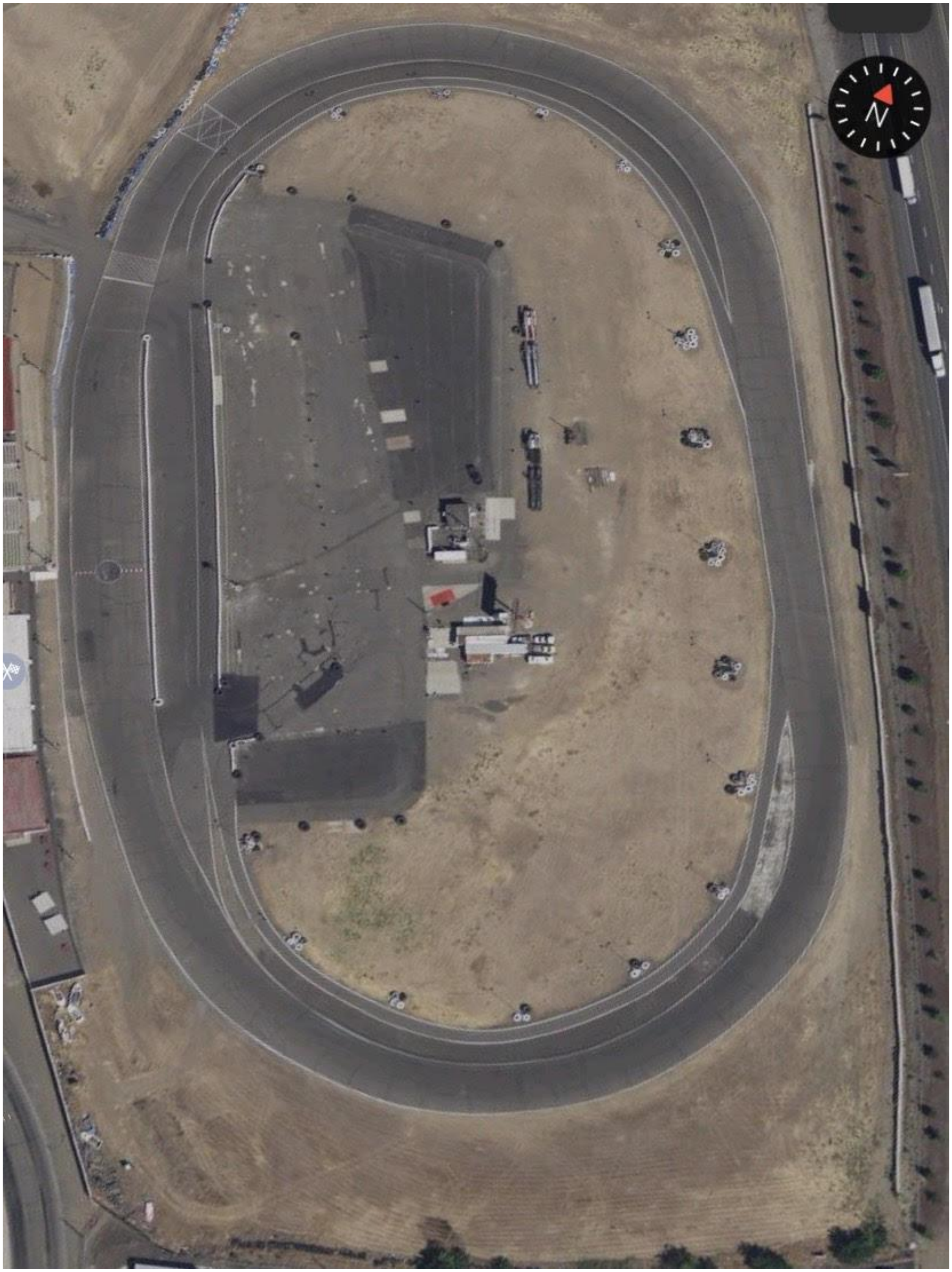
The vehicle will simply be raced around the track with the battery fully charged. Surface conditions on the track should be dry both racing days and the temperature difference shouldn’t be more than 10 degrees between the two days (temperature recorded at start of race).

Duration

There will be two days of racing, so the battery has plenty of time to charge. It's expected that each day will require 5 hours from the people involved. 2 hours for travel, 2 hours at the track, and 1 hour of storage is expected each day.

Place

The Yakima Speedway (pictured on the next page) address is 1600 Pacific Ave in Yakima, Washington. This project has not been granted access to this track and the track is closed until June 1st , 2020 or even later.


N

Resources Needed

1. Two people (One always the driver)
2. Catmobile with clutch assembly
3. Allen wrench
4. Two crescent wrenches
5. Two 4x4 wood blocks
6. A hammer
7. Trailer and Truck
8. Laptop with Excel
9. Outlet for charging battery
10. The racing track

Step-by-Step Procedure

Clutch's Affect on MPG:

4. Fully charge the battery. Record Temperature at the start of the race.
5. Race the EV with clutch until battery is drained. Record distance and time for run.
6. Fully charge the battery. Record temperature at the start of the race.
7. Race the EV w/o clutch until battery is drained. Record distance and time for run.
8. Compare distance traveled with clutch vs. w/o clutch.

Risk and Safety Concerns

Having no brakes is still a safety concern, but not so much for this test. The track is big enough where full speed turns may be very doable, especially on dry days. The speedway may not even allow the vehicle on the track without brakes. This test may not be exercisable without brakes, so that's why this project would focus on helping install a brake system for the electric vehicle.

Discussion

The ultimate challenge is that the track will be open only as early as June 1^{st}. If this track is closed, it is likely other tracks are closed due to the coronavirus response as well.

Deliverables

Results

Hill Coasting Test

Trial	1	2	3
Clutch Distance			
No Clutch Distance			
Row 2 minus Row 3			

Fully Charged Battery Distance Test

Trial	1	2	3
Clutch # of laps			
No Clutch # of laps			
Clutch Distance			
No Clutch Distance			
Clutch Trial Time			
No Clutch Trial Time			

Calculated Results

Hill Coasting Test

Given: 1. 500 lbs (EV and driver) 2. Certain Height on hill 3. Initial Velocity is zero

4. Final velocity is zero 5. 17 ft*lb torque rating for clutch

Find: Coasting distance with clutch and without clutch.

Assume: 1. Hill rolls into perfectly level surface. 2. Conservation of Energy applies

3. Same roughness of surface each trial 4. Air resistance can be neglected.

Method: 1. Apply method of conservation of energy 2. Incorporate the torque energy from the clutch to calculate the added distance it brings about.

Solution:

Fully Charged Battery Distance Test

Given: 1. (Certain Amount) of storage energy in battery. 2. 500 lbs (EV and Driver)

Find: The distance the EV will travel with the clutch and without the clutch.

Assume: 1. Same amount of energy is stored in battery for each trial.

2. No significant efficiency loss between charges

Method: 1. Conservation of Energy principles

Solution:

Success Criteria Values

Hill Coasting Test

If the clutch consistently allows the vehicle to coast 10 feet or more compared to when the vehicle doesn’t have a clutch, then the coasting test shows success for the efficiency requirement.

Fully Charged Battery Distance Test

Assuming the battery will last about an hour, the vehicle should travel a mile or more in distance with the clutch attached to the vehicle compared to when the clutch is removed. This would also give a “second opinion”, if you will, in promising that the efficiency requirement has been satisfied.

Conclusions

As the anticipated results show from an analysis using conservation of energy principles, the clutch could be very useful in counteracting the drag of the motor, and thus allowing the vehicle to go further with the same energy input. That would accomplish the mission statement for this project.

Appendix G1 – Procedure Checklists

Hill Coasting Test

1. Acquire all resources (check Test Procedure).
2. Safely strap the EV in the trailer and head to testing site.
3. Start at bottom of hill and move up foot by foot until the EV coasts for about 200 feet.
4. Perform the Test.
5. When trials are complete, pack up, strap the EV securely in the trailer, and head back to the Catmobile storage center.

Fully Charged Battery Distance Test

1. Acquire all resources (check Test Procedure).
2. Safely strap the EV in the trailer and head to testing site.
3. Make sure the battery is fully charged before performing the test.
4. Perform the Test.
5. When the trial is complete, pack up, strap the EV securely in the trailer, and head back to the Catmobile storage center.
6. Charge the battery at the storage center.
7. On the next day (or a different day) go through the checklist again, but this time race the EV without the clutch.

Appendix G2 – Data Forms

Results

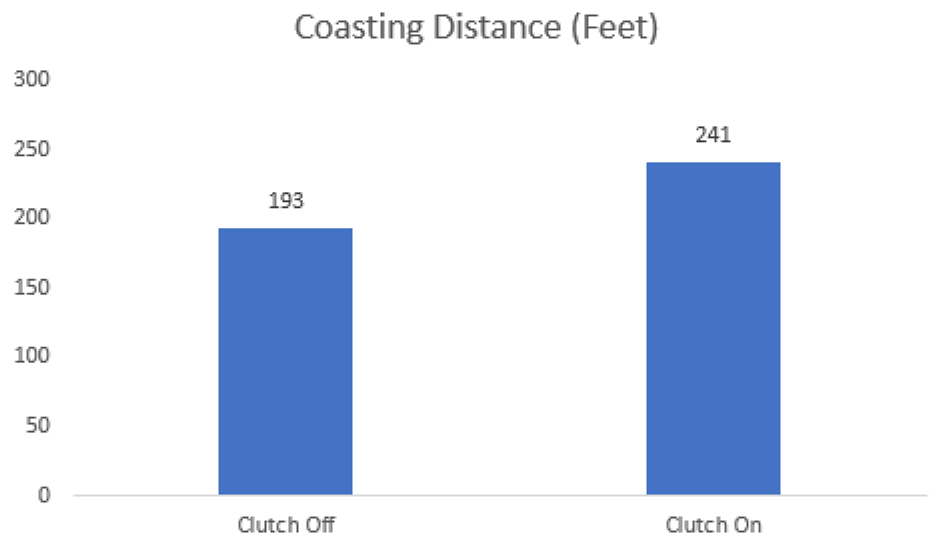
Hill Coasting Test

Trial	1	2	3
Clutch Distance			
No Clutch Distance			
Row 2 minus Row 3			

Fully Charged Battery Distance Test

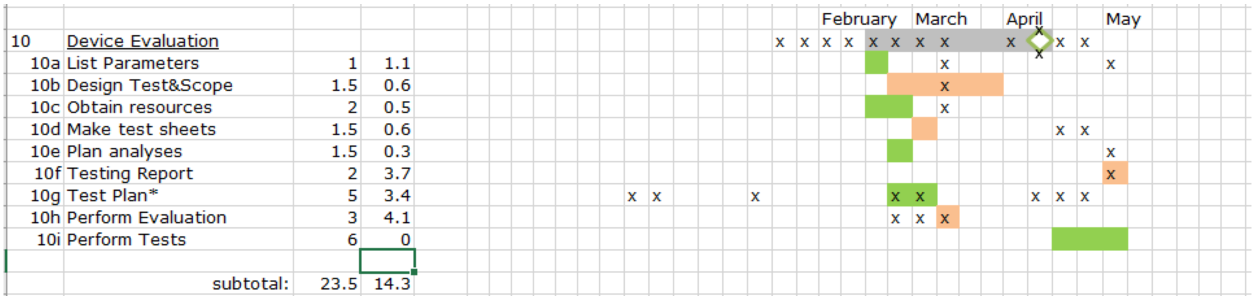
Trial	1	2	3
Clutch # of laps			
No Clutch # of laps			
Clutch Distance			
No Clutch Distance			
Clutch Trial Time			
No Clutch Trial Time			

Appendix G3 – Raw Data



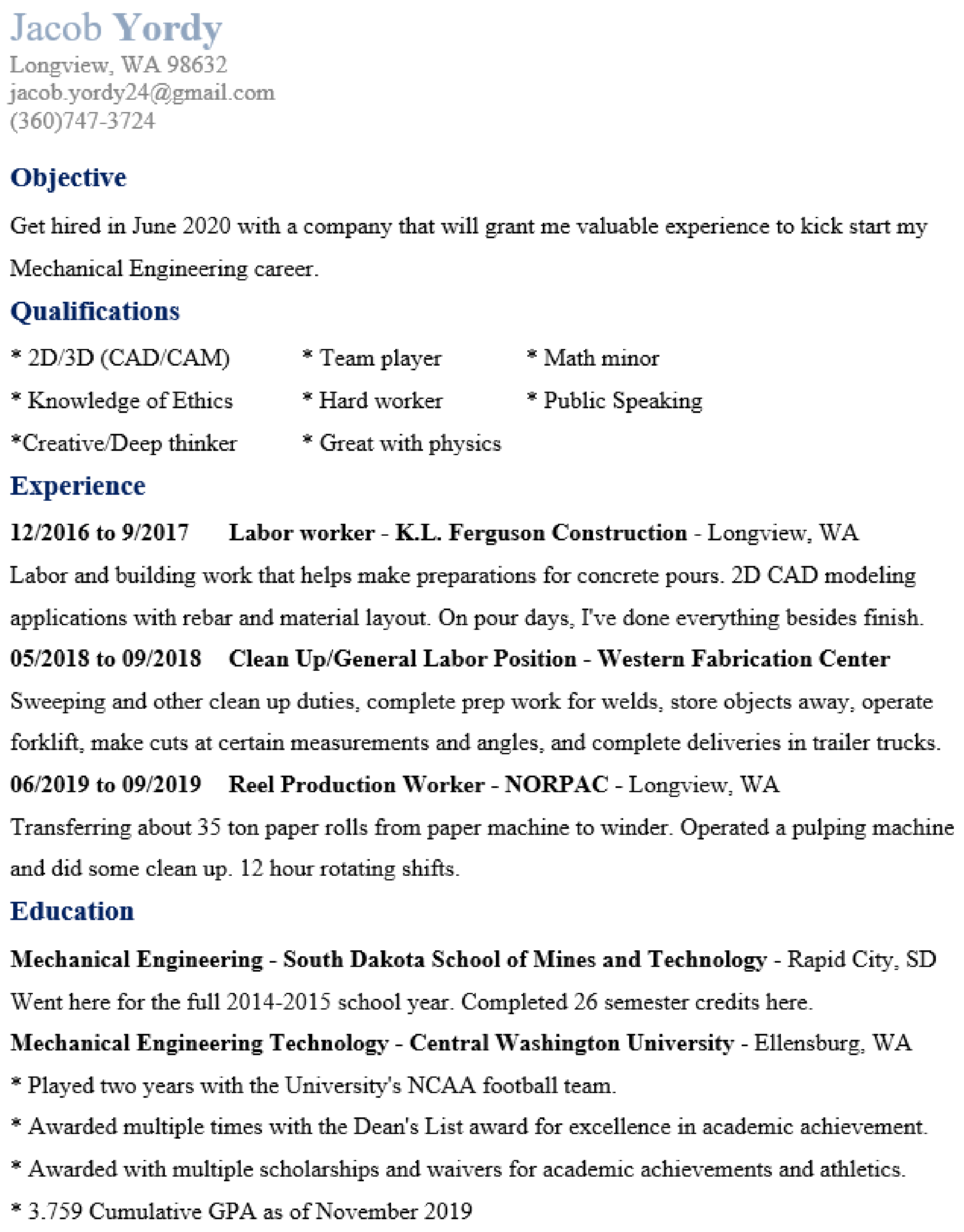
Appendix G4 - Evaluation Sheet

Appendix G5 – Gantt Chart



10	Device Evaluation		
10a	List Parameters	1	1.1
10b	Design Test&Scope	1.5	0.6
10c	Obtain resources	2	0.5
10d	Make test sheets	1.5	0.6
10e	Plan analyses	1.5	0.3
10f	Testing Report	2	3.7
10g	Test Plan*	5	3.4
10h	Perform Evaluation	3	4.1
10i	Perform Tests	6	0
	subtotal:	23.5	14.3

Appendix H – Resume



Jacob Yordy

Longview, WA 98632
jacob.yordy24@gmail.com
(360)747-3724

Objective

Get hired in June 2020 with a company that will grant me valuable experience to kick start my Mechanical Engineering career.

Qualifications

* 2D/3D (CAD/CAM)
* Knowledge of Ethics
*Creative/Deep thinker
* Team player
* Hard worker
* Great with physics
* Math minor
* Public Speaking

Experience

12/2016 to 9/2017 Labor worker - K.L. Ferguson Construction - Longview, WA

Labor and building work that helps make preparations for concrete pours. 2D CAD modeling applications with rebar and material layout. On pour days, I've done everything besides finish.

05/2018 to 09/2018 Clean Up/General Labor Position - Western Fabrication Center

Sweeping and other clean up duties, complete prep work for welds, store objects away, operate forklift, make cuts at certain measurements and angles, and complete deliveries in trailer trucks.

06/2019 to 09/2019 Reel Production Worker - NORPAC - Longview, WA

Transferring about 35 ton paper rolls from paper machine to winder. Operated a pulping machine and did some clean up. 12 hour rotating shifts.

Education

Mechanical Engineering - South Dakota School of Mines and Technology - Rapid City, SD

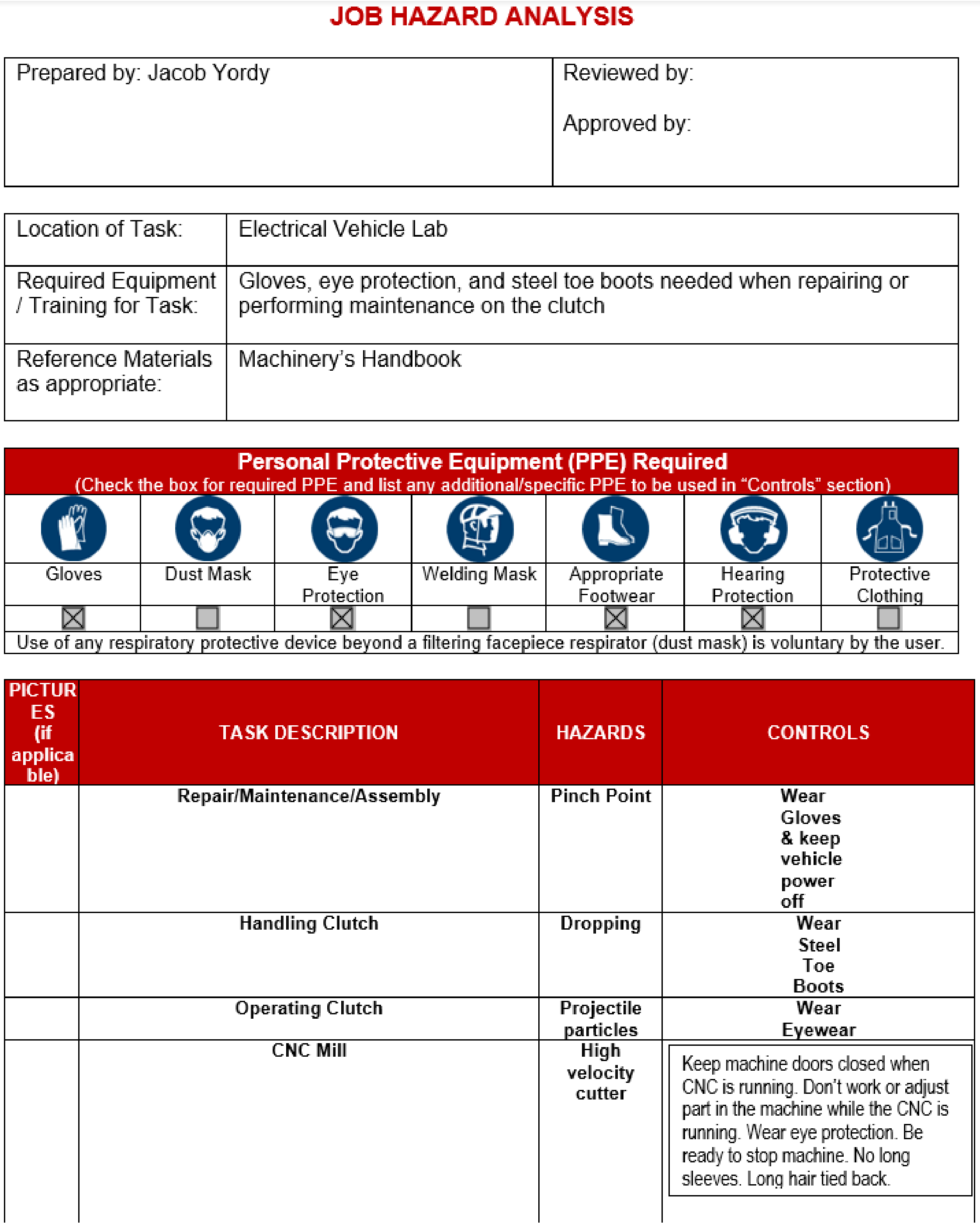
Went here for the full 2014-2015 school year. Completed 26 semester credits here.

Mechanical Engineering Technology - Central Washington University - Ellensburg, WA

* Played two years with the University's NCAA football team.
* Awarded multiple times with the Dean's List award for excellence in academic achievement.
* Awarded with multiple scholarships and waivers for academic achievements and athletics.
* 3.759 Cumulative GPA as of November 2019

The **Mechanical FE has also been **passed** by this student. FE taken on Jan. 25th, 2020.

Appendix J – Hazard Analysis



JOB HAZARD ANALYSIS

Prepared by: Jacob Yordy	Reviewed by: Approved by:

Location of Task:	Electrical Vehicle Lab
Required Equipment / Training for Task:	Gloves, eye protection, and steel toe boots needed when repairing or performing maintenance on the clutch
Reference Materials as appropriate:	Machinery's Handbook

Personal Protective Equipment (PPE) Required

(Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)

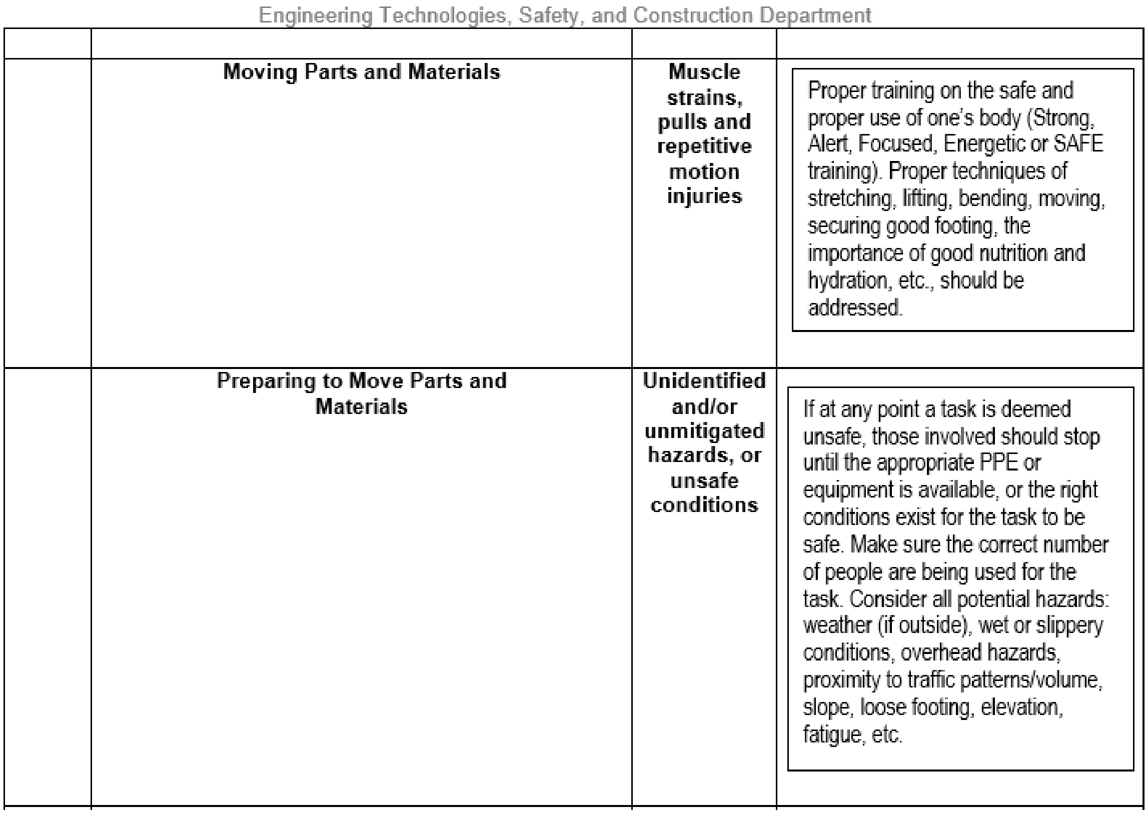
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☒	☐	☒	☐	☒	☒	☐

Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	Repair/Maintenance/Assembly	**Pinch Point**	**Wear Gloves & keep vehicle power off**
	Handling Clutch	**Dropping**	**Wear Steel Toe Boots**
	Operating Clutch	**Projectile particles**	**Wear Eyewear**
	CNC Mill	**High velocity cutter**	Keep machine doors closed when CNC is running. Don't work or adjust part in the machine while the CNC is running. Wear eye protection. Be ready to stop machine. No long sleeves. Long hair tied back.

Figure J 1-1a: Here are some safety precautions to follow when working with the clutch.

Picture 1 of 2.



Engineering Technologies, Safety, and Construction Department

	Moving Parts and Materials	**Muscle strains, pulls and repetitive motion injuries**	Proper training on the safe and proper use of one's body (Strong, Alert, Focused, Energetic or SAFE training). Proper techniques of stretching, lifting, bending, moving, securing good footing, the importance of good nutrition and hydration, etc., should be addressed.
	Preparing to Move Parts and Materials	**Unidentified and/or unmitigated hazards, or unsafe conditions**	If at any point a task is deemed unsafe, those involved should stop until the appropriate PPE or equipment is available, or the right conditions exist for the task to be safe. Make sure the correct number of people are being used for the task. Consider all potential hazards: weather (if outside), wet or slippery conditions, overhead hazards, proximity to traffic patterns/volume, slope, loose footing, elevation, fatigue, etc.

Figure J 1-1b: Here are some more safety considerations for the project. Picture 2 of 2.

Reference - UC Berkley.