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ASME Mini RC BAJA: Drivetrain

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By

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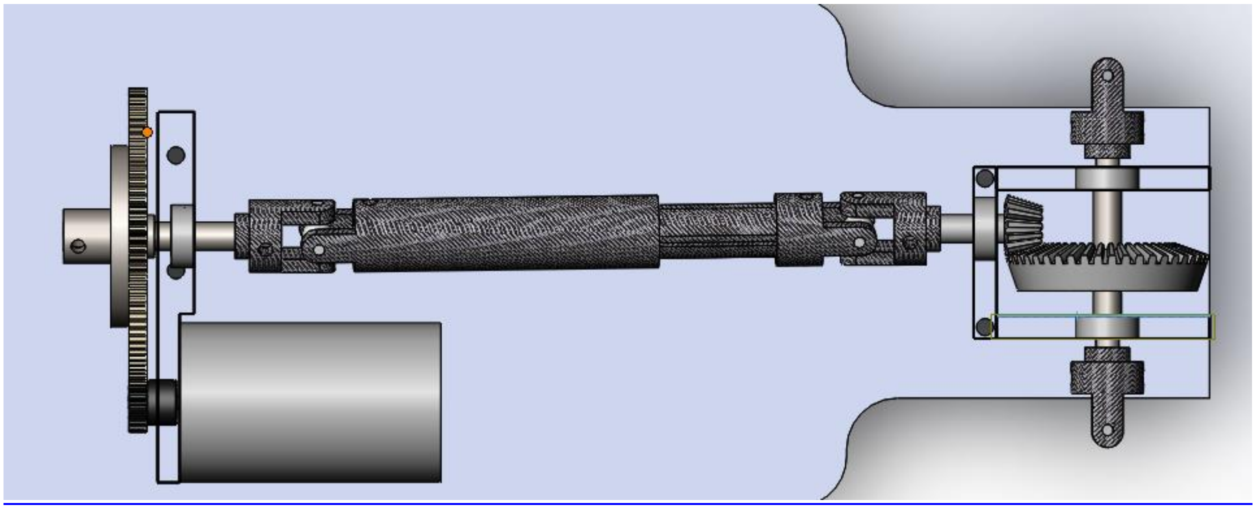

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INTRODUCTION

Problem/Motivation:

Every year ASME hosts an RC Baja contest that prompts engineering students to design, build and test an RC car. After the engineering process, the students compete against other teams in the region. In the 2014/2015 academic year, a team from Central Washington University designed a car to compete and ended up taking home the trophy. Although the Central team won, their car barely made it through the obstacles in the race. There were problems with the drive train and steering and suspension systems. These problems have prompted a team from this year's engineering class to redesign the entire RC car with emphasis on these systems.

This year's team consists of two engineers, Mike Cox and Jason Moore. A spare chassis from the previous team's car was graciously donated by Nathan Wilhelm for the engineers to start with. The goal is to design the new systems to fit onto this chassis. Mike Cox will be designing and constructing the steering and suspension systems while Jason Moore will be designing and constructing the drive train. The majority of this report will focus on the drivetrain of the RC car. The specific problem that this report is concerned with is that the new RC car needs a strong and durable drive train system that is capable of propelling the vehicle forward through various obstacles.

The motivation behind this project comes from Jason's interest in cars and the systems the propel cars and allow them function properly. This project will allow this engineer to further explore these interests and see what the engineering process behind these systems is all about.

Function Statement:

The drivetrain must be able to propel the vehicle forward without any problems and must be easy to assemble.

Requirements:

The following is a list design requirements for the drivetrain:

- Produce an output speed of 530-620 RPM or 25-30MPH for a tire that is 3 inches in diameter.
- The drive train can weigh no more than 3lb including the weight of the electric motor.
- The entire drive train system can cost no more than $250.
- The entire drive train must fit within a volume of 6.5x3x3 in^3.
- Must only use one brushed or brushless electric motor to propel the vehicle. Refer to appendix F section 4.2.
- Use only one 7.2 volt, 6 cell battery pack to propel the vehicle. Refer to appendix F section 4.2.
- The drivetrain assembly must be able to be assembled in less than 5 minutes when all the subassemblies are built.
- The Drivetrain must be able to be disassembled in less than 5 minutes when all the subassemblies are built.

Engineering Merit:

The engineering merit of this project comes from the analysis and design of the drivetrain. The drivetrain will require velocity ratios, torque, tangential force, allowable bending stress and allowable contact stress calculations for both spur and bevel gear designs. The main equations that will be used for gear optimization are Bending Stress (S_t) and Contact Stress (S_c) Numbers for both the bevel and spur gears.

For spur gears: $S_t = \frac{W_t P_d}{FJ} K_o K_s K_m K_B K_v$ and $S_c = C_p \sqrt{\frac{W_t K_o K_s K_m K_B K_v}{F D_p I}}$.

For bevel gears: $S_t = \frac{W_t P_d K_o K_s K_m K_v}{FJ}$ and $S_c = C_p \sqrt{\frac{W_t K_o K_m K_v C_s C_{xc}}{F D_p I}}$.

Also the weight of the drive train system will need to be designed in a way that distributes the weight more evenly on the rear half of the car instead of the rear axle. There is opportunity for optimization in the drivetrain design in the ways stated above.

Success Criteria:

The success criterion for this project depends on how well the drivetrain meets the following criteria:

- Is less than 3lbs
- Cost less than $250
- Fits within a volume of 3x3x6.5 in^3

This drive train will be considered a success if it meets the above requirements while also propelling the vehicle through that various stages of the RC Baja race without any failures.

The scope of this effort:

The scope of this project is the design and manufacture of the drivetrain for the RC car that is compliant with the ASME mini RC Baja Regulations. Mike Cox will focus on the steering and suspension aspect. The ultimate goal is to produce an RC car that performs well during the mini RC Baja competition.

Success of the project:

This project will be a success if the drive train system and the steering and suspension systems can come together and be assembled on the chassis without conflict. Further the success of this project depends on if these systems perform well and in unison to propel the car through the entire length of the mini Baja race.

DESIGN & ANALYSIS

Approach: The approach includes designing all the components necessary for a drivetrain. These components include the driveshaft, a spur gear reduction, a bevel gear reduction and the appropriate mounts. Once the design is finished, the components will be bought and manufactured from raw material and mounted on the chassis.

The engineering merit of this project can be exemplified through the use of a metric developed at CWU: RADD or Requirements, Analysis, Design and Drawings. For example, consider the requirement: the drivetrain must produce an output speed of 25-30MPH. To analyze the drive train to suit this requirement includes using velocity ratio, VR, and train value, TV, equations.

1. $VR = \frac{input\ RPM}{output\ RPM} = \frac{\#\ of\ Teeth\ in\ Gear}{\#\ of\ Teeth\ in\ Pinion}$

2. $TV = VR_1 * VR_2$

“The velocity ratio is the ratio of the rotational speed of the input gear to that of the output gear,” (Mott, pg302). Refer to figure 1 in appendix A which shows the VR and TV calculations. To find the VR to meet the 25-30MPH requirement requires a rotational speed. So after converting MPH to RPM using appropriate conversion factors, the equivalent rotational speed is 535RPM. Using this RPM as the output RPM and the input speed of the electric motor which is 17,500RPM, the velocity ratio can be calculated. Using the above equation, the velocity ratio comes to 31.7. This ratio translates to the design phase because standard gear sizes that are readily available must be used and the ratio of the number of teeth in the gear to that in the pinion must be less than 31.7. If this is achieved then the tires will spin at 30MPH or more. If the ration of number of teeth is more the 31.7 then the tires will spin at less than 30MPH. This design then translates into drawings of the actual gears used in the gear train and their specified number of teeth.

Description:

Figures 7 and 8 show the initial sketches of the entire assembly. Figure 7 shows the initial sketch of the titan 380 assembly which is the spur gear set with the motor and motor mount. Figure 8 shows the initial sketch of the bevel gear assembly with all of its respective compononents. Figure 9 shows a top view of the entire model and the final assembly. The final assembly consists of 3 main subassemblies including the bevel gear assembly as shown in figure 11 titan 380 assembly as shown in figure 12 and the driveshaft assembly as shown in figure 13.

Benchmark: The benchmark of this project is the previous year’s mini Baja RC car and another professionally manufactured RC car. The new car will be compared in various categories including:

- Speed
- Size
- Weight
- Cost

Performance Predictions: The drivetrain will be able to propel the RC car forward at 25 to 30 MPH with an applied torque to the wheel and tires of no more than 30lb-in.

To meet the 25-30MPH requirement standard gear sizes need to be implemented into the design to ensure availability and to keep cost down. As determined above in the RADD example, the product of the velocity ratios of the gear sets needs to be less than 31.7. To achieve this, an 18/96 tooth spur gear set and 15/45 tooth bevel gear set was used in the design. These gear sets give velocity ratios of 5.3 for the spur gears and 3.0 for the bevel gears. Normally an integer velocity ratio is not desired because of uneven wear. However, due the drive train’s short design life of only 10 hours max, wear is not an issue in this application. Using these selected gear sets, the TV comes out to be 15.9 which is less than 31.7 so this is acceptable.

Description of Analyses: The following is a list of each calculation found in figures 1 – 13 in appendix A.

1. The pinion spur gear analysis was broken up into different independent calculations with the purpose of making it more understandable. The bevel gear and the plastic spur gear analysis spreadsheet in figures 11 and 12 underwent nearly the same analysis only they

were done using a spreadsheet provided by R.L. Mott. Figure 2 shows the pitch diameters, center distance and gear teeth calculation for the both the pinion and gear for the spur gear set. The given information came from product specifications or previous analysis i.e. green sheets. The answers are highlighted and the equations relating these variables include: $\frac{N_g}{N_p} = \frac{n_p}{n_g}$ for the # of gear teeth, $D_p = {N_p}/{P_d}$ for the pitch diameter and $C - C = {N_g + N_p}/{2P_d}$ for the center to center distance of the pinion and gear.

N_g = # of gear teeth, N_p = # of pinion teeth, n_g = gear rpm, n_p = pinion rpm, D_p = pitch diameter and P_d = diametral pitch.

Using these equations, N_g = 96 teeth, D_p =0.375 inches, D_g = 2.0 inches and C-C = 1.19 inches.

2. Figure 3 shows the pitch line speed and the transmitted load calculations for the pinion spur gear. The pitch line equation is $V_t = {3.14 D_p n_p}/{12}$ and the transmitted load equation is $W_t = {33{,}000 * PWR}/{V_t}$. Using these equations and the known information, V_t = 1718 ft/min and the transmitted load is 10 lb.
3. Figure 4 shows the bending stress analysis of the pinion gear. The bending stress equation as previously stated is $S_t = \frac{W_t P_d}{FJ} K_o K_s K_m K_B K_v$. The K factors are found using figures in Mott's book. The bending stress comes out to be 9,537psi. This stress number is well within the appropriate range according to Mott.
4. Figure 5 shows the contact stress number which was determined using the equation $S_c = C_p \sqrt{\frac{W_t K_o K_s K_m K_B K_v}{F D_p I}}$. The contact stress was calculated to be 75,489psi. This contact stress is also within the appropriate range.

   Figures 1-5 are all relevant to ensure proper function of the drivetrain. The main points to note are the bending and contact stresses which require all of the previous analysis. If either of these numbers are too high then the gear teeth will fail causing a catastrophic failure of the entire drivetrain.
5. Figure 6 shows the analysis of the forces acting on the gear teeth. These calculations are needed for the set screw pin analysis in figure 7. Figure 6 uses simple trigonometry to determine the radial force (Wr) and the normal force (Wn). The transmitted load (Wt) was found in previous analysis. The angle is the pressure angle of the gear which is 20^o and this is a characteristic of standard gears. Using the given information, Wr = 5.5 lb and Wn = 10 lb.
6. Figure 7 shows the set screw analysis. The set screw pin was analyzed to see what the shear stress is. The shear stress equation is $\tau = F/A_s$. Using this equation the shear stress came out to be 0.0219Psi which is well under the material yield strength of 36Ksi.
7. Figure 8 shows the front spur gear shaft analysis which is being analyzed to find the max bending and shear stresses acting on the shaft. The torsional shear was 6661Psi and the bending stress was 74.6Psi and the vertical shear was 482Psi. All of these stresses are less than the material yield strength.
8. Figure 9a and 9b show the rear output shaft analysis to see the max bending and shear stresses acting on it. The main equations for this analysis are σ_{max} = MC/I for max bending stress, τ = VQ/IT for max vertical shear and τ = TC/J. The analysis yields a

bending stress of 165psi, a vertical shear of 43psi and a torsional shear of 6567psi. These stresses are less than the material yield strength of 71,000psi indicating the part will not fail under normal conditions.

9. Figure 10 shows the main drive shaft shear calculations to analyze the applied torque acting in it. Using similar equations as figure 8a and 8b, the torsional shear was 1780psi which is less than the material yield strength of 21,000psi indicating that it will not fail under normal conditions.
10. Figure 11 shows bending stress analysis for the plastic spur gear that will mate with the metal pinion. This analysis was completed using a spreadsheet provide by Mott and includes the same steps as explained above in steps 1 through 4. The bending stress came out to be 3652psi which is appropriate.
11. Figure 12 shows the bevel gear analysis using a similar spreadsheet. Again, this spread sheet covers all of the steps outlined above with small differences in the equations. The bevel gear spreadsheet shows the contact stress and bending stress and the equations are stated above in the “engineering merit” section. The bending and contact stresses in the pinion bevel gear are 15,205psi and 116,880psi. For the gear, the bending stresses come out to be 25,000psi.
12. Figures 13 and 14 show more forces acting on the spur gears and bevel gears. The important aspect here is the on shaft torque produced by the gears. The pinion spur gear shaft has an applied torque of 2 lb-in and the bevel gear shaft torque is 9.6 lb-in. These are important values because the requirements of this project state that the drivetrain can produce no more than 30lb-in of torque. Figures 13 and 14 show that the output torque meets this requirement.

Scope of Testing and Evaluation:

For the testing phase of this project, the idea is to assembly all the components to see they can indeed be assembled with relative ease. This is an important aspect because if a part malfunctions during race day, the part should be able to be easily replaced and the problem fixed. For the evaluation phase, the RC car will be tested on a test course that the student engineers will make up. The test course will include inclines, jumps, drops, bumps and various corners. The performance of the RC car will be evaluated on this test course.

Analysis:

i. The approach to this design consists of considering how many gear reductions are needed and how much space the drivetrain can take up. As previously stated, there will be two gear reductions.
ii. The first step of the design is to take the input speed and apply a gear reduction to a driveshaft shaft.
iii. The third step is applying the final gear reduction from the drive shaft to the rear axle.
iv. Calculated Parameters: One of the biggest parameters of the design is the space available. The drivetrain needs be small and compact as there are other components that need to be attached to the chassis. Because of this, bevel gears are needed to change the direction of the output to allow for the optimization of space.

v. Device Shape: The chassis is long and narrow which is why space is limited. With the use of a drive shaft, the bevel gears can be arranged in a manner that will take advantage of the available space.

vi. Tolerances, Kinematics, Ergonomics: The tolerances for the gear train need to be fairly precise to allow for proper operation and to prevent interference which may result in binding and also to prevent excessive backlash. The tolerances are shown in every drawing in appendix B. Some of the kinematics include the forces acting on the drive shaft as well as the secondary shaft that will be supported with bearings. Refer to the description of analysis.

Technical Risk Analysis, Safety Factors, Operation Limits:

The major risks of this project are time and cost. This project has a budget and it must be kept for the simple reason that no more money will be allotted to this project than what has been budgeted already. The schedule is also very important. The ASME competition is sometime in March and if the vehicle is not ready by this time, then this project will be a failure.

The RC drivetrain will be designed with a safety factor of 1 as this device is not supporting a person any way nor is anyone's life dependent on this car so there is no need to go beyond 1. The operational limits are important as well. The vehicle only needs to go 30MPH at most. Therefore any speed beyond this is unnecessary.

METHODS & CONSTRUCTION

Construction: The construction of the drivetrain for RC car will consist of mainly two sub-assemblies. The first sub-assembly will consist of the spur gear reduction and the second sub-assembly contains the bevel gear reduction. Refer to appendix B for general sketches of these two assemblies.

i. Description: Both sub-assemblies will have some parts that are made and some parts that are bought. The student engineer will produce the mounts for the motor, gears and driveshaft. The driveshaft, gears and bearings will be designed to standard and then purchased from an appropriate vendor. The ASME RC Baja Contest Rules permit the use of "purchased commercially available" components. See appendix F section 4.3.
   a. The spur gear sub-assembly will be made up of the following components:
      1. motor
      2. Pinion spur (48P 18T)
      3. Gear spur (48P 96T)
      4. Motor Mount
      5. Spur Gear shaft
      6. Spur Gear Adapter
      7. Bearings
      8. Necessary hardware
   b. The bevel gear sub-assembly will be made up of the following components:
      1. Pinion bevel gear
      2. Bevel gear
      3. Bevel gear mount
      4. Bevel gear adapter

5. Output shaft with universal joints
6. 2 sliding drive shafts with universal joints
7. Bearings
8. Necessary hardware

ii. Resources: The resources needed to produce the necessary components in these sub-assemblies include the rapid prototyping machine, milling machine, drill press and various hand tools. Most of the components were printed on the prototype with the exception of the two steel shafts. The shafts had to be machined on a mill. The hardest part about this process was determining how to secure the work on the mill in a manner that would allow the engineer to take the necessary cuts. After some time, a three jawed fixed chuck was used.

iii. Drawing Tree, Drawing ID's:

Refer to figure 15 in appendix B for a drawing tree containing all the assemblies and individual components that will make up the RC drivetrain. The motor mount is one of the most crucial elements of the entire drivetrain. This is because the location of the shaft holes for the motor shaft and the gear shaft must be a proper distance away from each other to allow for proper meshing of the gears (center distance). Since the student engineer will be manufacturing this part, constant monitoring of dimensions will be crucial.

The bevel gear mount is also a crucial component for similar reasons. If the mount is to successfully allow the rear bevel gears to mesh properly then these dimensions must also be monitored during the machining process.

The drawing tree is organized starting with the final assembly and then working its way down each sub-assembly. There are 24 items in the tree and each item has its own part number and/or drawing number.

iv. Parts list and labels:

Table 1 in appendix C shows a list of all the required parts for this project along with the quantity and drawing numbers. The list includes 20 parts. Some of which have part numbers and some have drawing numbers. If the item has a part number then it will be bought and if it has a drawing number then it will be manufactured. One item has a part number and a drawing number which means that it will be bought and then modified.

v. Manufacturing issues: The major manufacturing issue is time. The entire car must be built and tested by March. March is when the ASME competition is, although the exact date has not been released yet. This is why most of the tasks on the schedule don't exceed into March. Refer to table 3 in appendix E for the Schedule.

Other than time, there were issues with some of the 3-D printed parts in the steering and suspension systems. The All-Mount sheared twice where the A-arms connect to it. This was after the dimensions and geometry had been redesigned to produce the most strength for the available room. After some investigation, it was determined that the 3-D parts were full of small voids where they sheared and it was realized that the prototyper could not be used to produce the parts that were needed. Instead, an aluminum replacement part was machined and installed and is sufficient. This was the most major issue that occurred simply because it kept happening and it pushed the testing back a week.

Another general issue that manifested was simply working with plastic parts. Some plastic parts, both printed and purchased, had to be machined. The issue is that plastic parts are not very rigid which made machining rather difficult in some cases particularly with thinner plastic parts such as the spur gear in the front gear reduction.

vi. Discussion of assembly, sub-assemblies, parts, drawings (examples): The following is a list of each sub-assembly and the components to be manufactured. The exploded views include BOMs which show all the parts for that assembly.

1. Figure 19: This is the final assembly, with the bevel gear assembly and the spur gear assembly. These two assemblies are attached to the chassis with bolts and connected together with a driveshaft.
2. Figure 19.1: This is chassis pan drawing which shows the location of the mounting holes that need to be machined.
3. Figure 20: This is the bevel gear assembly which shows all the components for this assembly.
4. Figure 20.1: The bevel gear mount is shown here. This part will be 3-D printed at Central Washington University. The location of the bearing holes is crucial and must be monitored during the manufacturing process.
5. Figure 20.2: The bevel gear shaft is a fairly simple piece. It will be machined from 6mm round stock supplied by Central Washington University.
6. Figure 20.3: The bevel gear adapter will also be printed and it will attach the spur gear to the spur gear shaft.
7. Figure 21: This shows the spur gear sub-assembly exploded view with all the parts and components.
8. Figure 21.1: The spur gear mount will be printed. This part will support the motor and spur gear.
9. Figure 21.2: This shows the spur gear shaft which will be machined from 6mm round stock.
10. Figure 21.3: The spur gear adapter will attach the spur gear to the spur gear shaft.
11. Figure 21.4: The spur gear needs to be modified and have holes drilled to attach to the spur gear adapter.

TESTING METHOD

Introduction:

The RC car will be put through multiple tests upon its completion to see where it ranks in three major categories including speed, assembly time, weight and size (volume). The testing will take place in Hogue building on the campus of Central Washington University.

Method/Approach:

The following list goes into detail about the expectations for each category as well as how the testing will be performed.

1. Speed: The RC car will be tested for this characteristic by measuring its speed. The speed will be calculated by measuring the time it takes the RC car to go a set distance. This can only be done by allowing the car to accelerate to a constant speed before timing it. The target is at least 25MPH. Maneuverability will be measured next. This includes measuring the car's ability to handle sharp-radius turns with the purpose to see if the car is easy to control. This will be measured by seeing how fast the car can run down a line of cones spaced at equal distances.
2. Weight: This category refers to the weight of the drive train and not the weight of the entire car. To measure the weight of the drive train, it will be fully assembled including the spur gear and bevel gear assemblies, the driveshaft and any other components that were used in its construction. If the weight of the drive train is 3lb or less, as per requirements, then this part of the test is a success. It's important to note that the weight of the drivetrain does not include the chassis. This testing will be performed in Hogue using a simple scale to measure the drivetrain.

Test Procedures:

Below is a list of the test and procedure that will be performed at each location.

<u>Speed: Hogue Hall, Fluke Lab: Reference Table 4 and 4.1 in Appendix G</u>

1. Measure out a 20ft distance with a tape measure and put tape markers at 0ft and 20ft. Allow for 10ft before the 0ft marker location for acceleration.
2. Have one partner stand upstairs with a stopwatch, overlooking the 20ft distance.
3. Accelerate the RC car to a constant speed before the 0ft location.
4. Once car is at constant speed, record the time it takes for the car to span the 20ft distance.
5. Calculate the MPH that the car reached using the general equation Speed=distance/time and apply the proper conversions.
6. Repeat steps 3-5 while slowly increasing the speed until the car reaches at least 25MPH.
7. Measure and record in excel spreadsheet.

<u>Weight: Hogue Hall, Fluke Lab: Reference Table 6 and 6.1 in Appendix G</u>

1. Assemble the entire drivetrain assembly
2. Weigh entire assembly not including the chassis.
3. Record weight in excel spreadsheet.
4. Repeat three times for accuracy and find an average value.

<u>Volume: Hogue Hall, Fluke Lab: Reference Table 7 and 7.1 in Appendix G</u>

1. Measure overall height.
2. Measure overall width.
3. Measure overall length.
4. Calculate total volume.

<u>Assembly & Disassembly: Hogue Hall, Fluke Lab: Reference Table 8 and 8.1 in appendix G</u>

1. Start the timer and begin disassembly of the drivetrain.
2. Stop the timer when disassembly is complete.
3. Record time.
4. Reassemble drivetrain and record the time.
5. Stop the timer when reassembly is complete.

6. Record time.
7. Repeat 3-4 times and record data in excel spreadsheet and calculate the average time.

Deliverables:

Appendix G shows the testing data tables for all of the procedures outlined above. These tables will be filled out as the testing progresses. Once they are filled out, the information will be analyzed and included in the final testing report which will be added to appendix H.

BUDGET

This project is being funded by the student engineer Jason Moore and a set amount of $250 has been allotted for the drivetrain. Table 2 in appendix D shows the budget with data including price, quantity, estimated total price, actual total price and a description of each component of this build. After finding all the parts the estimated total cost was $185.51 however the actual price after buying the components is $196.27 which is over the estimated price but still within the budget.

The budget stems from motor and esc components that are critical to the RC car. It was originally thought that a brushless motor and ESC package was to be used which ranges from $100 to $400. Now however, a brushed system is being considered which range from $12-$80 for a motor and $40 to $100 for an ESC. The motor and ESC are the most expensive components in the drivetrain which is why the budget was based off of them.

SCHEDULE

The schedule is outlined in Appendix E. It is organized by task and date and the dates are in week long increments. The proposal makes up the first quarter of this academic year while the second quarter consists of building and testing. Normally the testing would be done in the third quarter but the ASME competition is in March so everything must be ready by then. This is why most tasks are completed by March on the schedule.

The first quarter consists of the proposal which is broken up into two main parts which are included in the schedule as well. These parts are the analysis and documentation. These are included in the schedule because these parts are estimated to take the most amount of time of all the tasks in the proposal. The documentation includes all of the drawings while the analysis is every calculation that needs to be performed. The total estimated amount of time the proposal will take including the documentation and analysis is 75.5 hours.

The second quarter will be the building phase and testing and evaluation phase. This is where the components need to be manufactured and assembled. This quarter is crucial and everything must be completed by March or this project will be a failure. For this reason, the schedule must be followed with precision to make sure deadlines are met.

After the ASME competition, the Source presentation will be the only thing left and the student engineer will have most of third quarter to modify the presentation from the ASME competition to suit the requirements of the Source Guidelines.

PROJECT MANAGEMENT

Human Resources: The student engineer, Jason Moore, will act as project manager, engineer and machinist. His responsibilities include designing and analyzing the various components, ordering the raw materials and necessary parts including the hardware, machining the components and also recording and tracking all ordered parts while maintaining the budget.

Physical Resources: The machining will be done in the machine shop in Hogue Hall. This machine shop has multiple lathes and various mills to perform the necessary machine work. This shop also has an assortment of measuring tools and devices to ensure the quality of the work being done.

Soft Resources: All of the design work will be performed using Solid Works 2015 which is a 3-D design software. With this software, the drive train can be modeled entirely and drawings can be made of all of the parts and assemblies.

Financial Resources: This project will be financed by the student engineer and a budget of $250 has been set as previously discussed.

DISCUSSION

Throughout the course of this project, many decisions had to be made about the design of the drive train. From the beginning a design that incorporated a driveshaft was desired and this characteristic never changed. However, the actual design did change. It was originally thought that three gear reductions with smaller gear pairs were needed. The resulting train value of these gear pairs came out to around 15. When attempting to incorporate 3 gear pairs and a main driveshaft into the space requirement, a space issue became apparent and it was realized that bevel gears were needed. Using 3 sets of bevel gears however, complicated the design and made the process more difficult overall.

After further research though, it was determined that the same train value could be achieved with only two gear sets. One spur gear set and one bevel gear set. One bevel gear set was going to have to be incorporated to transfer the output direction in the rear open differential and this was inevitable from the beginning. Using this design, the train value comes out to 15.9 which is close to the train value of 15 for the original design with three sets of bevel gears. This design is more practical due to its simpler construction with fewer components and so this project evolved around this.

One of the more difficult challenges was choosing the right motor for this application. It came down to two motors. One is a 380 12 turn electric motor and the other is a 550 19 turn electric motor. The 550 motor is a dimensionally bigger motor with the advantage of providing more torque then the 380. The 380 provides less torque but it has the advantage of being a smaller size. Both are relatively cheap at less than $20 for each. It’s difficult to determine the amount of torque need in an RC car since the load is constantly changing so more torque would be better but motors with more torque require more space. Fortunately, the bigger 550 motor can be managed in the design and still meet the space requirement so this was the motor that was chosen. The space requirement comes from the chassis that is being used which is long but relatively narrow which made this decision difficult. At the time, gear sizes were still being determined and so the center distance between the two mating spur gears was unknown. This was an issue simply because the 550 motor will only meet the space requirement if the center distance of the gear pair was less than 1.2 inches. Luckily it came out to be 1.18 as shown in Figure 1 in appendix A.

This tie's into a simpler task of choosing the mating gears. This process actually came before choosing the motor. Robert L. Mott provides spreadsheets for various types of gears including spur gears and bevel gears. Theses spreadsheets calculate many variables including but not limited to: output speed, center distance, face width, and bending and contact stresses with very few inputs. With such a valuable tool, calculating these variables for standard gears sizes becomes fairly easy. Standard gear sizes and their specifications are available on many RC websites and one can simply use this given information and insert it into the spreadsheets and have most of the relevant design information in no time at all.

During the construction phase all of the parts that were ordered and manufactured came together. Some of the difficulties stemmed for the bevel gears, the rapid prototype and the overall size of the components. The difficulty with the bevel gears was the spacing. Once the mount was printed and the components were in place, the spacing was off and the bevel gears were not meshing properly. Fortunately, various spacers and shims were purchased early on and were utilized in this situation. There were issues with the prototype as well, mainly the tolerances it was producing. Some key features on the motor mount were out of tolerance and so a change to the drawing was needed and a revision was made. The issue stemmed from the holes that fastened the motor to the mount. Refer to figure 21.1 in the appendix. These holes turned into slots and this solved the problem as it allowed for adjustment in the motor. Another difficulty with the overall project is the size of the parts. Every component is rather small which can make handling them rather difficult. Take the 2mm screws that fasten the bevel gear adapter to the bevel gear and 2mm nut that goes with it. The difficulty with small parts finding the correct tools needed. If the wrong tool is used then the part can be damaged to the point where a new one will need to be purchased.

Once the difficulties had been resolved, the components could be assembled properly and they turned out very nice. Refer to appendix I figure 22 for a picture of the spur gear and bevel gear assemblies. Everything fit together and slid into placed as it was meant too. Some key features are the flats on the output shafts which were necessary to drill holes and also so they can mate with the drive shafts which have opposite geometry as is standard in RC.

CONCLUSION

A drive train has been designed and analyzed that will meet the requirements outlined in the introduction. The necessary analysis has been completed for the various aspects of the design including the bending and contact stresses for the spur and bevel gear sets as well as the driveline analysis. A detailed parts list has been created as well as a corresponding budget including the prices of all the components and the total estimated price is under the set budget of $250. A respective schedule has also been created keep the principle investigator on track throughout the remainder of this project. With all this information, the drivetrain is ready to be created.

This project also meets all the requirements for a successful senior project including engineering merit, size and cost parameters, and is of interest to the principle investigator. The engineering merit is shown in much of the analysis and appendix A using such equations as bending stress and contact stress. $S_t = \frac{W_t P_d}{FJ} K_o K_s K_m K_B K_v$, $S_c = C_p \sqrt{\frac{W_t K_o K_s K_m K_B K_v}{F D_p I}}$. Specifically, engineering merit is shown in how these equations were used to help determine a practical design and thus the necessary drawings. The drive train also had strict size and weight parameters including the drivetrain system must weigh 3lb or less and fit within a 6.5x3x3in^3 volume. The final design meets both of these requirements. Further, budget was also a parameter as mentioned above and the estimated cost is under the budget requirement. Lastly, this drivetrain project is of great importance and interest to the principle investigator, Jason Moore, as he sees it as a chance to prove his engineering worth and to display everything he has learned throughout the course of his engineering education. Not only that, but Jason simply finds of interest the systems behind vehicles that allow them to function properly. He has been around cars his entire life and enjoys working on them.

ACKNOWLEDGEMENTS

The principle investigator would like to acknowledge the CWU Mechanical Engineering Technology department for its resources. It's physical and soft resources were of great help including CWU's instructors, Professor Pringle, Dr. Johnson, Professor Beardsley, Professor Bramble and Matt Burvee as well as CWU's machine shop and it's computer lab where much of the machining and modeling were done. Jason would also like to acknowledge the owners/operators of RC Hobbies Shop located in Covington Washington as they have provided Jason with much insight about RC truck design.

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APPENDIX A – Analysis

Figure 1

A	Jason Moore	RC Baja	11-16-15	1

Requirement → Achieve 25-30 MPH w/ standard gear sizes.

Given: → Motor input = 17,000 RPM

→ Output = 25-30 MPH

Sol'n

30 MPH → RPM

3" tire Ø = 0.785 ft

$$\left(\frac{30\,\text{Miles}}{\text{Hour}}\right)\left(\frac{5280\,\text{ft}}{1\,\text{mile}}\right)\left(\frac{1\,\text{Rev}}{2\pi\,\text{Rad}}\right)\left(\frac{1\,\text{Hour}}{60\,\text{Min}}\right)\left(\frac{1}{.785\,\text{ft}}\right) = \boxed{535\,\text{RPM}}$$

Standard RC Gears From RC Planet

Spur:

18 Tooth pinion

96 Tooth Gear

$$VR = \frac{N_G}{N_P} = \frac{96}{18}$$

$$VR_1 = 5.3$$

Bevel:

15 Tooth Pinion

45 Tooth Gear

$$VR = \frac{45}{15}$$

$$VR_2 = 3.0$$

For Entire Drive Train:

$$TV = \frac{n_P}{n_G} = \frac{17{,}000\,\text{RPM}}{535\,\text{RPM}} = 31.8$$ ← Actual TV Must not Exceed 31.8.

Actual TV With Selected Gears

$$TV = VR_1 \cdot VR_2 = (5.3)(3.0) = 15.9$$

$$15.9 \le 31.8 \rightarrow \checkmark$$

Figure 2

B | Jason Moore | RC Baja | 11-20-15 | 1

Spur Gear Analysis: Pitch Diameters, Center dist. & Gear teeth.

Given:

$P_d = 48$

$N_P = 18$

$n_P = 17{,}500$ RPM

$n_G = 3281$ RPM

Find: D_P, D_G, C-C, N_G

Sol'n

1. $$\frac{N_G}{N_P} = \frac{n_P}{n_G}$$

$$N_G = \frac{n_P N_P}{n_G} = \frac{17500(18)}{3281}$$

$N_G = 96$ teeth ← No interference

2. $D_P = N_P / P_d$

$= 18/48$

$D_P = 0.375$ inches

3. $D_G = N_G / P_d$

$= 96/48$

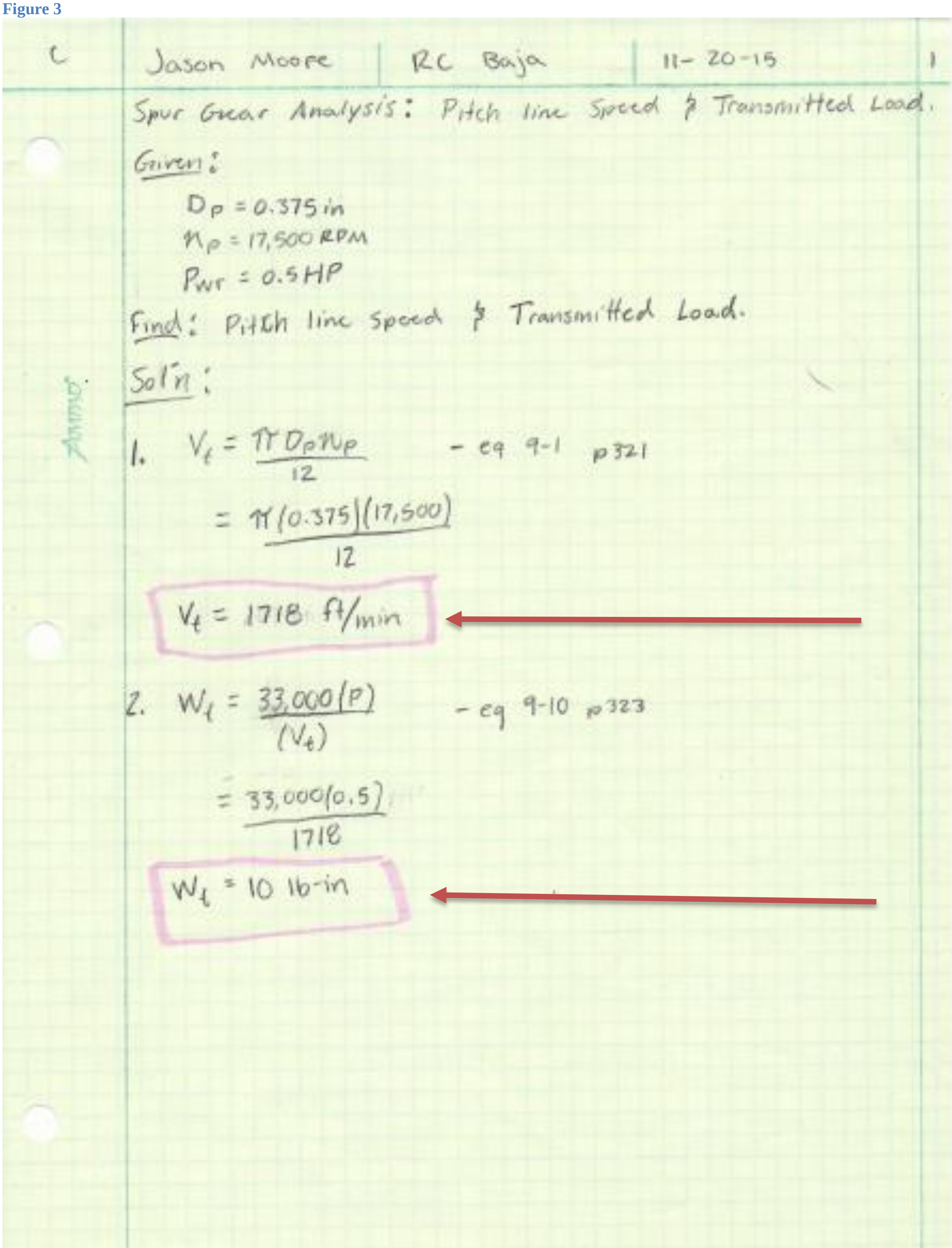
$D_G = 2.0$ inches

4. $C\text{-}C = (N_P + N_G) / 2P_d$

$= (18 + 96) / 2(48)$

C-C = 1.19 inches.

Figure 3



Jason Moore | RC Baja | 11-20-15 | 1

Spur Gear Analysis: Pitch line Speed & Transmitted Load.

Given:

$D_p = 0.375$ in

$n_p = 17{,}500$ RPM

$P_{wr} = 0.5$ HP

Find: Pitch line speed & Transmitted Load.

Sol'n:

1. $V_t = \frac{\pi D_p n_p}{12}$ — eq 9-1 p321

$= \frac{\pi (0.375)(17{,}500)}{12}$

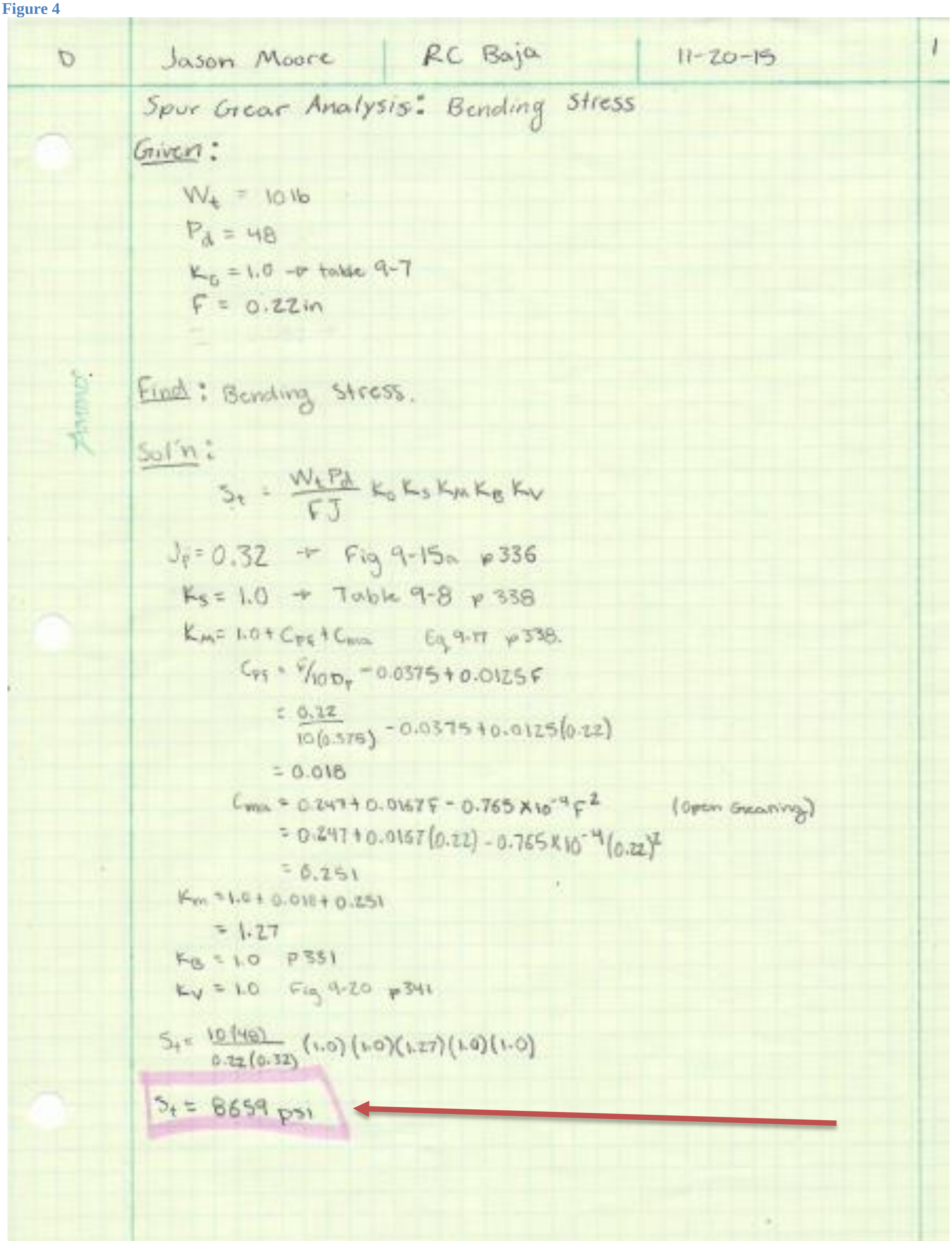
$V_t = 1718$ ft/min

2. $W_t = \frac{33{,}000(P)}{(V_t)}$ — eq 9-10 p323

$= \frac{33{,}000(0.5)}{1718}$

$W_t = 10$ lb-in

Figure 4



D | Jason Moore | RC Baja | 11-20-15 | 1

Spur Gear Analysis: Bending Stress

Given:

$W_t = 10\text{ lb}$

$P_d = 48$

$K_o = 1.0$ → table 9-7

$F = 0.22\text{in}$

Find: Bending Stress.

Sol'n:

$$S_t = \frac{W_t P_d}{F J} K_o K_s K_m K_B K_v$$

$J_p = 0.32$ → Fig 9-15a p 336

$K_s = 1.0$ → Table 9-8 p 338

$K_m = 1.0 + C_{pf} + C_{ma}$ Eq 9-17 p 338.

$C_{pf} = F/10D_p - 0.0375 + 0.0125F$

$= \frac{0.22}{10(0.375)} - 0.0375 + 0.0125(0.22)$

$= 0.018$

$C_{ma} = 0.247 + 0.0167F - 0.765\times10^{-4}F^2$ (Open Gearing)

$= 0.247 + 0.0167(0.22) - 0.765\times10^{-4}(0.22)^2$

$= 0.251$

$K_m = 1.0 + 0.018 + 0.251$

$= 1.27$

$K_B = 1.0$ p 331

$K_v = 1.0$ Fig 9-20 p 341

$S_t = \frac{10(48)}{0.22(0.32)}(1.0)(1.0)(1.27)(1.0)(1.0)$

$S_t = 8659\text{ psi}$

Figure 5

E | Jason Moore | RC Baja | 11-20-15 | 1

Spur Gear Analysis: Contact Stress:

Given:

$F = 0.22 in$

$D_p = 0.375 in$

$I = 0.082$ → Figure 9-21 p345.

Find: contact Stress Number:

Sol'n: $S_c = C_p \sqrt{\frac{W_t K_o K_s K_m K_v}{F D_p I}}$

$C_p = \sqrt{\frac{1}{\pi(((1-\nu_P^2)/E_P) + ((1-\nu_G^2)/E_G))}}$ Eq 9-20 p343

$\nu_P = 0.27$ $\nu_G = 0.39$

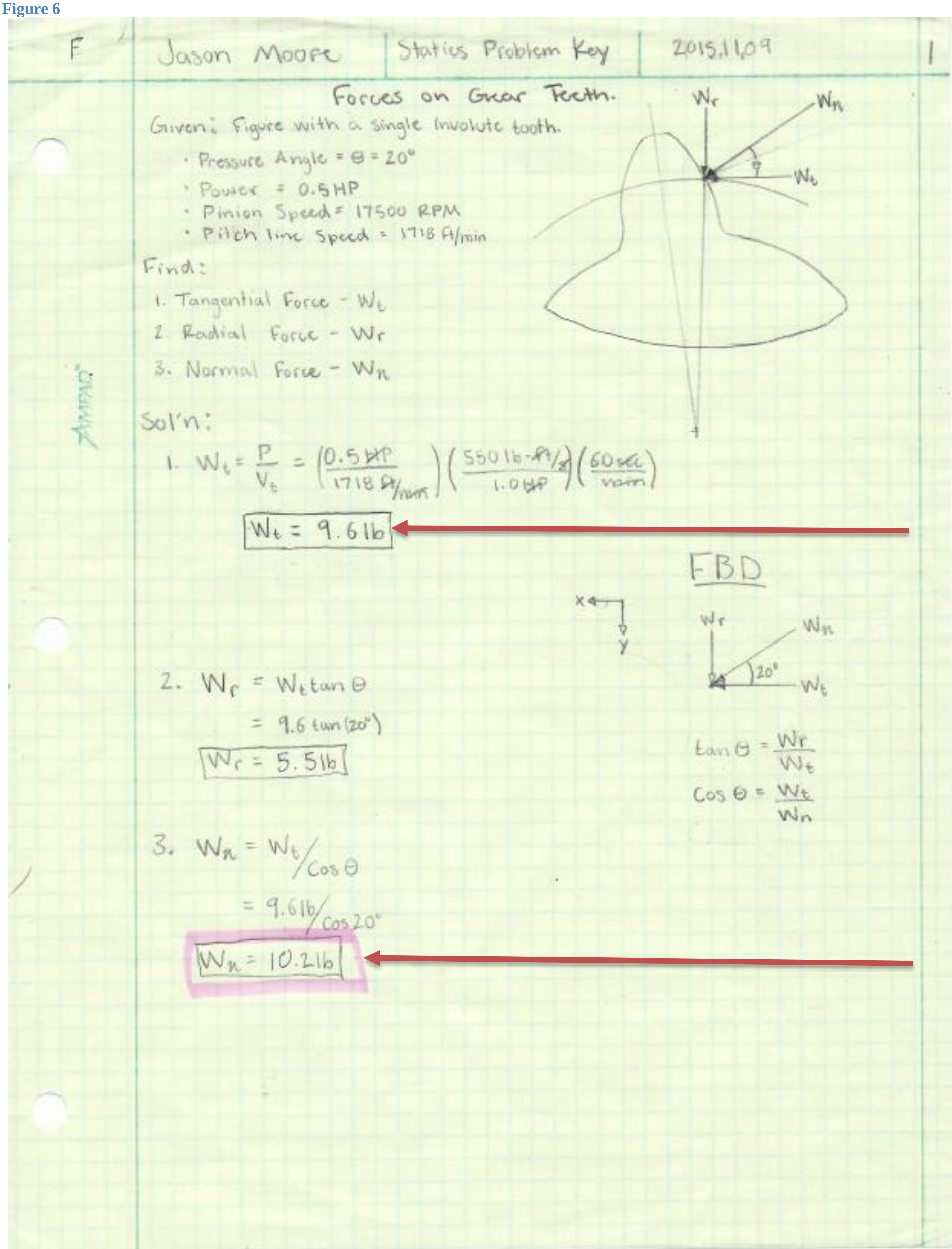
$E_P = 30 \times 10^6$ $E_G = 0.455 \times 10^6$

$C_p = 400$

$S_c = 400 \sqrt{\frac{10(1.0)(1.0)(1.27)(1.0)}{(0.22)(0.375)(0.082)}}$

$S_c = 17331 psi$

Figure 6



F | Jason Moore | Statics Problem Key | 2015.11.09 | 1

Forces on Gear Teeth.

Given: Figure with a single involute tooth.

- Pressure Angle = $\theta = 20°$
- Power = 0.5 HP
- Pinion Speed = 17500 RPM
- Pitch line Speed = 1718 ft/min

Find:

1. Tangential Force - W_t
2. Radial Force - W_r
3. Normal Force - W_n

Sol'n:

1. $W_t = \frac{P}{V_t} = \left(\frac{0.5\ HP}{1718\ ft/min}\right)\left(\frac{550\ lb\text{-}ft/s}{1.0\ HP}\right)\left(\frac{60\ sec}{min}\right)$

$W_t = 9.6\ lb$

2. $W_r = W_t \tan\theta$

$= 9.6 \tan(20°)$

$W_r = 5.5\ lb$

3. $W_n = W_t / \cos\theta$

$= 9.6\ lb / \cos 20°$

$W_n = 10.2\ lb$

$\tan\theta = \frac{W_r}{W_t}$

$\cos\theta = \frac{W_t}{W_n}$

Figure 7

G	Jason Moore	RC Baja	11-21-15	1

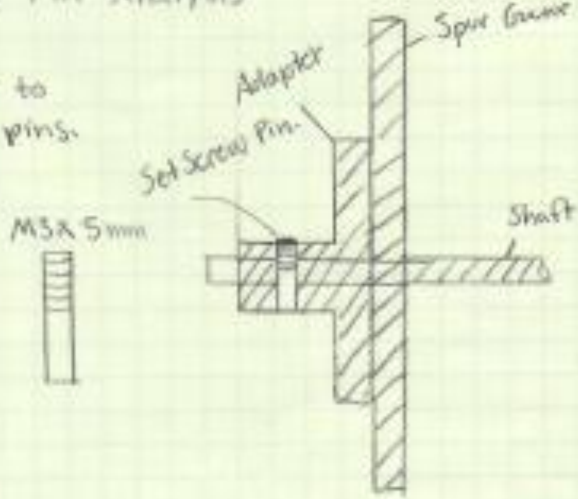
Set Screw Pin Analysis

Given

The Spur Gears are connected to the Shaft with Set screw pins.

dia. pin = 3mm = 0.118in

$W_n = 10.2 lb$



Cross Section.

Find

Shear Stress on pin.

Sol'n

$$\tau = F/A_s$$

$$F = W_n = 10.2 lb$$

$$A_s = 2(\pi r^2)$$

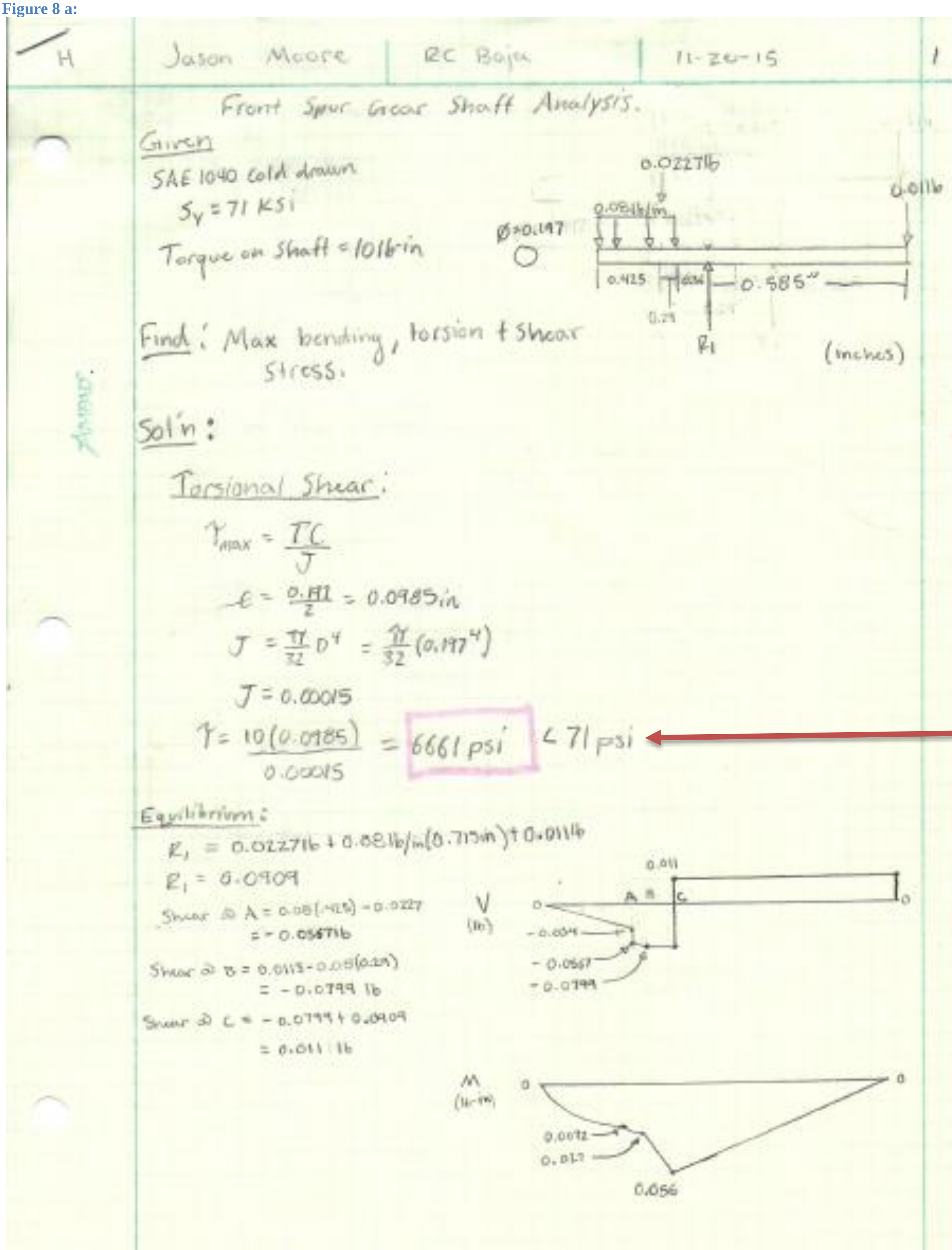
$$= 2(\pi(0.059^2))$$

$$\tau_{max} = 0.0219 psi$$

$S_y = 36 ksi$ → Grade 1 pg 1534 Machinery's Handbook.

$$\tau_{max} = 0.0219 psi < S_y = 36 ksi$$

Figure 8 a:



H | Jason Moore | RC Boju | 11-20-15 | 1

Front Spur Gear Shaft Analysis.

Given

SAE 1040 cold drawn

$S_y = 71$ KSi

Torque on Shaft = 10 lb·in

Ø=0.197

Find: Max bending, torsion & Shear stress.

Sol'n:

Torsional Shear:

$\tau_{max} = \frac{TC}{J}$

$c = \frac{0.197}{2} = 0.0985 in$

$J = \frac{\pi}{32} D^4 = \frac{\pi}{32}(0.197^4)$

$J = 0.00015$

$\tau = \frac{10(0.0985)}{0.00015} = 6661 psi < 71 psi$

Equilibrium:

$R_1 = 0.0227lb + 0.08 lb/in(0.715in) + 0.011lb$

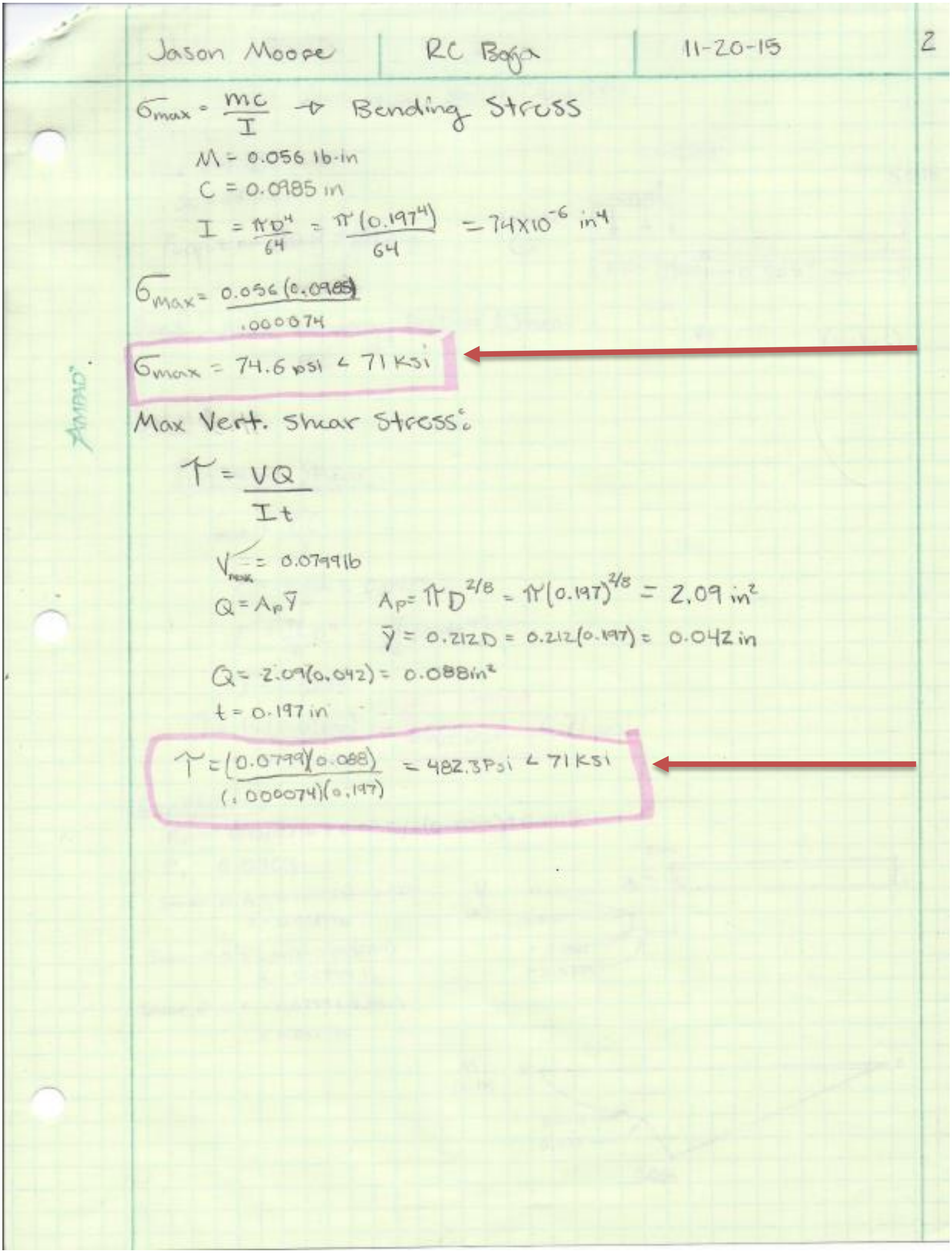
$R_1 = 0.0909$

Shear @ A = 0.08(.425) − 0.0227
= −0.0567lb

Shear @ B = 0.0113 − 0.08(0.29)
= −0.0799 lb

Shear @ C = −0.0799 + 0.0909
= 0.011 lb

Figure 8b:



Jason Moore | RC Baja | 11-20-15 | 2

$\sigma_{max} = \frac{Mc}{I}$ → Bending Stress

$M = 0.056$ lb-in

$C = 0.0985$ in

$I = \frac{\pi D^4}{64} = \frac{\pi(0.197^4)}{64} = 74\times10^{-6}$ in^4

$\sigma_{max} = \frac{0.056(0.0985)}{.000074}$

$\sigma_{max} = 74.6$ psi < 71 ksi

Max Vert. Shear Stress:

$\tau = \frac{VQ}{It}$

$V_{max} = 0.0799$ lb

$Q = A_p \bar{y}$ $\quad A_p = \pi D^{2/8} = \pi(0.197)^{2/8} = 2.09$ in^2

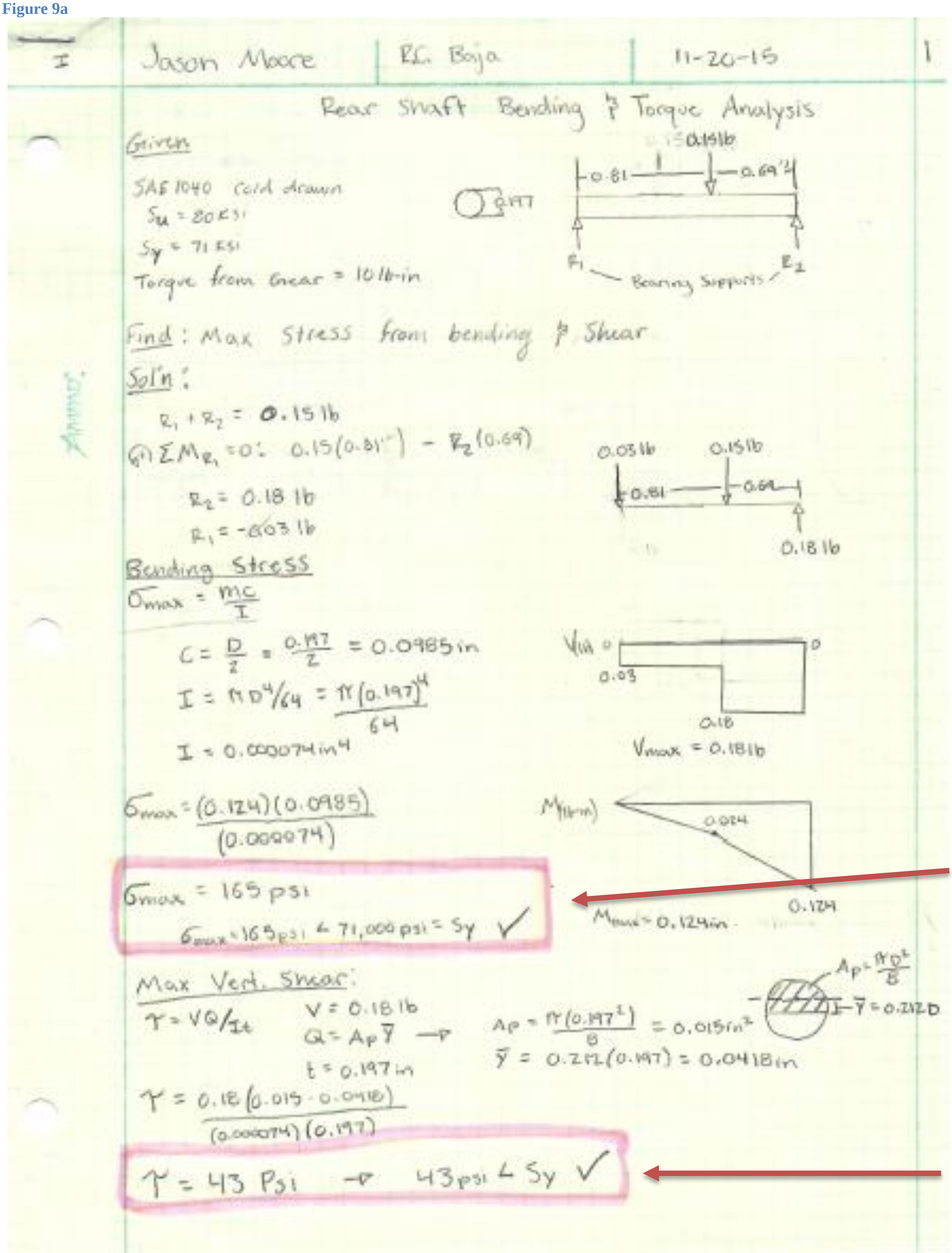
$\bar{y} = 0.212D = 0.212(0.197) = 0.042$ in

$Q = 2.09(0.042) = 0.088$ in^2

$t = 0.197$ in

$\tau = \frac{(0.0799)(0.088)}{(.000074)(0.197)} = 482.3$ Psi < 71 ksi

Figure 9a



I | Jason Moore | R.C. Baja | 11-20-15 | 1

Rear Shaft Bending & Torque Analysis

Given

SAE 1040 Cold drawn

$S_u = 80$ KSI

$S_y = 71$ KSI

Torque from Gear = 10 lb-in

Ø 0.197

0.15 lb; 0.81; 0.69"; R_1; R_2; Bearing Supports

Find: Max Stress from bending & Shear

Sol'n:

$R_1 + R_2 = 0.15$ lb

@ $\Sigma M_{R_1} = 0$: $0.15(0.81") - R_2(0.69)$

$R_2 = 0.18$ lb

$R_1 = -0.03$ lb

0.03 lb; 0.15 lb; 0.81; 0.69; 0.18 lb

Bending Stress

$\sigma_{max} = \frac{Mc}{I}$

$c = \frac{D}{2} = \frac{0.197}{2} = 0.0985$ in

$I = \pi D^4/64 = \frac{\pi(0.197)^4}{64}$

$I = 0.000074$ in^4

V(lb): 0; 0.03; 0.18; 0

$V_{max} = 0.18$ lb

$\sigma_{max} = \frac{(0.124)(0.0985)}{(0.000074)}$

M(lb-in): 0.024; 0.124

$\sigma_{max} = 165$ psi

$\sigma_{max} = 165$ psi < 71,000 psi = S_y ✓

$M_{max} = 0.124$ in

Max Vert. Shear:

$\tau = VQ/It$ $V = 0.18$ lb

$Q = A_p \bar{y}$ → $A_p = \frac{\pi(0.197^2)}{8} = 0.015$ in^2

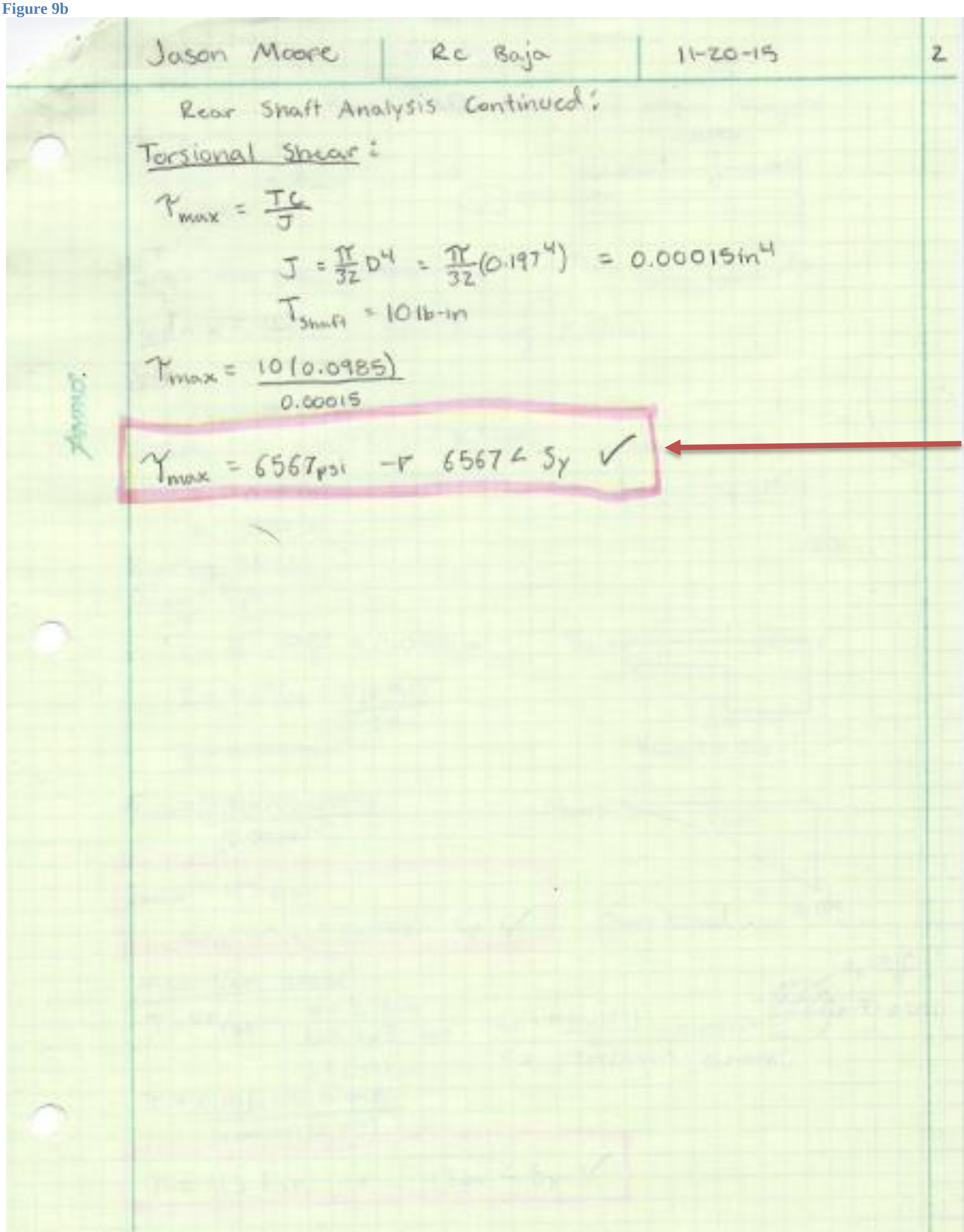
$t = 0.197$ in $\bar{y} = 0.212(0.197) = 0.0418$ in

$A_p = \frac{\pi D^2}{8}$; $\bar{y} = 0.212D$

$\tau = \frac{0.18(0.015 \cdot 0.0418)}{(0.000074)(0.197)}$

$\tau = 43$ Psi → 43 psi < S_y ✓

Figure 9b



Jason Moore | Rc Baja | 11-20-15 | 2

Rear Shaft Analysis Continued:

Torsional Shear:

$$\tau_{max} = \frac{Tc}{J}$$

$$J = \frac{\pi}{32} D^4 = \frac{\pi}{32}(0.197^4) = 0.00015 in^4$$

$$T_{shaft} = 10 \text{ lb-in}$$

$$\tau_{max} = \frac{10(0.0985)}{0.00015}$$

$$\tau_{max} = 6567 psi \rightarrow 6567 < S_y \checkmark$$

Figure 10

J 2

Drive Shaft Torsional Shear Calculations.

Given: • Nylon Drive Shaft.
• Applied torque from Gear Sets: 10 lb-in (from Gear Spreadsheets)
• Material Prop for Nylon: App 1 p738 R.L. Mott
$S_y = 21$ KSI
• 30 lb-in Max Torque Allowed from Requirements
• Actual Drive Shaft Cross Section:

Find: Max Actual Torsional Shear on Shaft.

Sol'n

$$\tau_{max} = T/Z_p \rightarrow Z_p = \pi(D^4 - d^4)/16D \quad \text{App 1 p720}$$

$$Z_p = \frac{\pi(0.3125^4 - 0.1563^4)}{16(0.3125)} = 0.00562 \text{ in}^3$$

$$\tau_{max} = \frac{10 \text{ lb-in}}{0.00562 \text{ in}^3} = 1780.3 \text{ psi}$$

Actual τ_{max} = 1780.3 psi

τ_{max} of Material = 21,000 psi

$$\text{Safetey Factor } N = \frac{21,000}{1780.3} = 11.8$$

N = 11.8 → Good

Figure 11: **Bending Stress for Plastic Gear:**

DESIGN OF PLASTIC SPUR GEARS				
Application:				
Paper shredder with electric motor drive				
Example Problem 9-7				
Initial Input Data:				
Input Power:	P =	0.5	hp	
Input Speed:	n_P =	17500	rpm	
Diametral Pitch:	P_d =	48		
Number of Pinion Teeth:	N_P =	18		
Desired Output Speed:	n_G =	3281	rpm	
Computed number of gear teeth:		96.01		
Enter: Chosen No. of Gear Teeth:	N_G =	96		
Computed data:				
Actual Output Speed:	n_G =	3281.3	rpm	
Gear Ratio:	m_G =	5.333		
Pitch Diameter - Pinion:	D_P =	0.375	in	
Pitch Diameter - Gear:	D_G =	2.000	in	
Center Distance:	C =	2.375	in	
Pitch Line Speed:	v_t =	1718.1	ft/min	
Transmitted Load:	W_t =	9.60	lb	
Secondary Input Data - Pinion:				
Tooth Form:	*20 degree full depth*			
Lewis Form Factor:	Y =	0.521		Table 9-15
Safety Factor:	SF =	1.50		Ref: Table 9-7
Material:		Nylon		
Allowable Bending Stress:	s_{at} =	12000	psi	Table 9-14 or Fig. 9-28
Required Face Width:	F =	0.111	in	
Enter: Specified Face Width:	F =	0.250	in	
Actual Bending Stress in Pinion:	s_t =	5307	psi	
Secondary Input Data - Gear:				
Tooth Form:	*20 degree full depth*			Same as for pinion
Lewis Form Factor:	Y =	0.757		Table 9-15
Safety Factor:	SF =	1.50		Same as for pinion
Material:		NYLON		
Allowable Bending Stress:	s_{at} =	12000	psi	Table 9-14 or Fig. 9-28
Face Width - Gear:	F =	0.250	in	Same as for pinion
Actual Bending Stress in Gear:	s_t =	3652	psi	Must be < s_{at}

Figure 12: **Bevel gear analysis:**

DESIGN OF BEVEL GEARS	APPLICATION:	*Load with moderate shock driven by an electric motor.*
		Example Problems 10-6, 10-7, 10-8 — *Both gear straddle mounted*

Initial Input Data:			
Input Power:	$P =$	*0.5*	hp
Input Speed:	$n_P =$	*3281*	rpm
Diametral Pitch:	$P_d =$	*32*	
Number of Pinion Teeth:	$N_P =$	*15*	
Desired Output Speed:	$n_G =$	*1094*	rpm
Computed number of gear teeth:		45.0	
Enter: Chosen No. of Gear Teeth:	$N_G =$	*45*	
Computed data:			
Actual Output Speed:	$n_G =$	1093.7	rpm
Gear Ratio:	$m_G =$	3.00	
Pitch Diameter - Pinion:	$D_P =$	0.469	in
Pitch Diameter - Gear:	$D_G =$	1.406	in
Pitch cone angle - Pinion:	$\gamma =$	18.43	degrees
Pitch cone angle - Gear:	$\Gamma =$	71.57	degrees
Outer cone distance:	$A_o =$	0.7412	in
Pitch Line Speed:	$v_t =$	403	ft/min
Transmitted Load:	$W_t =$	41	lb
Secondary Input Data:			
	Nom	Max	Max
Face Width Guidelines (in):	0.222	0.247	0.313
Enter: Face Width:	$F =$	*0.250*	in
Enter: Elastic Coefficient:	$C_p =$	*1900*	Table 9-10
Enter: Quality Number:	$A_v =$	*10*	Table 9-3
Enter: Bending Geometry Factors:			
Pinion:	$J_P =$	*0.235*	Fig. 10-15
Gear:	$J_G =$	*0.180*	Fig. 10-15
Enter: Pitting Geometry Factor:	$I =$	*0.074*	Fig. 10-19

Factors in Design Analysis:				
Load distribution factor, K_m:	From Equation 10-16			
Select from:	Factor, K_{mb}			
Both gears straddle mounted:	1.00			
One gear straddle mounted:	1.10			
Neither gear straddle mounted:	1.25			
Enter Factor, K_{mb}	*1.10*			
$K_m =$	1.10			
Overload Factor: $K_o =$	*1.00*	Table 9-7		
Bending Size Factor: $K_s =$	*0.49*	Figure 10-13 (for $P_d < 16$)		
Dynamic Factor: $K_v =$	1.217	Computed: Table 9-9		
Pitting Size Factor: $C_s =$	0.47	For $0.50 < F < 3.14$		
For $F < 0.50$, $C_s = 0.5$		For $F > 3.14$, $C_s = 0.83$		
Enter $C_s =$	0.5			
Service Factor: $SF =$	*1.00*	Use 1.00 if no unusual conditions		
Bending Reliability Factor: $K_R =$	*1.00*	Pitting: $C_R =$		1.00
Enter: Design Life:	*500*	hours	See Table 9-12	
Pinion - Number of load cycles: $N_P =$	9.8E+07	Y_N, Z_N: Pinion-Fig. 10-18; Gear-Fig. 10-20		
Gear - Number of load cycles: $N_G =$	3.3E+07	$N<10^3$	$10^3<N<10^7$	$N>10^7$
Bending Stress Cycle Factor: $K_L =$	*0.97*	2.70	0.69	0.98
Bending Stress Cycle Factor: $K_L =$	*0.74*	2.70	0.78	1.00
		$N<10^4$	$N>10^4$	
Pitting Stress Cycle Factor: $C_L =$	*1.12*	2.00	1.15	
Pitting Stress Cycle Factor: $C_L =$	*1.20*	2.00	1.23	
Stress Analysis - Bending:				
Pinion: Required $s_{at} =$	15,205	psi	See Fig. 10-17 or	
Gear: Required $s_{at} =$	26,022	psi	Table 10-4	
Stress Analysis - Pitting:	Assumes $C_{xc} = 1.5$ for properly crowned teeth			
Pinion: Required $s_{ac} =$	116,880	psi	See Fig. 10-21 or	
Gear: Required $s_{ac} =$	109,088	psi	Table 10-4	

Figure 13: **Forces on Spur gears:**

Problem 2	*Pressure angle =*	*20*	*degrees*
Chapter 9	*Power =*	*0.5*	*hp*
	pinion speed =	*17500*	*rpm*
	teeth in pinion =	*18*	
	teeth in gear =	*96*	
	diametral pitch =	*48*	
RESULTS:			
a	Gear speed =	3281.3	rpm
b	VR = m_G =	5.333	
c	pinion PD =	0.375	in
	gear PD =	2.000	in
d	center distance = C =	1.188	in
e	pitch line speed =	1718	ft/min
f	torque on pinion shaft =	2	lb in
	torque on gear shaft =	10	lb in
g	tangential force =	10	lb
h	radial force =	3	lb
I	normal force =	10	lb

Figure 14: **Forces on bevel gears:**

Bevel gears:			
Forces and torque for shaft and bearing load analysis:			
On Pinion Shaft - Torque:	T_P =	9.6007	lb-in
Mean radius of pinion:	r_m =	0.193	in
Enter: pressure angle:	ϕ =	20	degrees
On Pinion - Tangential load:	W_{tP} =	49.6	lb
On Pinion - Radial load:	W_{rP} =	17.1	lb
On Pinion - Axial load:	W_{xP} =	5.7	lb
On Gear Shaft - Torque:	T_G =	28.8	lb-in
On Gear - Tangential load:	W_{tG} =	49.6	lb
On Gear - Radial load:	W_{rG} =	5.7	lb
On Gear - Axial load:	W_{xG} =	17.1	lb

APPENDIX B - Drawings

Figure 15: **Drawing Tree**

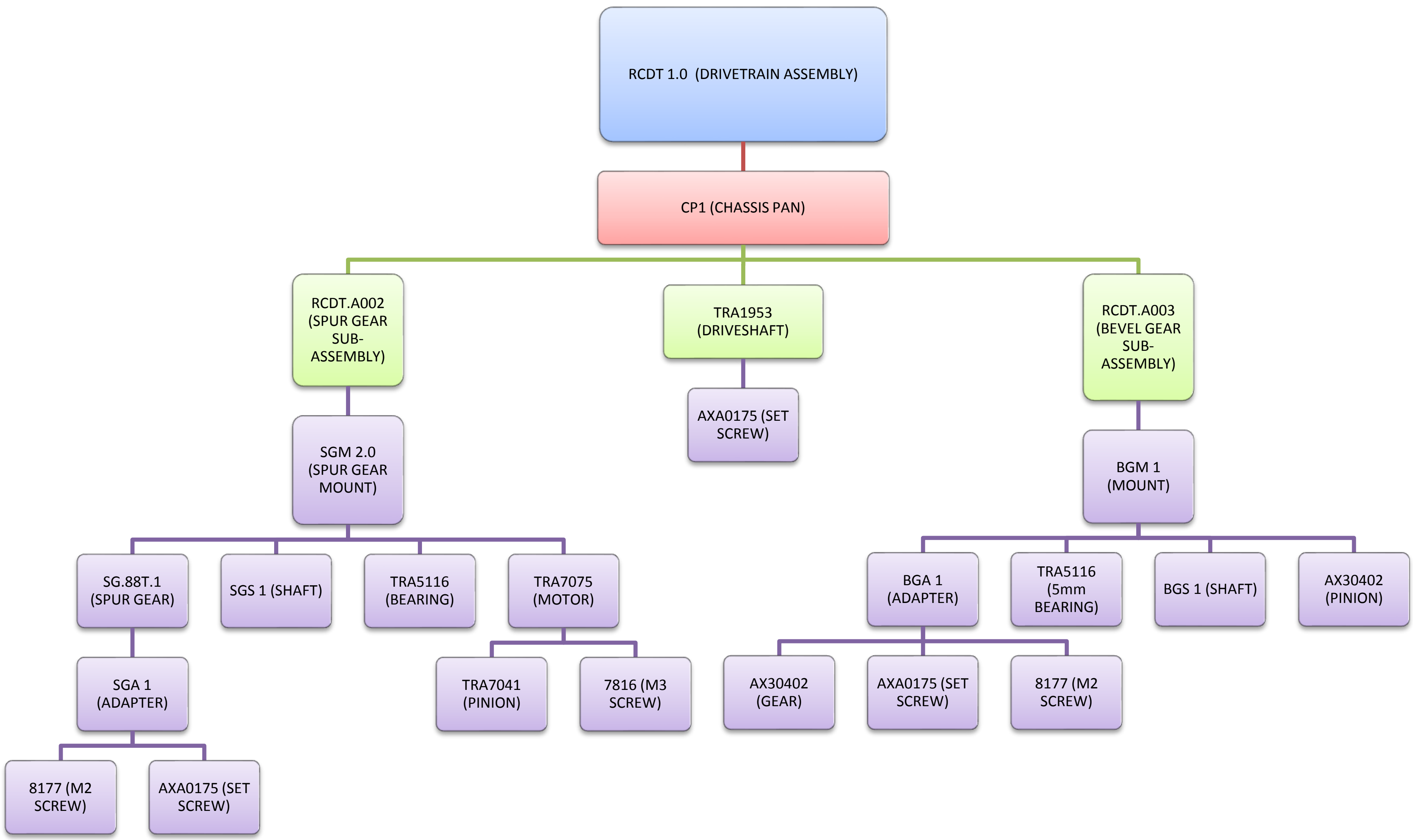


Figure 16: **Initial Sketch**

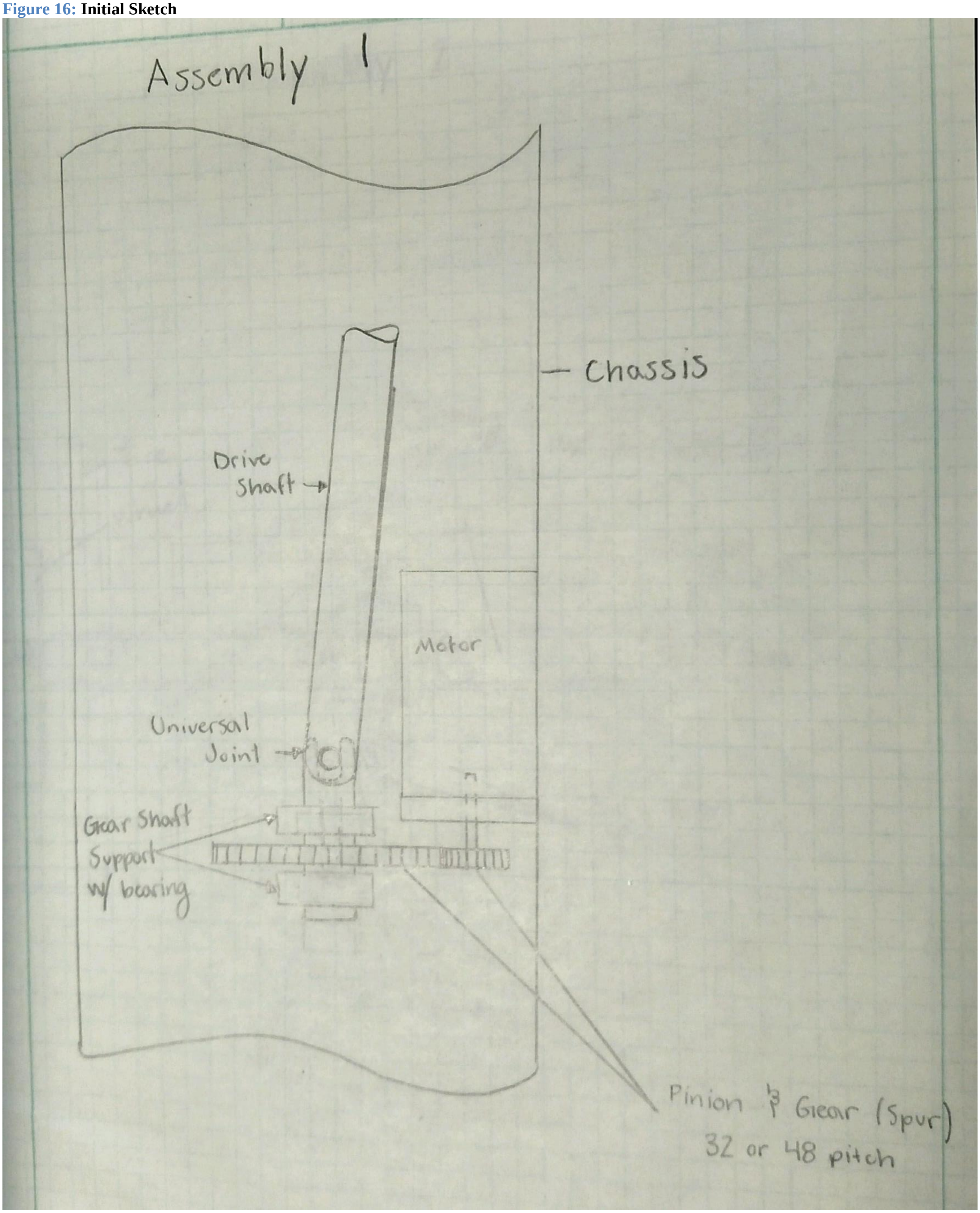


Figure 17: **Initial sketch of bevel gear assembly:**

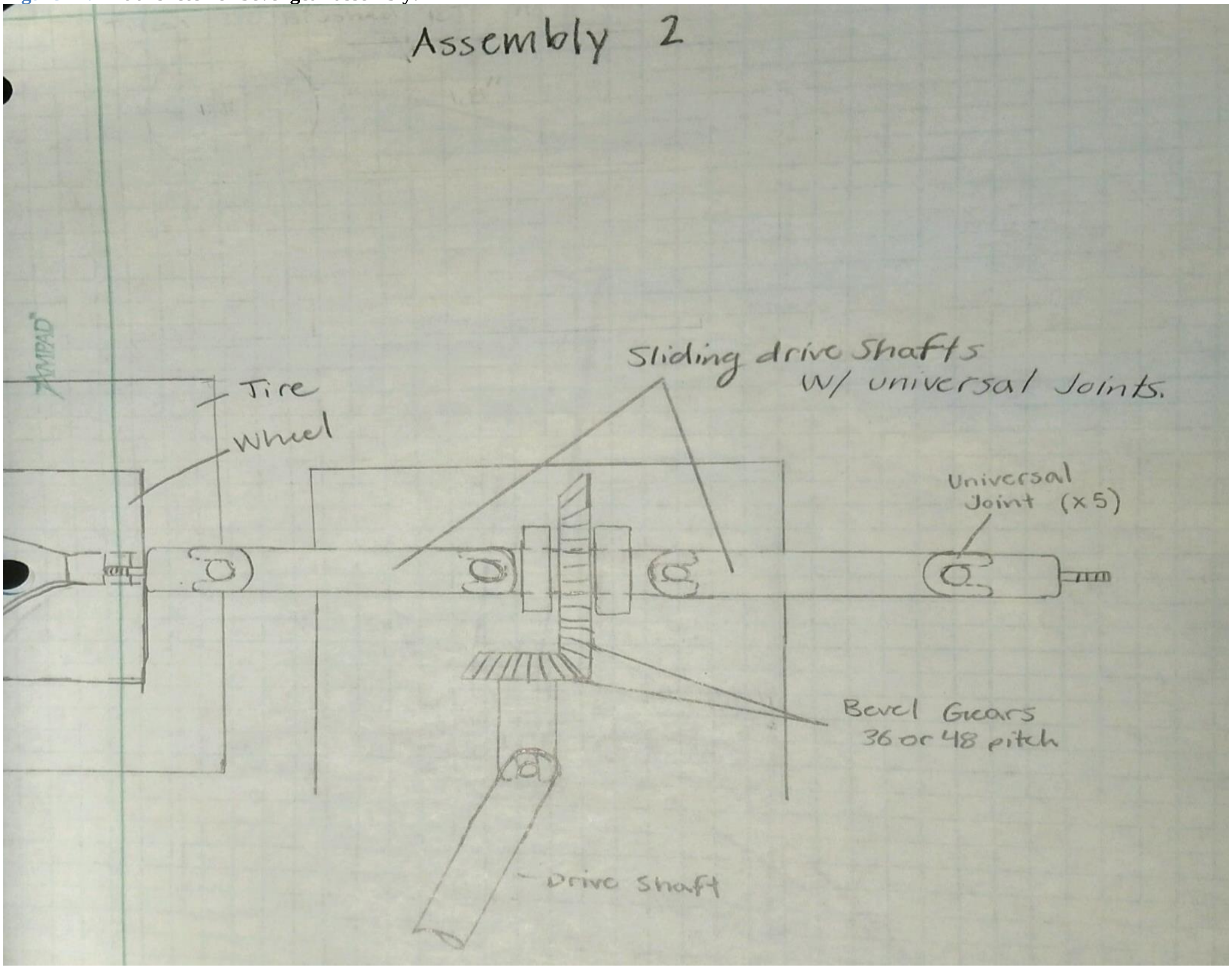


Figure 18: **Drive Train Model.**

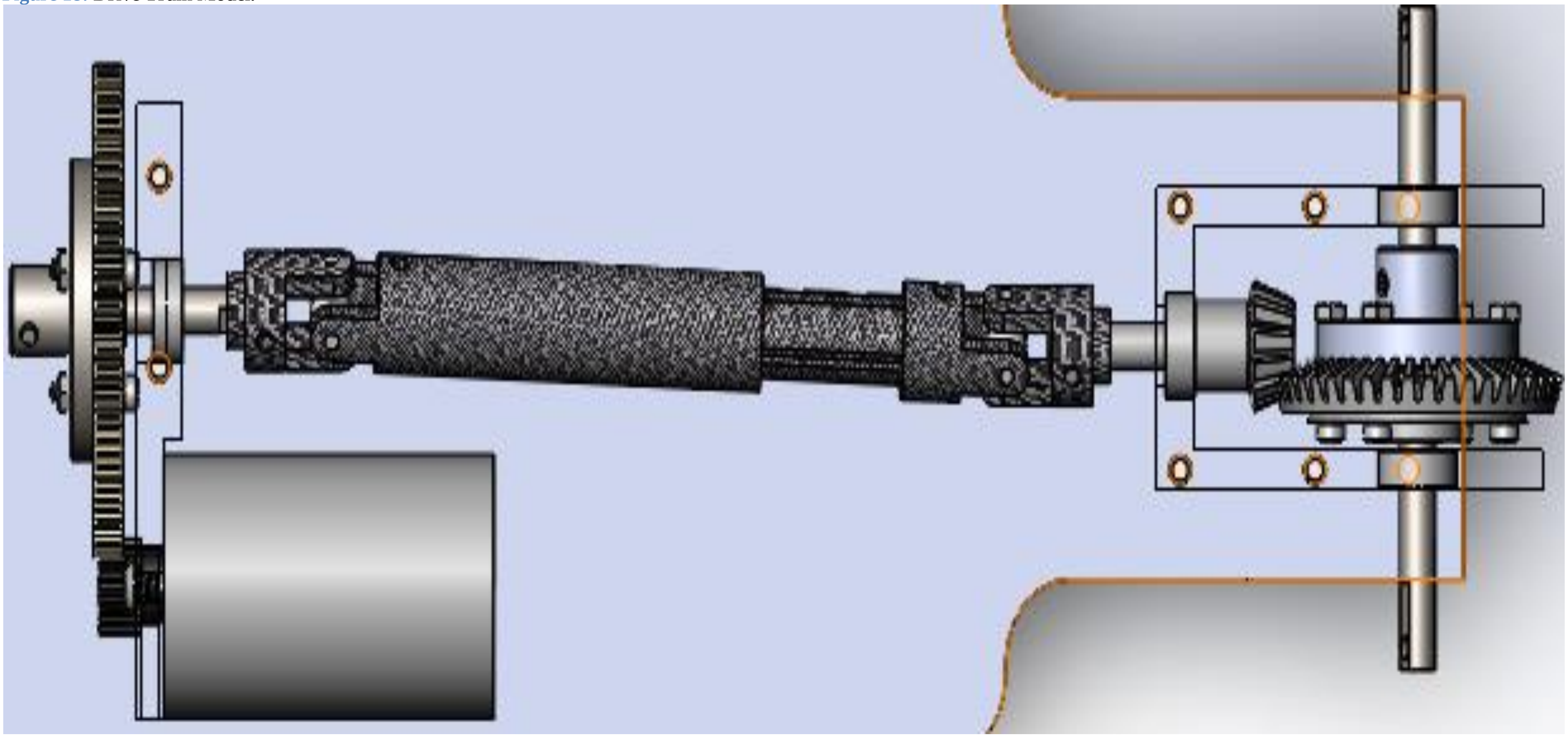


Figure 19a: **Drive Train BOM**

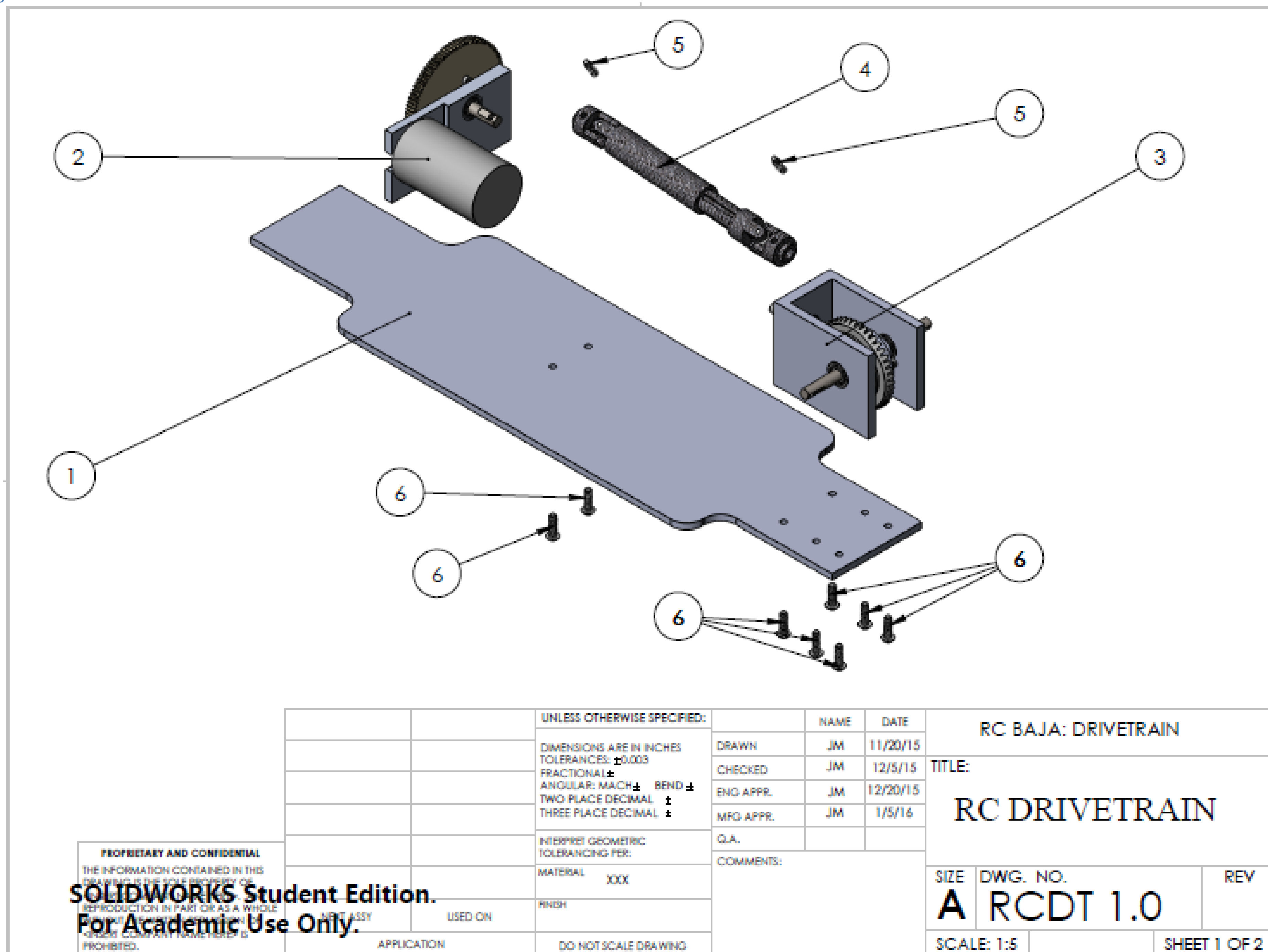


Figure 19b: **Drivetrain Assembly**

ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	CP 1	Chassis Pan	6061 ALuminum	1
2	RCDT.A003	BEVEL GEAR ASSEMBLY		1
3	RCDT.A002	Titan 380 18T Assembly		1
4	TRA1953	Drive Shaft	NNYLON	1
5	AXA0175	Screw Shaft M3x2.5x11mm	STEEL	2
6	7816	Button Socket Cap Screws M3 x 10	STEEL	8

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.003
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL XXX
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JM	11/20/15
CHECKED	JM	12/5/15
ENG APPR.	JM	12/20/15
MFG APPR.	JM	1/5/16
Q.A.		

COMMENTS:

NEXT ASSY USED ON
APPLICATION

RC BAJA: DRIVETRAIN
TITLE:
RC DRIVETRAIN
SIZE A DWG. NO. RCDT 1.0 REV
SCALE: 1:5 SHEET 2 OF 2

Figure 19.1: Chassis Pan:

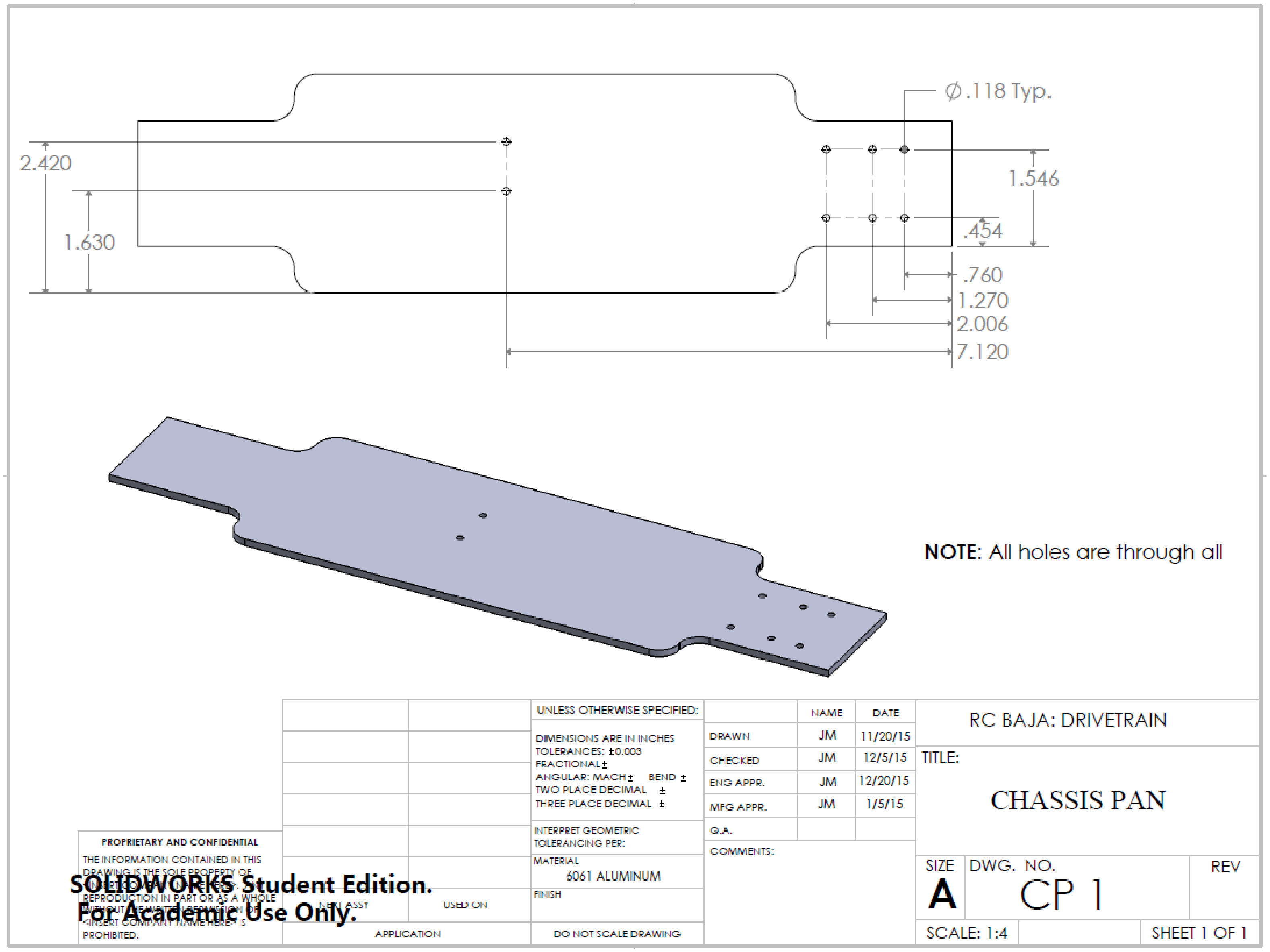


Figure 20a: **Bevel Gear BOM**

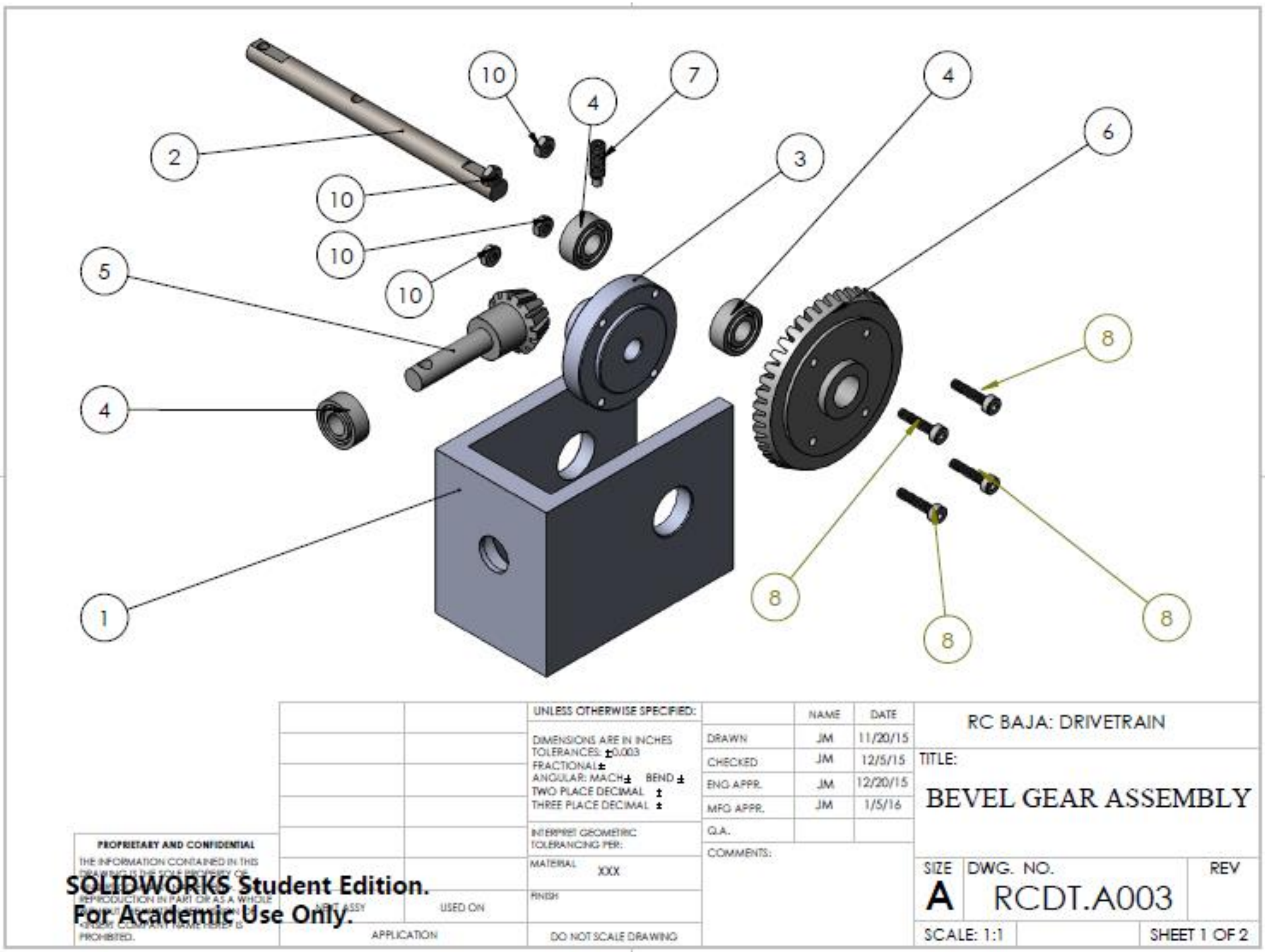


Figure 20b: **Bevel Gear BOM**

ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	BGM 1	BEVEL Gear MOUNT	ABS	1
2	BGS 1	BEVEL GEAR SHAFT	ABS	1
3	BGA 1	Bevel Gear Adapter	ABS	1
4	TRA5116	Bearing: 5x11x4mm	Steel	3
5	AX30402	Axial Bevel Gear Pinion	Steel	1
6	AX30402	Bevel Gear	Steel	1
7	AXA0175	Screw Shaft M3x2.5x11mm	Steel	1
8	8177	M3x0.5x10	Steel	4
9	6516	M2x0.4 Nut	Steel	4
10	**RCDT.A003**	**Bevel Gear Sub-Assembly**		**4**

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.003
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL XXX
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JM	11/20/15
CHECKED	JM	12/5/15
ENG APPR.	JM	12/20/15
MFG APPR.	JM	1/5/16
Q.A.		

COMMENTS:

RC BAJA: DRIVETRAIN

TITLE:

BEVEL GEAR ASSEMBLY

SIZE A | DWG. NO. RCDT.A003 | REV

SCALE: 1:1 | SHEET 2 OF 2

NEXT ASSY | USED ON

APPLICATION

Figure 20.1: **Bevel Gear Mount:**

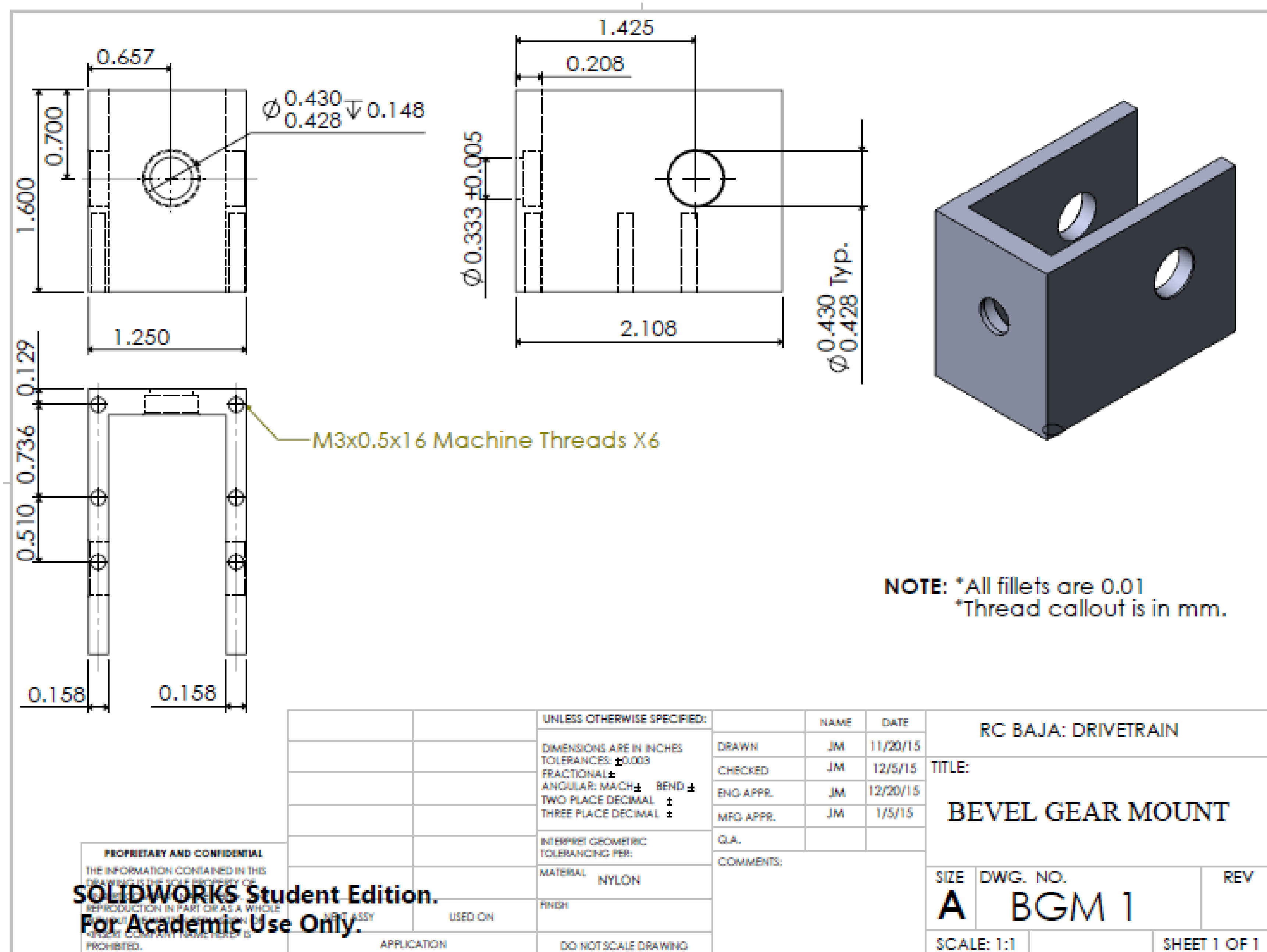


Figure 20.2: Bevel Gear Shaft:

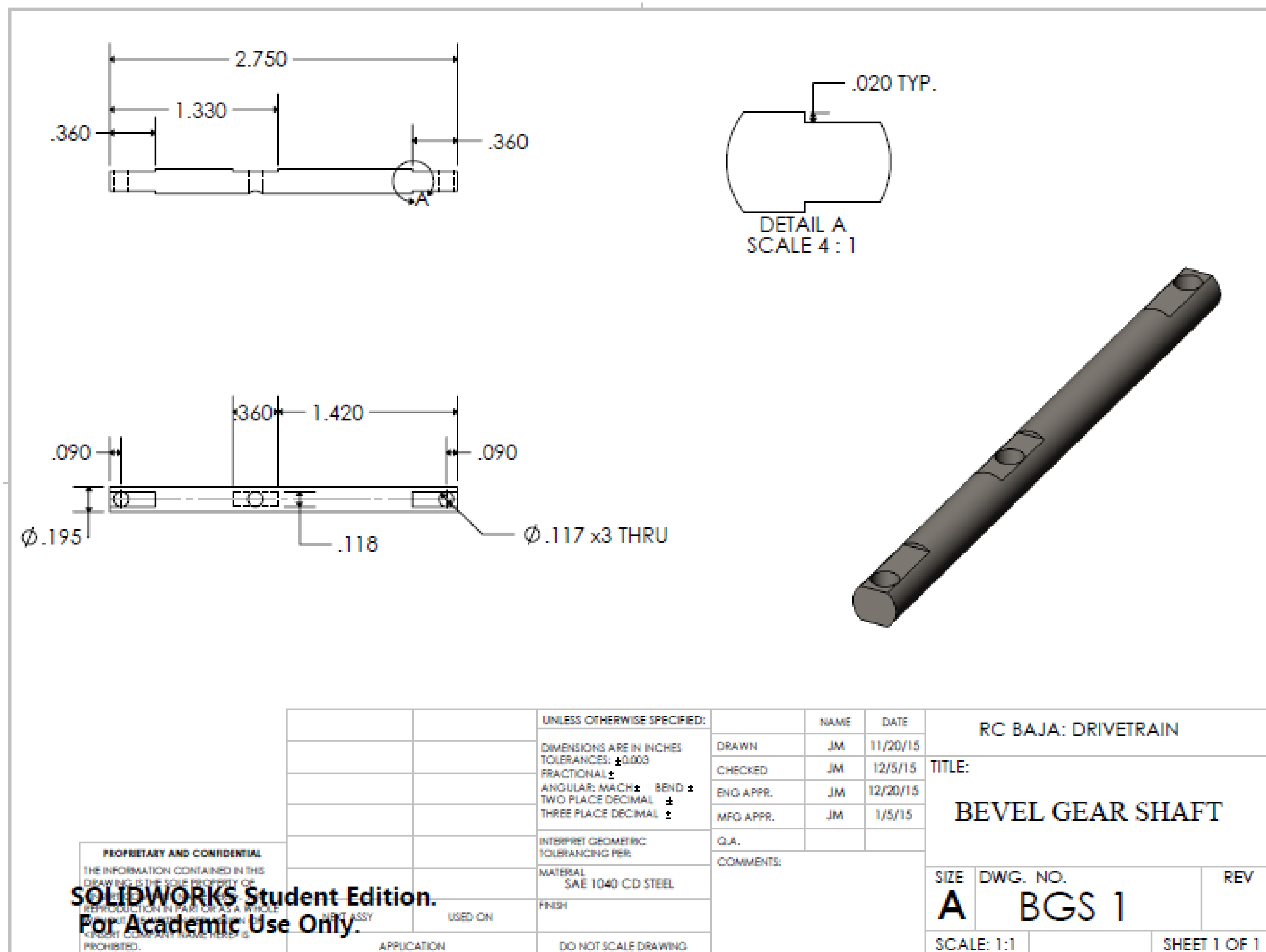


Figure 20.3: **Bevel Gear Adapter:**

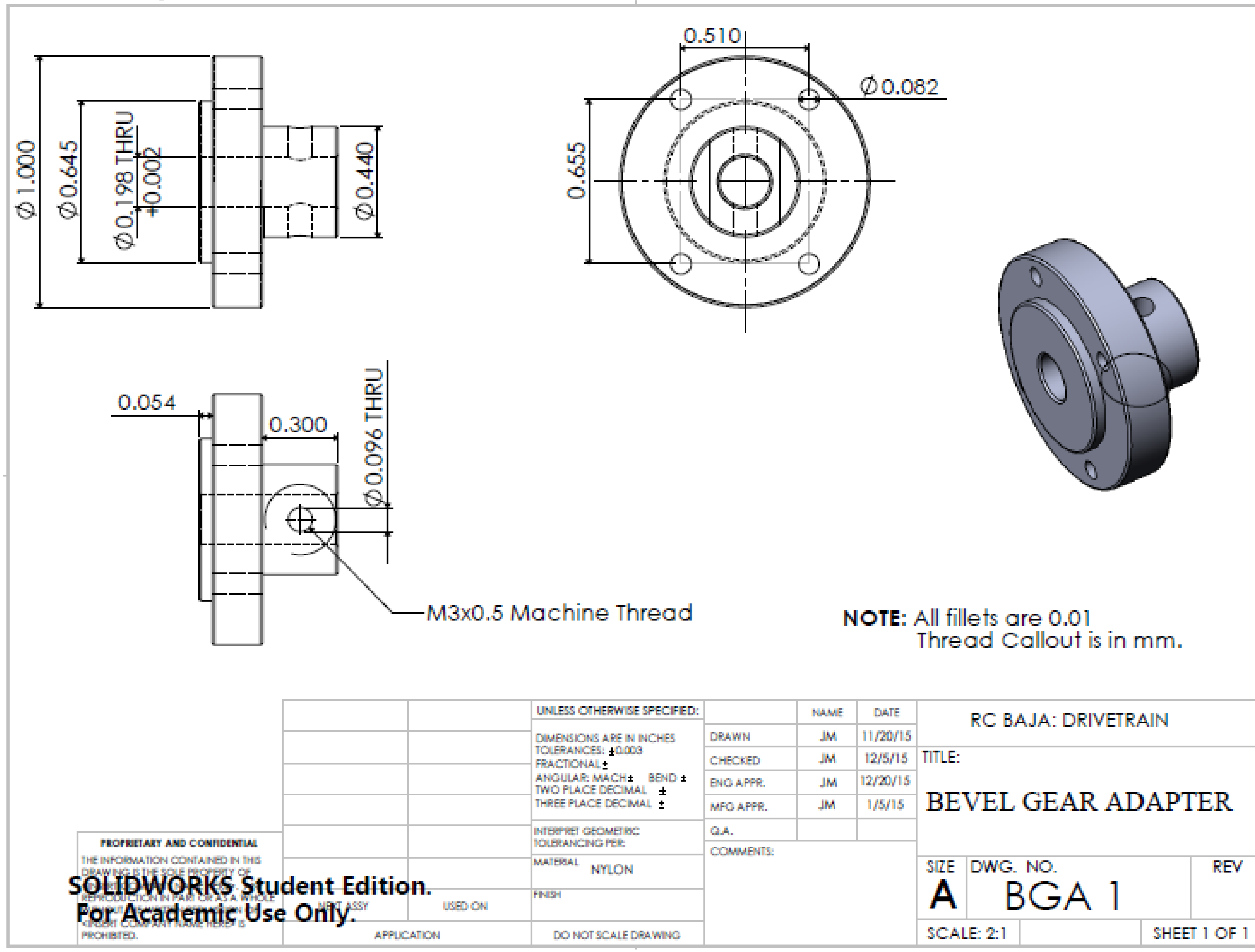


Figure 21a: **Titan 380 BOM**

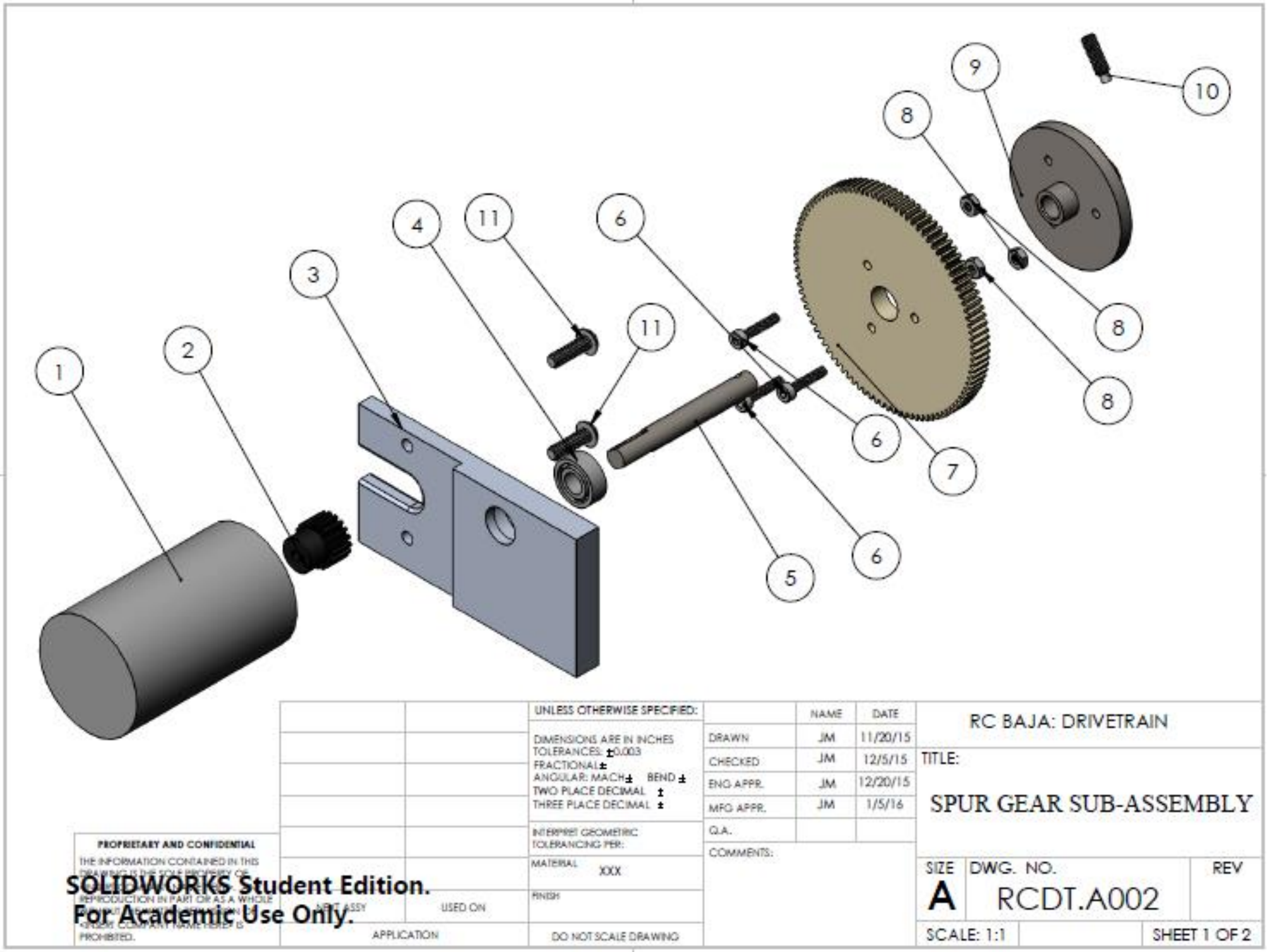


Figure 21b: Spur Gear Assembly

ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	TRA7075	Motor		1
2	TRA7041	Spur Gear 18T	Steel	1
3	SGM 1	Spur Gear Mount	ABS	1
4	TRA5116	Bearing	Steel	1
5	SGS 1	Spur Gear Shaft	SAE 1040 CD Steel	1
6	8177	M2x0.4x10mm cap screws	Steel	3
7	TLR232004	Spur Gear 88T	Nylon	1
8	6516	M2 Nuts	Steel	3
9	SGA 1	Spur Gear Adapter	ABS	1
10	AXA0175	M3x2.5 Screw Pin	Steel	1
11	7816	M3x0.5x10	Steel	2
12	**RCDT.A002**	**Spur Gear Sub-Assembly**		**1**

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.003
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL XXX
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JM	11/20/15
CHECKED	JM	12/5/15
ENG APPR.	JM	12/20/15
MFG APPR.	JM	1/5/16
Q.A.		

COMMENTS:

RC BAJA: DRIVETRAIN

TITLE:

SPUR GEAR SUB-ASSEMBLY

SIZE A DWG. NO. RCDT.A002 REV

SCALE: 1:1 SHEET 2 OF 2

NEXT ASSY USED ON
APPLICATION

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

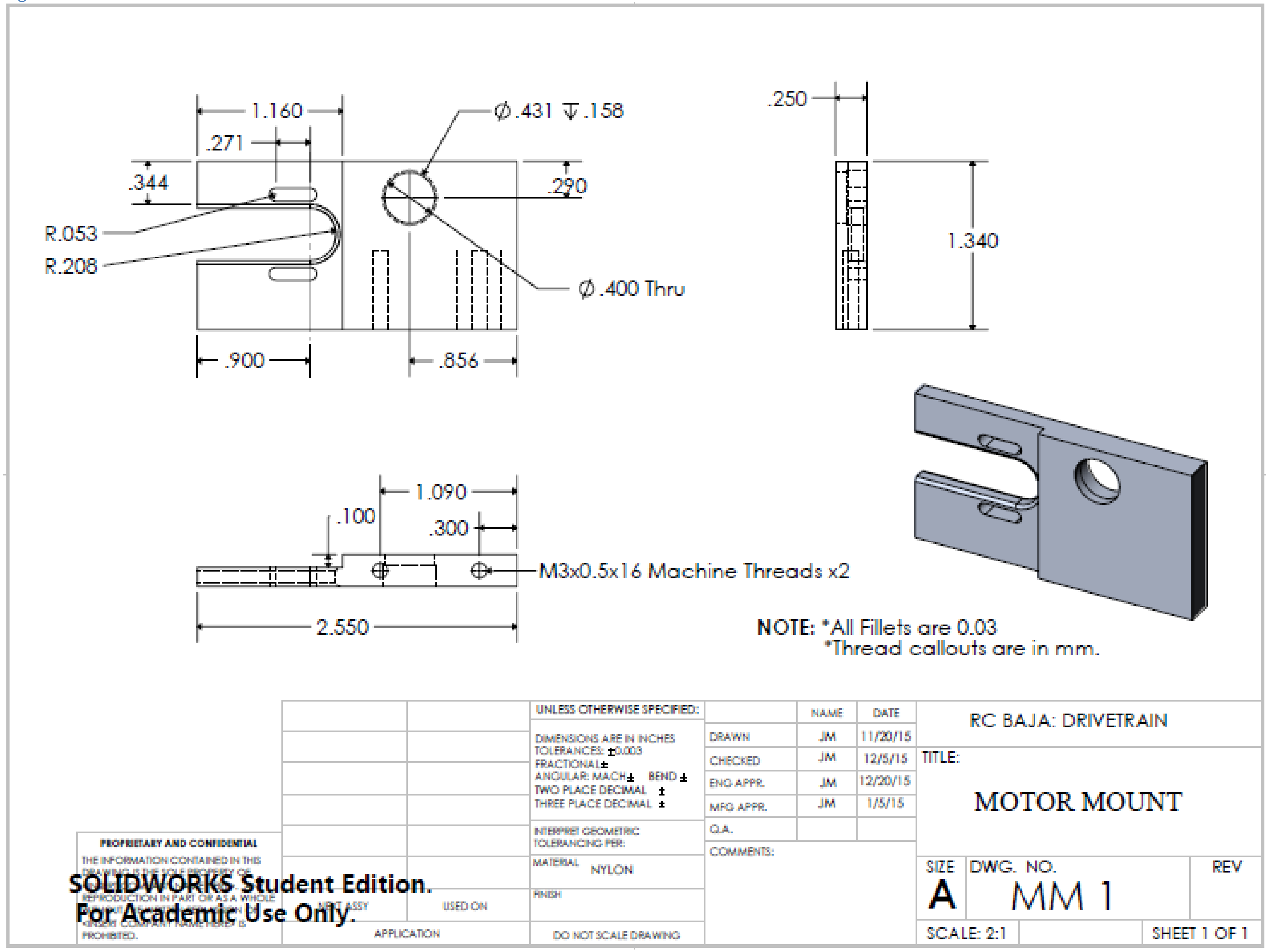


Figure 21.1: **Motor Mount**

Figure 21.2: Spur Gear Shaft

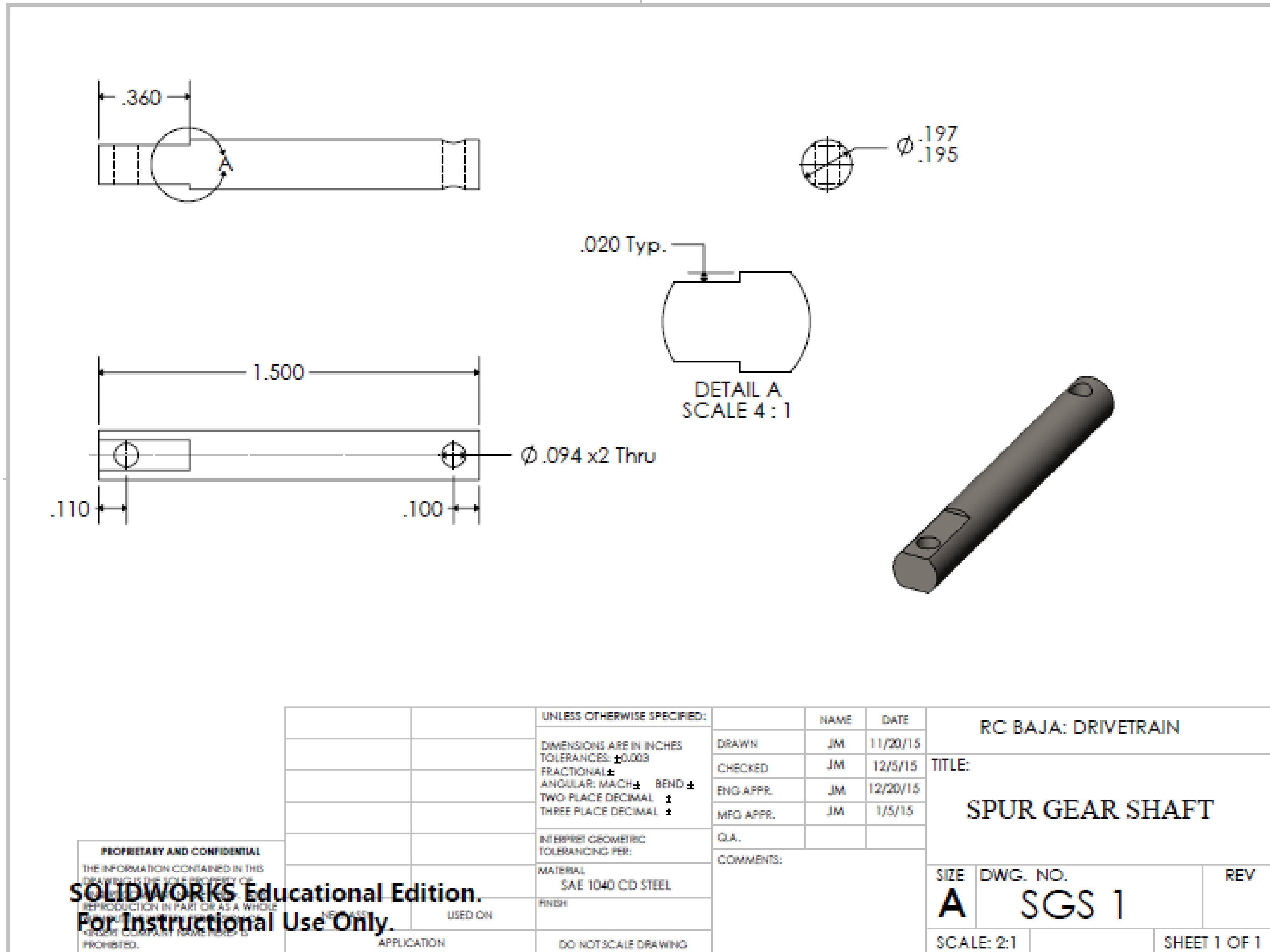


Figure 21.3: Spur Gear Shaft

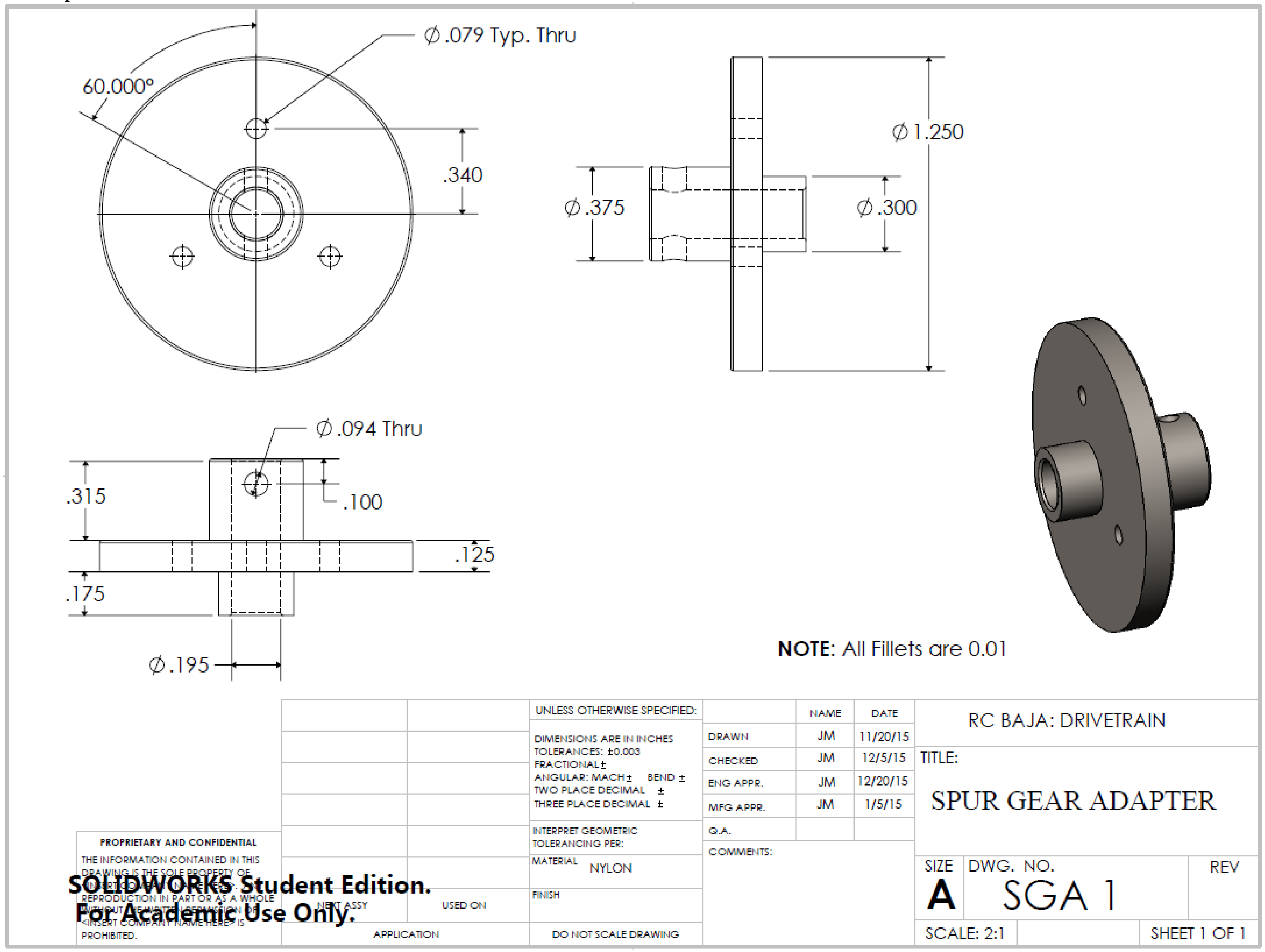
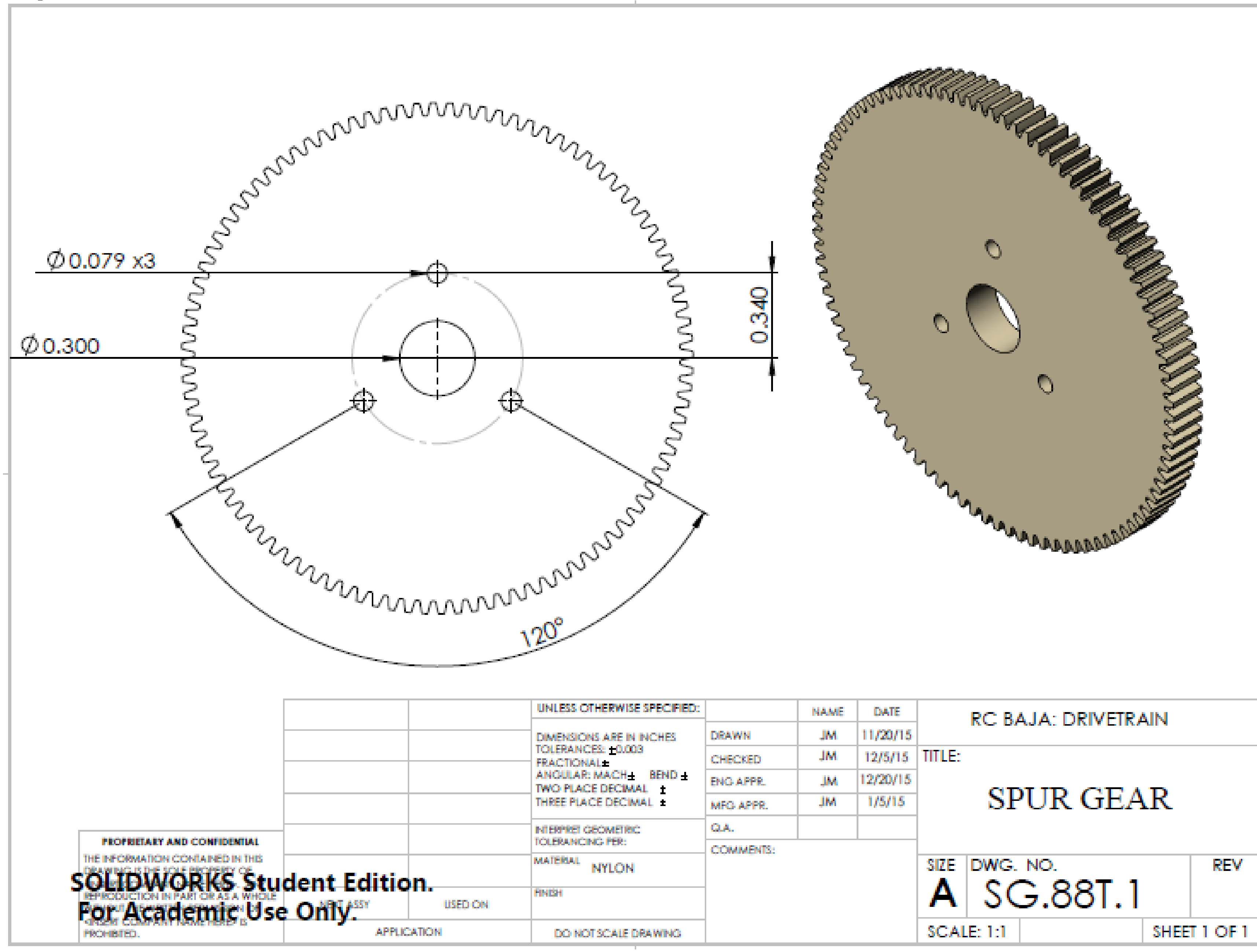


Figure 21.4: Spur Gear:



APPENDIX C – Parts List

Table 1:

Parts List				
Item #	Quantity	Part #	Description	Drawing # (if applicable)
1	1	N/A	Chassis Pan	CP 1
2	1	N/A	Spur Gear Mount	MM 1
3	1	TRA7041	48P 18T Pinion w/ 2.3mm shaft	N/A
4	1	N/A	Spur Gear Adapter	SGA 1
5	1	N/A	Spur Gear Shaft	SGS 1
6	1	TLR232004	48P 88T Plastic Gear	SG.88T.1
7	3	TRA1953	Sliding Driveshafts	N/A
8	1	N/A	Bevel Gear Mount	BGM 1
9	1	AX30402	Ring & Pinion Set	N/A
10	1	N/A	Bevel Gear Adapter	BGA 1
11	1	N/A	Bevel Gear Shaft	BGS 1
12	6	TRA5116	Bearings	N/A
13	1	AXA0175	Screw Shaft M3x2.5x11mm	N/A
14	20	TRA1985	Teflon Fiber Washers	N/A
15	1	TRA2216	Receiver Micro 4-Channel	N/A
16	1	TRA7075	Brushed Elctric Motor 1/16 Scale	N/A
17	1	TRA3024R	XL-2.5 ESC	N/A
18	10	6516	M2 nuts	N/A
19	10	8177	Socket Cap Screws M2 x 10	N/A
20	10	7816	Button Socket Cap Screws M3 x 10	N/A

APPENDIX D – Budget

Table 2:

Budget							
Item #	Quantity	Part #	Price ($)	Description	Vendor	Estimated Total Cost	Actual Total Cost
1	1	TRA7041	2.59	48P 18T Pinion w/ 2.3mm shaft	Amazon	2.59	2.27
2	1	TLR232004	4.99	48P 88T Plastic Gear	RC Hobbies	4.99	4.99
3	3	TRA1953	8.29	Sliding Driveshafts	Amazon	8.29	7.99
4	1	AX30402	31.5	Ring & Pinion Set	RC Hobbies	31.5	31.5
5	8	TRA5116	12.5	Bearings	RC Planet	12.5	12.5
6	1	AXA0175	4	Screw Shaft M3x2.5x11mm	RC Planet	4	4
7	20	TRA1985	1.51	Teflon Fiber Washers	Amazon	1.51	1.51
8	1	TRA2216	29.99	Receiver Micro 4-Channel	Amazon	29.99	25.43
9	1	TRA7075	13.27	Brushed Elctric Motor 1/16 Scale	Amazon	13.27	13.27
10	1	TRA3024R	49.99	XL-2.5 ESC	Amazon	49.99	45
11	1	TRA4628x	12.89	Steel Drive Yokes	Amazon	12.89	12.89
12	1	TRA1951	15.99	Assembled Driveshafts	Amazon	15.99	15.99
13	10	6516	0	M2 nuts	Beawest Fasteners	0	0
14	10	8177	0	Socket Cap Screws M2 x 10	Beawest Fasteners	0	0
15	10	7816	0	Button Socket Cap Screws M3 x 10	Beawest Fasteners	0	0
TAX & Shipping:							20.93
Totals:			187.51			187.51	198.27
Amount Budgeted:			250			250	250
Difference:			62.49			62.49	51.73

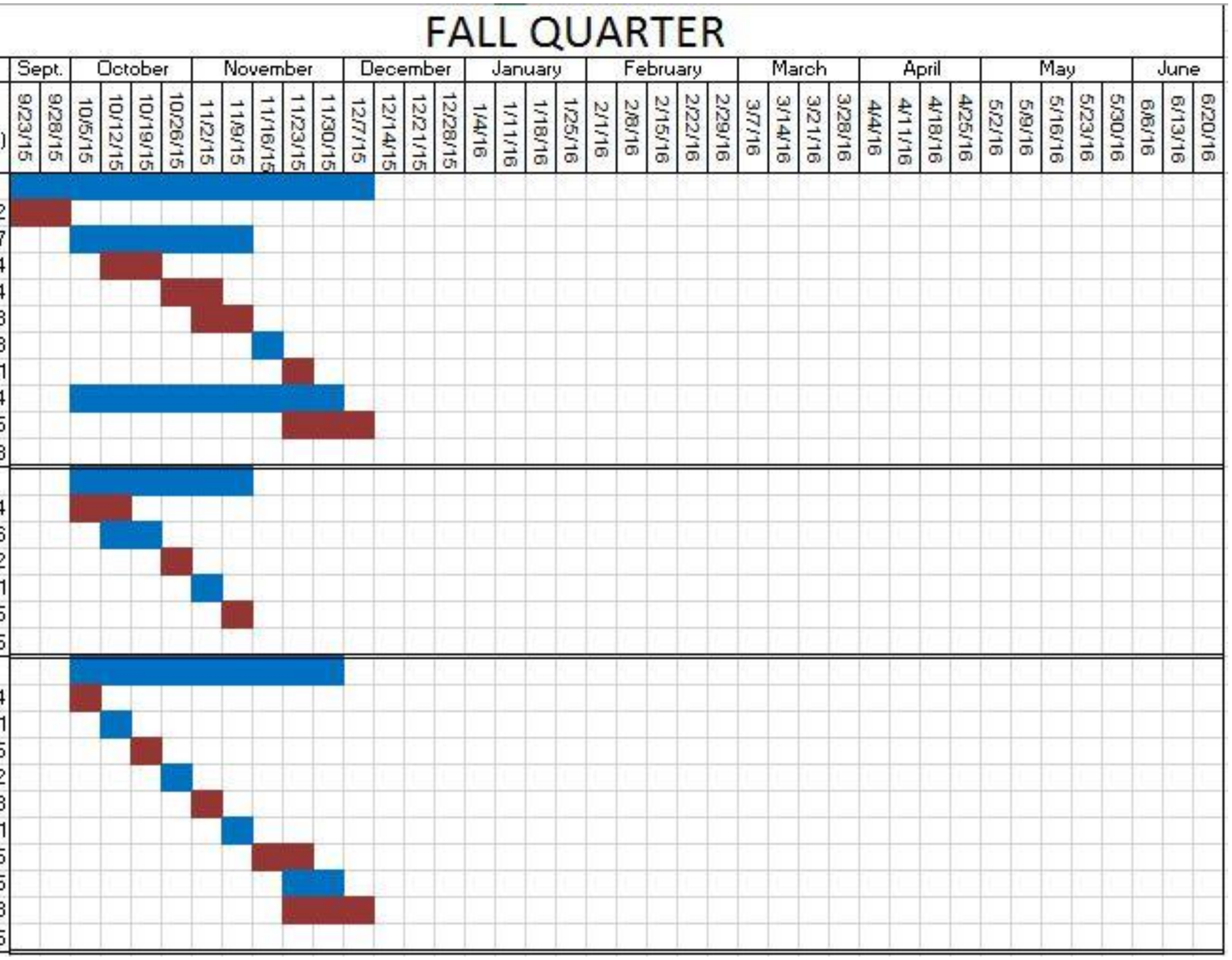
APPENDIX E – Schedule

Table 3: Schedule:

RC Baja Car: Drivetrain

Project Lead: Jason Moore

Task ID #	Description	Est. Time (hr)	Act. Time (Hr)
1	**Proposal**		
1a	Introduction	5	2
1b	Design & Analysis	14	17
1c	Methods & Construction	4	4
1d	Testing Methods	3	4
1e	Bugdet & Schedule	4	3
1f	Discussion	3	3
1g	Conclusion	2	1
1h	Documentation	10	14
1i	Appendix	13.5	15
	Subtotal	58.5	63
2	**Analysis**		
2a	Analysis of Spur Gear Set	4	4
2b	Analysis Bevel Gear Set	4	6
2c	Analysis of front shaft	2	2
2d	Analysis of Rear Output Shaft	2	1
2e	Analysis of Set screws	2	0.5
	Subtotal	14	13.5
3	**Documentation**		
3a	Drawing: Pinion (spur)	3	4
3b	Drawing: Gear (Spur)	3	1
3c	Drawing: Pinion (Bevel)	4	3.5
3d	Drawing: Gear (Bevel)	4	2
3e	Drawing: Driveshaft	1	3
3f	Drawing: Rear Output Shaft	1	1
3g	Drawing: Motor Mount	3	7.5
3h	Drawing: Bevel Gear Mount	3	5.5
3i	Update Website	5	3
	Subtotal	27	30.5



RC Baja Car: Drivetrain
Project Lead: Jason Moore

WINTER BREAK

Sept. | October | November | December | January | February | March | April | May | June

9/23/15, 9/28/15, 10/5/15, 10/12/15, 10/19/15, 10/26/15, 11/2/15, 11/9/15, 11/16/15, 11/23/15, 11/30/15, 12/7/15, 12/14/15, 12/21/15, 12/28/15, 1/4/16, 1/11/16, 1/18/16, 1/25/16, 2/1/16, 2/8/16, 2/15/16, 2/22/16, 2/29/16, 3/7/16, 3/14/16, 3/21/16, 3/28/16, 4/4/16, 4/11/16, 4/18/16, 4/25/16, 5/2/16, 5/9/16, 5/16/16, 5/23/16, 5/30/16, 6/6/16, 6/13/16, 6/20/16

Task ID #	Description	Est. Time (hr)	Act. Time (Hr)
4	**Proposal Modifications**		
4a	Project Schedule	10	7
4b	Project Parts List	2	3
4c	Design Review	4	7
	Subtotal	16	17

RC Baja Car: Drivetrain
Project Lead: Jason Moore

WINTER QUARTER

Sept. | October | November | December | January | February | March | April | May | June

9/23/15, 9/28/15, 10/5/15, 10/12/15, 10/19/15, 10/26/15, 11/2/15, 11/9/15, 11/16/15, 11/23/15, 11/30/15, 12/7/15, 12/14/15, 12/21/15, 12/28/15, 1/4/16, 1/11/16, 1/18/16, 1/25/16, 2/1/16, 2/8/16, 2/15/16, 2/22/16, 2/29/16, 3/7/16, 3/14/16, 3/21/16, 3/28/16, 4/4/16, 4/11/16, 4/18/16, 4/25/16, 5/2/16, 5/9/16, 5/16/16, 5/23/16, 5/30/16, 6/6/16, 6/13/16, 6/20/16

Task ID #	Description	Est. Time (hr)	Act. Time (Hr)
5	**Construction Process**		
5a	Buy Materials/Components	4	4
5c	Print Motor Mount	5	0.25
5d	Print Bevel Gear Mount	5	0.25
5e	Assemble Bearings in Mounts	1	0.5
5f	Print Gear Adapters	1	1.5
5g	Assemble gears to adapters	2	2.5
5h	Machine output shafts	4	5
5i	Assemble Gear Assemblies	5	2
5j	Troubleshoot Assembly	3	12
5k	Photograph & Document	2	2
	Subtotal	32	30
6	**Drive Train Evaluation**		
6a	List Parameters	2	1
6b	Obtain Resources	2	0.5
6c	Weigh all Components	2	2
6d	Perform Speed Test	1	1
6e	Perform Assembly Test	1	
6f	Volume Test	1	0.5
6i	Troubleshoot Drivetrain	4	4.5
6j	Photograph & Document	2	2
	Subtotal	15	11.5

SPRING QUARTER

RC Baja Car: Drivetrain			
Project Lead: Jason Moore			
Task ID #	**Description**	**Est. Time (hr)**	**Act. Time (Hr)**
7	**Deliverables**		
7a	Edit Presentation For Source	1	1
7b	Practice Presentation	2	0.5
7c	Source Presentation	2	2
7d	Finalize Report	2	1.5
7e	Make Presentation Outline	0.5	0.5
7f	Make Presentation	1	0.5
7g	Practice Presentation	0.5	0.5
7h	Update Website	4	2
7i	Final Presentation	0.5	0.5
	Subtotal	13.5	9
		Est.	**Act.**
	Total Project Hours	135	174.5
8	**Project Milestones**		
8a	Finish Proposal		
8b	Finish Assembly		
8c	Passes All Tests and Meet Req.		
8d	Compete in Mini Baja Race		
8e	Submitted Completed Project		

Month	Weeks
Sept.	9/23/15, 9/28/15
October	10/5/15, 10/12/1, 10/19/1, 10/26/1
November	11/2/15, 11/9/15, 11/16/1, 11/23/1, 11/30/1
December	12/7/15, 12/14/1, 12/21/1, 12/28/1
January	1/4/16, 1/11/16, 1/18/16, 1/25/16
February	2/1/16, 2/8/16, 2/15/16, 2/22/16, 2/29/16
March	3/7/16, 3/14/16, 3/21/16, 3/28/16
April	4/4/16, 4/11/16, 4/18/16, 4/25/16
May	5/2/16, 5/9/16, 5/16/16, 5/23/16, 5/30/16
June	6/6/16, 6/13/16, 6/20/16

APPENDIX F – Expertise and Resources

4.2 Mandatory Components:

Radio-controlled car parts which you must use, as specified here, without alterations. You must use the motor and the battery pack as specified below; these are the only sources of power that can be used for propulsion:

Propulsion Motor: One per vehicle. Propulsion motor may perform additional functions, and additional motors may be carried on the vehicle for other purposes, but only one motor may propel the vehicle. Any motor which conforms to current-vintage **ROAR** brushed or brushless specifications and manufacture is legal. “Brushed” motors: http://www.roarracing.com/approvals/smotor.php “Brushless” motors: http://www.roarracing.com/approvals/brushlessmotors.php ROAR” motors from previous-years’ vintages are also legal. If ROAR identification doesn't show on the motor, bring the box or literature.

Propulsion Battery Pack: One per vehicle. The propulsion battery-pack may perform additional functions, and additional batteries of other types may be carried on the vehicle for other purposes, but only one battery-pack may propel the vehicle. Propulsion battery-pack is defined as: any 7.2 volt battery-pack intended for RC use, any milliamp-hour rating. The vehicle’s batteries may be of any chemistry except lithium-polymer or other possibly-flammable type. Batteries may be un-wrapped and wired separately but not altered internally; bring the original case or wrapper to show type and classification. Teams may bring and swap-out more than one battery-pack to minimize “re-charging” downtime. Battery must be securely mounted to vehicle.

4.3 Purchased or Custom Made Components, Make or Buy, It’s your choice: Commercially-manufactured car parts which you may select and purchase, subject to these limitations; you may also make any of these items:

A. Transmitter, receiver, servo's: Your choice, make or buy, with proper Channel.
B. Speed control: Any available RC style – e.g. mechanical, resistor, or electronic – is okay. Home-made controls can be of any common RC style. Separate dedicated batteries just for your controls are acceptable, but they may not help propel the vehicle.

    a. Wheels, shocks, tank-treads, springs, hubs and spindles. Tires and traction devices that would leave marks on the venue’s floors will not be allowed.

C. Multiple servo's are okay.
D. Store-bought universal joints are okay.
E. Nuts, bolts, shafting, ordinary hardware and machine components; transistor and chip components.
F. Differentials made by the team from pre-existing separate components, or "toy-kit" (e.g: Erector SetTM; LegoTM) differentials, ARE acceptable. Differentials sold or intended for radio-controlled vehicles are NOT acceptable. You must describe the origin of your differential unit.
G. Non-functional ornaments. Body, if used, shall not interfere with inspection of car components.

"YOU MAKE IT” = the rest of the car.

APPENDIX G - Testing Data

Table 4: For Procedure 1

Speed test: Hogue Hall, Fluke Lab				
Trail	Time (sec)	Distance (ft)	Conversion Factor	Speed (MPH)
1	1.12	20	0.682	12.2
2	1.37	20	0.682	10.0
3	1.126	20	0.682	12.1
4	0.99	20	0.682	13.8
5	1.1	20	0.682	12.4
AVERAGE	1.14	20	0.682	12.4
Conversion Factor: feet per second to miles per hour				
feet to miles		Seconds to Hours		Factor
1 m/5280ft		3600s/1Hr		0.681818182
0.000189394		3600		

Table 5: For Procedure 2

Assembly/Disassembly Test		
Trial	Disassembly Time (min-sec)	Assembly Time (min-sec)
1	4:11	4:58
2	4:05	4:54
3	4:19	5:02
AVG	4:11	4:58

Table 6: For Procedure 3

Weight Test	
Trial #	Weight (lbs)
1	2.67
2	2.66
3	2.67
AVG	2.67

Table 7: For Procedure 4:

Volume Test	
Dimension	Value
Overall Length	6.2
Overall Width	3
Overall Height	2.8
Total Volume	52.08 in^3

APPENDIX H – Evaluation Sheet

Table 4.1: For Procedure 1

Speed test: Hogue Hall, Fluke Lab				
Trail	Time (sec)	Distance (ft)	Conversion Factor	Speed (MPH)
1		20	0.682	
2		20	0.682	
3		20	0.682	
4		20	0.682	
5		20	0.682	
AVERAGE		20	0.682	
Conversion Factor: feet per second to miles per hour				
feet to miles		Seconds to Hours		Factor
1 m/5280ft		3600s/1Hr		0.681818182
0.000189394		3600		

Table 5.1: For Procedure 2

Assembly/Disassembly Test		
Trial	Disassembly Time (min-sec)	Assembly Time (min-sec)
1		
2		
3		
AVG		

Table 6.1: For Procedure 3

Weight Test	
Trial #	Weight (lbs)
1	
2	
3	
AVG	

Table 7: For Procedure 4:

Volume Test	
Dimension	Value
Overall Length	
Overall Width	
Overall Height	
Total Volume	

APPENDIX I – Testing Report

Introduction: For the drivetrain on the RC car, a speed, assembly and disassembly, weight and volume test were performed. The requirements and parameters for this project included a speed of 20-25mph, a 5 minute assembly and disassembly time, a 3lb weight limit (of only drivetrain components) and a 6.5x3x3 volume. From initial calculations it was predicted that car would achieve at least 20mph, weigh less than 3lbs, fit within the required volume and be assembled and disassembled in less than 5 minutes. All of the appropriate data was taken with the necessary units and presented in tables. Refer to Appendix G for the testing data.

Method/Approach: The resource needed to complete these test include tape, tape measure, stopwatch, simple hand tools such as hex keys, and a scale. The data was initially gathered on raw data sheets at the location of the test and then processed later in excel and organized into tables. These tests were fairly simple and no special tools or resources were need for the test procedures. The procedures included gathering the appropriate supplies for the given test, perform the test, record the results and then clean up. The only operational limitations occurred with the speed test where the battery pack and motor were the biggest determinates of the actual speed of the car. There were some energy losses in the actual drivetrain itself as well. Due to the simplicity of these tests, there is no need for high precision or accuracy and nothing was recorded past 0.1 (units) and most weren't recorded past the decimal. All of the tests were performed multiple times for accuracy however. The only data manipulated occurred with the speed test because it was recorded in feet/second and had to be converted to MPH which is, again, another simply manipulation.

Test procedures: To perform all four tests took 4-4.5 hours. The speed test took one hour, the assembly and disassembly tests took two hours and the weight and volume tests took a little over an hour to perform. The longest test being the assembly test because the drivetrain was repeatedly assembled and disassembled and each took roughly 5 minutes and each was repeated three times. All of the test were performed in Hogue hall where the resources were available. The following are the procedures for each of the 4 tests that were performed.

<u>Speed: Hogue Hall, Fluke Lab: Reference Table 4 and 4.1 in Appendix G</u>

1. Measure out a 20ft distance with a tape measure and put tape markers at 0ft and 20ft. Allow for 10ft before the 0ft marker location for acceleration.
2. Have one partner stand upstairs with a stopwatch, overlooking the 20ft distance.
3. Accelerate the RC car to a constant speed before the 0ft location.
4. Once car is at constant speed, record the time it takes for the car to span the 20ft distance.
5. Calculate the MPH that the car reached using the general equation Speed=distance/time and apply the proper conversions.
6. Repeat steps 3-5 five times while slowly increasing the speed until the car reaches at least 25MPH.
7. Measure and record in excel spreadsheet.

<u>Assembly & Disassembly: Hogue Hall, Fluke Lab: Reference Table 5 and 5.1in appendix G</u>

8. Start the timer and begin disassembly of the drivetrain.
9. Stop the timer when disassembly is complete.

10. Record time.
11. Reassemble drivetrain and record the time.
12. Stop the timer when reassembly is complete.
13. Record time.
14. Repeat 3-4 times and record data in excel spreadsheet and calculate the average time.

<u>Weight: Hogue Hall, Fluke Lab: Reference Table 6 and 6.1 in Appendix G</u>

5. Disassemble drivetrain assembly from chassis.
6. Weigh drivetrain 3-4 times for accuracy.
7. Record weights in table.
8. Calculate average.

<u>Volume: Hogue Hall, Fluke Lab: Reference Table 7 and 7.1 in Appendix G</u>

5. Measure overall height.
6. Measure overall width.
7. Measure overall length.
8. Calculate total volume.
9. Repeat 3-4 times for accuracy.
10. Record data in table.

The biggest risk concerned with these tests was time due to various deadlines that had to be met. The only safety concern is with the speed test. There was potential for it to hit someone at its max speed however, since it didn't reach 20 MPH this concern dissipated. The area was marked of just to be safe anyways. Another smaller risk was that some of the components could have been lost because they are so small and hard to handle. Because of this, extreme organization took place during the assembly and disassembly tests.

Deliverables: For the speed test, it was predicted to go about 20MPH (max speed) but after performing the test, the average speed was around 12MPH due to various losses in the drivetrain and the power supply. A bigger motor would be an economical and relatively easy achieve the 20MPH requirement. The assembly and disassembly tests resulted in times under 5 minutes with disassembly taking 4:12 minutes (average) and assembly taking 4.58 minutes (average). The weight test also did well with the drivetrain weighing in at 2.67lb and the volume test resulted in a 6.2X3X2.8 in^3 Volume. Overall the test were considered a success other than the speed test. It's worth noting that the speed test was based off the output RPM of the motor and the gear ratio and not the power supply and loss in the gear sets and drive shafts.

Figure 22 1: **Speed and alignment testing**

APPENDIX J - Resume

Jason Moore

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Ravensdale WA, 98051
253-569-6922
Jason400m@live.com

Objective:

- Secure a challenging yet rewarding mechanical engineering internship or entry level position that will help me gain valuable work experience and expand my knowledge to better prepare me for a future engineering career.
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Education:

Central Washington University , ABET Accredited
2011-Present

- Major: Bachelor's Degree, Mechanical Engineering Technology
- Minor: Business Administration
- Expected Graduation Date: June, 2016
- Member of Honors Society
- Senior Project: Design, build and test ASME mini Baja RC drivetrain

Enumclaw High School Diploma 2010

- Two years of Automotive Technology
- One year of Welding

Work Experience:

Assembly Department, *Sase Company Inc.*
2010-Present

- Assemble various parts into subassemblies for industrial concrete diamond grinding machines by means of torqueing, pressing, using jigs etc.
- Completing the final details of the machines such as testing, labeling, and checking the quality of the finished product.
- Check parts for conformity to insure they meet the standards required and inform management of any flaws or defects to the parts or machines during the assembly process.
- **Experience Leadership Project**, *Central Washington University* Fall, 2011
- This was a leadership camp where we were split into teams and given challenges to overcome with the purpose to build on our value of teamwork, communication and trust so we would learn effective leadership styles and techniques.

Assembly, *Helac Corporation* Summer, 2013

- Assemble small subassemblies for hydraulic rotary actuaries.
- Drill and lock caps onto helical components.
- Clean and wash parts to ensure no foreign objects get into the hydraulic assembly.

***Asset* Renovation and Maintenance**, *Greater Seattle Area* Whenever Needed

- My role was to assist the general contractor which included pressure washing, paint preparation, painting, fence building, basic plumbing etc.

Relevant Courses:

Mechanical Engineering Technology Courses, *Central Washington University*

IET160 Two-Dimensional Modeling

- Hands on training in the operation of AutoCAD's design and drafting software.
- Some practice using Rhino software.

IET265 Three-dimensional modeling

- Design of parts, assemblies and working drawings using SolidWorks software.

MET 255 Basic machining

- Hands on experience with basic metal working machines and processes.

MET 355 Advanced Machining and CNC programming

- Hands on training with automated machines and processes.
- Machining of metallic and non-metallic materials.

EET 221 Basic Electricity

- Training with the basic principles of AC, DC, series and parallel circuits with some emphasis on the theories of resistance and capacitance.

MET 357 Welding

- Hands on training with arc welding, oxyacetylene welding and cutting, MIG, TIG, and plastic welding.

Jason Moore

253-569-6922
Jason400m@live.com

Relevant Courses:

Business Administration Minor Courses, *Central Washington University*

HRM 381, Management of Human Resources

- Practice of HR strategies, methods of training and retaining workers and public relations.

MGT 380, Organizational Management

- Introduction to the history and development of management ideas and contemporary practice with an overview of the major elements of the managerial function.

MKT 360, Principles of Marketing

- Introduction to the function and process of marketing concepts including market opportunities, product decisions, promotion and communication strategies etc.

BUS 241, Legal Environment of Business

- Introduction to legal reasoning, ethics in business, the law of contracts and personal property.

Technical Skills Courses, *Central Washington University*

COM 345, Business and Professional Speaking

- Oral communication in career and professional settings with a focus on public presentations, briefings, and persuasion.

English 310, Technical Writing

- Practice in writing analytical and technical reports with emphasis on gathering primary data.

IT 101, Information Technology

- Basic skills in Windows including Microsoft Word, Excel, PowerPoint and Access.

Clubs/Volunteering /Accomplishments:

- Certified SolidWorks Associate – Mechanical Design
- Honors Society Certification
- Society of Manufacturing Engineers Club
- Volunteered at VEX Robotics competition – Central Washington University
- Volunteered at Boo Central – Central Washington University
- Saul Hass Walk – Enumclaw, Washington
- Portland Brain Tumor Walk – Portland, Oregon
- Volunteered over 30hrs at Fright Factory – Buckley, Washington

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References are available upon request.