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R/C Mini Baja: Drivetrain

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R/C Mini Baja: Drive Train

By

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MET 489C

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ABSTRACT

A device is needed that can power the back wheels of R/C car and allow it to drive smoothly. This drivetrain also has to transmit power to the axles in an acceptable height range to comply with the frame and suspension. The project was supported by a team member who designed the frame and suspension. The design of this project consists of two sub-assemblies that make up the drive train assembly. The transmission assembly uses gears to convert the rotational speed from the motor to the drive shaft. The gearbox assembly also uses gears and converts the rotational speed from the drive shaft to the output shaft which powers the axles. To transmit the power from the electric motor to the wheels the two gear pairs and two shafts are needed. The spur pinion is attached to the motor and mates with the spur gear to drive the drive shaft. The driven shaft also has two u-joints at the end of it to make up the height difference between the drive shaft and driven shaft. The gear box houses the bevel pinion and gear which mate to rotate the output shaft to power the vehicle. This device was tested to meet the requirements of the project. The device transmitted the rotational motion of the motor to the rear wheels of the vehicle, had an acceptable total gear ratio of 12.5:1, met the weight requirement of less than 1 pound, and costed less than $200.

1: INTRODUCTION

Motivation:
This project was motivated by a need for a device that would compete in the Mini Baja R/C race. It was also motivated by the author's interest and experience in driving R/C cars. Building an R/c car from scratch and buying the necessary parts will also help in gaining knowledge in how they work.

Function Statement:
The R/C car needs to be able to compete in a race and a device is needed that will accept power from the R/C car motor and transmit it to the wheels

Requirements:
The device will conform to the following requirements and be optimized for performance, cost, and size:

- Be able to compete in a sprint and off-road race
- The drivetrain is required that would weigh less than 1 pound
- The drivetrain must fit in the available space on the chassis plate
- Accept 19740 RPM from electric motor
- Transmit HP to the rear axel
- Take rotary motion in one axis to a perpendicular axis
- The drivetrain must have a gear reduction to allow the vehicle to drive at 20 MPH
- The total cost of the drivetrain must me less than $200 not including electronic components

Engineering Merit:
This project covers analyses that determine torque and rotational speed being transmitted. For example an engineering equation used for this was Torque = Power / Angular Velocity. To transmit the rotational speed, velocity ratios were used to determine gears to have compliant turn ratios and design parameters. In supporting components forces were calculated to determine how much stress would be applied to those parts.

Scope of Effort:
This project will not cover the whole vehicle just the drivetrain assembly. The rest of the R/C car will be covered by the suspension and frame.

Success Criteria:
This project will need to allow the R/C car to compete while meeting the requirements of the ASME Design Competition. This project will be successful if the drivetrain allows the R/C car to meet the requirements and successfully drive forward at about 20 MPH. It should be able to operate on smooth and off-road surfaces. The drivetrain components will also need to stay secure on the R/C car while in motion.

Success Scenario:
The way this project can be successful is racing in the R/C Mini Baja Competition and being competitive against opponents. This will be done by doing analyses to meet the requirements giving a design parameter that can be shown in a drawing.

2: DESIGN ANALYSIS

Approach:
The approach for this project was to start with the rotational output speed from the drive shaft on the motor and figure out how to transfer that to the rear axle. Then the housing and connecting components were determined and designed to support the drivetrain.

Design Description:
This R/C car was designed to power the rear axle and steer the front axle. The drivetrain design covers the power being transmitted to the rear axle and the parameters needed to achieve this. A double gear reduction was designed for to smoothly transmit power from the electric motor to the wheels.

Benchmark:
Schedules and characteristics of previous R/C Mini Baja projects can be used as benchmarks to compare performance.

Performance Predictions:
The main goal for the performance of the drivetrain is that the car drives smoothly at a constant speed. In Appendix A3, using the gear ratio calculated, the predicted maximum speed was 20.16 MPH.

Description of Analyses:
To get the R/C car to drive smoothly an analysis is done in Appendix A1 to determine a turn ratio for a constant speed. To get this turn ratio, an analysis on a double gear reduction is used and calculated for the separate ratios in Appendix A2. When a ratio is calculated that works for two gears, a corrected speed can be calculated in Appendix A3. Also using these gear ratios, in Appendix A4-6 analyses on gear parameters can be calculated. Next an analysis can be done on torque in the shafts using the power and angular velocity calculated in Appendix A7. With those torque values, analyses can be done to determine the forces on the shafts and bearings calculated in Appendix A8-9. To find design parameters for the shafts, an analysis can be done to determine a minimum diameter when designing with a specific material which is calculated in Appendix A10. With these shafts, a key width and depth can be chosen so an analysis can be done to determine the minimum length and stresses of the key, calculated in Appendix A11. In Appendix A12, an analysis is done to determine the distance and angle between the two offset shafts.

Scope of Testing and Evaluation:
Tests will be done on the R/C car after it is built and assembled. This project will cover testing on the drivetrain to determine the maximum speed, acceleration time, and driving ability on different surfaces.

Analyses:
For the required speed of 20 MPH an analysis on a turn ratio is needed that would reduce the shaft speed of 19740 RPM to 1566.6 RPM. In Appendix A1, the total gear ratio was calculated by converting 20 MPH to an output speed measured in RPM and then dividing the maximum speed by the output speed. This resulted in a turn ratio of about 12.5:1. To get this ratio a double gear reduction is shown in Appendix A2 with a transmission ratio and a differential ratio. Since a standard gear ratio for a pair of bevel gears rotating an axle in a gear box is around 3:1, a ratio of 2.5:1 was chosen to equal 5:1 for the transmission ratio to get to the total gear ratio of 12.5:1. With these two ratios chosen, an estimated max speed of 20.16 MPH with a rotational speed of 1579.2 RPM was calculated in Appendix A3.

To get the necessary gear reduction the first pair of gears were calculated to have 16 teeth on the pinion and 80 teeth on the gear, these calculations and dimensions of the gear pair can be found in Appendix A4 and A5. The second pair of gears had to drive the axle shaft with the driven shaft perpendicular to it so bevel gears had to be used. The pinion was calculated to have 12 teeth and the gear needed 30 teeth to complete the full gear reduction. These calculations and dimensions of the gear pair can be found in Appendix A6.

To find torque power is divided by angular velocity and converted to lb*in. Calculated in Appendix A7, the torque on the drive shaft was 0.385 lb*in, the driven shaft had 1.925 lb*in, and the axle shaft had 4.813 lb*in. With these torque values, the forces on the spur gears were calculated to have a tangential force of 2.31 lb and a radial force of 0.84 lbs. The forces on the bevel gears can also be calculated from these values. The pinion tangential force was 3.06 lb, the pinion radial force was 1.03 lb, the pinion axial force was 0.41 lb, the gear tangential force was 3.06 lb, the gear radial force was 0.41 lb, and the gear axial force was 1.03 lbs. This was calculated in Appendix A8. With these tangential, radial, and axial forces the maximum bending moments and bearings forces were calculated in Appendix A9. The maximum bending moment in the driven shaft was 1.51 lb*in and the maximum bending moment in the axle shaft was 3.48 lb*in. Bearing A had a radial force of 2.69 lb, Bearing B had a radial force of 0.60 lb and a thrust force of 0.41 lb, Bearing C had a radial force of 1.63 lb, and Bearing D had a radial force of 1.64 lb and a thrust force of 1.03 lbs.

Using the torque and maximum bending moments in the driven and axle shafts, the minimum diameters can be found for the chosen material. For carbon steel SAE 1020 the minimum diameters of the driven shaft and axle shaft were 0.162 in and 0.214 in calculated in Appendix A10. For these two shafts, a standard shaft diameter above the calculated minimum was chosen to be 0.25 in. With that shaft diameter, two carbon steel SAE 1018 shafts were chosen with key depths of 3/64 in and key widths of 3/32 in. For the axle key the length was calculated to be 0.6 in, with a shear stress of 684.52 psi, and a compressive stress of 1369.03 psi. For the driven shaft the length was calculated to be 0.2 in, with a shear stress of 821.33 psi, and a compressive stress of 1642.67 psi. These calculations can be found in Appendix A11. To find the distance and angle between the driven shaft and the bevel pinion the u-joint lengths, connecting shaft clearance length, and bearing height difference will need to be used. In Appendix A12, the distance was calculated to be 1.46 in and an angle of 51.25° between the two u-joints.

Device Parts, Shapes and Conformation:
An aspect of the design that was not directly referenced in the analyses was the motor housing size. It was designed to create small clearance between the motor and chassis plate while keeping the motor secure. This determined the height of the center of the drive shaft which was used in the design of the bearing housings to determine the height of the holes.

Device Assembly:
This device covers the drivetrain assembly which is split up into two main components that work together, the transmission and the gearbox, with many parts that make up this assembly shown in Appendix B14-16.

Tolerances, Kinematics and Ergonomics:
Tolerances for this project will need to be around +/- 0.01 inches. A small tolerance is necessary for this project especially for parts like gears so they interface correctly. Since this device is human operated, it is designed to drive smoothly which is why it was not designed to have the fastest top speed possible.

Technical Risk Analysis:
The largest risk in this project is the manufacturing, specifically cutting down the stock material to the correct size and using high powered machines. This hazard will be avoided by using safety precautions as well as having supervision while in the machine lab. A job hazard analysis can be found in Appendix J. The safety factor used was 2.5 for gear and shaft calculations. This safety factor keeps the R/C car from failing under normal operating conditions and testing will be done to ensure this.

3. METHODS & CONSTRUCTION

Description:
Most of the parts of this project need to be purchased and then assembled because it is more practical and cost efficient than manufacturing them with the resources available. The 3-D printing machine in the CWU lab will be used for parts related to housing or support parts.

Drawing Tree and Drawing ID's:
In Appendix B17 there is a drawing tree with preliminary parts towards the bottom and the completed assembly at the top. Also all the parts necessary in each sub assembly are shown grouped together.

Parts List and Labels:
Parts list shown in Appendix C.

1. Electric Motor (1) Output 19740 RPM, Case Length 50mm, Case Diameter 35.8mm
2. Spur Pinion (1) 20 teeth, Pd=48, d_o = 0.375in, Set Screw Hole = 0.125in
3. Spur Gear (1) 80 teeth, Pd = 48, D_o = 1.708in
4. Bevel Pinion (1) 14 teeth, P_d = 8, d_o = 0.625in
5. Bevel Gear (1) 36 teeth, P_d = 8, D_o = 1.5in
6. Key (1) Width = 3/32in, Height = 3/32in, Length = 0.5in

7. Drive Shaft (1) Length = 4in, Diameter = 1/4in, Key Width = 3/32in, Key Depth = 3/64in, Hole Diameter = 4mm
8. Driven Shaft (1) Length = 3.125in, Diameter = 3/16in, Hole Diameter = 3/32in
9. Adapter Shaft (1) Length = 0.89in, Diameter = 1/4in, Hole Diameter = 4mm
10. Spur Bushing (1) OD = 0.9in, ID = 0.25in, Length = 0.5in, Bore OD = 0.375in, Key Width = 3/32in, Key Depth = 3/64in
11. Bevel Bushing (1) OD = 0.9in, ID = 3/8in, Length 0.55in, Bore OD = 0.5in
12. Bevel Pinion Sleeve (1) OD = 0.31in, ID = 3/16in, Length = 0.35in, Hole Diameter = 3mm
13. Drive Cup (2) Length = 16mm, OD = 11mm, ID = 5mm, Set Screw Hole = 4mm
14. Bearing ¼ (2) OD = 3/8in, ID = 1/4in, w = 1/8in
15. Bearing 3/16 (3) OD = 3/8in, ID = 3/16in, w = 1/8in
16. Bearing Housing (1) Dimensions 1.25x0.375x1.35in, Height to Center of Hole = 0.975in, Bearing Hole Diameter = 3/8in
17. Gearbox (1) Dimensions 2.5x2.25x3.3in, Height to Center of Holes = 1.5in, Bearing Hole Diameter = 3/8in
18. Motor Housing Base (1) Dimensions 2.243x2.075x0.337in,
19. U-Joints (2) ID = 0.31in with set screw hole, OD = 0.55in, Total Length at 0º deflection = 1.34in
20. Shaft Sleeves (3) OD = 0.31in, ID = ¼ in, Length = 0.35in, Hole Diameter = 4mm
21. Bolt M4x20 (5) Attaches u-joints to shafts and bearing housing to chassis plate
22. Bolt M4x10 + nuts (3) Attaches spur bushing to spur gear
23. Bolt M4x25 + nuts (4) Attaches motor housing
24. Bolt M2x12 (5) Attaches bevel bushing to bevel gear and bevel bushing to driven shaft
25. Screw M3x5 (2) Attaches motor to housing
26. Set Screw M3x4 (1) Attaches spur pinion to motor
27. Set Screw M4x5 (4) Attaches drive cups to driven shaft and u-joint to bevel pinion sleeve
28. Pin M3x6 (1) Attaches bevel pinion sleeve to bevel pinion
29. Motor Housing Mount (1) Dimensions 2.243x0.138x1.421in, Height to Center of Holes = 1.5in, Bearing Hole Diameter = 3/8in
30. Bearing Housing Block (1) Dimensions 1.25x0.375x0.138in, Bolt Hole diameter = 4mm
31. Nut M4 (12) Fastens M4 bolts
32. Nut M2 (5) Fastens M2 bolts

Manufacturing Issues:

The labs at CWU have the capability of manufacturing gears but not at the smaller size that this drivetrain requires. Also the housings for the bearings need to have a hole size that is more accurate than the 3-D printer provides, so the size will have to be adjusted after printing.

Another manufacturing issue in this design is the difference in height between the drive shaft and the pinion gear in the gearbox. This was accounted for with two u-joints which will be held together by an adapter shaft and the ends connected to the drive shaft and the bevel pinion. Another manufacturing issue was that the bevel pinion shaft diameter was much smaller than the u-joint inner diameter. This was modified for by designing a sleeve that can be 3-D printed to fit between the u-joint and pinion shaft and has a hole for a pin to go through and screw into the u-joint side hole.

When the shaft sleeves were 3-D printed to accommodate for the difference between the outer diameter of the shafts and inner diameter of the u-joints it was discovered that they could not print to a close enough tolerance to fit around the 1/4in shafts and were too small and not strong enough to be altered to fit. To solve this problem, bronze sleeves were ordered from a supplier with a much closer tolerance and with this stronger material, holes could be drilled through the side for the screws that will go through the u-joints and shafts. The motor housing also had issues with tolerances when 3-D printed. The holes in the motor housing needed to be a precise distance apart to position the spur gears to mesh correctly. Since the original 3-D printed design for this did not work it was redesigned to be cut out of aluminum and then marked and drilled through to give a higher precision on the hole distances. To modify the motor housing, the design was changed to have the base of the original 3-D printed housing attached on top of the new "L" shaped aluminum part by being bolted down. The aluminum couldn't just be attached to the front because the plastic did not 3-D print solid so it was unable to be threaded and screwed into. This modification also effected the bearing housing since it raised the height of the motor and the drive shaft, therefore the bearing housing block had to be added to keep the drive shaft bearings at the same height.

Assembly, Sub-Assembly, Parts, Drawings:

The design of this project consists of two sub-assemblies that make up the drivetrain assembly. The transmission assembly uses gears to convert the rotational speed from the motor to the drive shaft. The gearbox assembly also uses gears and converts the rotational speed from the drive shaft to the output shaft which powers the axles. To transmit the power from the electric motor to the wheels the two gear pairs and two shafts are needed. The spur pinion is attached to the motor with the set screw included in the part. The spur gear mates with the pinion to rotate the drive shaft parallel to the motor and is attached to the driven shaft with the spur bushing and key. The driven shaft also has two u-joints at the end of it to get up to the height that the bevel pinion needs to be in the gear box. The gear box houses the bevel pinion and gear which mate to rotate the axle shaft to power the vehicle. There are three holes in the gearbox with bearings fixed in. The one on the front face supports the end of the pinion and the holes on the two sides support the driven shaft.

The first part of this project to be manufactured is the key, shown in Appendix B1. Also ordered and cut to the correct length are the three shafts which are located in Appendix B2-4. Next, the 3-D printed support components which are the spur and bevel bushings, bevel pinion sleeve, bearing housing, gearbox, and motor housing base located in Appendix B5-10 respectively. Other manufactured parts shown in Appendix B11-13 are the shaft sleeves, motor front mount, and bearing housing block. Then the drivetrain assembly drawing is in Appendix B14-16 showing all the components of the drivetrain. Pictures of the SolidWorks assemblies of the drivetrain and the entire R/C car are shown in Appendix B18, as well as construction and device pictures in Appendix B19-21.

4. TESTING METHOD

Introduction:
The main tests for the drivetrain of the RC car are determining how well it drives. The speed can be tested for accuracy compared to calculations. This can be tested on smooth and off-road surfaces.

Method and Approach:
The actual speed can be calculated by recording distance and time of the car once it has got up to a constant speed. For this test a stopwatch and tape measure are needed. Once this speed is calculated, acceleration can also be found by recording how long it takes for the device to get to top speed.

Test Procedure Description:
Space will be needed for this testing procedure. A track won't be necessary, but the open area in Hogue Hall can be used with cones set up to measure distances. For off-road testing areas outside on campus can be used. A more detailed procedure is shown in the testing report in Appendix I.

An aspect that will be tested to ensure the drivetrain is functional is how well the gears mesh together. This was a more difficult part of construction and had to be redesigned so the teeth would actually mate together. This will have to be tested more thoroughly to make sure not only that it functions, but that they also are not mated together too close or too far away. If the gears are not mated correctly, they would be subjected to more wear effecting the sustainability of the drivetrain. An incorrect mating of the gears could also have a potential risk of losing contact between teeth during operation from driving off terrain or taking a sharp turn.

The first test that was done was the maximum speed test. The results from this test were lower than the expected speeds because the device was unable to convert the full rotational speed of the motor to the axles without skipping teeth and falling out of alignment in the gearbox. There was also a part failure in this test with the plastic bushing breaking where it held the bevel gear to the driven shaft. This was due to a stress concentration in the geometry of the part and a large amount of torque in that area so to reinforce this a strong epoxy was used. Also the bearing holding the bevel pinion in the gearbox came out due to the high rotational speed. This was corrected by making a new part out of aluminum to cover the outer ring of the bearing and hold it in place. After this test there were also modifications made to the project covering frame and suspension to correct the angle of the wheels putting less stress on the drivetrain. With these corrections being made, the speed will be tested again to compare results and see if there has been improvement to get the speed closer to the predicted value.

The second test was the acceleration test. This tests how well the drivetrain gets the vehicle up to its max speed and maintains that speed for an extended distance. Since manufacturing improvements were being made up until the competition to make sure it worked, it was just tested for functionality in a 60 feet drag race and then the results were recorded from the event. The expected results were slower than the max speed test since this one had to start from rest, but it ended up only being slightly slower due to the improvements made.

The device was also tested for functionality on off-road terrain during the event. The off-road terrain provides a challenge for the drivetrain because of an increase of friction compared to smooth flat surfaces because the same amount of power transferred to the axles will not drive it as fast. In the Mini Baja course there was a section with a ramp going onto a slight downhill covered in bark. This test was not results based since it was just a success or fail outcome. The car drove through the bark obstacle in a practice run and in the competition making it a successful test.

Deliverables:
Max speed will be compared to the predicted value. The ability to handle off-road terrain will also be evaluated to see how much of a difference is made. The raw data from testing is shown in Appendix G and the data evaluation sheets used to collect the data are shown in Appendix H.

5. BUDGET/SCHEDULE/PROJECT MANAGEMENT

Proposed Budget:
To assemble this project, 32 different parts are needed with a total of 71 parts. Since this project has multiple expensive electronic components, the budget for non- electronic parts was set to be no more than $200. After adding up all the purchased parts and the cost to 3-D print the other parts the total part cost came out to be under $200 meeting the requirement. A labor cost also needs to be factored into the budget and for this project with an estimated number of hours spent working on it to be 116.5 so far with the actual total being 125. This increased the total build cost to be $1377.49, but is not what the actual budget for the project is though because the principle engineer is a student doing the project for the requirements of the MET major so labor costs are not compensated. This leaves a budget of $127.49 to be covered by the principle engineer.

Changes in the proposed budget were made in the manufacturing process. The largest change was due to the parts list being revised. This decreased the total cost because the original budget accounted for the electronic parts most of which can be obtained from the extra parts the CWU MET program has from past Mini Baja R/C cars. Another aspect that impacted the budget was the shipping and tax costs. These costs were estimated incorrectly before they were actually ordered, but it did not increase the total budget by too much more than originally planned. Also the 3-D printing was done at the MEC in Samuelson Hall instead of Hogue Hall as originally planned because the MEC charges hourly rather than by size which decreased the printing cost. These values were determined in Appendix D.

The only change made to the budget during testing was the added labor hours. The amount of time spent on correcting manufacturing issues want not anticipated in the proposed schedule. When issues came up in testing, modifications had to be made to reconstruct or add new parts and then test the requirement again. There was not any added part or material cost because the only parts added to the drivetrain during testing were constructed out of scrap aluminum from the CWU machine shop. These machined parts added the necessary strength in the components to not fail under the stress from operation in testing.

Proposed Schedule:

For this project to be completed, a schedule is needed to give the project better organization and optimization of time. This schedule covers deliverables of a draft proposal, analyses, documentation, a final proposal, part construction, device construction, and the MET 489 course required deliverables. Each of these milestones also have tasks that need to be completed in order to reach the milestones. The total time estimated it would take to complete all designing, constructing, and testing of this project was 143.5 hours with 128 hours estimated up though construction. The actual total up to date hours spent on this project so far is 123.5 hours and the actual subtotal for construction was slightly higher than the estimated time due to scheduling issues. This schedule is mapped out in the Gantt Chart in Appendix E1 and E2.

A scheduling issue that was run into was the 3-D printing taking over a week after delivering the STL files due to all of their printers being down except one. This caused the project to be slightly behind on the second manufacturing milestone with those parts in progress. Luckily multiple parts were able to be printed at the same time so once the order went through all seven 3-D printed parts would be received. To get back on track the first steps of manufacturing the three shafts had to be moved up to the fifth week of winter quarter and altering 3-D printed parts for press fits had to be moved back.

Redesigns also had an impact on the schedule. The original proposed design and analysis was not expected to work exactly as planned, but with multiple parts added and others edited along with slight modifications in the overall design, the project got off schedule. Changes had to be made to the Gantt Chart during construction, but that got the project back on schedule and allowed the device to be assembled and working by the deadline.

Revisions in the schedule had to be made to accommodate for testing reports and the competition. The device had to be working reliably by these deadlines to be successful in the tests. When testing the device for functionality, issues were found that needed modifications which affected the schedule. The major device issues that came up while testing were the bevel bushing breaking and the front bearing slipping out of the gearbox. This was resolved by manufacturing a new bushing out of aluminum and a plate to attach to the gearbox to hold the bearing in. To stay on track, extra hours were added into the schedule for these modifications.

Project Management:

This project will succeed due to the availability of appropriate technical expertise and resources. Easily obtainable test equipment is available to use for this project to test its effectiveness. The principal engineer will provide expertise in designing, constructing, and testing a mechanical device and their resume is shown in Appendix K.

6. DISCUSSION

The goal of this project was to determine a way for the device to transmit power to the wheels and then design for more efficient and optimized ways of doing that. At first the design idea was to power and steer the front axle of the R/C car which could have been done, but was providing problems with interference between the steering and the drivetrain. A rear axle powered design introduced advantages for the R/C car by making the assemblies less complicated therefore decreasing the chance for error. This also spread out the components on the chassis plate giving more options for orientation of the attached parts. The spacing of parts worked out with the final design well because this drivetrain uses a double gear reduction which takes up more space that some other drivetrain designs. The previous design also didn't leave enough space for the critical electronic components like the motor, speed controller, receiver, and battery needed to drive the vehicle.

The analyses were very crucial to the design of this project because most of the drawings had a design parameter that was reliant on an analysis calculation. An example specific to this device would be a gear because there is no good way to design a gear without having calculated parameters to use for the most important features in the gear. Design limitations were also found through analyses by calculating the minimum allowable shaft diameter for the amount of torque on the shafts and calculating the maximum range the universal joints could offset the height of the two shafts.

Once parts were 3-D printed, modifications were needed to be made. Specifically on the Bearing Housing, Motor Housing, and Gear Box the hole sizes were purposely designed with too high of an interference fit with the bearings. Since the bearings needed to be applied to those parts with force fits, the 3-D printer didn't have the precision necessary for this type of fit. Therefore, the parts were designed to be 3-D printed with hole diameters of 0.370 inches for the bearings with outer diameters of 0.375 inches. Then, the holes would need to be reamed out to a range of 0.3740 to 0.3745 inches.

Many changes had to be made to drawings and the parts list during construction. Multiple parts had to be added to the parts list and new drawings had to be made and updated into the assembly model. Since the principle engineer had limited experience working in machine labs and building mechanical devices, the original proposed plans had to be altered. Also in the design and analysis phase, not enough plans were made for combining this project with the other project covering the other half of the R/C car. Components added to connect the two projects were the drive cups and the design of the gearbox had to be altered to account for the frame being lower than anticipated. These unplanned events affected the schedule which had to be frequently changed throughout the months of construction with extended hours added towards the end.

Once the device was functioning, it was clear that testing needed to be done to pinpoint areas that need improvements. While it was a working device, optimizations can be made to prepare to complete the course and compete well against other R/C cars. An issue found in testing was the stress concentration in the bevel gear bushing where the diameter decreases. This ended up breaking during testing due to it having to attach the gear to the driven shaft rotating at a high RPM and holding the gear in place while under additional pressure from the pinion gear. To solve this the bushing was manufactured out of aluminum so the shape could be kept the same, but the material strength was increased to be stronger than the plastic. This improvement also helped with off-road driving since with the increased friction from an uneven rough surface, there is more stress put on the gears to rotate the axles at the same speed. This was shown to be successful in testing because after the modification was made, the device was able to drive off the jump and through the bark obstacle of the Mini Baja course.

Overall there is not much financial risk in this project as the most expensive parts are the tires and electronic components. Also the total price being $127.49 is reasonable for the types of components necessary for the project. A preliminary design that had a large impact on the budget was the gearbox being solid without any cutouts besides the bearing holes. This design resulted in a lot of unnecessary material being used and adding to the price. To counteract this problem in the next design, some sections were cut out of the gearbox which ended up decreasing the volume of the gearbox from $7.42in^3$ to $3.88in^3$ and drastically decreasing the printing price for the part.

7. CONCLUSION

The design of the drivetrain for the Mini Baja R/C car complies with the requirements needed for a successful device to be built. This device has been planned out, analyzed, and designed to meet the function requirements for an R/C car drivetrain. The necessary parts have been specified that work with the design and did not run into any major problems with components in analyses. These requirements work for a successful senior project because of the engineering merit which was used in calculating parameters to efficiently operate the drivetrain. The most important analyses for the design of this device were calculating torque and angular speed because with those values, stresses and forces can be found so the drivetrain can be designed to not fail while subjected to these unavoidable stresses and forces. The device was constructed and although it did not meet all of the requirements of functioning consistently, the device worked to some degree, meaning modifications can be made during testing to improve the project. The goal for the second quarter of the project was to construct a functioning device. This goal was met by the R/C car constructed because it was able to drive forward, and in reverse while also steering. This was a solid foundation for a device that will be able to meet the requirements after testing and slight modification preparing it for competition. The device was tested to see if it could drive the vehicle and get up to its top speed and also drive through off-road terrain. When operating issues came up, additional time had to be spent modifying and adding two parts which were then tested again. After testing and modifications, the R/C car was able to compete in the Mini Baja competition. This was an extensive learning experience for the principal having to plan, construct, and test while making many changes along the way. This gave experience in time management for a project with a long process and many requirements to meet.

8. ACKNOWLEDGEMENTS

This project would not have been possible without support from CWU having a provided machine shop and 3-D printer. Support was given through advice from the current and former MET faculty members: Charles Pringle, Craig Johnson, John Choi, and Roger Beardsley. Also assistance and advice in manufacturing was given from Matt Burvee and Eric Arlt. This project was also supported by the suspension and frame of the R/C car being designed by group partner Sheynia Martin.

9. REFERANCES

Machine Elements in Mechanical Design – Mott

APPENDIX A1

Kyle Aitken | MET 489 | RC Car Drivetrain

Given: Mabuchi RS-540SH-7520

At Max Efficiency: Rotational Speed = 19740 RPM   Torque = 30.6 mN-m
Current = 13.0 Amps   Output Power = 63.2 W

Traxxas TRA 6873R Wheel Dimmensions

OD = 109 mm   Hex = 12 mm
W = 43 mm

Find: - Requirements for Design Speed of 20 MPH
- Total Turn Ratio

Solution:

$$1\ \text{Rev} = \pi(OD) = 342.43\ \text{mm}$$

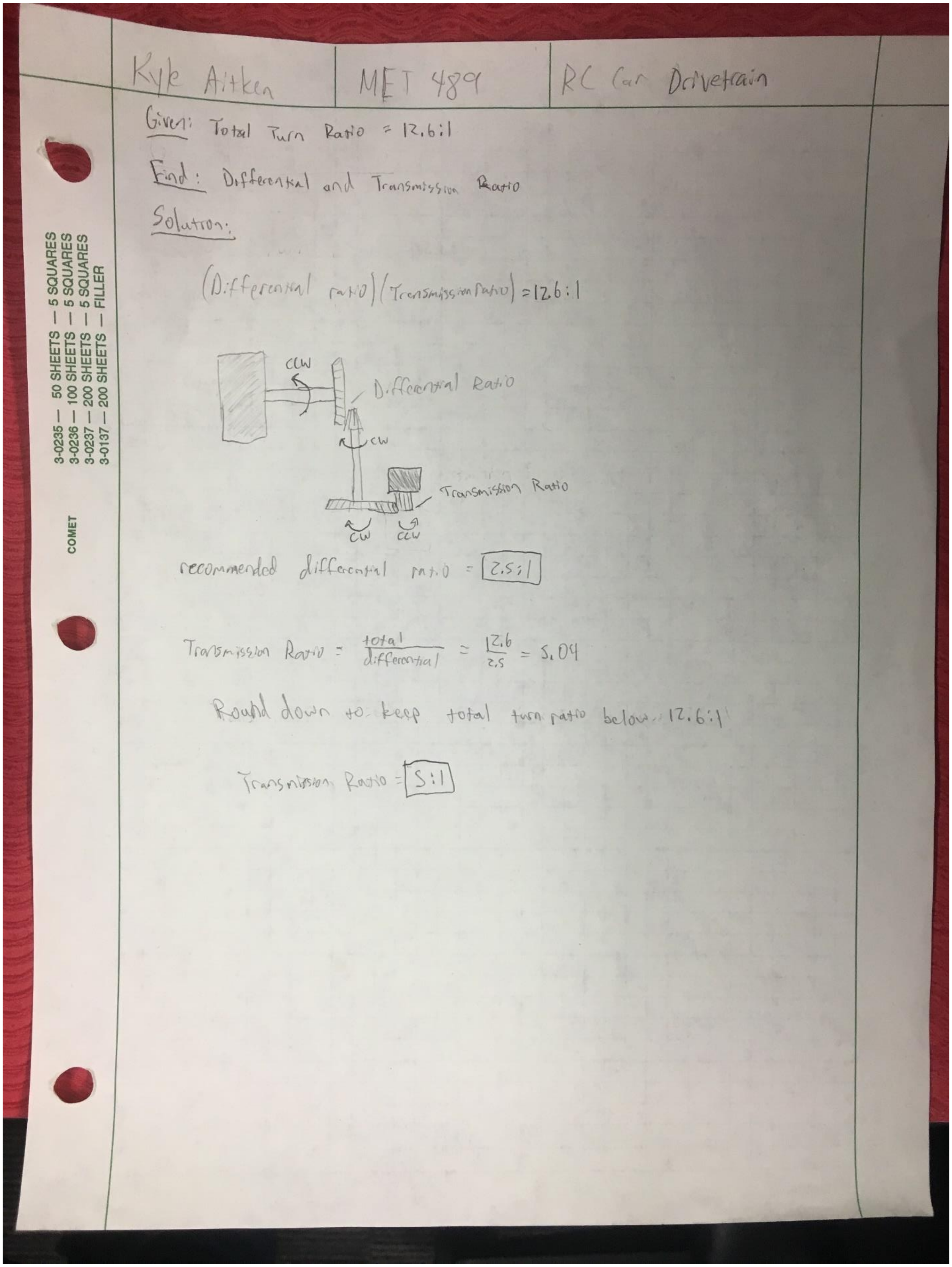
Design Speed

$$\left(\frac{20\ \text{miles}}{\text{hr}}\right)\left(\frac{1609.34\ \text{m}}{1\ \text{mile}}\right)\left(\frac{1000\ \text{mm}}{1\ \text{m}}\right)\left(\frac{1\ \text{Rev}}{342.43\ \text{mm}}\right)\left(\frac{1\ \text{hr}}{60\ \text{min}}\right) = \boxed{1566.59\ \text{RPM}}$$

$$\text{Total Turn Ratio} = \frac{\text{Max Motor RPM}}{\text{Output RPM}} = \frac{19740\ \text{RPM}}{1566.59\ \text{RPM}} = 12.6$$

$$\text{Total Turn Ratio} = \boxed{12.6:1}$$

APPENDIX A2



Kyle Aitken | MET 489 | RC Car Drivetrain

Given: Total Turn Ratio = 12.6:1

Find: Differential and Transmission Ratio

Solution:

$$(\text{Differential ratio})(\text{Transmission ratio}) = 12.6:1$$

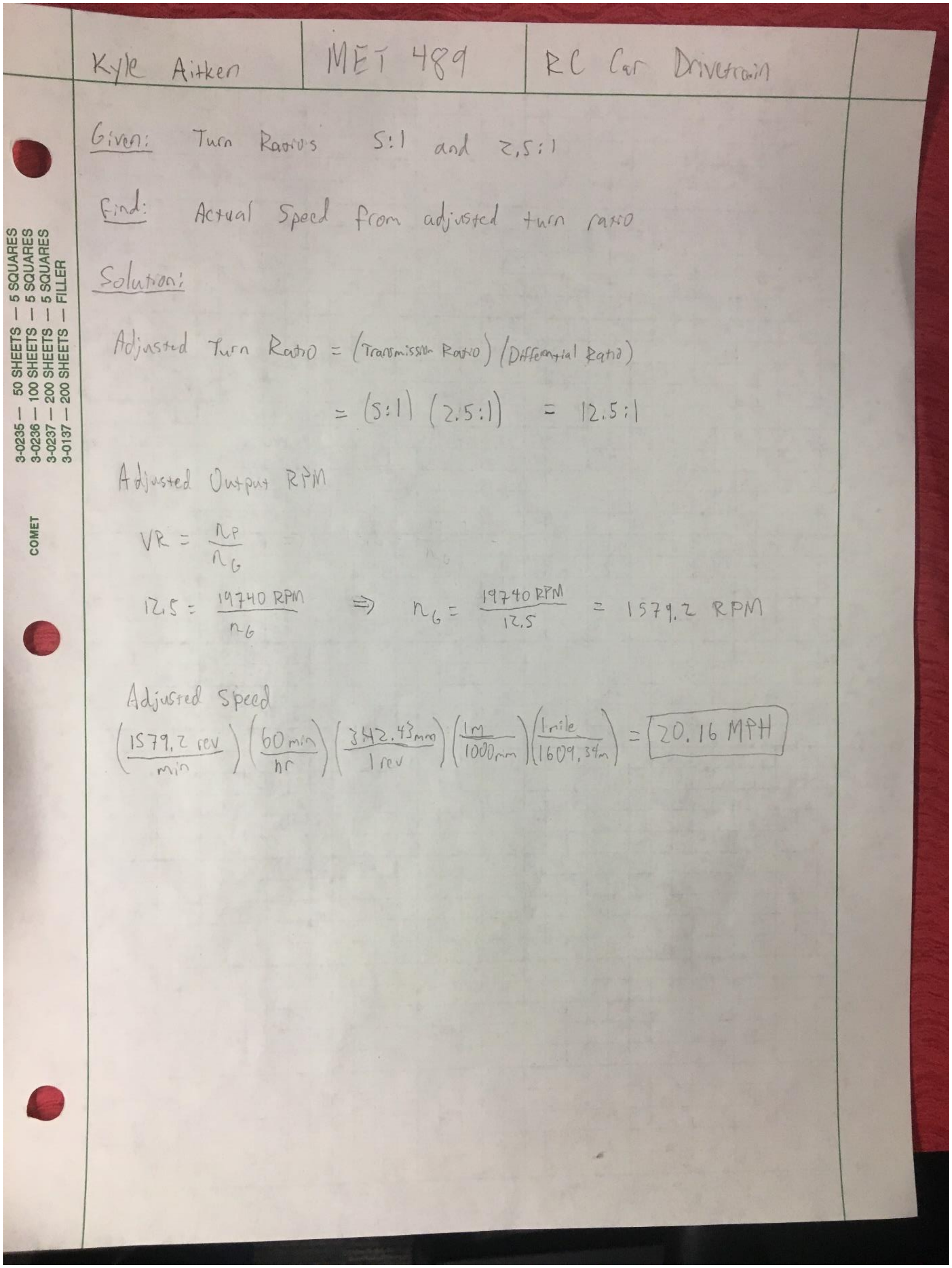
recommended differential ratio = $\boxed{2.5:1}$

$$\text{Transmission Ratio} = \frac{\text{total}}{\text{differential}} = \frac{12.6}{2.5} = 5.04$$

Round down to keep total turn ratio below 12.6:1

Transmission Ratio = $\boxed{5:1}$

APPENDIX A3



Kyle Aitken | MET 489 | RC Car Drivetrain

Given: Turn Ratios 5:1 and 2.5:1

Find: Actual Speed from adjusted turn ratio

Solution:

Adjusted Turn Ratio = (Transmission Ratio) (Differential Ratio)

$$= (5:1)(2.5:1) = 12.5:1$$

Adjusted Output RPM

$$VR = \frac{n_P}{n_G}$$

$$12.5 = \frac{19740 \text{ RPM}}{n_G} \Rightarrow n_G = \frac{19740 \text{ RPM}}{12.5} = 1579.2 \text{ RPM}$$

Adjusted Speed

$$\left(\frac{1579.2 \text{ rev}}{\text{min}}\right)\left(\frac{60 \text{ min}}{\text{hr}}\right)\left(\frac{342.43 \text{ mm}}{1 \text{ rev}}\right)\left(\frac{1 \text{ m}}{1000 \text{ mm}}\right)\left(\frac{1 \text{ mile}}{1609.34 \text{ m}}\right) = \boxed{20.16 \text{ MPH}}$$

APPENDIX A4

Kyle Aitken	ME7489	RC Car Drivetrain

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

Given: Pinion with a set screw able to fit to a shaft diameter of 3.17 mm

Material: Aluminum 7075

$P_d = 48$
$N_P = 16$
$n_P = 19740$ RPM
$VR = 5$

Find: Dimensions of Transmission Pinion

Solution:

Pitch Diameter $D_P = \frac{N_P}{P_d} = \frac{16}{48} = \underline{0.333\text{ in}}$

Module $m = \frac{D_P}{N_P} = \frac{0.333}{16} = \underline{0.0208\text{ in}}$

Outside Diameter $D_O = \frac{(N_P+2)}{P_d} = \frac{16+2}{48} = \underline{0.375\text{ in}}$

Circular Pitch $p = \frac{\pi D_P}{N_P} = \frac{\pi(0.333)}{16} = \underline{0.065\text{ in}}$

Addendum $a = 1.00m = \underline{0.0208\text{ in}}$

Dedendum $b = 1.25m = (1.25)(.0208) = \underline{0.0260\text{ in}}$

Root Diameter $D_R = D_P - 2b = 0.333 - 2(.0260) = \underline{0.281\text{ in}}$

Clearance $c = 0.25m = 0.25(.0208) = \underline{0.0052\text{ in}}$

Whole Depth $h_t = a + b = 0.0208 + 0.0260 = \underline{0.0468\text{ in}}$

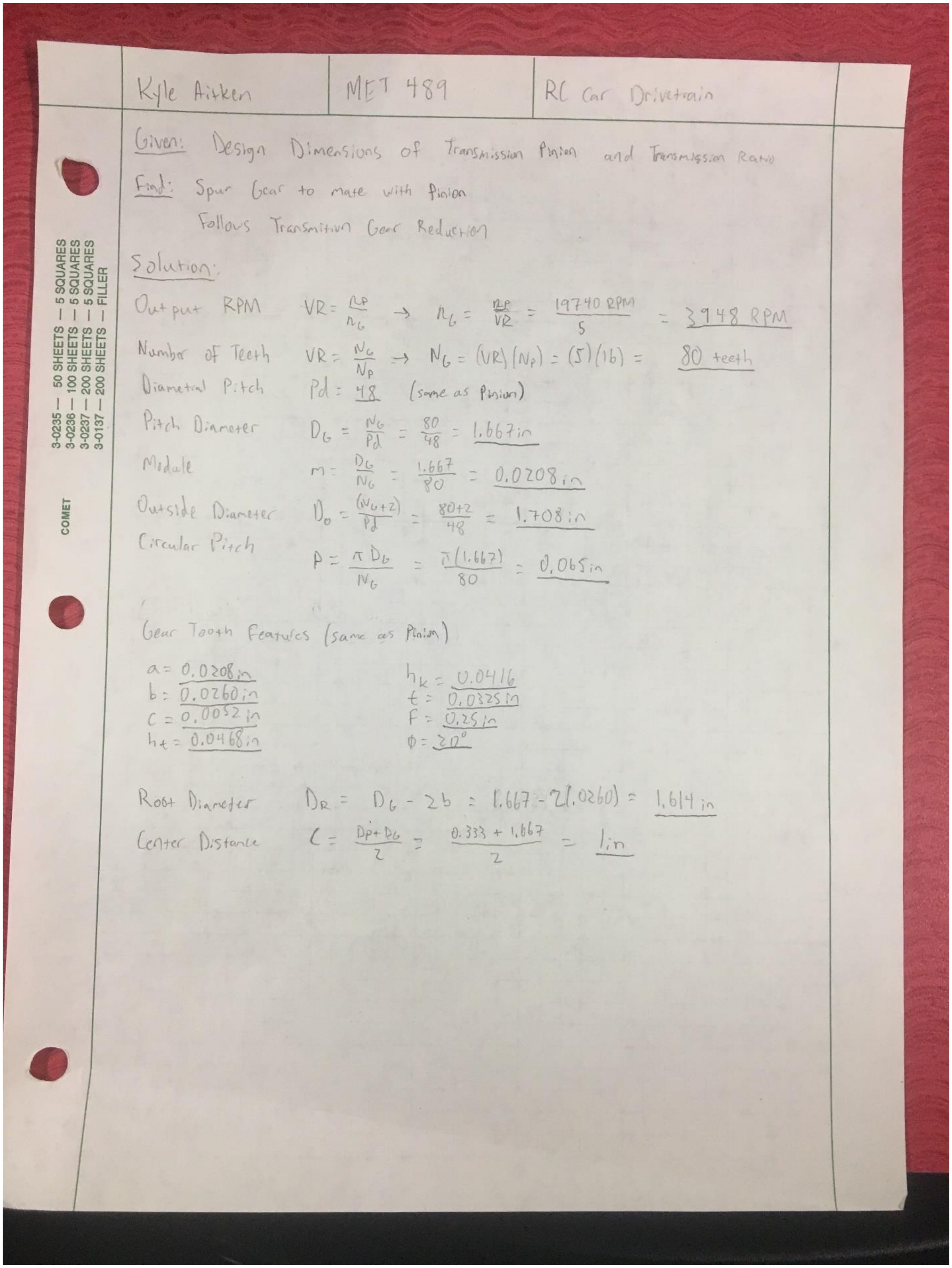
Working Depth $h_k = 2a = 2(.0208) = \underline{0.0416}$

Tooth Thickness $t = \frac{p}{2} = \frac{0.065}{2} = \underline{0.0325\text{ in}}$

Face Width $F = \frac{12}{P_d} = \frac{12}{48} = \underline{0.25\text{ in}}$

Pressure Angle $\phi = \underline{20^\circ}$ (common value)

APPENDIX A5



Kyle Aitken	MET 489	RC Car Drivetrain

Given: Design Dimensions of Transmission Pinion and Transmission Ratio

Find: Spur Gear to mate with Pinion

Follows Transmition Gear Reduction

Solution:

Output RPM $VR = \frac{n_P}{n_G} \rightarrow n_G = \frac{n_P}{VR} = \frac{19740\ RPM}{5} = \underline{3948\ RPM}$

Number of Teeth $VR = \frac{N_G}{N_P} \rightarrow N_G = (VR)(N_P) = (5)(16) = \underline{80\ teeth}$

Diametral Pitch $Pd = \underline{48}$ (same as Pinion)

Pitch Diameter $D_G = \frac{N_G}{Pd} = \frac{80}{48} = \underline{1.667 in}$

Module $m = \frac{D_G}{N_G} = \frac{1.667}{80} = \underline{0.0208 in}$

Outside Diameter $D_o = \frac{(N_G+2)}{Pd} = \frac{80+2}{48} = \underline{1.708 in}$

Circular Pitch $p = \frac{\pi D_G}{N_G} = \frac{\pi(1.667)}{80} = \underline{0.065 in}$

Gear Tooth Features (same as Pinion)

$a = \underline{0.0208 in}$ $h_k = \underline{0.0416}$
$b = \underline{0.0260 in}$ $t = \underline{0.0325 in}$
$c = \underline{0.0052 in}$ $F = \underline{0.25 in}$
$h_t = \underline{0.0468 in}$ $\phi = \underline{20^\circ}$

Root Diameter $D_R = D_G - 2b = 1.667 - 2(.0260) = \underline{1.614 in}$

Center Distance $C = \frac{D_P + D_G}{2} = \frac{0.333 + 1.667}{2} = \underline{1 in}$

APPENDIX A6

Kyle Aitken	MET 489	RC Car Drivetrain	1/2

Given: Straight Bevel Gear minimum number of teeth for Pinion = 12
Standard Diametral Pitch for Straight Bevel Gears = 8
Differential Gear Ratio = 2.5:1
$n_P = 3948$ RPM

Find: Dimensions of Straight Bevel Gear Pair
Follows Differential Gear Ratio

Solution:

Diametral Pitch: $P_d = \underline{8}$

Number of teeth in Pinion: $N_P = \underline{12}$

Gear Ratio: $m_G = \underline{2.5}$

Number of teeth in Gear: $N_G = (m_G)(N_P) = (2.5)(12) = \underline{30}$

Output RPM: $VR = \frac{n_P}{n_G} \rightarrow n_G = \frac{n_P}{VR} = \frac{3948}{2.5} = \underline{1579.2 \text{ RPM}}$

Pitch Diameters: $d = \frac{N_P}{P_d} = \frac{12}{8} = \underline{1.5 \text{ in}}$

$D = \frac{N_G}{P_d} = \frac{30}{8} = \underline{3.75 \text{ in}}$

Pitch Cone Angles: $\gamma = \tan^{-1}\left(\frac{N_P}{N_G}\right) = \tan^{-1}\left(\frac{12}{30}\right) = \underline{21.80^\circ}$

$\Gamma = \tan^{-1}\left(\frac{N_G}{N_P}\right) = \tan^{-1}\left(\frac{30}{12}\right) = \underline{68.20^\circ}$

Outer Cone Distance: $A_o = \frac{(0.5)(D)}{\sin(\Gamma)} = \frac{(0.5)(3.75)}{\sin(68.2)} = \underline{2.019 \text{ in}}$

Nominal Face Width: $F_{nom} = 0.30 A_o = (.3)(2.019) = \underline{0.606 \text{ in}}$

Maximum Face Width: $F_{max} = \frac{A_o}{3} = \frac{2.019}{3} = \underline{0.673 \text{ in}}$

Face Width: $0.606 < F < 0.673 \rightarrow F = \underline{0.650 \text{ in}}$

Mean Cone Distance: $A_m = A_o - 0.5F = 2.019 - (.5)(.65) = \underline{1.694 \text{ in}}$

Mean Circular Pitch: $p_m = \left(\frac{\pi}{P_d}\right)\left(\frac{A_m}{A_o}\right) = \left(\frac{\pi}{8}\right)\left(\frac{1.694}{2.019}\right) = \underline{0.329 \text{ in}}$

Mean Working Depth: $h = \left(\frac{2.00}{P_d}\right)\left(\frac{A_m}{A_o}\right) = \left(\frac{2}{P_d}\right)\left(\frac{1.694}{2.019}\right) = \underline{0.210 \text{ in}}$

Clearance: $c = 0.125h = (.125)(.210) = \underline{0.026 \text{ in}}$

Mean Whole Depth: $h_m = h + c = .210 + .026 = \underline{0.236 \text{ in}}$

Kyle Aitken	MET 489	RC Car Drivetrain	2/2

Mean Addendum Factor: $c_1 = 0.210 + \frac{0.290}{(m_G)^2} = .21 + \frac{.29}{(2.5)^2} = \underline{0.256}$

Gear Mean Addendum: $a_G = c_1 h = (.256)(.21) = \underline{0.054\text{ in}}$

Pinion Mean Addendum: $a_P = h - a_G = .21 - .054 = \underline{0.156\text{ in}}$

Gear Mean Dedendum: $b_G = h_m - a_G = .236 - .054 = \underline{0.182\text{ in}}$

Pinion Mean Dedendum: $b_P = h_m - a_P = .236 - .156 = \underline{0.080\text{ in}}$

Gear Dedendum Angle: $\delta_G = \tan^{-1}\left(\frac{b_G}{A_m}\right) = \tan^{-1}\left(\frac{.182}{1.694}\right) = \underline{6.13^\circ}$

Pinion Dedendum Angle: $\delta_P = \tan^{-1}\left(\frac{b_P}{A_m}\right) = \tan^{-1}\left(\frac{.08}{1.694}\right) = \underline{2.70^\circ}$

Gear Outer Addendum: $a_{oG} = a_G + .5F\tan\delta_P = .054 + (.5)(.65)\tan(2.7)$

$a_{oG} = \underline{0.2073\text{ in}}$

Pinion Outer Addendum: $a_{oP} = a_P + .5F\tan\delta_G = .156 + (.5)(.65)\tan(6.13)$

$a_{oP} = \underline{0.1909\text{ in}}$

Gear Outside Diameter: $D_o = D + 2a_{oG}\cos\Gamma = 3.75 + 2(.2073)\cos(68.2)$

$D_o = \underline{3.904\text{ in}}$

Pinion Outside Diameter: $d_o = d + 2a_{oP}\cos\gamma = 1.5 + 2(.1909)\cos(21.8)$

$d_o = \underline{1.854\text{ in}}$

APPENDIX A7

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

COMET

Kyle Aitken | MET 489 | RC Car Drivetrain

<u>Given:</u> Maximum Output Power from motor = 90 W

Angular Velocity of Drive Shaft = 19740 RPM

Angular Velocity of Driven Shaft = 3948 RPM

Angular Velocity of Axle Shaft = 1579.2 RPM

<u>Find:</u> Torque on Drive Shaft and Driven Shaft

<u>Solution:</u>

Drive Shaft

$$T_1 = \frac{P}{\omega_1} = \left(\frac{90\,W}{19740\,RPM}\right)\left(\frac{1\,rev}{2\pi\,rad}\right)\left(\frac{60\,sec}{1\,min}\right)\left(\frac{1\,J/s}{1\,W}\right)\left(\frac{1\,N\text{-}m}{1\,J}\right)\left(\frac{1\,lb\text{-}ft}{1.356\,N\text{-}m}\right)\left(\frac{12\,in}{1\,ft}\right) = \boxed{0.385\ lb\text{-}in}$$

Driven Shaft

$$T_P = (T_1)\left(\frac{\omega_1}{\omega_2}\right) = (0.385\,lb\text{-}in)\left(\frac{14740\,RPM}{3948\,RPM}\right) = \boxed{1.925\ lb\text{-}in}$$

$$T_G = (T_1)\left(\frac{\omega_1}{\omega_3}\right) = (0.385\,lb\text{-}in)\left(\frac{19740\,RPM}{1579.2\,RPM}\right) = \boxed{4.813\ lb\text{-}in}$$

APPENDIX A8

Kyle Aitken	MET 489	RC Car Drivetrain

Given: Torque of Drive shaft = 0.385 lb-in Torque of Driven Shaft = 4.813 lb-in
Pitch Diameter of Gear on DriveShaft = 0.333 in, Pitch Diameter of Pinion on Driven Shaft d = 1.5 in, D = 3.75 in
Pressure angle of 20°, Pitch Cone Angles $\gamma = 21.8°$ $\Gamma = 68.2°$
Pitch Diameters $d = 1.5\text{ in}$ $D = 3.75\text{ in}$ Face width = 0.65 in

Find: forces in Drive Shaft and Driven Shaft

Solution:

Drive Shaft

Tangential Force

$$W_t = \frac{T}{(\frac{1}{2}D)} = \frac{0.385\text{ lb-in}}{(\frac{1}{2})(.333\text{ in})} = \boxed{2.312\text{ lb}}$$

Radial Force

$$W_r = W_t \tan\phi = (2.312\text{ lb})\tan(20) = \boxed{0.842\text{ lb}}$$

Driven Shaft

Pinion Tangential Force

$$W_{tP} = \frac{T_P}{r_m}$$

$$r_m = \frac{d}{2} - \left(\frac{F}{2}\right)\sin\gamma$$

$$r_m = \frac{1.5\text{ in}}{2} - \left(\frac{.65\text{ in}}{2}\right)\sin(21.8) = 0.629\text{ in}$$

$$W_{tP} = \frac{1.925\text{ lb-in}}{0.629\text{ in}} = \boxed{3.060\text{ lb}}$$

Pinion Radial Force

$$W_{rP} = W_t \tan\phi \cos\gamma = (3.060\text{ lb})\tan(20)\cos(21.8) = \boxed{1.034\text{ lb}}$$

Pinion Axial Force

$$W_{xP} = W_t \tan\phi \sin\gamma = (3.060\text{ lb})\tan(20)\sin(21.8) = \boxed{0.414\text{ lb}}$$

Gear Tangential Force

$$R_m = \frac{D}{2} - \left(\frac{F}{2}\right)\sin\Gamma$$

$$R_m = \frac{3.75\text{ in}}{2} - \left(\frac{.65\text{ in}}{2}\right)\sin(68.2)$$

$$R_m = 1.573\text{ in}$$

$$W_{tG} = \frac{T_G}{R_m} = \frac{4.813\text{ lb-in}}{1.573\text{ in}}$$

$$W_{tG} = \boxed{3.060\text{ lb}}$$

Gear Radial Force

$$W_{rG} = W_t \tan\phi \cos\Gamma = (3.060\text{ lb})\tan(20)\cos(68.2) = \boxed{0.414\text{ lb}}$$

Gear Axial Force

$$W_{xG} = W_t \tan\phi \sin\Gamma = (3.060\text{ lb})\tan(20)\sin(68.2) = \boxed{1.034\text{ lb}}$$

APPENDIX A9

Kyle Aitken | MET 489 | RC Car Drivetrain | 1/3

Given: $W_{tP} = 3.060\ lb$ $\quad W_{tG} = 3.060\ lb$

$W_{rP} = 1.034\ lb$ $\quad W_{rG} = 0.414\ lb$

$W_{xP} = 0.414\ lb$ $\quad W_{xG} = 1.034\ lb$

$r_m = 0.629\ in$ $\quad R_m = 1.573\ in$

Find: Reaction forces on the bearings supporting shafts carrying bevel gears

Solution: $x = R_m = 1.573\ in$ $\qquad y = r_m = 0.629\ in$

$a = x - 1.00 = 1.573 - 1.00 = 0.57\ in$

$b = 4.25 - x = 4.25 - 1.573 = 2.68\ in$

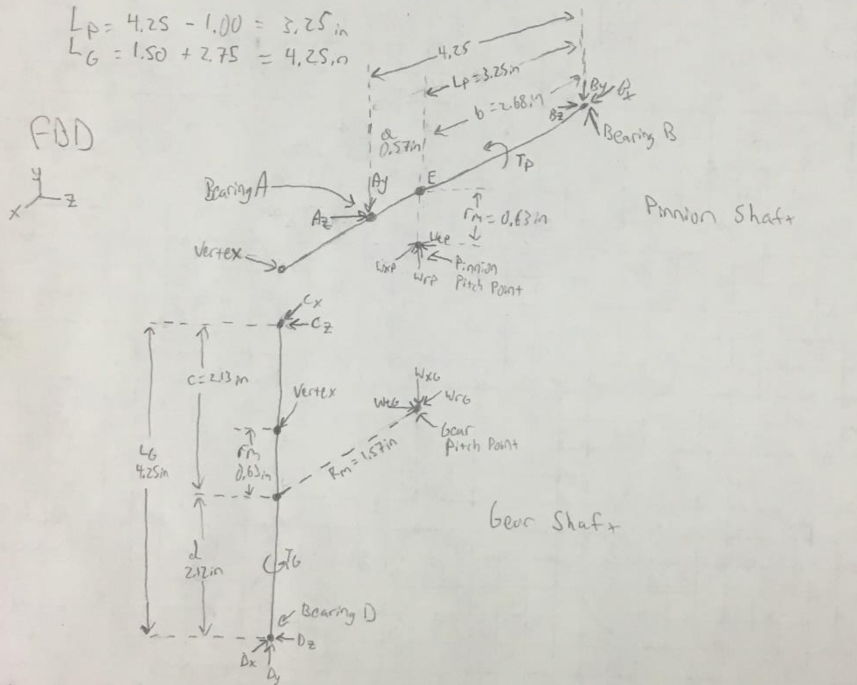
$c = 1.50 + y = 1.50 + 0.629 = 2.13\ in$

$d = 2.75 - y = 2.75 - 0.629 = 2.12\ in$

$L_P = 4.25 - 1.00 = 3.25\ in$

$L_G = 1.50 + 2.75 = 4.25\ in$

FBD



X-Z Plane

$$\Sigma M_A = 0 = W_{tP}(a) - B_Z(L_P) = (3.060\ lb)(0.57\ in) - B_Z(3.25\ in)$$

$$B_Z = 0.54\ lb$$

$$\Sigma M_B = 0 = W_{tP}(b) - A_Z(L_P) = (3.06\ lb)(2.68\ in) - A_Z(3.25\ in)$$

$$A_Z = 2.52\ lb$$

Kyle Aitken | MET 489 | RC Car Drivetrain | 2/3

X-Y Plane

$\Sigma M_A = 0 = W_{rp}(a) + W_{xp}(r_m) - B_y(L_p) = (1.03\,lb)(.57in) + (0.41lb)(0.63in) - B_y(3.25in)$

$B_y = 0.26\ lb$

$\Sigma M_B = 0 = W_{rp}(b) + W_{xp}(r_m) - A_y(L_p) = (1.03lb)(2.68in) + (.41lb)(.63in) - A_y(3.25in)$

$A_y = 0.93\ lb$

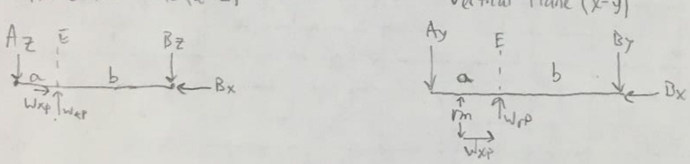
$\Sigma F_x = 0 = B_x - W_{xp} = B_x - 0.41lb \Rightarrow B_x = 0.41\ lb$

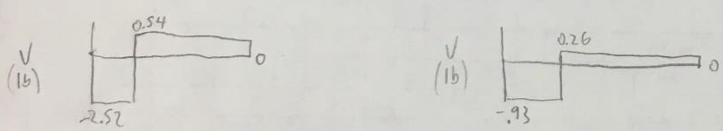
Resulting Forces in y and z components

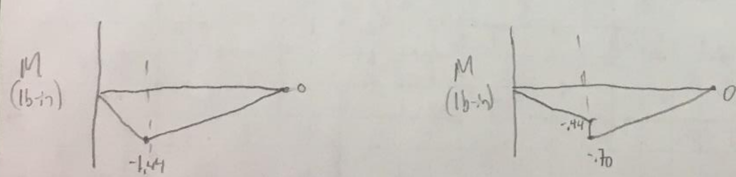
$A = \sqrt{A_y^2 + A_z^2} = \sqrt{.93^2 + 2.52^2} = 2.69\ lb$

$B = \sqrt{B_y^2 + B_z^2} = \sqrt{.26^2 + .54^2} = 0.60\ lb$

Horizontal Plane (x-z) | Vertical Plane (x-y)







$M_{Ez} = (-2.52)(0.57) = -1.44\ lb\text{-}in$

$M_{Ey} = (-.26)(2.68) = -0.70\ lb\text{-}in$

$-.70lb\text{-}in + (.63)(.41) = -.44\ lb\text{-}in$

Max Bending Moment $= \sqrt{M_{Ey}^2 + M_{Ez}^2}$

$= \sqrt{-.44^2 + -1.44^2} = \underline{1.51\ lb\text{-}in}$

Kyle Aitken	MET 489	RC Car Drivetrain	3/3

X-z Plane

$$\Sigma M_C = 0 = W_{tG}(c) - D_z(L_G) = (3.06)(2.13) - D_z(4.25)$$
$$D_z = 1.534\,lb$$

$$\Sigma M_D = 0 = W_{tG}(d) - C_z(L_G) = (3.06)(2.12) - C_z(4.25)$$
$$C_z = 1.526\,lb$$

X-y Plane

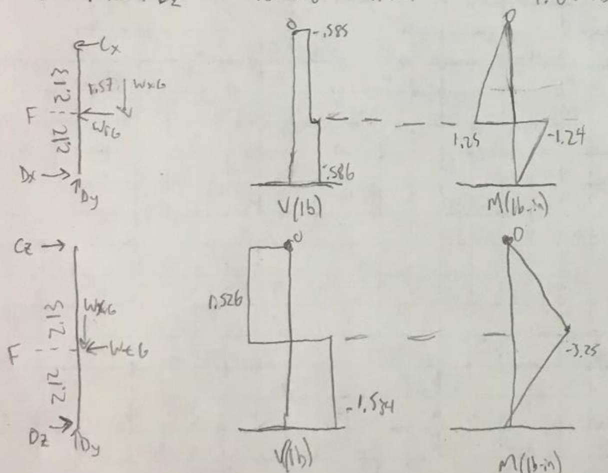
$$\Sigma M_C = 0 = W_{rG}(c) + W_{xG}(R_m) - D_x(L_G) = (.41)(2.13) + (1.03)(1.57) - D_x(4.25)$$
$$D_x = 0.586\,lb$$

$$\Sigma M_D = 0 = W_{rG}(d) + W_{xG}(R_m) - C_x(L_G) = (.41)(2.12) + (1.03)(1.57) - C_x(4.25)$$
$$C_x = 0.585\,lb$$

$$D_y = W_{xG} = 1.034\,lb$$

Resulting Forces

$$C = \sqrt{C_x^2 + C_z^2} = \sqrt{0.585^2 + 1.526^2} = 1.63\,lb$$
$$D = \sqrt{D_x^2 + D_z^2} = \sqrt{0.586^2 + 1.534^2} = 1.64\,lb$$



$$M_{Fx} = (-.586)(2.12) = -1.24\,lb\text{-}in$$
$$(2.13)(.585) = 1.25\,lb\text{-}in$$

$$M_{Fz} = (-1.534)(2.12) = -3.25\,lb\text{-}in$$

Max Bending Moment

$$\sqrt{M_{Fx}^2 + M_{Fz}^2} = \sqrt{1.24^2 + 3.25^2}$$
$$= \underline{3.48\,lb\text{-}in}$$

Bearing A: 2.69 lb radial

Bearing B: 0.60 lb radial, 0.41 lb thrust

Bearing C: 1.63 lb radial

Bearing D: 1.64 lb radial, 1.034 lb thrust

APPENDIX A10

Kyle Aitken | MET 489 | RC Car Drivetrain

Given: Driven Shaft Torque $T = 1.925$ lb-in
Axle Shaft Torque $T = 4.813$ lb-in

Max Bending Moment in Driven Shaft $M = 1.51$ lb-in
Max Bending Moment in Axle Shaft $M = 3.48$ lb-in

Find: Minimum Diameter for Driven Shaft and Axle Shaft

Solution:

Material: Carbon Steel SAE 1020 $s_n = 21$ ksi $\quad S_{ys} = 60$ ksi

$C_m = 0.8$ (cast steel)
$C_{st} = 1.0$ (bending stress)
$C_R = 0.81$ (reliability of 0.99)
$C_s = 1.0$ $(D \leq 0.3 \text{ in})$

$$S_{ys} = \frac{S_y}{\sqrt{3}}$$

$$S_y = 60\text{ ksi}\,(\sqrt{3}) = 103.923 \text{ ksi}$$

$$s'_n = s_n (C_m)(C_{st})(C_R)(C_s)$$

$$s'_n = 21\text{ ksi}\,(.8)(1.0)(.81)(1.0) = 13.608 \text{ ksi}$$

Standard Design Factor $N = 2.5$

Shoulder Fillet well-rounded $K_t = 1.5$

Driven Shaft

$$D = \left[\left(\frac{32N}{\pi}\right)\sqrt{\left(\frac{K_t M}{s'_n}\right)^2 + \frac{3}{4}\left(\frac{T}{s_y}\right)^2}\,\right]^{1/3} = \left[\left(\frac{32(2.5)}{\pi}\right)\sqrt{\left(\frac{(1.5)(1.51\text{ lb-in})}{13{,}608\text{ psi}}\right)^2 + \frac{3}{4}\left(\frac{1.925\text{ lb-in}}{103{,}923\text{ psi}}\right)^2}\,\right]^{1/3}$$

$$D_{min} = \left[(25.465)\sqrt{\left(1.665(10^{-4})\text{ in}\right)^2 + \frac{3}{4}\left(1.852(10^{-5})\text{ in}\right)^2}\,\right]^{1/3} = \boxed{0.162 \text{ in}}$$

Axle Shaft

$$D = \left[\left(\frac{32(2.5)}{\pi}\right)\sqrt{\left(\frac{(1.5)(3.48\text{ lb-in})}{13{,}608\text{ psi}}\right)^2 + \frac{3}{4}\left(\frac{4.813\text{ lb-in}}{103{,}923\text{ psi}}\right)^2}\,\right]^{1/3}$$

$$D_{min} = \left[(25.465)\sqrt{\left(3.836(10^{-4})\text{ in}\right)^2 + \frac{3}{4}\left(4.631(10^{-5})\text{ in}\right)^2}\,\right]^{1/3} = \boxed{0.214 \text{ in}}$$

Standard Shaft Diameter to use for both shafts

$$\boxed{0.25 \text{ in}}$$

APPENDIX A11

Kyle Aitken | MET 489 | RC Car Drivetrain | 1/2

<u>Given:</u> Shaft Diameter = 0.25 in

Key Depth = 3/64 in

Key Width = 3/32 in

Same for Driven and Axle Shafts

Torque on Driven Shaft = 1.925 lb-in

Torque on Axle Shaft = 4.813 lb-in

Key Material Carbon Steel SAE 1018

$S_u = 64$ ksi

$S_y = 54$ ksi

$N = 2.5$

<u>Find:</u> Key Length for Driven Shaft and Axle Shaft

Shearing and Compressive Stresses

<u>Solution:</u>

$$\tau_d = \frac{0.5 S_y}{N} = \frac{(.5)\,54\text{ ksi}}{2.5} = 10.8\text{ ksi} \qquad \sigma_d = \frac{S_y}{N} = \frac{54\text{ ksi}}{2.5} = 21.6\text{ ksi}$$

Driven Shaft

Minimum Required Key Length for Shear

$$L_{min} = \frac{2T}{\tau_d D W} = \frac{2(1.925\text{ lb-in})}{(10{,}800\text{ psi})(.25\text{ in})(3/32\text{ in})} = 0.015\text{ in}$$

Minimum Required Key Length for Compression

$$L_{min} = \frac{4T}{\sigma_d D H} = \frac{4(1.925\text{ lb-in})}{(21{,}600\text{ psi})(.25\text{ in})(3/64\text{ in})} = 0.015\text{ in}$$

Minimum Required Key Length if Key Material is Weakest

$$L_{min} = \frac{4TN}{D W S_y} = \frac{4(1.925\text{ lb-in})(2.5)}{(.25\text{ in})(54{,}000\text{ psi})(3/32\text{ in})} = 0.015\text{ in}$$

Axle Shaft

Minimum Required Key Length for Shear

$$L_{min} = \frac{2T}{\tau_d D W} = \frac{2(4.813\text{ lb-in})}{(10{,}800\text{ psi})(0.25\text{ in})(3/32\text{ in})} = 0.038\text{ in}$$

Minimum Required Key Length for Compression

$$L_{min} = \frac{4T}{\sigma_d D H} = \frac{4(4.813\text{ lb-in})}{(21{,}600\text{ psi})(.25\text{ in})(3/64\text{ in})} = 0.038\text{ in}$$

Minimum Required Key Length if Key Material is Weakest

$$L_{min} = \frac{4TN}{D W S_y} = \frac{4(4.813\text{ lb-in})(2.5)}{(.25\text{ in})(3/32\text{ in})(54{,}000\text{ psi})} = 0.038\text{ in}$$

Kyle Aitken	MET 489	RC Car Drivetrain	2/

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

Face width for Bevel Gear on Axle Shaft = 0.65 in

$.65 in > L > .038 in$ $\boxed{L = 0.6 in}$

$$\tau = \frac{F}{A_s} = \frac{T}{(D/2)\,WL} = \frac{2T}{DWL} = \frac{2(4.813\ lb\text{-}in)}{(.25in)(3/32in)(0.6in)} = \boxed{684.52\ psi}$$

$$\sigma = \frac{F}{A_c} = \frac{T}{(D/2)(L)(H/2)} = \frac{4T}{DLH} = \frac{4(4.813\ lb\text{-}in)}{(.25in)(.6in)(6/64in)} = \boxed{1369.03\ psi}$$

Face width for Spur Gear on Driven Shaft = 0.25 in

$.25in > L > .015 in$ $\boxed{L = 0.2 in}$

$$\tau = \frac{2T}{DWL} = \frac{2(1.925\ lb\text{-}in)}{(.25in)(3/32in)(.2in)} = \boxed{821.33\ psi}$$

$$\sigma = \frac{4T}{DLH} = \frac{4(1.925\ lb\text{-}in)}{(.25in)(.2in)(6/64in)} = \boxed{1642.67\ psi}$$

APPENDIX A12

Kyle Aitken | MET 489 | RC Car Drivetrain

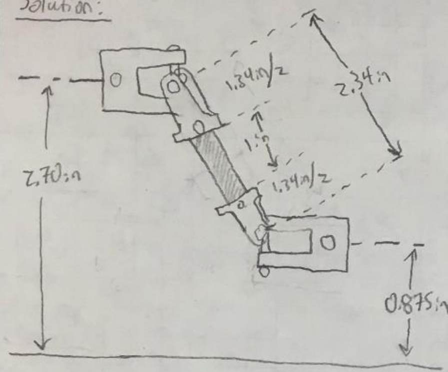
Given: 2 U-Joint Couplers
ID = 0.31 in
OD = 0.55 in
L = 1.34 in
Clearance Shaft Length = 1 in

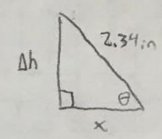
Height for Centerline of Driven Shaft = 0.875 in

Height for Centerline of Axle Shaft = 2.70 in

Find: Angle and distance between U-Joints

Solution:





$$\Delta h = 2.70in - 0.875in = 1.825in$$

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

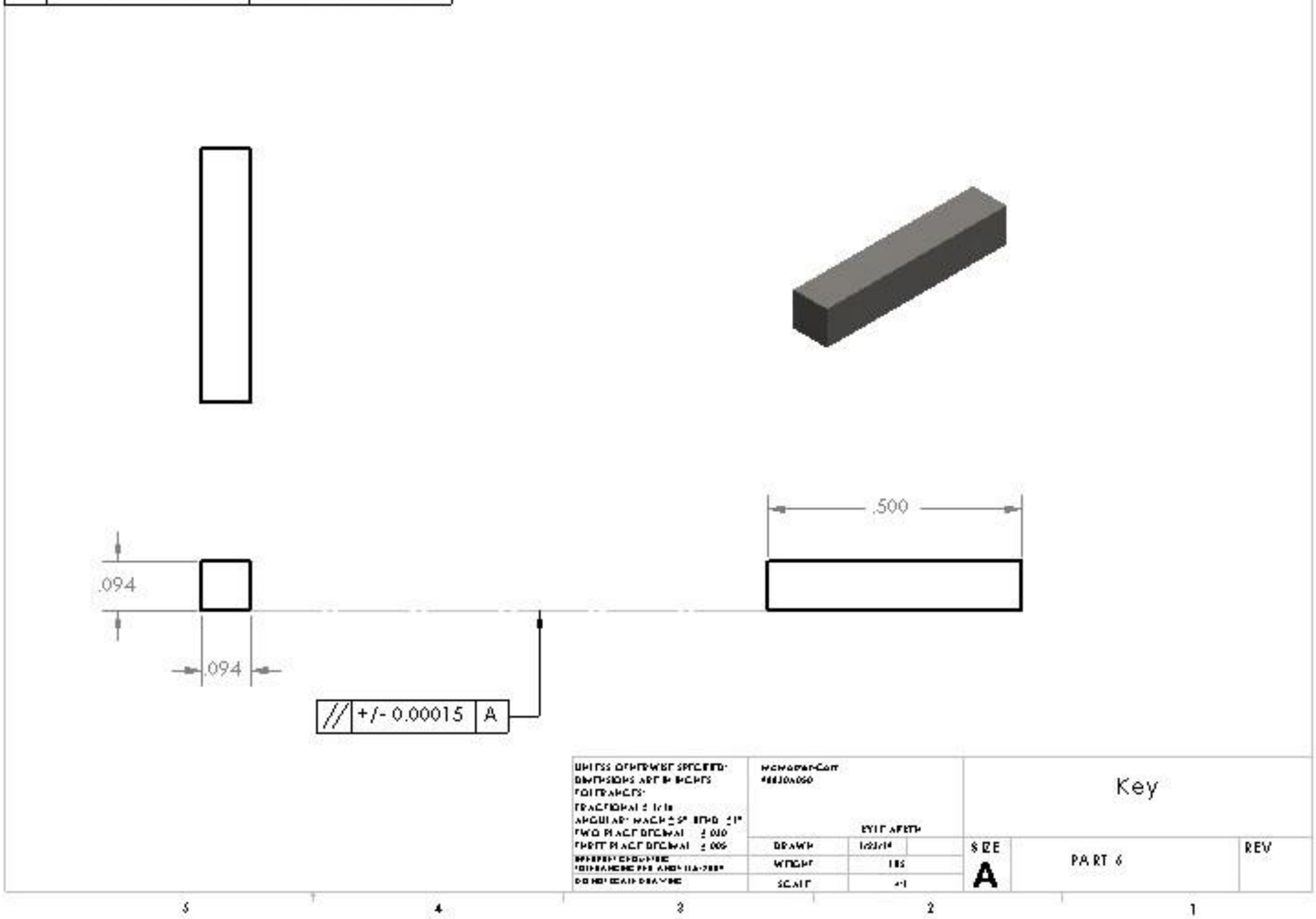
$$x = \sqrt{2.34in^2 - 1.825in^2} = \boxed{1.46in}$$

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

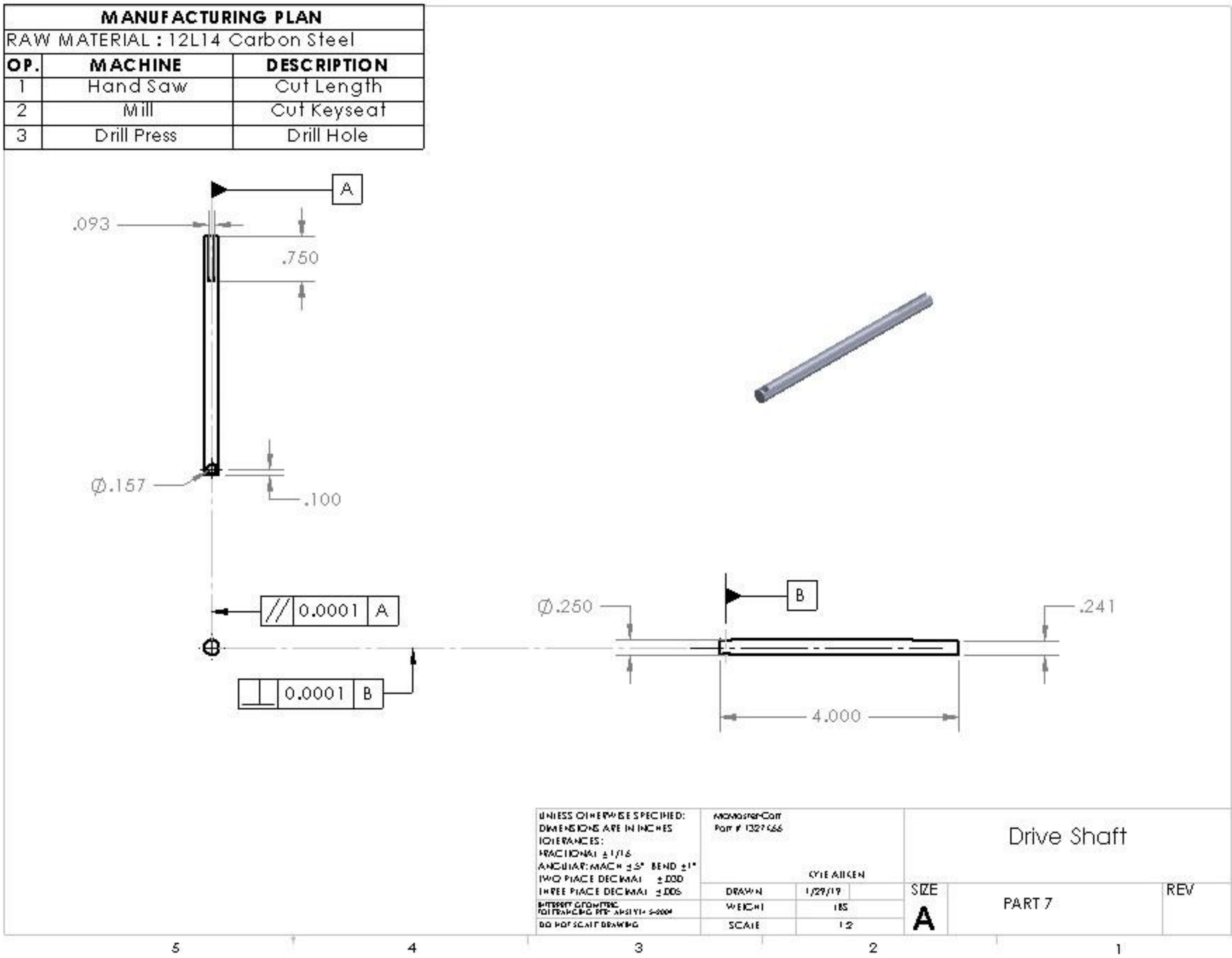
$$\theta = \sin^{-1}\left(\frac{1.825in}{2.34in}\right) = \boxed{51.25°}$$

APPENDIX B1

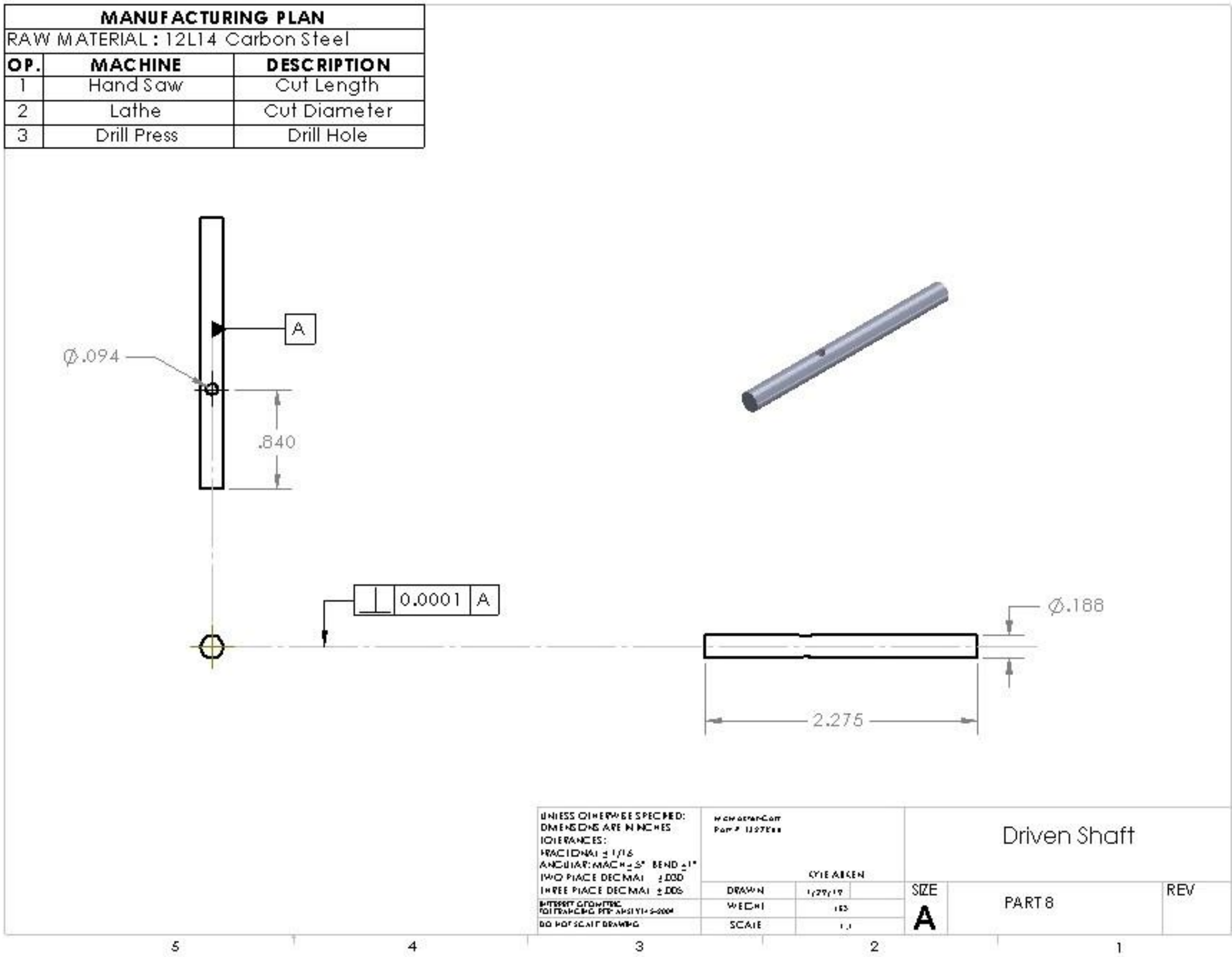
MANUFACTURING PLAN		
RAW MATERIAL : STEEL		
OP.	MACHINE	DESCRIPTION
1	HAND SAW	CUT TO LENGTH



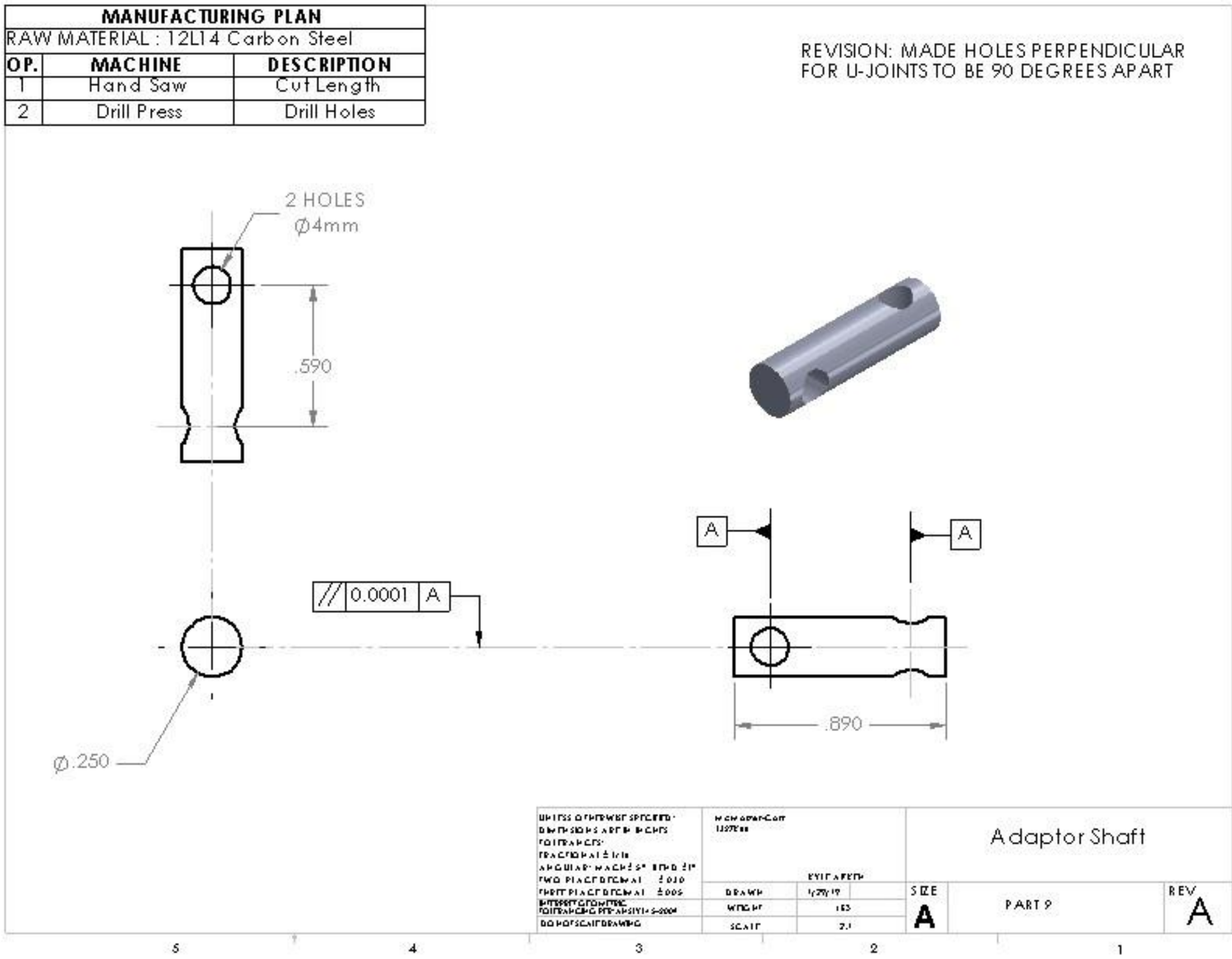
APPENDIX B2


MANUFACTURING PLAN
RAW MATERIAL : 12L14 Carbon Steel
OP. | MACHINE | DESCRIPTION
1 | Hand Saw | Cut Length
2 | Mill | Cut Keyseat
3 | Drill Press | Drill Hole
A
.093
.750
Ø.157
.100
0.0001 A
0.0001 B
Ø.250
B
.241
4.000
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
ANGULAR: MACH ±.5° BEND ±1°
TWO PLACE DECIMAL ±.030
THREE PLACE DECIMAL ±.005
DO NOT SCALE DRAWING
DRAWN
1/29/19
WEIGHT
SCALE
1:2
Drive Shaft
SIZE
A
PART 7
REV
5
4
3
2
1

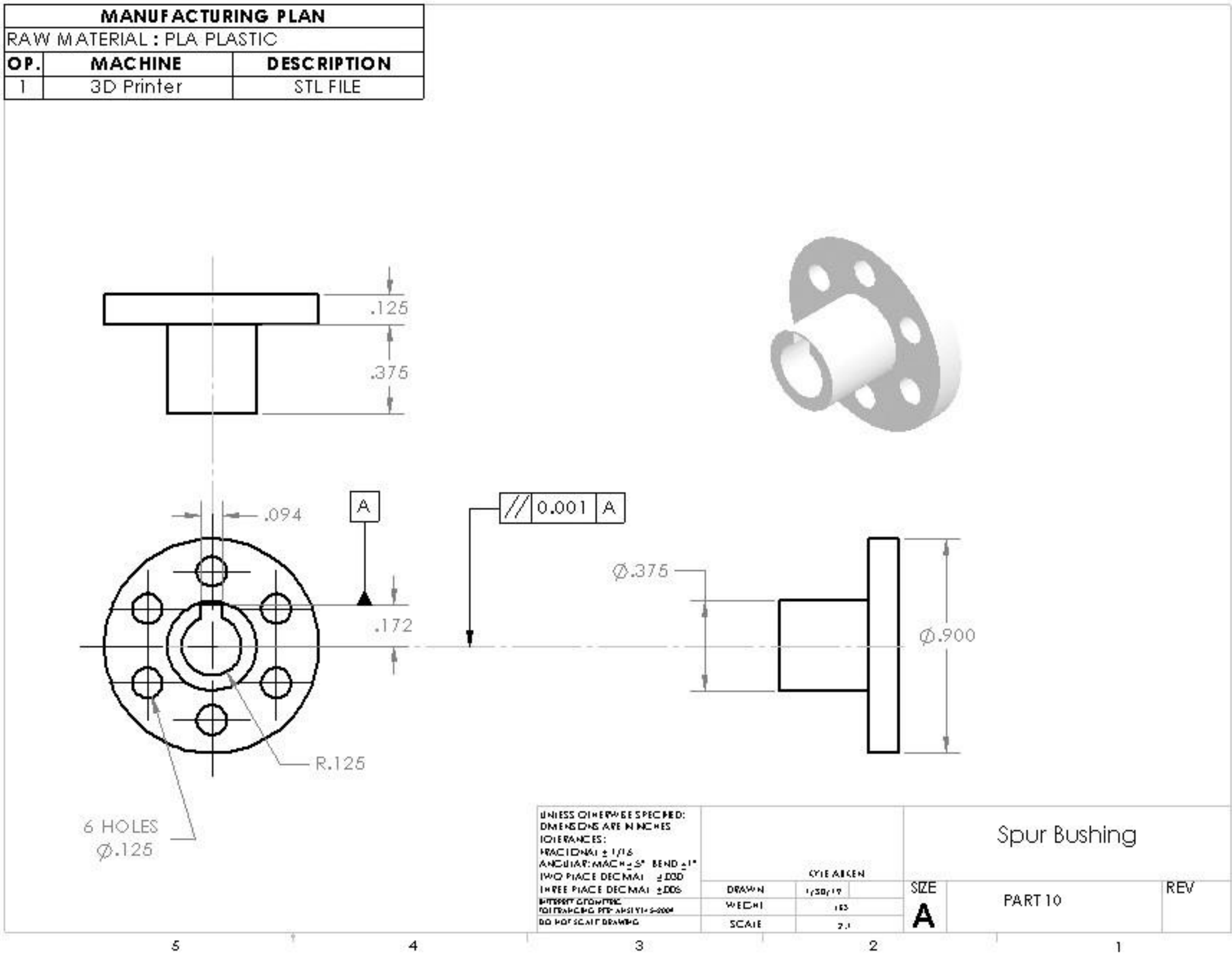
APPENDIX B3


MANUFACTURING PLAN
RAW MATERIAL : 12L14 Carbon Steel
OP. MACHINE DESCRIPTION
1 Hand Saw Cut Length
2 Lathe Cut Diameter
3 Drill Press Drill Hole
A
Ø.094
.840
0.0001 A
Ø.188
2.275
Driven Shaft
SIZE
A
PART 8
REV
DRAWN
SCALE
5
4
3
2
1

APPENDIX B4

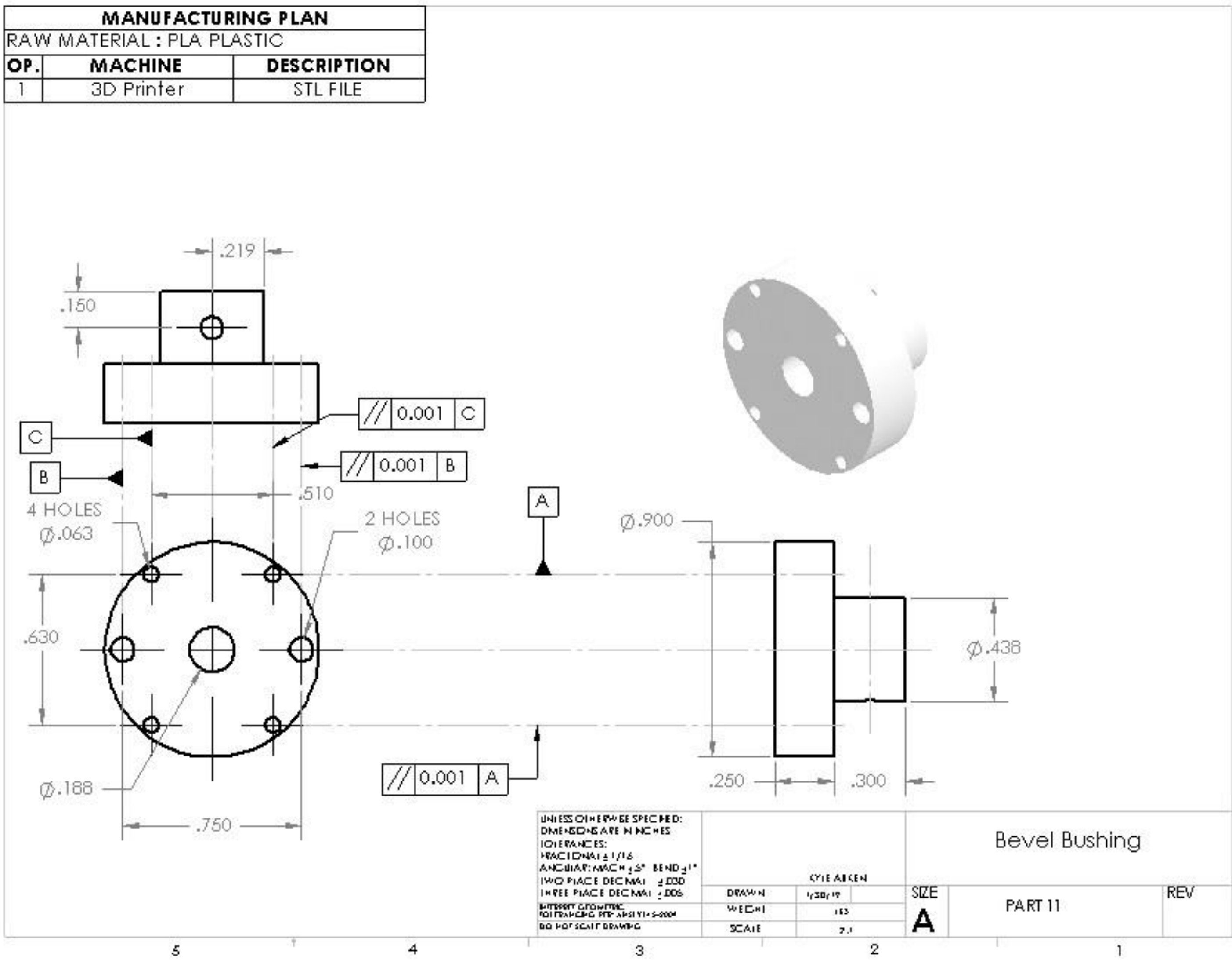

MANUFACTURING PLAN
RAW MATERIAL : 12L14 Carbon Steel
OP.
MACHINE
DESCRIPTION
1
Hand Saw
Cut Length
2
Drill Press
Drill Holes
REVISION: MADE HOLES PERPENDICULAR
FOR U-JOINTS TO BE 90 DEGREES APART
2 HOLES
Ø4mm
.590
A
A
0.0001
A
Ø.250
.890
Adaptor Shaft
SIZE
A
PART 9
REV
A

APPENDIX B5

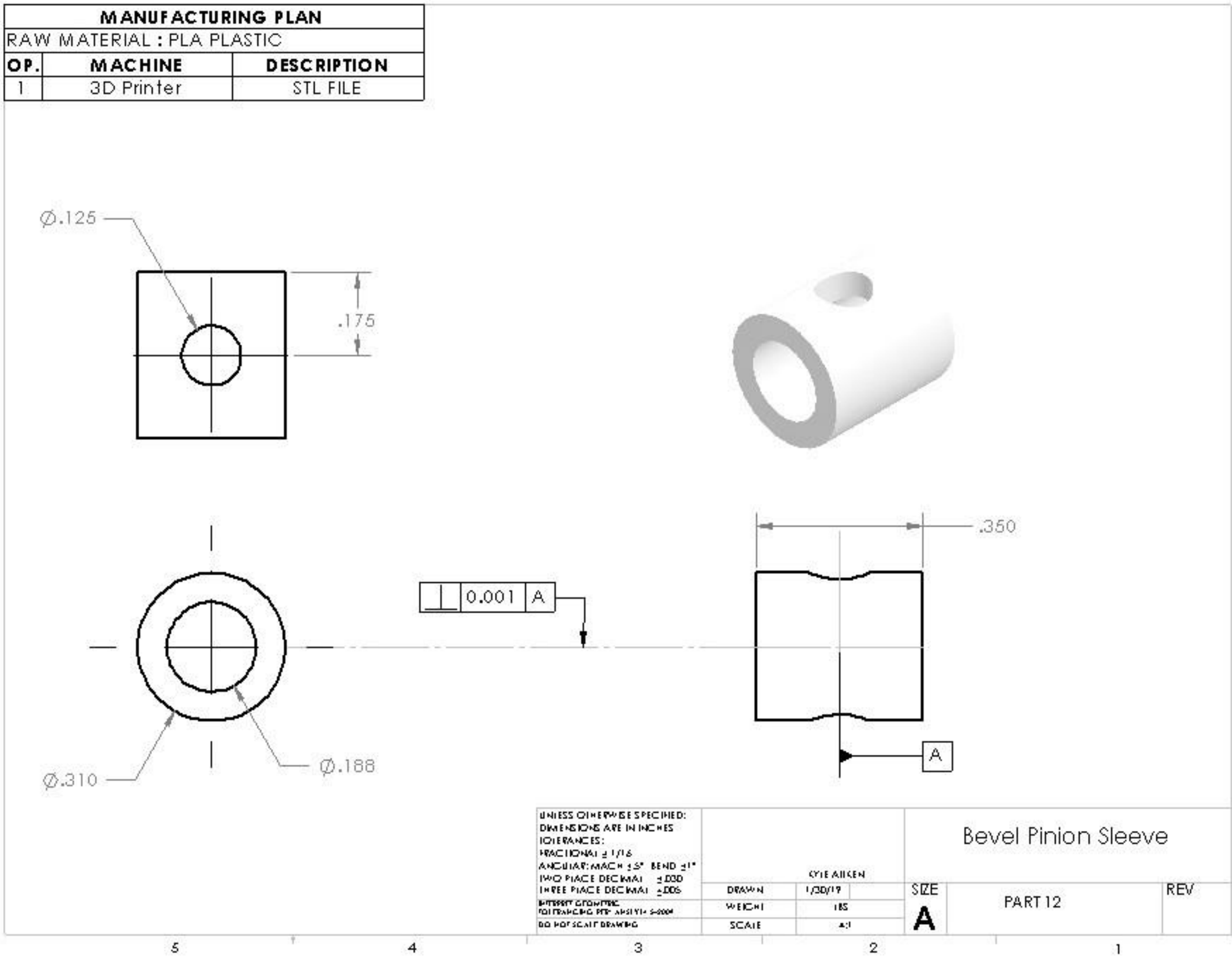


MANUFACTURING PLAN
RAW MATERIAL : PLA PLASTIC
OP. MACHINE DESCRIPTION
1 3D Printer STL FILE
.125
.375
.094
A
0.001 A
Ø.375
.172
Ø.900
R.125
6 HOLES
Ø.125
Spur Bushing
SIZE
A
PART 10
REV
DRAWN
WEIGHT
SCALE
5
4
3
2
1

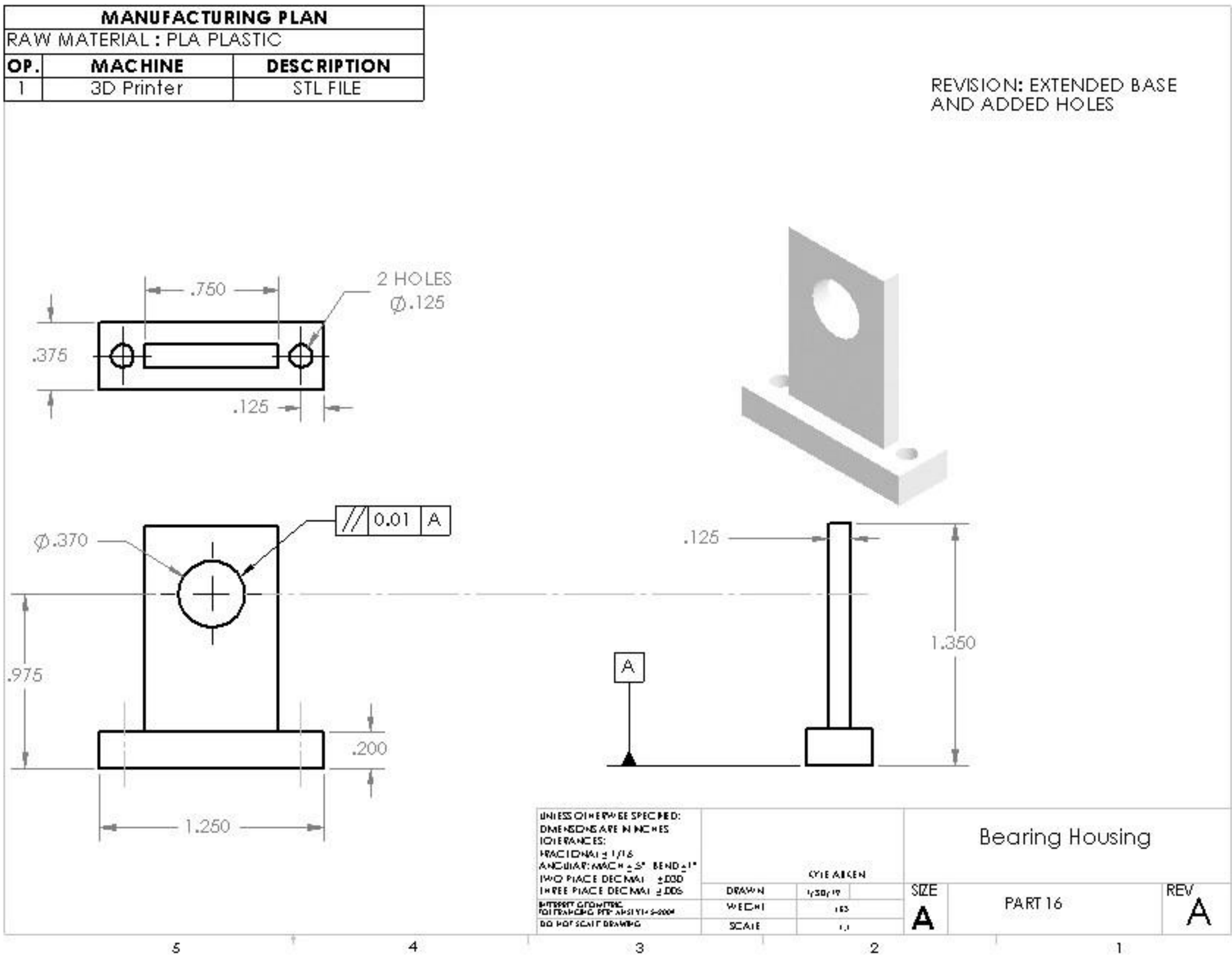
APPENDIX B6


MANUFACTURING PLAN
RAW MATERIAL : PLA PLASTIC
OP.
MACHINE
DESCRIPTION
1
3D Printer
STL FILE
.219
.150
C
B
// 0.001 C
// 0.001 B
.510
4 HOLES
Ø.063
2 HOLES
Ø.100
A
Ø.900
.630
Ø.438
Ø.188
// 0.001 A
.250
.300
.750
Bevel Bushing
DRAWN
SCALE
SIZE
A
PART 11
REV
5
4
3
2
1

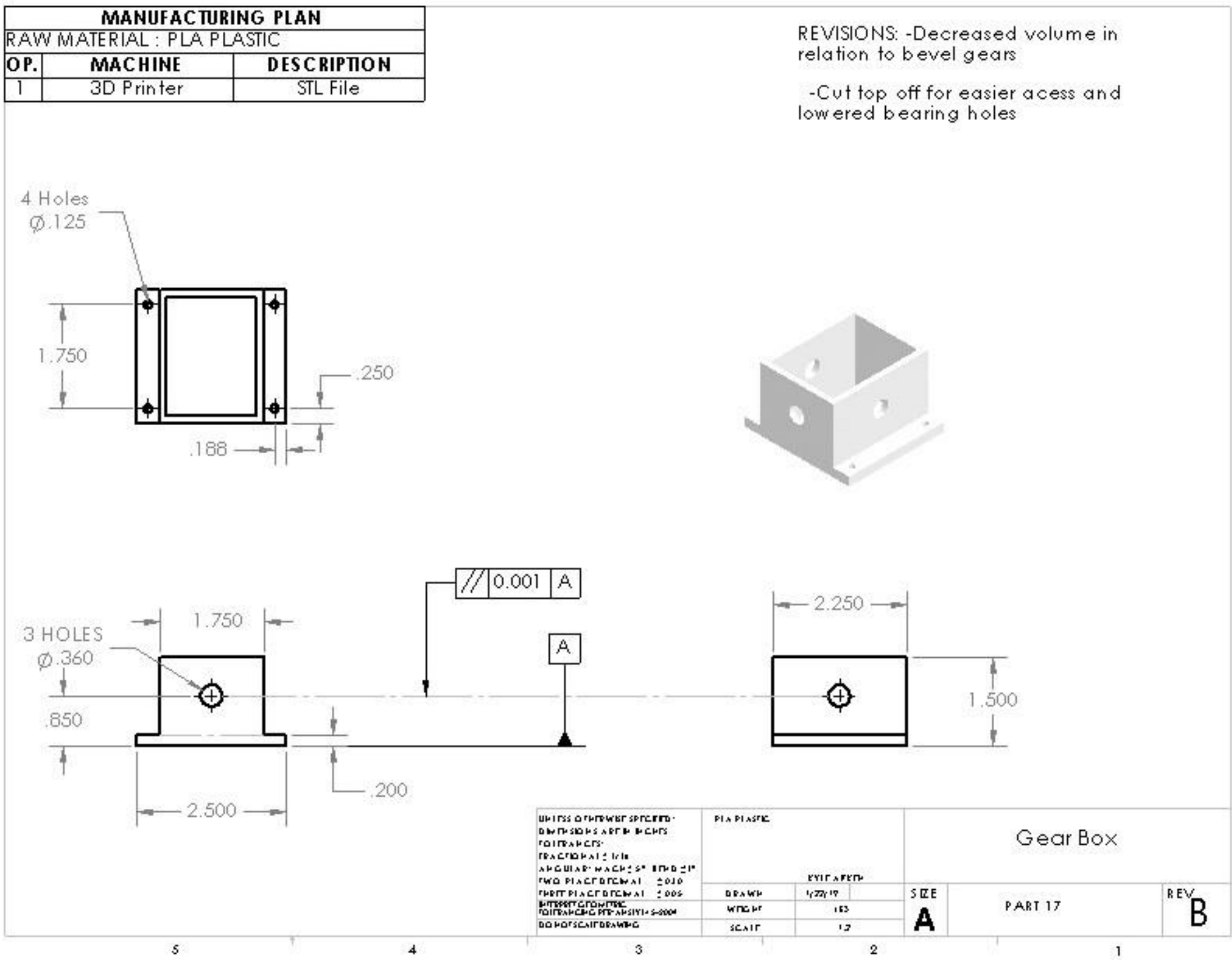
APPENDIX B7


MANUFACTURING PLAN
RAW MATERIAL : PLA PLASTIC
OP.
MACHINE
DESCRIPTION
1
3D Printer
STL FILE
Ø.125
.175
.350
0.001
A
Ø.310
Ø.188
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ±.5° BEND ±1°
TWO PLACE DECIMAL ±.030
THREE PLACE DECIMAL ±.005
DO NOT SCALE DRAWING
DRAWN
WEIGHT
SCALE
KYLE AIKEN
1/30/19
Bevel Pinion Sleeve
SIZE
A
PART 12
REV
5
4
3
2
1

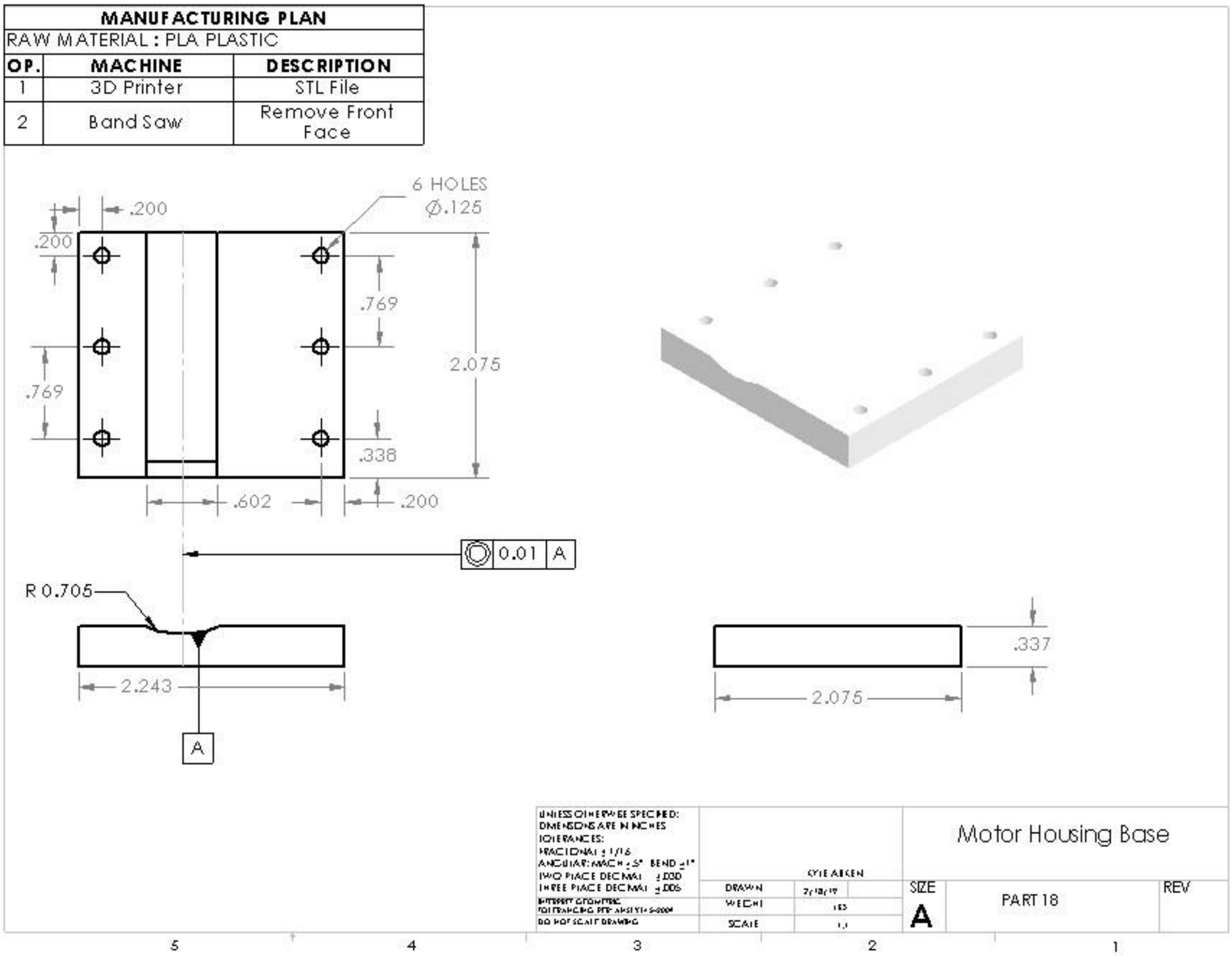
APPENDIX B8


MANUFACTURING PLAN
RAW MATERIAL : PLA PLASTIC
OP. | MACHINE | DESCRIPTION
1 | 3D Printer | STL FILE
REVISION: EXTENDED BASE AND ADDED HOLES
.750
2 HOLES ∅.125
.375
.125
∅.370
0.01 A
.975
.200
1.250
.125
1.350
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
Bearing Housing
DRAWN
WEIGHT
SCALE
SIZE
A
PART 16
REV
A
5
4
3
2
1

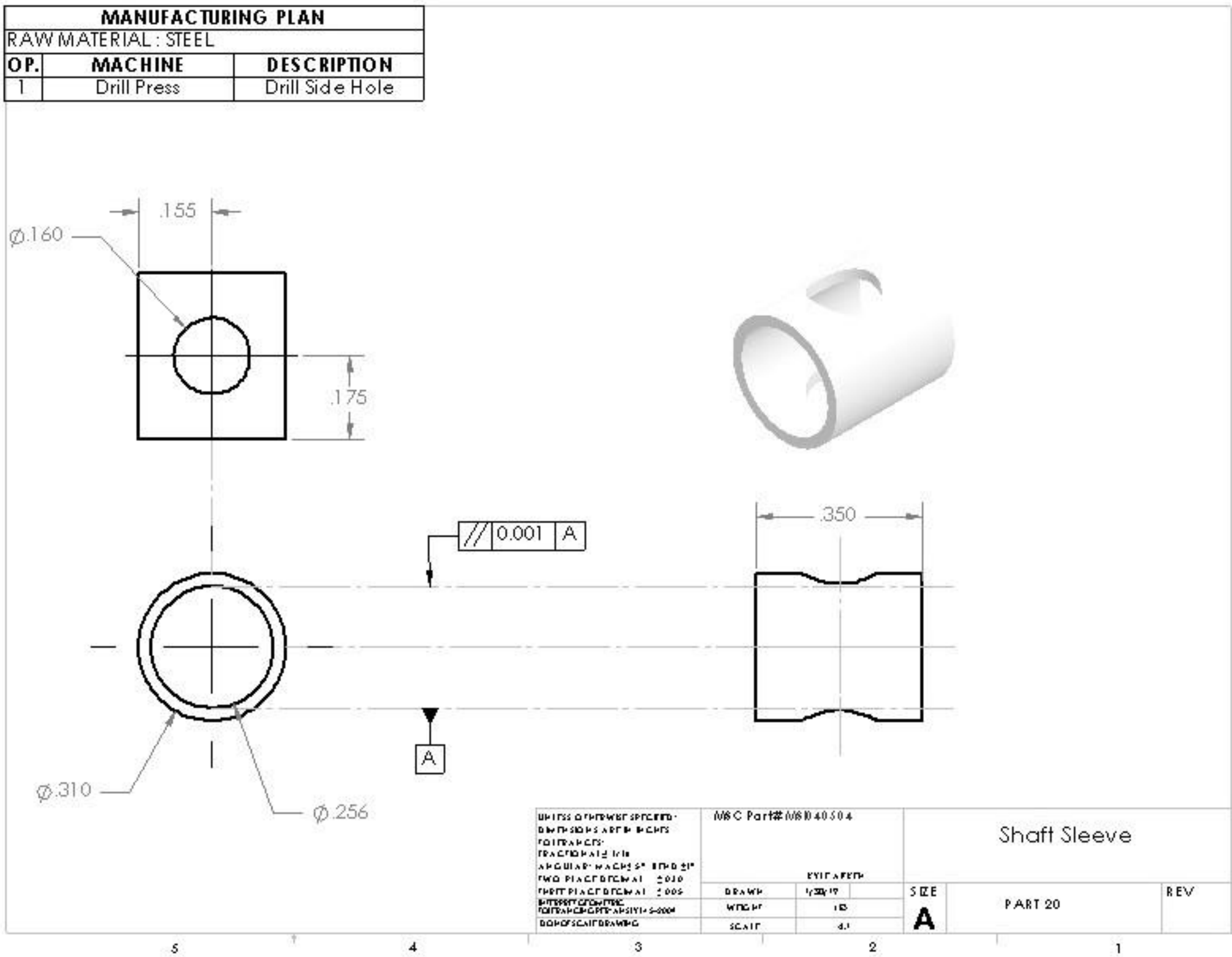
APPENDIX B9


MANUFACTURING PLAN
RAW MATERIAL : PLA PLASTIC
OP. | MACHINE | DESCRIPTION
1 | 3D Printer | STL File
REVISIONS: -Decreased volume in relation to bevel gears
-Cut top off for easier acess and lowered bearing holes
4 Holes
Ø.125
1.750
.250
.188
3 HOLES
Ø.360
.850
1.750
0.001 A
A
.200
2.500
2.250
1.500
PLA PLASTIC
DRAWN
SCALE
Gear Box
SIZE
A
PART 17
REV
B
5
4
3
2
1

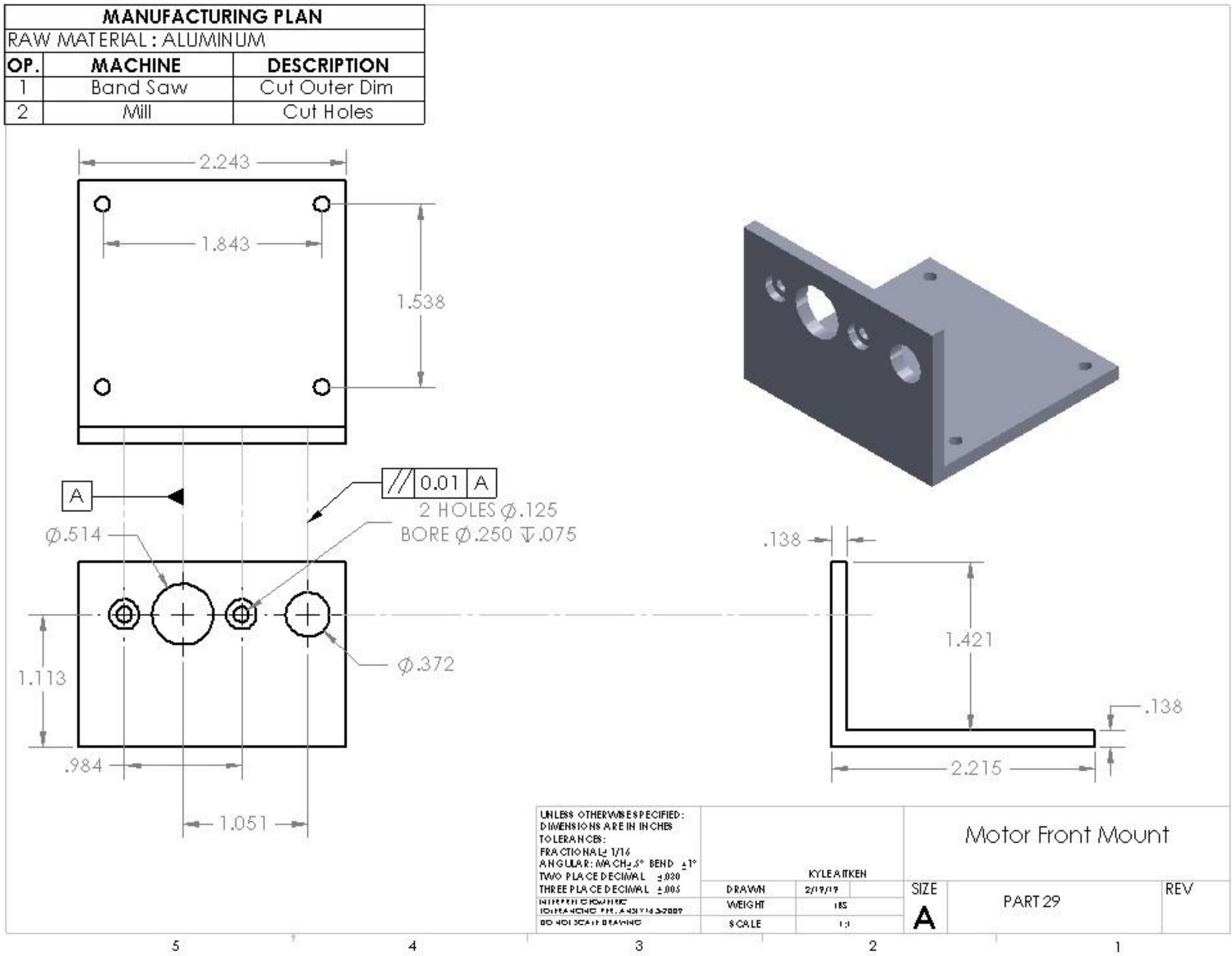
APPENDIX B10



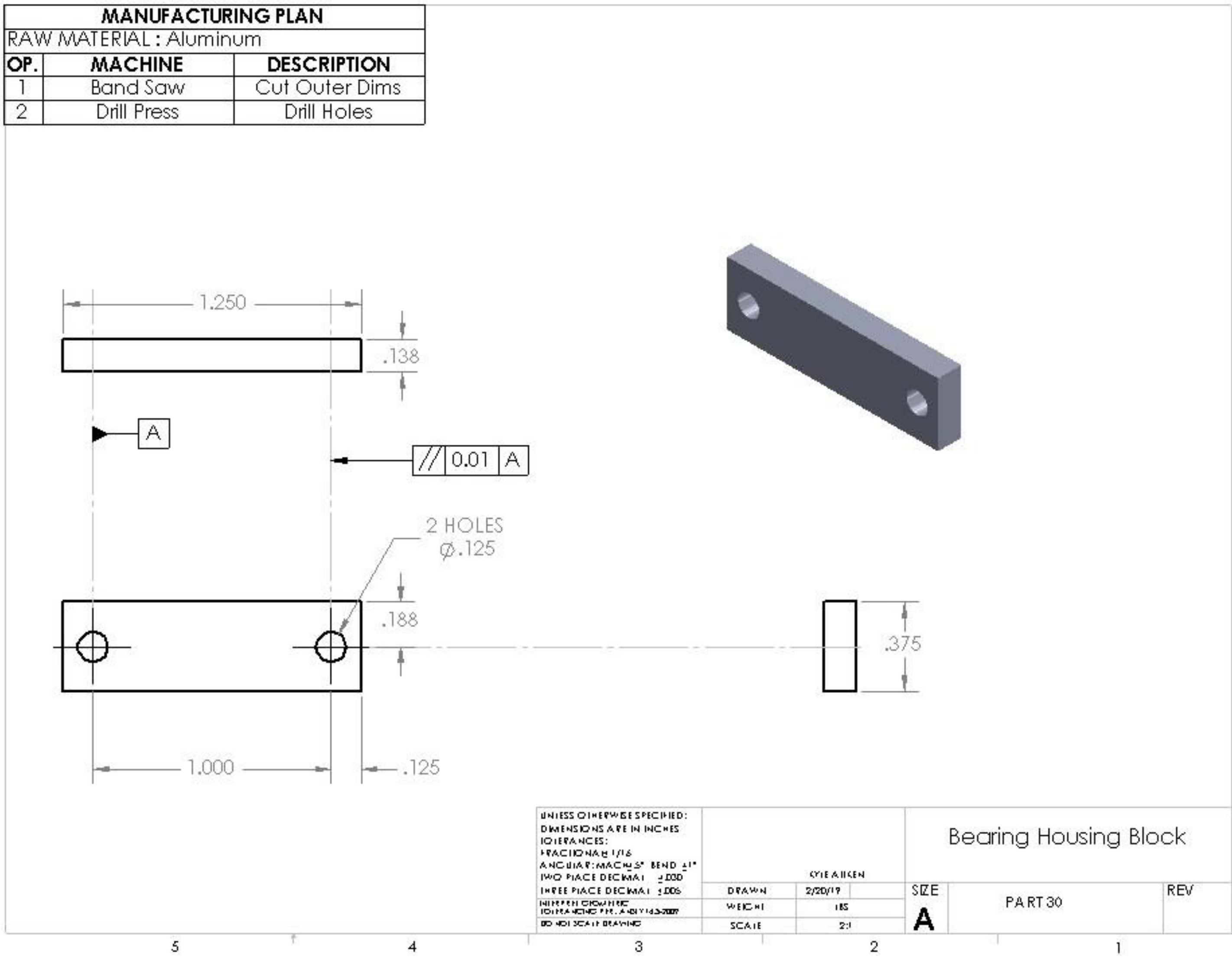
APPENDIX B11



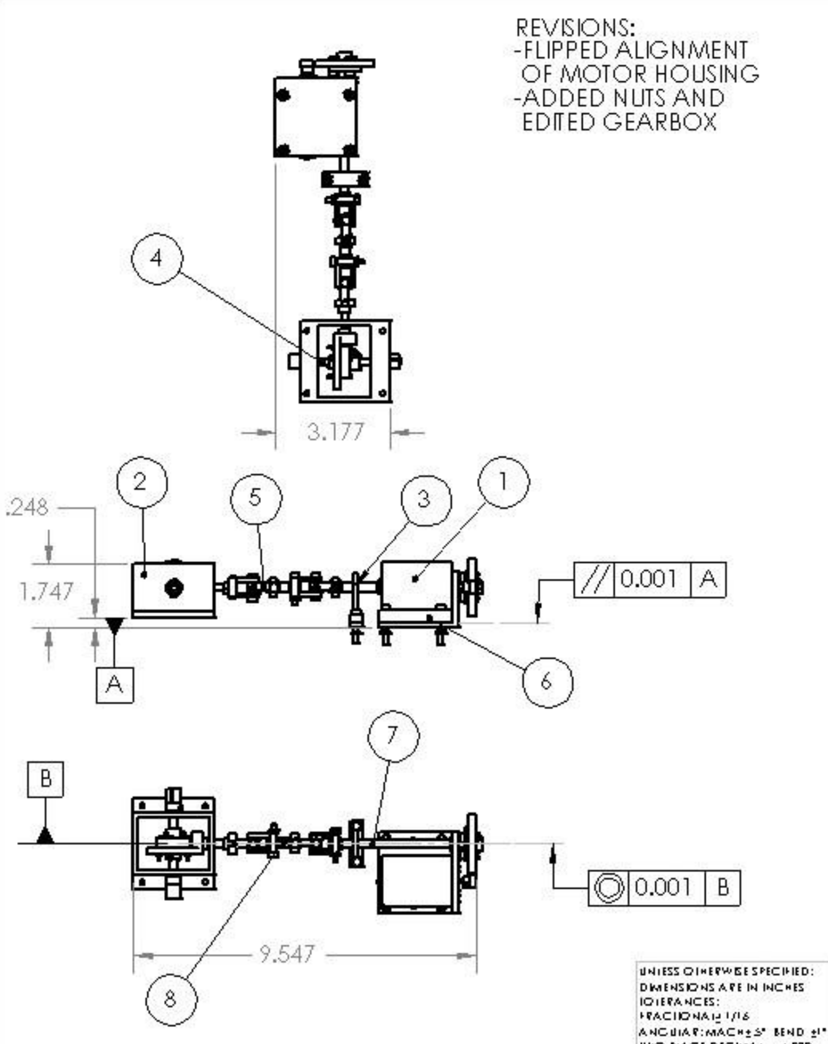
APPENDIX B12



APPENDIX B13



APPENDIX B14



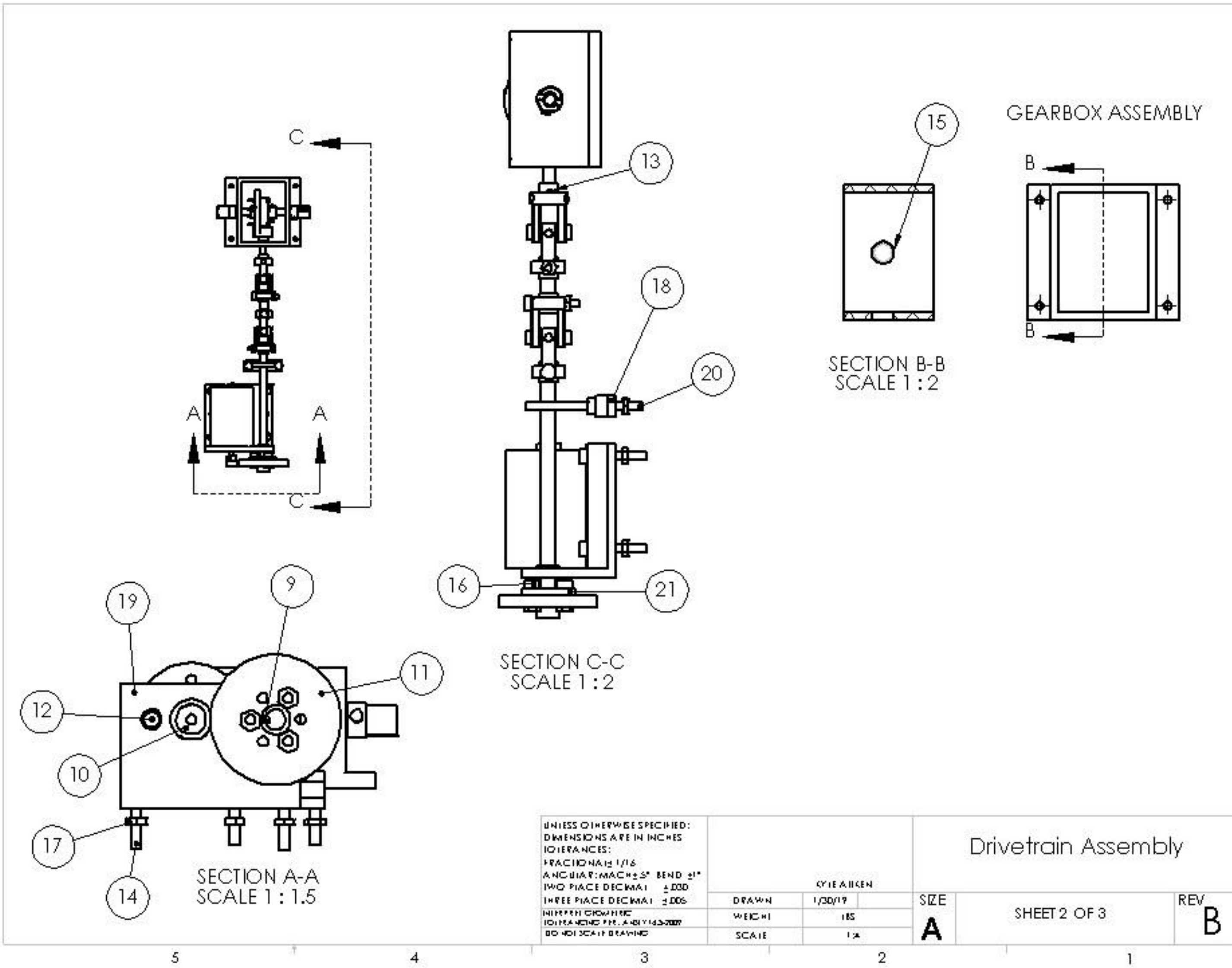
ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	1	Motor	1
2	17	Gearbox	1
3	16	Bearing Housing	1
4	8	Driven Shaft	1
5	19	U-Joints	2
6	18	Motor Housing Base	1
7	7	Drive Shaft	1
8	9	Adaptor Shaft	1
9	6	Key	1
10	2	Spur Pinion	1
11	3	Spur Gear	1
12	25	Screw M3x5	2
13	28	Pin M3x6	1
14	23	Bolt M4x25	4
15	15	Bearing 3/16	3
16	22	Bolt M4x10	3
17	31	Nut M4	12
18	30	Bearing Housing Block	1
19	29	Motor Front Mount	1
20	21	Bolt M4x20	5
21	10	Spur Bushing	1
22	27	Set Screw M4x5	4
23	26	Set Screw M3x4	1
24	11	Bevel Bushing	1
25	13	Drive Cup	2
26	14	Bearing 1/4	2
27	20	Shaft Sleeve	3
28	5	Bevel Gear	1
29	24	Bolt M2x12	5
30	12	Bevel Pinion Sleeve	1
31	32	Nut M2	5
32	4	Bevel Pinion	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± .5° BEND ± 1°
TWO PLACE DECIMAL ± .030
THREE PLACE DECIMAL ± .005
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5-2009
DO NOT SCALE DRAWING

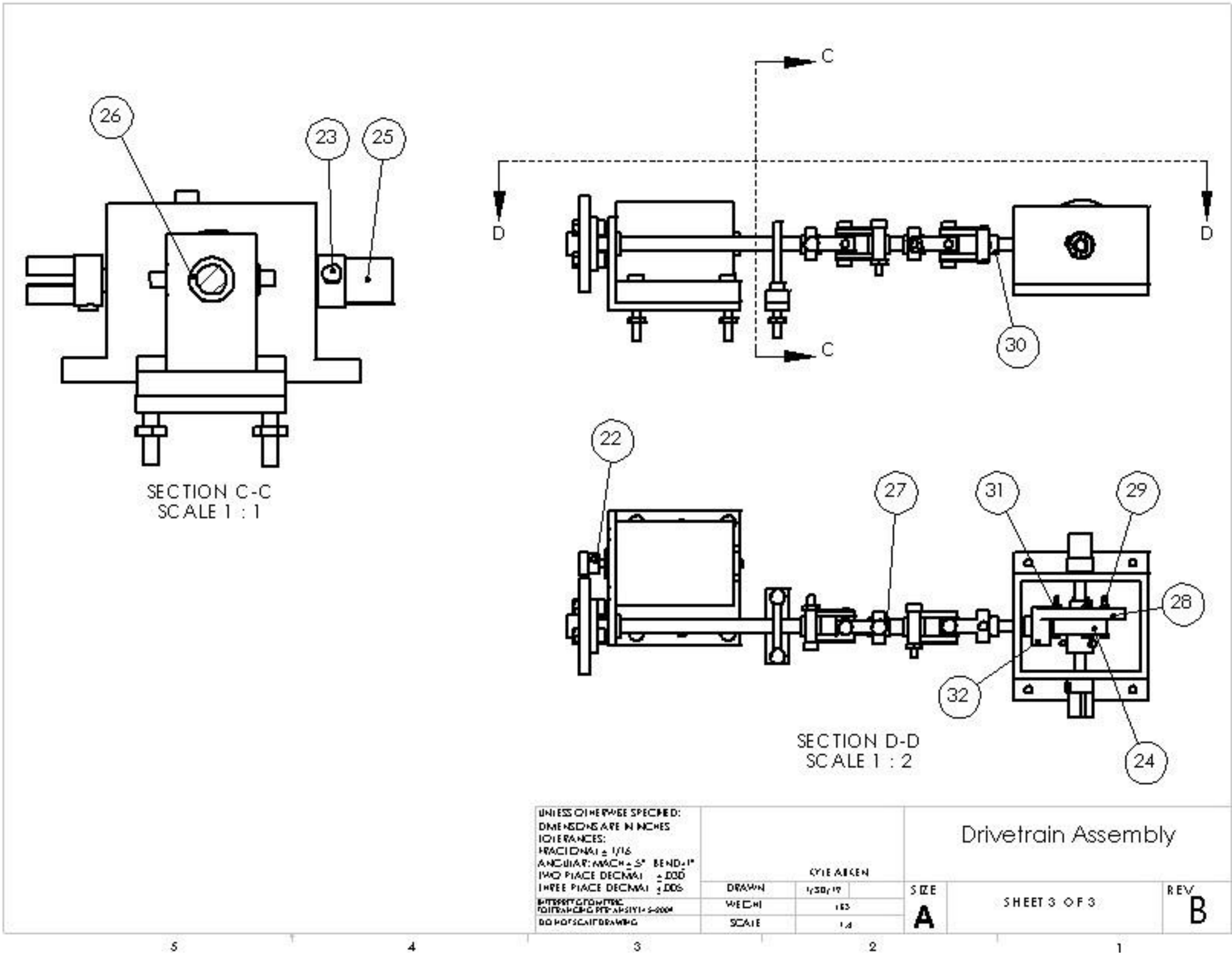
	KYLE AIKEN	Drivetrain Assembly	
DRAWN	1/30/19	SIZE A	SHEET 1 OF 3	REV B
WEIGHT	LBS		
SCALE	1:X		

5 4 3 2 1

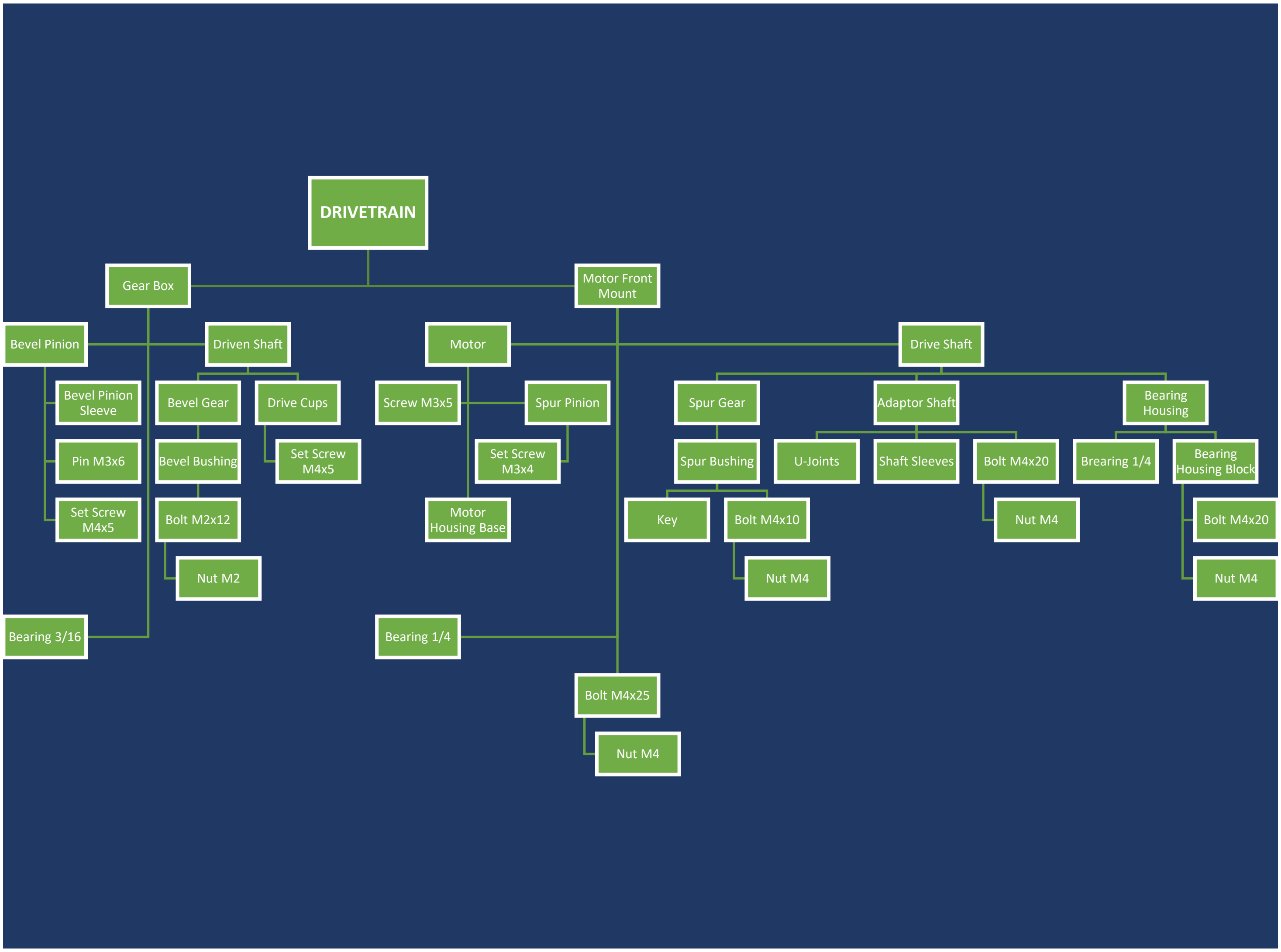
APPENDIX B15



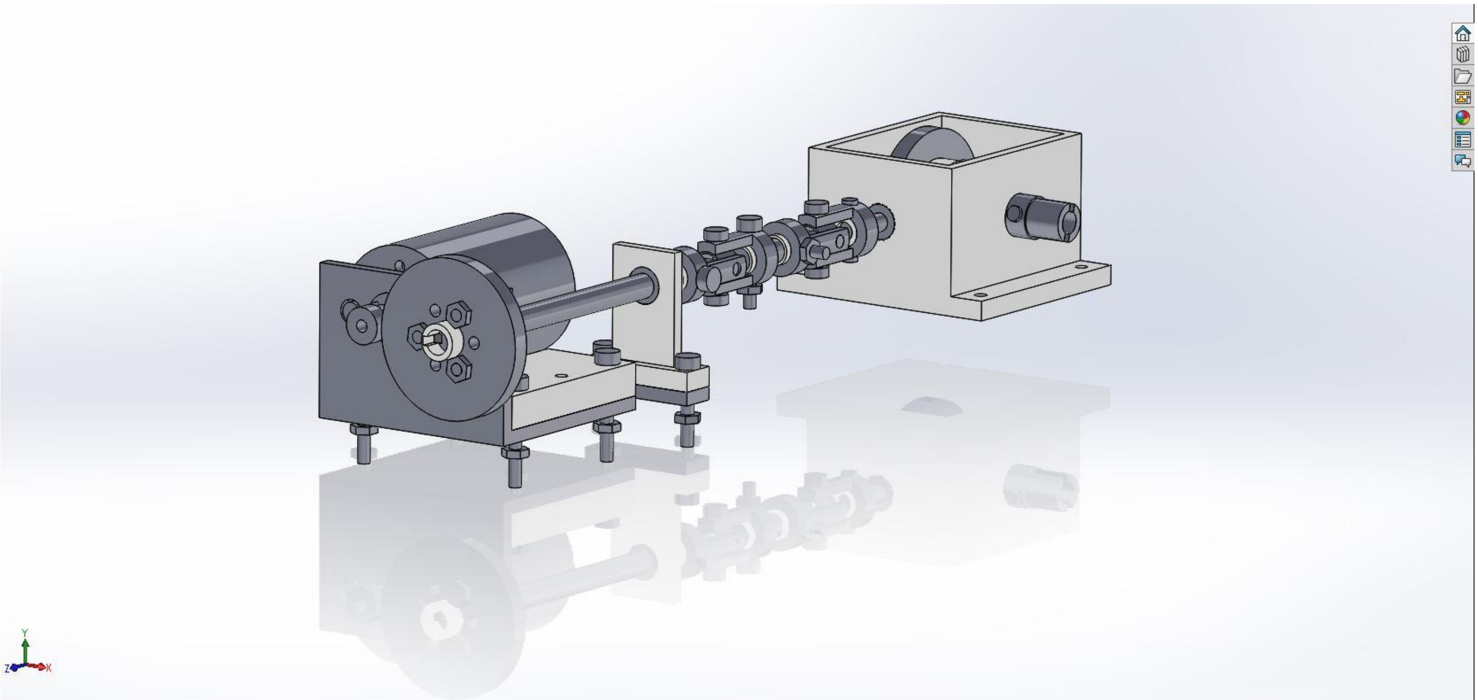
APPENDIX B16

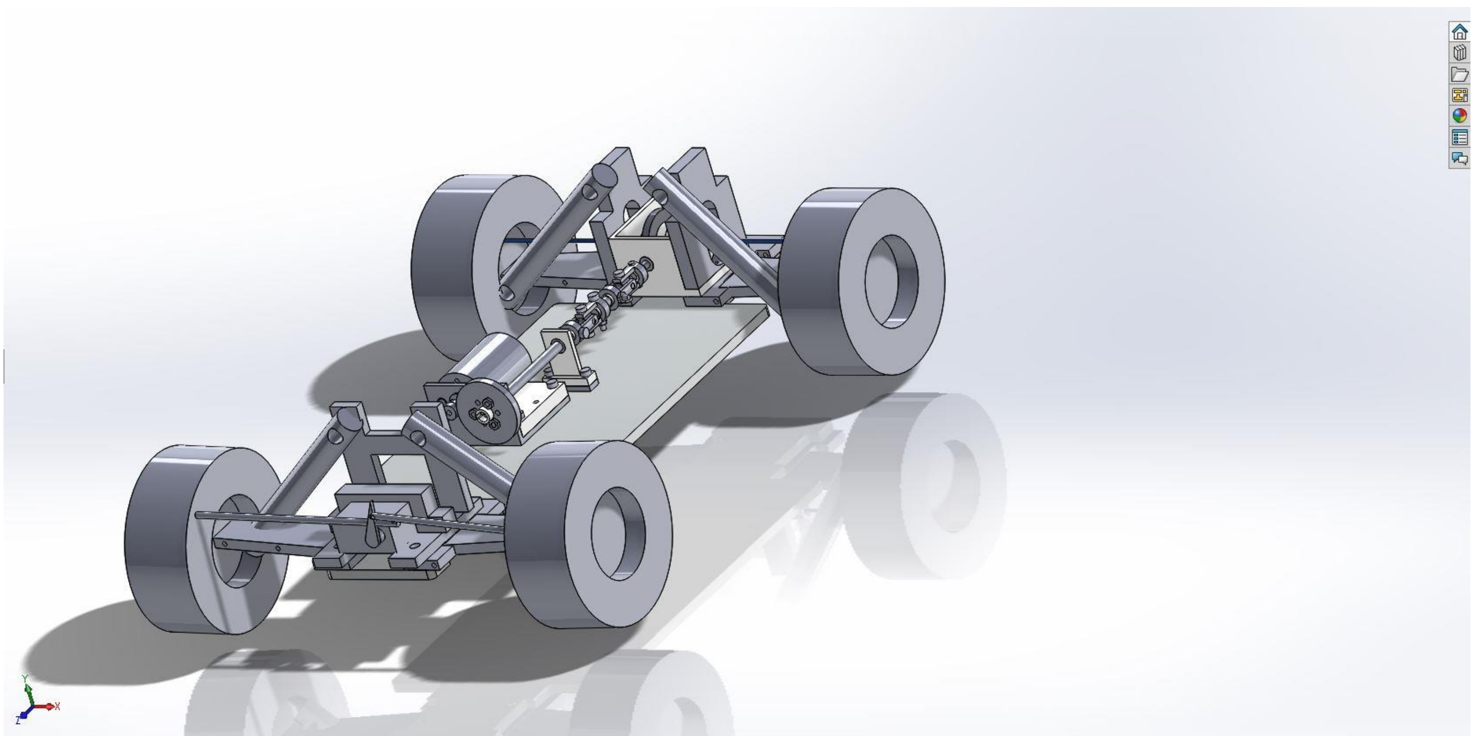


APPENDIX B17

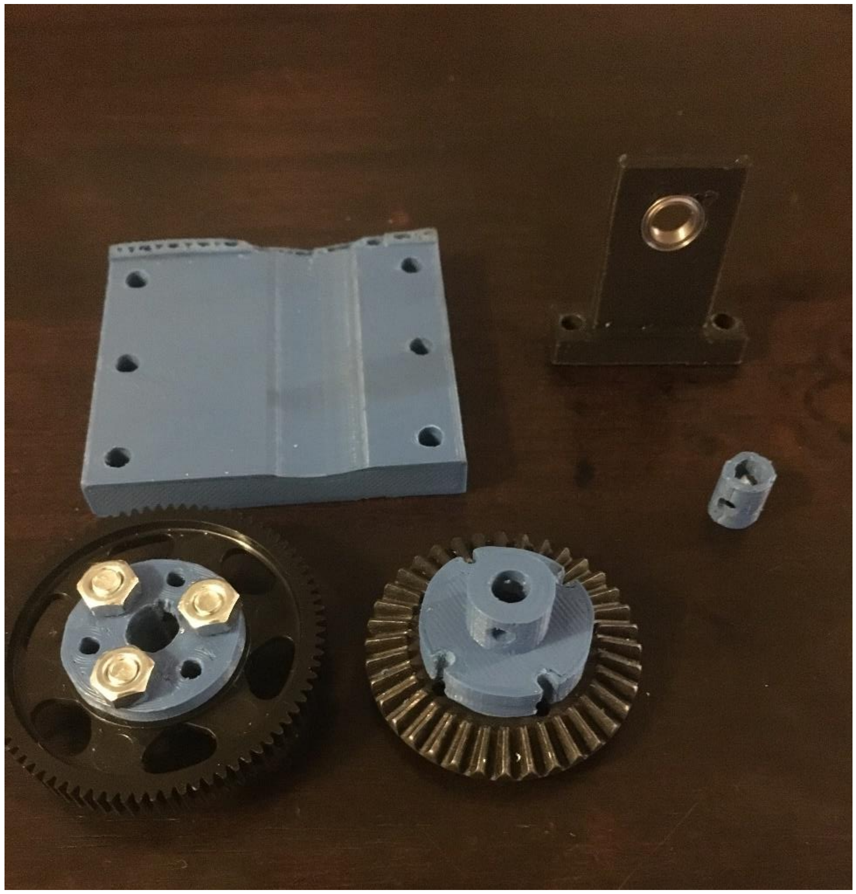


APPENDIX B18

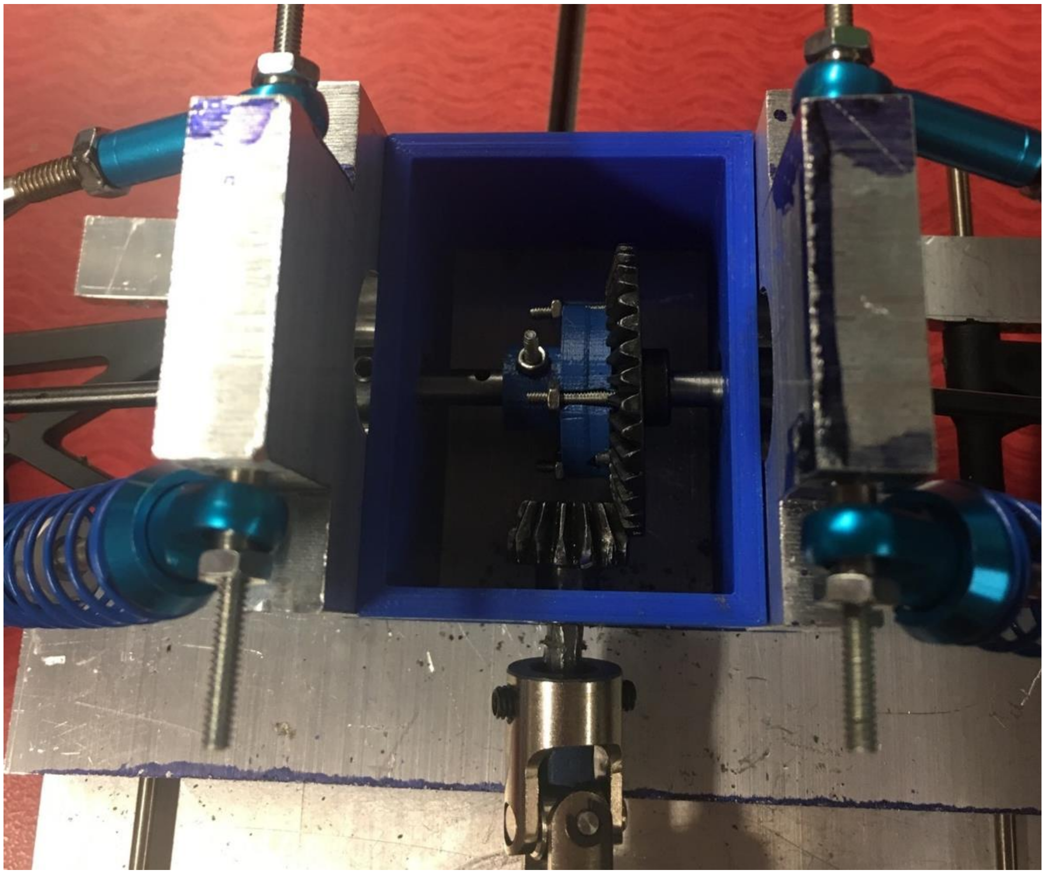


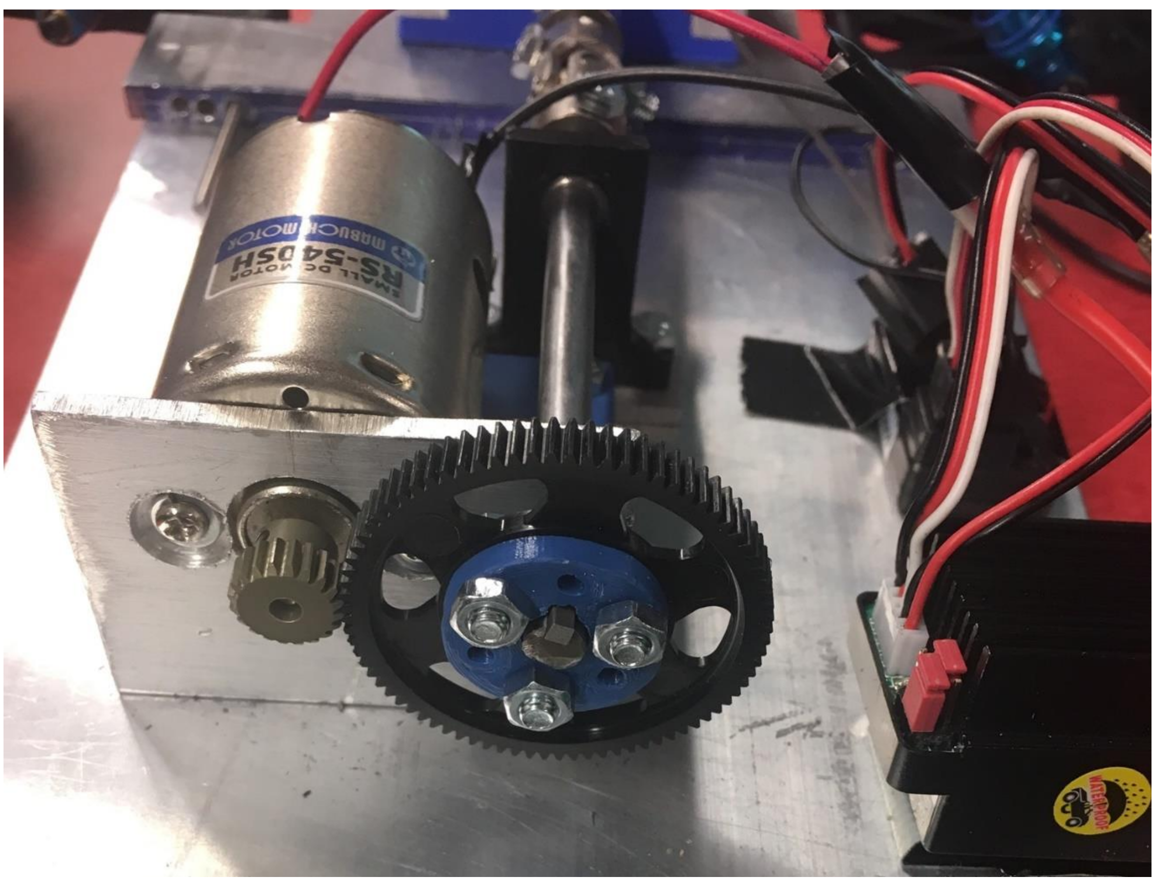


APPENDIX B19

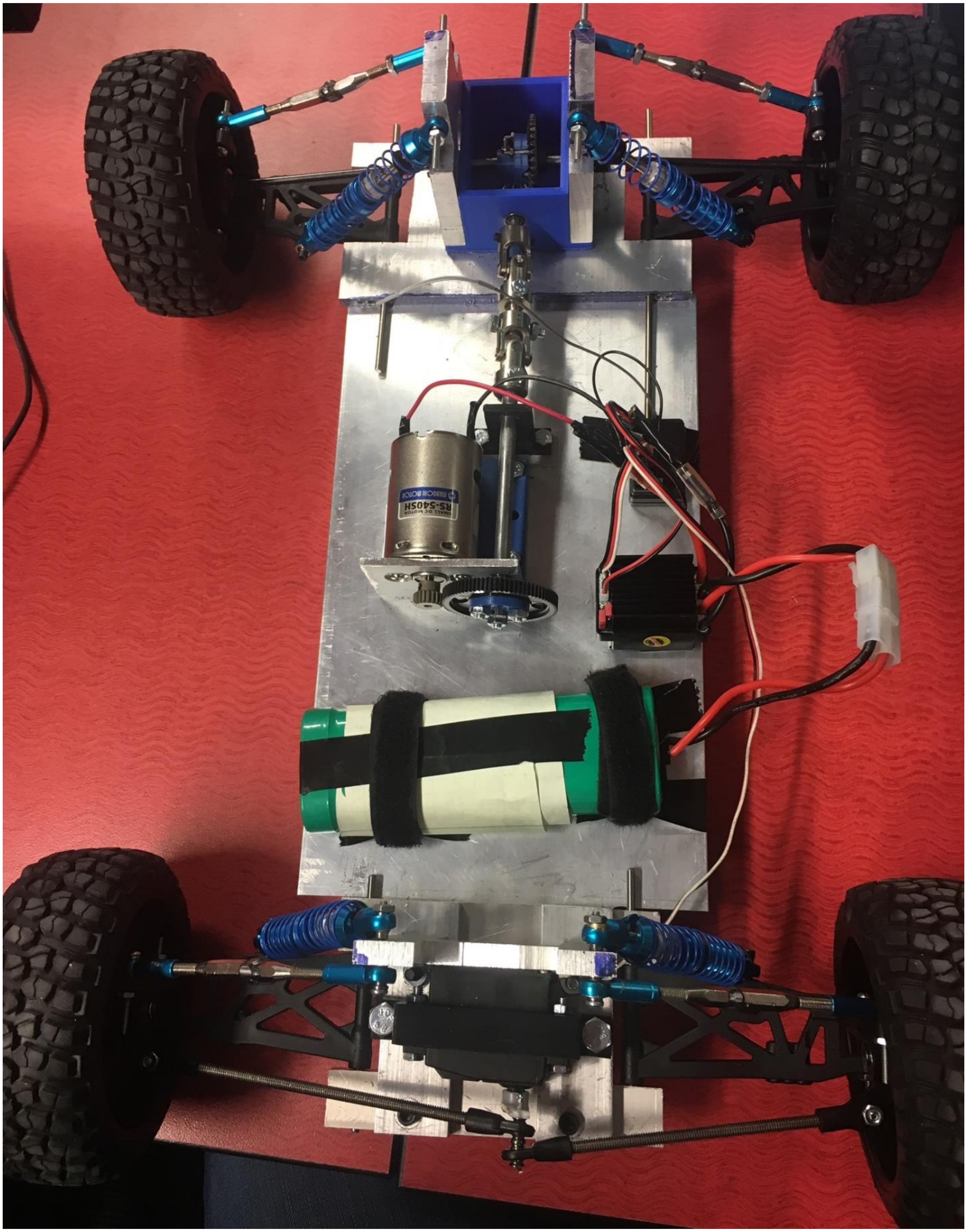


APPENDIX B20

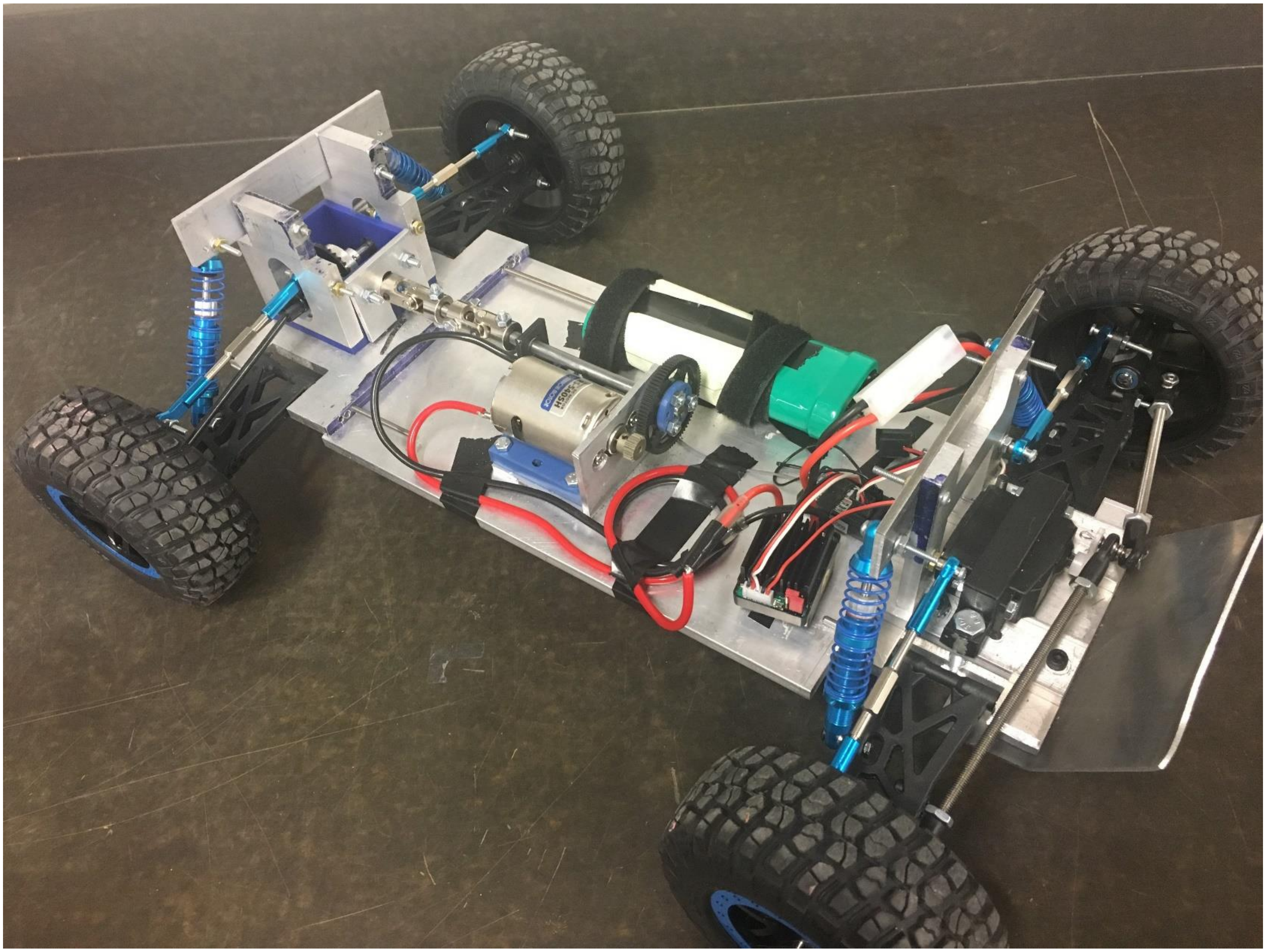




APPENDIX B21



APPENDIX B21



APPENDIX C

Part ID	Part Description	Part Quantity	Buy/ Mfg/ Print
1	Motor	1	Buy
2	Spur Pinion	1	Buy
3	Spur Gear	1	Buy
4	Bevel Pinion	1	Buy
5	Bevel Gear	1	Buy
6	Key	1	Mfg
7	Drive Shaft	1	Mfg
8	Driven Shaft	1	Mfg
9	Adapter Shaft	1	Mfg
10	Spur Bushing	1	Print
11	Bevel Bushing	1	Print
12	Bevel Pinion Sleeve	1	Print
13	Drive Cup	2	Buy
14	Bearing 1/4 X 3/8	2	Buy
15	Bearing 3/16 X 3/8	3	Buy
16	Bearing Housing	1	Print
17	Gearbox	1	Print
18	Motor Housing Base	1	Print
19	U-Joints	2	Buy
20	Shaft Sleeves	3	Mfg
21	Bolt M4x20	5	Buy
22	Bolt M4x10	3	Buy
23	Bolt M4x25	4	Buy
24	Bolt M2x12	5	Buy
25	Screw M3x5	2	Buy
26	Set Screw M3x4	1	Buy
27	Set Screw M4x5	4	Buy
28	Pin M3x 6	1	Buy
29	Motor Front Mount	1	Mfg
30	Bearing Housing Block	1	Mfg
31	Nut M4	12	Buy
32	Nut M2	5	Buy

APPEDIX D

Item ID	Item Description	Item Source	Brand Info	Model/SN	Price/Cost ($/Hour)	Quantity (hours)	Cost Subtotals
1, 25	Electric Motor	eBay	Mabuchi	RS-540	13.19	1	13.19
2, 26	Spur Pinion	Amazon	GoolRC	48DP 16T	1.8	1	1.80
3	Spur Gear	Amazon	Team Associated	TC6 80T 48DP	3.55	1	3.55
4, 5	Bevel Pinion and Gear	Active Powersports	HPI Racing	105551	21.99	1	21.99
6	Keystock	McMaster-Carr	McMaster-Carr	98830A050	0.94	1	0.94
7,8,9	0.25 Shaft	McMaster-Carr	McMaster-Carr	1327K66	16.45	1	16.45
10-12, 16-18	Printed Parts	CWU	MEC	PLA	1	12.46	12.46
13, 27	Drive Cups	Amazon	Redcat Racing	B00D25G9T6	7.99	1	7.99
14	Bearings 1/4	Amazon	Advantage Racing Products	R168-ZZ	0.99	2	1.98
15	Bearings 3/16	Amazon	TRBRC	TRB-100493	1	3	3.00
19	U-Joint	Amazon	uxcell	A16121400UX0550	8.65	2	17.30
20	Shaft Sleeves	MSC	Igus	MSI040504	0.65	2	1.30
21, 31	Bolt M4x10 + nuts	CWU	Fastenal	M4x10mm	N/A	N/A	0.00
22, 31	Bolt M4x25 + nuts	CWU	Fastenal	M4x25mm	N/A	N/A	0.00
23, 31	Bolt M2x12 + nuts	Amazon	uxcell	M2x12mm	0.04	10	0.40
24, 32	Bolt M3x5	CWU	Fastenal	M3x5mm	N/A	N/A	0.00
28	Pin M3x6	Amazon	uxcell	M3x6mm	0.17	1	0.17
29	Motor Front Mount	CWU	N/A	Aluminum	N/A	N/A	0.00
30	Bearing Housing Block	CWU	N/A	Aluminum	N/A	N/A	0.00
						Drivetrain Total Cost:	102.52
Non-Drivetrain Parts							
	Battery	Amazon	Powerextra	B01DZACEUA	15.99	1	15.99
	Motor ESC	Amazon	Hobbypower	B00DU49XXS	8.98	1	8.98
						All Parts Total Cost:	127.49

APPENDIX E1

Gantt Chart
X to indicate work

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

PROJECT TITLE: Mini Baja Drivetrain
Principal Investigator: Kyle Aitken

TASK: ID	Description	Duration Est. (hrs)	Actual (hrs)	%Com	S	October				November				Dec		January				February				March	April	May	June
1	Proposal																										
1a	Outline	1	1		X																						
1b	Intro	2	1			X	X																				
1c	Methods	2	1.5						X	X	X																
1d	Analysis	5	3								X	X	X	X													
1e	Discussion	5	2									X	X														
1f	Parts and Budget	5	3								X	X															
1g	Drawings	4	2									X	X														
1h	Schedule	1	3										X														
1i	Summary & Appx	4	2											X													
	subtotal:	29	18.5																								
2	Analyses																										
2a	Total Turn Ratio	0.5	1							X																	
2b	Gear Turn Ratios	0.5	1							X																	
2c	Speed Requirements	0.5	1							X																	
2d	Spur Pinnion Design	1	1								X	X															
2e	Spur Gear Design	1	1								X	X															
2f	Bevel Gear Pair	1	2									X	X														
2g	Shaft Torque	0.5	1										X														
2h	Shaft Forces	1	3										X														
2i	Bearing Forces	1	4										X	X													
2j	Shaft Minimum Diameter	1	2											X													
2k	Key Lengths and Stresses	1	2											X													
2l	Clearance Distance Between U-Joints	1	1												X												
	subtotal:	10	20																								
3	Documentation																										
3a	Part 1 Motor	1	0.5			X																					
3b	Part 2 Spur Pinnion	2	0.5			X																					
3c	Part 3 Spur Gear	2	0.5			X																					
3d	Part 4 Bevel Pinion	2	0.5				X																				
3e	Part 5 Bevel Gear	2	0.5				X																				
3f	Part 6 Key	1	0.5					X																			
3g	Part 7 Drive Shaft	1	1					X	X																		
3h	Part 8 Driven Shaft	1	1.5					X	X																		
3i	Part 9 Adapter Shaft	1	0.5						X																		
3j	Part 10 Spur Bushing	2	1							X	X																
3k	Part 11 Bevel Bushing	3	1							X	X																
3l	Part 12 Bevel Pinion Sleeve	1	1								X																
3m	Part 13 Drive Cup	1	2														X										
3n	Part 14 Bearing 1/4 X 3/8	1	0.5											X													
3o	Part 15 Bearing 3/16 X 3/8	1	0.5											X													
3p	Part 16 Bearing Housing	2	1								X																
3q	Part 17 Gearbox	3	4									X	X	X													
3r	Part 18 Motor Housing	2	1.5								X	X	X														
3s	Part 19 U-Joint	1	2											X	X	X											
3t	Part 20 Shaft Sleeve	1	1											X													
3u	Part 21 Bolt M4x10	1	0.5														X										
3v	Part 22 Bolt M4x10	1	0.5														X										
3w	Part 23 Bolt M4x25 + nuts	0.5	0.5															X									
3x	Part 24 Bolt M2x12 + nuts	0.5	0.5															X									
3y	Part 25 Bolt M3x5	0.5	0.5															X									
3z	Part 26 Set Screw M3x4	0.5	0.5																X								
3aa	Part 27 Set Screw M4x5	0.5	0.5																X								
3ab	Part 28 Pin M3x6	0.5	0.5															X									
3ac	Part 29 Motor Front Mount	2	2.5																		X						
3ad	Part 30 Bearing Housing Block	0.5	0.5																								
3ae	Part 31 Nut M4	0.5	0.5																								
3af	Part 32 Nut M2	0.5	0.5																								
3ag	ANSIY14.5 Compl*	4	2													X	X	X	X	X	X						
	subtotal:	43.5	31.5																								
4	Proposal Mods																										
4a	Project Drivetrain Schedule	3	3												X												
4b	Project Drivetrain Part Inv.	2	2													X											
4c	Crit Des Review*	4	3													X											
	subtotal:	9	8																								

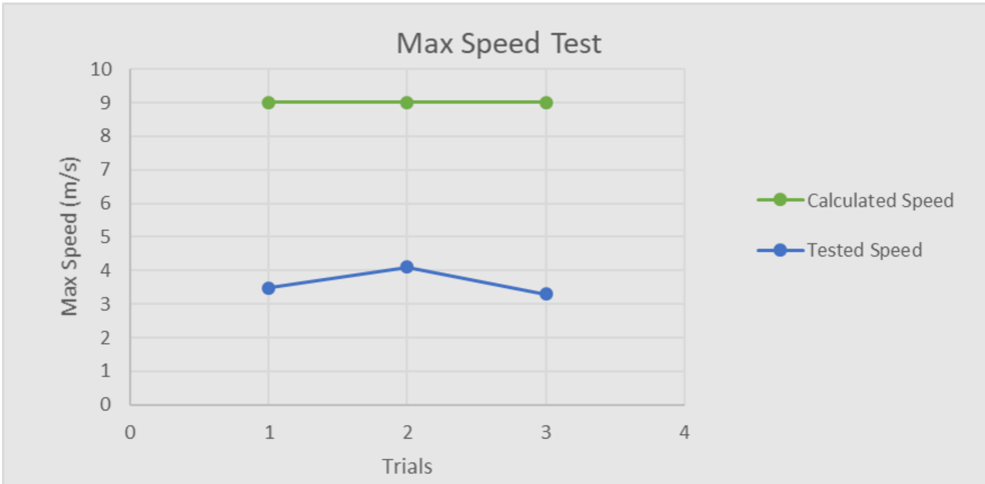
APPENDIX E2

5	Part Construction																																				
5a	Buy Part 1	0.5	0.5													X																					
5b	Buy Part 25	0.5	0.5													X																					
5c	Buy Part 2	0.5	0.5													X																					
5d	Buy Part 26	0.5	0.5													X																					
5e	Buy Part 3	0.5	0.5													X																					
5f	Buy Part 7	0.5	0.5													X																					
5g	Buy Part 8	0.5	0.5													X																					
5h	Buy Part 9	0.5	0.5													X																					
5i	Buy Part 19	0.5	0.5														X																				
5j	Buy Part 14	0.5	0.5													X																					
5k	Manufacture Part 18	1	0.5																	X	X																
5l	Manufacture Part 16	1	0.5																X	X																	
5m	Buy Part 6	0.5	0.5													X																					
5n	Buy Part 4	0.5	0.5														X																				
5o	Buy Part 5	0.5	0.5														X																				
5p	Manufacture Part 17	0.5	1																X	X																	
5q	Manufacture Part 10	1	0.5																X																		
5r	Manufacture Part 11	1	0.5																X	X																	
5s	Buy Part 13	0.5	0.5																	X																	
5t	Buy Part 27	0.5	0.5																	X																	
5u	Buy Part 15	0.5	0.5																	X																	
5v	Buy Part 12	0.5	0.5																X																		
5w	Buy Part 20	0.5	0.5																		X																
5x	Manufacture Part 6	0.5	0.5																	X																	
5y	Manufacture Part 9	1	1																	X	X																
5z	Manufacture Part 7	1	1.5																	X	X	X															
5aa	Manufacture Part 8	1	2.5																	X	X	X															
5ab	Buy Part 21	0.5	0.5																		X																
5ac	Buy Part 31	0.5	0.5																		X																
5ad	Buy Part 22	0.5	0.5																			X															
5ae	Buy Part 23	0.5	0.5																			X															
5af	Buy Part 24	0.5	0.5																			X															
5ag	Buy Part 32	0.5	0.5																			X															
5ah	Buy Part 28	0.5	0.5																		X																
5ai	Manufacture Part 20	0.5	0.5																				X														
5aj	Manufacture Part 29	1.5	2.5																				X														
5ak	Manufacture Part 30	0.5	0.5																				X														
5al	Take Part Pictures	0.5	0.5																				X														
5am	Take Construction Videos	0.5	0.5																			X	X														
5an	Update Website	0.5	0.5																		X																
5ao	Manufacture Plan*	1	2														X	X																			
	subtotal:	25.5	28																				◇														
6	Device Construct																																				
6a	Assemble Transmittion	2	3																																		
6b	Assemble Gear Box	2	3																			X	X														
6c	Assemble Drivetrain	2	4																			X	X														
6d	Assemble R/C Car	4	6																				X	X													
6e	Take Dev Pictures	0.5	0.5																					X													
6f	Update Website	0.5	0.5																					X													
	subtotal:	11	17																					◇													
7	Device Evaluation																																				
7a	List Parameters	1	1																									X									
7b	Design Test&Scope	5	4																									X	X								
7c	Obtain resources	1	0.5																											X							
7d	Make test sheets	3	2																											X							
7e	Plan analyses	2	1																										X								
7f	Test Plan	2	2																										X								
7g	Perform Evaluation	6	4																											X	X	X					
7h	Take Testing Pics	1	0.5																														X				
7i	Update Website	0.5	0.5																															X			
	subtotal:	21.5	15.5																															◇			
8	495 Deliverables																																				
8a	Get Report Guide	1	0.5																																		
8b	Make Rep Outline	1	1																													X					
8c	Write Report	4	2																													X	X	X			
8d	Make Slide Outline	2	1																																	X	
8e	Create Presentation	3	1																															X			
8f	Make CD Deliv. List	0.5	0.5																																	X	
8g	Write 495 CD parts	2	1																																	X	
8h	Update Website	1	0.5																																X	X	
8i	Project CD	1	0.5																																		X
	subtotal:	15.5	7.5																																		◇
	Total Est. Hours=	143.5	131			=Total Actual Hrs																															
Note:	Deliverables*																																				
	Draft Proposal	◇														◇																					
	Analyses Mod	◇															◇																				
	Document Mods	◇																					◇														
	Final Proposal	◇																	◇																		
	Part Construction	◇																							◇												
	Device Construct	◇																									◇										
	Device Evaluation	◇																																	◇			
	495 Deliverables	◇																																			◇

APPENDIX F

The principal engineer has expertise on the subject from experience in other MET courses. School resources can be used for this project but will most likely not be necessary.

APPENDIX G



Drag Race average velocity in the two attempts were 7.43 and 7.67 ft/s.

APPENDIX H

Max Speed Test

Trial #	Distance (m)	Time (s)	Velocity (m/s)
Trial 1	3		
Trial 2	3		
Trial 3	3		
Trial 4	3		
Trial 5	3		

Drag Race Speed Test

Trial #	Distance (ft)	Time (s)	Velocity (ft/s)
Trial 1	60		
Trial 2	60		

APPENDIX I

Test Report

Introduction:

- Requirements: The requirements of this project was to allow the device to drive and compete against other R/C cars.
- Parameters of interest: Speed, Functionality, off-road driving.
- Predicted performance: Speed was predicted with no losses but ended up being lower.
- Data Acquisition: Timed tests and completion tests.
- Schedule: The testing schedule is shown in the gantt chart in appendix B1-B2.

Method/Approach:

- Resources: For the competition space was needed for the events. The Fluke lab was used for the drag race and slalom, and the patio outside Hogue Hall was used for the mini baja. Volunteers were necessary for these events to officiate and keep time. Tape was used to mark the start and finish of the drag race and slalom, and 2 liter bottles were used as the obstacles for the slalom. Wood ramps were used for the baja course and stopwatches were used to record times.
- Data capture/doc/processing: Data was recorded in tables shown in appendix A.
- Test procedure overview: Resources need to be collected then trials need to be recorded.
- Operational limitations: Operations were limited by the maximum power output from the motor.
- Precision and accuracy discussion: The time was recorded with a precision of 0.01 seconds
- Data storage/manipulation/analysis: Time recorded, calculated with distance to determine average speed.
- Data presentation: Pictures and videos of testing are shown on the project website.

Test Procedure:

- Summary/overview: This test is to determine how fast the device drives the vehicle. In addition to this, it will also determine that the device functions.
- Specify time, duration: 4/8/19, 0.5 hours
- Place: Hogue Hall or outside. Any open area will work
- Resources needed: Tape, tape measure, stopwatch
- Specific actions to complete the test
    - Step 1: Find area to do test
    - Step 2: Measure out 10 meters and mark with two pieces of tape
    - Step 3: Set up R/C car about 10 meters in front of the first marker
    - Step 4: Turn on car and controller
    - Step 5: Gradually accelerate until it reaches maximum speed
    - Step 6: Start stopwatch when front wheels reach first marker and stop time at the second marker
    - Step 7: Calculate speed by dividing the 10 meters by the time recorded

- Step 8: Repeat steps for at least three trials to get reliable results

- Risk, safety, evaluation readiness: There is low risk in operating an R/C car with no serious safety hazards involved
- Discussion: The speed the vehicles drives needs to be tested in order to race at a competitive speed. After this test, modifications can be made to drive at a more optimal speed.

Deliverables:

- Parameter values: Successfully drove in events, Successfully drove through off-road terrain.
- Calculated values: Speed test average of 3.63 m/s and drag race test average speed of 7.55 ft/s.
- Success criteria values: Functioning, driving off-road, competing in speed test.
- Conclusion:

The first test that was done was the maximum speed test. The results from this test were lower than the expected speeds because the device was unable to convert the full rotational speed of the motor to the axles without skipping teeth and falling out of alignment in the gearbox. There was also a part failure in this test with the plastic bushing breaking where it held the bevel gear to the driven shaft. This was due to a stress concentration in the geometry of the part and a large amount of torque in that area so to reinforce this a strong epoxy was used. Also the bearing holding the bevel pinion in the gearbox came out due to the high rotational speed. This was corrected by making a new part out of aluminum to cover the outer ring of the bearing and hold it in place. After this test there were also modifications made to the project covering frame and suspension to correct the angle of the wheels putting less stress on the drivetrain. With these corrections being made, the speed will be tested again to compare results and see if there has been improvement to get the speed closer to the predicted value.

The second test was the acceleration test. This tests how well the drivetrain gets the vehicle up to its max speed and maintains that speed for an extended distance. Since manufacturing improvements were being made up until the competition to make sure it worked, it was just tested for functionality in a 60 feet drag race and then the results were recorded from the event. The expected results were slower than the max speed test since this one had to start from rest, but it ended up only being slightly slower due to the improvements made.

The device was also tested for functionality on off-road terrain during the event. The off-road terrain provides a challenge for the drivetrain because of an increase of friction compared to smooth flat surfaces because the same amount of power transferred to the axles will not drive it as fast. In the Mini Baja course there was a section with a ramp going onto a slight downhill covered in bark. This test was not results based since it was just a success or fail outcome. The car drove through the bark obstacle in a practice run and in the competition making it a successful test.

APPENDIX J

JOB HAZARD ANALYSIS

{Insert description of work task here}

Prepared by: Kyle Aitken	Reviewed by: Approved by:

Location of Task:	Machine Lab
Required Equipment / Training for Task:	Basic Machining Training
Reference Materials as appropriate:	Machine Elements in Mechanical Design- Mott

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
	Machining	**Using high powered machines to cut materials**	

APPENDIX K

KYLE AITKEN
| 209 E. 14th Ave. #29 | Ellensburg, WA 98926 | AitkenK@cwu.edu | (206) 650-0047 |

OBJECTIVE

A position working as an Engineer in order to grow professionally

EDUCATION

Bachelor of Science in Mechanical Engineering Technology Exp. Spring 2019
Specialization: **Design**
Central Washington University, Ellensburg WA

Achievements/Activities

Dean's List Winter 2018, Spring 2018
ASME Club 2017 - 2019
Fundamentals of Engineering Exam Exp. Summer 2019

SKILLS

Auto-Cad
Microsoft Excel
SolidWorks
Machining
Dynamics: Thermo/Fluid
Physics and Statics
Strengths of Materials

EXPERIENCE

Capstone Project Fall 2018 – Spring 2019
Mini Baja R/C car
Drivetrain Assembly

Mukilteo Water & Wastewater District (Summer Employee) 2015-2018
Operate and repair on JLG lift
Inspect and operate hydrants
Assisted installation of water meters
Used GIS mapping system
Landscaping
Worked on different teams

References available upon request