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RC Baja: DriveTrain

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MET Senior Capstone Projects

RC Baja: Drivetrain

By

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Abstract

The American Society of Mechanical Engineers (ASME) annually hosts an RC Baja challenge, testing a RC car in three events: slalom, acceleration and Baja. Although ASME will not be holding an event this year, CWU will be holding an event with three RC Baja car teams from CWU as well as other teams from local colleges. The RC car that is tested in these events is designed and manufactured typically in teams of two. The RC car that each team submits must be able to complete these events to score points. One part of great importance for the RC car is the drivetrain. The drivetrain of the RC car will need to operate continuously through each event and without interfering with the remaining components of the RC car, namely the suspension and steering designed by Hunter Jacobson. The RC car for this year features a 540 DC electric motor cradled in a 3D printed mount. A gear reduction of 5.14:1 is accomplished with a 14 tooth pinion and 72 tooth gear. The gear is on a shaft with a timing belt sheave. This belt then drives the rear axle. The design of the drivetrain incorporates a simple and effective design that can be repaired easily if necessary and fulfils the design specifications outlined by ASME. The design of the RC cars drivetrain has been tested to verify the requirement that it will reach a top speed of 25 mph.

1: INTRODUCTION

Description:

Every year Central Washington University or ASME puts on a design build competition for RC Baja cars to compete against different teams in the school or region and race their cars through different courses. For this competition there is a need to design a functioning drivetrain, chassis, steering, and suspension for an RC car to compete against other RC cars in an array of racing competitions including Acceleration, Slalom, and Baja.

Work on the project will be divided between the two partners, Nick Paulay and Hunter Jacobson. Nick will be working on the Drivetrain/Chassis and Hunter will be working on the Suspension/Steering. The drivetrain is going to be the main focus of the engineering work in this proposal with the majority of the analysis focused on its design. From past projects, the problems that groups have generally faced have been with reliability and functionality of the drivetrain components. To combat any problems with the drivetrain, it will be designed to be as simple as possible with parts being interchangeable on the fly if needed. The chassis will be made to support the weight of the drivetrain, suspension, and steering while also being as lightweight as possible.

Motivation:

The desire to design the best overall car for a racing competition was the real motivation behind doing this project for our senior project. Being able to compete against other teams with our design and seeing how it compares and performs is a large part of why there was a drive to pick this project.

Function Statement:

Devices are needed to make our RC car drive by applying power from the motor to the wheels as well as a chassis to hold the cars components together during 3 different races (Acceleration, Slalom, and Baja) and figuring out the best overall design to manage each style of race, all while competing against other race teams.

Requirements:

- The car must be conceived, designed, and fabricated by students without any direct involvement from professional engineers, automotive engineers, or related professionals.
- One propulsion motor per vehicle: Any motor which conforms to current-vintage ROAR brushed or brushless specifications and manufacture is legal.
- One battery per vehicle: any 7.2 volt battery-pack intended for RC use.
- Baja TIME-LIMIT, equivalent to running the full course at 1.0 MPH.
- Car must weigh under 5 pounds.
- Must be able to sustain 25 mph at full speed.
- Keep cost below $500 for Drivetrain.
- Drivetrain height restriction of 3 inches off of chassis base.
- Battery will sustain power for 10 minute to motor at full power without dropping RPM’s

- Motor will maintain a temperature below 150° F at max load.
- Construction, mounting, and deconstruction of the entire drivetrain will take less than 10 minutes to keep design as simple and as resistant to failure as possible.
- The motor mount will be able to tension the belt with all the gears mounted

Engineering Merit

The engineering merit for this project comes from the calculations in the analysis section of Appendix A for the design of the drivetrain based off of the requirements set forth in section 1d. The scope of the analysis will be laid out step by step in the analysis description section 2c. The design of the drivetrain will include velocity ratios, spur and timing pulley design, torque, bending stress, contact stress, torsional stress, and other analysis based off of "Mott's: Machine Elements in Mechanical Design" and "Marks Standard Handbook for Mechanical Engineers". The RADD metric will be used to ensure proper documentation for the listed requirements.

Scope of this effort:

Focus is mainly going to be on making the drivetrain. An in depth look based off of the motor RPM and the desired speed reveals we will be needing a double reduction drivetrain, utilizing spur gears for the first reduction and a timing belt for the second reduction.

Success of the project:

Success of the project relies on the completion of a sound drivetrain without any slippage, breakdowns or major problems while completing each course. It also relies on the reliability of the design and production of parts, as well as the correct design calculations to make those produced parts. If the project can meet its requirements in section 1d as well as reach its calculated speed based off of the analysis provided in Appendix A, then the project will have a shot of meeting its benchmark of getting first place in the competition

DESIGN & ANALYSIS

Approach: Proposed Solution

The approach to this engineering problem includes designing all the components for a functioning drivetrain. The components needed for a complete and functioning design include a spur gear reduction, a timing belt reduction, the appropriately sized shafts, bearings, mounts, axles, wheels, and additional hardware. Upon completion of the design and proposal, the parts will be purchased or manufactured from raw material and constructed. Upon completion of the construction, the testing phase will commence as stated in the schedule in Appendix E.

RADD Metric:

The engineering merit of a project such as this one needs supporting documentation to prove the requirements listed can be accomplished. For instance, the requirement that this car needs to be able to travel 25mph at max speed is supported by documentation in the analysis section of Appendix A. In this requirement, the analysis uses a few equations to design the drivetrain. Since we have an input and an output RPM, there is going to need to be a gear reduction. A gear reduction uses an equation called a velocity ratio to help determine gear sizing.

- $VR = \frac{input\ RPM}{output\ RPM}$

Due to having such a large ratio, a double reduction drive was needed. A second equation was then needed to find the Final Drive Ratio (FDR), also known as Train Value (TV).3

- $FDR = VR_1 \times VR_2$

Using this analysis to suit the requirement, the design description (Section 2b) for the drivetrain then shows sketches and descriptions of the drivetrain which helps support the analysis. The final drawings of the design can then be found in Appendix B. The requirements, analysis, design and drawings makes up the RADD metric that is used to properly display the engineering merit of this project.

Design Approaches:

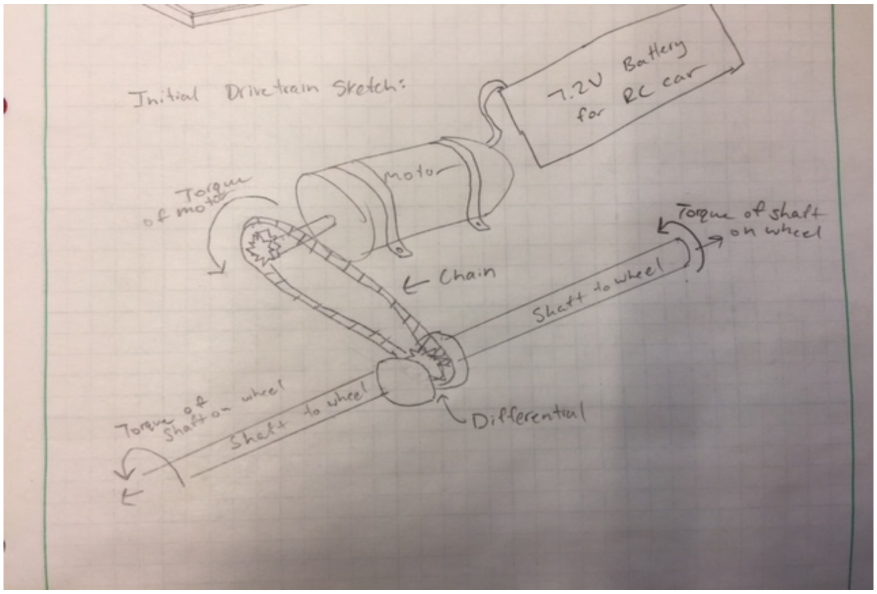
Initial design concept: The design of this drivetrain is based off of using an electric motor powered by a 7.2V battery to drive a chain connected to a differential via sprockets on motor and differential to power both wheels. Decision to go with chain is to reduce slippage on initial acceleration compared to a belt drive.

The motor turning will result in a torque on the chain which will cause the chain to move which will turn the gears in the differential which will in turn rotate the axels turning the wheels. We will be reusing a DC electric motor from a previous RC project.

Updated approach: The motor is mounted in a bracket with two set screws on the shaft face. The first spur gear is mounted on the motor shaft attached via press fit. This will mesh with the double mounted spur gear/timing belt pulley. The double mounted pulleys are idling on a shaft that is mounted on the motor mount block with two ball bearings. The timing belt pulley will then drive a timing belt to the rear axle timing belt pulley on the rear axle which will then drive the rear axle. It is proposed to not use a differential in this case to reduce the margin of error for parts to fail in the system as well as have full power to both wheels at all times which will benefit us in the acceleration and Baja races, however it will make the slalom race more difficult than it would be if we had a differential due to the outside wheel on a turn not turning more than the inside wheel would.

Design Description

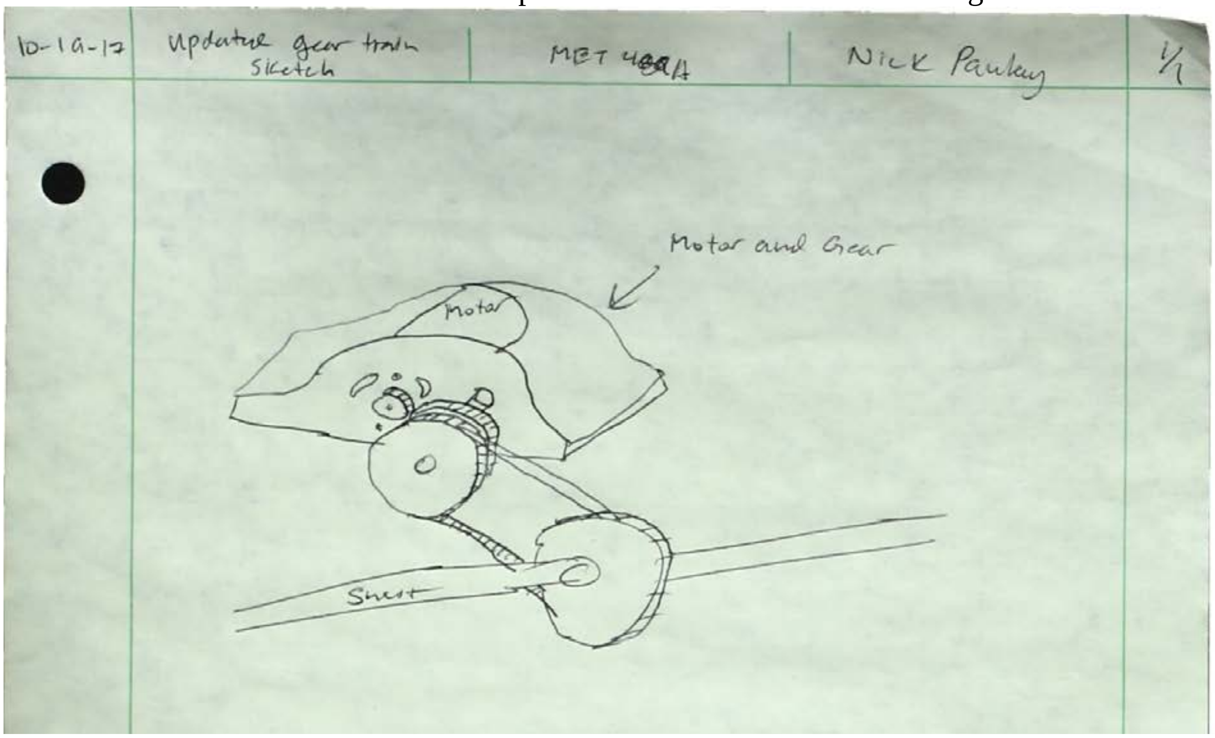
Initial Drivetrain Sketch:

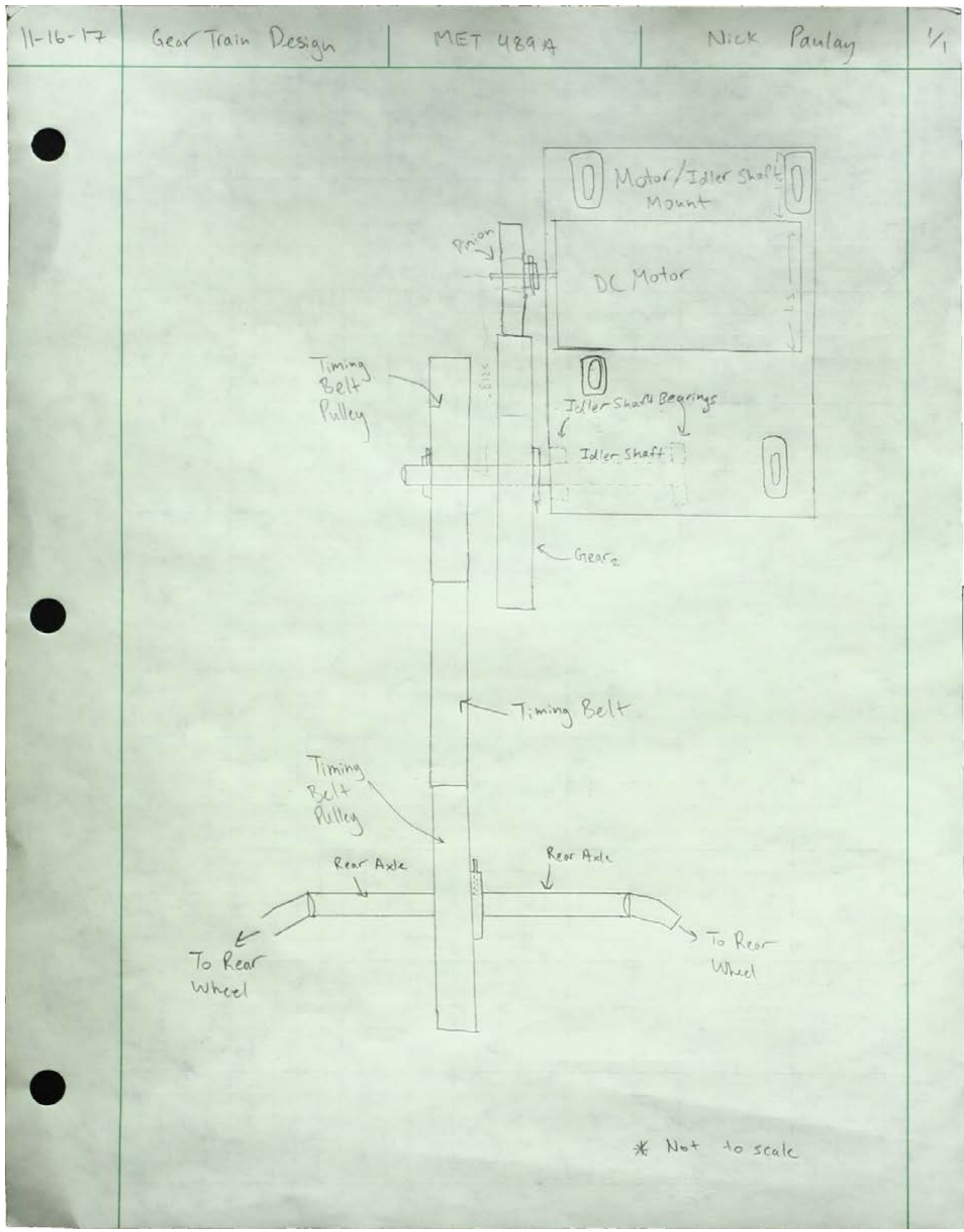


Initial Design Description:

Initially the design was a simple chain drive directly to the rear axle from the motor but after looking at the motor specifications and the cars desired speed, it was realized that the car would need more than a single reduction drive train. After doing more analysis on the design, it was determined that it would need to be a double reduction drivetrain utilizing spur gears and a timing belt to power the rear axle at the right speed to be successful in the competition.

Below is the updated sketch of the drivetrain design:





Updated Design Description: The motor is mounted in a bracket with two set screws on the shaft face. The gear coming off of the motor shaft attached via press fit mesh with the double mounted spur gear/timing belt pulley. The double mounted pulleys are idling on a shaft that is mounted to two ball bearing in the motor mount block. The timing belt pulley will then drive a timing belt which will power the rear axle.

Benchmark:

Overall, the goal of this project and competition is to design the best car in every aspect compared to the other cars being designed for the competition. We can compare the cars abilities in other ways outside of just the competition results.

- Weight
- Speed
- Cost

Alongside the competition, these three classes can also be weighed into the conversation to decide best overall design. If the best car was the lightest, fastest and cost the least, then hypothetically it would be the best of the competition. These factors can be set as a personal benchmark for the project alongside the competition results.

Performance Predictions:

The drivetrain of this vehicle will be able to make the car go at least 25mph based off of the standard gears specified in the analysis that were picked based off of the velocity ratios for each reduction.

In order for this requirement to work, standard gear sizes will need to be used. In previous calculations, the two velocity ratios were made equal. Due to the equal velocity ratios the standard gear sizes were closer together in size. This caused a smaller center distance than would be allowed if an idler shaft was going to be used. The updated sizes to make that idler shaft work with its bearings will be a pinion with 14 teeth and a gear with 72 teeth.

The car should be in the Top 2 in the competition for the Baja race due to the large 130cm size of the tire climbing over 2x4 wood logs and other obstacles it may face. It also shouldn't have any wheel spin due to not having a differential and a direct drive to both rear tires. Both of these factor will allow greater traction and give a reason to believe the car will place in the Top 2 of the competition in the Baja event.

Analysis Description:

This list of analysis descriptions takes you step by step for the calculations in Appendix A.

1. Analysis 1 shows the calculation for finding the axle rotational speed based off of a desired top speed and the tire diameter size. First the speed is converted from miles/hour to inches/minute. We use the equation:

   $$Vehicle\ Speed = Circumference\ x\ RPM$$

   The speed being inches/minute, circumference being in Inches and RPM in rotations/minute. With these units the calculation will work out. We have vehicle speed and tire circumference so we can then solve for RPM which turns out to be approximately 1643 RPM. Moving forward with the drivetrain design, this value will be known as the desired output RPM.

2. The next analysis is the beginning of the actual drivetrain design. There is now an input RPM which was given from the Mabuchi Motor Specification sheet located in Appendix F, as well as our desired output speed. The final drive ratio equation is then used to determine the ratio between the two RPM's.

$$FDR = \frac{input\ RPM}{output\ RPM}$$

The FDR turned out to be about 12.2:1. Mott's "Table 8-7" on page 287 shows that for 20^o involute full depth tooth form, the maximum ratio between mating spur gear teeth to ensure no interference is 6.31:1. Obviously the 12.2:1 is larger than the 6.31:1 so a double reduction is necessary.

C-C Distance: $C - C = \frac{N_p+N_g}{2P_d}$

Accounting for the center to center distance first to ensure room for the idler shaft parallel to the motor, a C-C of 1.34 inches is found. The first set of spur gears will have a velocity ratio of 5.14:1. The pinion will have 14 teeth and the gear will have 72 teeth. The second reduction velocity ratio can be found from the equation:

$$FDR = VR_1 * VR_2$$

VR_2 ends up becoming 2.37:1 after plugging in the known values.

3. Continuing with the gear design on sheet 3, the VR_2 was 2.37:1. With this knowledge, we can use small gear sizes to conserve space and weight. The difference in number of teeth will be smaller than the first reduction due to the smaller velocity ratio. Say $Pulley_1$ had 14 teeth. Multiply that by the VR and the result is about 33.2 teeth. The next standard gear size is 36 teeth for a 0.200 in pitch belt pulley.

Now that we have the Timing Belt pulley sizes we can determine the C-C distance between the pulleys along with the appropriate belt length/size to buy. Equation 7-8:

$$D_2<C\text{-}C<(3(D_2+D_1))$$

From this we can say that the C-C Distance of the pulleys is between 2.27 and 10.17 inches. To conserve space the distance will be about 4". We can then find the pitch length or length of the belt using Equation 7-3:

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 + D_1)^2}{4C}$$

From this equation we were able to size a Gates XL-0.200 timing belt at 14 inches long with 70 teeth from their belt guide.

4. Analysis page 4 shows a summary of every gear and belt that will need to be bought with its corresponding specs off of the McMaster Carr and Gates website. The gears are the most important part of the drivetrain and will likely be bought. The shafts will likely be machined.

5. The next analysis sheet shows the horsepower and pitch line speed calculation. Horsepower of the motor can be calculated off of the given info from the motor spec sheet in Appendix F. The equation for Horsepower is:

$$HP = \frac{nIE}{746}$$

This equation gave us a horsepower of about 0.06 HP, this was then verified using engineering toolbox due to it seeming lower than expected.

The next calculation was finding the pitch line speed. This is used to assist in finding the transmitted load. Using equation 9-1 from Motts:

$$V_t = \frac{pi * D_p * \ n_p}{12}$$

This gave a pitch line speed of approximately 2,298 ft/min. This will be used in the next analysis for finding the transmit loads on the teeth.

6. This next analysis sheet shows the forces on the teeth of the gears. We found the forces that G_1 would put on G_2. The tangential, radial and normal force are to be found using the tangential force equation and basic geometry.

Tangential Force:

$$W_t = \frac{Pwr}{V_t}$$

The figure in Analysis 6 shows the way the radial, normal and tangential forces interact on the tooth and how to solve for each one based off of the tangential force found of $0.86lb_f$. Using cosine we were able to find the normal force of 0.91 lb_f and tangent to find the radial force on the teeth of 0.314 lb_f. From these values we will be able to find the bending stress in the teeth as well as the contact stress and the shear stress in the set screw pin to make sure that they won't fail.

7. Analysis 7 shows the process of finding the Bending stress in the teeth on the second spur gear transmitted from the pinion. We can use bending stress equation from Mott:

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

From this equation and all the givens found from the tables and graphs in the book, the bending stress is about 612 psi. This is less than the bending stress of the material.

8. Analysis 8 shows the calculation for finding the contact stress of the gear. Using the equation:

$$S_c = C_p \sqrt{\left(\frac{W_t K_o K_s K_m K_v}{F D_p I}\right)}$$

We have the tangential force from the previous calculation as well as F; the gear width, pitch diameter, and everything else was taken from the textbook charts and tables in the section where the equation was found. The contact stress ended up being about 23,300 psi which is within spec for the material we are using. The contact stress is concerned with the design life and pitting which is not a big concern due to the design life being so short.

9. The 9th analysis sheet is concerned with the shear stress in the set screw for the driven spur gear. The equation for shear stress was used:

$$\tau = \frac{F}{A}$$

If we use the normal force of 0.91 lb_f and the cross sectional area of 0.044 in^2 then we will get a shear stress in the screw of 20.8 psi which is nowhere near the yield strength of steel at 36 ksi.

10. The following greensheet shows the calculation for determining the deflection force required to tension the belt to the required tension which was also found in this analysis. Using the tensioning guide located in Appendix F from the SDP/SI website, the deflection force was first found using the equation shown:

$$Deflection\ force = \left(\frac{T_{st} + \left(\frac{t}{L}\right)Y}{16}\right)$$

From this equation, the force of 4.326 lb. was found. This is the force required to be able to tension the belt using a force tensioning tool. The next calculation was then to discover the belt deflection distance to ensure a properly tensioned belt. The force found before is approximately equal to the tension the belt needs to be at. A general rule of thumb is to have the belt deflection distance be 1/64th of the distance span. With our distance span of 4” from Analysis 3, this gives us a deflection distance of about 0.0625”.

11. The next sheet shows the torque applied to the rear and the max torsional stress that the shaft receives. Using a torque equation:

$$T = PWR * \frac{5252}{RPM}$$

The torque on the rear shaft will be 0.19 ft-lb of force on the shaft. This torque can then be applied to the torsional stress equation:

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

Using the torque calculated, radius of the shaft, and polar moment of inertia of a circular shape, the max torsional stress of 31.7 psi was calculated.

12. The last analysis on the drive train was finding the max angle that the driveshaft will move off of horizontal when sitting on the ground. The max angle is 10^o which is based off of it being lifted off the ground. With the set-up we have, the driveshaft will be at an approximate angle of 9.8^o which is rather close to the 10^o max angle. Once the car is on the ground and under the load it should move close to 0^o.

Update: Post Construction/Winter Quarter

13. After assembly had been completed, more analysis was necessary when the rear axle 36 tooth pulley would not fit in its space. The only one that was able to fit was the 14 tooth gear that was on the idler shaft. After looking at alternative possibilities, the suspension that had been machined could not be altered enough to make it possible for a different pulley to be placed in the space so a second pulley was purchased of the same size as the first pulley. This makes the second "reduction" no longer a reduction and instead was just 1:1. For the analysis, a new final drive ratio was needed to be determined as well as the projected output velocity at full speed. A new belt length was also necessary to calculate.

    The new final drive ratio came out to 5.12:1. The max theoretical velocity of the car is now 59 mph, unfortunately this is unrealistic because the motor can't possibly give that much torque to the rear wheels. Expecting it to be able to go around 25mph still in the shorter distances.

14. The updated belt pulleys required an updated belt size as well so using the belt length equation a 12inch XL 3/8 wide belt was purchased.

15. The last analysis done was a torsional stress calculation in the shafts going out to the wheels. The shafts themselves were purchased and are adjustable but for simplicity the smallest diameter of the shaft was found and an analysis of the average length was done using the torsional deformation equation found in the Mott Machine design textbook. The torsional deformation came out to 0.14 degrees which is perfectly fine for this application.

Scope of testing and evaluation:

The scope of testing this project is focused around the ease of assembly and disassembly of the drivetrain. There will be minimum time between races that we will have to fix issues with the drivetrain if a part breaks so that is our first focus. With that in mind, the design of the drivetrain was really taken into account with tensioning the belt and taking the parts out of the motor bracket, and the rear axle. It was decided that beyond this that 3 main tests would be taken into consideration. The first test is that the drivetrain will be able to make the car get up to a speed of 25 mph. The real determining factor is the acceleration of this test for the acceleration event. If it takes an extended amount of time to reach that speed then the acceleration event will be a bust. The second test is make sure that the motor won't overheat after continuous use. We will be looking into the motor's temperature after 10 minutes of use and that it maintains an outside temperature of 150^{o} F. The third test we will perform is that the entire drivetrain can be assembled and disassembled in less than 10 minutes to keep the design simple.

Analysis:

I. The initial approach to understanding the problem was to do some research on remote controlled car drivetrains and how they operate. The first step to the analysis was to determine what set-up was going to be used. We were given the drive source which is a small DC electric motor.

II. The next step was determining how many and what type of reductions were going to be used to drive the wheels. The set-up we went with was the spur gear initial reduction and the timing belt secondary reduction. The hard decision here was whether or not to use a differential or not. The design would have a greater element of risk with the drive due to the complexity of the differential. It was decided to go without to keep the drive simple which was important to the design from the beginning. From here we set out doing calculation on the drivetrain which are shown in the analysis description section above.

III. Tolerances: One of the main design parameters that needed to be considered was the space available for the drivetrain to sit. The drivetrain was designed right of center, so the majority of the weight is going to be on the right side of the chassis. Although a small amount of weight this shouldn't change the design at all.

Technical Risk Analysis

The main risks associated with this project is time and money. This projects competition is actually a few weeks before the senior projects are due so this project needs to be done earlier than the other senior projects. With that said there are only a few parts like the motor mount and shafts and pins that are going to be made while the rest of the gears are going to be bought or donated. The budget is going to be tight on this as shown in the budget section below.

METHODS & CONSTRUCTION

Construction

The construction of the drivetrain for this project is going to be of two assemblies connected by a timing belt. The first assembly has the motor/idler shaft mount with the 540 DC electric motor and spur gear reduction and the first pulley in the second timing belt reduction mounted on its idler shaft. The second assembly has the rear axle shaft with the second timing belt pulley and the rear axle shaft driving the wheels. The construction of the drivetrain has to wait until the chassis and suspension has been assembled because it mounts onto the chassis and thru the suspension. Upon completion of construction, adjustments are going to be needed for belt tension, motor set-up including soldering wire to motor leads and setting up the controls and receiver which are being borrowed from Professor Beardsley of the M.E.T department.

Description

Assemblies will have a mix of produced and purchased parts. The engineer will produce the mounts for the motor, bearings, driveshaft, and shafts to rotate about. The driveshaft, gears and bearings will be designed to mesh without interference and modeled in Solidworks to show the mechanics work before buying and constructing. The contest rules permit the use of purchased components shown in the Appendix resources section. Full rules and regulations for the competition as far as building is in the resources section. The list of the assembly of each part is detailed below:

A) Assembly 1- Motor/Idler Shaft mount with mounted spur gear reduction
   1) Mabuchi 540 DC Electric Motor
   2) Pinion Spur Gear 32P 12 teeth
   3) Gear spur 32P 72 Teeth
   4) Timing Belt Pulley 14 tooth
   5) Idler shaft 1/4in steel 4in Length
   6) 2, ¼ in idler shaft bearing
   7) 2, bearing holders
   8) Motor and idler shaft mount
   9) Hardware

B) Assembly 2- Timing belt reduction/rear axle shaft
   1) XL-0.200 Gates Timing belt 14inch 70 tooth
   2) Timing Belt pulley 14 tooth
   3) 3inch 1/4” Rear axle shaft
   4) 2, ¼” inch mounted bearings
   5) Hardware
   6) Shafts out to Wheels
   7) 4, 5.1” OD Wheels

Resources

Purchased components will be resourced online through the least expensive websites for each part while other parts will be made in Hogue Hall using the machine shop and 3D printing lab. The mounts and supports will be 3D printed and the shafts will be machined using an engine lathe. The time spent doing this is donated through the school so there is no labor cost. The 3D printer will require a payment for the material to print the parts but the use of the machine is free.

Drawing Tree

The drawing tree is located in Appendix B with the other drawings. It contains the visual aid of all the assemblies and components to each assembly. The drawing tree is organized starting with the complete assembly and working its way down each assembly and breaking it into components.

Part List

A list of the parts used will be in the parts table in Appendix C detailing the part number, part description, estimated cost and actual cost. Overall there is 15 parts excluding hardware.

Manufacturing Issues

The major manufacturing issue is time. The entire car must be built and tested by the end of the winter quarter. The ASME competition is sometime right after we get back from break. Another issue is with 3D printing the bracket for the motor and idler shaft. The center distance between the two shafts that rotate the gears need to be almost perfect because the gears need to mesh and not interfere with each other. The drivetrain didn't have many manufacturing issues but the suspension components were sent out to get water-jet cut to save time.

TESTING

Introduction

Testing methods must be in response to requirements listed in the Requirements section. A minimum of 3 tests will be conducted on the requirements. The first requirements is that the motor at full throttle for 10 minutes won't reach a temperature above 150^{o} F. This test must be done to ensure the motor won't start to melt the 3D printed motor mount. The second requirement tested is maintaining the speed calculated by the analysis in Appendix A. Both of these requirements are relevant to the success of the project and therefor will be tested to produce satisfactory results. The last test will be the construction and deconstruction of the drivetrain which will need to take less than 10 minutes to accomplish. If this can be accomplished then it has been determined that the design is simple enough and repairs could possibly be made if necessary.

Method/Approach/Procedure

These requirements will be put to different tests to find if they are satisfactory or not. The first test that we will do is that the motor at full throttle for 10 minutes won't reach a temperature above 150^{o} F. This is to determine the motor won't have any issues mating with the 3D printer material and that it won't overheat. This test can be approached in two different ways. The first is using a laser temperature thermometer to check the temperature after 10 minutes of full power.

The second method is hooking up a temperature sensor to the electric motor to determine its temperature using a fluke multi meter. Both way will work to determine the temperature and both may be used. To test the second requirement that is maintaining the speed calculated by the analysis in Appendix A, we have two options. For the second test we have two ways for calculating the speed of the car after assembly.

1. Using a speed gun to measure speed in MPH over multiple trials to get an average top speed.
2. Setting a distance the car must travel once full speed has been hit and clocking the time it takes for the car to travel that distance over multiple trials to determine its top speed.

The next requirement to test is that the cars drivetrain can be assembled and disassembled in less than 10 minutes. To test this the entire drivetrain described in this proposal must be mounted on the car and disassembled. Then it must be reassembled and driven to determine it was put back together properly.

Deliverables

Appendix G shows the testing data for all of the procedures. 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/Schedule/Project Management

Budget

The original budget for this car was to keep the components of the drivetrain under $500. Once realizing the actual costs of some of these parts such as the motor and gears. The estimated cost for the parts is going to be around $240 which is detailed in appendix C. Once the construction phase has begun the actual costs of parts and materials will come in. Labor costs are going to be disregarded for work performed by the engineer/machinist on the project and will be referred to as “school work” for costs. Funding for this project will be coming from personal funds or donations by the CWU MET program such as reused or repurposed parts. Once construction begins, parts that may be repurposed from past projects will be determined.

The budget originally listed was within $50 of all the parts purchased. Currently extra parts were bought after some parts were found to not fit right so returns will be sent out during the transition to testing and a refund will be awarded so the actual cost around $220 will be more accurate. Full budget came out of personal funds and the resources provided by Professor Beardsley in his part bins.

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 fall quarter of this year while the second quarter consists of construction and tweaking/adjusting the fit of the cars parts together. The third quarter has the ASME RC Baja competition, SOURCE presentations and the final report due. Week to week tasks are outlined in the excel schedule in Appendix E for each quarter. Tasks are broken up into hours taken to achieve and are estimated hours. The total amount of hours to complete this project is estimated to be around 66 hours. Once the winter quarter has commenced the actual hours will be estimated to determine an error percentage in the initial estimate.

The schedule took an overhaul after fall quarter and many new features have been added including new tasks for winter and spring quarter, a completion percentage column and updated hours to the tenths of an hour. Winter quarter before had a big block as the schedule and that was fixed into its actual timeline for each task. After revising the Gannt chart with all the new tasks, an extra 20 hours of work had been added bringing the total up to 84.8 hours of work in total. Spring quarter hasn't been clarified as far as what's going to happen with the RC Baja competition and project presentations including SOURCE so the schedule was estimated until further information on those events becomes available. Looking into spring quarter, historically the Baja competition takes place a few weeks after school starts up; generally sometime in April. Central Washington University's SOURCE presentations will be taking place Wednesday, May 16, 8:00-5:30 pm and Thursday, May 17, 2018, 8:00 am- 5:30 pm on the Ellensburg campus in the Student Union and Recreation Center (CWU Website). Generally students in the MET department present their senior projects to the school during this time.

Project Management

Human Resources: Nick Paulay will act as project manager, engineer and machinist. His responsibilities on this project include analyzing drivetrains in other applications and applying a modified design to the project. This includes designing the various components through engineering calculations, ordering the materials and parts and actually machining them. The machining will be done in the machine shop in Hogue Hall. This machine shop has the engine lathe necessary to turn the shafts for the drivetrain. The design work will be performed using SolidWorks and engineering paper as well as online resources to check work. Solidworks will model the parts in the assembly to show that it works in theory. This project will be financed by the student engineer and a budget of $500 was set. It looks as though this was about double the amount needed however.

DISCUSSION

Moving forward with this project from the beginning there was constant changes being made. Initially the design was a simple chain drive directly to the rear axle from the motor but after looking at the motor specifications and the cars desired speed, it was realized that the car would need more than a single reduction drive train. After doing more analysis on the design, it was determined that it would need to be a double reduction drivetrain utilizing spur gears and a timing belt to power the rear axle at the right speed to be successful in the ASME competition.

From there the design was set about making it easy to tension the belt drive while not messing with the gears and it was decided that if the motor and spur gears were mounted on a block, then the belt could be tensioned with the block using tensioning set screws to hold the block down while the tension was checked. The light duty aspect of the recommended belt by Professor Beardsley makes it easy to hand tension. Other problems stemmed from this design however when the initial spur gear reduction calculations were done. The idler shaft that was going to be rotating on bearings parallel to the motors was clashing with the motor. The center distance between the two shafts was way too small. To fix this issue to allow the bearings and shaft to fit nicely next to the motor, a larger spur gear was made. This then solved the problem but not entirely. The height requirement was getting dangerously close to the limit set and continuous monitoring of the set-up upon construction phase will be the real determining factor if that requirement can be met in the end. For now there hasn't been any other issues to discuss, until winter quarter.

CONCLUSION

Every year Central Washington University or ASME puts on a design build competition for RC Baja cars to compete against different teams in the school or region and race their cars through different courses. This year partners Nick Paulay and Hunter Jacobson will be entering their RC car into the competition. For this competition there was a need to design a functioning drivetrain, chassis, steering, and suspension for an RC car to compete against other RC cars in an array of racing competitions including Acceleration, Slalom, and Baja. Work on the project was divided between the two partners. Nick will be working on the Drivetrain/Chassis and Hunter will be working on the Suspension/Steering. The drivetrain was the main focus of the engineering work in the proposal with the majority of the analysis focused on its design. From past projects, the problems that groups have generally faced have been with reliability and functionality of the drivetrain components. To combat any problems with the drivetrain, it was designed to be as simple as possible with parts being interchangeable on the fly if needed.

This drivetrain project is of great importance and interest to Nick to prove his engineering skills and to show the fundamentals of the courses he has taken while at Central to complete his degree. The drivetrain for the car has been appropriately modeled and shown to operate in the design software. The requirements and engineering merit were both reasonable accomplishments to achieve for this project and the project should function based off the design submitted.

ACKNOWLEDGEMENTS

The engineer designing this project would like to thank CWU MET department for all of its resources. Professor Beardsley, Dr. Johnson, Professor Pringle, Professor Bramble were all help with assisting on the design and creative thinking process that went along with this project so far. The engineer would also like to thank the engineering department for its use of the shop and 3D printing machines.

Resources

- Hibbeler, R. C. Statics and Mechanics of Materials. Upper Saddle River, N.J.: Pearson/Prentice Hall, 2004. Print.
- Mott, Robert L. Machine Elements in Mechanical Design. Upper Saddle River, N.J.: Pearson/Prentice Hall, 2004. Print.
- https://www.mcmaster.com/
- https://www.gates.com/~/media/files/gates/industrial/power-transmission/catalogs/gatesmectrol_belt_pulley_catalog.pdf

APPENDIX A – Analyses

Analysis 1: Calculating rear axle RPM at 25MPH (Full Speed)

10-19-17 | Axle RPM | MET 489A | Nick Pawlay | 1/1

~~Axl~~

Given: 25 mph top speed, 130mm OD tires

Find: RPM of ~~wheels~~ axle driving wheels

$$\frac{25 \text{ miles}}{1 \text{ hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 0.416 \text{ miles/min}$$

$$\frac{0.416 \text{ miles}}{1 \text{ min}} \times \frac{63{,}360 \text{ in}}{1 \text{ miles}} = 26{,}400 \text{ in/min}$$

Circumference: 130 mm → 5.118 in

$$5.118 \times \pi = 16.078 \text{ in}$$

Circumference × RPM =

$$16.07 \times \text{RPM} = 26{,}400 \text{ in/min}$$

$$\boxed{\text{Axle RPM} = 1642.8 \text{ RPM @ 25 mph}}$$

11-17-17	Gear Design Update	MET 489 H	Nick Paulay	1/2

Given: Input RPM : 20,040 , Output RPM = 1643 RPM

Find: First / Second reduction ratios

Solution:

$$TV = \frac{20{,}040}{1643} = \boxed{12.2:1}$$ Double Reduction needed!

- Second gear needs to be larger to allow room for Idler Shaft, Worried about Center-Center Distance

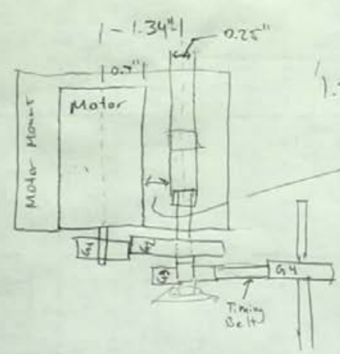
If we make Gear 1 : 14 teeth
Gear 2 : 72 teeth

$$VR = \frac{72}{14} = 5.14:1$$ ⟵ 1st Reduction

$$\frac{12.2:1}{5.14:1} = 2.37:1$$ ⟵ 2nd Reduction

$$C\text{-}C \text{ distance} = (N_p + N_g)/2P_d$$
$$= \frac{(14+72)}{2(32)}$$
$$= 1.34'' \longleftarrow$$

$1.34'' - 0.7'' - \frac{0.25''}{2} = 0.51''$ – Distance between Motor and Idler shaft ✓



$1.34 - 0.7 - \frac{0.25}{2} = 0.51''$ ✓

Continued ⟶

11-17-17 | Gear Design Update | MET 484 A | Nick Paulay | 2/2

Given: TV: 12.2 : 1 — First Reduction : 5.14 : 1

Second Reduction : 2.37 : 1

N_P : 14 teeth

N_G = 72 teeth

Find: Timing Belt Pulleys

XL - 0.200 Timing belt

Solution: Same shaft as Gear 2 so shaft diameter needs to stay the same 1/4".

Smallest Gear with 1/4" shaft Dia.

- 14 tooth — 1.12" OD ⟵
- 2 side flanges

14 tooth × 2.37 = 33.18 tooth → next size up

- 36 tooth - 5/16 shaft Diameter ⟵
- no flange - 2.272" OD

Range of belt pitch lengths (Outer Circle distance)

⟶ 5" - 77"

Range of Center Distances — 7-8 Equation

$$D_2 < C < (3(D_2 + D_1))$$

$$2.272'' < C < (3(2.272'' + 1.12''))$$

$$2.272'' < C < 10.176''$$

Center Distance for Timing belt pulleys should be between 2.27" and 10.17".

Assume we make it $\underline{\underline{4''}}$ C-C distance.

Pitch Length : Eq: 7-3 → $L = 2C + 1.57(D_2 + D_1) + \dfrac{(D_2 + D_1)^2}{4C}$

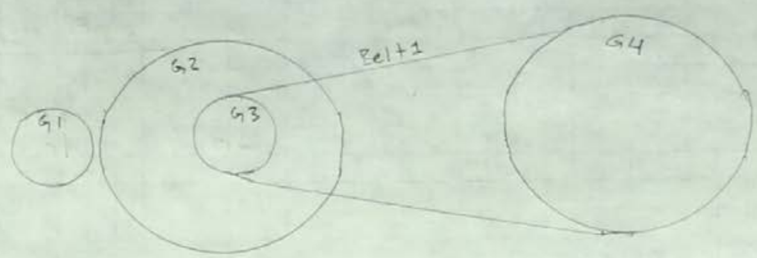
$$L = (2 \times 4'') + 1.57(2.277 + 1.12) + \frac{(2.272 + 1.12)^2}{4(4)}$$

$$L = 8'' + 5.325'' + 0.719''$$

$\boxed{L = 14''}$ ⟵ Gates standard belt size 14" Belt Length / 70 tooth pitch ⟵

An

Gear Summary – McMaster-Carr Website



G1 - Spur Gear

- $P_d = 32$
- $N_p = 14$
- Brass
- $n_p = 20{,}040$ RPM
- 20° Pressure Angle
- Press Fit
- Shaft Diameter = 1/8"
- $D_p = 0.438$
- OD = 0.5"

G2 - Spur Gear

- $P_d = 32$
- $N_g = 72$
- Stainless Steel
- $n_p = 3898$ RPM
- 20° Pressure Angle
- Set Screw
- Shaft Diameter = 1/4"
- $D_p = 2.25$"
- OD = 2.31"

G3 - Timing Belt Pulley XL

- $N_p = 14$
- Side Flanges
- Pitch - 0.200"
- OD 1.12"
- Steel
- Set Screw

G4 - Timing Belt Pulley XL

- $N_4 = 36$
- no side flange
- Pitch 0.200"
- OD: 2.272"
- Steel
- Set Screw

Timing Belt

- 14" Length
- 70 tooth
- XL - 0.200"
- Gates Brand

11/17/17	HP Calculation / Pitch line speed	MET 489	Nick Paulay	1/1

HP Calculation

Given: RS-540SH-6527 Brushed Motor

Max $\eta_{motor} = 0.65$, 9.55 Amps , Voltage: 7.2V

Find: Motor Output HP

Solution:

$$HP = \eta I E / 746 \qquad 1\ HP = 746W$$

$$= \frac{0.65 \times 9.55\ Amps \times 7.2V}{746\ W/_{1HP}}$$

$$HP = \boxed{0.0599\ HP} \longleftarrow$$ Verified with engineering toolbox.com ✓

Pitch Line Speed / Transmitted Load

Given: $D_P = 0.438''$

$n_P = 20{,}040\ RPM$

$PWR = 0.06\ HP$

Find: Pitch line speed, Transmitted load

Solution:

$$V_t = \frac{\pi D_P n_P}{12}$$ – Equation 9-1 pg 321

$$V_t = \frac{\pi (0.438'' \times 20{,}040 RPM)}{12} =$$

$$\boxed{V_t = 2{,}297.9\ ^{ft}/_{min}} \longleftarrow$$

$$W_t = \frac{33{,}000(Pwr)}{(V_t)} = \frac{33000\,(0.06\ HP)}{2297.9\ \frac{ft}{min}}$$ – Equation 9-9 pg 323

$$\boxed{W_t = 0.86\ lb} \longleftarrow$$

11/19/17 | Forces On Gear Teeth | MET 489A | Nick Pauley | 1/1

Given: - Pressure Angle 20° - Pinion Speed: 20,040 RPM
- Power: 0.06 HP - Pitch Line Speed: 2297 ft/min

Find: - Tangential Force Wt
- Radial Force W_r
- Normal Force Wn

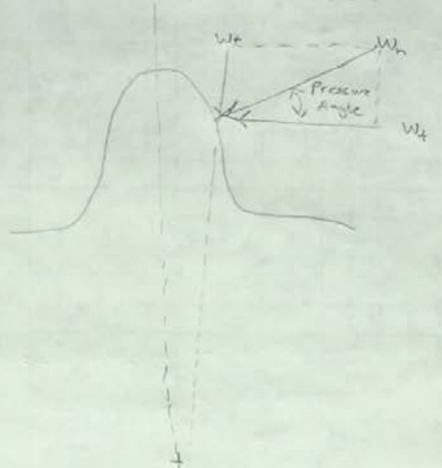


Figure 9-3

Solution:

Tangential Force W_t

$$W_t = \frac{P}{V_t} = \frac{0.06\,HP}{2297\,ft/min}\left(\frac{550\,lb_f\text{-}ft/s}{1\,HP}\right)\left(\frac{60\,sec}{1\,min}\right) = 0.86\,lb_f \longleftarrow$$

Radial Force Wr

$$W_r = W_t \tan \theta$$

$$W_r = 0.86\,lb\,(\tan 20°) = 0.314\,lb_f \longleftarrow$$

Normal Force W_n

$$W_n = W_t / \cos \phi$$

$$W_n = \frac{0.86\,lb_f}{\cos 20°} = 0.91\,lb_f \longleftarrow$$

11-30-17 | Bending Stress in Gear Teeth | MET 4?? | Nick Paulay | 1/1

Given: W_t = tangential Force, P_d = diametral pitch

F = face width, J = geometry factor = $\frac{Y}{K_t}$ = $\frac{\text{Lewis form factor}}{\text{stress concentration}}$

Find: J, Bending Stress in tooth

Solution:

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

$W_t = 0.86\ lb_f$ $\quad P_d = 32$ $\quad F = 3/16"$

$J = 0.24$ $\quad K_o = 1.00$ $\quad K_s = 1.00$ $\quad K_m = 1.00$ $\quad K_B = 1.00$ $\quad K_v = 1.0$

$$S_t = \frac{(0.86\ lb_f)(32)}{(3/16\ in)(0.24)}(1.00^5)$$

$\boxed{S_t = 612\ PSI}$ ←

$S_{at} = 5\ ksi$

$612\ psi < 5\ ksi$ ✓

11-30-17	Contact Stress	MET 489A	Nick Paulay

Given: $C_p = 2300\ psi$; $W_t = 0.86\ lb_f$ $K_o = 1.00$ $K_s = 1.00$

$K_m = 1.00$ $K_v = 1.00$ $F = 3/16''$ $D_p = 0.438$ $I = 0.102$

Find: Contact Stress

Solution: Equation $S_c = C_p \sqrt{\frac{W_t K_o K_s K_m K_v}{F D_p I}}$

$$S_c = 2300\ psi \sqrt{\frac{(0.86\ lb_f)(1.00)^4}{(3/16'')(0.438'')(0.102)}}$$

$$= \boxed{23{,}304\ psi}$$

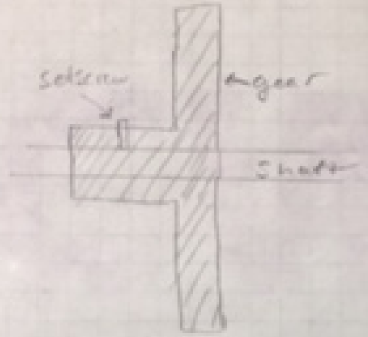
Small enough with minimal design life where pitting won't be a problem.

11-30-17	Set screw pin analysis	MET 4804	Nick Paulos	1/1

Given: $W_h = 0.91$ lb $D = 0.118''$

Find: Shear stress on pin

Solution:



$\tau = \frac{F}{A}$ $F = W_h = 0.91$ lb

$A = \pi D^2 = \pi (0.118)^2$

$=$

$\tau = \frac{0.91 \text{ lbs}}{\pi (0.118)^2}$

$\tau = 20.8$ psi < 36 ksi ✓

11/28/17	Belt tension	MET 489A	Nick Pauley	1/1

Given: Belt length = 14"   4" Center - Center Distance

G3 => N = 14 teeth   Assume using gates belt

G4 => [illegible] = 36 teeth

→ Info from Gates website

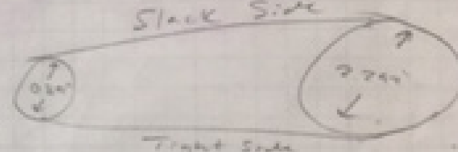
Find: Belt Tension / Belt Deflection

Solution: SDP/SI website Tensioning Guide

- Use a tensioning tool

Deflection Force = recommended Tension

HP = Input HP = 0.06 HP
PD = 0.8in
RPM = 3299 RPM



$$\text{Deflection Force}_{min} = \frac{T_{st} + \left(\frac{t}{L}\right) Y}{16} \text{ (lbf)}$$

$$= \frac{4 lbs + \left(\frac{4 in}{0.2 in}\right) 3.30}{16}$$

t = Span length
L = Belt pitch
Y = Constant table a
T_{st} = Static tension

Deflection Force = $\boxed{4.325 \text{ lbf}}$ = Tension Force ←

4" Span

1/64" belt deflection per inch

Belt Deflection = 4" × 1/64 = $\boxed{0.0625\text{" deflection}}$ ←

Use tensioning tool!

11-30-17	Torsional Stress in Rear Axle	MET 480 A	Nick Pauley	1/1

Forces will be transmitted to rear shaft of 0.86 lbf.

<u>Find</u>: Max torsional stress and torque in rear axle shaft.

<u>Solution</u>:

$$\text{Torque} = \frac{Pwr}{n} = \frac{0.06\,HP}{1643\,\frac{\text{rotations}}{\text{min}}}$$

$$\text{Torque} = \frac{HP \times 5252}{RPM}$$ equation from online source to get end unit of ft-lbf

$$= \frac{0.06 \times 5252}{1643}$$

$$T = \boxed{0.19\ ft\text{-}lb_f}$$

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

T = Torque = 0.19 ft-lbf

c = radius of shaft = 0.15625

J = polar moment of inertia

$$J = \frac{\pi}{32} D^4 = \frac{\pi}{32}\left(\tfrac{5}{16}''\right)^4 = 0.000936$$

$$\tau_{max} = \frac{0.19(.15625)}{0.000936} = \boxed{31.7\ psi}$$

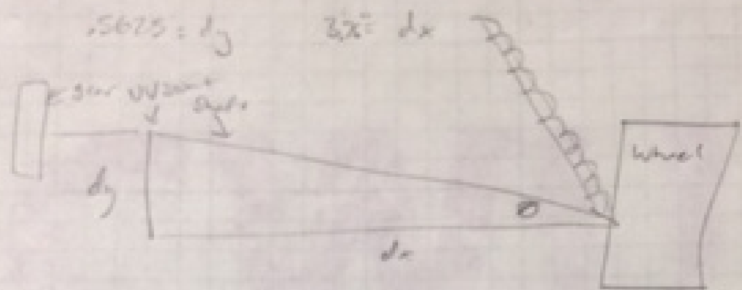
11-30-17 | Max drive shaft angle | MET 458A | Nick Pauley | 1/1

2.5"

.375 Travel

Given: Max drive angle 10° based off of suspension.

$.5625 = d_y$ $\quad 3.25 = d_x$



Find: Actual angle off horizontal sitting on ground

Solution:

$$\theta_{max} > \theta_{actual}$$

$$\tan\theta = \frac{d_y}{d_x}$$

$$\theta = \tan^{-1}\left(\frac{.5625"}{3.25"}\right)$$

$$\theta = 9.8^\circ$$

$$9.8^\circ < 10^\circ \checkmark$$

3-13-18	Nick Paulay	MET 491B	Drivetrain Update	1/1

Given: Gear 1 : 14 teeth Pulley 1 : 14 teeth
Gear 2 : 72 teeth Pulley 2 : 14 teeth

Find: Updated VR, Theoretical Velocity

Solution:

$VR_1: \frac{72T}{14T} = 5.14:1$

$VR_2: \frac{1}{1} = 1:1$

$\boxed{\text{Drive Ratio : } 5.14:1}$:(

At this ratio at full speed of 20,040 RPM motor rpm, the shaft rpm will be 3,898 rpm and a 1:1 ratio will make the wheels spin at 3898 rpm

Wheel Circumference = 5.118 in × π = 16.08 in

16.08 × 3898 rpm = 62,679.64 in/min

$62{,}679.64 \frac{in}{min} \times \frac{1 mile}{63{,}360 in} = 0.989 \frac{mil}{min}$

$0.989 \frac{mile}{min} \times \frac{60 min}{1 hr} = \boxed{59.3 \text{ mph}}$

This value is unrealistic due to the motor not being a high torque application and not taking friction into account. Car also is not built to sustain 60 mph.

2-21-18	Belt Length Revision	MET 4BA C	Nick Paulay	1/1

Given
Revision Belt Length $OD = 1.12''$

Find
$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 + D_1)^2}{4C}$ $C = 4.5$ inches

Solution

$L = 2(4.5) + 1.57(1.12 + 1.12) + \frac{(1.12 + 1.12)^2}{4(4.5)}$

$L = 9 + 3.5168 + 0.2787$

$\boxed{L = 12.8 \text{ inches}}$

2-26-18	Torsional Stress in Rear Axle	MET 484B	Nick Paulay	1/1

Given:

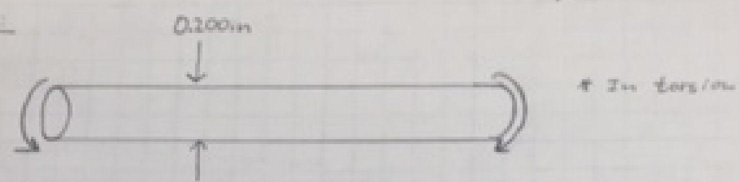
Shaft Diameter 0.200in Length: 4in

Assume HP to shaft is 0.06HP $\frac{1}{8}$in motor

Equation; $\text{Torque} = \frac{63000\,(\text{Pwr})}{n}$, 3500 rpm

Find: Torsional Deformation in degrees

Solution:



Torque: $T = \frac{63{,}000\,(0.06\text{HP})}{3{,}500\text{ rpm}} = 1.08 \text{ in-lb}$

Torsional Deformation:

$$\phi = \frac{TL}{GJ}$$

$$\phi = \frac{(1.08\text{ in-lb})(4\text{ in})}{\left(11.5\times10^{6}\frac{\text{lb}}{\text{in}^2}\right)(0.000157)}$$

$T = 1.08$ in-lb

$L = 4$ in

$G = 11.5\times10^{6}$ psi

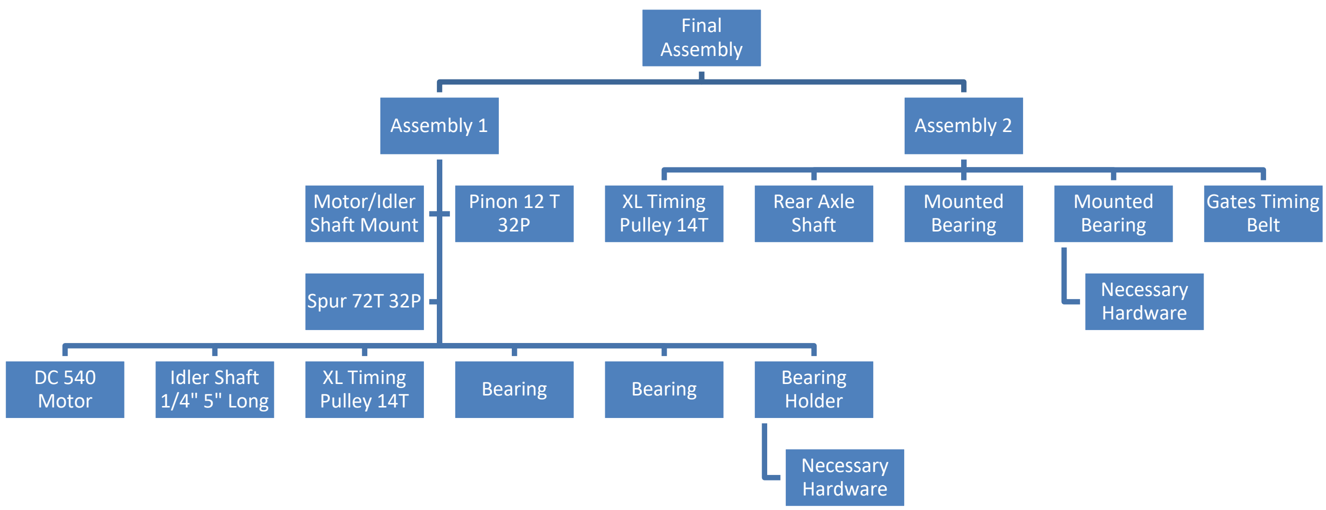
$J = \frac{\pi}{32}(0.200\text{ in})^4$

$J = 0.000157$

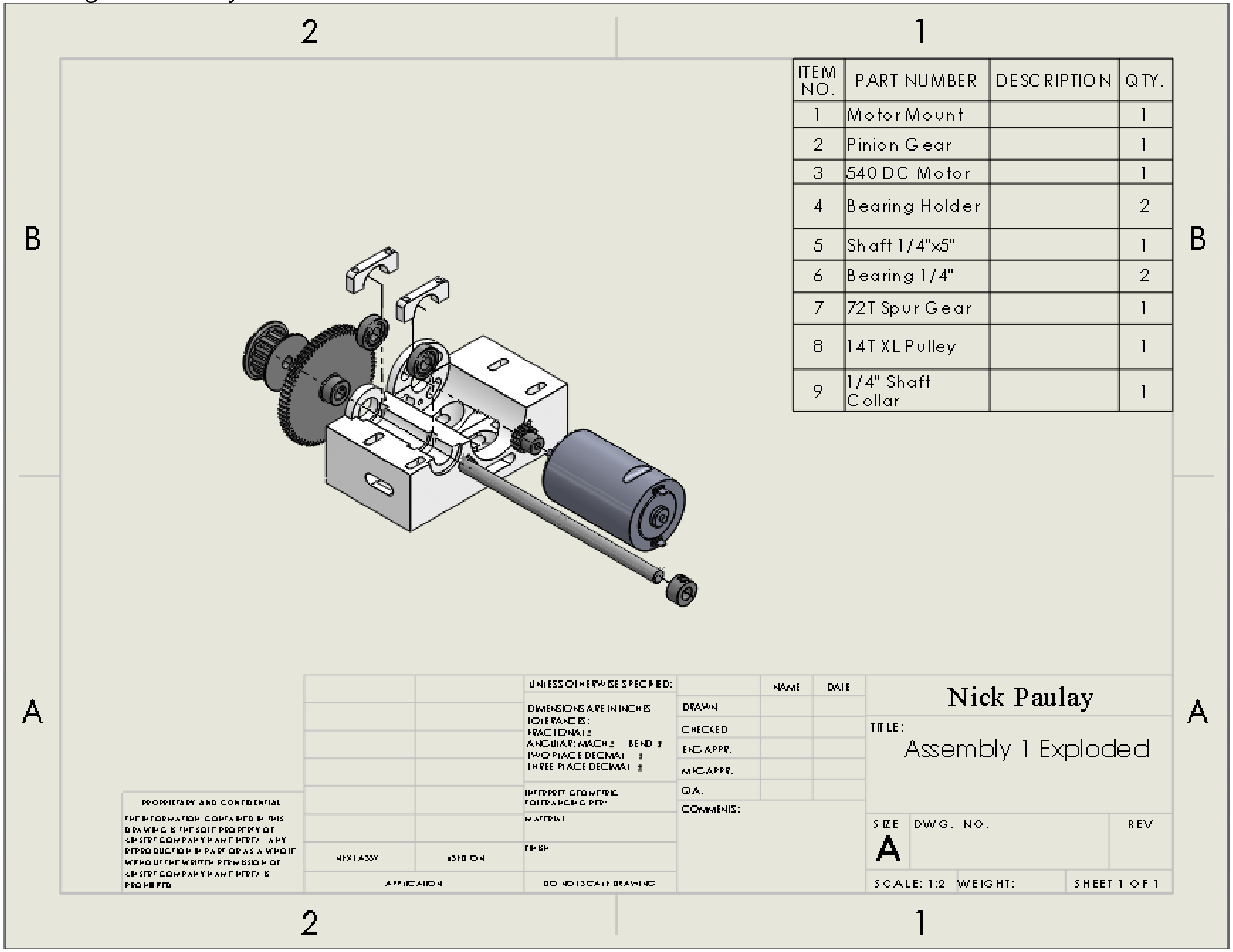
$\phi = 0.00239$ rad

$$\phi = (0.00239)\left(\frac{180^\circ}{\pi\text{ radian}}\right) = \boxed{0.14^\circ \text{ of deformation}}$$

APPENDIX B –Assembly drawings, Sub-assembly drawings, Part drawings, Drawing Tree

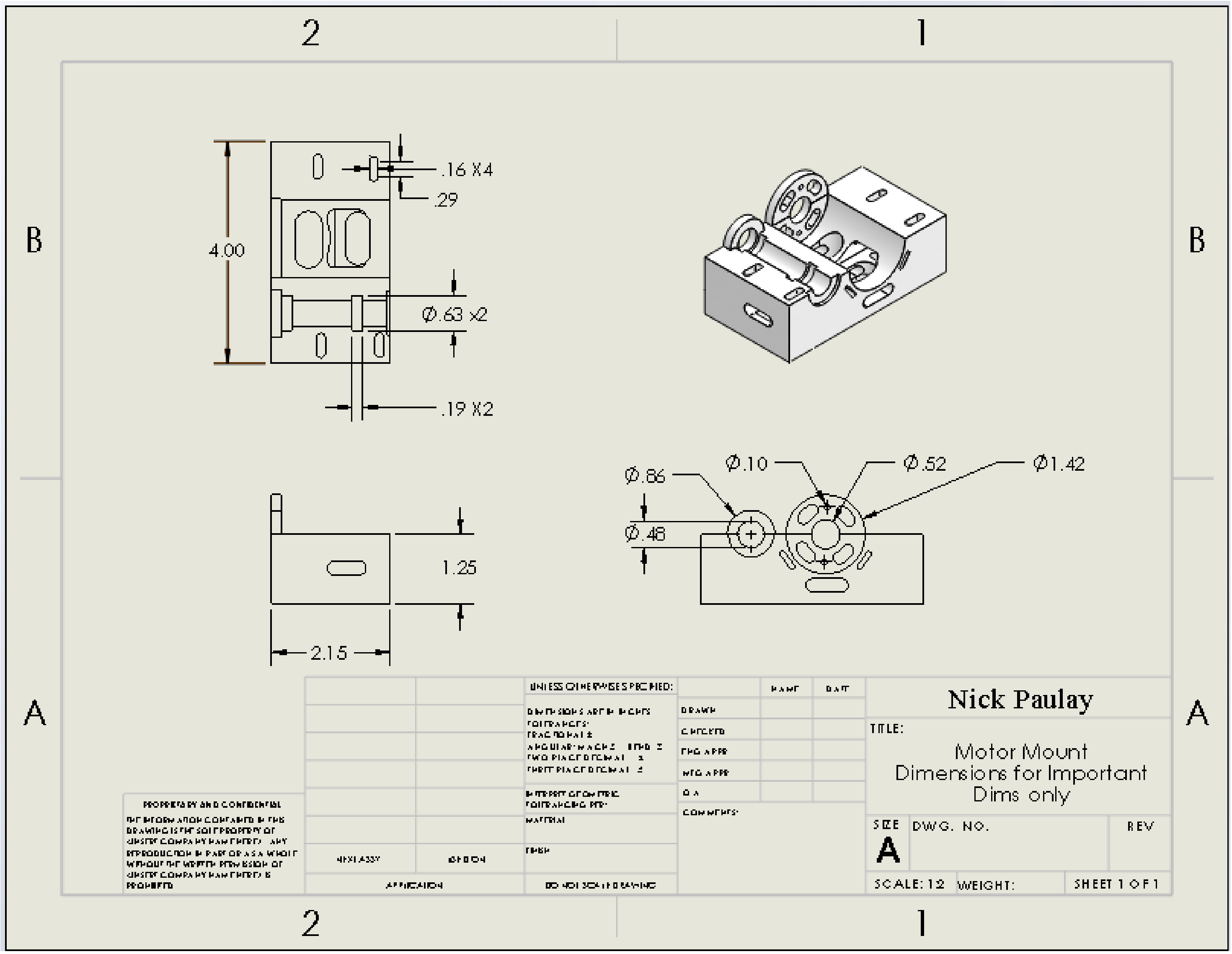


Drawing 1: Assembly 1

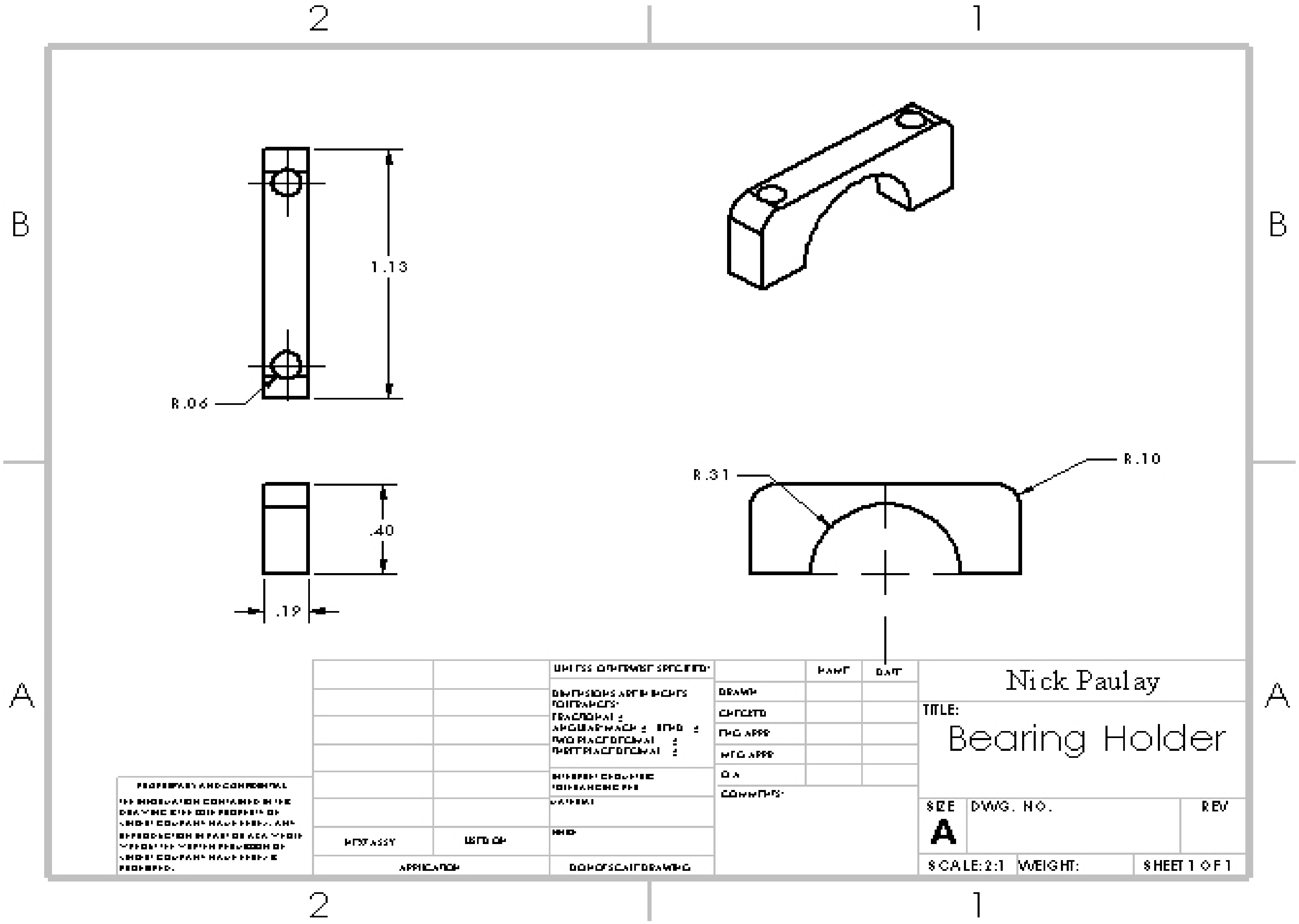


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Motor Mount		1
2	Pinion Gear		1
3	540 DC Motor		1
4	Bearing Holder		2
5	Shaft 1/4"x5"		1
6	Bearing 1/4"		2
7	72T Spur Gear		1
8	14T XL Pulley		1
9	1/4" Shaft Collar		1

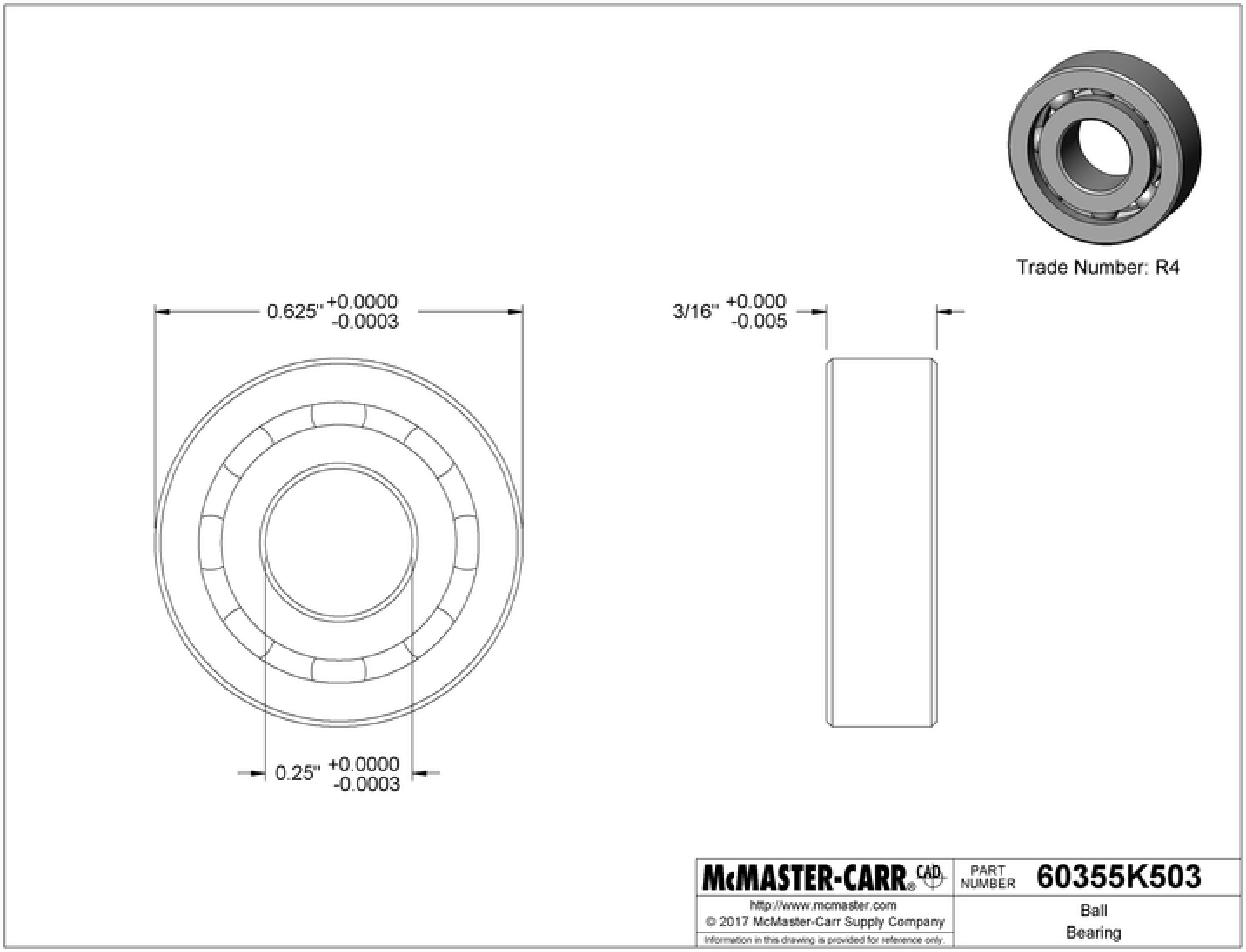
Drawing B2: Mabuchi RS-540SH-6527 Motor/Idler Shaft Mount with Vent Holes for Cooling



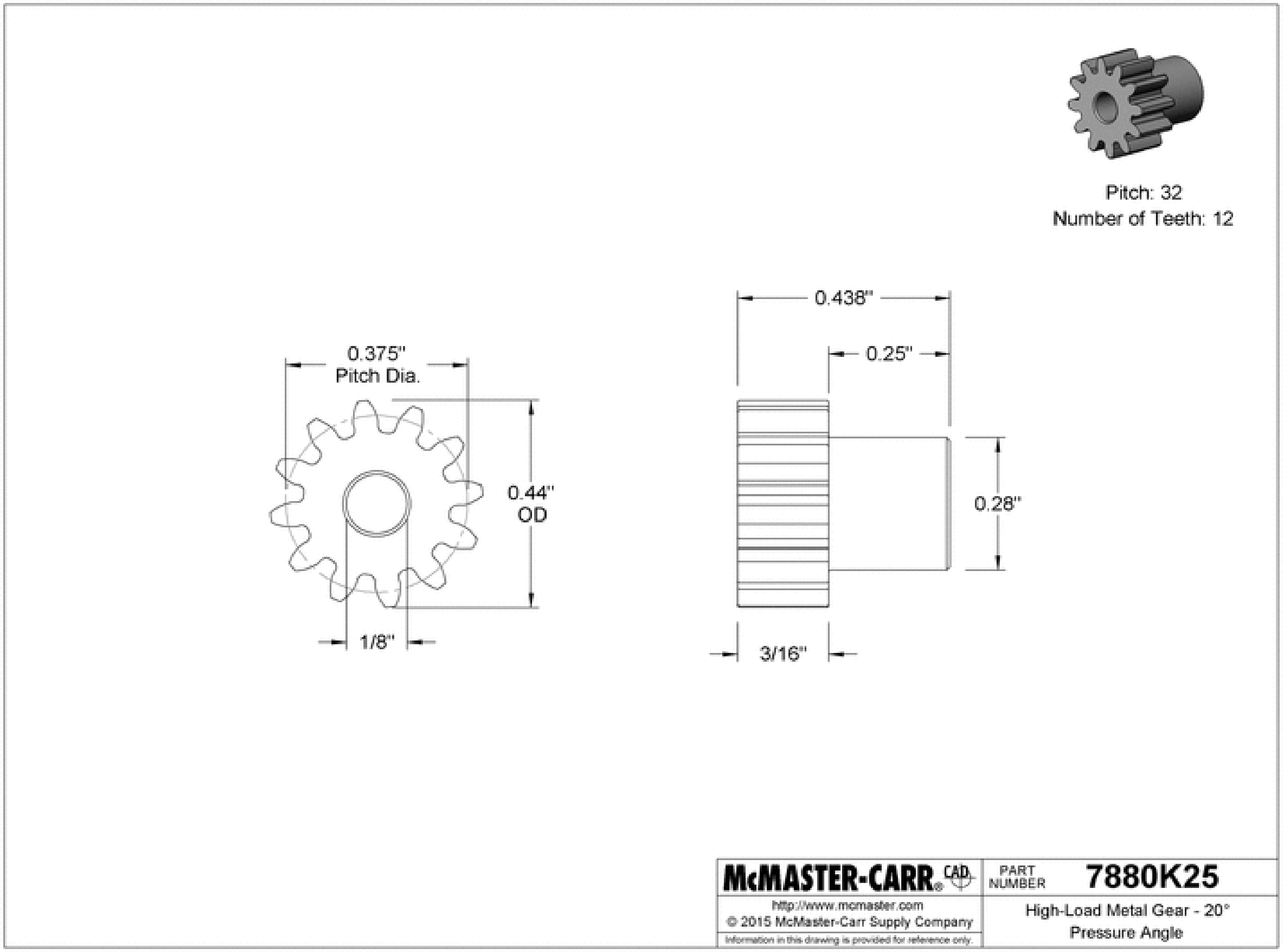
Drawing 3: Bearing Holder



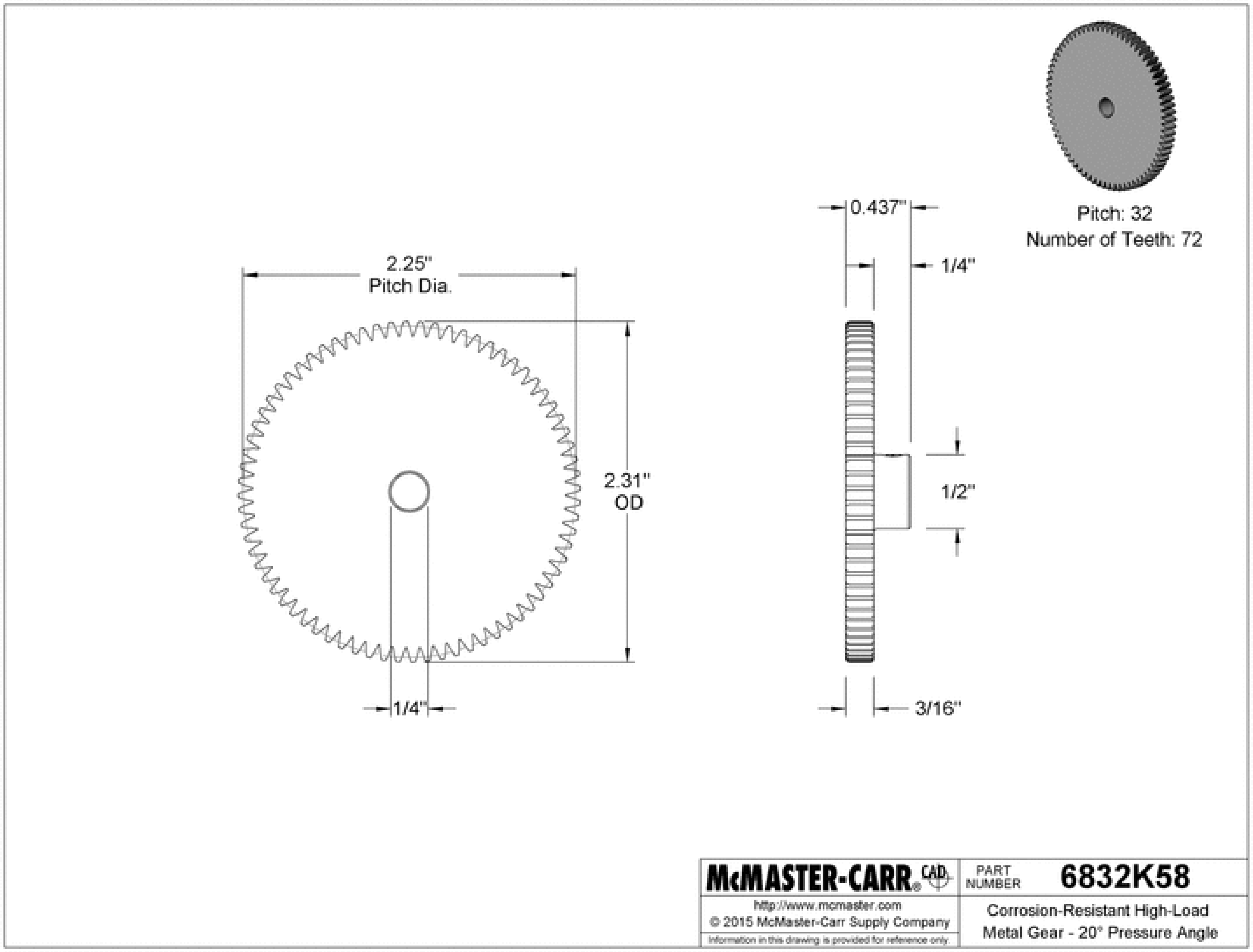
Drawing 4: Ball Bearing



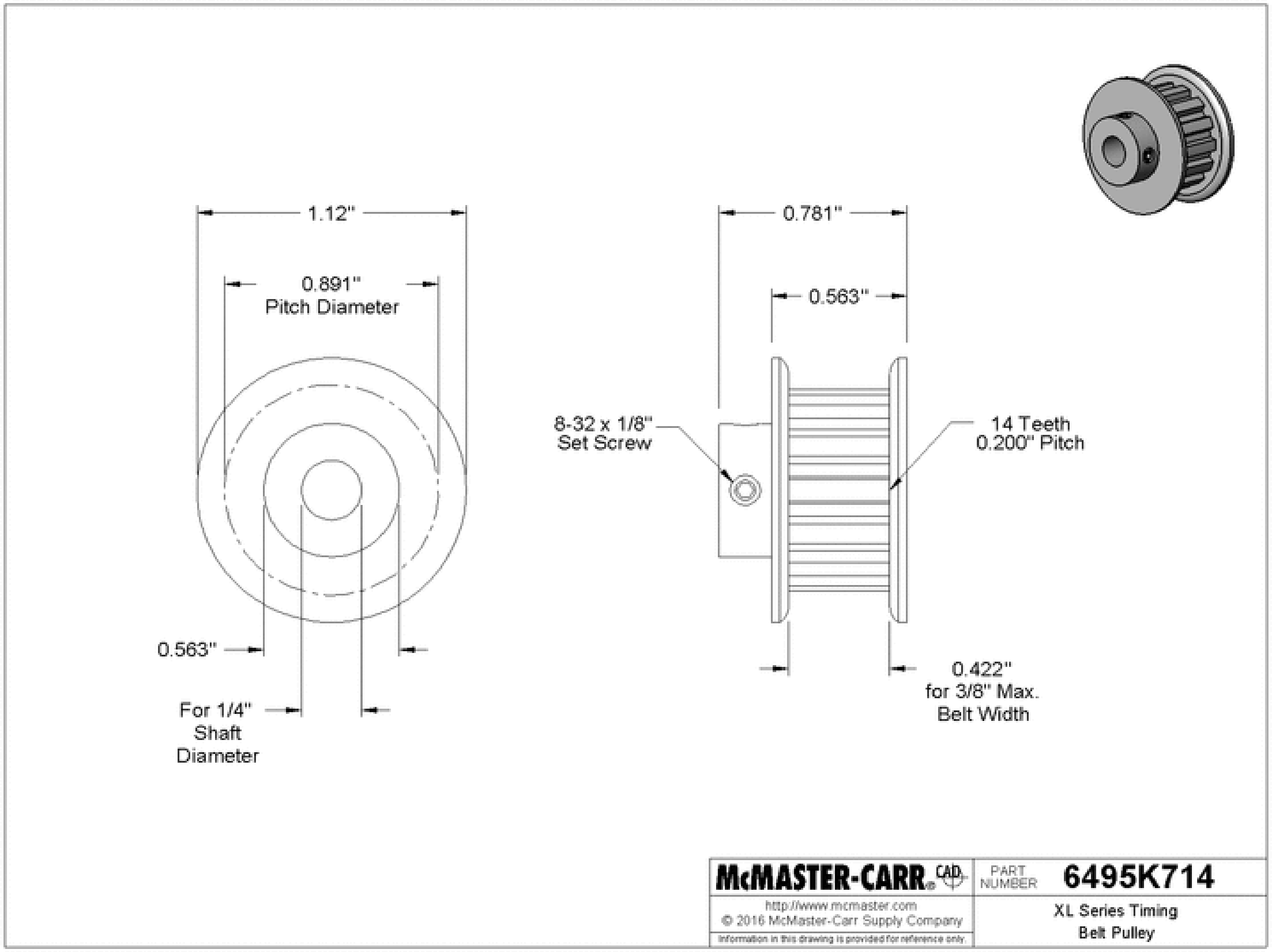
Drawing 5: Pinion Gear



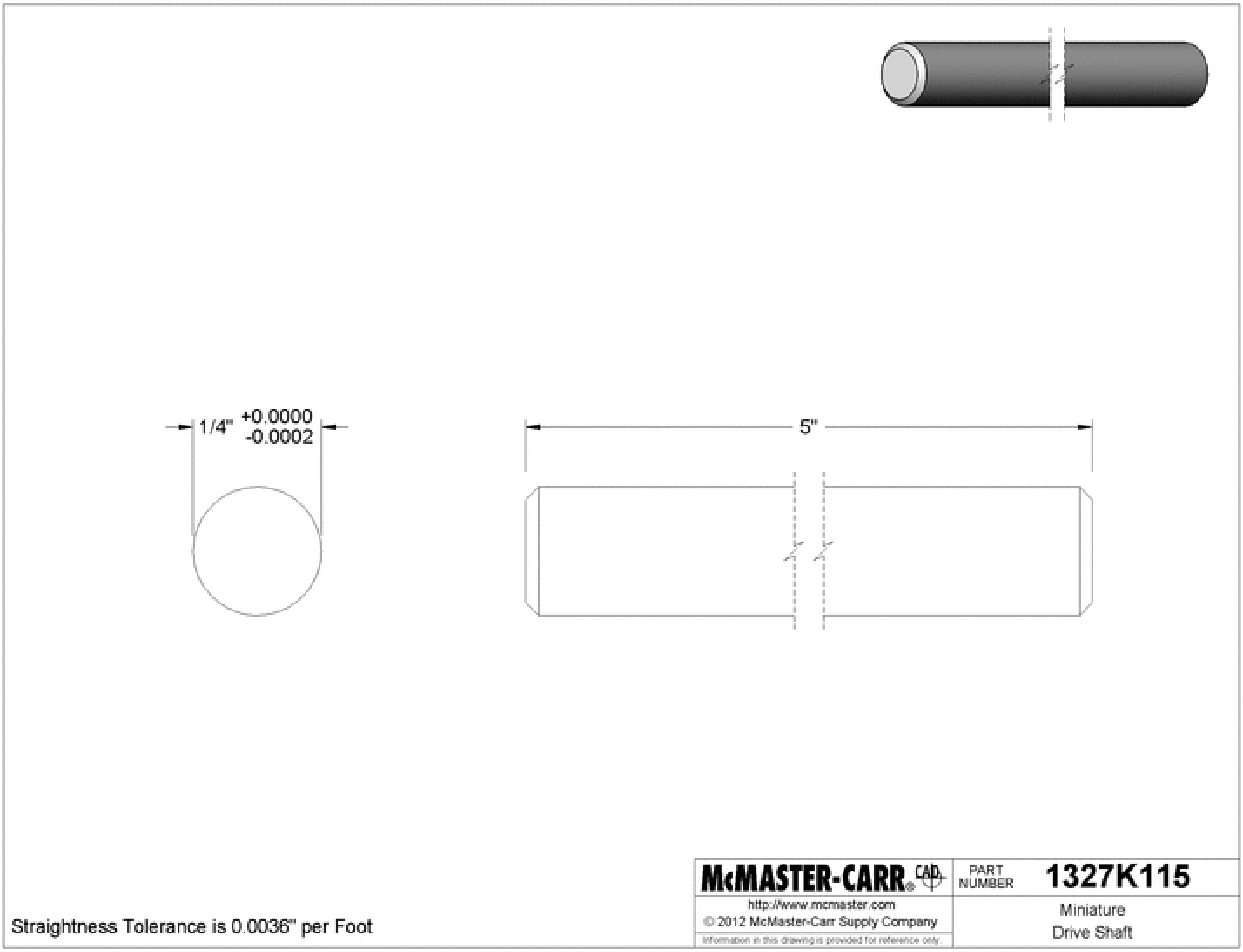
Drawing 6: Spur Gear



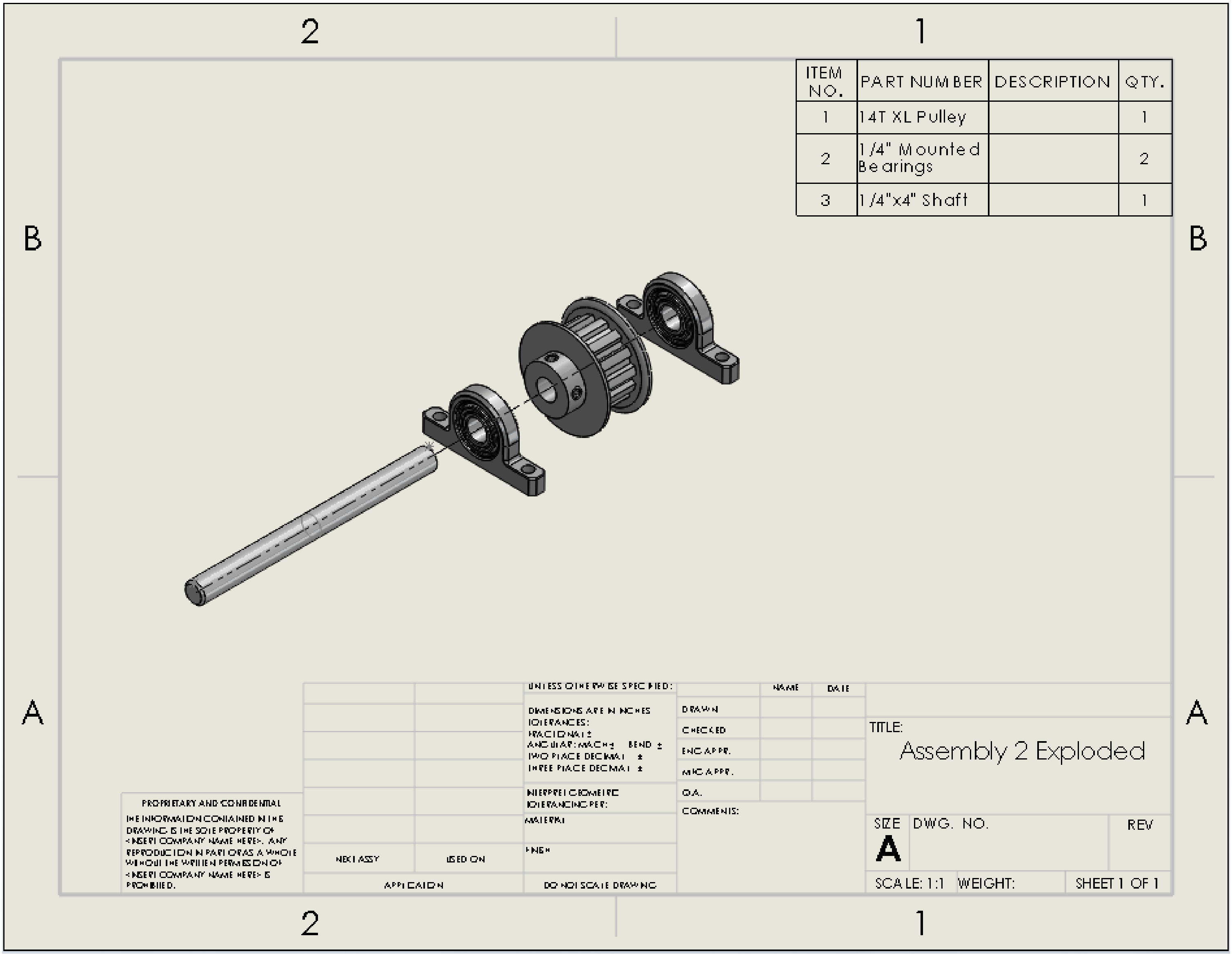
Drawing 7: Timing Pulley



Drawing 8: Idler Shaft

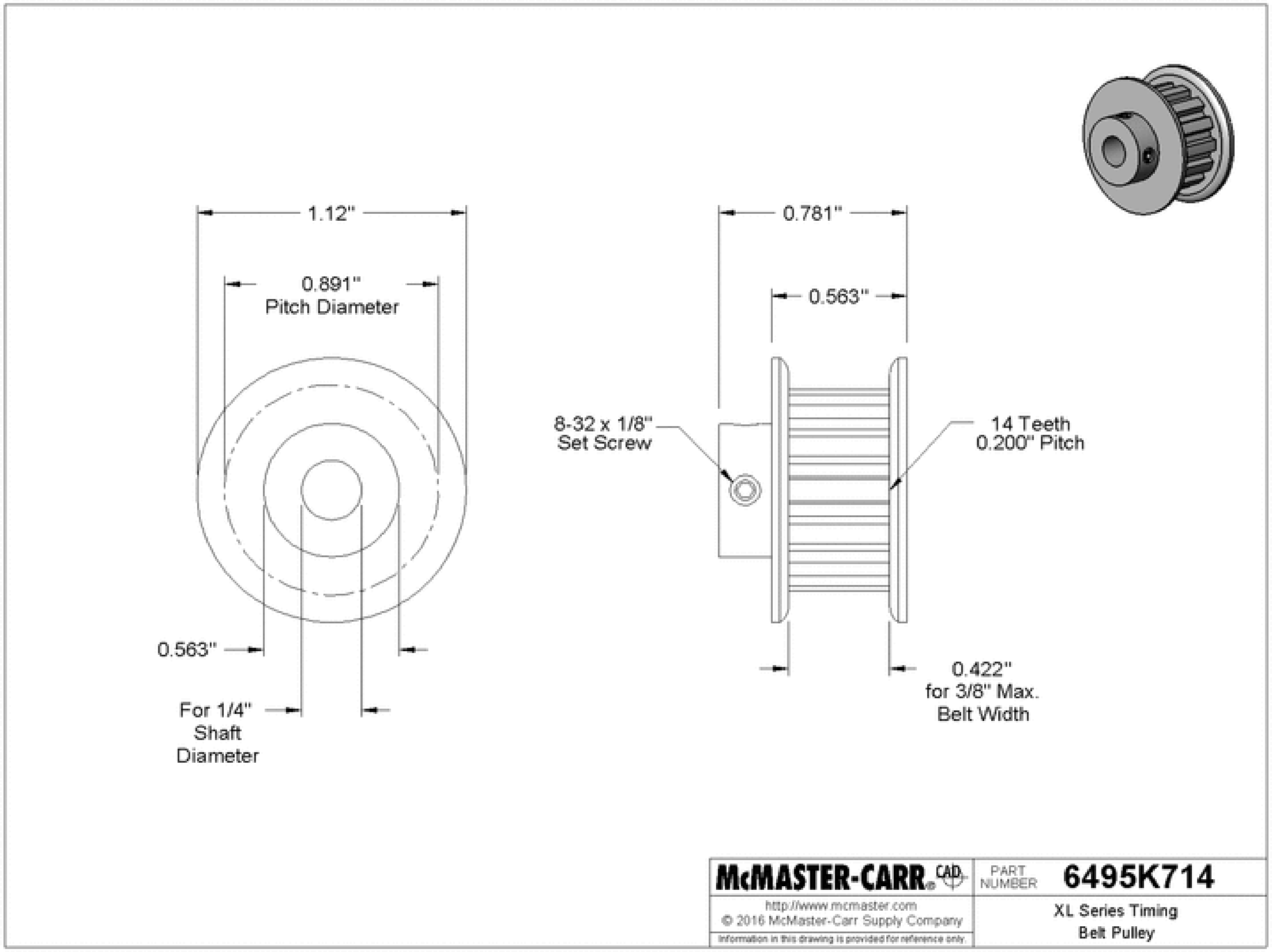


Drawing 9: Assembly 2

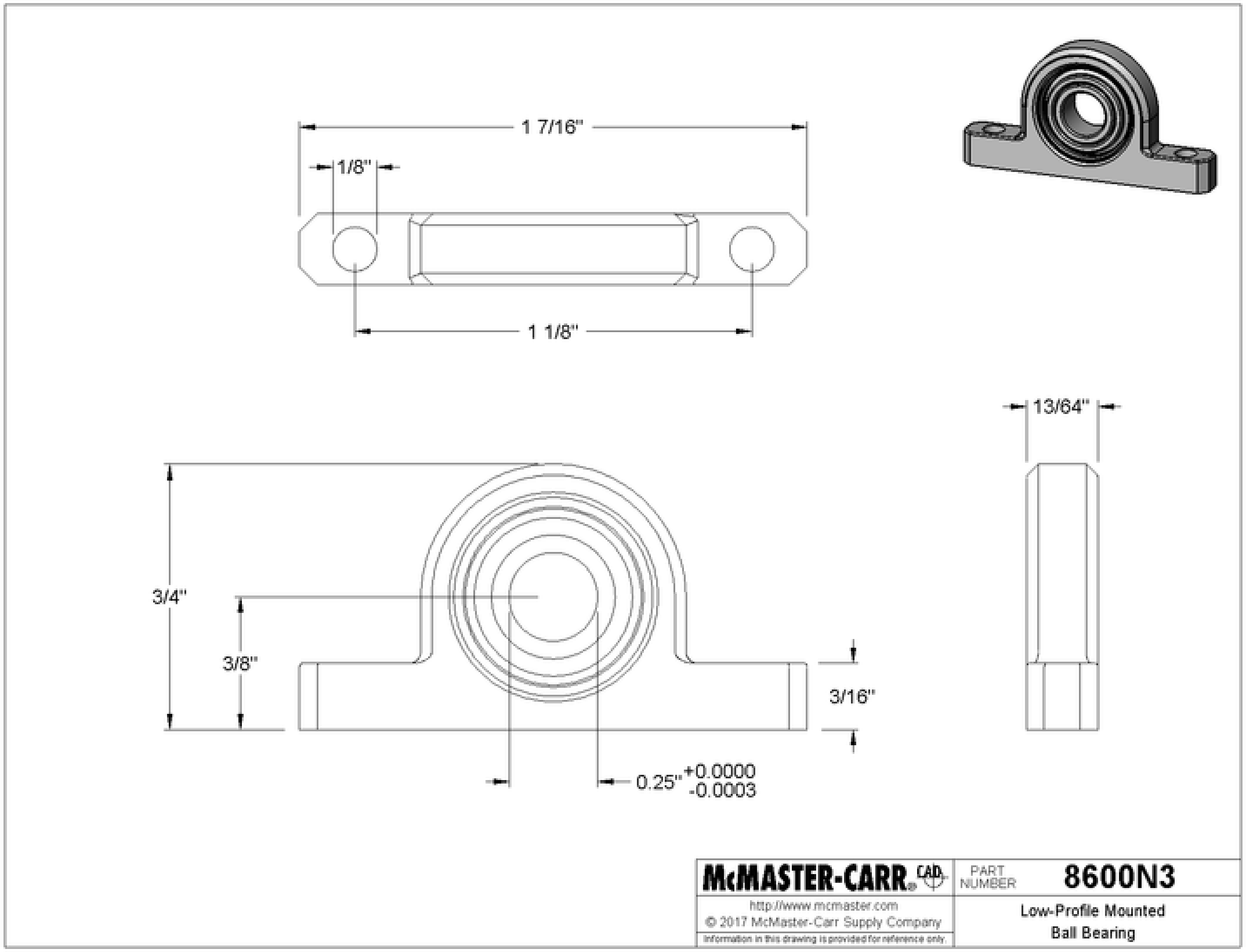


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	14T XL Pulley		1
2	1/4" Mounted Bearings		2
3	1/4"x4" Shaft		1

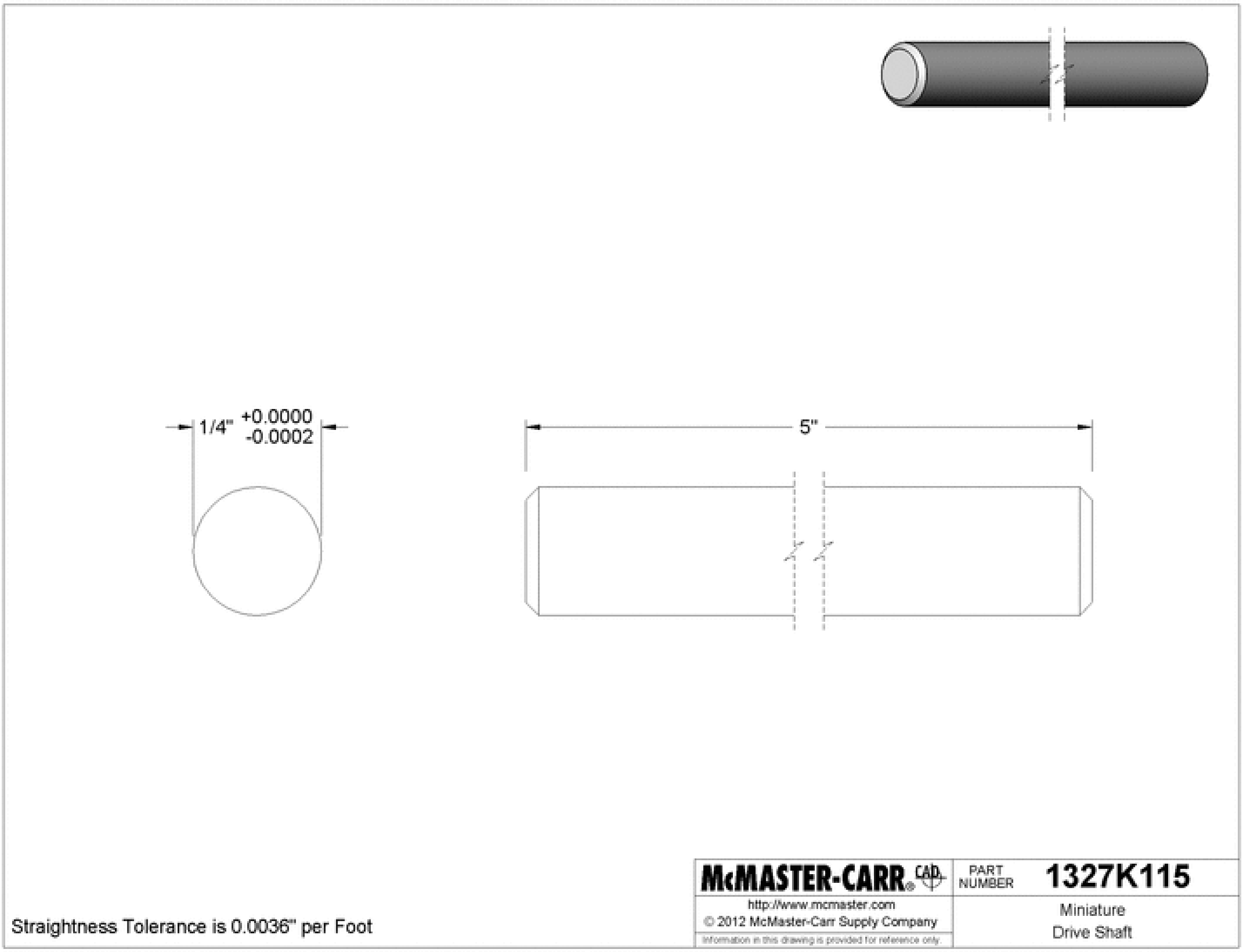
Drawing 10: Timing Pulley Rear Axle



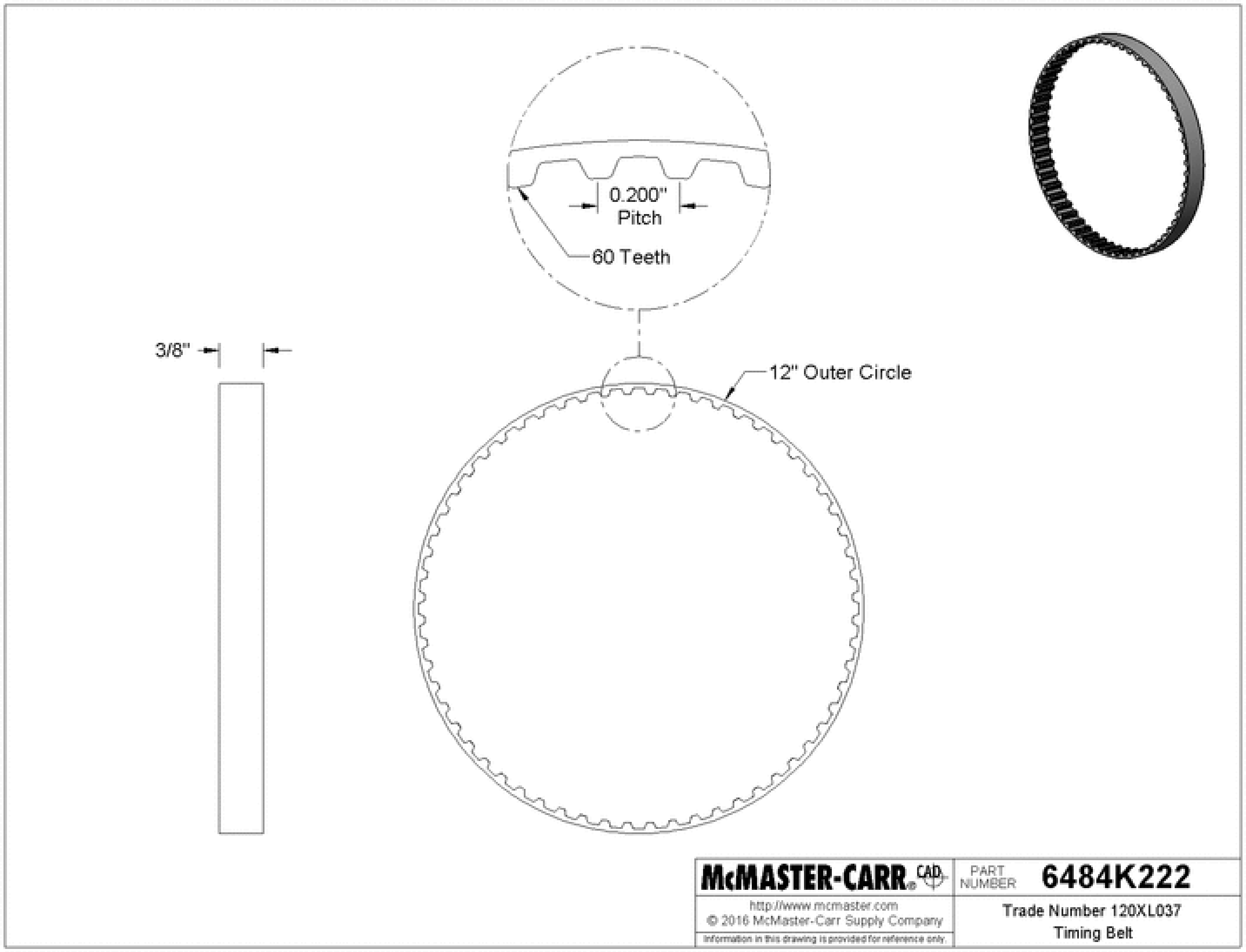
Drawing 11: Rear axle Bearings



Drawing 11: Rear axle shaft



Drawing 12: XL Timing Belt 12”



APPENDIX C – Parts List and Costs

Part Identification	Part Description	Source	Estimated Cost	Actual Cost
RS-540SH-6527	540 DC Electric Motor	Hobby King	$4.37	$ 12.23
3D Modeled Motor Mount	3D Model Motor Mount/Bearing Holders	CWU Printing Lab	$30	$ 37.82
Gears	1 Pinion, 2 Idler, 1 Driven Pulley	McMaster Carr	$96.12	$ 98.14
Idler Axle /Rear Axle	¼ in Steel rod 5 inch	Machine Shop	$10	$ 2.69
Set Screws ¼ inch / misc hardware	Common screws and bolts	Hardware Store	$20	$ 20.00
Wheels	5.11inch Mounted wheels RC	Amazon/Hobby Shop	$30	$ 26.00
Bearings	2, 1/4inch bearing	McMaster Carr	$41.82	$ 11.54
Axles	5/16 Axle to Wheel	Amazon	$20.00	$ 19.99
Timing belt	XL-0.200 12 inch	Gates.com	$10.99	$ 3.18
Shop Time			Donated by M.E.T	
Totals Cost			$263.30	$ 231.59

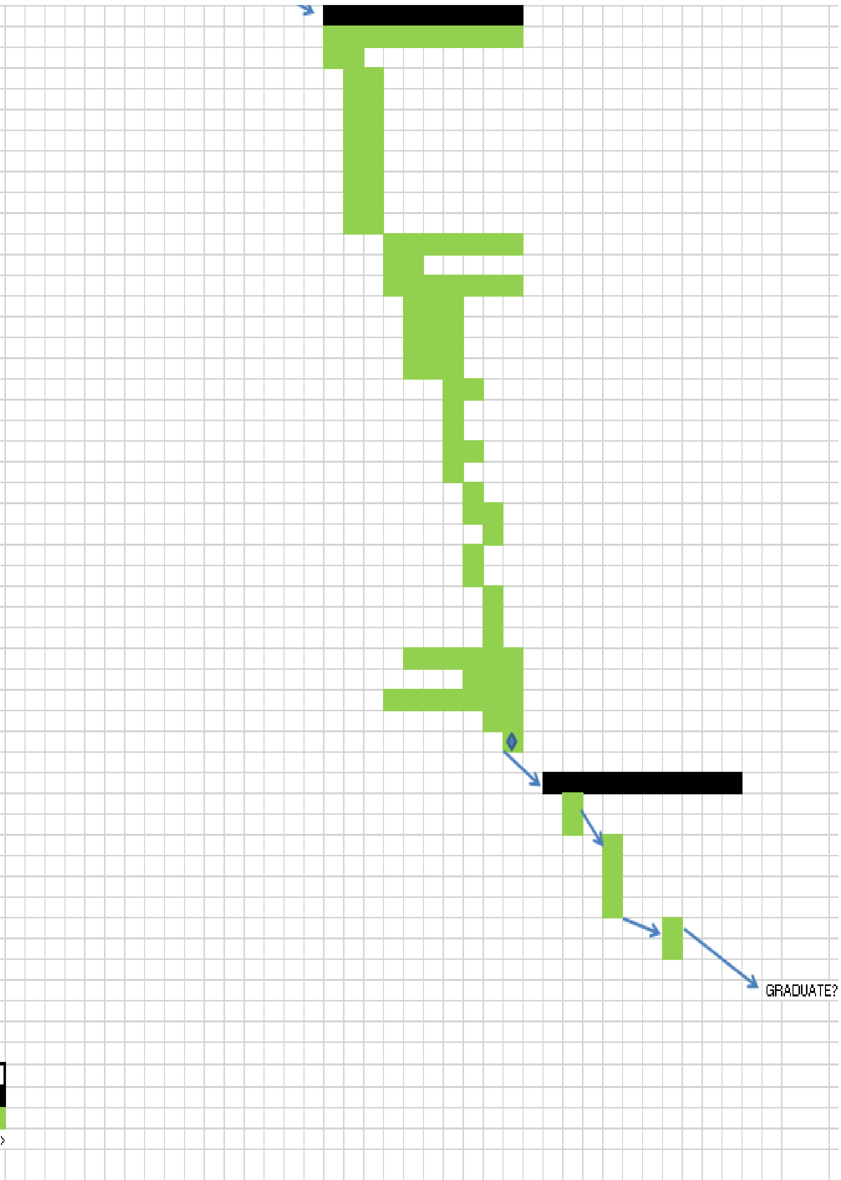
APPENDIX D – Budget

The budget has been described in the budget section as well as shown in Appendix C in the parts list and cost.

APPENDIX E – Schedule/Gannt Chart

PRIORIT	Task #	TASK	Hours	Comp. %
1.001		**FALL**		
1.011		INTRO TO COURSE		
1.021		DETERMINE PROJECT		
	1	RC Baja	1	0.01
1.031	2	PROBLEM DEFINITION		0.01
	3	Function Statement	0.25	0.01
1.041	4	INTRODUCTION		0.01
	5	Write project description	0.3	0.02
	6	Write Motivation	0.3	0.02
	7	Write Funtion Statement	0.15	0.02
	8	Write requirments	0.5	0.03
	9	Write Engineering Merit	0.5	0.04
	10	Write Scope of Effort	0.15	0.04
	11	Write Success Criteria	0.15	0.04
1.051	12	DESIGN & ANALYSIS		0.04
	13	Write approach	0.4	0.04
	14	Write design description	0.2	0.05
	15	Write Benchmark	0.2	0.05
	16	Write Performance Predictions	0.3	0.05
	17	Write Description of Analysis	2	0.08
	18	Write Scope of testing	0.3	0.08
	19	Write Analysis	0.5	0.08
	20	Write Tolerances	0.1	0.09
	21	Write Technical Risk Analysis	0.2	0.09
1.052	22	GREEN SHEET ANALYSES		0.09
	23	12 total	12	0.23
1.053	24	DRAWINGS		0.23
	25	11 total	6	0.30
1.061	26	METHODS & CONSTRUCTION		0.30
	27	Write Construction	0.5	0.31
	28	Write Description	0.4	0.31
	29	Write Drawing Tree	0.5	0.32
	30	Write parts list	0.5	0.32
	31	Write Manufacturing Issues	0.4	0.33
1.062	32	RADD		0.33
	33	Write one RADD example	0.5	0.33
1.071	34	TESTING METHOD		0.33
	35	Write Introduction	0.6	0.34
	36	Write Method/Approach	0.6	0.35
	37	Write Deliverables	0.1	0.35
1.081	38	BUDGET/SCHEDULE/PROJ		0.35
	39	Write Budget Plan	0.75	0.36
	40	Write Schedule/Gantt Chart	2	0.38
1.091	41	DISCUSSION		0.38
	42	Write Evolution of the design	0.5	0.39
	43	Write Risk Analysis	0.1	0.39
	44	Write Problems	0.2	0.39
1.101	45	CONCLUSION		0.39
	46	Write about project	0.25	0.39
	47	Reiterate Performance Predictions	0.25	0.40
1.111	48	SUBMITT PROPOSAL		0.40
	49	Turn in to canvas	0.1	0.40

54	2.001	50	**WINTER**		0.40
55	2.011	51	Construction begins		0.40
56		52	3D print mounts	2	0.42
57		53	Purchase 4 Gears from Mcmaster Carr	0.5	0.43
58		54	Purchase motor	0.25	0.43
59		55	Purchase raw material	0.15	0.43
60		56	Write prep sheet for machining	1	0.44
61		57	Machine steel rod to appropriate size	1	0.46
62		58	Purchase bearings	0.15	0.46
63		59	Purchase misc hardware	0.5	0.46
64		60	Purchase timing belt	0.25	0.47
65		61	**Start assembly**	10	0.58
66		62	Press Bearings into 3D Mount	0.5	0.59
67		63	Motor and gears assembled	0.5	0.60
68		64	Write prep sheet for machining	0.5	0.60
69		65	Machine steel rod to appropriate length	1	0.61
70		66	Reassemble for proper fit	0.5	0.62
71		67	Complete Assembly 1	1	0.63
72		68	Rear Axle rough assembly	0.5	0.64
73		69	Write prep sheet for machining	0.5	0.64
74		70	Machine steel rod to appropriate length	1	0.66
75		71	Reassemble for proper fit	1	0.67
76		72	Write prep sheet for machining	0.5	0.67
77		73	Machine steel rod to appropriate end diameter	1	0.68
78		74	Mount shafts from wheels to rear pulley shaft	0.5	0.69
79		75	Ensure proper alignment of shaft to wheel	0.5	0.70
80		76	Layout holes w/partner for mounting Assembly 2 to chas:	0.5	0.70
81		77	Mount Assembly 2 to chassis	0.5	0.71
82		78	Tension belt between the assemblys	0.25	0.71
83		79	Layout Holes for assembly 1	0.5	0.72
84		80	Mount Assembly 1 to chassis	0.5	0.72
85		81	Make adjustments if needed	3	0.76
86		82	Purchase or make misc parts	1	0.77
87		83	Coordinate mesh of systems with partner	5	0.83
88		84	Adjust design more	1	0.84
89	2.111	85	COMPLETED CONSTRUCTION		0.84
90		86			0.84
91		87	**SPRING**		0.84
92	3.021	88	RC Competition		0.84
93		89	Place 1st!	3	0.88
94	3.041	90	POSTER MADE for SOURCE		0.88
95		91	Design poster	5	0.94
96		92	Print out on plotter	1	0.95
97		93	Get dressed up	0.5	0.95
98	3.071	94	SOURCE PRESENTATION		0.95
99		95	Show off years project	2	0.98
100		96	Turn in Final Report on Canvas	2	1.00
101					
102			Total Hours	84.8	
103					
104					
105			**LEGEND**		
106			PROJECT PHASE		
107			TASK		
108			TASK (Continued Revisions)		--->
109			COMPLETION OF TASK PRIOR TO MOVING ON		



RS-540RH/SH

MABUCHI MOTOR
Carbon-brush motors

OUTPUT : 5.0W~90W (APPROX)

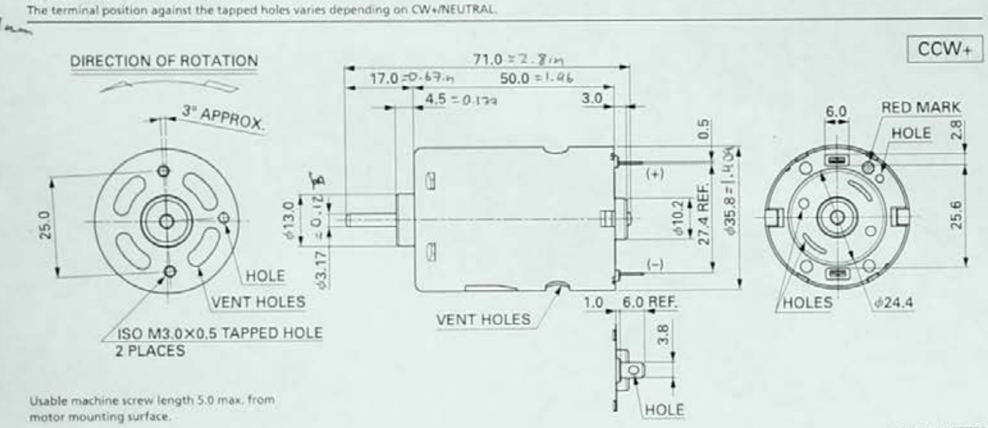
WEIGHT : 160g (APPROX)

Typical Applications **Home Appliances :** Vacuum Cleaner
Cordless Power Tools : Drill / Screwdriver / Cordless Garden Tool / Air Compressor
Toys and Models : Radio Control Model

MODEL		VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY					STALL		
		OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	TORQUE		CURRENT
				r/min	A	r/min	A	mN·m	g·cm	W	mN·m	g·cm	A
RS-540RH-6530	(*1)	3.6~6.0	6V CONSTANT	19200	1.30	15980	6.45	15.1	154	25.3	90.3	920	32.0
RS-540RH-7522	(*1)	3.6~4.8	4.8V CONSTANT	20200	1.90	16510	8.50	14.3	146	24.8	78.5	800	38.0
RS-540SH-7520	(*1)	4.8~7.2	7.2V CONSTANT	23400	2.40	19740	13.0	30.6	312	63.2	196	1998	70.0
RS-540SH-6527	(*1)	4.8~9.6	9.6V CONSTANT	23400	1.60	20040	9.55	31.0	316	64.9	216	2202	57.0

(*1) CCW shifted commutation (CCW+)
The terminal position against the tapped holes varies depending on CW+/NEUTRAL.

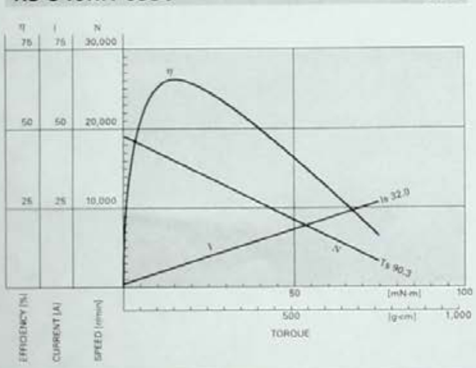
1in=25.4mm



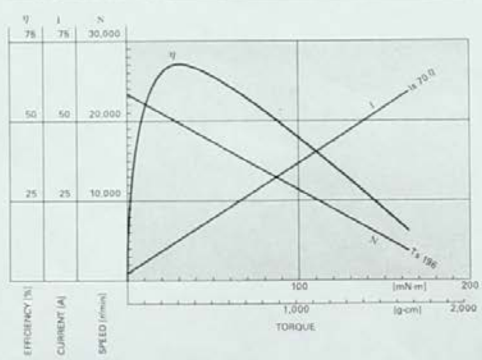
Usable machine screw length 5.0 max. from motor mounting surface.

UNIT: MILLIMETERS

RS-540RH-6530 6.0V



RS-540SH-7520 7.2V



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Additional guidelines that may be useful in designing registration critical drive systems are as follows:

- Select PowerGrip GT2 or trapezoidal timing belts.
- Design with large pulleys with more teeth in mesh.
- Keep belts tight, and control tension closely.
- Design frame/shafting to be rigid under load.
- Use high quality machined pulleys to minimize radial runout and lateral wobble.

SECTION 10 BELT TENSIONING

10.1 What Is Proper Installation Tension

One of the benefits of small synchronous belt drives is lower belt pre-tensioning in comparison to comparable V-belt drives, but proper installation tension is still important in achieving the best possible drive performance. In general terms, belt pre-tensioning is needed for proper belt/pulley meshing to prevent belt ratcheting under peak loading, to compensate for initial belt tension decay, and to prestress the drive framework. The amount of installation tension that is actually needed is influenced by the type of application as well as the system design. Some general examples of this are as follows:

Motion Transfer Drives: Motion transfer drives, by definition, are required to carry extremely light torque loads. In these applications, belt installation tension is needed only to cause the belt to conform to and mesh properly with the pulleys. The amount of tension necessary for this is referred to as the minimum tension (T_{st}). Minimum tensions, on a per span basis, are included in **Table 9**, on page **T**-30. Some motion transfer drives carry very little torque, but have a need for accurate registration requirements. These systems may require additional static (or installation) tension in order to minimize registration error.

Normal Power Transmission Drives: Normal power transmission drives should be designed in accordance with published torque ratings and a reasonable service factor (between 1.5 and 2.0). In these applications, belt installation tension is needed to allow the belt to maintain a proper fit with the pulleys while under load, and to prevent belt ratcheting under peak loads. For these drives, proper installation tension can be determined using two different approaches. If torque loads are known and well defined, and an accurate tension value is desired, **Equation (10-1)** or **Equation (10-2)** should be used. If the torque loads are not as well defined, and a quick value is desired for use as a starting point, values from **Table 10** can be used. All static tension values are on a per span basis.

$$T_{st} = \frac{0.812\,DQ}{d} + mS^2 \quad \text{(lbf)} \tag{10-1}$$

(For drives with a Service Factor of 1.3 or greater)

$$T_{st} = \frac{1.05\,DQ}{d} + mS^2 \quad \text{(lbf)} \tag{10-2}$$

(For drives with a Service Factor less than 1.3)

where:
T_{st} = Static tension per span (lbf)
DQ = Driver design torque (lbf in.)
d = Driver pitch diameter (in.)
S = Belt speed/1000 (ft./min.)
where Belt speed = (Driver pitch diameter x Driver rpm)/3.82
m = Mass factor from **Table 9**

Table 9 Belt Tensioning Force

Belt	Belt Width	*m*	*Y*	Minimum T_{st} (lbf) Per Span
2 mm GT2	4 mm	0.026	1.37	1.3
	6 mm	0.039	2.05	2.0
	9 mm	0.058	3.08	3.0
	12 mm	0.077	4.10	4.0
3 mm GT2	6 mm	0.077	3.22	2.2
	9 mm	0.120	4.83	3.3
	12 mm	0.150	6.45	4.4
	15 mm	0.190	8.06	5.5
5 mm GT2	9 mm	0.170	14.9	8.4
	15 mm	0.280	24.9	14.1
	20 mm	0.380	33.2	18.7
	25 mm	0.470	41.5	23.4
3 mm HTD	6 mm	0.068	3.81	2.5
	9 mm	0.102	5.71	4.3
	15 mm	0.170	9.52	7.8
5 mm HTD	9 mm	0.163	14.9	6.3
	15 mm	0.272	24.9	12.0
	25 mm	0.453	41.5	21.3
MXL	1/8"	0.003	1.40	1.0
	3/16"	0.004	2.11	1.7
	1/4"	0.005	2.81	2.3
XL	1/4"	0.010	3.30	3.2
	3/8"	0.015	4.94	5.1
L	1/2"	0.19	10.00	13.0
	3/4"	0.29	18.00	19.0
	1"	0.38	25.00	25.0
T2.5	4 mm	*	0.3	0.2
	6 mm		0.55	0.45
	10 mm		1.05	0.92
T5	6 mm	*	7	2.25
	10 mm		17	5.62
	16 mm		27	8.99
T10	16 mm	*	73	24.73
	25 mm		133	44.96

NOTE: Y = constant used in **Equations (10-4)** and **(10-5)**.
* Not available at press time.

Registration Drives: Registration drives are required to register, or position accurately. Higher belt installation tensions help in increasing belt tensile modulus as well as in increasing meshing interference, both of which reduce backlash. Tension values for these applications should be determined experimentally to confirm that desired performance characteristics have been achieved. As a beginning point, use values from **Table 10** multiplied by 1.5 to 2.0.

Table 10 Static Belt Tension, T_{st} (lbf) Per Span – General Values

Belt	4 mm	6 mm	9 mm	12 mm	15 mm	20 mm	25 mm
2 mm GT2	2	3	4	5	—	—	—
3 mm GT2	—	8	11	15	19	25	—
5 mm GT2	—	—	18	22	27	35	43
3 mm HTD	—	5	9	12	16	22	—
5 mm HTD	—	—	13	18	24	33	43
T2.5	0.34	0.67	1.37	—	—	—	—
T5	—	3	7	—	12	—	—
T10	—	—	—	—	28	—	41

Belt	1/8"	3/16"	1/4"	5/16"	3/8"	7/16"	1/2"
MXL	2	3	3	4	5	—	—
XL	2	3	4	5	6	8	9

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Most synchronous belt applications often exhibit their own individual operating characteristics. The static installation tensions recommended in this section should serve as a general guideline in determining the level of tension required. The drive system should be thoroughly tested to confirm that it performs as intended.

10.2 Making Measurements

Belt installation tension is generally measured in the following ways:

Force/Deflection: Belt span tension can be measured by deflecting a belt span 1/64" per inch (0.4 mm per 25 mm) of span length at midspan, with a known force (see **Figure 20**). This method is generally convenient, but not always very accurate, due to difficulty in measuring small deflections and forces common in small synchronous drives. The force/deflection method is most effective on larger drives with long span lengths. The static (or installation) tension (T_{st}) can either be calculated from **Equation (10-1)** or **Equation (10-2)**, or selected from **Table 9** or **Table 10**. The deflection forces can be calculated from **Equation (10-4)** and **Equation (10-5)**. The span length can either be calculated from **Equation (10-3)**, or measured. If the calculated static tension is less than the minimum T_{st} values in **Table 9**, use the minimum values.

$$t = \sqrt{CD^2 - \left(\frac{PD - pd}{2}\right)^2} \qquad \textbf{(10-3)}$$

where:
- t = Span length (in.)
- CD = Drive center distance (in.)
- PD = Large pitch diameter (in.)
- pd = Small pitch diameter (in.)

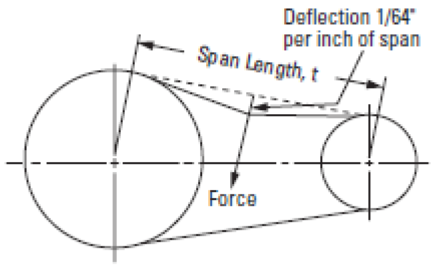

Fig. 20 Force/Deflection Method

$$\text{Deflection force, Min.} = \frac{T_{st} + \left(\frac{t}{L}\right) Y}{16} \quad \text{(lbf)} \qquad \textbf{(10-4)}$$

$$\text{Deflection force, Max.} = \frac{1.1\,T_{st} + \left(\frac{t}{L}\right) Y}{16} \quad \text{(lbf)} \qquad \textbf{(10-5)}$$

where:
- T_{st} = Static tension (lbf)
- t = Span length (in.)
- L = Belt pitch length (in.)
- Y = Constant, from **Table 9**

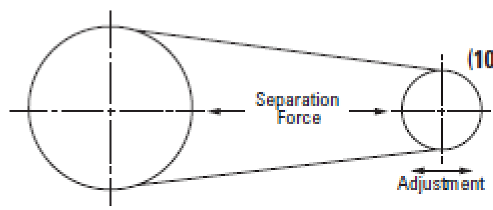

Fig. 21 Shaft Separation Method

Shaft Separation: Belt installation tension can be applied directly by exerting a force against either the driver or driven shaft in a simple 2-point drive system (see **Figure 21**). The resulting belt tension will be as accurate as the force applied to driver or driven shaft. This method is considerably easier to perform than the force/deflection method and, in some cases, more accurate.

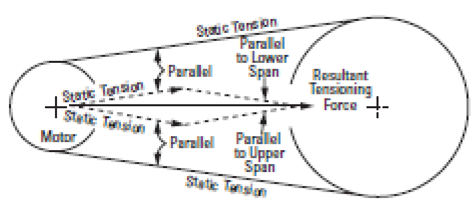

Fig. 22 Single Tension Vector Force

In order to calculate the required shaft separation force, the proper static tension (on a per span basis) should first be determined as previously discussed. This tension value will be present in both belt spans as tension is applied. The angle of the spans with respect to the movable shaft should then be determined. The belt spans should be considered to be vectors (force with direction), and be summed into a single tension vector force (see **Figure 22**). Refer to **SECTION 14 BELT PULL AND BEARING LOADS** for further instructions on summing vectors.

Linear Belt Specifications

				XL	L	H	H-HF	XH	T5	AT5	ATL5
Pitch (Imperial and Metric)				.200"	.375"	.500"	.500"	.875"	5 mm	5 mm	5 mm
Ultimate Tensile Strength per Inch or 25 mm Belt Width	Steel		lbf/in	759	1474	1605	2369	3204	759	1602	2369
			N/25 mm	3375	6555	7140	10540	14250	3375	7125	10540
	Kevlar		lbf/in	1882	1727	1818	N/A	3639	1200	1877	N/A
			N/25 mm	8370	7682	8085	N/A	16185	5332	8350	N/A
	Stainless Steel		lbf/in	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
			N/25 mm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Max. Allowable Belt Tension per Inch or 25 mm Belt Width	Steel	Open Ended	lbf/in	192	371	436	534	854	189	396	526
			N/25 mm	853	1652	1939	2377	3801	840	1761	2340
		Welded	lbf/in	96	186	218	267	427	94	198	198
			N/25 mm	427	826	970	1189	1900	420	880	880
	Kevlar	Open Ended	lbf/in	209	276	243	N/A	400	180	272	N/A
			N/25 mm	930	1229	1081	N/A	1778	801	1210	N/A
		Welded	lbf/in	157	207	182	N/A	300	140	204	N/A
			N/25 mm	698	922	810	N/A	1334	687	908	N/A
	Stainless Steel	Open Ended	lbf/in	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
			N/25 mm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Welded	lbf/in	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
			N/25 mm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Allowable Effective Tension for Belt Teeth (15 and more teeth in mesh)			lbf/in	180	360	441	441	879	200	290	290
			N/25 mm	800	1600	1960	1960	3910	890	1290	1290
Specific Belt Weight	Steel		lbf/ft/in	0.036	0.059	0.066	0.072	0.180	0.037	0.055	0.062
			kgf/m/cm	0.021	0.035	0.039	0.042	0.105	0.022	0.032	0.036
	Kevlar		lbf/ft/in	0.033	0.052	0.055	N/A	0.155	0.033	0.046	N/A
			kgf/m/cm	0.019	0.030	0.032	N/A	0.091	0.020	0.027	N/A
	Stainless Steel		lbf/ft/in	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
			kgf/m/cm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Specific Belt Stiffness (Open Ended)	Steel		lbf/in	47950	92800	109000	133600	213600	47950	100500	133600
			N/mm	8400	16255	19085	23400	37410	8400	17605	23400
	Kevlar		lbf/in	52250	69100	60700	N/A	100000	52250	69100	N/A
			N/mm	9155	12100	10635	N/A	17500	9155	12100	N/A
	Stainless Steel		lbf/in	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
			N/mm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Min. No. of Pulley Teeth	Steel and Kevlar			10	10	14	12	18	10	15	15
	Stainless Steel			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Min. Pitch Diameter (Inch or mm)	Steel and Kevlar		inch or mm	.64"	1.19"	2.23"	1.91"	5.01"	16 mm	24 mm	24 mm
	Stainless Steel		mm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Min. Diameter of Tensioning Idler Running on Back of Belt	Steel and Kevlar		in/mm	1.125"/30 mm	2.375"/60 mm	3.125"/80 mm	2.375"/60 mm	5.875"/150 mm	1.125"/30 mm	2.375"/60 mm	2.375"/60 mm
	Stainless Steel		in/mm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Available in FDA Compliant Construction (85 Shore A Urethane)				Yes	Yes	Yes			Yes		
Standard Colors (N=Natural, W=White)				N	N	N,W	N	N	N,W	W	W

Calculating Belt Weight

Imperial Units
Belt Weight = (Specific Belt Wt, lbf/ft/in) x (Belt Length, ft) x (Belt Width, in)
e.g. 200 ft of H600, Steel Cord
Belt Weight = 79 lbs = (0.066 lbf/ft/in) x (200 ft) x (6 in)
Metric Units
Belt Weight = (Specific Belt Wt, kgf/m/cm) x (Belt Length, m) x (Belt Width, cm)
e.g. 100 meters of 150T10, Steel Cord
Belt Weight = 111 kg = (0.074kgf/m/cm) x (100 m) x (15 cm)

Service Temperature Range	
–5° C to 70° C (23° F to 158° F)	
Hardness	
92 Shore A - Standard PU, 85 Shore A - FDA Compliant PU	
Coefficient of Friction	
Urethane vs. UHMWPE (dry)	
Urethane vs. Steel (dry)	0.5 to 0.7
Urethane vs. Aluminum (dry)	0.5 to 0.6
Urethane vs. UHMWPE (dry)	0.2 to 0.4
Nylon vs. Steel (dry)	0.2 to 0.4
Nylon vs. UHMWPE (dry)	0.1 to 0.3

Gates Synchro-Power (Cast) Belts

Gates Synchro-Power belts, **cast belts**, are produced on dedicated tooling and are available from stock in the sizes listed. For belt lengths not listed, please consult a Gates Mectrol applications engineer.

Belt Length, inches

No. of Teeth	XL	L	H
Pitch	.200"	.375"	.500"
40		15	
48			24
50		18.75	
54		20.25	27
55	11		
56		21	
60	12	22.5	30
64		24	
65	13		
66			33
67	13.4		
68		25.5	
70	14		
72		27	36
75	15		
76		28.5	
78			39
80	16	30	
84			42
85	17		
86		32.25	
90	18		45
92		34.5	
95	19		
96			48
97	19.4		
98		36.75	
100	20		
102			51
104		39	
105	21		
110	22		
112		42	
115	23		
120	24	45	
125	25		
130	26		

Available Widths

Pitch	Min.	Max.	Max. Width Exceptions
XL	.250"	11.81"	
L	.375"	11.81"	
H	.375"	11.81"	
T2.5	4 mm	300 mm	240 mm max width for belt lengths 120 mm, 145 mm
T5	6 mm	300 mm	240 mm max width for belt lengths 150 mm, 165 mm
DT5	6 mm	300 mm	
T10	10 mm	300 mm	
DT10	10 mm	300 mm	
AT5	6 mm	300 mm	
AT10	16 mm	300 mm	

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RADD:

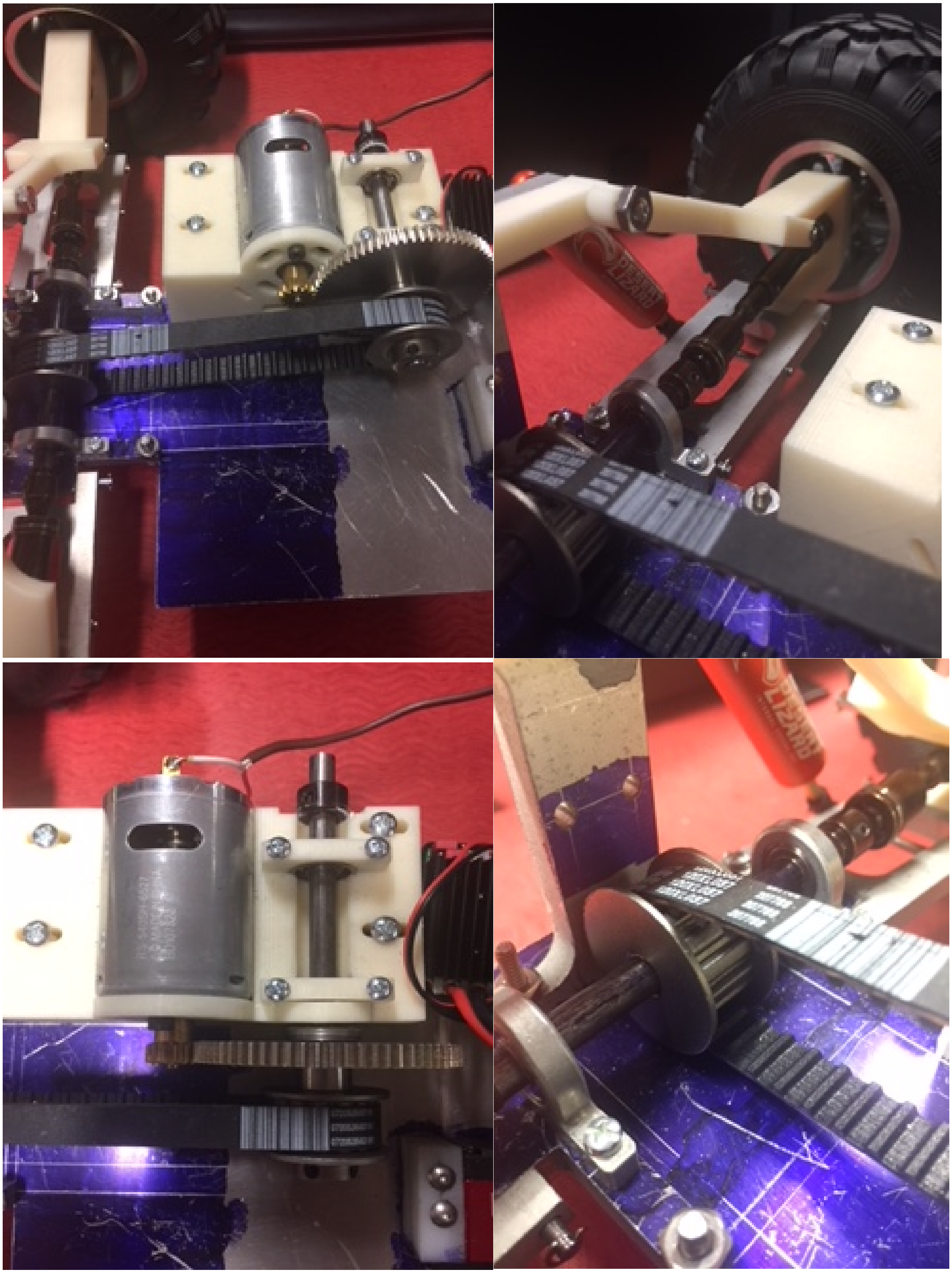
Requirement: Drivetrain Gears must be no higher than 3 inches off of frame base.

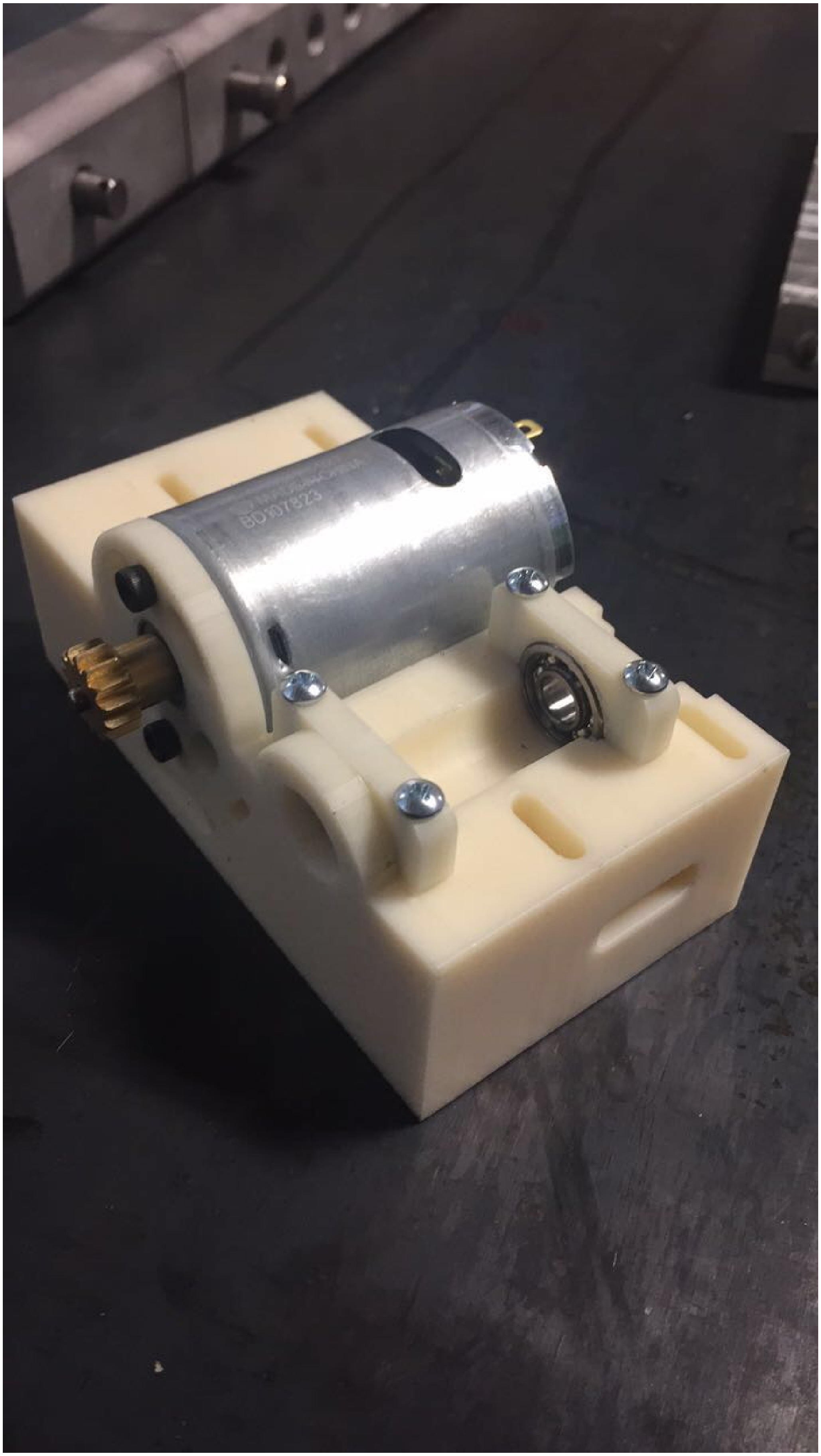
Analyses: Green Sheets show highest gear size will be 2.25" + Shroud to protect gears + 0.5" max!
=2.75" < 3.00"

Design: Greensheets shown will be transferal into Solidworks drawings/design

Documentation: Appendix A in Proposal
Analysis in Website

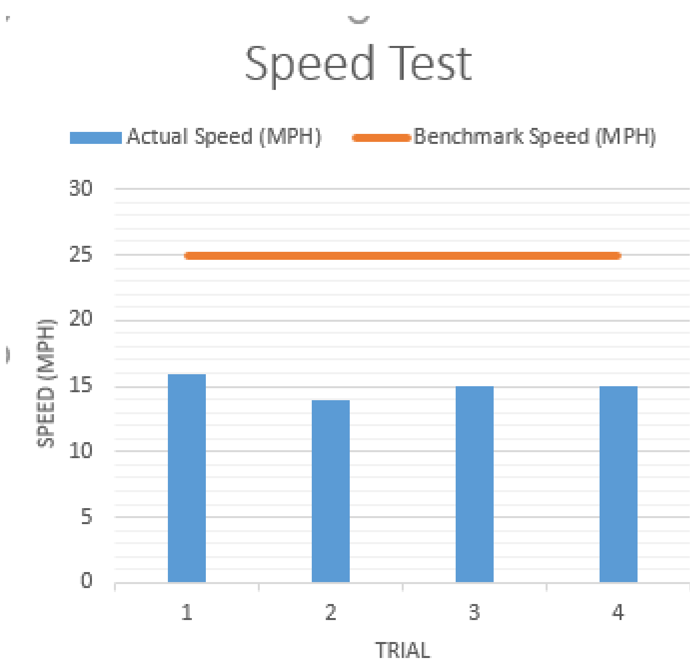
Photos:





APPENDIX G – Evaluation sheet (Testing)

Test	Expected result	Actual Result	Test Comments
Maintain 25 MPH	Pass	Fail	Top Speed 16mph
Maintain 25 MPH	Pass	Fail	Top Speed 15mph
Maintain 25 MPH	Pass	Fail	Top Speed 14mph
Maintain 25 MPH	Pass	Fail	Top Speed 15mph
Motor Temp <150°F	Pass	Pass	Motor Temp 145F
Motor Temp <150°F	Pass	Pass	Motor Temp 142F
Motor Temp <150°F	Pass	Pass	Motor Temp 137F
Motor Temp <150°F	Pass	Pass	Motor Temp 146F
<10 minutes to assemble/disassemble	Pass	Pass	9:05 min and ran after
<10 minutes to assemble/disassemble	Pass	Pass	9:25 min and ran after
<10 minutes to assemble/disassemble	Pass	Pass	8:55 min and ran after
<10 minutes to assemble/disassemble	Pass	Pass	9:30 min and ran after



APPENDIX H – Testing Report

Introduction:

Testing methods must be in response to requirements listed in the Requirements section. A minimum of 3 tests will be conducted on the requirements. The first requirements is that the motor at full throttle under load for 10 minutes won't reach a temperature above 150^{o} F. This test must be done to ensure the motor won't start to melt the 3D printed motor mount. The second requirement tested is maintaining the speed calculated by the analysis in Appendix A. Both of these requirements are relevant to the success of the project and therefor will be tested to produce satisfactory results. The last test will be the construction and deconstruction of the drivetrain which will need to take less than 10 minutes to accomplish. If this can be accomplished then it has been determined that the design is simple enough and repairs could possibly be made if necessary. The design of the car should be able to fulfill the test requirements set forth. The requirements set forth were stated based off of the calculations done and should be able to be completed and pass unless a design change has to happen. These tests will be completed according to the schedule in the Gantt chart which is attached in the bottom of the testing report.

Testing Methods:

These tests will be done throughout the course of the spring quarter with assistance from Professor Beardsley in acquiring the necessary equipment to complete the tests. Testing will be done throughout the quarter and will be done with multiple trials to ensure that the test results are not skewed by outlying data. Each test will be a simple Pass/Fail with comments for each trial completed.

Testing Procedure:

These requirements will be put to different tests to find if they are satisfactory or not. The first test that we will do is that the motor at full throttle for 10 minutes won't reach a temperature above 150^{o} F. This is to determine the motor won't have any issues mating with the 3D printer material and that it won't overheat. This test can be approached in two different ways. The first is using a laser temperature thermometer to check the temperature after 10 minutes of full power. The second method is hooking up a temperature sensor to the electric motor to determine its temperature using a fluke multi meter. Both way will work to determine the temperature and both may be used.

To test the second requirement; maintaining the speed calculated by the analysis in Appendix A, we have two options.

3. Using a speed gun to measure speed in MPH over multiple trials to get an average top speed.
4. Setting a distance the car must travel once full speed has been hit and clocking the time it takes for the car to travel that distance over multiple trials to determine its top speed.

Either test procedure is acceptable; the 2nd being more likely as it requires only a stopwatch and tape to mark a set distance. A long flat and straight path is needed to be able to get up to the max velocity. Results will be recorded in the testing results

The next requirement to test is that the cars drivetrain can be disassembled and reassembled in less than 10 minutes. To test this the entire drivetrain described in this proposal must be mounted on the car, then the timer is started and the drive system is disassembled and reassembled inside the 10 minute time frame. After the test is completed the car will be driven to ensure that it was indeed put back together correctly.

APPENDIX J – Resume

Nick Paulay

19004 73rd Ave NE Kenmore, WA | (425) 327-4524 | nickfpaulay@gmail.com

OBJECTIVE

To obtain a 2018 Summer Internship

EDUCATION

Bachelor of Science in Mechanical Engineering Technology — **Fall 2018**
Central Washington University, Ellensburg, WA
Cumulative GPA: 3.12

Completed Major Courses:

- Statics, Strength of Materials, Thermodynamics, Fluid Dynamics, Heat Transfer, 2D and 3D Modeling, Basic Machining, Metallurgy, Applications of Strength of Materials, Energy Systems, Senior Project 1, Mechanical Design, Project Cost Analysis

Activities & Leadership

President, CWU Tennis Club — **09/17-Present**
Practice Coordinator, CWU Tennis Club — **09/15-6/17**
Research Project, Stream Rehabilitation, S.T.E.P. Program, CWU — **09/14-6/15**
Senior Project, Design Build R.C. Car Drive Train, M.E.T. Dept., CWU — **09/17-6/18**
ASME Club Member, M.E.T Dept., CWU — **09/16-Present**

PROFESSIONAL SKILLS AND CERTIFICATIONS

Microsoft Office Suite including Word, PowerPoint, Excel & Outlook, Certified SolidWorks Associate (CSWA), AutoCAD, Bluebeam Revu, MD Solids, Simulation Mechanical

ADDITIONAL SKILLS/INTERESTS

- 8+ years' experience in home renovation/remodeling and construction
- Student Pilot

EXPERIENCE

Estimating Intern | The Walsh Group — **06/17 - 09/17**

- Reviewed specifications, plans, costs, submittals, schedules and future bid packages
- Assisted with surveying for concrete form work placements and elevations using a total-station
- Compiled concrete truck tickets and organized data into an Excel spreadsheet
- Created takeoffs for quantities of concrete based off of construction plans and BIM models

Parks Irrigation and Lawn Specialist | City of Redmond — **07/16 - 09/16**

- Analyzed irrigation systems to stop and prevent leaks to save the city money on water
- Learned how to use different equipment to cut grass as well as maintain the equipment

Shuttle Driver | Summit at Snoqualmie — **02/16 - 03/17**

- Engaged with passengers to create a welcoming environment at the resort

Delivery Puller | The Home Depot — **07/15 - 09/15**

- Worked independently to complete fulfillments for delivery
- Utilized strong multi-tasking abilities to retrieve products for deliveries as well as interact with customers to help them with any questions they might have