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RC Baja-Drivetrain & Steering

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RC Baja-Drivetrain & Steering

By

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&
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ABSTRACT

There was a need for an RC car that would turn the power of a brushless motor into torque to the wheels, in order for it to move forward and backward. The car needed to meet given requirements in order to compete in the annual American Society of Mechanical Engineers (ASME) RC Baja competition. The team requirements were to reach a top speed of 20 mph, turn 60° in both directions, survive a three-foot drop, and spend no more than $500 total on the project. In order to meet the requirements, the device chosen was an RC Baja that had a floating rear end. The Baja was broken down into two categories, the drivetrain and steering, which was completed by the principal engineer, and the chassis and suspension which was completed by Colton Hague. The complete device was modeled in SolidWorks based off of a two-wheel drive floating rear end vehicle. The assembly was then broken down into sub-assemblies which had certain parts that were manufactured as well as purchased. The principal engineer and Colton combined the sub-assemblies at the end in order to construct the device, as it was built on SolidWorks. After successfully completing construction, several tests were done to determine if the Baja was ready to race. All requirements above were met, and the device successfully competed in the competition.

Contents

1. INTRODUCTION

a. Description

The RC Baja project entails designing and constructing a radio-controlled vehicle that is able to maneuver different courses with varying obstacles, turns, and jumps. The vehicle must be able to turn, start, and stop at any given time. The vehicle must comply with all of the set requirements in order to be qualified to compete. The project will consist of two team members who will work on separate scopes of the vehicle. The overall goal is to have an RC Baja that is able to compete in the annual ASME event.

b. Motivation

This project was motivated by a need for a device that would turn the power of a brushless motor into torque to the wheels. Building an RC Baja vehicle will help in gaining knowledge in how a real car works by learning the different steering, drivetrain, and suspension parts.

c. Function Statement

The RC Baja vehicle must be able to maneuver left to right as well as go forward and backward by providing power from the motor to the wheels. The RC Baja must also be able to stop and start at any time.

d. Requirements

The RC Baja must meet the ASME RC Baja Race requirements:

- One propulsion motor that powers the vehicle.
- One propulsion battery pack that is a 7.2 Volt 6 cell RC battery.
- Three or more wheels that are not in a straight line or on tank-treads.
- No more than $500 spent on total project.
- Must reach a top speed of 20 mph.
- Must turn 60° in both directions.
- Must be dropped from a height of three feet above the ground.

e. Engineering Merit

Analyses will need to be done to determine what the appropriate gear size and ratios will need to be in order for the vehicle to reach the max speed of 20 mph. There will need to be analyses done on the drive shaft as well to make sure it can transmit the correct horsepower without failure. Finally, a very important analysis will be done on the front tie rods to ensure proper placement and length for steering.

f. Scope of Effort

The scope of the project that Tucker will provide is the drivetrain as well as the steering components of the vehicle. This includes the driveshaft, all of the necessary gearing, rear axle, front tie rods, the rear differential housing, the steering servo, as well as the speed controller, with appropriate mounting hardware for each.

g. Success Criteria

The success of this project will be determined on the final RC Baja competition at the end of the year. It will be successful if it places in the top five spots, without any major breakdowns, disqualifications, or failures.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

The design for the RC Baja was determined based off of the motor that was chosen. When the motor was chosen, the max rpm and power output could easily be calculated. After this was done, it was just a matter of getting the power from the motor to the rear differential. The gearing from the motor to the rear axle was chosen based off of the top speed requirement. The minimum requirement was that the Baja had to reach a top speed of 20 miles per hour. An analysis had to be done to determine what the gear ratios needed to be from the motor to the drive line, and also the differential gears from the drive line to the rear axle. The tire size also had to be taken into consideration when doing the analysis. The bigger the tire, the longer it takes for them to spin, which slows the Baja down. After carefully analyzing the rpm and tire size, the gear ratios were calculated.

Once there was power to the rear wheels, the steering needed to be determined. The front steering system was a simple design that utilized a steering servo and two turn buckles. The servo was mounted to the chassis in between the front tires. Then, one turn buckle went from the servo to each of the front hubs.

b. Design Description

The design of the RC Baja was based around the chassis of car. The chassis was laser cut using a high-tech cutter from a company on the west side. Then, the parts were mounted onto the chassis by aligning with the pre-drilled holes and bolted down using M2.5 and M3 bolts and nuts. The parts that were bolted to the chassis include a motor mount, battery, steering servo mount, transmission gear mount, shock towers, and finally the stabilizer arm tower. All of the pre-drilled holes needed to be very accurate in order for all of the parts to align.

c. Benchmark

The model that will be referenced is the HPI Baja 5B FLUX RTR RC car. The model number for this specific car is 107684.

d. Performance Predictions

The RC Baja will reach a maximum top speed of about 25 miles per hour based on the gearing from the motor to the differential. The RC Baja will also be able to turn at a 60-degree angle from straight, both in the left and right directions.

e. Description of Analysis

Analysis A-2 in the appendix shows the max rpm and torque of the motor. The two calculations are very important in determining what gearing is needed for the RC Baja. The vehicle must reach a top speed of at least 20 miles per hour. Based off of the top speed and the rpm maximum of the motor, the gearing was determined, as shown in analysis A-3.

f. Scope of Testing and Evaluation

The scope of testing for the RC Baja project is going to be performance. The top speed, acceleration, turning radius, and the drop test will all be evaluated during testing. The four things being tested are all equally important to determine if the car was successful.

g. Analysis

In appendix A-4, an analysis of the rear axle was done. The overall length and diameter were calculated. Then, in appendix B, drawing 20-006, there is a SolidWorks drawing that is based off of the analysis done in appendix A-4.

h. Device: Parts, Shapes, and Conformation

The design of the transmission gear ratio was based off of the max rpm that the motor produces. The top speed that the Baja needed to reach was known, which made the gear ratios an easy calculation for the transmission and differential.

The size of the drive shaft was chosen based off of the max torque that the motor produces. Then, a safety factor of three was chosen in order to calculate the actual amount of torque that would be applied to the drive shaft. Once the torque was found on the drive line, the correct size was chosen.

i. Device Assembly

The assembly addresses the engineering problem by taking the power from a brushless motor and transferring it to the rear wheels in order to move forward and backward. Several gears were needed to get the correct rpm to the rear wheels. There was also a drive line and universal joint that was needed to get the power to the correct location. It also uses a steering servo and turn buckles to turn the front tires left and right. The servo is bolted to a servo mount which bolts to the chassis. The turn buckles connect from the servo to the hubs in order for them to turn.

j. Technical Risk Analysis

The technical risk for the RC Baja project is the timeline and budget. If something does not work as predicted, it will cost money out of pocket as well as lost time, which could be dangerous due to a tight schedule. However, after construction was completed, the schedule was met, and the budget did not go over. The overall project was successful because there was an extra $50 in the budget and the Baja was fully functional one week before the due date which allowed for minor adjustments.

k. Failure Mode Analysis

The failure mode for the drive line was addressed by determining the maximum amount of torque that was allowed on it. Too much torque and it could break, but too little torque and the max speed would not be reached. The drive line is one of the most critical parts of the project due to the unique design. By choosing a floating rear end, the drive line had to be very long to reach from the transmission that is bolted on the rear of the chassis all the way to the differential that comes off of the rear axle.

l. Operation Limits and Safety

An important safety limit is the drop test. The drop test should not be performed multiple times because it will be very hard on the RC Baja. The Baja should only be dropped for testing reasons no more than three times. One of the testing requirements was also to run the Baja full speed into a wall. The test could do some serious damage to the Baja, which is why it is only going to be done one time. The Baja will need to be inspected thoroughly after running into the wall because of the high impact force. If anything breaks severely enough, the part will need to be re-made and attached to the Baja in order for it to function properly again.

3. METHODS & CONSTRUCTION

a. Methods

This project was conceived, analyzed, and designed at home from a computer with the aid of SolidWorks, mentors, and the internet. Due to online classes, the majority of the work had to be done from home. The remote desktop was a very useful tool as it allowed the engineer to login to CWU computers for SolidWorks as well as other applications at any time. That way, the design could continue to move forward, without being on campus. Many parts of the Baja were ordered from Amazon, while the remaining parts were manufactured in the CWU machine shop. The plastic parts were made in a 3D printer in the Samuelson building on campus using PLA and resin. The metal parts were made in the CWU machine shop out of Aluminum and Steel using different machines and tools. Planning was very critical as the project construction advanced through winter quarter. Important deadlines had to be hit on time effectively and efficiently. The engineer set coordinated dates and times for the CWU machine shop in order to produce the necessary parts for construction on schedule and in the budget.

i. Process Decisions

There were several important parts that needed to be designed and 3D printed for the Baja. The original plan was to print them using MakerBot Filament. The reason for MakerBot was because it is strong, durable, and accurate. However, after further research, the material switched to PLA. PLA is durable, cheap, and easy to print, which was essential for the project to stay on budget and on schedule. Printing out of PLA was fast and easy. The parts were designed on SolidWorks and emailed straight to the 3D printer in Samuelson as an STL file. The part would then begin to print. If there was a design issue with the part, the part could easily be re-designed and sent back to the printer to be printed. Although PLA worked great for printing the majority of the parts, a few parts were too intricate and small to accurately print using PLA. For the few parts that PLA did not work for, the design switched to a resin material, which uses a different printer. Resin printing is also very cheap and timely. After re-printing the parts in resin, all dimensions and tolerances were hit very accurately.

The second decision for manufacturing was the rear differential. The differential could have been purchased, but it was also easier to manufacture so that the dimensions would be exactly perfect for the Baja. The rear differential is connected to the rear axle housing as one component. The axle housing is made out of hollow steel rods that have a 1mm larger inner diameter than the axle shaft size. That way, the housing is not in contact with the axle shaft and the shaft can spin freely. The differential incased the differential gears as well as a portion of the drive line. That way, a gear locker was not necessary. The design meshes the gears together perfectly while allowing all parts to spin freely. The rear axle housing has tight tolerances because the axle that goes inside of it has tight tolerances in order to spin properly while maintaining contact with both differential gears. The axle must be able to sit in the housing without having any play from front to back and side to side.

b. Construction

i. Description

The RC Baja was built in two main sections. The first being the chassis and suspension which was assembled first. Then, the drivetrain and steering components were added. A total of 19 parts were purchased and six parts were manufactured. The manufactured parts include the motor mount, transmission, the rear axle, the rear differential housing, the drive line, and the trailing arm mounts. The rear axle was manufactured at home with tools provided by a mentor. It was made out of aluminum with steel reinforcement. The drive line was purchased but needed parts added to it before it was complete. The rest of the remaining parts were 3D printed in the Samuelson building on campus using PLA and resin.

ii. Drawing Tree, Drawing ID's

In Appendix B, a drawing tree is available showing the process from full assembly to preliminary parts.

iii. Parts

Most of the parts that were purchased did not require any secondary processing. The design was based off of the dimensions of purchased parts for easier assembly. The idea was to order the parts and be able to mount them straight to the Baja without any other processing. It cut down on time and expenses. However, there were some exceptions. The drive gear for the differential was mounted into the end of the drive line which meant the gear had to be pinned into the end of the shaft. That also meant that the drive shaft needed a hole drilled into the end of it in order to get the gear to slide into it. The idea behind the design was to eliminate having another part made to connect the gear to the drive shaft. The front servo turn buckles also needed some secondary processing. The turn buckles that were purchased were too long, so they needed to be cut down and re-threaded.

iv. Manufacturing Issues

One manufacturing issue came about with the rear differential case. The case had to be printed four different times. The reasoning for the re-prints was because of printer error and also design error. Twice, the print was incorrect because of inaccurate measuring of the drive shaft diameter. The drive shaft sits inside of the differential case, so the hole for it had to be exact in diameter and in length. After the design was corrected, the printer got too warm and printed a very ugly part that did not meet the measurements or tolerances. After three prints, the fourth print came out exactly perfect for everything to line up properly. Even with the several re-prints, the construction was still on schedule.

Another construction issue was with the motor mount and the motor itself. The motor mount was two separate pieced that bolted around the motor to keep it from moving. However, the mount was made out of PLA so it could not get a tight enough grip on the motor to keep it from spinning. When power was sent to the motor, the whole thing would spin in the mount causing the wires to bind up. The issue was fixed by carefully putting a bead of epoxy between the top of the motor and the mount. The epoxy fixed the issue.

v. Discussion of Assembly

The first sub-assembly is the motor mount. The mount has a top and bottom that goes around the motor and bolts to the chassis. Then, there is the rear axle housing that the axle goes inside of that the trailing arms will mount too. Inside of the housing there are two differential gears that mesh which allows the axle to turn. There is also a sub-assembly for the steering servo that bolts to the chassis. The steering servo mount will keep the servo steady and unable to move. The final sub-assembly for the RC Baja is the transmission gear mount. The design consists of a plate that bolts to the chassis with two holes going through it. The motor will sit flush to the plate and the output shaft will go through the plate for one of the spur gears to mount too. The other hole will have a bearing in it for the drive shaft to sit in. The plate allows the gears to be sturdy in order to lower the rpm of the drive shaft.

4. TESTING

a. Introduction

Several things were tested after successfully completing the RC Baja. First, the Baja needed to reach a top speed of at least 20 mph. Second, the front wheels had to be able to turn 60° from parallel in both directions. Lastly, the RC Baja needed to track a straight line for 20 feet.

b. Method/Approach

To test the top speed of the RC Baja, a speedometer app was downloaded on the principal engineers' phone. The app was developed to track the and record current and top speed. The phone was then taped to the top of the battery with the speedometer being displayed. The Baja then started at one end of the Hogue foyer and accelerated to the other side of the foyer. The top speed was read from the app and recorded. The test was done three times and the average top speed was taken. When testing the top speed requirement, the pinion gear on the motor shaft got stripped because it was the wrong pitch. A new gear was ordered to fix the issue. Also, a small part was added to the car that had a bearing pressed into it. The part was bolted onto the very back of the chassis to keep the drive shaft aligned. The part re-assured that the large spur gear did not move. To test the turning requirement, the turning radius was first calculated by hand using the wheelbase and the turning angle. Then, a circle with the calculated radius was marked on the floor. The Baja started on the circle and made a full circle as sharp as possible. There was a sharpie attached to the middle rear of the Baja that traced the circle made by the turn. The angle was determined. The test was done three times. The tracking test was done by placing blue painters' tape in a straight line in the center of the Hogue foyer. The tape was 20 feet in length. The Baja was then centered at one end of the tape and slowly accelerated over the tape without touching the steering. Zip ties were added to the Baja that went from the bottom of the rear shock tower mount to the rear axle housing. The zip ties were added on both sides of the Baja to prevent the rear axle from floating left or right. Due to the design of the rear axle, it was able to float left and right while driving which made the line tracking test nearly impossible. The car would drift left or right without touching the steering. However, after adding the zip ties, the rear axle no longer drifted, and the car tracked perfectly straight.

c. Test Procedure

For the top speed requirement of the RC Baja, there needed to be a large, flat, and smooth concrete pad so that the car had plenty of time to accelerate from a stop up to top speed. To fulfill the requirement, the Hogue south foyer was used. The foyer gave to Baja enough time to accelerate to top speed while also being able to slow down before the other side. The turning requirement was also completed in the Hogue foyer. The RC Baja needed enough room to complete a full circle without hitting any obstacles. Finally, to complete the tracking test, the center of the Hogue foyer will be utilized. The area in the middle of the foyer was perfect to lay a 20 foot piece of tape down in a straight line, and have the Baja track the line.

d. Deliverables

Below is the test sheet that was used while testing. The test that was been completed is the top speed test, as well as the line tracking test. The top speed requirement was set at 20 miles per hour. While testing the top speed, there was an issue with the pinion gear that was attached to the motor shaft. The pinion gear was a replacement gear that did not have the same pitch as the driven gear. Since the pitches of the two gears were different, the small pinion gear teeth got stripped very quickly. The RC Baja reached a speed of just 10 miles per hour before the gear was ruined. A new gear was ordered that had the correct pitch of the original. The test was then repeated two more times and the top speed was recorded. On the third attempt, the car successfully reached the top speed requirement.

RC Baja: Testing Sheet
Tucker Odegaard
Colton Hague

Trial	**Top Speed**	**Angle of Turn (L, R)**	**Tracking Test**
1	**10 mph**	**55°, 59°**	**Unsuccessful**
2	**17 mph**	**58°, 61°**	**Successful**
3	**21 mph**	**61°, 61°**	**Successful**

Requirements	**Pass**	**Fail**
Top Speed	**X**	
Turn Angle	**X**	
Line Tracking Test	**X**	

5. BUDGET

a. Parts

The overall project budget did not exceed the predicted budget. Approximately 91% of the budget was consumed throughout the project. All parts have been ordered and paid for. There were some added costs with the 3D printed parts. Several parts needed re-printed, due to small errors or malfunctions. However, the costs to reprint were very marginal and did not eat up too much of the budget.

There were three major parts that took up a third of the budget. The parts were the motor, the battery, and the controller. Each of the items were expensive but absolutely necessary for the successful completion of the project. Many other smaller less expensive parts were needed as well, which start to add up quickly when ordering.

b. Outsourcing

The only part on the project that was outsourced was the chassis. The chassis was laser cut by a company in Seattle, WA free of charge. Getting the chassis laser cut was a big advantage because of the precision and high tolerance that laser cutting provides.

c. Labor

Labor costs were estimated based off of standard 3D printing rates which was found online to be $20/hr. There was an estimated 10 hours of 3D printing needed to print parts for the RC Baja. The estimated labor cost for the project came out to $200.

d. Estimated Total Project Cost

The total cost of the project was estimated to be about $450. To date, all parts have been ordered and counted for. As the project stands, a total of $409.85 was spent. The project stayed just under the estimated budget. All parts were ordered from Amazon Prime, which worked very well. Everything arrived 2-5 days from the purchase date.

No more parts are needed for the project to continue. However, there were two extra 3D printed parts that needed printed that were not part of the original budget, but the costs were low. After all was said and done, the project used 91% of the predicted budget.

e. Funding Source

The cost of the project was supported by personal funds. The team members split up cost and made it as equal as possible. The original budget was designed around the idea of personally funding the project.

6. Schedule

a. Design

The design portion of the project was putting together a design that met certain requirements. The drive train and steering portion had many different parts that were required. The first thing that was found was the motor that will be used to power the Baja. Once the motor was chosen, the gear ratios and the correct tire sizes were chosen based off of the top speed requirement. Then, the parts were modeled on SolidWorks in order to create an assembly drawing of the complete Baja. All parts of the Baja were modeled using SolidWorks, but not all parts were built, as some needed to be purchased. Models of the parts were needed in order to create the assembly. A detailed schedule can be found in appendix E. At the start of the quarter, the lead times for ordered parts was a potential issue. However, as the quarter progressed, it was determined that the lead times for all parts was very minimal.

b. Construction

During the construction of the RC Baja, the schedule had to be manipulated in order to have a working device at the end of the quarter. Open lab time in the machine shop during the quarter was very limited so having designed parts ready to build was a necessity. One particular issue that stood out during construction was the differential housing. The design had to be slightly modified in order for it to work correctly. The hole in the front of the housing that the drive shaft went through had to be extruded into the housing. The idea behind the re-design was to support a longer portion of the shaft so that it could not move in or out or side to side. By adding the extra support, the two gears in the differential will be kept together without any slipping. The re-design forced the part to be 3D printed three different times, which took up a big portion of time. However, the total time spent on the project to date is less than the estimated number of hours. There was a total of 116 hours estimated to design and build the Baja. So far, only 106 of those hours have been used.

c. Testing

Overall, the testing of the RC Baja met the scheduled finished date. However, the first test, which was finding the top speed, was delayed by three days. The reason for the delay was because of a failed pinion tooth that attached to the motor shaft. In order to fix the issue, a new pinion needed to be ordered from amazon, which took three days to be delivered. Once the new pinion was installed, testing resumed. No major issues became apparent while completing the other two tests. Some minor adjustments needed to be made but time for that was already estimated for in the schedule. A total of ten hours was estimated to get all three of the tests completed. After testing, the estimate was very accurate as exactly ten hours were used to fully complete testing. Even though the top speed test went over by two hours, the other two tests took an hour less than the estimate, which balanced out the estimate.

7. Project Management

a. Human Resources

The principal engineer will provide their knowledge by designing the drivetrain and steering. The knowledge comes from obtaining a mechanical engineering degree as shown in Appendix H. There were also mentors that helped aid in the design of the project.

b. Physical Resources

The physical resources that are needed for the project are in Hogue hall in the machine shop. The drill press, lathe, and several hand tools will all need to be used in order to produce the parts needed for the build. A metric tap and die set will be used for threads as well as other small miscellaneous tools.

The 3D printers located in Samuelson Hall are also going to be utilized to produce high quality 3D printed parts for the build.

c. Soft Resources

SolidWorks was the main software used for the project. All of the parts for the project were modeled in SolidWorks in order to create drawings for manufacturing. The drawings were then either sent to the 3D printer or used while building parts in the machine shop.

d. Financial Resources

There is no sponsor for the drivetrain and steering portion of the project. All parts will be paid out of pocket by the engineer.

8. DISCUSSION

a. Design

The goal of the RC Baja drivetrain and steering was to transfer the power from a brushless motor to the rear wheels effectively and efficiently. The idea was to maximize power and torque of the motor in order to have the Baja be as fast as possible, while still having good acceleration. During the design process, it was essential that each part of the car worked together in an assembly for successful construction later on.

The first thing that needed to be determined, after the motor was chosen, was the gearing of the transmission and the rear differential. The driveshaft needed to be rotated much slower than the motor, and the rear axle needed to be geared down from the driveshaft. However, the Baja still needed to be able to go at least twenty miles per hour in order to meet one of the set requirements. After doing some analyzing, it was determined that the gear ratio of the transmission would be 5.0:1 and the gear ratio of the rear differential would be 3.73:1. The gear ratios chosen were common ratios that were easily able to be found and purchased online. After doing some further calculations with the gear ratios, the Baja will reach a top speed of about 22 miles per hour, which will satisfy one of the requirements. The gearing that was chosen will provide great low-end torque, which will be an advantage for the tight maneuvering on the track.

Another important aspect to the design was determining the torque on the driveshaft. The driveshaft is one of the most important parts on the Baja. The driveshaft is what delivers power to the rear wheels in order to move the Baja. The driveshaft has to be able to withstand the torque from the motor without bending or breaking. The gearing from the motor to the driveshaft allows the driveshaft to spin much slower than the output shaft of the motor. Without the gears, the drive shaft would spin much too fast and break. The maximum torque on the driveshaft was first calculated to determine an appropriate safety factor. The safety factor was then decided to be a 3.0. By using the correct transmission gear ratio, the safety factor was satisfied by calculating the actual torque on the driveshaft to be a third of the allowed torque.

The last analysis that was needed in order to satisfy the top speed requirement of the Baja was the tire size. The size of the tires has a major impact on the top end speed. The speed of the axle was determined by using the calculated gear ratios as well as the output rpm of the motor shaft. Once the axle speed was found, the correct tire size could be determined because the minimum speed that the Baja had to reach was known.

b. Construction

During the construction phase of the RC Baja, many obstacles and challenges have become apparent. The original design had the driven differential gear going into the end of the drive shaft and being pinned, using the original hole in the driveshaft, so it would not spin. However, while constructing the assembly part, the gear was cut down too much and the hole drilled through it for the pin was much too large. This caused the gear to break because the stress on the hole was too much. The assembled part was then re-designed so that the original hole in the drive shaft was no longer used to pin the gear. The drive shaft had a new hole drilled through it so that a 1/8” pin could be pressed in to pin the gear. That way, the stress on the hole of the gear was much less and will not break.

Another issue that came up was the rear axle. The rear axle differential that encases the differential gears and the end of the drive shaft was 3D printed. The initial design had the rear axle housing having an outside diameter of 10mm. However, this changed due to the stock that could be found. The outside diameter changed to 8mm which did not work with the original 3D printed differential. The holes in the differential cover were too large which meant that the axle housing could not connect to the differential. After re-designing, the holes were made smaller in the differential cover in order to fix the initial design. The hole for the drive shaft was also slightly too small in the original differential cover. The hole was made .5mm larger in order to have a tight fit on the drive shaft.

The last major issue during construction was with the steering servo. Finding the right length turn buckles to connect the steering servo to the front hubs was not possible. All of the turn buckles were either too short or too long. The solution was to buy turn buckles that were too long and take one of the buckles completely off. Then, the exact length that they needed to be was measured and the turn buckle shaft was cut to length. Then, it was re-threaded using a die, and the turn buckle end could then be screwed back on. It was a relatively simple fix that solved a complex problem.

c. Testing

During the testing phase of the project, a few issues became apparent with the Baja. The first test was the top speed test. The first time the test was attempted, the Baja only reached a top speed of 10 miles per hour before it came to a stop. After further examining the Baja, the issue was with the small pinion gear that attached to the drive shaft of the motor. The gear had been switched out due to an earlier gear failure. However, the new gear was a different pitch than the driven gear that it meshed with, which caused all of the teeth on the pinion to strip off. The test resulted in a failure and a correct pitched gear had to be ordered. After re-testing with the correct pitched gear, the Baja was able to reach a top speed of 21 miles per hour, which resulted in a pass for the top speed test.

The second test that was performed on the Baja was the line tracking test. A 20-foot piece of tape was stuck to the ground in a straight line and the Baja was placed at one end of the tape. It then accelerated over the tape without touching the steering to see if any of the tires crossed the tape. The test took three attempts due to some adjusting that was needed on the front end. The adjustments were necessary because during construction, the turn buckles were attached using visual inspection, instead of measuring to make sure they were the exact right length. The steering turn buckles needed slightly adjusted so that it did not pull to the right. The adjustment was as simple as disconnecting the right turn buckle from the servo and tightening the end by one full turn. Also, the turn buckles that control the toe of the tires needed adjusted so that each tire was the same. After fine tuning the front end, the Baja's tires were able to stay between the tape and the test was a pass.

The final test that was done on the Baja was a turning test. The test was to determine how sharp the front wheels could turn in each direction. The Baja was set on a piece of paper with the tires pointing straight forward. Then, the tires were turned fully in each direction, marking the center of the tire and then measuring the angle. One of the turn buckles had to be mounted higher up on the servo in order to clear the chassis. Once the angle on the turn buckle was higher, the turn buckle did not interfere with the chassis and the test successfully met the requirements.

9. CONCLUSION

In conclusion, a model of the RC Baja has been conceived, analyzed and designed that meets the given requirements of the engineers and of the final race requirements. All parts have been specified, sourced, and budgeted for acquisition based off of a detailed schedule and budget. The project meets all of the requirements for a successful senior project, including having adequate engineering merit in design and structural areas, a proper budget and schedule within the constraints of our resources at CWU, and finally the great interest the principal engineer has in the project. Each component has been carefully designed by first being analyzed and then drawn to ensure the proper size and fit on the project. Each part was then built based off of each of the respected drawings. The parts were combined to produce a working device by the end of winter quarter. The RC Baja is now ready to be tested using the initial design requirements.

10. ACKNOWLEDGEMENTS

The CWU machine shop aided in the construction of the design by providing the necessary tools and machines to accurately and precisely build the parts for the RC Baja.

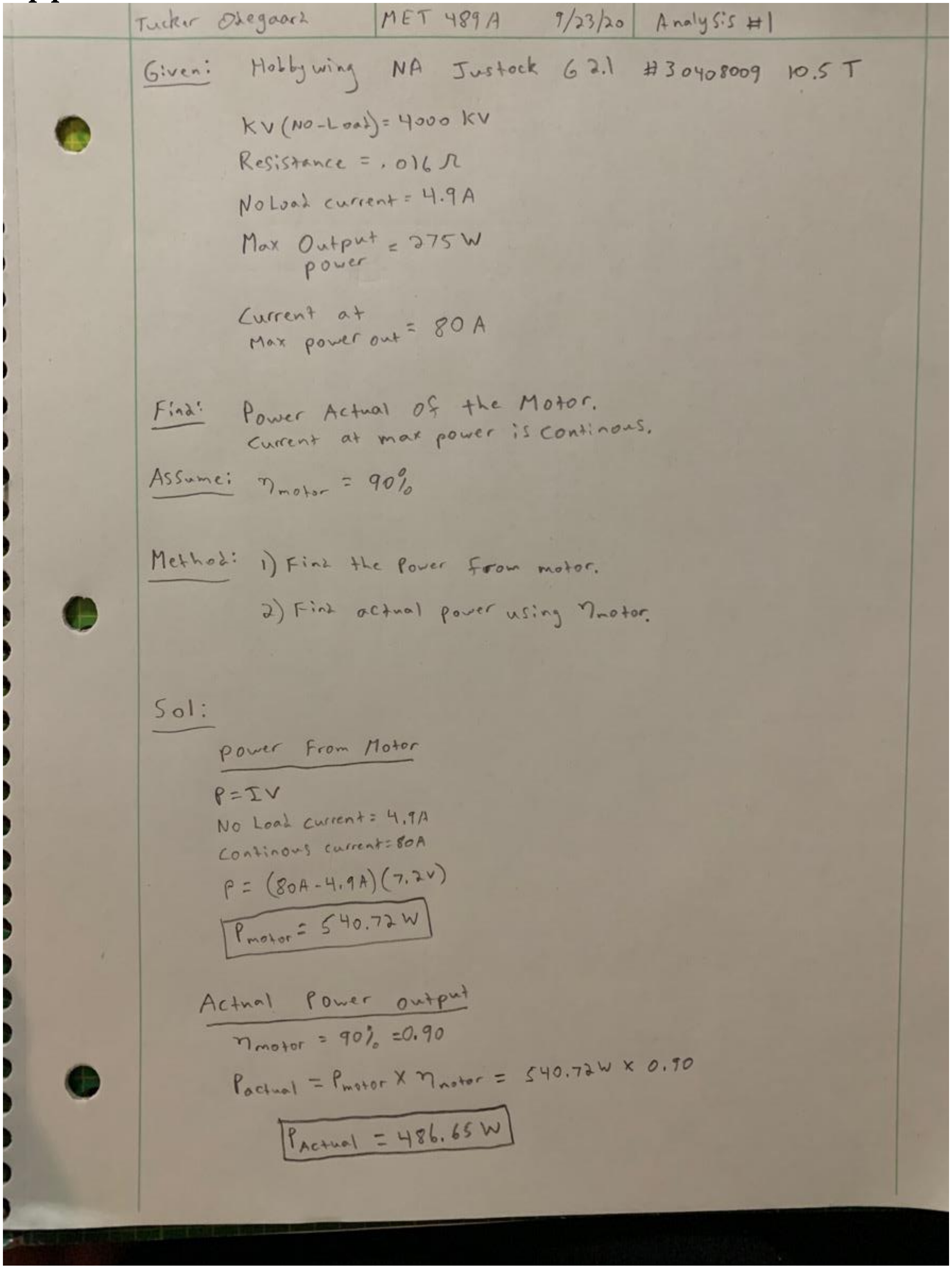
Samuelson Hall on CWU campus was utilized very often for the 3D printers they have available. Several different parts were 3D printed for the RC Baja over the course of the build.

Charles Pringle and John Choi also mentored the principal engineer by answering any questions as well as providing feedback on different aspects of the project.

References

APPENDIX A - Analysis

Appendix A-1



Tucker Odegaard | MET 489A 9/23/20 | Analysis #1

Given: Hobbywing NA Justock G2.1 #30408009 10.5T

KV (No-Load) = 4000 KV

Resistance = .016 Ω

No Load current = 4.9A

Max Output power = 275 W

Current at Max power out = 80 A

Find: Power Actual of the Motor. Current at max power is continous.

Assume: $\eta_{motor} = 90\%$

Method:
1) Find the Power from motor.
2) Find actual power using η_{motor}.

Sol:

Power From Motor

$P = IV$

No Load current: 4.9A

Continous current: 80A

$P = (80A - 4.9A)(7.2V)$

$\boxed{P_{motor} = 540.72\,W}$

Actual Power output

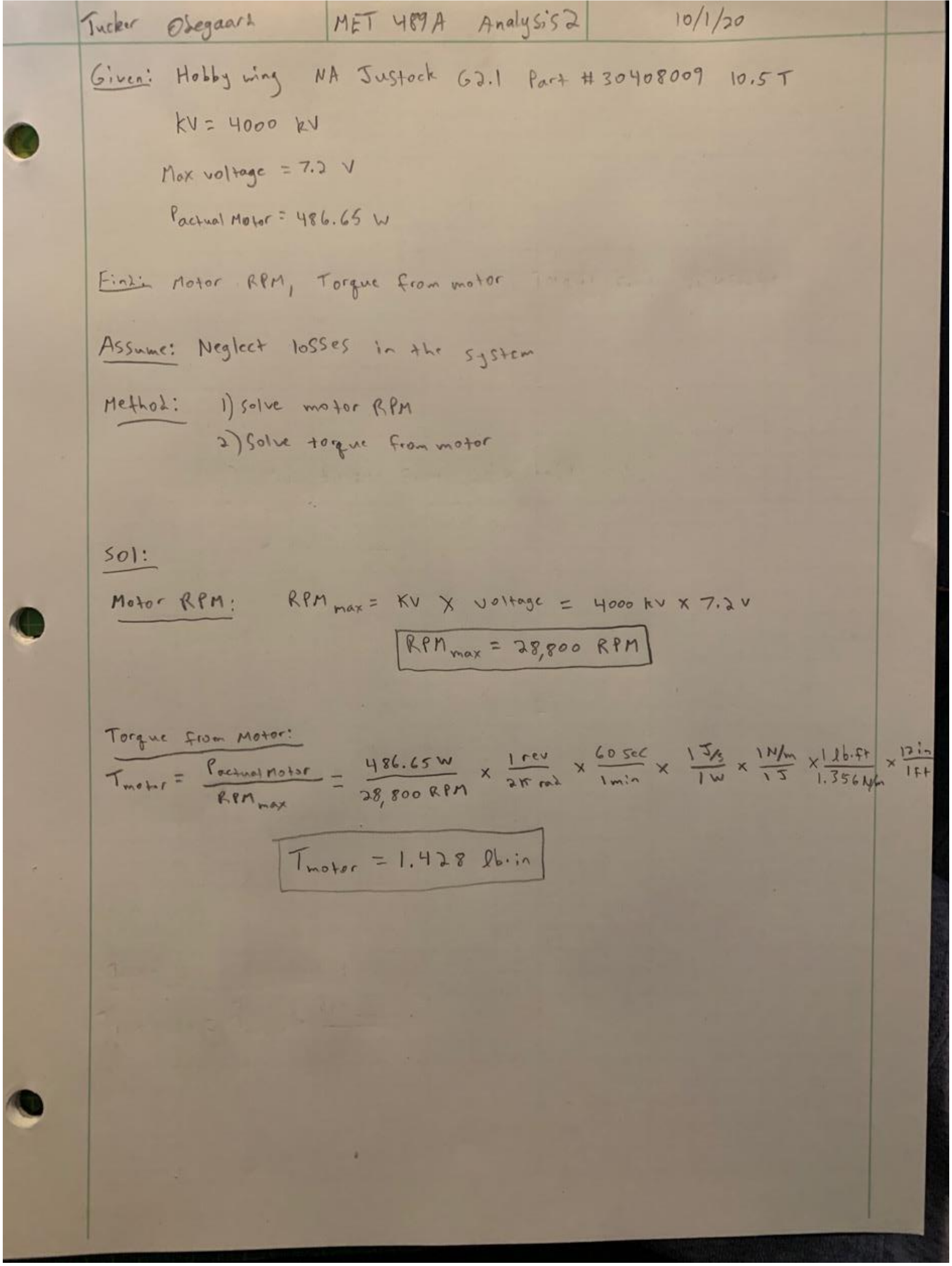
$\eta_{motor} = 90\% = 0.90$

$P_{actual} = P_{motor} \times \eta_{motor} = 540.72W \times 0.90$

$\boxed{P_{Actual} = 486.65\,W}$

(Figure A-1: Actual Power of Motor.)

Appendix A-2



Tucker Odegaard | MET 489A Analysis 2 | 10/1/20

Given: Hobby wing NA Justock G2.1 Part # 30408009 10.5 T

$KV = 4000\ kV$

Max voltage $= 7.2\ V$

$P_{actual\ Motor} = 486.65\ W$

Find: Motor RPM, Torque from motor

Assume: Neglect losses in the system

Method:
1) solve motor RPM
2) Solve torque from motor

Sol:

Motor RPM: $RPM_{max} = KV \times voltage = 4000\ kV \times 7.2\ V$

$$\boxed{RPM_{max} = 28{,}800\ RPM}$$

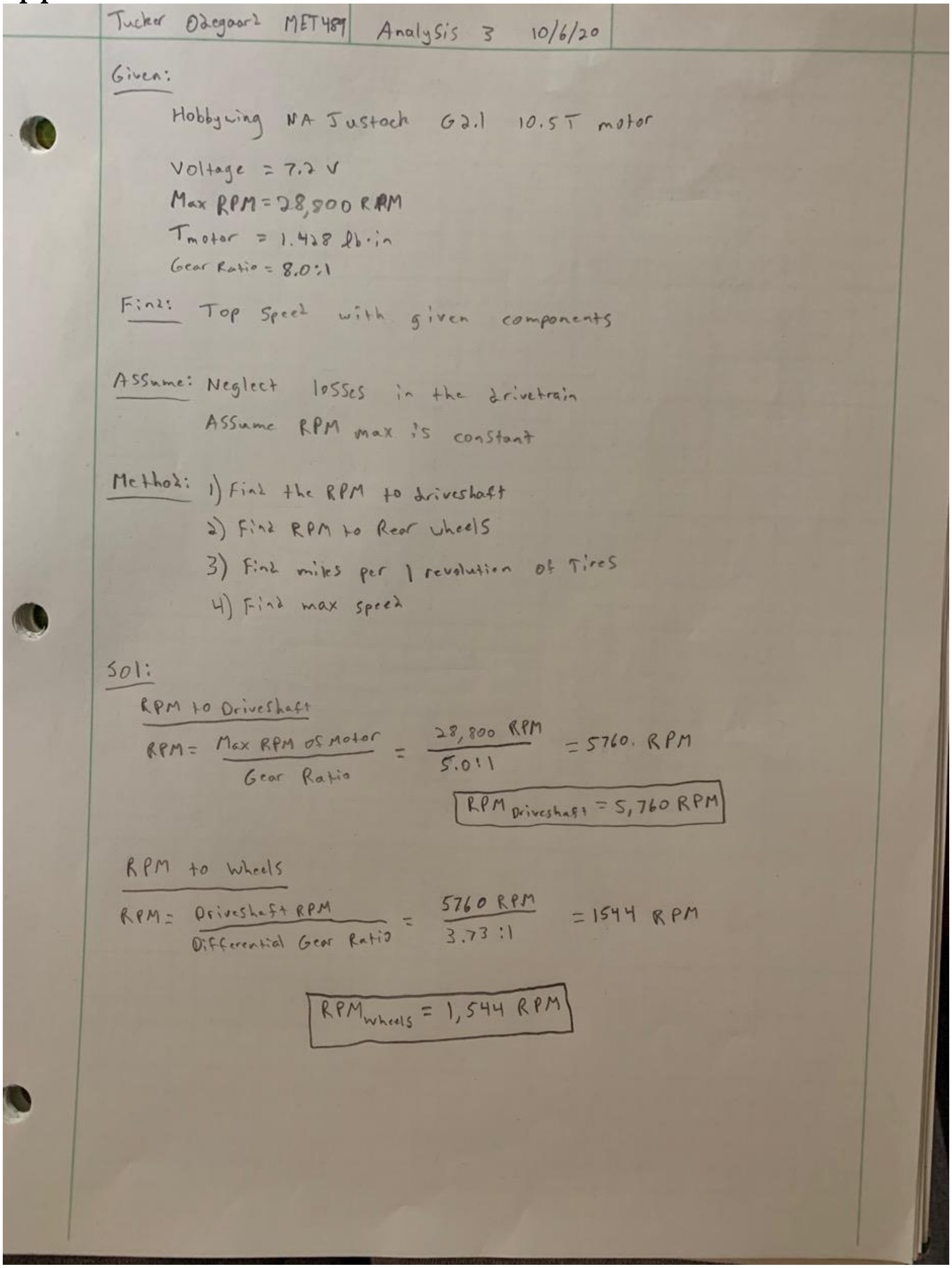
Torque from Motor:

$$T_{motor} = \frac{P_{actual\ Motor}}{RPM_{max}} = \frac{486.65\ W}{28{,}800\ RPM} \times \frac{1\ rev}{2\pi\ rad} \times \frac{60\ sec}{1\ min} \times \frac{1\ J/s}{1\ W} \times \frac{1\ N/m}{1\ J} \times \frac{1\ lb \cdot ft}{1.356\ N/m} \times \frac{12\ in}{1\ ft}$$

$$\boxed{T_{motor} = 1.428\ lb \cdot in}$$

(Figure A-2: Max Motor RPM and Torque of Motor.)

Appendix A-3



Tucker Odegaard MET489 | Analysis 3 10/6/20

Given:

Hobbywing NA Justock G2.1 10.5T motor

Voltage = 7.2 V

Max RPM = 28,800 RPM

T_{motor} = 1.428 lb·in

Gear Ratio = 8.0:1

Find: Top Speed with given components

Assume: Neglect losses in the drivetrain

Assume RPM max is constant

Method:
1) Find the RPM to driveshaft
2) Find RPM to Rear wheels
3) Find miles per 1 revolution of Tires
4) Find max speed

Sol:

RPM to Driveshaft

$$RPM = \frac{\text{Max RPM of Motor}}{\text{Gear Ratio}} = \frac{28{,}800\ \text{RPM}}{5.0:1} = 5760.\ \text{RPM}$$

$$\boxed{RPM_{Driveshaft} = 5{,}760\ \text{RPM}}$$

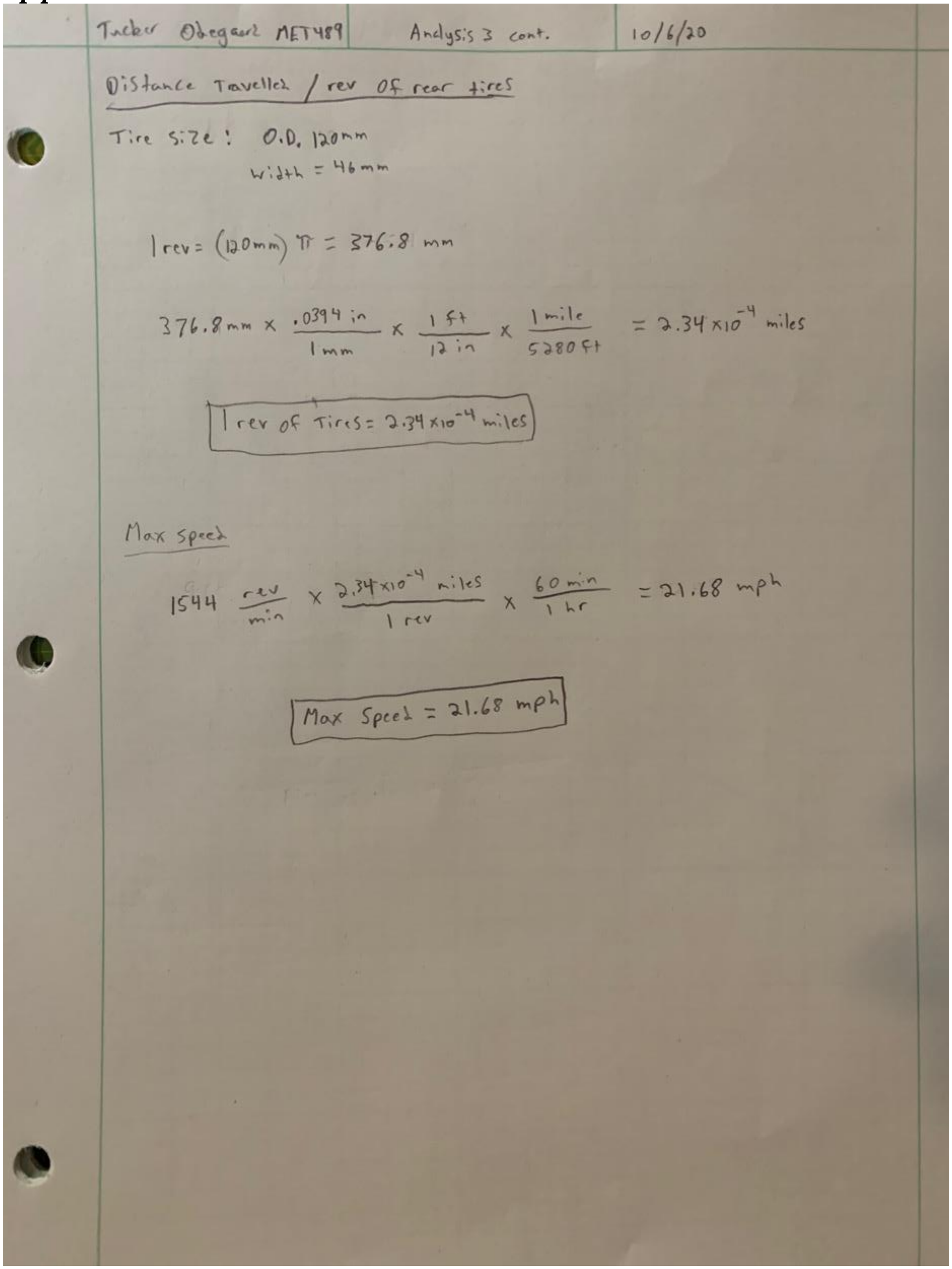
RPM to Wheels

$$RPM = \frac{\text{Driveshaft RPM}}{\text{Differential Gear Ratio}} = \frac{5760\ \text{RPM}}{3.73:1} = 1544\ \text{RPM}$$

$$\boxed{RPM_{wheels} = 1{,}544\ \text{RPM}}$$

(Figure A-3: Max Speed and Gear Ratios.)

Appendix A-3 Cont.



Tucker Odegaard MET489 | Analysis 3 cont. | 10/6/20

Distance Travelled / rev of rear tires

Tire size: O.D. 120mm

width = 46mm

$$1\,rev = (120mm)\,\pi = 376.8\ mm$$

$$376.8mm \times \frac{.0394\ in}{1\ mm} \times \frac{1\ ft}{12\ in} \times \frac{1\ mile}{5280\ ft} = 2.34\times10^{-4}\ miles$$

$$\boxed{1\ rev\ of\ Tires = 2.34\times10^{-4}\ miles}$$

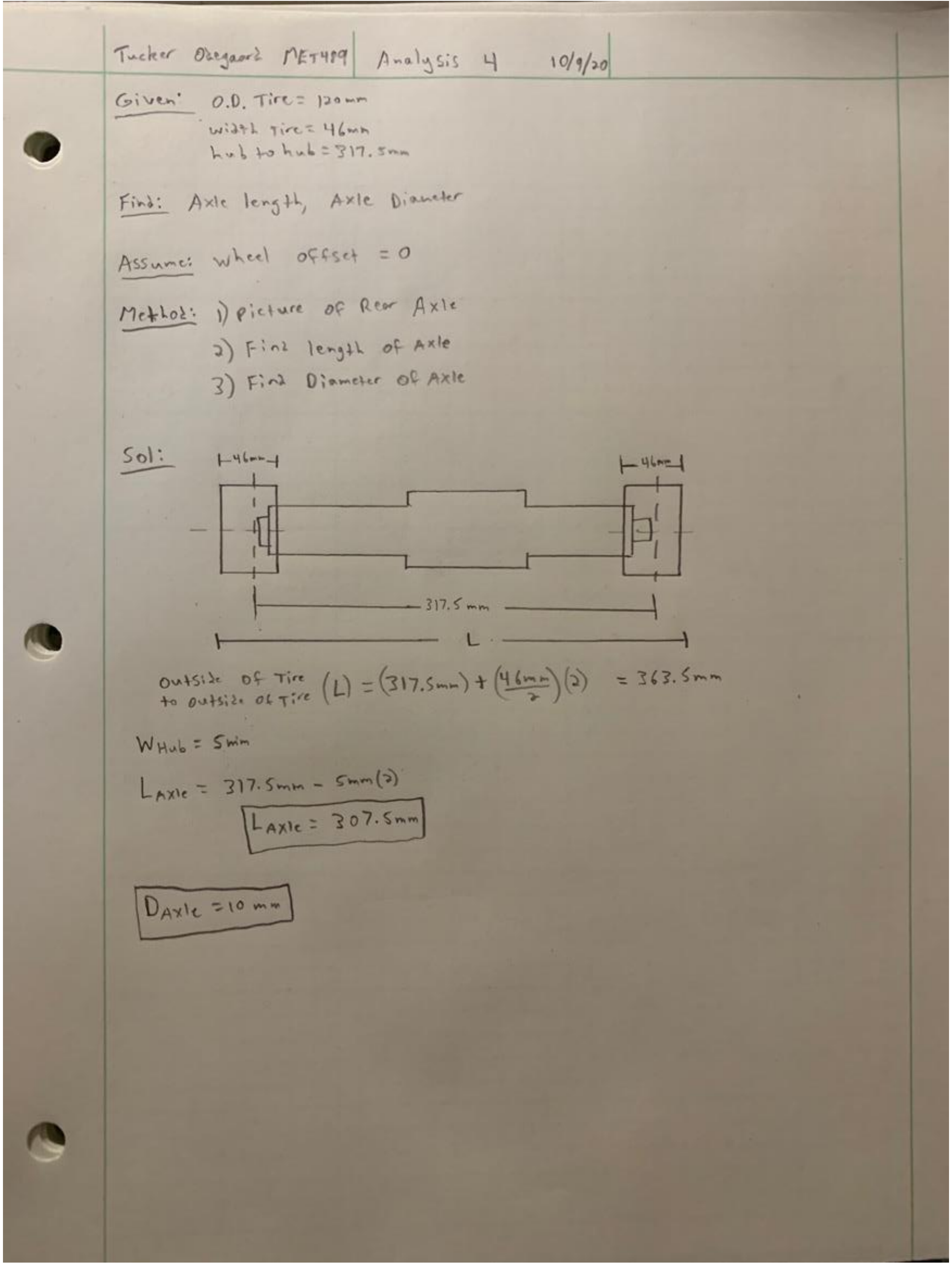
Max speed

$$1544\ \frac{rev}{min} \times \frac{2.34\times10^{-4}\ miles}{1\ rev} \times \frac{60\ min}{1\ hr} = 21.68\ mph$$

$$\boxed{Max\ Speed = 21.68\ mph}$$

(Figure A-3: Max Speed and Gear Ratios.)

Appendix A-4



Tucker Odegaard MET489 | Analysis 4 | 10/9/20

Given: O.D. Tire = 120 mm
width Tire = 46mm
hub to hub = 317.5mm

Find: Axle length, Axle Diameter

Assume: wheel offset = 0

Method: 1) picture of Rear Axle
2) Find length of Axle
3) Find Diameter of Axle

Sol:

outside of Tire to outside of Tire $(L) = (317.5mm) + \left(\frac{46mm}{2}\right)(2) = 363.5mm$

$W_{Hub} = 5mm$

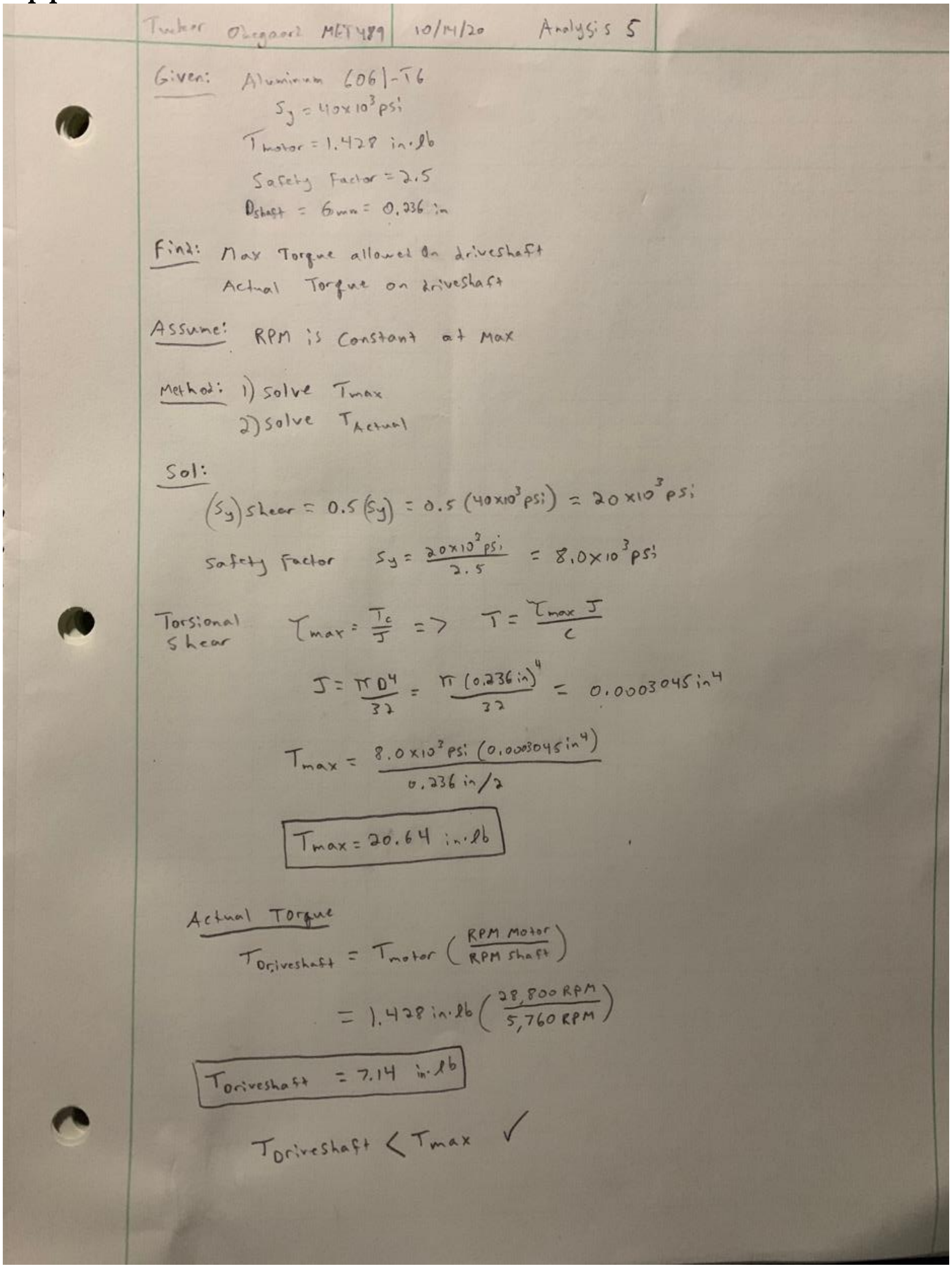
$L_{Axle} = 317.5mm - 5mm(2)$

$\boxed{L_{Axle} = 307.5mm}$

$\boxed{D_{Axle} = 10 mm}$

(Figure A-4: Axle Length and Diameter.)

Appendix A-5



Tucker Odegaard MET489 | 10/14/20 | Analysis 5

Given: Aluminum 6061-T6

$S_y = 40 \times 10^3$ psi

$T_{motor} = 1.428$ in·lb

Safety Factor = 2.5

D_{shaft} = 6mm = 0.236 in

Find: Max Torque allowed on driveshaft

Actual Torque on driveshaft

Assume: RPM is Constant at Max

Method: 1) solve T_{max}

2) solve T_{Actual}

Sol:

$$(S_y)_{shear} = 0.5(S_y) = 0.5(40 \times 10^3 \text{ psi}) = 20 \times 10^3 \text{ psi}$$

Safety factor $S_y = \frac{20 \times 10^3 \text{ psi}}{2.5} = 8.0 \times 10^3 \text{ psi}$

Torsional Shear $\tau_{max} = \frac{Tc}{J} \Rightarrow T = \frac{\tau_{max} J}{c}$

$$J = \frac{\pi D^4}{32} = \frac{\pi (0.236 \text{ in})^4}{32} = 0.0003045 \text{ in}^4$$

$$T_{max} = \frac{8.0 \times 10^3 \text{ psi} (0.0003045 \text{ in}^4)}{0.236 \text{ in}/2}$$

$$\boxed{T_{max} = 20.64 \text{ in·lb}}$$

Actual Torque

$$T_{Driveshaft} = T_{motor}\left(\frac{\text{RPM Motor}}{\text{RPM Shaft}}\right)$$

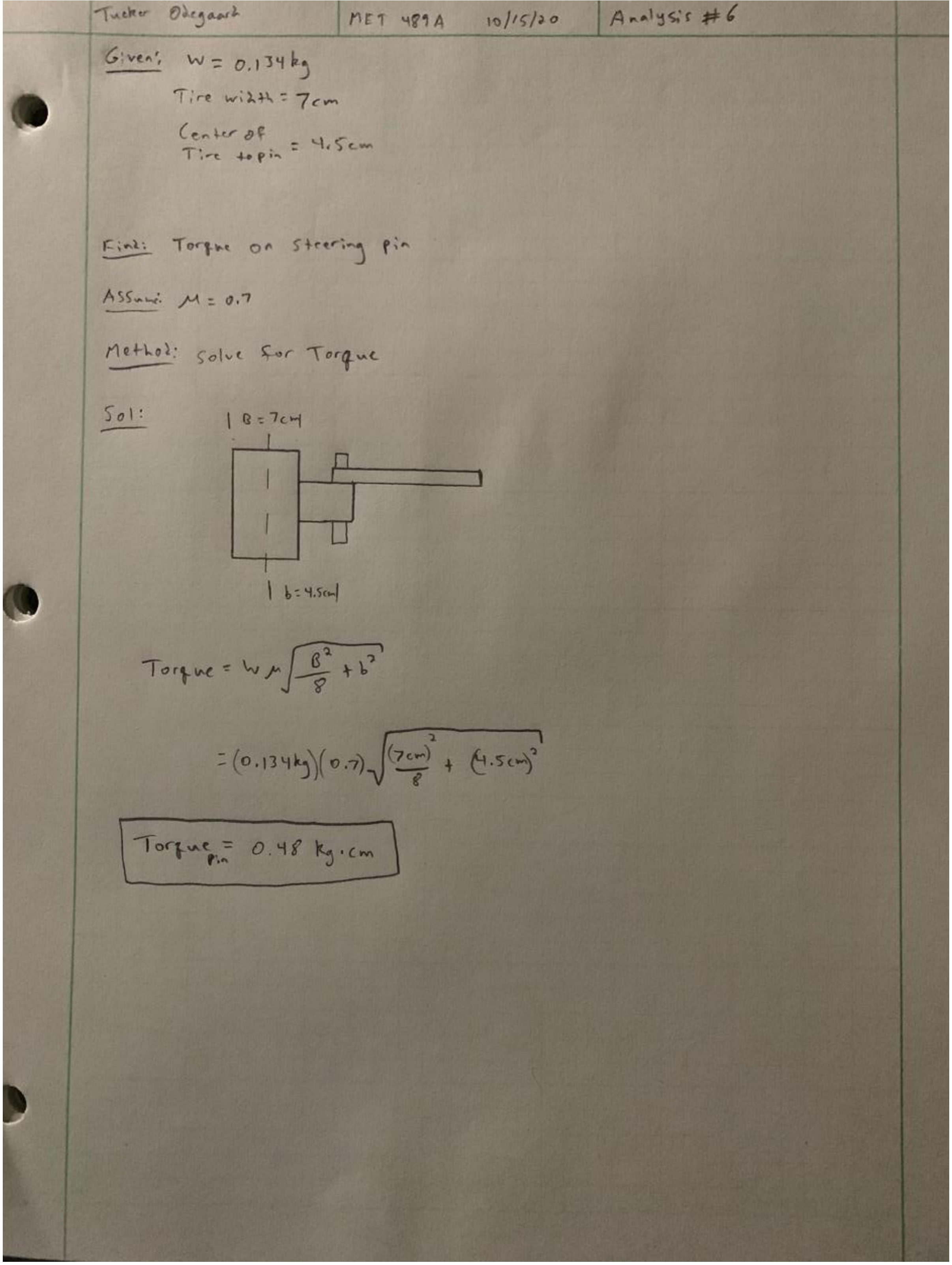
$$= 1.428 \text{ in·lb}\left(\frac{28{,}800 \text{ RPM}}{5{,}760 \text{ RPM}}\right)$$

$$\boxed{T_{Driveshaft} = 7.14 \text{ in·lb}}$$

$T_{Driveshaft} < T_{max}$ ✓

(Figure A-5: Driveshaft Torque.)

Appendix A-6



Tucker Odegaard | MET 489A 10/15/20 | Analysis #6

Given: W = 0.134 kg

Tire width = 7cm

Center of Tire to pin = 4.5cm

Find: Torque on Steering pin

Assume: $\mu = 0.7$

Method: Solve for Torque

Sol:

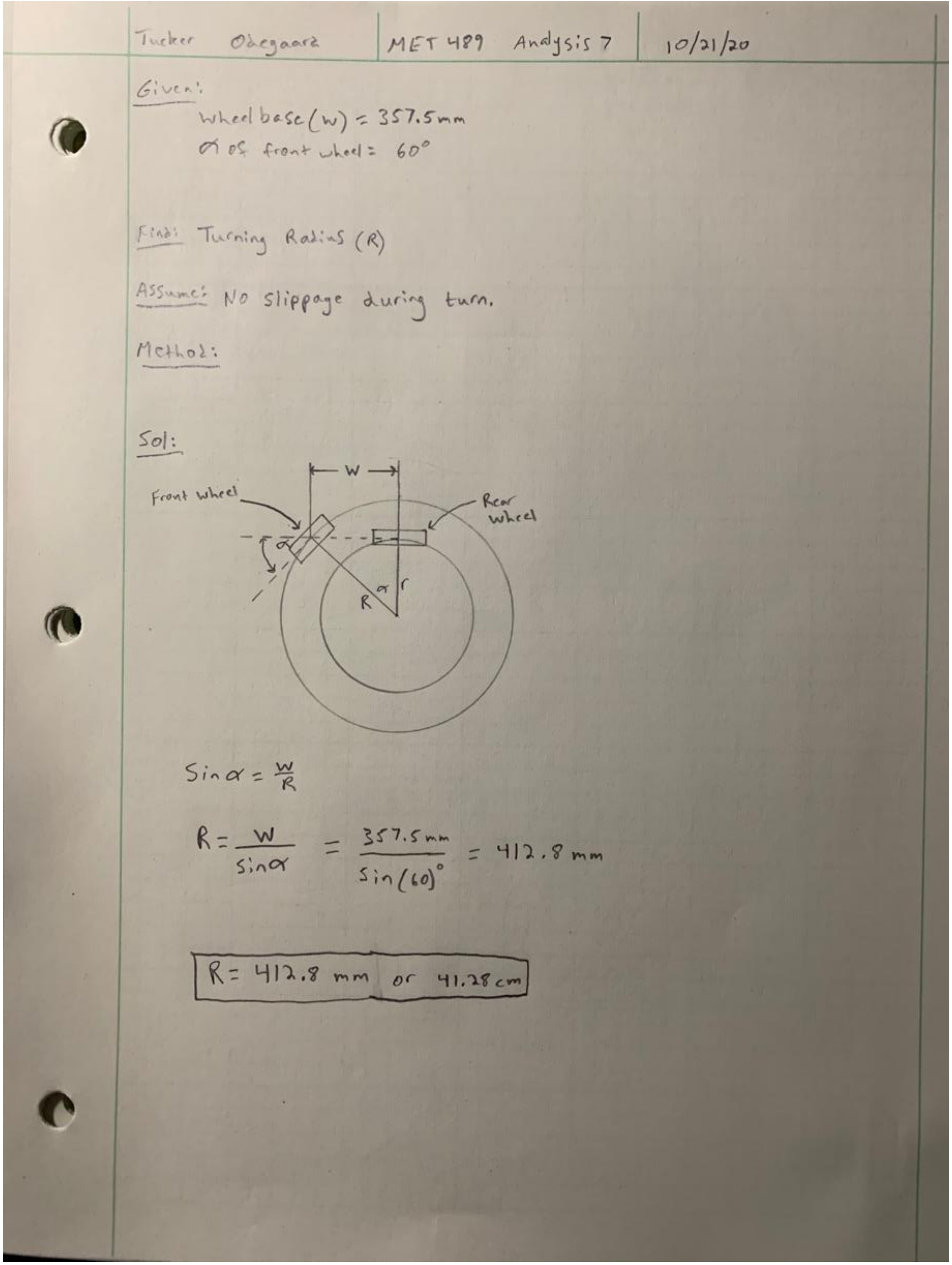
$$\text{Torque} = W\mu\sqrt{\frac{B^2}{8} + b^2}$$

$$= (0.134\text{kg})(0.7)\sqrt{\frac{(7\text{cm})^2}{8} + (4.5\text{cm})^2}$$

$$\boxed{\text{Torque}_{\text{Pin}} = 0.48\ \text{kg}\cdot\text{cm}}$$

(Figure A-6: Torque on Steering Pin.)

Appendix A-7



Tucker Odegaard | MET 489 Analysis 7 | 10/21/20

Given:

wheel base (w) = 357.5mm

α of front wheel = 60°

Find: Turning Radius (R)

Assume: No slippage during turn.

Method:

Sol:

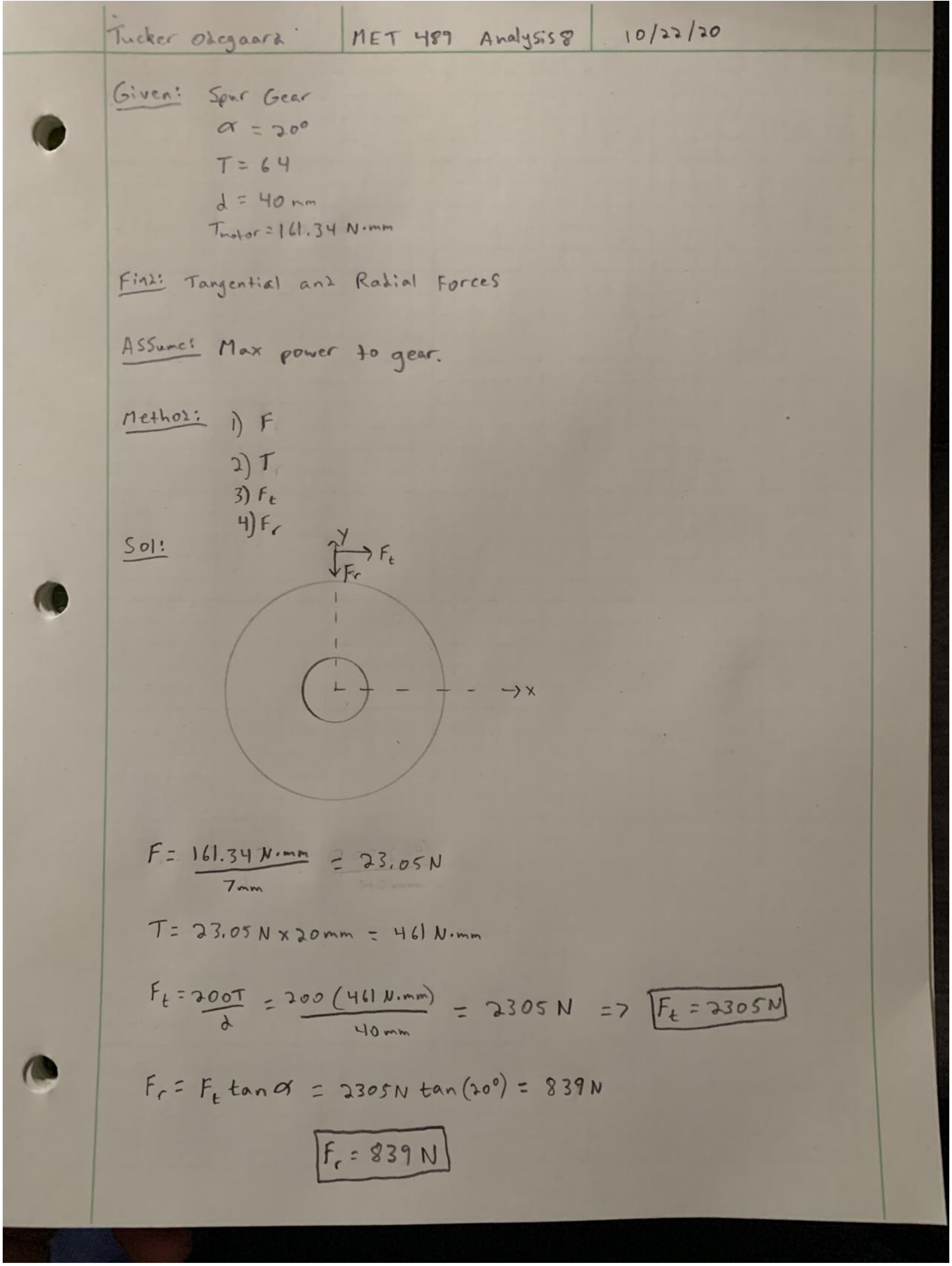
$$\sin\alpha = \frac{W}{R}$$

$$R = \frac{W}{\sin\alpha} = \frac{357.5\,\text{mm}}{\sin(60)^\circ} = 412.8\,\text{mm}$$

$$\boxed{R = 412.8\,\text{mm} \text{ or } 41.28\,\text{cm}}$$

(Figure A-7: Turning Radius.)

Appendix A-8



Tucker Odegaard | MET 489 Analysis 8 | 10/22/20

Given: Spur Gear

$\alpha = 20^\circ$

$T = 64$

$d = 40\ \text{mm}$

$T_{motor} = 161.34\ \text{N}\cdot\text{mm}$

Find: Tangential and Radial Forces

Assume: Max power to gear.

Method:
1) F
2) T
3) F_t
4) F_r

Sol:

$$F = \frac{161.34\ \text{N}\cdot\text{mm}}{7\text{mm}} = 23.05\text{N}$$

$$T = 23.05\text{N} \times 20\text{mm} = 461\ \text{N}\cdot\text{mm}$$

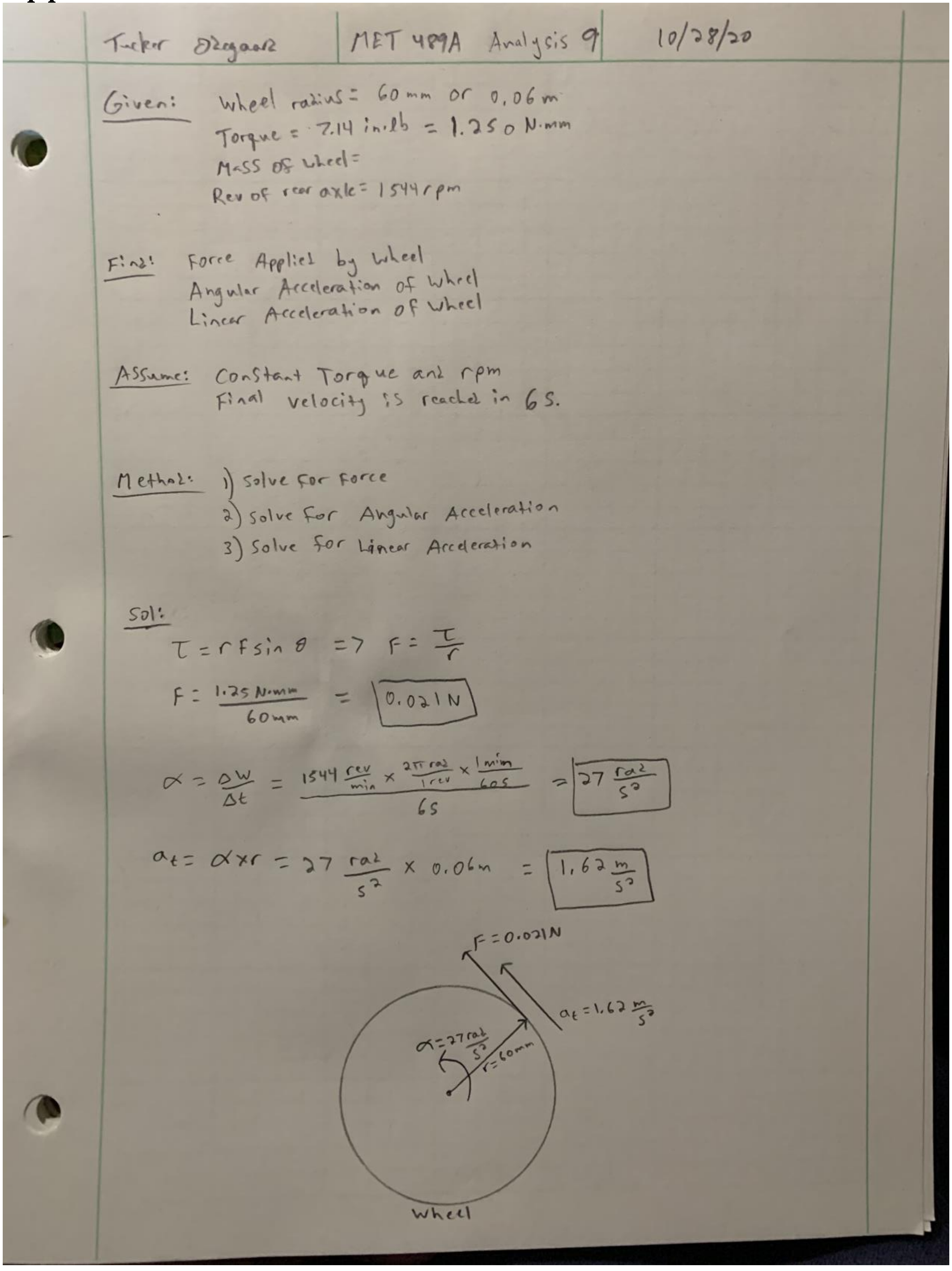
$$F_t = \frac{200T}{d} = \frac{200\,(461\ \text{N}\cdot\text{mm})}{40\ \text{mm}} = 2305\ \text{N} \Rightarrow \boxed{F_t = 2305\text{N}}$$

$$F_r = F_t \tan\alpha = 2305\text{N}\ \tan(20^\circ) = 839\text{N}$$

$$\boxed{F_r = 839\ \text{N}}$$

(Figure A-8: Tangential and Radial Force on Spur Gear.)

Appendix A-9



Tucker Odegaard | MET 489A Analysis 9 | 10/28/20

Given: Wheel radius = 60 mm or 0.06 m
Torque = 7.14 in·lb = 1.250 N·mm
Mass of wheel =
Rev of rear axle = 1544 rpm

Find: Force Applied by wheel
Angular Acceleration of wheel
Linear Acceleration of wheel

Assume: Constant Torque and rpm
Final velocity is reached in 6 s.

Method:
1) Solve for Force
2) Solve for Angular Acceleration
3) Solve for Linear Acceleration

Sol:

$$\tau = rF\sin\theta \Rightarrow F = \frac{\tau}{r}$$

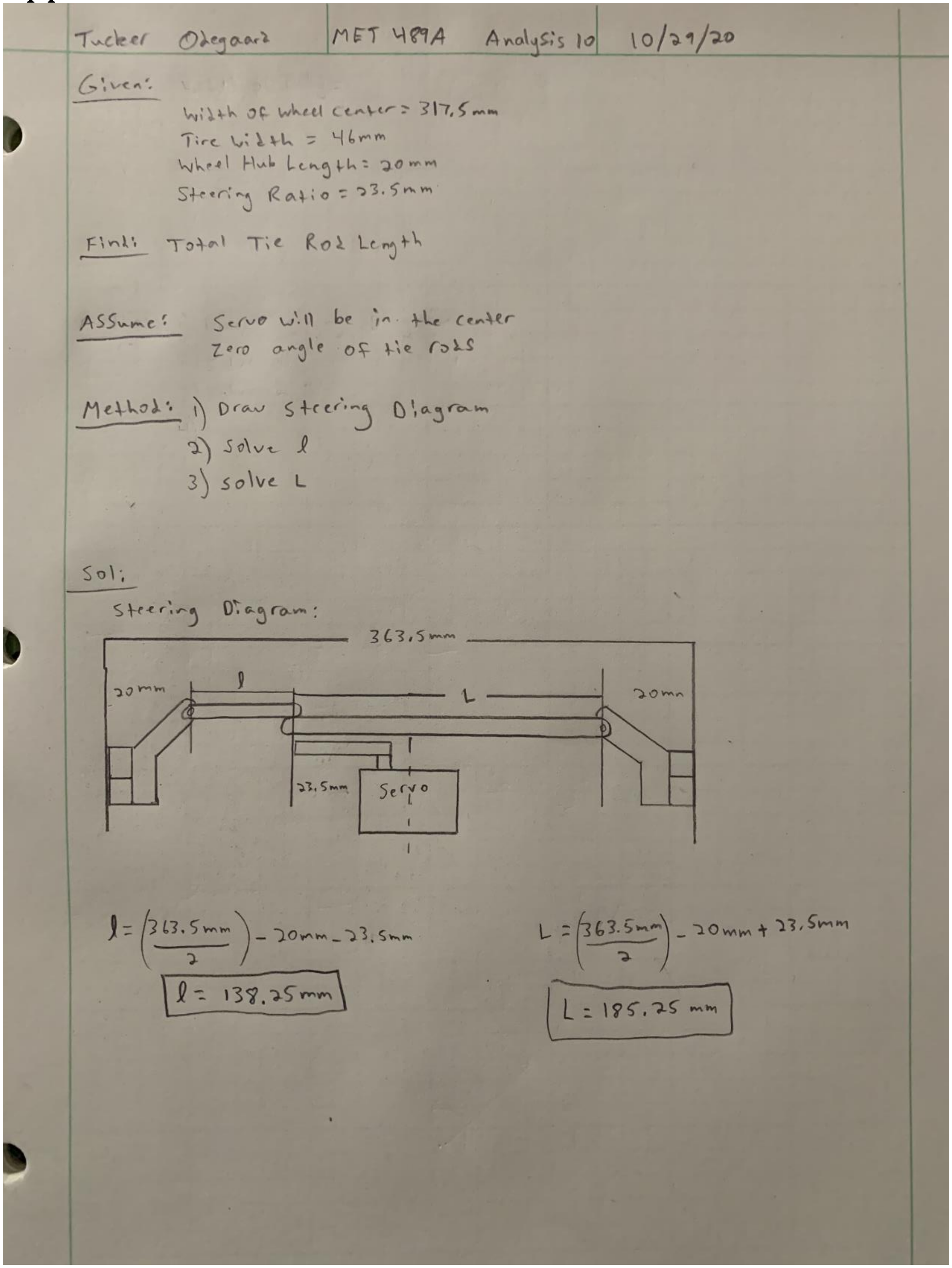
$$F = \frac{1.25\ \text{N·mm}}{60\text{mm}} = \boxed{0.021\text{N}}$$

$$\alpha = \frac{\Delta w}{\Delta t} = \frac{1544\frac{\text{rev}}{\text{min}} \times \frac{2\pi\ \text{rad}}{1\ \text{rev}} \times \frac{1\ \text{min}}{60\text{s}}}{6\text{s}} = \boxed{27\ \frac{\text{rad}}{\text{s}^2}}$$

$$a_t = \alpha \times r = 27\ \frac{\text{rad}}{\text{s}^2} \times 0.06\text{m} = \boxed{1,62\ \frac{\text{m}}{\text{s}^2}}$$

(Figure A-9: Angular Acceleration, Linear Acceleration, Force on Rear Wheels.)

Appendix A-10



Tucker Odegaard | MET 489A | Analysis 10 | 10/29/20

Given:

Width of wheel center = 317.5mm
Tire width = 46mm
Wheel Hub Length = 20mm
Steering Ratio = 23.5mm

Find: Total Tie Rod Length

Assume: Servo will be in the center
Zero angle of tie rods

Method:
1) Draw steering Diagram
2) Solve l
3) solve L

Sol:

Steering Diagram:

$$l = \left(\frac{363.5mm}{2}\right) - 20mm - 23.5mm$$

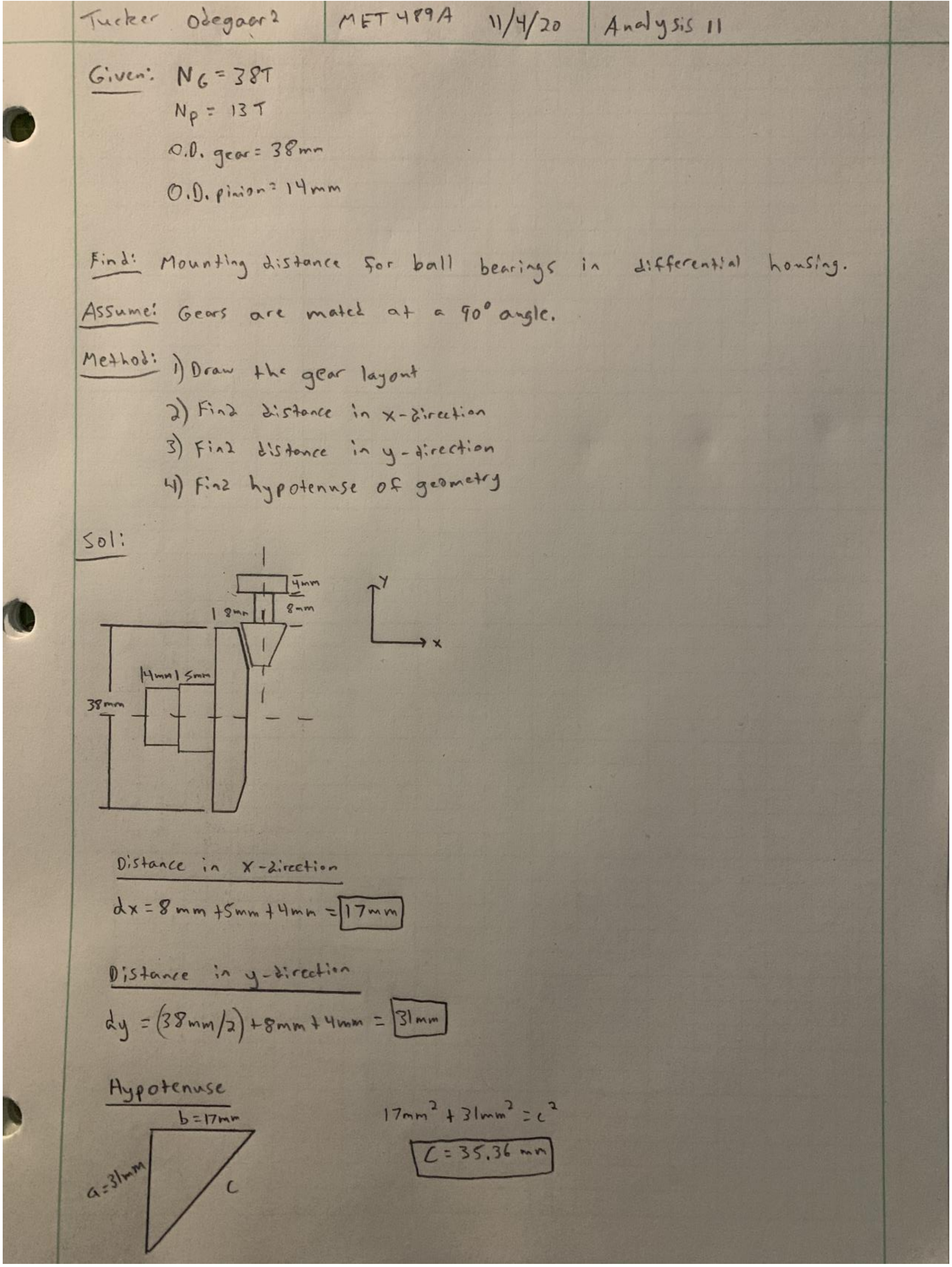
$$\boxed{l = 138.25mm}$$

$$L = \left(\frac{363.5mm}{2}\right) - 20mm + 23.5mm$$

$$\boxed{L = 185.25 mm}$$

(Figure A-10: Left and Right Tie Rod Lengths.)

Appendix A-11



Tucker Odegaard | MET 489A | 11/4/20 | Analysis 11

Given: $N_G = 38T$

$N_P = 13T$

O.D. gear = 38mm

O.D. pinion = 14mm

Find: Mounting distance for ball bearings in differential housing.

Assume: Gears are mated at a 90° angle.

Method:
1) Draw the gear layout
2) Find distance in x-direction
3) Find distance in y-direction
4) Find hypotenuse of geometry

Sol:

Distance in X-direction

$$dx = 8\,mm + 5mm + 4mm = \boxed{17mm}$$

Distance in y-direction

$$dy = (38mm/2) + 8mm + 4mm = \boxed{31mm}$$

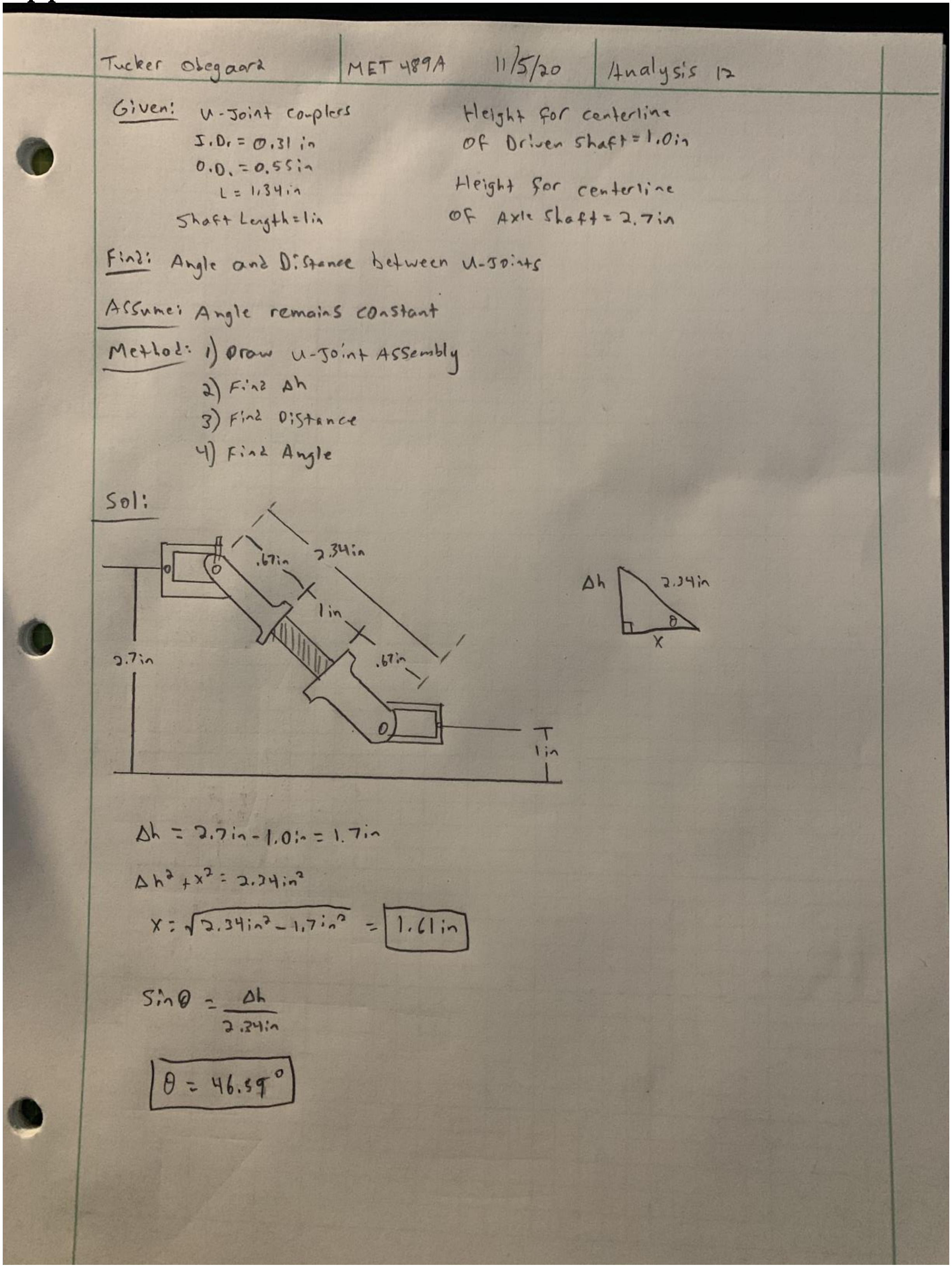
Hypotenuse

$$17mm^2 + 31mm^2 = c^2$$

$$\boxed{C = 35.36\ mm}$$

(Figure A-11: Rear axle ball bearing locations.)

Appendix A-12



Tucker Obegaard | MET 489A | 11/5/20 | Analysis 12

Given: U-Joint couplers

I.D. = 0.31 in

O.D. = 0.55in

L = 1.34in

Shaft Length = 1in

Height for centerline of Driven Shaft = 1.0in

Height for centerline of Axle Shaft = 2.7in

Find: Angle and Distance between U-Joints

Assume: Angle remains constant

Method:
1) Draw U-Joint Assembly
2) Find Δh
3) Find Distance
4) Find Angle

Sol:

$$\Delta h = 2.7in - 1.0in = 1.7in$$

$$\Delta h^2 + x^2 = 2.34in^2$$

$$x = \sqrt{2.34in^2 - 1.7in^2} = \boxed{1.61in}$$

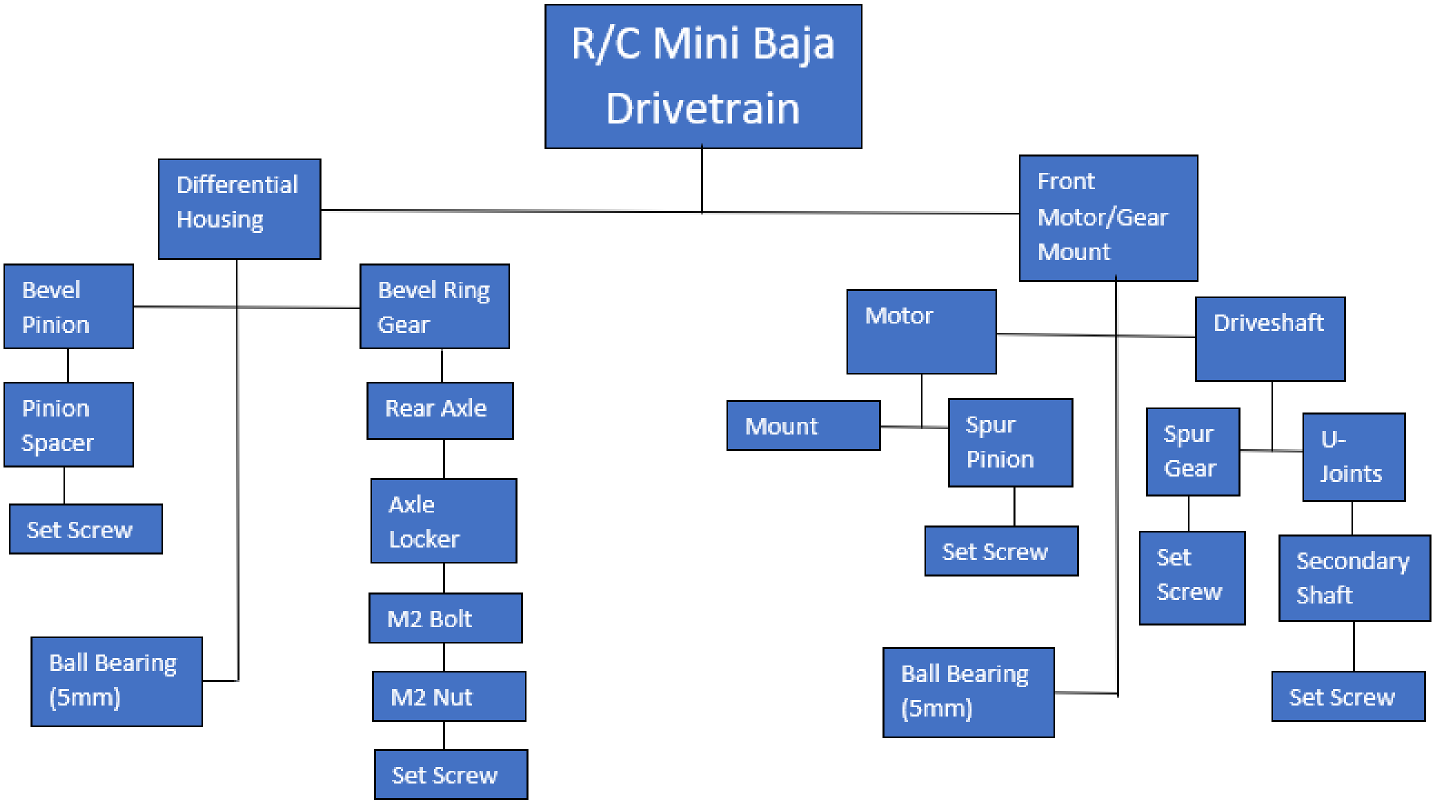
$$\sin\theta = \frac{\Delta h}{2.34in}$$

$$\boxed{\theta = 46.59^\circ}$$

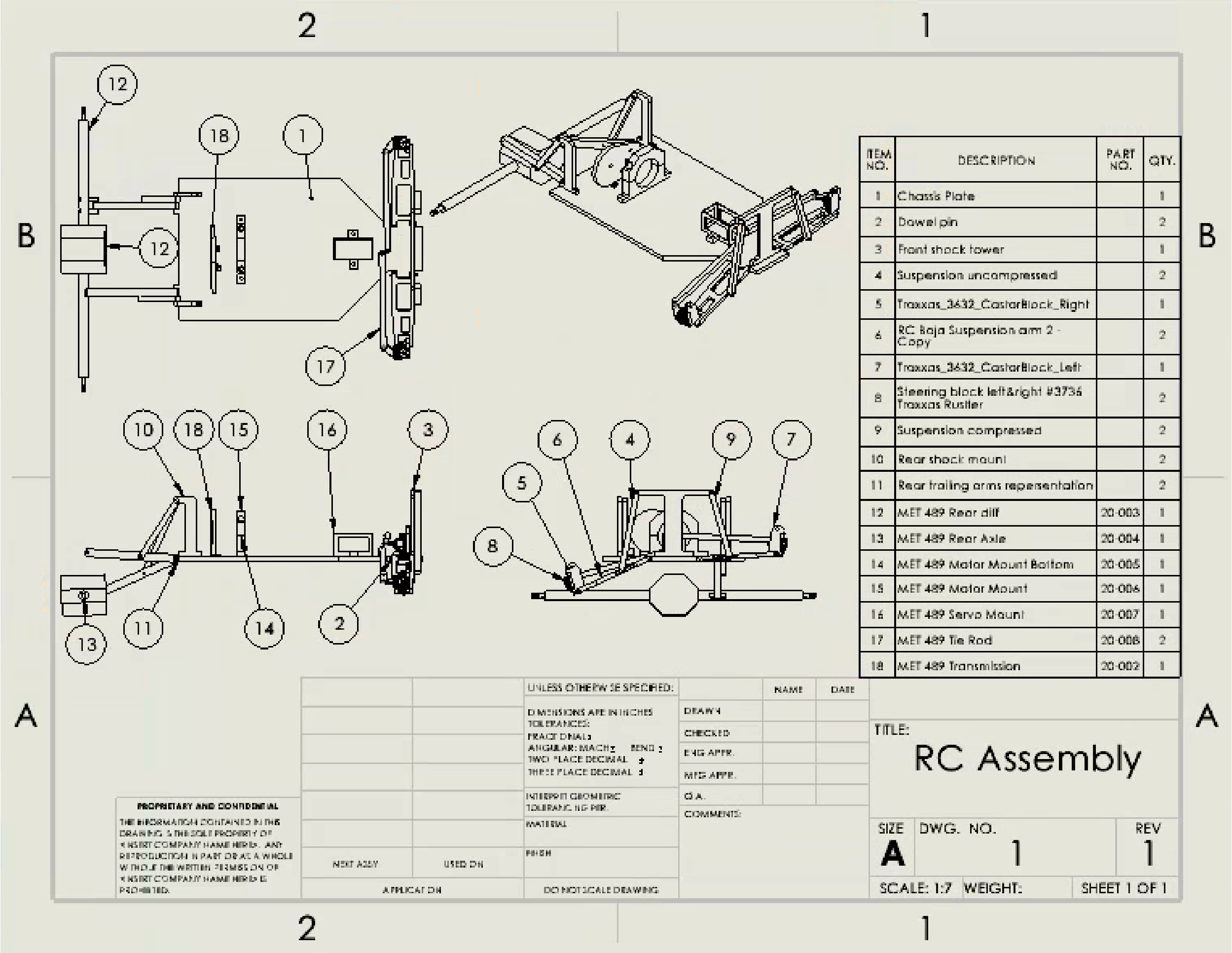
(Figure A-12: Angle and Distance Between U-Joints)

APPENDIX B – Drawings

Appendix B – Drawing Tree

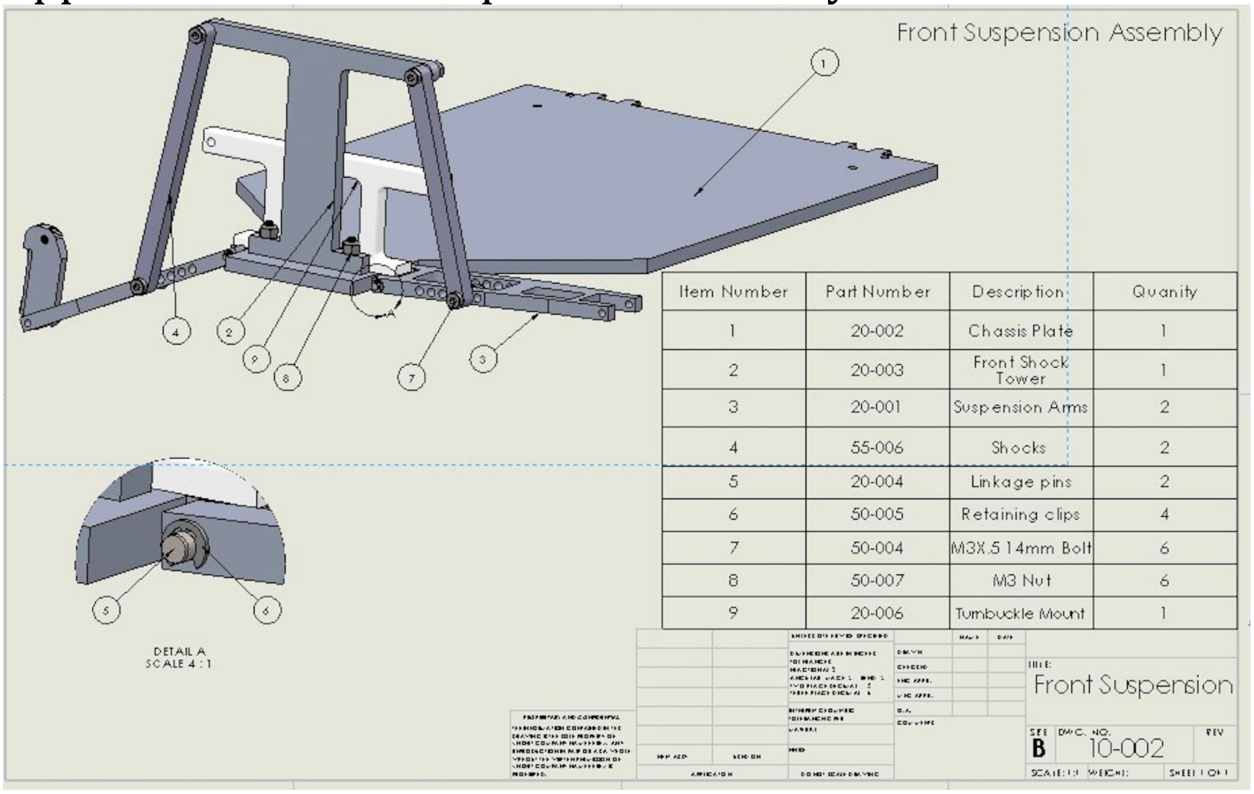


Appendix B – RC Assembly



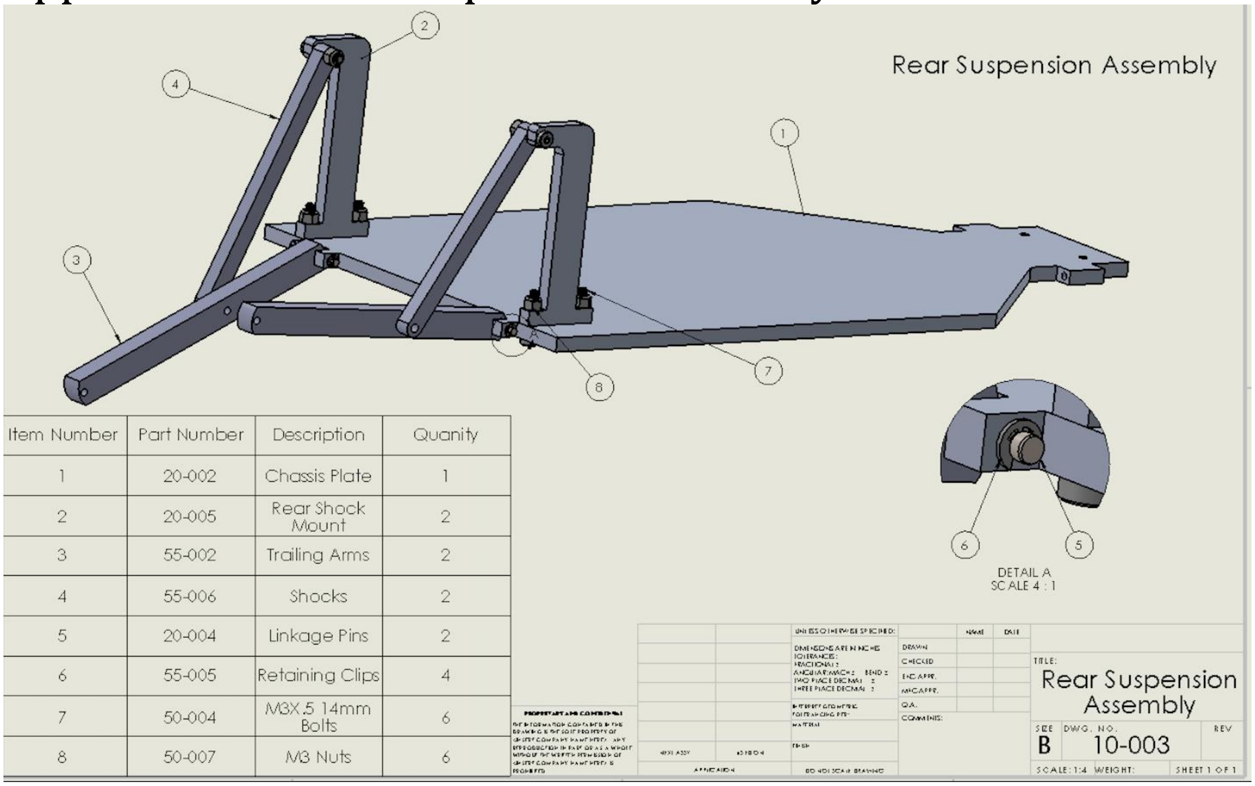
ITEM NO.	DESCRIPTION	PART NO.	QTY.
1	Chassis Plate		1
2	Dowel pin		2
3	Front shock tower		1
4	Suspension uncompressed		2
5	Traxxas_3632_CastorBlock_Right		1
6	RC Baja Suspension arm 2 - Copy		2
7	Traxxas_3632_CastorBlock_Left		1
8	Steering block left&right #3736 Traxxas Rustler		2
9	Suspension compressed		2
10	Rear shock mount		2
11	Rear trailing arms repersentation		2
12	MET 489 Rear diff	20-003	1
13	MET 489 Rear Axle	20-004	1
14	MET 489 Motor Mount Bottom	20-005	1
15	MET 489 Motor Mount	20-006	1
16	MET 489 Servo Mount	20-007	1
17	MET 489 Tie Rod	20-008	2
18	MET 489 Transmission	20-002	1

Appendix B – Front Suspension Assembly



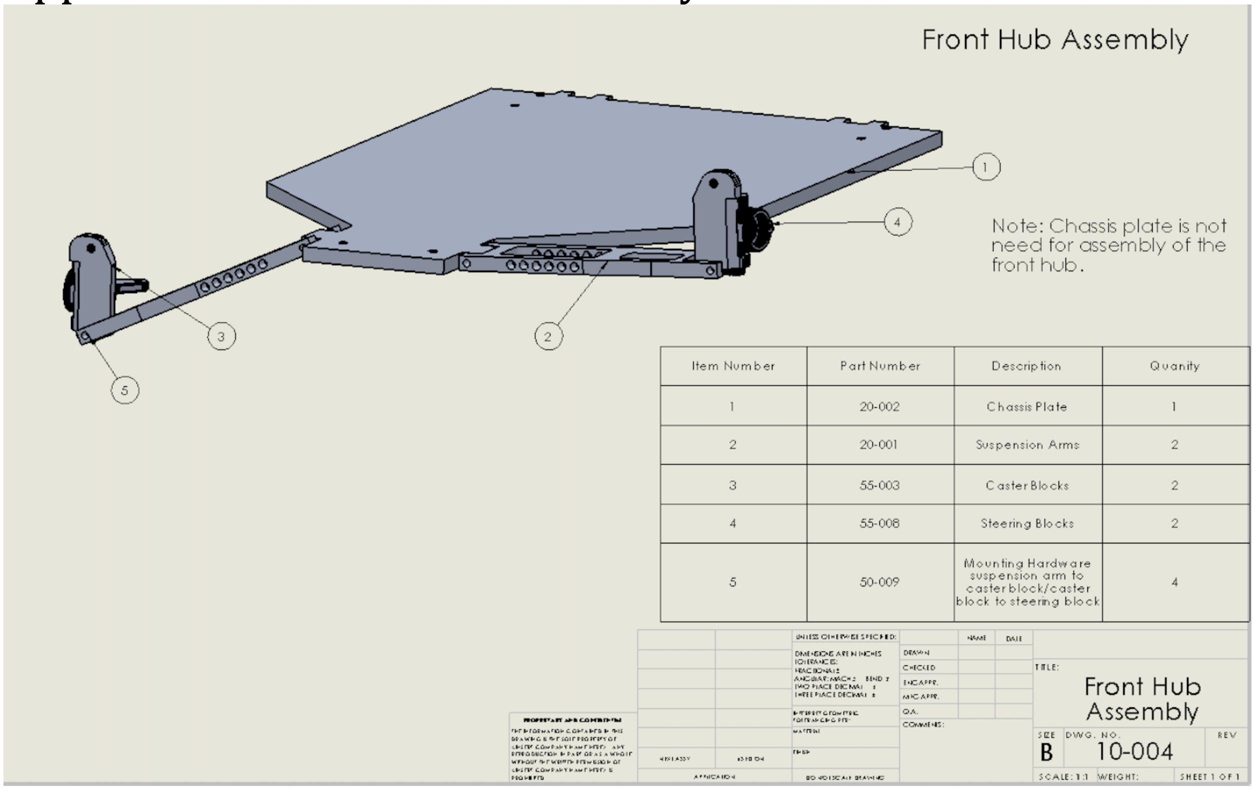
Item Number	Part Number	Description	Quanity
1	20-002	Chassis Plate	1
2	20-003	Front Shock Tower	1
3	20-001	Suspension Arms	2
4	55-006	Shocks	2
5	20-004	Linkage pins	2
6	50-005	Retaining clips	4
7	50-004	M3X.5 14mm Bolt	6
8	50-007	M3 Nut	6
9	20-006	Tumbuckle Mount	1

Appendix B – Rear Suspension Assembly



Item Number	Part Number	Description	Quanity
1	20-002	Chassis Plate	1
2	20-005	Rear Shock Mount	2
3	55-002	Trailing Arms	2
4	55-006	Shocks	2
5	20-004	Linkage Pins	2
6	55-005	Retaining Clips	4
7	50-004	M3X.5 14mm Bolts	6
8	50-007	M3 Nuts	6

Appendix B – Front Hub Assembly

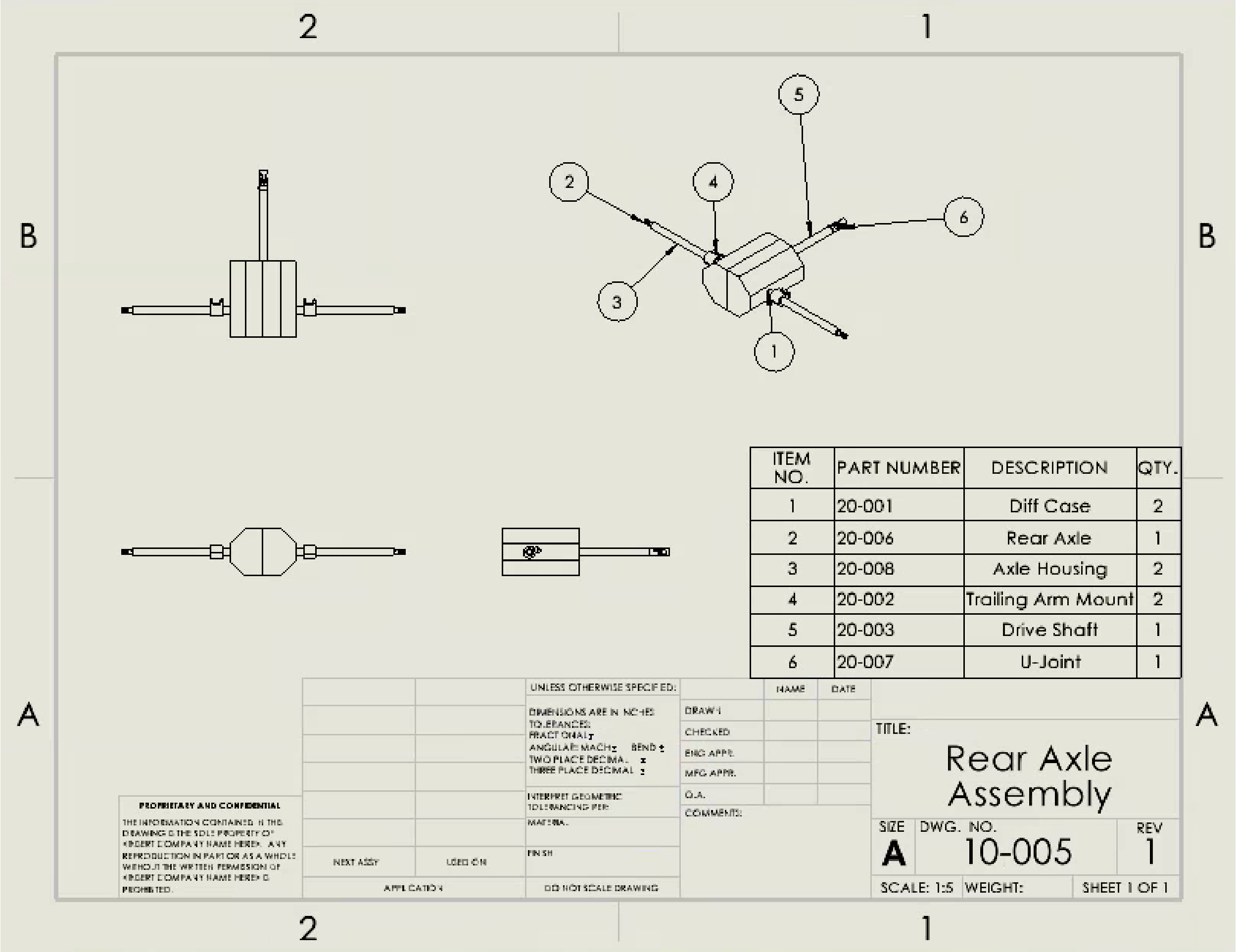


Front Hub Assembly

Note: Chassis plate is not need for assembly of the front hub.

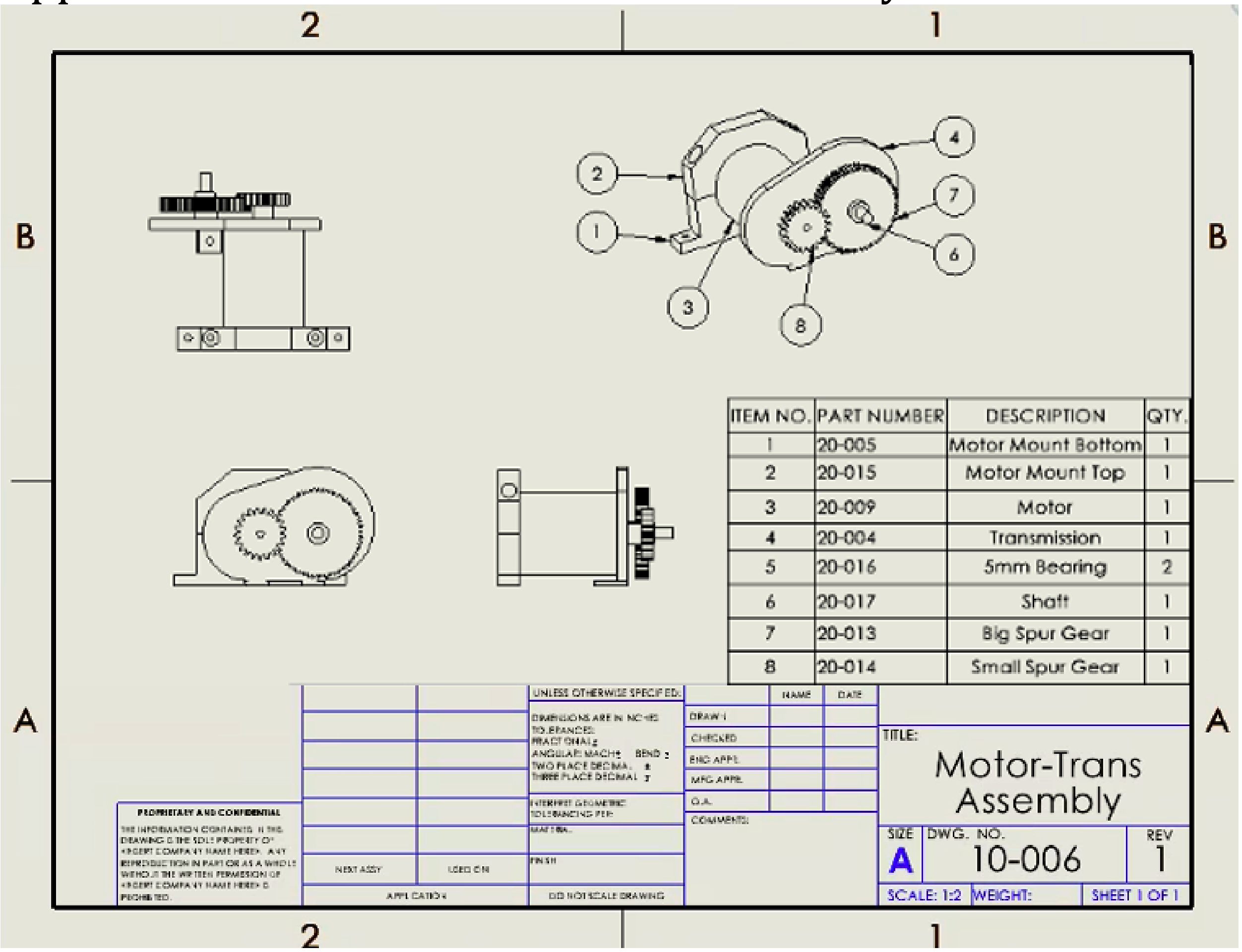
Item Number	Part Number	Description	Quanity
1	20-002	Chassis Plate	1
2	20-001	Suspension Arms	2
3	55-003	Caster Blocks	2
4	55-008	Steering Blocks	2
5	50-009	Mounting Hardware suspension arm to caster block/caster block to steering block	4

Appendix B – Rear Axle Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-001	Diff Case	2
2	20-006	Rear Axle	1
3	20-008	Axle Housing	2
4	20-002	Trailing Arm Mount	2
5	20-003	Drive Shaft	1
6	20-007	U-Joint	1

Appendix B – Motor-Transmission Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-005	Motor Mount Bottom	1
2	20-015	Motor Mount Top	1
3	20-009	Motor	1
4	20-004	Transmission	1
5	20-016	5mm Bearing	2
6	20-017	Shaft	1
7	20-013	Big Spur Gear	1
8	20-014	Small Spur Gear	1

TITLE: Motor-Trans Assembly

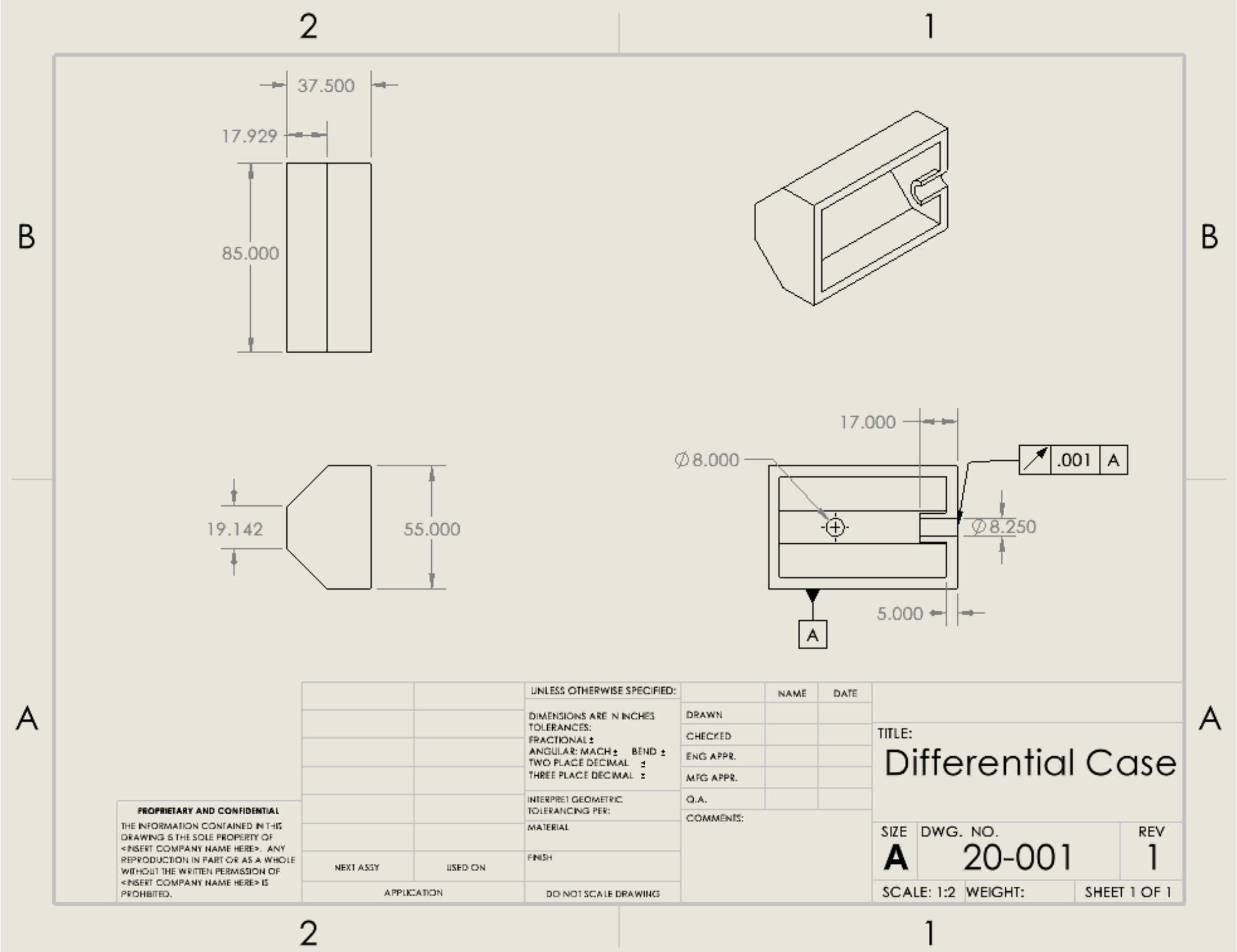
SIZE A

DWG. NO. 10-006

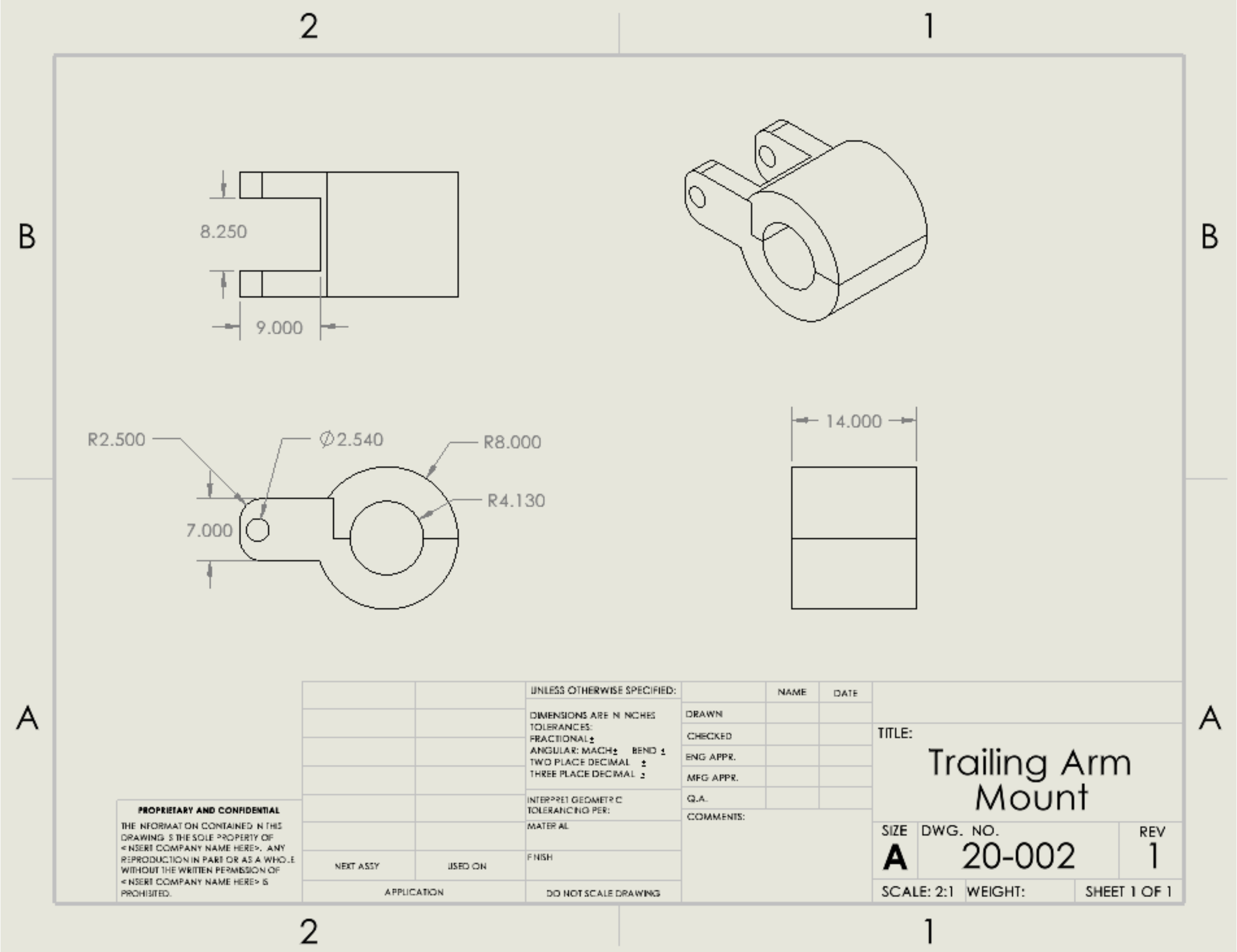
REV 1

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

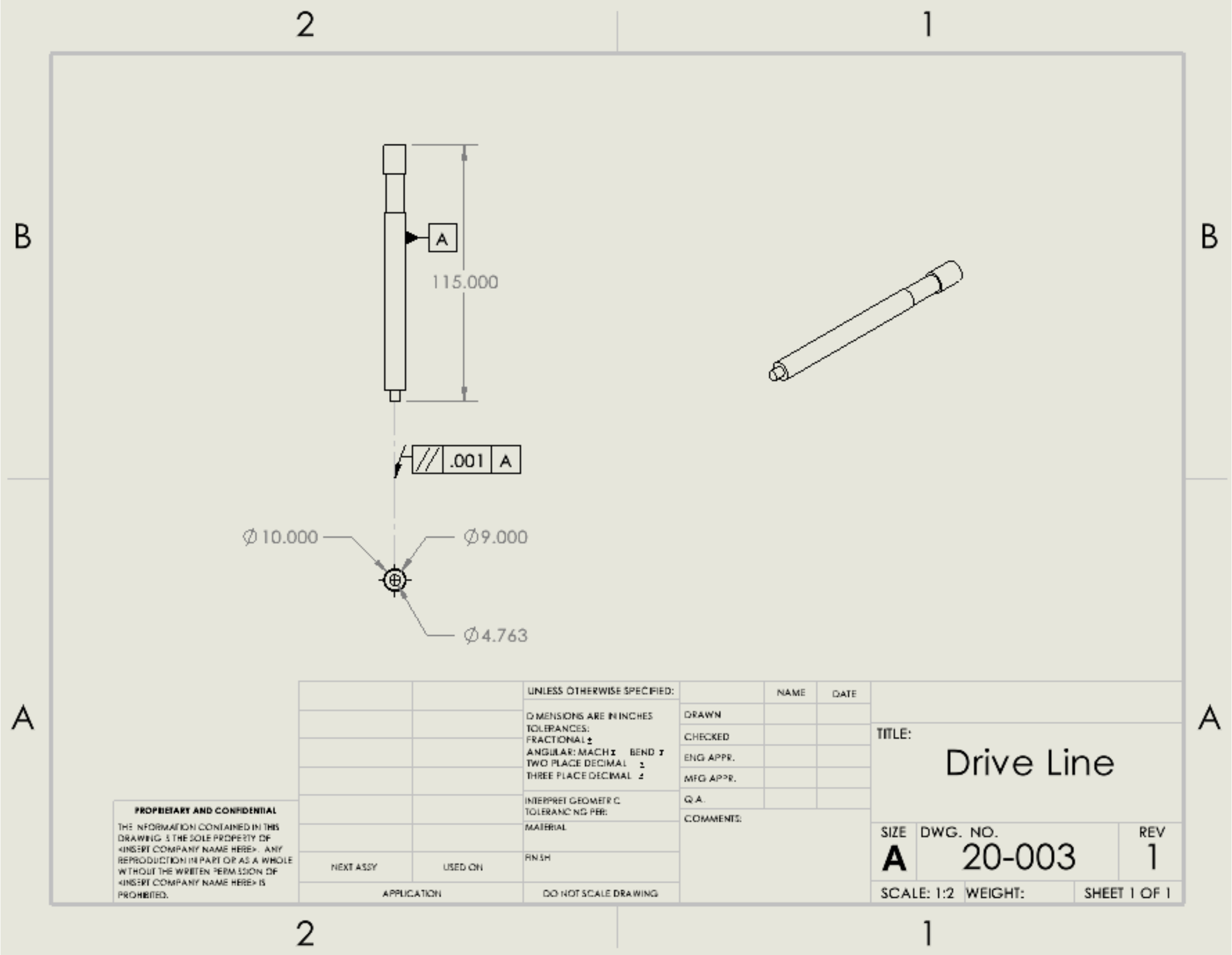
Appendix B – Differential Case



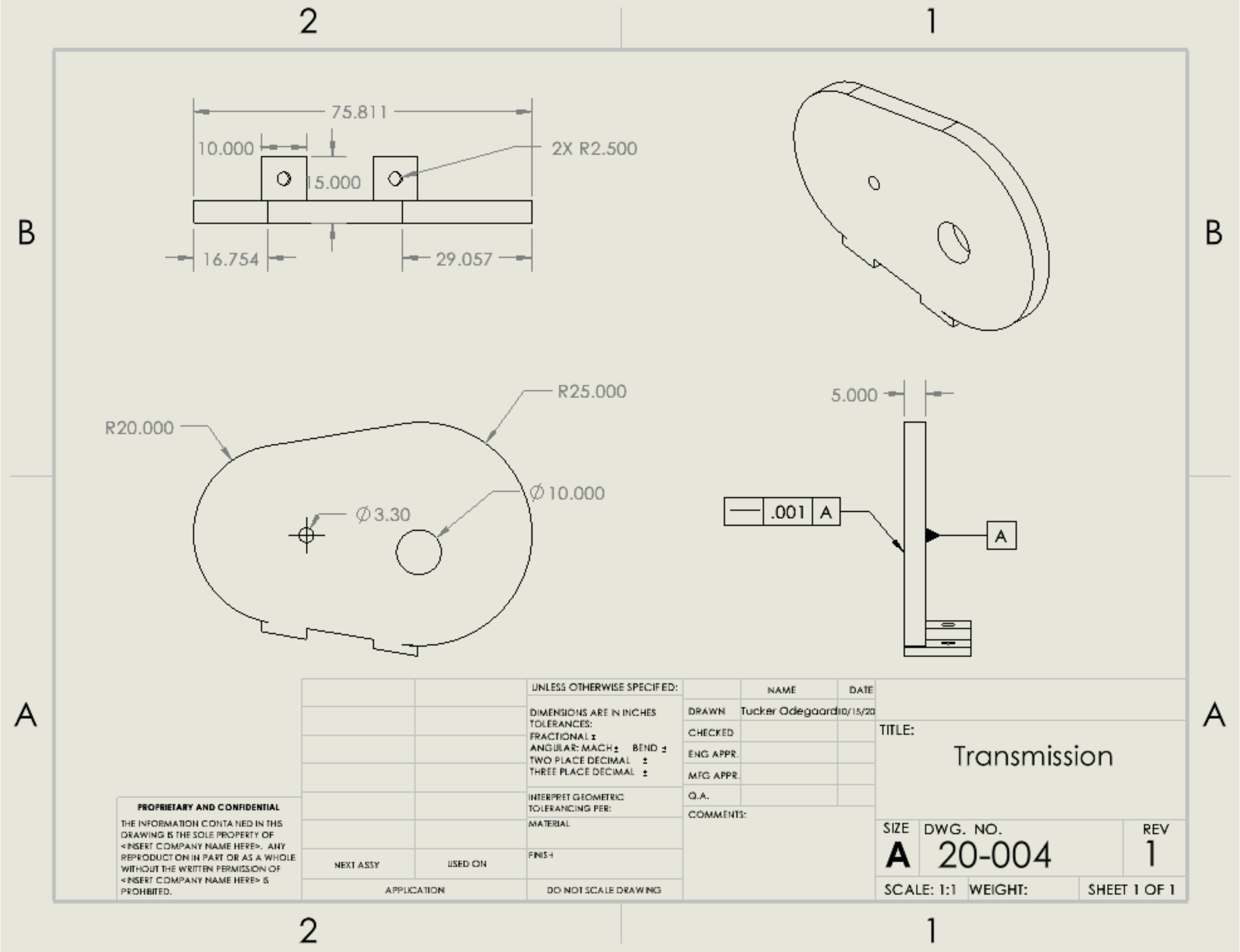
Appendix B – Trailing Arm Mount



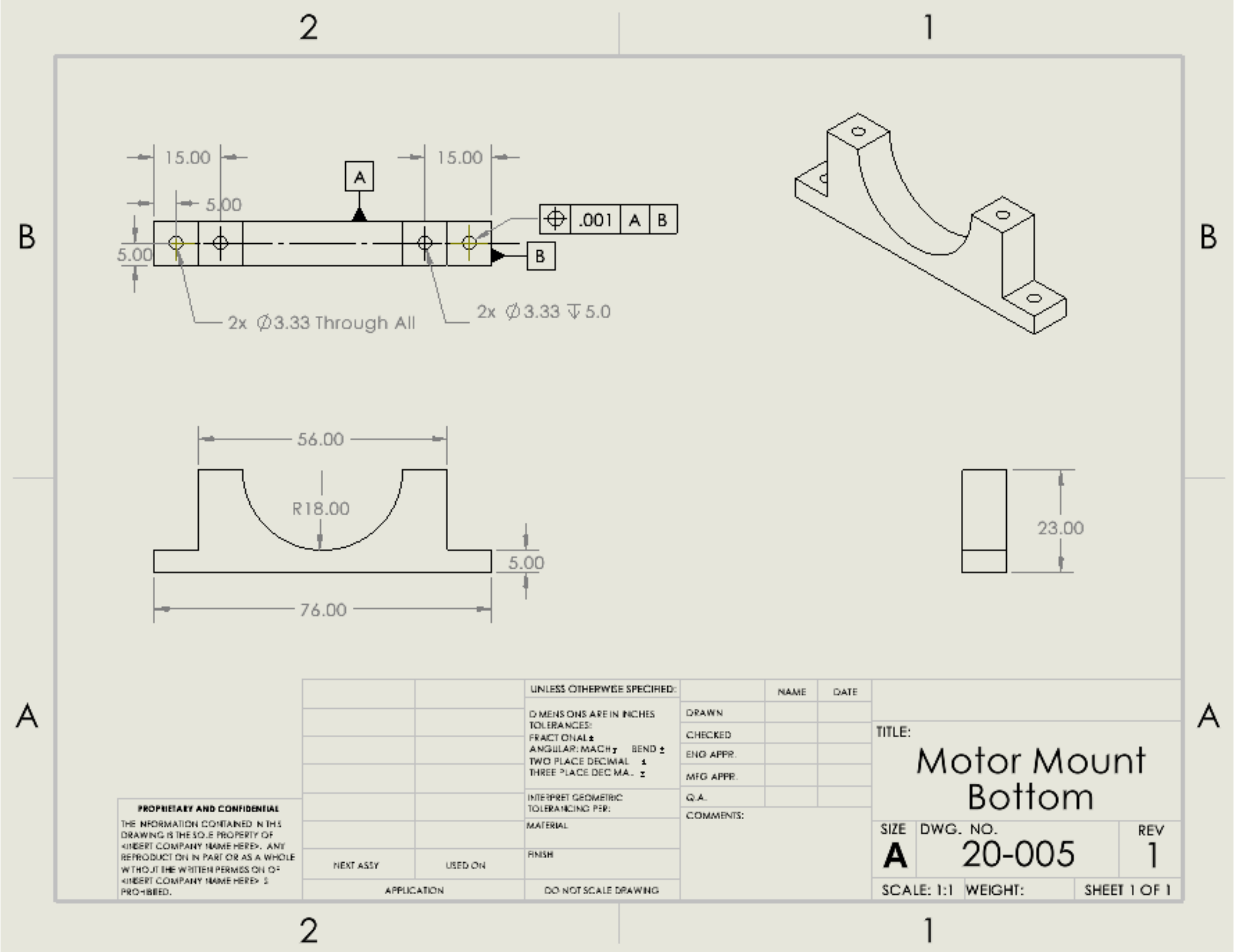
Appendix B – Drive Line



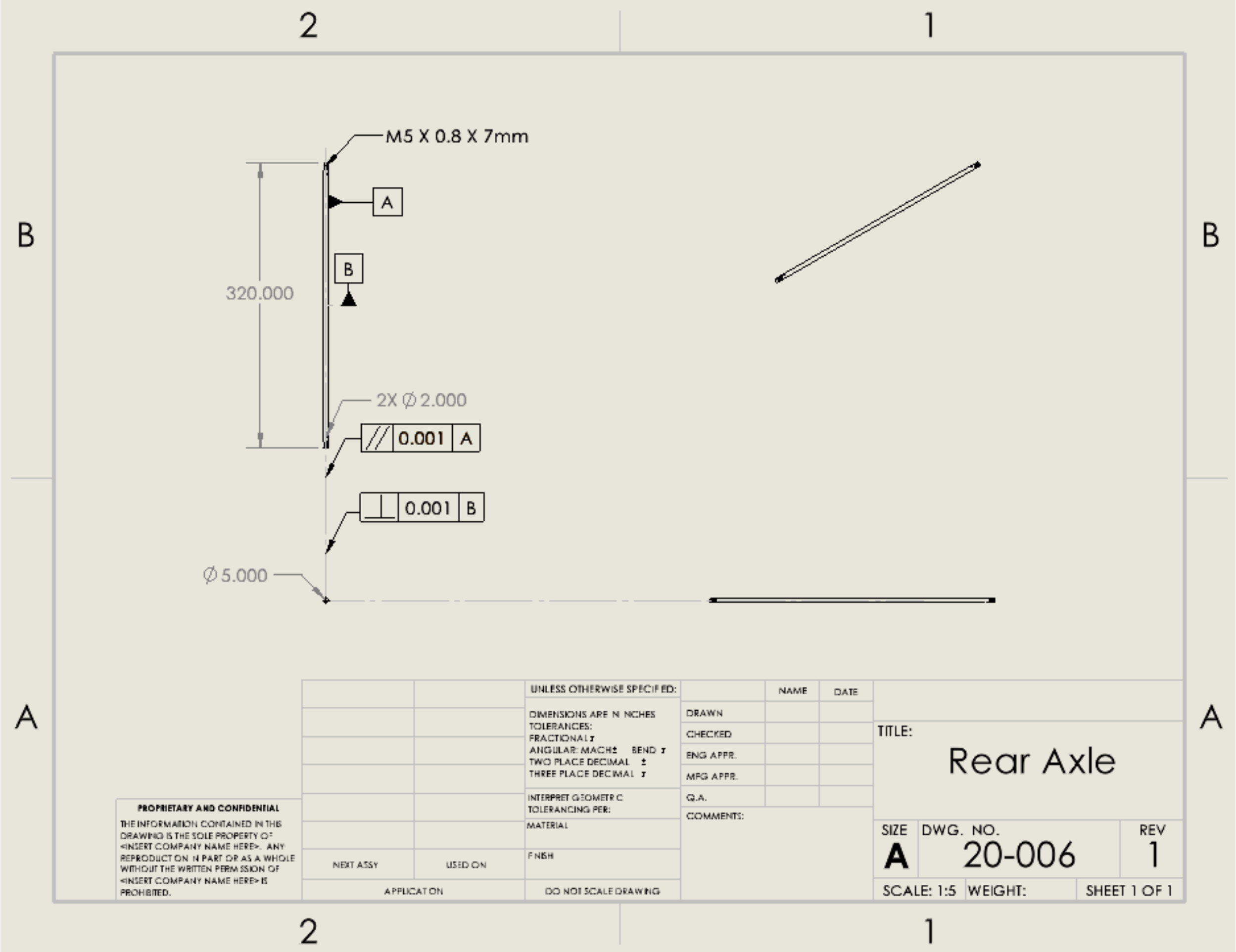
Appendix B – Transmission



Appendix B – Motor Mount Bottom



Appendix B – Rear Axle



APPENDIX C – Parts List and Costs

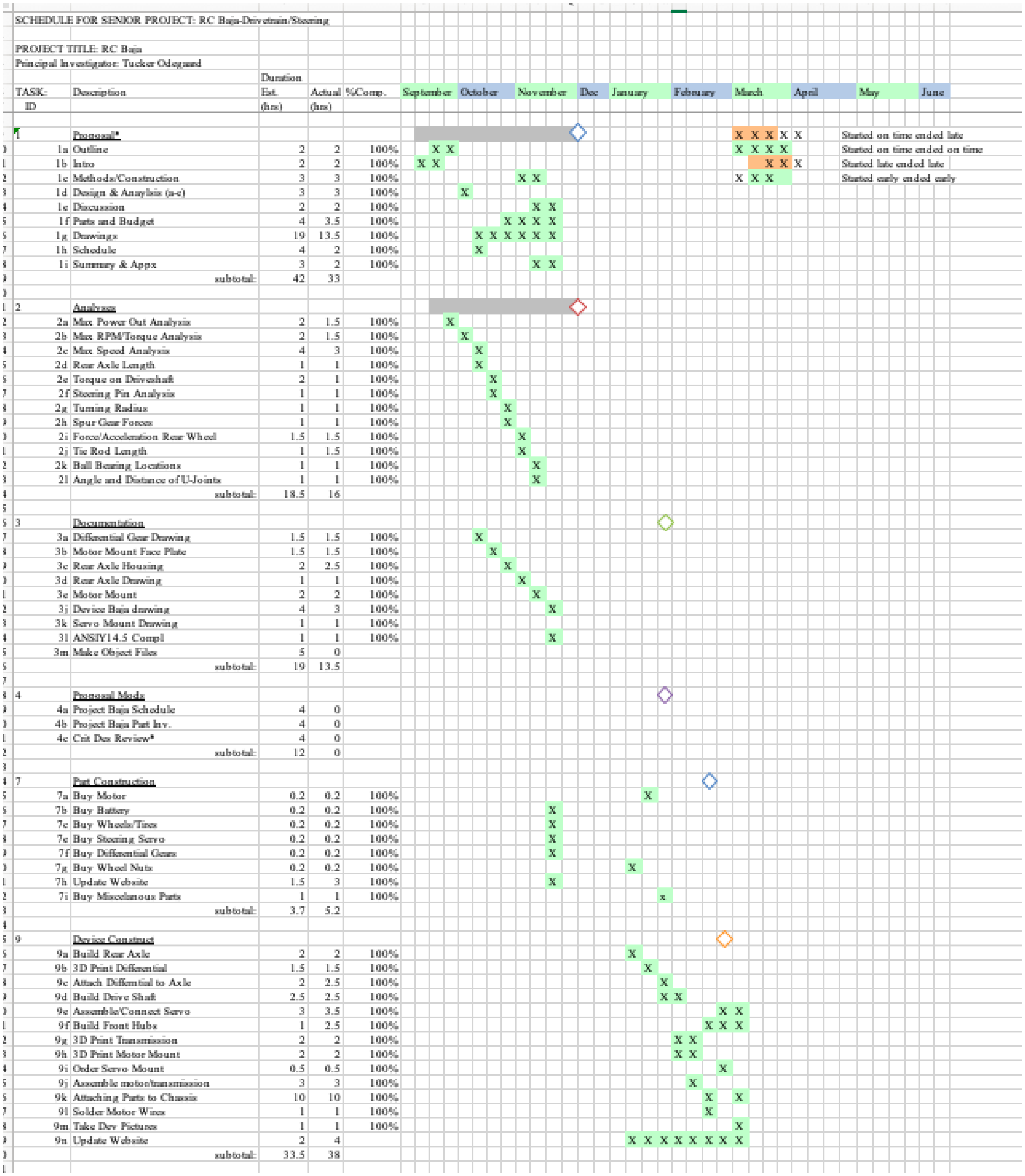
Part Number	Qty	Part Description	Source	Cost	Disposition
AX30395	1	Diff Gears	HobbyPark	$30.20	Order 11/5
B001QLFP16	1	Diff Gears	Amazon	$36.80	Order 1/26
11184 & 11181	1	Spur Gear	Hobbypark	$15.21	Order 11/10
B07V45SG6R	2	Wheels & Tires (2)	HHoo	$36.78	Order 11/10
B004A8V3D6	1	Battery	Venom	$47.21	Order 1/10
B089218ZW9	1	Battery Charger	Amazon	$16.23	Order 2/16
B073F92G2S	1	Steering Servo	Amazon	$19.21	Order 11/10
B07LCBJD65	1	Servo Mount	Amazon	$9.74	Order 2/22
30408009	1	Motor	Hobbywing	$58.99	Order 1/10
FLT20190905K-0064	1	U-Joint Set (2)	Amazon	$18.91	Order 1/27
B07PS3ZGR5	1	Speed Controller	Hobbywing	$30.99	Order 1/15
B07TBK9PR6	1	Drive Line	Amazon	$32.21	Order 11/5
B08GLGNYWY	1	12 mm Wheel Nut (4)	Amazon	$8.69	Order 1/15
B08B3DPH1Y	1	Steering Turn Buckle	Amazon	$16.23	Order 2/10
B001MIKPZE	1	Steering Turn Buckle	Amazon	$14.07	Order 2/19
B07DPMVVKN	1	Controller	Amazon	$64.97	Order 2/8
a19092000ux1257	1	Bearings (10)	Amazon	$9.19	Order 1/26
g20011600ux0023	1	Bearings (10)	Amazon	$9.74	Order 2/21
004-008-014	1	Stainless Steel Rod (2)	Amazon	$10.82	Order 1/26
B07KJHP2KL	1	Aluminum Shaft (2)	Amazon	$9.66	Order 1/13
LBODAA1102	1	Plastic Epoxy	Fred Meyer	$4.00	Buy 2/1
LB20AA5781	1	Metal Epoxy	Fred Meyer	$4.00	Buy 2/1
	1	Miscellaneous	Ace	$10.00	Buy 2/1
20-002	1	Transmission	3D Print	$5	Build by 1/20
20-003	1	Differential Gear Box	3D Print	$10	Build by 1/20
20-004	1	Rear Axle	Machine Shop	$10	Build by 1/20
20-005	1	Motor Mount Bottom	3D Print	$2	Build by 1/20
20-006	1	Motor Mount Top	3D Print	$2	Build by 1/20
20-007	2	Trailing Arm Connector	3D Print	$2	Build by 2/10
			TOTAL	**$544.85**	
			INDIVIDUAL	**$409.85**	

Note: Highlighted parts were split between both team members.

APPENDIX D – Budget

Item	Qty	Description	Cost
Total Parts (Ordered)	22	All parts ordered online	$378.85
Manufactured Parts	6	3D Prints and Machine Shop Costs	$31.00
Total			**$409.85**

APPENDIX E – Schedule



SCHEDULE FOR SENIOR PROJECT: RC Baja-Drivetrain/Steering

PROJECT TITLE: RC Baja
Principal Investigator: Tucker Odegaard

TASK: ID	Description	Duration Est. (hrs)	Actual (hrs)	%Comp.	September				October				November				Dec		January				February				March				April				May				June	
1	Proposal*																◇										X	X	X	X	X			Started on time ended late						
1a	Outline	2	2	100%			X	X																			X	X	X	X				Started on time ended on time						
1b	Intro	2	2	100%		X	X																						X	X	X			Started late ended late						
1c	Methods/Construction	3	3	100%									X	X													X	X	X					Started early ended early						
1d	Design & Anaylsis (a-c)	3	3	100%					X																															
1e	Discussion	2	2	100%										X	X																									
1f	Parts and Budget	4	3.5	100%								X	X	X	X																									
1g	Drawings	19	13.5	100%						X	X	X	X	X	X																									
1h	Schedule	4	2	100%						X																														
1i	Summary & Appx	3	2	100%										X	X																									
	subtotal:	42	33																																					
2	Analyses																◇																							
2a	Max Power Out Analysis	2	1.5	100%				X																																
2b	Max RPM/Torque Analysis	2	1.5	100%					X																															
2c	Max Speed Analysis	4	3	100%						X																														
2d	Rear Axle Length	1	1	100%						X																														
2e	Torque on Driveshaft	2	1	100%							X																													
2f	Steering Pin Analysis	1	1	100%							X																													
2g	Turning Radius	1	1	100%								X																												
2h	Spur Gear Forces	1	1	100%								X																												
2i	Force/Acceleration Rear Wheel	1.5	1.5	100%									X																											
2j	Tie Rod Length	1	1.5	100%									X																											
2k	Ball Bearing Locations	1	1	100%										X																										
2l	Angle and Distance of U-Joints	1	1	100%										X																										
	subtotal:	18.5	16																																					
3	Documentation																					◇																		
3a	Differential Gear Drawing	1.5	1.5	100%						X																														
3b	Motor Mount Face Plate	1.5	1.5	100%							X																													
3c	Rear Axle Housing	2	2.5	100%								X																												
3d	Rear Axle Drawing	1	1	100%									X																											
3e	Motor Mount	2	2	100%										X																										
3j	Device Baja drawing	4	3	100%											X																									
3k	Servo Mount Drawing	1	1	100%																																				
3l	ANSIY14.5 Compl	1	1	100%											X																									
3m	Make Object Files	5	0																																					
	subtotal:	19	13.5																																					
4	Proposal Mods																					◇																		
4a	Project Baja Schedule	4	0																																					
4b	Project Baja Part Inv.	4	0																																					
4c	Crit Des Review*	4	0																																					
	subtotal:	12	0																																					
7	Part Construction																								◇															
7a	Buy Motor	0.2	0.2	100%																	X																			
7b	Buy Battery	0.2	0.2	100%											X																									
7c	Buy Wheels/Tires	0.2	0.2	100%											X																									
7e	Buy Steering Servo	0.2	0.2	100%											X																									
7f	Buy Differential Gears	0.2	0.2	100%											X																									
7g	Buy Wheel Nuts	0.2	0.2	100%															X																					
7h	Update Website	1.5	3	100%											X																									
7i	Buy Miscellanous Parts	1	1	100%																		x																		
	subtotal:	3.7	5.2																																					
9	Device Construct																									◇														
9a	Build Rear Axle	2	2	100%															X																					
9b	3D Print Differential	1.5	1.5	100%																X																				
9c	Attach Diffential to Axle	2	2.5	100%																	X																			
9d	Build Drive Shaft	2.5	2.5	100%																	X	X																		
9e	Assemble/Connect Servo	3	3.5	100%																					X	X														
9f	Build Front Hubs	1	2.5	100%																				X	X	X														
9g	3D Print Transmission	2	2	100%																		X	X																	
9h	3D Print Motor Mount	2	2	100%																		X	X																	
9i	Order Servo Mount	0.5	0.5	100%																					X															
9j	Assemble motor/transmission	3	3	100%																			X																	
9k	Attaching Parts to Chassis	10	10	100%																				X		X														
9l	Solder Motor Wires	1	1	100%																				X																
9m	Take Dev Pictures	1	1	100%																						X														
9n	Update Website	2	4																X	X	X	X	X	X	X	X														
	subtotal:	33.5	38																																					

APPENDIX F – Expertise and Resources

There was a need for an RC Baja expert for programming the speed controller and motor. Most of the programming was completed by the principal engineer, but the motor would only spin forward. One of the requirements was that the Baja needed to go forward and backward. That is when the expert came into play. He was able to quickly program the speed controller to get the motor to spin forward and backward.

APPENDIX G – Testing Report

Introduction:

During the testing of the RC Baja, the top speed, turning angle, and line tracking results will be found. The requirements for the project are as follows:

Requirements:

- The RC Baja must reach a top speed of at least 20 miles per hour.
- The RC Baja must turn 60 degrees in both directions.
- The RC Baja must track a straight line for at least 20 feet.

Predicted Performance:

The predicted performance for the top speed of the RC Baja was 22 miles per hour. The calculation was based off of the motor output RPM and the gearing that was used to get the correct speed to the rear wheels. The calculation neglected any friction between the tires and the ground.

The predicted performance for the turning angle was 60 degrees in both directions from parallel, which was determined from the steering servo capabilities.

The predicted performance for the line tracking test was that the Baja tracked a straight line without pulling to the left or right.

Data Acquisition:

Data during the test will be collected by using a speedometer app to track the top speed, a protractor and tape for the turning angle, and a tape measure and tape for the line tracking. A phone video camera will also be used to record each of the tests.

Schedule:

The schedule for this testing is related to the due dates of the Spring Senior Project course. The testing was completed during the allotted time period of the beginning of the quarter to the due date of the testing report. Some complications occurred during the testing that altered planned test dates, more details can be found on the Gantt chart included in Appendix G5.

Method/Approach:

Resources:

During the testing process some resources were needed to complete the test. Each test had a requirement for a team of two people. One person was required to operate the R/C car, while another was required for taking time measurements or angle measurements and recording the data on the tables. All other resources were used from acquired equipment that was common in the household such as measuring equipment and timing equipment (iPhone).

Data capture/doc/processing:

Data capture was done by human. The data capture only required a person to use a phone to record and also visually see the tests to see if they were successful. The data was then recorded on the testing sheet.

Test Procedure Overview

The testing procedures that can be found in the following pages of the report consist of three different tests, top speed, line tracking, and turning angle. The top speed test utilized a phone app to record the top speed of the Baja. The line tracking test was to determine if the front end was properly aligned by driving it in a straight line. The turning angle test was done by turning the front tires fully left and right and determining the angle from parallel. All three tests were done in the Hogue Hall south foyer on a smooth concrete floor.

Operational Limitations:

Limitations in the testing come from human error. The turning angle test is hard to determine exactly what degree the wheel turned to by using a protractor. More precise equipment would lead to more accurate results. The device limitations are that it needs two people in order to do any testing.

Precision and Accuracy Discussion:

During the testing, the precision and accuracy of timing the R/C car can vary. To narrow down the possibility of error, everything was carefully recorded on a phone. Therefore, every aspect of the test could be reviewed in slow motion to reduce the chance for error. The precision of the steering angle measurements remained around +/- 2.0 degrees of deviation per measurement.

Data Storage, Analysis, and Presentation:

Data was stored in a Word document that listed each of the tests and what the passing requirement for each was. There was also a handwritten document that contained raw data calculations. The results of the tests will be presented with graphs and charts.

Test Procedures:

Test #1 – RC Baja Top Speed

Summary:

This procedure documents the process of recording the RC Baja top speed test. The RC Baja has been designed and constructed by two students in the Mechanical Engineering Technology program in order to satisfy the senior project requirement. The Baja was designed in order to reach a top speed of at least 20 miles per hour.

Time: The test was conducted on 4/8/21 from 11:30 am to 12:30 pm in the Hogue Hall south foyer. There was 10 minutes of gathering equipment and setting up prior to the test. After the test, there was 20 minutes to record data and return equipment.
Place: Hogue Hall foyer, Central Washington University campus in Ellensburg, WA.
Required equipment includes:

- Phone camera
- Speedometer app on phone
- Blue Painters Tape
- RC Car and Remote

Risk: The risk associated with the speed test is something breaking on the car while running it at full speed. The gears spin very fast at full speed and could cause them to chip off teeth. Multiple trials could be hard on the car as it is stopping and accelerating multiple times.

The test procedure is as follows:

1. Collect equipment:
    a. Phone camera from a personal phone.
    b. Blue painters' tape from home.
    c. Speedometer app from a personal phone.
    d. RC Car and remote from home.
2. Go to Hogue Hall foyer on south side of building.
3. Make sure foyer is clear and there is no debris or large objects on the floor.
4. Open the speedometer app on one of the phones.
5. Place the phone on the RC Baja next to the battery.
6. Secure the phone using blue painter's tape.
7. Place the car at one end of the foyer and turn it on.
8. The other person will use their phone to record the car.
9. Once recording has started, the driver of the car will start accelerating it across the foyer.
10. The person recording will record the car from start to stop.
11. Once the car has reached full speed, hold it at that speed for approximately two seconds.
12. Slowly de-accelerate the car to a stop.
13. Examine the phone that is taped to the car to read the top speed that it recorded.
    a. Make sure to get video evidence of the recording.
14. Reset the app so that a new test can be ran.
15. Repeat steps 7 through 14 two more times to get an accurate top speed measurement.
16. Take the average of the three trials to determine the top speed of the RC Baja.
17. If the average was 20 mph or greater, the requirement was successfully met.

18. Check off the box that asks if the requirement was met on the testing sheet provided in the engineering report.
19. Return all equipment back to proper locations.

Discussion:
During the testing, some issues occurred. First, the pinion gear attached to the motor output shaft got stripped during the first test. The reason was because it was a different pitch than the driven gear. A new pinion had to be ordered that was the correct pitch. Another issue was the drive shaft. There needed to be a bearing holder on the top of the drive shaft so that the shaft could not move. The part was 3-D printed and installed. Once the issues were resolved, testing resumed and went smoothly.

Test #2 – RC Baja Line Tracking Test

Summary:
This procedure documents the process of recording the RC Baja line tracking test. The RC Baja has been designed and constructed by two students in the Mechanical Engineering Technology program in order to satisfy the senior project requirement. The Baja was designed in order to track a straight line for at least 20 feet.

Time: The test was conducted on 4/27/21 from 11:30 am to 12:30 pm in the Hogue Hall south foyer. There was 10 minutes of gathering equipment and setting up prior to the test. After the test, there was 20 minutes to record data and return equipment.
Place: Hogue Hall foyer, Central Washington University campus in Ellensburg, WA.
Required equipment includes:

- Phone camera
- Blue Painters Tape
- RC Car and Remote
- Tape Measure

Risk: The risk associated with the tracking test is it not being able to track a straight line. The front steering rods could be adjusted differently which makes the car pull from one side to the other.

The test procedure is as follows:

1. Collect equipment:
    a. Phone camera from a personal phone.
    b. Blue painters’ tape from home.
    c. Tape measure from home.
    d. RC Car and remote from home.
2. Go to Hogue Hall foyer on south side of building.
3. Make sure foyer is clear and there is no debris or large objects on the floor.
4. Place a small piece of tape down on the floor.
5. From the piece of tape, measure out 20 feet and place another piece of tape down.
6. Once 20 feet is marked out, lay a continuous strip of tape the entire 20-foot length.
    a. Be sure to lay it as straight as possible to get accurate results.
7. Place the Baja at one end of the strip of tape by centering it with the tape having the tires behind the tape.
8. Turn the Baja on.
9. Open the video app on the phone and begin to record.
10. Slowly start accelerating the Baja without touching the steering.
11. Accelerate the Baja until it has reached the other end of the tape.
12. Make sure the entire test is recorded.
13. Once the Baja reaches the other side of the tape, let it come to a stop and stop the recording.
14. Determine if the test passed or failed by looking at the video.
15. The test failed if any one of the tires crossed the blue tape.
16. If the Baja stayed centered over the tape, the test was successful.

17. Mark an X on the testing sheet under the Line tracking test.
18. Pull up the tape from the floor and throw away.

Discussion:

During testing, one thing needed worked on in order to pass the test. The first few times the test was attempted, the car started to track far left or far right. In order to fix the issue, the rear axle needed to track completely straight. The rear axle tracked straight once a zip tie was put on that went from the rear shock tower to the rear axle connecter. The zip ties ensured that the axle count housing could not shift left or right. The solution worked and the car successfully completed the test.

Test #3 – RC Baja Steering Angle

Summary:
This procedure documents the process of recording the RC Baja turning angle test. The RC Baja has been designed and constructed by two students in the Mechanical Engineering Technology program in order to satisfy the senior project requirement. The Baja was designed in order to turn 60 degrees from parallel in both the left and right directions.

Time: The test was conducted on 5/6/21 from 11:30 am to 12:30 pm in the Hogue Hall south foyer. There was 10 minutes of gathering equipment and setting up prior to the test. After the test, there was 20 minutes to record data and return equipment.
Place: Hogue Hall foyer, Central Washington University campus in Ellensburg, WA.
Required equipment includes:

- Phone camera
- Pen
- RC Car and Remote
- Protractor
- Printer Paper

Risk: The risk associated with the turning angle test is that the steering servo will not be able to turn the tires far enough.

The test procedure is as follows:

1. Collect equipment:
   a. Phone camera from a personal phone.
   b. RC Car and remote from home.
   c. A stack of printer paper from home.
   d. A pen and protractor from home.
2. Go to Hogue Hall foyer on south side of building.
3. Make sure foyer is clear and there is no debris or large objects on the floor.
4. Lay one piece of printer paper on the floor.
5. Place the front two tires of the Baja on the sheet of paper so that they are centered.
6. Mark a spot on the center of the tire tread on each front tire.
   a. The mark will be referenced to determine the turning angle.
7. With the tires point straight ahead, draw a small line on the sheet of paper that lines up with the mark on the tire.
   a. The line on the paper will be used to reference the angle.
8. Turn the tires all the way to the right and hold them there.
9. Make another line on the sheet of paper that is lined up with the mark on the tire.
   a. There should be a total of four small lines of the sheet of paper (two for each tire).
10. Turn the tires all the way to the left and hold them.
11. Draw a line that lines up with the mark on the tire.
12. Now, using the original line that was made when the tires were straight, measure the angle of the new line.

13. Repeat for each tire measuring both the left and right turn angles from parallel.
14. Mark an X on the testing sheet under the steering angle test.
15. Discard the printer paper and return all tools home.

Discussion:
The test was successful, and nothing needed to be modified or fixed.

Deliverables

Once the testing was completed, the data was recorded on a green sheet and later entered into the testing data sheet. The blank data testing sheet can be found in Appendix G2 and the completed data testing sheet can be found in Appendix G3. During testing, there were several parts of the Baja that either needed replaced, re-manufactured, or adjusted in order to reach the desired outcome. After the Baja work was completed, all three of the tests reached the desired outcomes and were successful.

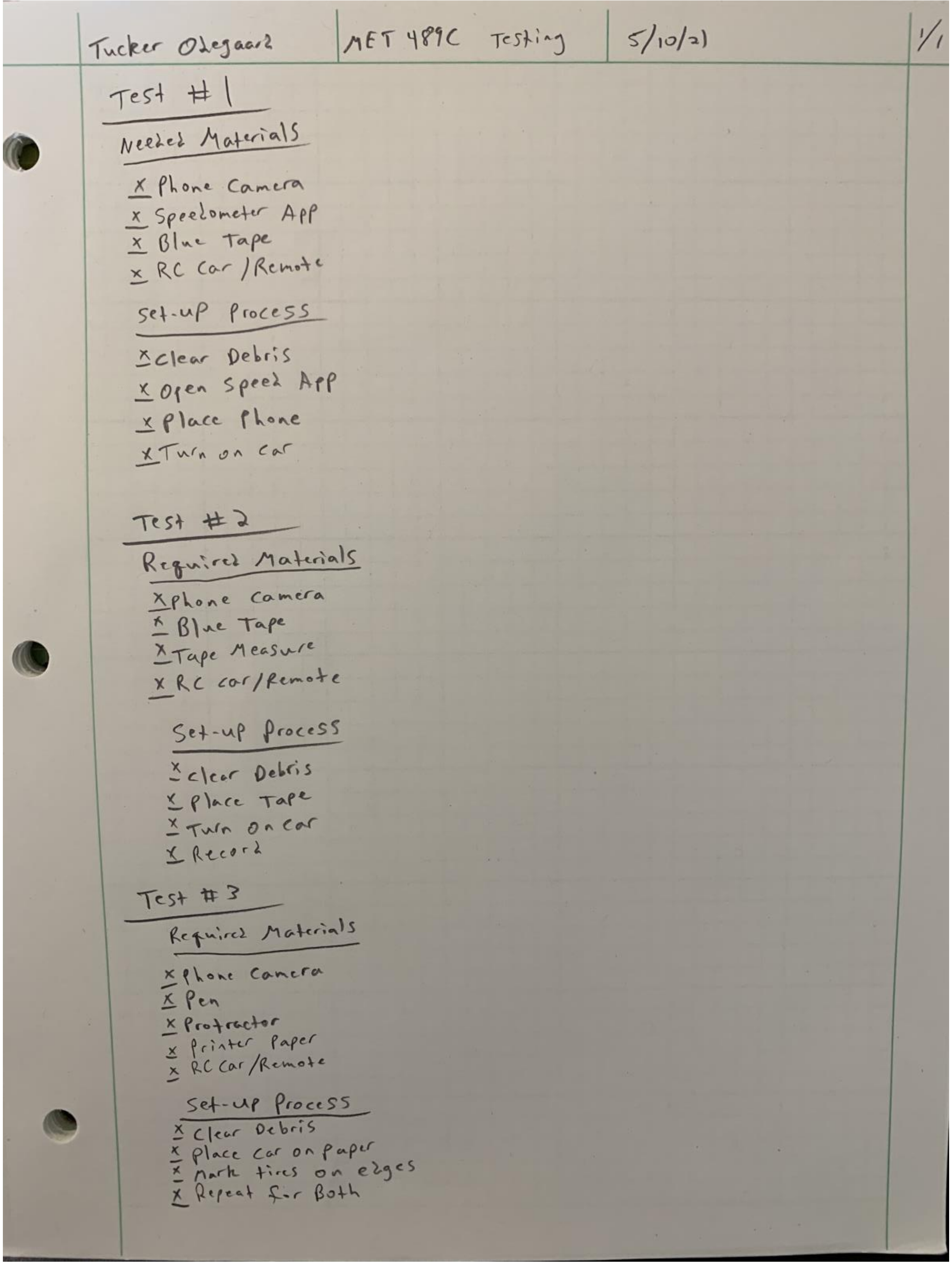
The top speed of the Baja needed to be at least 20 miles per hour to satisfy the first testing requirement. The calculations for the top speed were based off of the motor rpm from the manual. However, some losses occurred from the type of battery that was used, as well as friction from bearings. The calculated top speed of the Baja was 25 miles per hour; however, the fasted recorded speed of the Baja was only 21 miles per hour. The speed also varied with the surface that it was being tested on. For example, grass and asphalt had a significant negative impact on top speed whereas smooth concrete was excellent for testing on.

The line tracking test was a measure of how well the angle of the A-arms and the toe of the front tires were. The Baja needed to travel straight over a piece of tape on the floor for at least 20 feet. After completing the test, it was determined that the steering arm buckles were correctly adjusted so that the tires were aligned with each other. Since the tires were equally aligned, the Baja did not pull to the left or right, which resulted in a straight-line tracking.

During the steering angle test, the results showed that the angle the tires turned was over the predicted value. The steering servo had adjustments that allowed the tires to turn 61 degrees in both directions. The steering angle allowed the Baja to maneuver different turns without having any understeer.

After finished the tests of the RC Baja car, it is apparent that more improvement could be done to the drivetrain. Specifically, an improvement could be made in order to increase the overall velocity. To improve the performance, the power to the motor would need to be accurately checked to make sure the motor output shaft is rotating as fast as it should be. Once the rpm was measured, different gear ratios could be done in order to speed up the driveshaft that powers the real wheels. Overall Baja weight reduction would be an important data point to look at. The weight of the Baja slows the vehicle down. In order to decrease the weight, a chassis plate with a smaller thickness could be used. However, the Baja car was successful and met all three of the testing requirements. The Baja was fully functional and was able to compete in the annual ASME Baja race. The Baja made it through all three of the ASME courses with minimal damage.

Appendix G1 – Procedure Checklist



Tucker Odegaard
MET 489C Testing
5/10/21
1/1

Test #1

Needed Materials

x Phone Camera
x Speedometer App
x Blue Tape
x RC Car / Remote

Set-up Process

x Clear Debris
x Open Speed App
x Place Phone
x Turn on Car

Test #2

Required Materials

x Phone Camera
x Blue Tape
x Tape Measure
x RC car/Remote

Set-up Process

x clear Debris
x Place Tape
x Turn On Car
x Record

Test #3

Required Materials

x Phone Camera
x Pen
x Protractor
x Printer Paper
x RC Car/Remote

Set-up Process

x Clear Debris
x Place Car on Paper
x Mark tires on edges
x Repeat for Both

Appendix G2 – Data Forms

Trial	**Top Speed**	**Angle of Turn (L, R)**	**Tracking Test**
1			
2			
3			

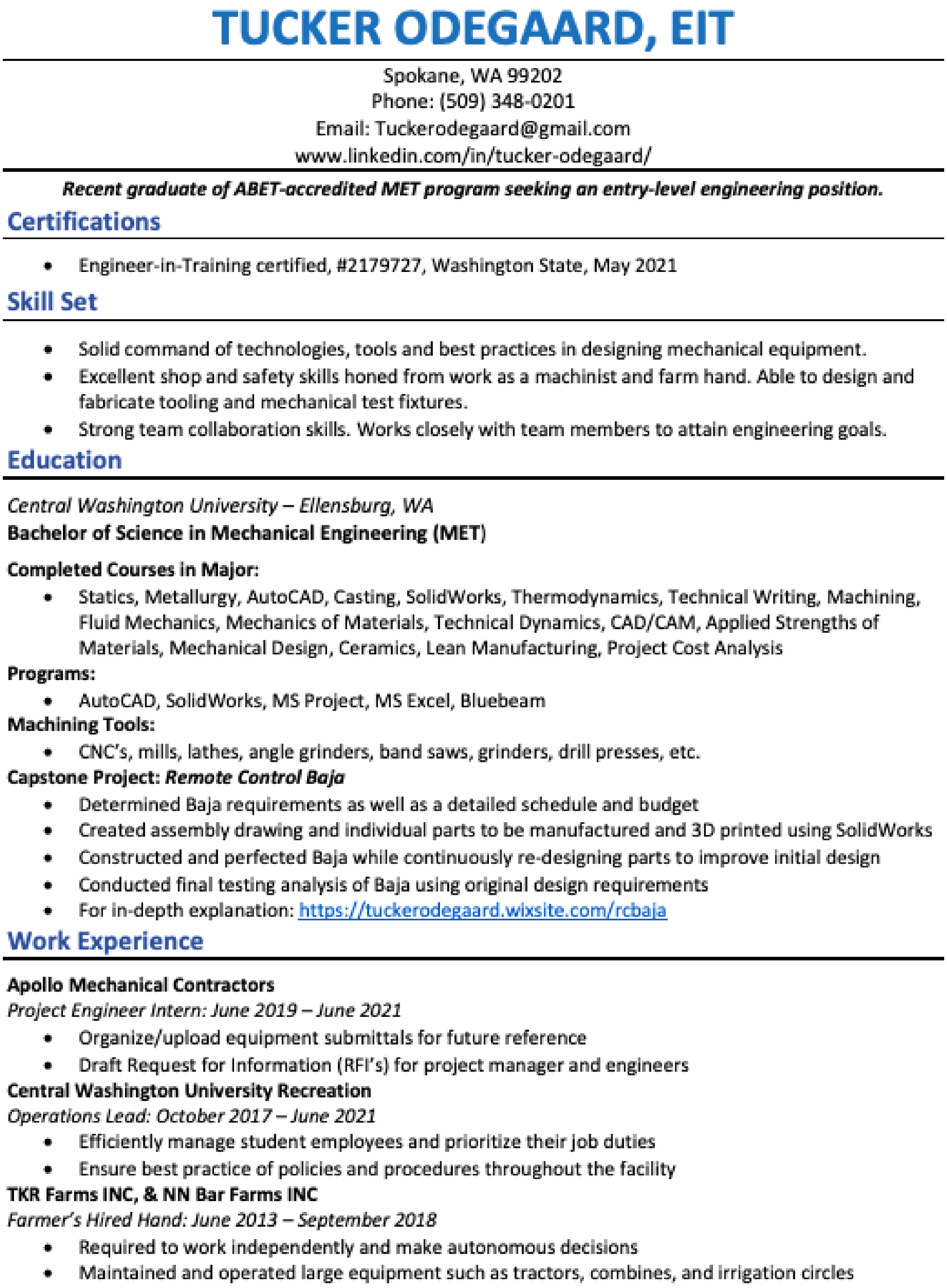
Requirements	**Pass**	**Fail**
Top Speed		
Turn Angle		
Line Tracking Test		

Appendix G3 – Raw Data

Trial	**Top Speed**	**Angle of Turn (L, R)**	**Tracking Test**
1	**10 mph**	**55º, 59º**	**Unsuccessful**
2	**17 mph**	**58º, 61º**	**Successful**
3	**21 mph**	**61º, 61º**	**Successful**

Requirements	**Pass**	**Fail**
Top Speed	**X**	
Turn Angle	**X**	
Line Tracking Test	**X**	

APPENDIX H – Resume



TUCKER ODEGAARD, EIT

Spokane, WA 99202
Phone: (509) 348-0201
Email: Tuckerodegaard@gmail.com
www.linkedin.com/in/tucker-odegaard/

Recent graduate of ABET-accredited MET program seeking an entry-level engineering position.

Certifications

- Engineer-in-Training certified, #2179727, Washington State, May 2021

Skill Set

- Solid command of technologies, tools and best practices in designing mechanical equipment.
- Excellent shop and safety skills honed from work as a machinist and farm hand. Able to design and fabricate tooling and mechanical test fixtures.
- Strong team collaboration skills. Works closely with team members to attain engineering goals.

Education

Central Washington University – Ellensburg, WA
Bachelor of Science in Mechanical Engineering (MET)

Completed Courses in Major:

- Statics, Metallurgy, AutoCAD, Casting, SolidWorks, Thermodynamics, Technical Writing, Machining, Fluid Mechanics, Mechanics of Materials, Technical Dynamics, CAD/CAM, Applied Strengths of Materials, Mechanical Design, Ceramics, Lean Manufacturing, Project Cost Analysis

Programs:

- AutoCAD, SolidWorks, MS Project, MS Excel, Bluebeam

Machining Tools:

- CNC's, mills, lathes, angle grinders, band saws, grinders, drill presses, etc.

Capstone Project: *Remote Control Baja*

- Determined Baja requirements as well as a detailed schedule and budget
- Created assembly drawing and individual parts to be manufactured and 3D printed using SolidWorks
- Constructed and perfected Baja while continuously re-designing parts to improve initial design
- Conducted final testing analysis of Baja using original design requirements
- For in-depth explanation: https://tuckerodegaard.wixsite.com/rcbaja

Work Experience

Apollo Mechanical Contractors
Project Engineer Intern: June 2019 – June 2021

- Organize/upload equipment submittals for future reference
- Draft Request for Information (RFI's) for project manager and engineers

Central Washington University Recreation
Operations Lead: October 2017 – June 2021

- Efficiently manage student employees and prioritize their job duties
- Ensure best practice of policies and procedures throughout the facility

TKR Farms INC, & NN Bar Farms INC
Farmer's Hired Hand: June 2013 – September 2018

- Required to work independently and make autonomous decisions
- Maintained and operated large equipment such as tractors, combines, and irrigation circles