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R/C Baja: Drivetrain

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R/C Baja: Drivetrain

By

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ABSTRACT

The Central Washington University Mechanical Engineering Technology Department hosts an annual R/C Baja competition in which R/C cars fabricated by student teams are put through a series of courses and tests to determine which team's vehicle is best. The goal of this project was to create a functioning drivetrain that conveys power from the battery to the wheels and provides control of the vehicle. A list of requirements for the drivetrain was created to ensure that the vehicle will not only function, but that it will actually succeed in the competition. These requirements included that the vehicle must achieve a maximum speed that exceeds 20 mph and retain the capacity to produce maximum power for more than 15 minutes. To achieve this, preliminary calculations were completed that utilized principles from kinematics, basic electricity and mechanics of materials to ensure that these requirements would be met. Following this, 3D models and assemblies of the drivetrain and vehicle were produced. These steps culminated in the construction of the vehicle which utilized multiple construction methods such as machining and 3D printing. The finalized vehicle performed as intended with its maximum speed exceeding 25 mph and retained the capacity to produce maximum power in excess of 30 minutes.

Key words: Kinematics, 3D printing, R/C Car

This will be done in tandem with the other engineering team member, Ryan Laframbois, who will be responsible for the vehicle’s chassis, suspension, and steering. There are a number of requirements for the design of the vehicle that will not only ensure that the vehicle runs, but that it will perform well in the competition.

Contents

1. INTRODUCTION

a. Description

R/C Baja is an annual competition hosted by CWU that puts R/C cars fabricated by student engineering teams through a series of courses and tests. Fabrication of the R/C car consists of the construction of the chassis, suspension, steering and drivetrain. The focus of this proposal will be the construction and analysis of the drivetrain.

b. Motivation

The motivation for this project consists of a desire to compete against other student teams and win every aspect of the R/C Baja competition. This requires the application of everything learned over the course of the MET program.

c. Function Statement

To convey power from the battery to the wheels and provide control of the vehicle.

d. Requirements

1. R/C must be able to reach a speed of greater than or equal to 20mph.
2. Powertrain must contain at least one 7.2v battery.
3. The vehicle must achieve a minimum acceleration of 5 m/s^2.
4. Battery must sustain power to drivetrain for at least 15 minutes without a reduction in max speed.
5. The final cost of the battery and drivetrain must remain under $400.
6. The battery and drivetrain assembly must remain under 2 inches in height measured from the chassis.
7. The vehicle must not bottom out if dropped from a distance of 2ft.
8. The spur gear, outdrive cups, and rear axles must not shear when experiencing 10 lb-in or torque.
9. The main drivetrain components must not exceed a temperature that will damage the materials adhering them to the vehicle. (Battery,ESC<160F, Motor<176F)
10. The motor and battery housing must withstand an impact from the housed components if the vehicle were to crash going 25mph.

e. Engineering Merit

Successful completion of this project will require the implementation of all information learned over the course of the MET program. There will be a preliminary design stage, construction, analyses/testing stage. Merit will be provided to the project by the calculations and analyses of every aspect of the drivetrain and steering system. These calculations and analyses will be performed using engineering principles from mechanics of materials, basic electricity, and gear design from mechanics of materials.

f. Scope of Effort

As stated in the introduction, the focus of this proposal and the attached calculations, analyses, construction and testing will be on the drivetrain.

g. Success Criteria

R/C Baja successfully completes all aspects of the R/C competition.

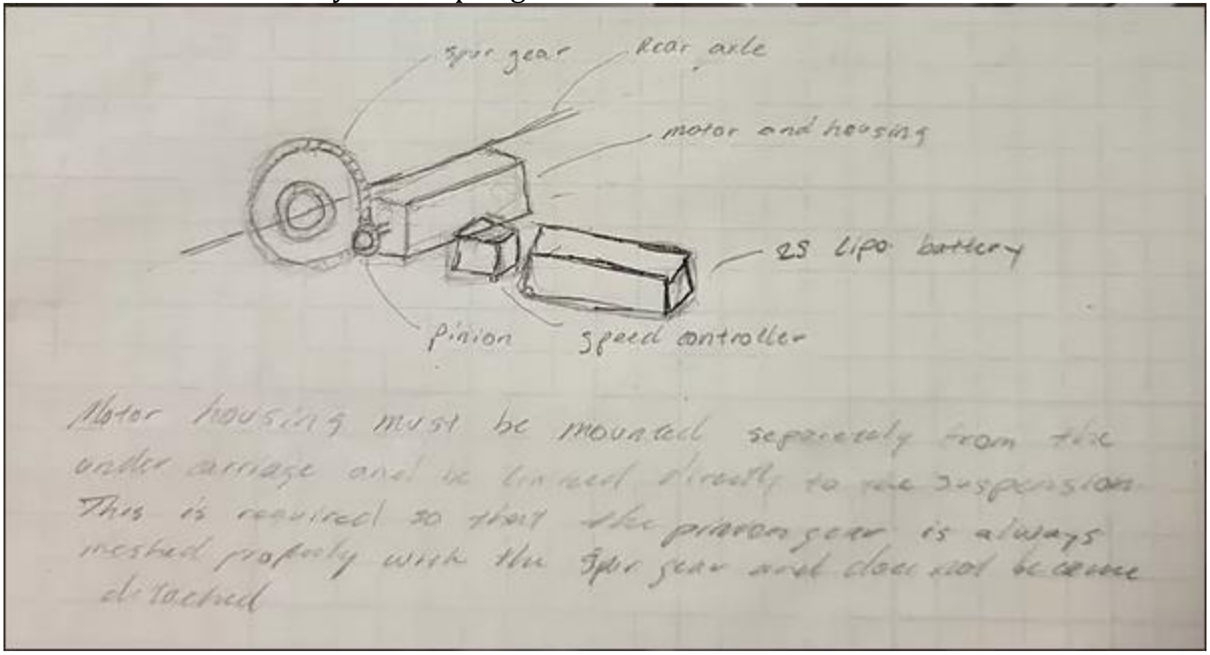
2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

The function of the drivetrain is to convey power from the battery to the wheels and provide control of the vehicle. There is a list of requirements that must be met but at the most basic level the drivetrain must make the vehicle move. The design was initiated by researching commonly used drivetrain designs for R/C vehicles. After thorough analysis using a decision matrix, it was decided that a direct-drive drivetrain would be the most optimal design based on the criteria of the decision matrix. The engineer was highly confident that this system would be capable of meeting the stipulated requirements and be able to succeed in the competition. Belt and chain drives as well as various designs that utilized gear reductions and driveshafts were considered but discarded.

b. Design Description

The R/C car will be utilizing a direct drive system. This system is designed so that the pinion gear from the motor shaft meshes directly with the spur gear that is connected to the rear axles. The spur gear also functions as the differential as a ball bearing differential is housed inside the body of the spur gear.



Motor housing must be mounted separately from the under carriage and be linked directly to the suspension. This is required so that the pinion gear is always meshed properly with the spur gear and does not become detached

Figure 1: Preliminary design sketch of direct drive drivetrain system

c. Benchmark

The design and performance of this vehicle is compared to the Team Associated Pro4 SC10 1/10 RTR 4WD Brushless Short Course Truck w/2.4GHz Radio (General Tire). Based on the competition requirements and the structure of the courses and tests, this vehicle would perform exceptionally well, hence why it was chosen as the benchmark.

d. Performance Predictions

There are numerous predictions and requirements for the performance of this vehicle that all will be corroborated by analyses. The engineer predicts the vehicle to be able to travel at a maximum speed of 25 mph and be able to travel up a 45-degree ramp due to the suitable torque produced by the drivetrain system.

e. Description of Analysis

Twelve analyses were done for the design of the vehicle that determined what the characteristics of a component should be, whether a pre-purchased component was suitable, and what methods should be used in the construction of the vehicle. A variety of engineering methods were used to complete the analyses while also adhering to RADD principles. Each analysis was based on a requirement and resulted in a design parameter. Mechanics of materials ended up being the most utilized method due to direct drive systems producing a lot of torque making multiple components vulnerable to torsional shear (Appendix A4.1 & A4.2). Additionally, housing thicknesses for the motor and battery must be determined to ensure that they do not come free in the event of a high-speed collision (Appendix A6 & A8). These analyses either determined what a component size should be or determined whether a pre-purchased part was the right size. Principles from basic electricity were also utilized to determine the power output from the motor and battery system (Appendix A1) as well as an approximation for how long the vehicle can be run at full speed (Appendix A11). Other methods such as kinematics were utilized to ensure that all requirements are being met.

f. Scope of Testing and Evaluation

The maximum achievable speed and acceleration will both be tested to determine if the vehicle's performance will meet the performance requirements and be on par with the stipulated benchmark. Maximum temperature of the battery and motor will also be measured to determine if the heat has any chance of damaging internal components.

g. Analysis

i. Analysis 1

Requirement 1 stipulates that the vehicle must be able to reach a speed of greater than or equal to 20mph. Analysis 1 was completed to identify the power output from the engine given the max current, no load current, Kv rating and battery voltage. These calculations were completed using basic principles from thermodynamics and will aid in calculating the maximum speed achievable by the drivetrain design. The actual power output was calculated to be 370.962 W. This is documented in appendix A01.

ii. Analysis 2

Requirement 1 stipulates that the vehicle must be able to reach a speed of greater than or equal to 20mph. Requirement 8 stipulates that the spur gear, outdrive cups, and rear axles must not shear when experiencing 1.5 lb-in or torque. Analysis 2 was completed to identify the max RPM and Torque output of the motor. Motor RPM was calculated by multiplying the Kv rating with the voltage output of the battery. This was calculated to be 24,420 RPM. The max Torque was calculated by dividing the Power output of the motor and dividing it by the maximum RPM. This was then converted to lb-in. This was found to be 0.978 lb-in. These calculations will aid in determining the maximum speed of the vehicle as well as determining suitable dimensioning for the rear end components (rear axles, spur gear, outdrive cups. These calculations are documented in appendix A02.

iii. Analysis 3

Requirement 1 states that the vehicle must achieve a minimum speed of 20mph. Analysis 3 was completed to determine the minimum speed of the vehicle. The RPM of the rear axles was first calculated by dividing the max motor rpm by the final drive ratio. This value came out to be 2442 rpm. The outside circumference of the tires was then calculated to determine the distance travelled in a single revolution. This value was multiplied by the calculated rear axle rpm to find the maximum speed of 30.5 mph. This is documented in appendix A03.

iv. Analysis 4

Requirement 8 stipulates that the spur gear, outdrive cups, and rear axles must not shear when experiencing 10 lb-in or torque. Analysis 3 was completed to analyze whether a set of axles the engineer was interested in purchasing would be suitable, given this requirement. The torsional shear stress formula from mechanics of materials was utilized to complete this analysis. Using the specifications from the axles, the maximum allowable torque was calculated to be 40.91 lb-in**.** This value was then compared to the calculated allowable torsional shear stress which came out to be 6.125 lb-in. This analysis determined the axles to be suitable. The specifications of these axles are documented in drawing 55-002 (Appendix B07).

v. Analysis 5

Analysis 5 was completed to find the correct length of the two axle sections given the dimensions of the outdrive cups on either part of the spur gear, the spur gear itself, and the hub-to-hub distance. This was done assuming that the spur gear would be centered in the rear of the chassis.

vi. Analysis 6

Requirement 10 stipulated that the motor and battery housing must withstand an impact from the housed components if the vehicle were to crash going 25mph. This analysis was completed to determine the required thickness of the motor housing to meet this requirement. Material information gained from MATWEB, kinematics, and the shear stress formula from mechanics of materials were all used to complete the calculations. The impact force of the motor was calculated to be 13.16 kilonewtons. This value was then used to calculate the impact stress of 13.38 MPa which was converted to 1.94 ksi. The allowable shear stress was calculated by dividing the yield strength in shear of the material by the factor of safety. The allowable stress came out to be 12.33 ksi. The diameter of the housing, impact stress and allowable stress were all then used to calculate the minimum required thickness of 0.122in. The smallest thickness 6061 t6 aluminum plates can be purchased at is 1/8in which will be suitable. This value is documented in the drawing 20-003 (Appendix B-08).

vii. Analysis 7

Requirement 10 stipulated that the motor and battery housing must withstand an impact from the housed components if the vehicle were to crash going 25mph. This analysis was completed to determine the required thickness of the Battery housing to meet this requirement. Material information gained from MATWEB, kinematics, and the shear stress formula from mechanics of materials were all used to complete the calculations. These calculations are documented in appendix A08.

viii. Analysis 8

Requirement 8 states that the spur gear, outdrive cups, and rear axles must not shear when experiencing 1.5 lb-in or torque. An analysis was performed to determine the tangential, radial, and normal forces acting on the spur gear when the motor is running at full power. Gear analysis from mechanical design was utilized to complete this analysis. The tangential, radial, and normal forces came out to be 4.083lb, 0.36lb, and 4.098lb respectively. These values will later be used to determine if the selected gearing is suitable for this application. These values are documented in appendix A08.

ix. Analysis 9

The requirement for the housing components stipulated that they must resist an impact from the motor and battery if the vehicle were to crash at a speed of 25 mph. In addition to this, there is a budgetary requirement that stipulates the entire cost of the project must remain under $400. An analysis was completed to determine which material would be best suited for these components. The cost, strength and ease of manufacturing was analyzed for ABS, PLA and 6061 t-6 aluminum. This resulted in the selection of 6061 t-6 aluminum as the material for these components. The material selection that resulted from this analysis can be found in the specified material in drawings 20-001, 20-003, and 20-004 (Appendix B09, B11, and B12).

x. Analysis 10

The requirement stipulated by the engineer working on the suspension was that the vehicle must not bottom out if dropped from a distance of two feet. This resulted in dimensions for the vehicle. An analysis was completed to determine what the angle between the outdrive cup of the spur gear and the center of the wheel would be. An angle of 36.97 degrees was calculated. This is documented in appendix A10.

xi. Analysis 11

Requirement 4 stipulates that the vehicle must run for a minimum of 15 minutes without a reduction in speed. This analysis was completed to determine how long the battery will maintain the vehicle while the motor is running at its maximum rpm. This resulted in the confirmation that the stipulated requirement will be successfully met as the fully charged battery will maintain the motor at this speed for more than an hour. A drawing of the battery can be found in drawing 55-001.

h. Device: Parts, Shapes, and Conformation

The design of the gearing and differential was based on a spur gear, pinion and differential provided by the other engineering team member. It was determined from research that this material as well as tooth ratio would be suitable for the application. The material and dimensioning of the axles were determined from the rpm and torque produced by the motor as well as the dimensions of the wheels and chassis provided by the engineer responsible for them. The material and dimensioning of the housing components were determined from the weight of the components they would be housing, and the maximum speed of the vehicle. The safety factors for each of these components was determined by the magnitude of stress the component would be under, how critical the component is to the function of the vehicle, and the cost of fixing the component. As an example, if the rear axles broke, the vehicle would not function and new axles would have to be ordered. Axles are not particularly expensive though it would be time consuming to

i. Device Assembly

The full drivetrain assembly must provide power and control of the vehicle. Multiple subassemblies will first be completed before the full assembly of the drivetrain and then vehicle. The provision of power and control of the vehicle will be incorporated by the motor and housing, battery and housing, as well as the rear end assembly. This method of creating smaller subassemblies should streamline the full vehicle assembly as well as revealing any design or construction flaws before they pose any serious risk to the schedule of the construction phase.

j. Technical Risk Analysis

The simplicity of this design negates many of the technical risks that might be associated with other more involved drivetrain systems. However, there are still risks present. The immediate maximum power to the wheels of the vehicle will make the vehicle difficult to control on a track where the vehicle will constantly be slowing down and accelerating when turning. This risk can be mitigated by spending time with the vehicle once it is completed to become familiarized with how it controls. Another risk posed by this system is the high amount of torque produced. At maximum power and under no load, the motor spins at a rate of 24,420 RPM. This has the potential to shear components of the rear end such as the outdrive cups and axles. This risk will be mitigated by using components made of the correct materials that are also correctly sized for the application.

k. Failure Mode Analysis

The most prominent and concerning loading that will occur on the components will be shear loading. As stated in the technical risk analysis, multiple rear end components are vulnerable to torsional shear caused by the high torque. A maximum loading analysis was completed for the rear axles and the outdrive cups that utilized the torsional shear stress formula to calculate the maximum allowable torque on those components. This was then compared to the calculated actual torque to determine if the component material and dimensions were suitable. Another maximum loading analysis was done for the motor and battery housing components that calculated the maximum allowable impact stress on the housings. These analyses utilized kinematics and the shear stress formula from mechanics of materials.

l. Operation Limits and Safety

3. METHODS & CONSTRUCTION

a. Methods

This project was conceived, analyzed, and designed from home and within the Hogue Hall facilities with the aid of internet research, expert advice from faculty members, and access to the Solidworks software through the school. Many of the critical components will be ordered from outside resources and many will be fabricated from aluminum in the Hogue Hall machine shop or 3D printed using the printers available in Hogue Hall 119. Planning will be very critical moving forward regarding the completion of the proposed design and the construction schedule. The engineering team will make a meticulously designed construction schedule that will allow for access to the critical tools.

i. Process Decisions

Material:

Many of the critical components for the vehicle require fabrication. It came down to the decision of whether to 3D print these components using PLA or to buy bulk aluminum and machine the components in the machine shop. It was decided that machined aluminum components would be the best fit for the motor housing. The differential and a portion of the motor housing will be 3d printed. A 3D print out of PLA was selected for the differential housing. It was determined that the differential housing would not be under any considerable amount of stress and that attempting to manufacture the components out of aluminum would be near impossible considering the unique geometries. The base and rear of the motor housing will also be 3d printed as the geometries would also pose many difficulties if they were to be made out of aluminum (geometries, thickness etc.). It was determined that if the aluminum bracket could fit snugly around the motor, that any horizontal movement by the motor in case of an accident would be negligible and the rear housing made out of PLA would be more than strong enough to keep the motor in position. The analysis that determines this is can be found in appendix A. See appendix F for the decision matrix.

Fabrication process for Housing Components:

Once 6061-T6 aluminum was selected for the majority of the housing components, the fabrication process must be decided. Machining, laser cutting and stamping were all considered. Due to the criteria of cost, ease of fabrication, and strength after process, machining was decided as the most effective method for these components. The motor housing in particular requires hand shaping to create the radial shape to bracket the motor and the flanges to secure it to the chassis. As stated in the material process decision, 3D printing will be utilized for the differential housing and the base and rear of the motor housing. The only post processing necessary will be using a drill press to drill the holes for the fasteners. A decision matrix was constructed to create more informed decisions regarding these processes. This can be found in Appendix-F.

Fabrication Process for Pinion Gear:

Gearing requires a high amount of precision. It would most likely not be suitable to attempt to manufacture it in house, as the precision would not be up to par. This component will be outsourced and purchased from amazon.

b. Construction

i. Description

There will be two major subgroups to the full vehicle assembly; the drivetrain and chassis/suspension. Many of the vehicle components will be fabricated by the engineering team utilizing the tools available in the machine lab while the majority will be purchased from online sources. Assembly of the entire vehicle will also require access to the machine lab.

ii. Drawing Tree, Drawing ID's

Appendix B-1 shows the drawing tree for the entire project, from the purchased parts to the entire vehicle assembly. The drivetrain assembly consists of four sub-assemblies, the differential & housing, motor & housing, battery & housing and ESC & housing. It was decided that this path would be the most efficient as each assembly was grouped on the basis of parts having to be physically put together. As an example, the motor must be secured by the housing, or the two halves of the differential housing must be secured together. Please reference Appendix B for the drawing tree as well as all part drawings and sub-assemblies.

iii. Parts

Appendix C-1 shows a tabulated breakdown of all material and parts required for the assembly of the drivetrain. Currently, it is being assumed that none of the purchased components will require secondary processing. However, this could change quickly if there is a design change. Many of the housing components (i.e., motor housing, esc housing) will require in house fabrication. The aluminum will be purchased in bulk, and then machined to specifications in the Hogue Machine Lab. Machining is the main process group that will be utilized, while 3D printing will play a more secondary role as it will only be used in the fabrication of one component. However, the components will be fabricated using different machining methods. The dye, mill, band saw, hammer & vice, and drill press will all be utilized. The band saw will be used to cut the required material out of the bulk aluminum, the mill will be used to remove excess material, the dye will be used to shape the circular geometry, hammer and vice will be used to shape the orthogonal geometry, and the drill press will be used to put in the holes for the fasteners.

iv. Manufacturing Issues

Manufacturing issues will most likely stem directly from the parts that require fabrication. There is ample opportunity to experience failure in the fabrication as the engineering team does not have significant training on many of the tools available in the Hogue machine lab. Inaccurate and imprecise cuts with the band saw, failures in the shaping process and the 3D printing process failing in some way as is common are all realistic and concerning risks in the fabrication process. Another risk would be parts not showing up as ordered. In the case that the required part cannot be re-ordered, it will require secondary processing to ensure that it fits the specifications of the vehicle design. This has not been an issue thus far with more than 80% of the parts and materials ordered. Two attempts have been made thus far on the motor housing. Both attempts have seen the flanges break off of the aluminum bracket This failure stems from inaccurate placement of the bends and the attempt to adjust their placement, which results in the flange snapping off. This process failure will be rectified on the next attempt by ensuring accurate preliminary markings for the bend to ensure that it will not need reshaping once the bend has been made. Issues have also been had when using the bandsaw to cut out the required material before shaping. The band saw tends to pull the material away from the guard which can result in the cut not looking particularly clean or straight. This will fortunately not pose any serious issues outside of its aesthetic.

v. Discussion of Assembly

Full assembly of the vehicle was completed by 03/03/2022. After some serious design flaws were noted, a partial redesign of the drivetrain system was necessary. Once the preliminary design, other due diligence was completed and all necessary parts and components obtained, the assembly begin on 03/01/2022. The engineering team strategized that the most efficient method of assembly would be to start with the diff and diff housing and then work forward along the length of the chassis. This would ensure that the components with the tightest tolerances (with respect to where they are placed on the chassis) are placed first. Components that have a lot of leeway with respect to placement on the chassis (Battery, ESC) were incorporated last.

4. TESTING

a. Introduction

This is an R/C vehicle 1/10th scale. The main testing for the drivetrain will include maximum speed, acceleration and temperature.

b. Method/Approach

Speed) The maximum achievable speed will be tested by recording the time it takes to cover a set distance on a flat smooth surface. The vehicle will be run at full throttle for a set distance before approaching the marked section in which the data will be recorded. The maximum achievable acceleration can be tested by measuring how much time elapses between the vehicle starting from a stop and reaching its maximum achievable speed on a flat smooth surface. The maximum temperature produced by the drivetrain can be measured by running the vehicle at maximum speed for a given amount of time and measuring the temperature of the motor using a thermistor tipped thermometer in a room at room temperature.

The approach to the maximum speed test was modified to prevent damage to the gearing and the vehicle as a whole. The change in approach pertained to choosing a testing space in which the vehicle would be less likely to experience a severe collision. Additionally, a much longer wind-up distance has been added to prevent gear slipping and other general wear and tear on the drivetrain system. The approach for the temperature test was modified due to damage sustained to the vehicle. The front suspension tower had broken which resulted in the vehicle being unable to propel itself forward. To complete the test, the vehicle was propped up so that the wheels were not in contact with the ground. Due to less load being on the drivetrain components, the vehicle was run at full throttle for a longer time to mimic the output the components would be experiencing if the vehicle were moving. The approach to the acceleration test has also been modified to prevent damage to gearing. Due to issues with gear slipping, it was decided that a more gradual approach must be taken when applying the throttle during the acceleration test. This change will prevent severe damage to the drivetrain system at the cost of slightly less precise data for the test.

c. Test Process

The test process for measuring the maximum achievable speed will include measuring out a set starting and stopping distance and using an app that will record the maximum speed achieved within that set distance. The test process for measuring acceleration will include measuring out a set distance, then using an app that will record the maximum acceleration achieved over that distance by the vehicle. The process for measuring temperature will include using a laser temperature gun to measure the temperature of the battery and motor after the vehicle had been travelling at maximum speed for a currently undefined amount of time. There have been multiple failures when attempting to test the vehicle. During the initial attempt at a maximum speed test, the driveshaft experienced a fatigue failure. A new driveshaft was immediately made but when testing out the functionality of the driveshaft, the vehicle experienced a collision and broke a steering knuckle. This was rectified but when testing out the functionality of the vehicle again, the differential housing experienced a failure. Because of the quick succession of component failures, no testing has been able to be completed as of yet. The engineering team is confident that testing will begin once a new differential housing is incorporated.

d. Deliverables

Measured values will be compared to predicted values to determine whether requirements were met. In addition to the data provided, copious amounts of pictures and videos will be taken of the vehicle in testing. For the maximum speed test, the predicted value was calculated to be approximately 20.58 mph. The predicted value for acceleration based on the predicted maximum speed and the torque and weight is approximately 6.5 ft/s^2. The data collected during testing showed a maximum speed of 20 mph and a maximum acceleration of 6.8 m/s^2. The temperature test showed a maximum temperature for all components in a range of 70-77 degrees Fahrenheit. This temperature range is far from the danger zone in which the parts fastening the components to the chassis will be put at risk.

5. BUDGET

This project will be managed using effective project management techniques (i.e., usage of Gantt chart and ensuring time on task) and the usage of effective cost reduction techniques (i.e., finding the cheapest yet most reliable supplier of components).

a. Parts

Critical Parts are the Motor, ESC, Battery, Material for Motor Housing, Pinion and Spur Gear, and Axle pieces. These are considered critical parts because they are the main components that make the drivetrain function and will be the costliest. These parts have been purchased and are ready to be incorporated into the vehicle. Purchasing went relatively smoothly with the exception of the axles. Due to the engineering team not communicating effectively, the wrong axles were ordered. A new set has been purchased and the proper steps have been taken to ensure effective communication in the future. Once the first iteration of the vehicle was completed, the engineering team realized that the drivetrain system could not produce enough torque to initiate movement from a complete stop. This necessitated the design and fabrication of a modified system that included parts that had not been purchased (i.e. gearing) and components that had not been fabricated (i.e. driveshaft). As a result, unexpected costs arose for materials and labor. The engineer responsible for the drivetrain saw a 5% increase in material cost and a 31% increase in labor costs. Due to the overestimation in material and labor cost when the budget was developed, neither cost category exceeded the allotted amount. However, this had the potential to much more serious if the project had been gone about differently. To mitigate this risk in the future, the engineer must be more diligent in the analysis to ensure that major design changes do not have to made on the fly.

No costs were incurred during repairs to the vehicle during the testing phase. All component failures were contained to 3D printed parts. 3D printing in Hogue was free for the engineering team. No other components had to be purchased for repairs to the vehicle

All parts required for this system are listed in Appendix-C.

b. Outsourcing

Motor, ESC, Battery, gearing and axles are all components that will be outsourced from other companies. This has fortunately gone smoothly with the only hitch being the wrong set of axles being ordered. Other components will be machined or 3D printed in house. Fortunately, all 3D prints were provided without charge by Mr. Berkshire.

c. Labor

It is estimated that this project will require 400 labor hours. At a rate of $30/hr. the total labor cost would be estimated at $12,000.

Testing produced more labor costs as the testing procedures required time as well as repairs to the vehicle when a component failed. The vehicle required approximately 15 hours of repairs, not including 3D printing time. This was anticipated in the original development of the labor budget so it did not exceed the allotted amount. To further mitigate the risk in the future, the engineering team should more thoroughly analyze and anticipate the types of repairs that would be required based on the testing that is being carried out.

d. Estimated Total Project Cost

The estimated total cost for materials and other components is approximately $300. It would be reasonable to assume that shipping and taxes would cost an additional $50. No additional cost should be required as the rest of the labor will be provided by the team and school equipment. As of winter quarter, these estimations have remained accurate

e. Funding Source

The cost of this project is supported by out-of-pocket funding by the engineering team.

6. Schedule

a. Design

The design portion of this project consists of research of the topic, creating a preliminary design (i.e., rough sketches), analyses turned in on a weekly basis to further define and corroborate design ideas, solidworks modeling and drawings to finalize the proposed design and provide the necessary information for the construction portion of the project. A proposal will be completed in tandem with the above stated tasks to document all related work.

Each task and the estimated time to complete it was made towards the beginning of fall quarter and utilized a Gantt chart. This is referenced in Appendix-E.

The first five weeks of the quarter unfortunately did not go to plan as the principal engineer did not adhere to the original time estimations and scheduling. These shortcomings have been rectified and the project is back on track and likely to be successful.

b. Construction

All necessary materials and parts were successfully acquired within the time frame stipulated in the Gannt chart. Some issues have been encountered during the fabrication of components which has caused a departure from the construction schedule. As an example, the original differential housing 3D print (task 4a) was found to be unsuitable which pushed back the completion of it almost a week and a half forward. The task was estimated to take approximately 10 hours, however it will most likely be closer to 20 hours due to the re-print and redesign. Due to miscalculations pertaining to the torque, the entire drivetrain system had to be redesigned and fabricated over the first week of march. All tasks relating to the construction were crushed into 72 hours. Though the engineering team departed from the schedule, A working device was ready for presentation on 3/14.

c. Testing

The testing portion of this project consists of rigorous testing of the completed vehicle. The testing pertained to the maximum speed, maximum acceleration, heat, and differential deflection. Originally, the engineer had scheduled the drivetrain system testing to be completed prior to the R/C baja competition on 4/18. Due to multiple component failures during the first attempts at testing, only one of the four tests had been completed by this point. During the competition, the vehicle collided with a wall which broke multiple components. This set back testing another week. Fortunately for the engineering team, the procedure relating to the maximum acceleration test and maximum speed test were relatively simple and were able to both be completed in one day. All testing for the drivetrain system was done by 5/3, almost a full two weeks after originally planned. If the testing schedule were to be constructed again, the engineer would factor in component failures and more evenly distribute the testing across the length of the quarter.

7. Project Management

There are a number of risks associated with this project. Each risk must be defined and solutions must be discussed to mitigate these risks. These risks include inability to access mentors, poor time management, inability to access the machine lab, inability to access solidworks, and exceeding the allotted budget. Risks pertaining to access to tools (machine lab and solidworks) are the biggest risk faced in this project as these tools are necessary to complete the project. Strategies to mitigate these risks pertain mostly to scheduling. With proper scheduling and time on task these risks will be almost nonfactors and a successful project is highly likely. Proper budgeting and analysis of purchased parts will negate the risk of going over budget.

a. Human Resources

There are a number of risks pertaining to human resources for this project. The most present and persistent risk is access to mentors (i.e., faculty and other staff) who can help guide the project in addition to reviewing completed work. This expertise is critical and the project will most likely be unsuccessful without it. This will be managed by building a schedule that incorporates in person access to the faculty. This includes access to office hours and completing deliverables before class so that they may be reviewed by the faculty before submission. Contingencies, such as email are available if the need arises. A secondary risk is mismanagement of time on task by the engineering team. Time management techniques must be consistently employed so that effective time on task occurs throughout all phases of the project.

b. Physical Resources

The most critical physical resource required for this project is access to the machine lab. This is realistically the only location available that has the tools necessary to fabricate the required parts for the vehicle. Without access, this project cannot move forward. The winter quarter schedule will be constructed such that access to this lab will not be hindered.

c. Soft Resources

As the solidworks software is not currently available outside of the Hogue Hall computer labs, access to these labs is paramount. The risk of not being available during the open hours is the greatest risk pertaining to soft resources. This risk will be mitigated by ensuring that the winter quarter work and class schedule will allow for access to these labs.

d. Financial Resources

The greatest risk pertaining to the finances of this project is exceeding the allotted budget. As this is being paid out of pocket, there is not a significant amount of excess cost that can be covered. This risk will be mitigated by performing the necessary due diligence on all material that will be ordered and ensuring that it is in fact what is necessary to make this project succeed.

8. DISCUSSION

a. Design

The design of this project was initiated by researching the different types of commonly used drivetrains in R/C vehicles. The R/C Baja Competition requirements stipulate that a propulsion battery pack must be used in the vehicle. Based on the gathered information, a direct drive battery powered drivetrain was selected as the preliminary design idea. There were numerous reasons for this selection. Direct drive is a very simple system that doesn't have as many moving parts as a drivetrain system that utilizes gear reductions. Additionally, the low-end torque and related acceleration would be beneficial for many of the courses and tests.

A risk was noted in discussions between the engineering team that the direct drive system may make the vehicle difficult to control, as well as making components vulnerable to shearing. It was decided however that the benefits of this system outweighed the concerns. A 3300KV motor was selected as its power production was a suitable middle ground. The instantaneous power made by direct drive would negate the need for a higher-powered motor, as it would most likely make the vehicle more difficult to control and may possibly cause some components to fail. The competition's battery propulsion pack requirement specifically states that a 7.2-volt 6 cell r/c battery or a 7.4V 2S Lipo battery may be utilized. A 5200 mAh 7.4V 2S Lipo was selected due to its high current output when compared to similar lithium-ion batteries.

One of the biggest challenges encountered over the course of the design was the construction of the rear axle. This developed from a lack of communication between the engineering team and required a change in design. This failure can be avoided in the future by ensuring that frequent discussion pertaining to the design is had between the engineering team before any modeling is completed. The design of the chassis required the spur gear to be centered in the rear and for the axle to be in two separate parts that can move vertically independently of each other. Typical direct drive construction consisted of a solid rear axle with the spur gear off center. The engineer went about solving this by designing a bevel gear system and mounting the motor centered and lengthwise on the chassis. This allowed the spur gear to still be centered and use outdrive cups so that the axles may move independently. A variety of methods were considered for the motor, battery and ESC housings. Multiple factors were taken into consideration. These included cost, ease of manufacturability, and strength requirements. 6061 T6 aluminum was found to be the most optimal material due to cost and strength. Additionally, the housing will not be damaged by the heat given off by the components.

b. Construction

Numerous changes were made to part designs after further analysis by the engineer responsible for the drivetrain. It was determined that the flange lengths of the Housing, Motor (CD20-001) were too large to fit within the suspension system being implemented by the other member of the engineering team. This required the length of the flanges to be adjusted to a more appropriate length. This was change was fortunately made before any fabrication had begun.

As with any project that requires any sort of fabrication, there is a chance that parts might not come out how they were expected to. While still early in the fabrication and construction phase of this project, concern over this risk turned out to be well warranted. The Housing, Diff Part 1 (CD20-004) was 3D printed when the design was deemed suitable by the engineering team. During inspection of the part, the engineering team realized that the spur gear would not fit in the housing. This occurred due to a request by the engineer responsible for the chassis to reduce the overall length of the housing so that it would fit within the suspension system. This change was implemented to the 3D model without much thought by the engineer responsible for the drivetrain system after assuming the change would be okay. Additionally, it was found out that the slots for the bearings to sit in were also too small and need to be widened. This occurred as a result of the responsible engineer not taking into consideration that a slot the same exact width of the bearing would require a force fit, which unfortunately is not possible due to part not being sufficiently strong enough to not break during a force fit. This experience was fortunately early in the manufacturing process and allowed for valuable takeaways as the engineering team moves forward with manufacturing other parts. The most important of these takeaways was the fact that due-diligence regarding the inspection of a model must be more in depth and thorough before any manufacturing actually takes place. Another failure in this process was the engineer responsible for the drivetrain ordering the wrong axle types. This poses a minor issue as R/C axles are not particularly expensive. However, this does not negate the fact that money was wasted as the proper due-diligence was not performed before ordering the axles.

The Engineering team believes that it was successful in the selection of the manufacturing methods as all issues that have been encountered in the processes have been relatively minor. The largest of these issues was the lack of documentation provided (i.e. pictures) by the individual hired to 3d print the parts).

c. Testing

Testing began as of March 2022. Numerous issues arose with the vehicle when initiating testing. When attempting the maximum speed test, the driveshaft experienced a fatigue failure and had to be remade. When testing out the new driveshaft, the vehicle experienced a collision a snapped a steering knuckle. When the engineering team felt comfortable enough to attempt a speed test again, the differential housing failed. This was more unfortunately far more severe than anticipated and required a redesign of the housing. The engineer responsible for the drivetrain determined that a deflection test of the diff housing should be carried out before the maximum speed test. The reasoning for this was that if the diff housing deflected more than 1cm along its top plane, the gears would continue to slip and all other attempts at acceleration and speed tests would most likely end in failure. Testing procedures for the acceleration and speed test were modified to ensure that if the vehicle veers off course, it will not experience any severe collisions. During the R/C Baja competition, the vehicle experienced a collision in which multiple components of the steering and suspension system failed. Vehicle repairs and component replacements took approximately a week to complete.

The testing phase has now been completed. Testing was completed as of 05/04/2022. Once the final repairs were completed, testing went very smoothly and without incident.

9. CONCLUSION

The R/C Baja competition puts R/C vehicles constructed by student teams through a series of courses and tests to determine which team's vehicle is best. The R/C Baja Drivetrain functions to convey power from the battery to the wheels and provide control of the vehicle. Twelve analyses were completed to ensure the stipulated requirements are met. All analyses utilized engineering methods, such as mechanics of materials, principles from basic electricity and thermodynamics. All analyses utilized Requirements, Analysis, Design Parameter and documentation (RADD) in which a requirement was analyzed and resulted in a design parameter that can be seen in either a part or assembly drawing. Analyses A1-A4 utilized basic electricity and mechanics of materials to calculate power output, torque, maximum speed and maximum allowable torque based on the components being used. Analyses A6, A8 and A9 utilized mechanics of materials and kinematics to determine construction methods and material for housing components to ensure that the vehicle will survive high speed impacts. All project phases have now been completed as of 06/06/2022. Though the design of the vehicle underwent a number of changes, the vehicle did end up meeting the requirements stipulated at the beginning of this document. The construction and testing phase suffered from numerous issues. These included design failures and component failures that set the project behind. These issues were fortunately remedied in a timely manner and both phases were completed prior to the deadlines. The vehicle was in fact competitive in the competition though it suffered a structural failure during the baja race.

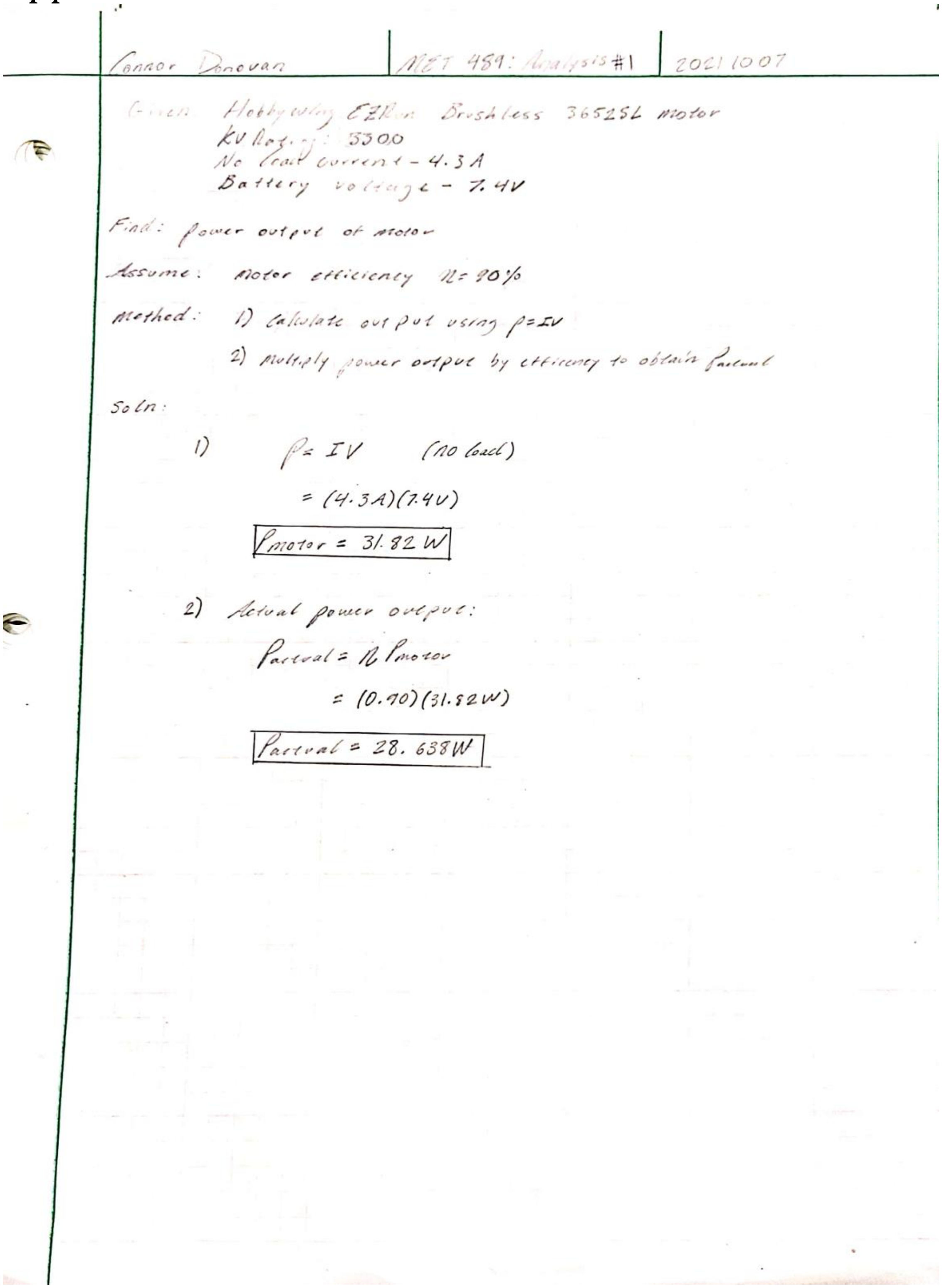
10. ACKNOWLEDGEMENTS

Professor Charles Pringle and Dr. John Choi mentored the principal engineer. Without their expert guidance this project would likely not be successful. Additionally, the other engineering team member, Ryan Lafrombois, put a tremendous amount of work into the chassis, suspension and steering. He also provided expert guidance at times as he had previous experience with R/C Vehicles.

References

APPENDIX A - Analysis

Appendix A01 – Power from Motor



Connor Donovan | MET 489: Analysis #1 | 20211007

Given: Hobbywing EZRun Brushless 3652SL motor
KV Rating: 3300
No load current – 4.3 A
Battery voltage – 7.4V

Find: power output of motor

Assume: Motor efficiency $\eta = 90\%$

Method: 1) Calculate output using $P = IV$

2) Multiply power output by efficiency to obtain P_{actual}

Soln:

1) $P = IV$ (no load)

$= (4.3A)(7.4V)$

$\boxed{P_{motor} = 31.82\ W}$

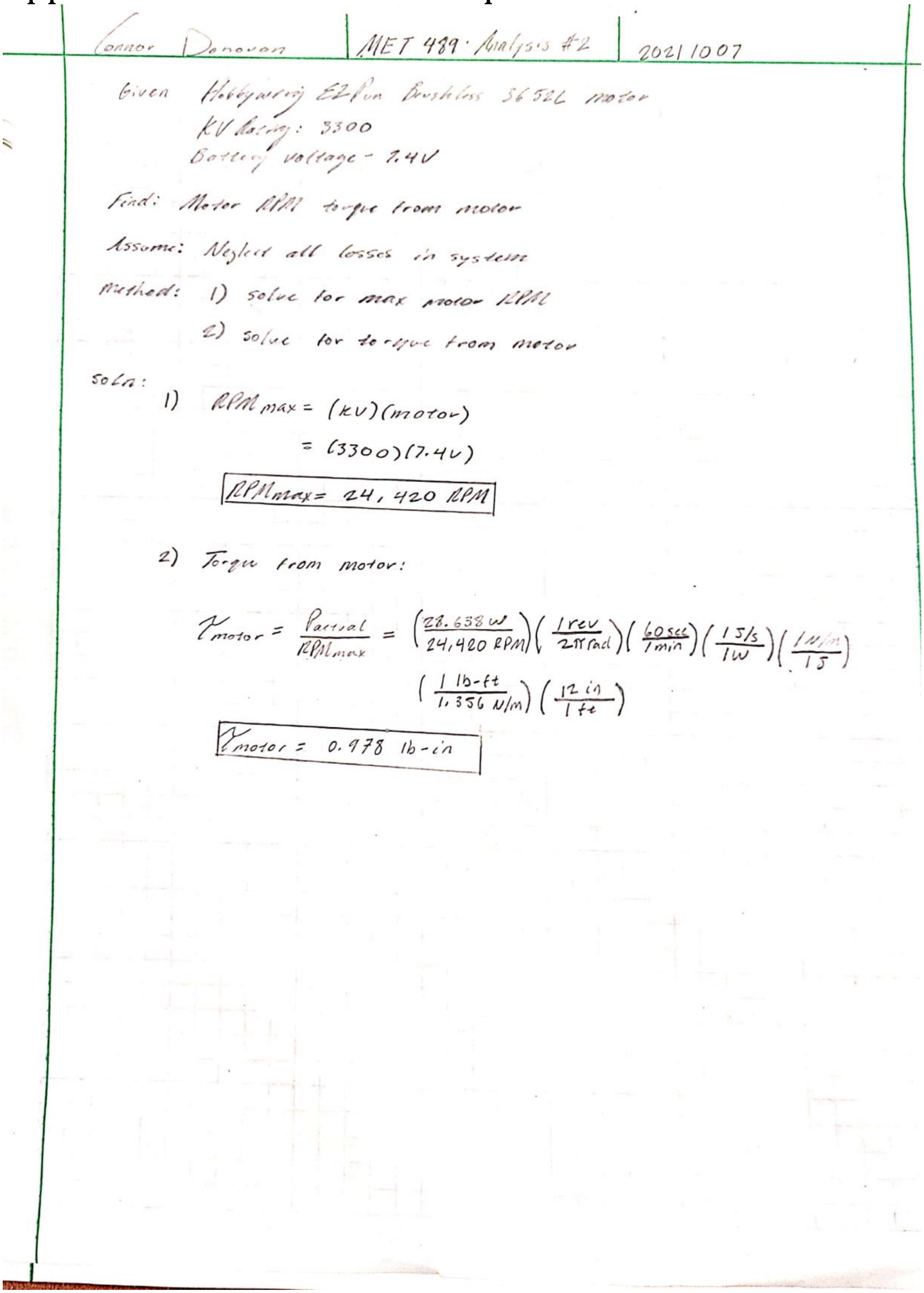
2) Actual power output:

$P_{actual} = \eta P_{motor}$

$= (0.90)(31.82W)$

$\boxed{P_{actual} = 28.638W}$

Appendix A02 – RPM and Torque from Motor



Connor Donovan | MET 489 · Analysis #2 | 20211007

Given Hobbywing EZRun Brushless 3652L motor
KV Rating: 3300
Battery voltage - 7.4V

Find: Motor RPM torque from motor

Assume: Neglect all losses in system

Method: 1) solve for max motor RPM
2) solve for torque from motor

soln:

1) $RPM_{max} = (kV)(motor)$

$= (3300)(7.4V)$

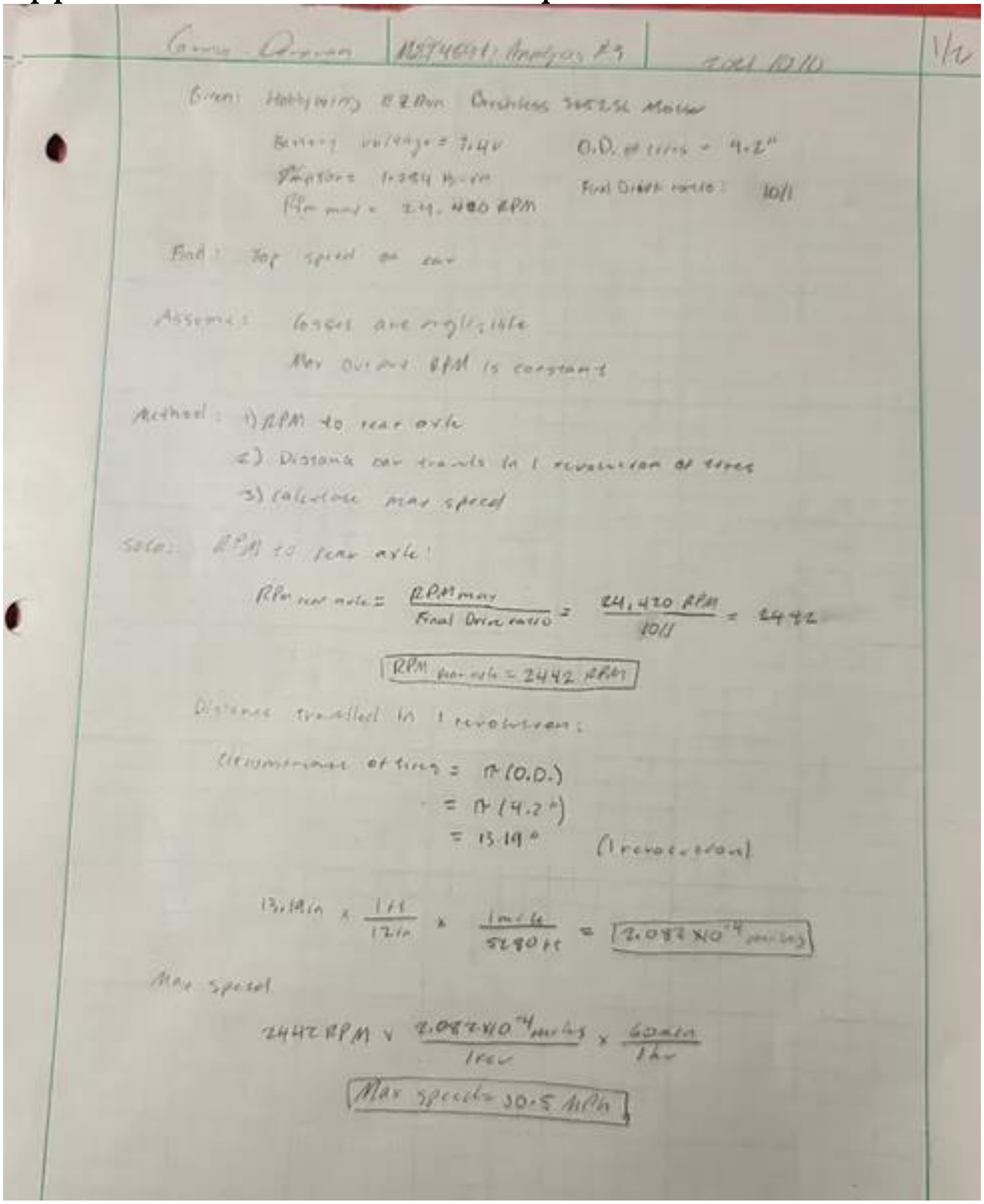
$$\boxed{RPM_{max} = 24,420\ RPM}$$

2) Torque from motor:

$$\tau_{motor} = \frac{P_{actual}}{RPM_{max}} = \left(\frac{28.638\ W}{24,420\ RPM}\right)\left(\frac{1\ rev}{2\pi\ rad}\right)\left(\frac{60\ sec}{1\ min}\right)\left(\frac{1\ J/s}{1\ W}\right)\left(\frac{1\ N/m}{1\ J}\right)\left(\frac{1\ lb\text{-}ft}{1.356\ N/m}\right)\left(\frac{12\ in}{1\ ft}\right)$$

$$\boxed{\tau_{motor} = 0.978\ lb\text{-}in}$$

Appendix A03 – RPM and Torque from Motor



[illegible] | MET4691: Analysis #3 | [illegible] | 1/2

Given: Hobbywing EZRun Brushless 3652SL Motor

Battery voltage = 7.4V
Torque = 1.384 lb-in
RPM max = 24,480 RPM

O.D. of tires = 4.2"
Final Drive ratio: 10/1

Find: Top speed of car

Assume: Losses are negligible
Max output RPM is constant

Method: 1) RPM to rear axle
2) Distance car travels in 1 revolution of tires
3) Calculate max speed

Soln: RPM to rear axle:

$$RPM_{rear\ axle} = \frac{RPM_{max}}{\text{Final Drive ratio}} = \frac{24{,}420\ RPM}{10/1} = 2442$$

$$\boxed{RPM_{rear\ axle} = 2442\ RPM}$$

Distance travelled in 1 revolution:

$$\text{Circumference of tires} = \pi(O.D.) = \pi(4.2") = 13.19" \quad \text{(1 revolution)}$$

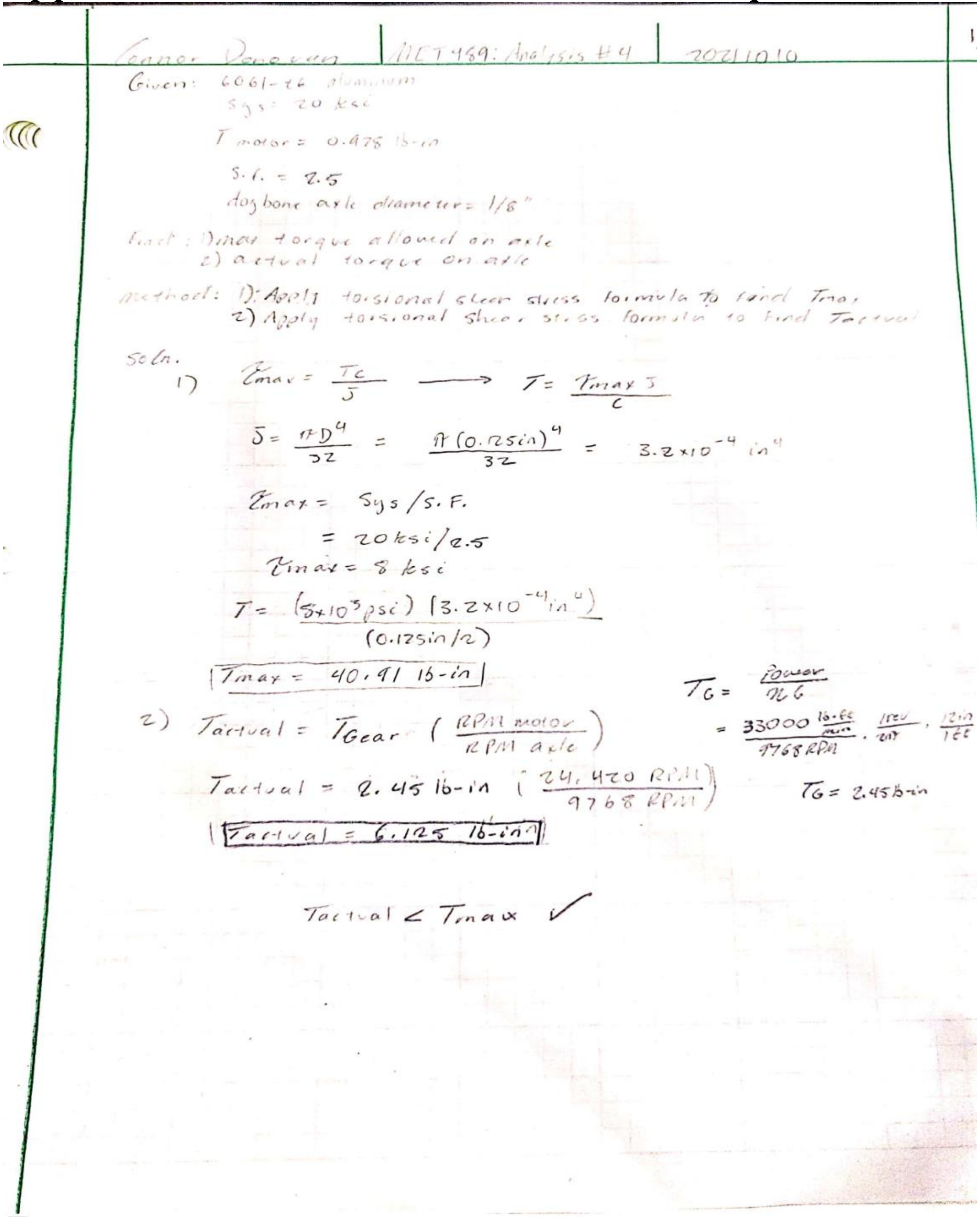
$$13.19\,in \times \frac{1\,ft}{12\,in} \times \frac{1\,mile}{5280\,ft} = \boxed{2.082 \times 10^{-4}\ miles}$$

Max speed

$$2442\,RPM \times \frac{2.082 \times 10^{-4}\ miles}{1\,rev} \times \frac{60\,min}{1\,hr}$$

$$\boxed{\text{Max speed} = 30.5\ MPH}$$

Appendix A04 – Allowable and actual torque on axle



Connor Donovan | MET 489: Analysis #4 | 20211010

Given: 6061-t6 aluminum
$S_{ys} = 20$ ksi

$T_{motor} = 0.978$ lb-in

S.F. = 2.5
dogbone axle diameter = 1/8"

Find: 1) max torque allowed on axle
2) actual torque on axle

method: 1): Apply torsional sheer stress formula to find T_{max}
2) Apply torsional sheer stress formula to find T_{actual}

soln.

1) $\tau_{max} = \frac{Tc}{J} \longrightarrow T = \frac{\tau_{max} J}{c}$

$J = \frac{\pi D^4}{32} = \frac{\pi (0.125in)^4}{32} = 3.2 \times 10^{-4}\ in^4$

$\tau_{max} = S_{ys} / S.F.$

$= 20ksi / 2.5$

$\tau_{max} = 8$ ksi

$T = \frac{(8 \times 10^3 psi)(3.2 \times 10^{-4} in^4)}{(0.125in/2)}$

$\boxed{T_{max} = 40.91\ lb\text{-}in}$

$T_G = \frac{Power}{n_G}$

$= \frac{33000 \frac{lb \cdot ft}{min}}{9768 RPM} \cdot \frac{1 rev}{2\pi} \cdot \frac{12 in}{1 ft}$

2) $T_{actual} = T_{Gear} \left(\frac{RPM\ motor}{RPM\ axle} \right)$

$T_{actual} = 2.45\ lb\text{-}in \left(\frac{24,420\ RPM}{9768\ RPM} \right)$

$T_G = 2.45$ lb-in

$\boxed{T_{actual} = 6.125\ lb\text{-}in}$

$T_{actual} < T_{max}$ ✓

Appendix A05 – Rear Axle Length

Connor Donovan | MET489A: Analysis #5 | 20211020 | 1/

Given: Tire Ø = 4.2" * U-cup + spur gear dimensions on diagram

Width tire = 1.73"

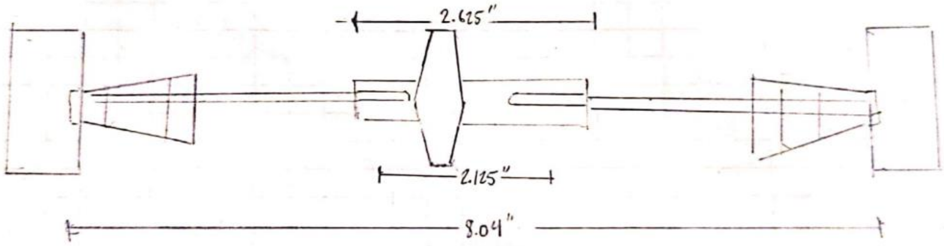
Hub - Hub = 8.04"

Find: Rear axle length

Assume: 1) Tires are equal distance away from other side of chassis
2) spur gear is centered in back of chassis

Method: 1) calculate length of axle using dimensions from the spur gear + U-cup assembly

Soln.



$$L_{axle} = \frac{8.04'' - 2.125''}{2}$$

$$\boxed{L_{axle} = 2.9575''}$$

Appendix A06 – Stress analysis and thickness calculation for motor housing

Connor Donovan | MET416: Analysis #6 | 20211028 | 1/2

Given: 6061-T6 Aluminum –

$S_{ys} = 1/2\ S_y = 1/2\ 37\ ksi = 18.5\ ksi$

$M_{motor} = 218\,g$

$\varnothing = 36\,mm$

$F.S. = 1.5$

Find: Can the motor housing withstand a high velocity impact from the motor in the case of a crash

Assume:
- vehicle is travelling at max speed (25 mph)
- Motor is fit snugly in housing (impact distance ≤ 1 mm)

Method:
1) Conversions
2) Impact strength of motor
3) Calculate the area of the motor housing absorbing the impact
4) Calculate τ_{allow} and τ_{impact}
5) Calculate wall thickness

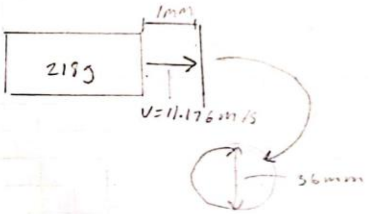
Soln.

1) $\frac{25\,mph}{2.237} = 11.176\ m/s$

2) $KE = 1/2\,mv^2$

$= 1/2\,(218g)(11.176\,m/s)^2$

$= 13.16\,J$



$13.16\,J \longrightarrow 13.16\ N/m$

$F_{impact} = KE/\text{Distance traveled}$

$= \frac{13.16\,N/\cancel{m}}{1\times10^{-3}\,\cancel{m}}$

$F_{impact} = 13.61\ kN$

3) $A = \pi r^2$

$= \pi(18\,mm)^2$

$A = 1017\,mm^2$

4) $\tau_{allow} = S_{ys}/F.S.$

$= 18.5\,ksi/1.5$

$\tau_{allow} = 12.33\ ksi$

$\tau_{impact} = P/A$

$= 13.61\,kN / 1017\,mm^2$

$= 13.38\,MPa$

$\downarrow$

$\tau_{impact} = 1.94\ ksi$

5) $t = \frac{(\varnothing)(\tau_{impact})(1/2)}{\tau_{allow}}$

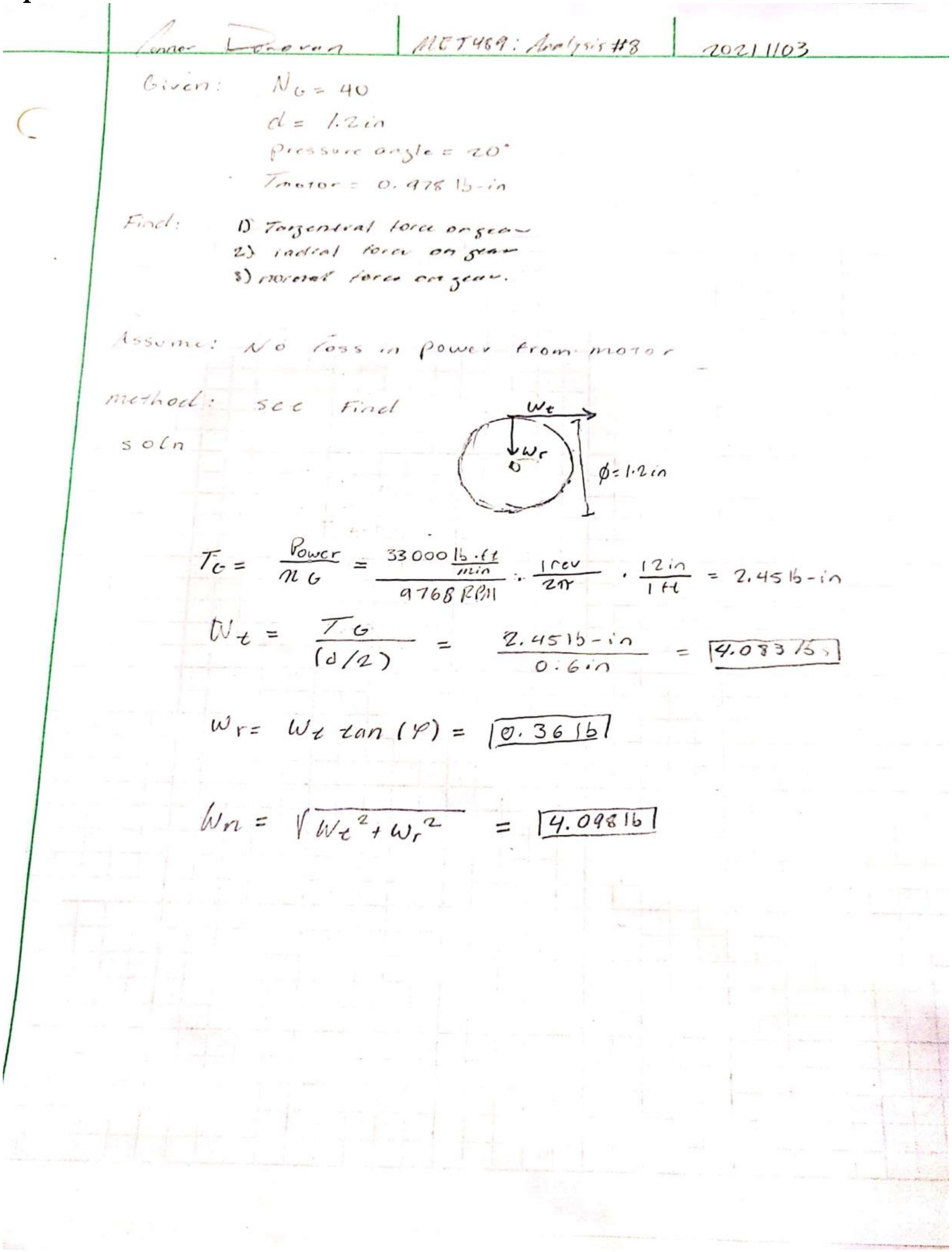
$36\,mm \longrightarrow 1.42\,in$

$t = \frac{(1.42\,in)(1.94\,ksi)(1/2)}{12.33\,ksi}$

$\boxed{t = 0.112\,in}$

Scanned with CamScanner

Appendix A07 – Tangential, Radial, and Normal Forces on Spur Gear



Conner Donovan | MET489: Analysis #8 | 20211103

Given: $N_G = 40$

$d = 1.2 in$

pressure angle = 20°

$T_{motor} = 0.978$ lb-in

Find:
1) Tangential force on gear
2) radial force on gear
3) normal force on gear.

Assume: No loss in power from motor

method: see Find

soln

W_t

W_r

$\phi = 1.2 in$

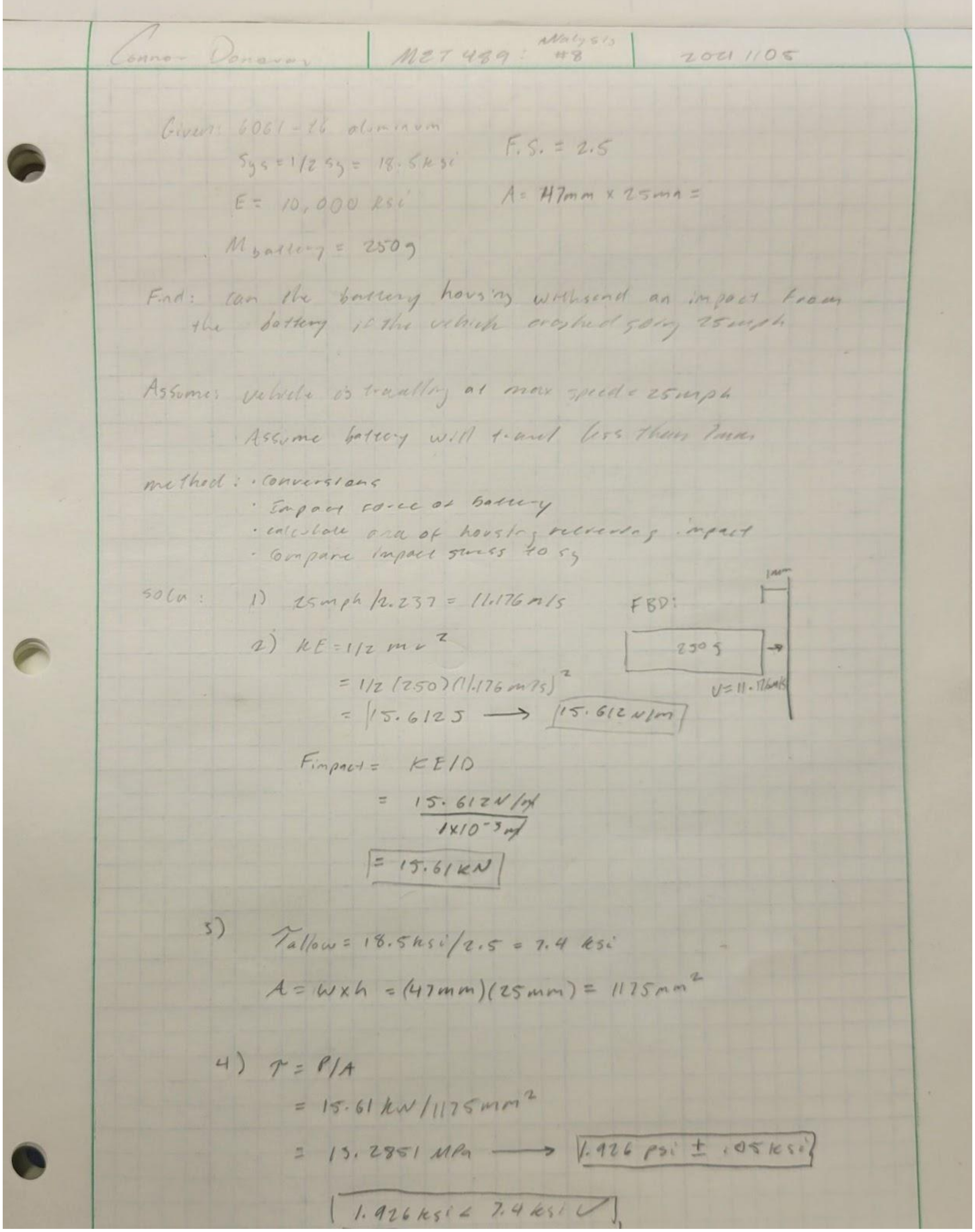
$$T_G = \frac{Power}{n_G} = \frac{33000 \frac{lb \cdot ft}{min}}{9768\ RPM} \cdot \frac{1\ rev}{2\pi} \cdot \frac{12\ in}{1\ ft} = 2.45\ lb\text{-}in$$

$$W_t = \frac{T_G}{(d/2)} = \frac{2.45\ lb\text{-}in}{0.6\ in} = \boxed{4.083\ lbs}$$

$$W_r = W_t \tan(\varphi) = \boxed{0.36\ lb}$$

$$W_n = \sqrt{W_t^2 + W_r^2} = \boxed{4.098\ lb}$$

Appendix A08 – Stress analysis on battery housing



Connor Donovan | MET 489: Analysis #8 | 2021 1105

Given: 6061-T6 aluminum

$S_{ys} = 1/2\ S_y = 18.5\ ksi$

$E = 10{,}000\ ksi$

$M_{battery} = 250g$

$F.S. = 2.5$

$A = 47mm \times 25mm =$

Find: can the battery housing withsend an impact from the battery if the vehicle crashed going 25mph

Assume: vehicle is travelling at max speed = 25mph

Assume battery will travel less than 1mm

method:
- Conversions
- Impact force of battery
- calculate area of housing recieving impact
- Compare impact stress to S_y

soln:

1) $25mph / 2.237 = 11.176\ m/s$

FBD:

1mm

250g

$V = 11.176 m/s$

2) $KE = 1/2\ m v^2$

$= 1/2\ (250)(11.176\ m/s)^2$

$= 15.612J \longrightarrow \boxed{15.612\ N/m}$

$F_{impact} = KE/D$

$= \dfrac{15.612\ N/\cancel{m}}{1\times10^{-3}\ \cancel{m}}$

$\boxed{= 15.61\ kN}$

3) $\tau_{allow} = 18.5\ ksi / 2.5 = 7.4\ ksi$

$A = w \times h = (47mm)(25mm) = 1175mm^2$

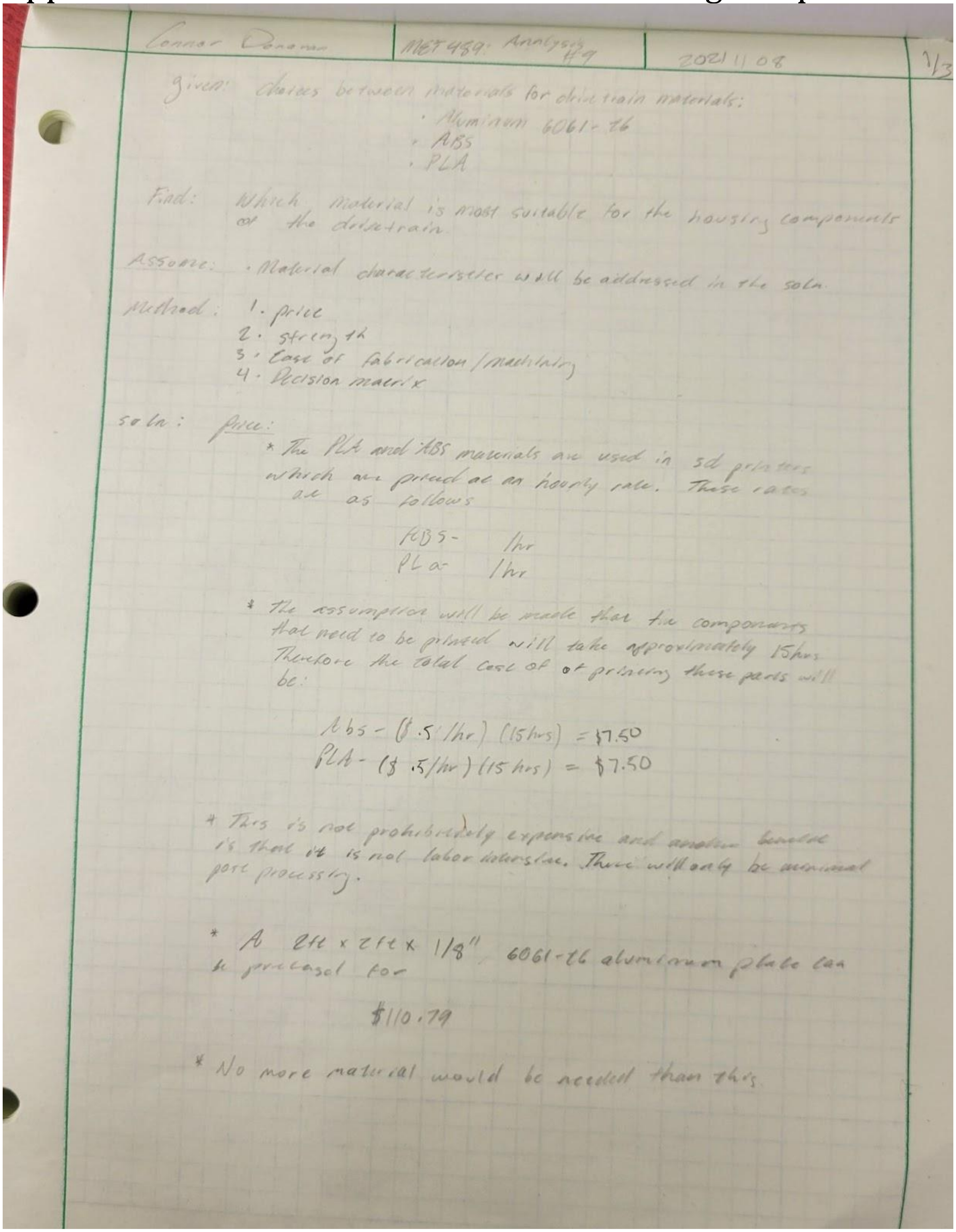
4) $\tau = P/A$

$= 15.61\ kN / 1175mm^2$

$= 13.2851\ MPa \longrightarrow \boxed{1.926\ psi \pm .05\ ksi}$

$\boxed{1.926\ ksi < 7.4\ ksi\ \checkmark}$

Appendix A09 – Material selection for housing components



Connor Donovan | MET 489: Analysis #9 | 2021 11 08 | 1/3

given: choices between materials for drivetrain materials:
- Aluminum 6061-t6
- ABS
- PLA

Find: Which material is most suitable for the housing components of the drivetrain.

Assume: · Material characteristics will be addressed in the soln.

Method:
1. price
2. strength
3. ease of fabrication / machining
4. Decision matrix

soln: price:

* The PLA and ABS materials are used in 3d printers which are priced at an hourly rate. These rates are as follows

ABS - /hr
PLA - /hr

* The assumption will be made that the components that need to be printed will take approximately 15hrs. Therefore the total cost of ~~of~~ printing these parts will be:

Abs - ($ .5 /hr) (15hrs) = $7.50
PLA - ($ .5/hr) (15 hrs) = $7.50

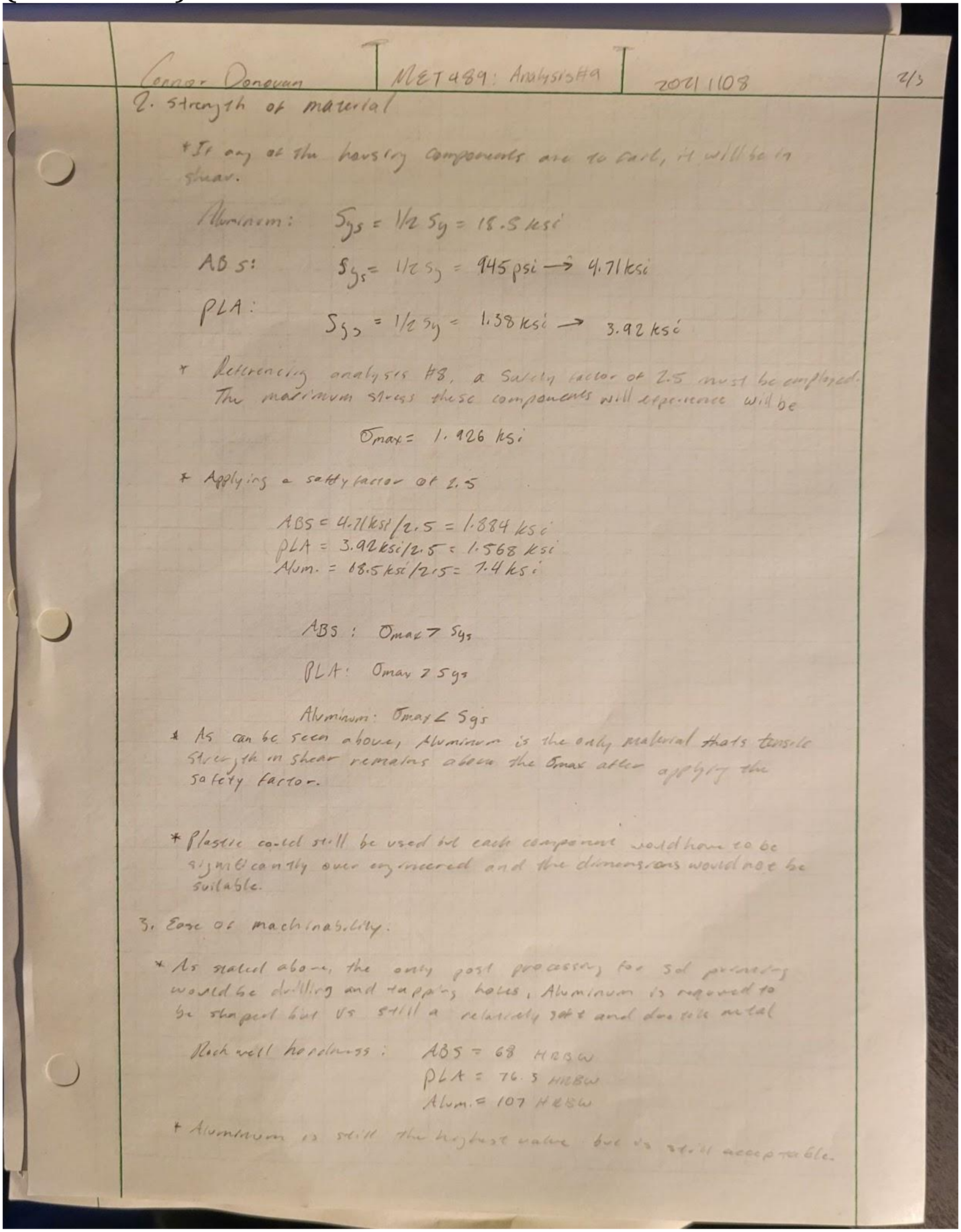
* This is not prohibitively expensive and another benefit is that it is not labor intensive. There will only be minimal post processing.

* A 2ft × 2ft × 1/8", 6061-t6 aluminum plate can be purchased for

$110.79

* No more material would be needed than this.

Appendix A09 – Material selection for housing components (continued)



Connor Donovan | MET489: Analysis#9 | 20211108 | 2/3

2. Strength of material

*If any of the housing components are to fail, it will be in shear.

Aluminum: $S_{ys} = 1/2\, S_y = 18.5\ ksi$

ABS: $S_{ys} = 1/2\, S_y = 945\ psi \rightarrow 4.71\ ksi$

PLA: $S_{ys} = 1/2\, S_y = 1.38\ ksi \rightarrow 3.92\ ksi$

* Referencing analysis #8, a safety factor of 2.5 must be employed. The maximum stress these components will experience will be

$\sigma_{max} = 1.926\ ksi$

* Applying a safety factor of 2.5

ABS = $4.71\ ksi / 2.5 = 1.884\ ksi$
PLA = $3.92\ ksi / 2.5 = 1.568\ ksi$
Alum. = $18.5\ ksi / 2.5 = 7.4\ ksi$

ABS: $\sigma_{max} > S_{ys}$

PLA: $\sigma_{max} > S_{ys}$

Aluminum: $\sigma_{max} < S_{ys}$

* As can be seen above, Aluminum is the only material thats tensile strength in shear remains above the σ_{max} after applying the safety factor.

* Plastic could still be used but each component would have to be significantly over engineered and the dimensions would not be suitable.

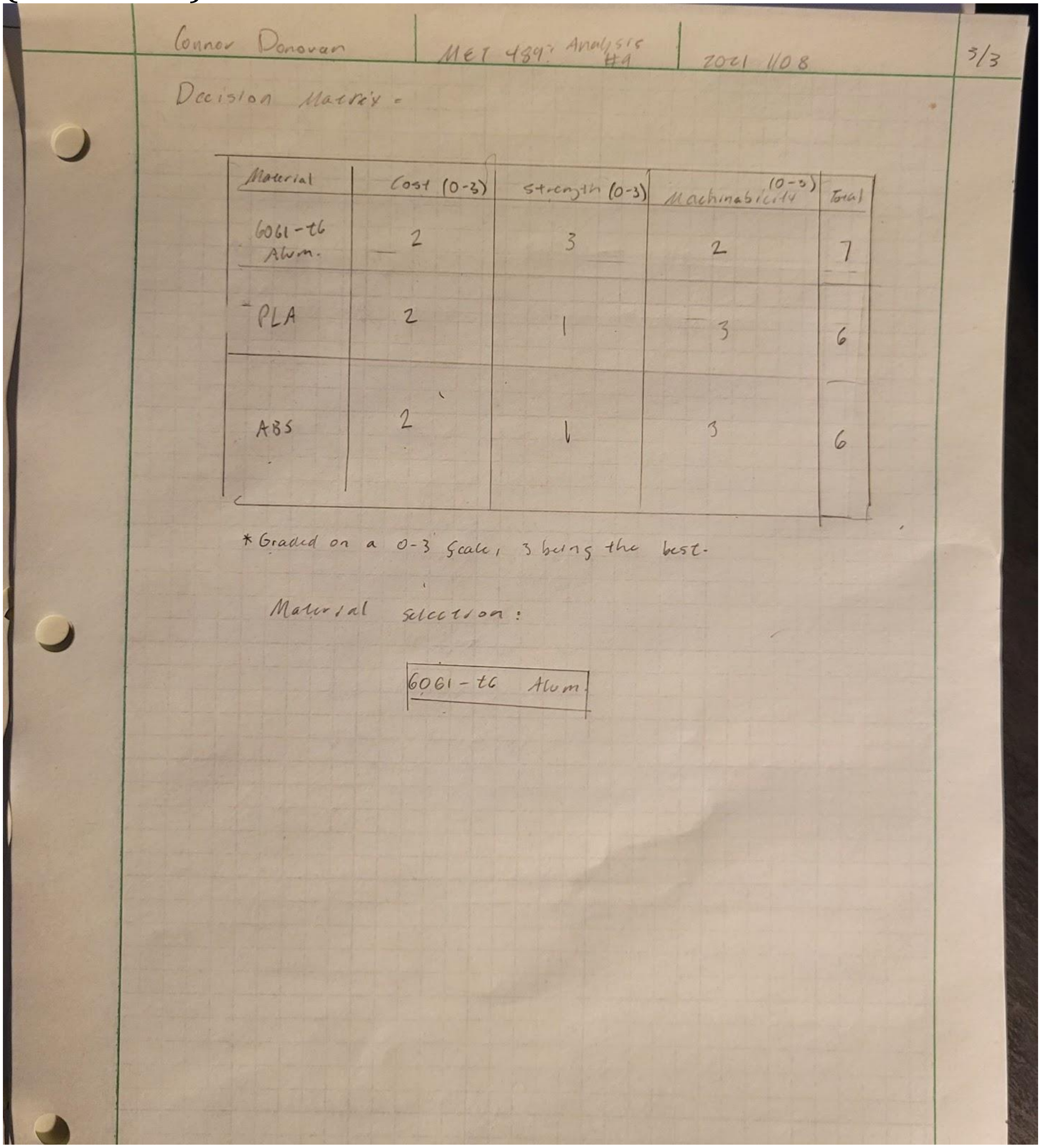
3. Ease of machinability:

* As stated above, the only post processing for 3d printing would be drilling and tapping holes. Aluminum is required to be shaped but is still a relatively soft and ductile metal

Rockwell hardness: ABS = 68 HRBW
PLA = 76.5 HRBW
Alum. = 107 HRBW

* Aluminum is still the highest value but is still acceptable.

Appendix A09 – Material selection for housing components (continued)



Connor Donovan | MET 489: Analysis #9 | 2021 11/08 | 3/3

Decision Matrix -

Material	Cost (0-3)	Strength (0-3)	Machinability (0-3)	Total
6061-t6 Alum.	2	3	2	7
PLA	2	1	3	6
ABS	2	1	3	6

* Graded on a 0-3 scale, 3 being the best.

Material selection:

$\boxed{\text{6061-t6 Alum.}}$

Appendix A10 – Angle Between outdrive cups and hub

MET 490
MET 489:

Connor Donovan	Analysis #10	2021 1108

Given: 2 outdrive cups

$O.D. = 0.60\ in$

Length of axle = 5.52 in

$O.D._{tire} = 4.20\ in$

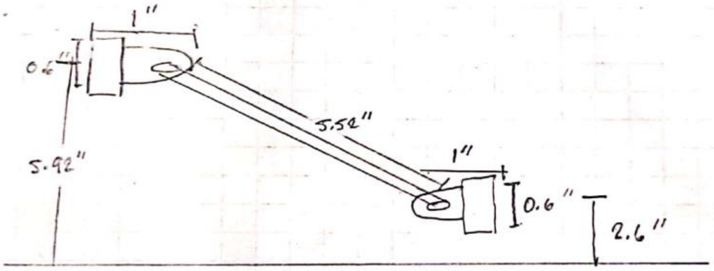
Height of spur gear from ground = 5.92 in

Find: Angle between spur gear and tires

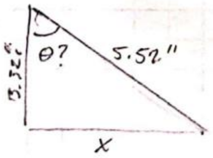
Assume: No load on vehicle

Method: 1) Diagram
2) calculate distance between outdrive cups and tire
3) calculate angle

Soln.



2.) $\Delta h = 5.92in - 2.60in = 3.32\ in$



$x = \sqrt{5.52in^2 - 3.32in^2}$

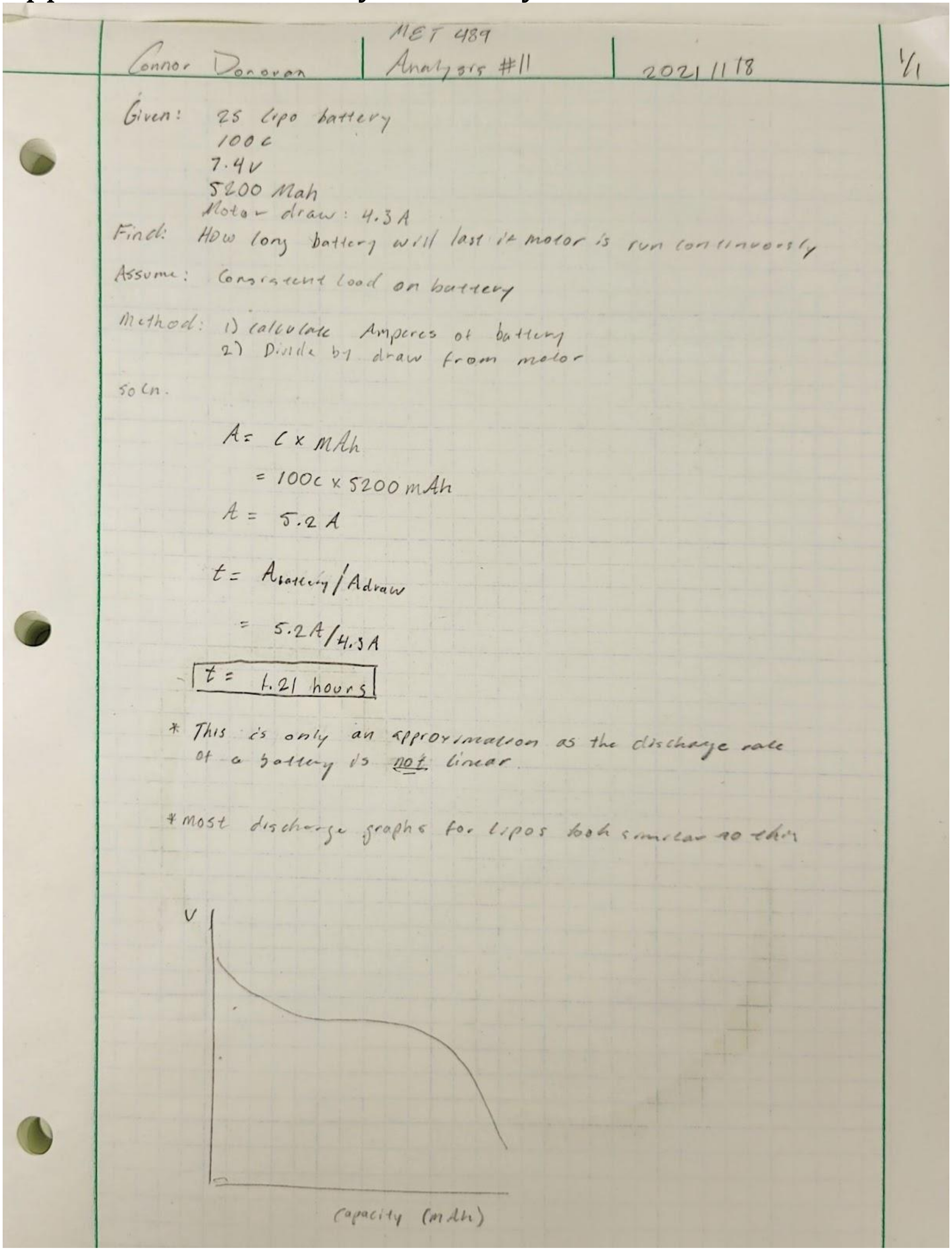
$x = 4.41\ in$

3.) $\theta = \sin^{-1}\left(\frac{\Delta h}{hyp.}\right)$

$= \sin^{-1}\left(\frac{3.32}{5.52}\right)$

$\boxed{\theta = 36.97°}$

Appendix A11 – Battery Life Analysis



Connor Donovan | MET 489 Analysis #11 | 2021/11/18 | 1/1

Given: 2S lipo battery
100C
7.4V
5200 Mah
Motor draw: 4.3A

Find: How long battery will last if motor is run continuously

Assume: Consistent load on battery

Method: 1) calculate Amperes of battery
2) Divide by draw from motor

soln.

$$A = C \times mAh$$

$$= 100c \times 5200\,mAh$$

$$A = 5.2\,A$$

$$t = A_{battery} / A_{draw}$$

$$= 5.2A / 4.3A$$

$$\boxed{t = 1.21 \text{ hours}}$$

* This is only an approximation as the discharge rate of a battery is <u>not</u> linear.

* most discharge graphs for lipos look similar to this

APPENDIX B - Drawings

Appendix B01 – Drawing Tree

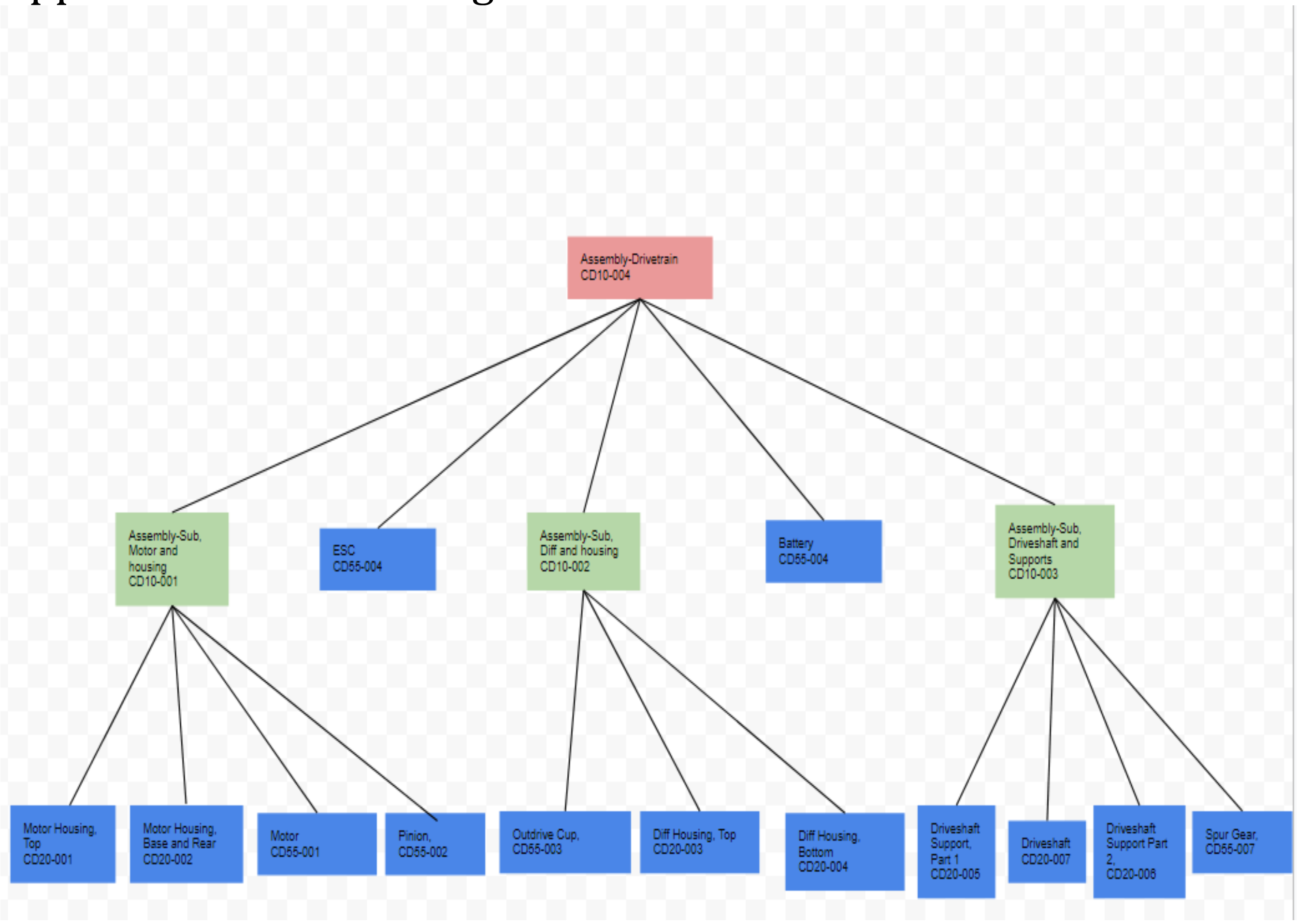
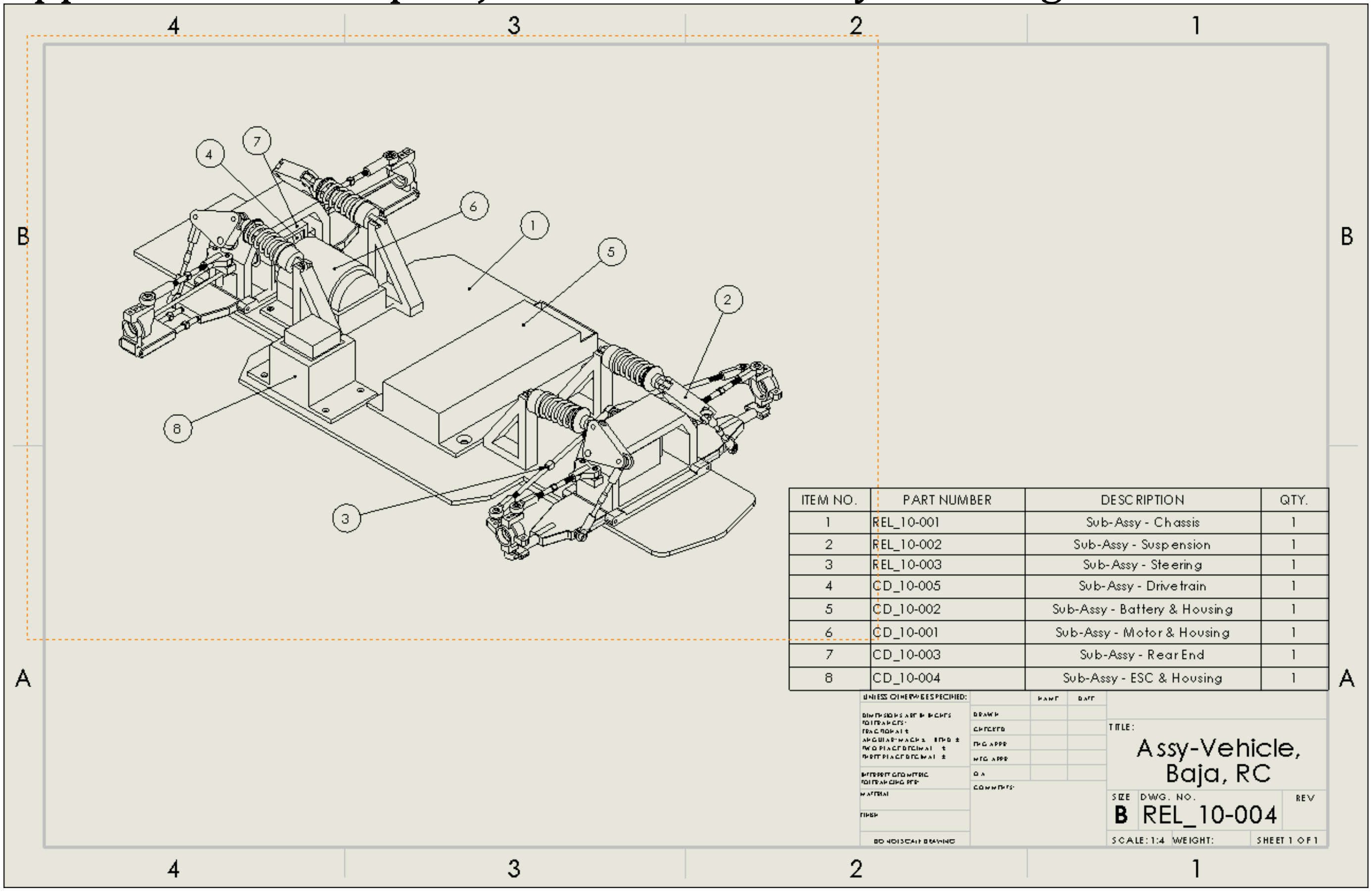


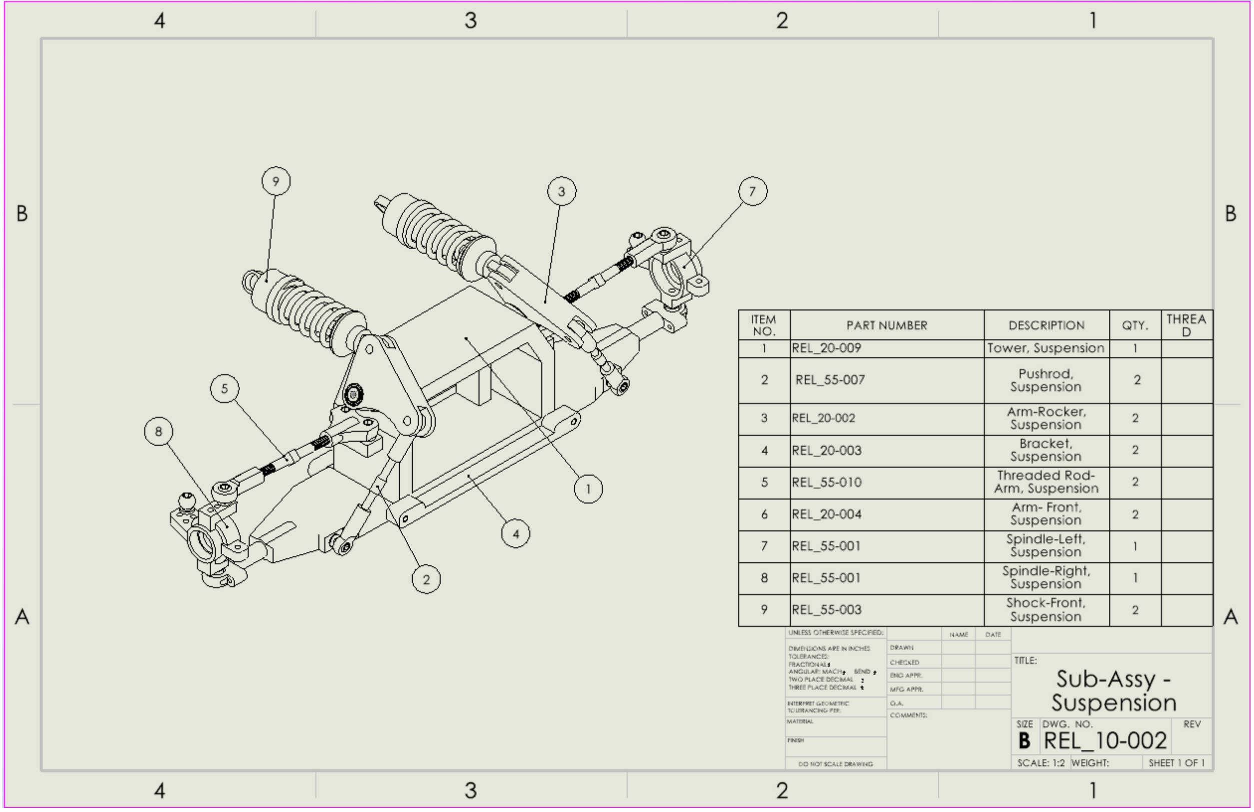
Figure 1: Drawing Tree

Appendix B02 – Top Baja Vehicle Assembly Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	REL_10-001	Sub-Assy - Chassis	1
2	REL_10-002	Sub-Assy - Suspension	1
3	REL_10-003	Sub-Assy - Steering	1
4	CD_10-005	Sub-Assy - Drivetrain	1
5	CD_10-002	Sub-Assy - Battery & Housing	1
6	CD_10-001	Sub-Assy - Motor & Housing	1
7	CD_10-003	Sub-Assy - Rear End	1
8	CD_10-004	Sub-Assy - ESC & Housing	1

Appendix B3 – REL_10-002 – Sub-Assembly, Suspension



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	THREAD
1	REL_20-009	Tower, Suspension	1	
2	REL_55-007	Pushrod, Suspension	2	
3	REL_20-002	Arm-Rocker, Suspension	2	
4	REL_20-003	Bracket, Suspension	2	
5	REL_55-010	Threaded Rod-Arm, Suspension	2	
6	REL_20-004	Arm- Front, Suspension	2	
7	REL_55-001	Spindle-Left, Suspension	1	
8	REL_55-001	Spindle-Right, Suspension	1	
9	REL_55-003	Shock-Front, Suspension	2	

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

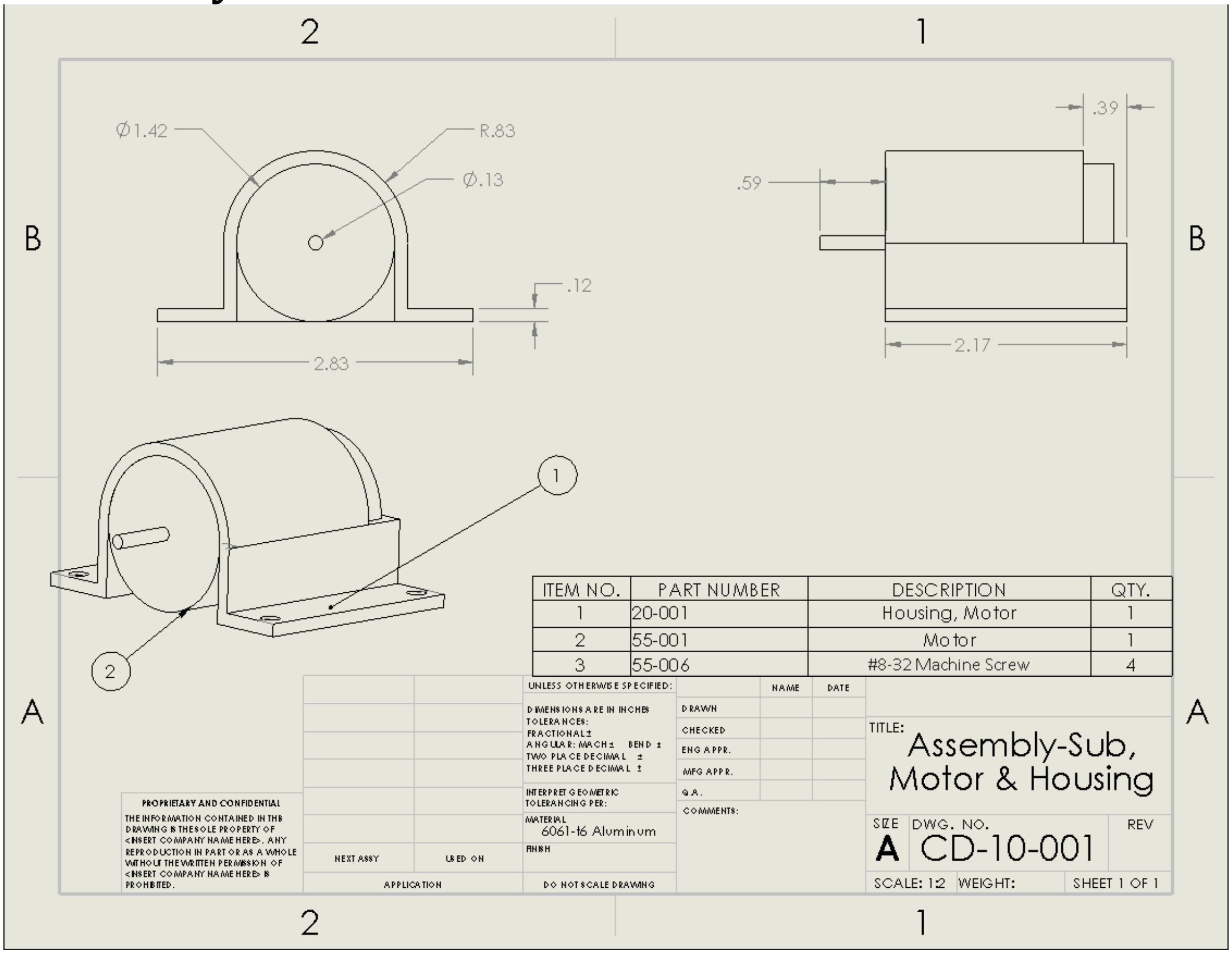
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Sub-Assy - Suspension

SIZE B
DWG. NO. REL_10-002
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

Appendix B03 –CD10-001 Motor & Housing Sub-Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-001	Housing, Motor	1
2	55-001	Motor	1
3	55-006	#8-32 Machine Screw	4

PROPRIETARY AND CONFIDENTIAL

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NEXT ASSY
USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-t6 Aluminum
FINISH
DO NOT SCALE DRAWING

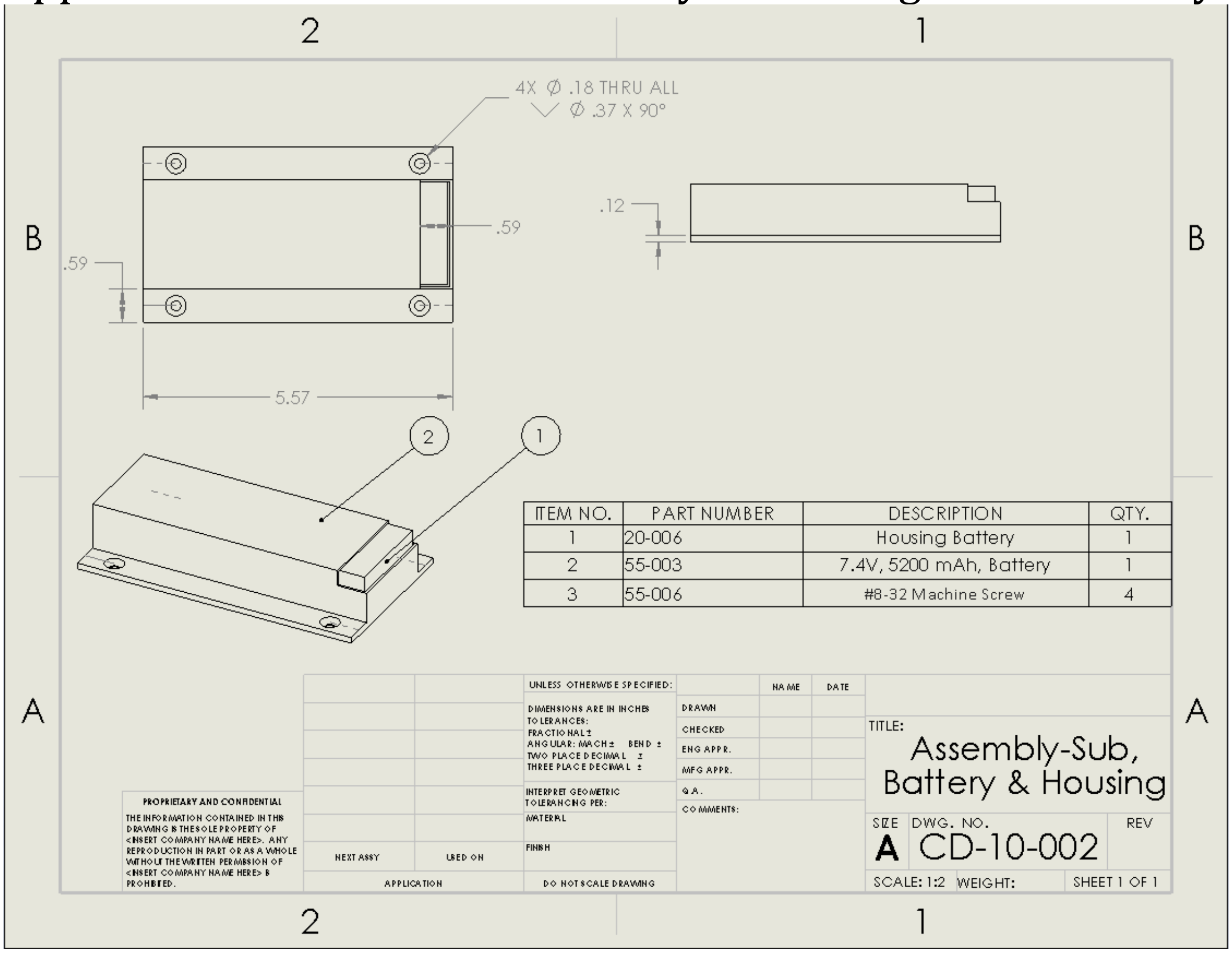
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Assembly-Sub, Motor & Housing

SIZE A
DWG. NO. CD-10-001
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

Appendix B04 –CD10-002- Battery & Housing Sub-Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-006	Housing Battery	1
2	55-003	7.4V, 5200 mAh, Battery	1
3	55-006	#8-32 Machine Screw	4

PROPRIETARY AND CONFIDENTIAL

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NEXT ASSY
USED ON
APPLICATION

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

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

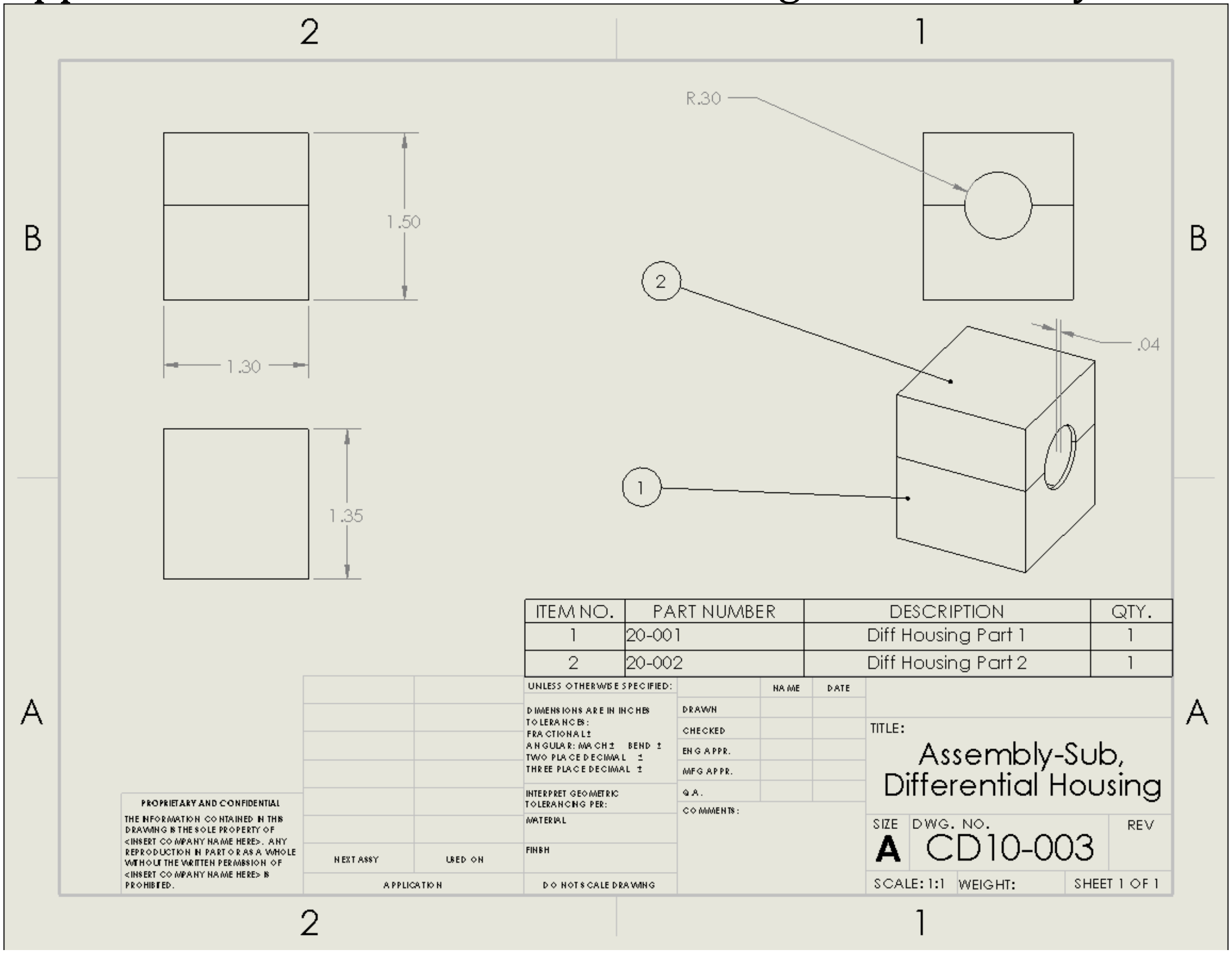
COMMENTS:

TITLE:
Assembly-Sub, Battery & Housing

SIZE A
DWG. NO. CD-10-002
REV

SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

Appendix B05 – CD10-003-Diff Housing Sub-Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-001	Diff Housing Part 1	1
2	20-002	Diff Housing Part 2	1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Assembly-Sub, Differential Housing

SIZE A
DWG. NO. CD10-003
REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

NEXT ASSY USED ON
APPLICATION

PROPRIETARY AND CONFIDENTIAL

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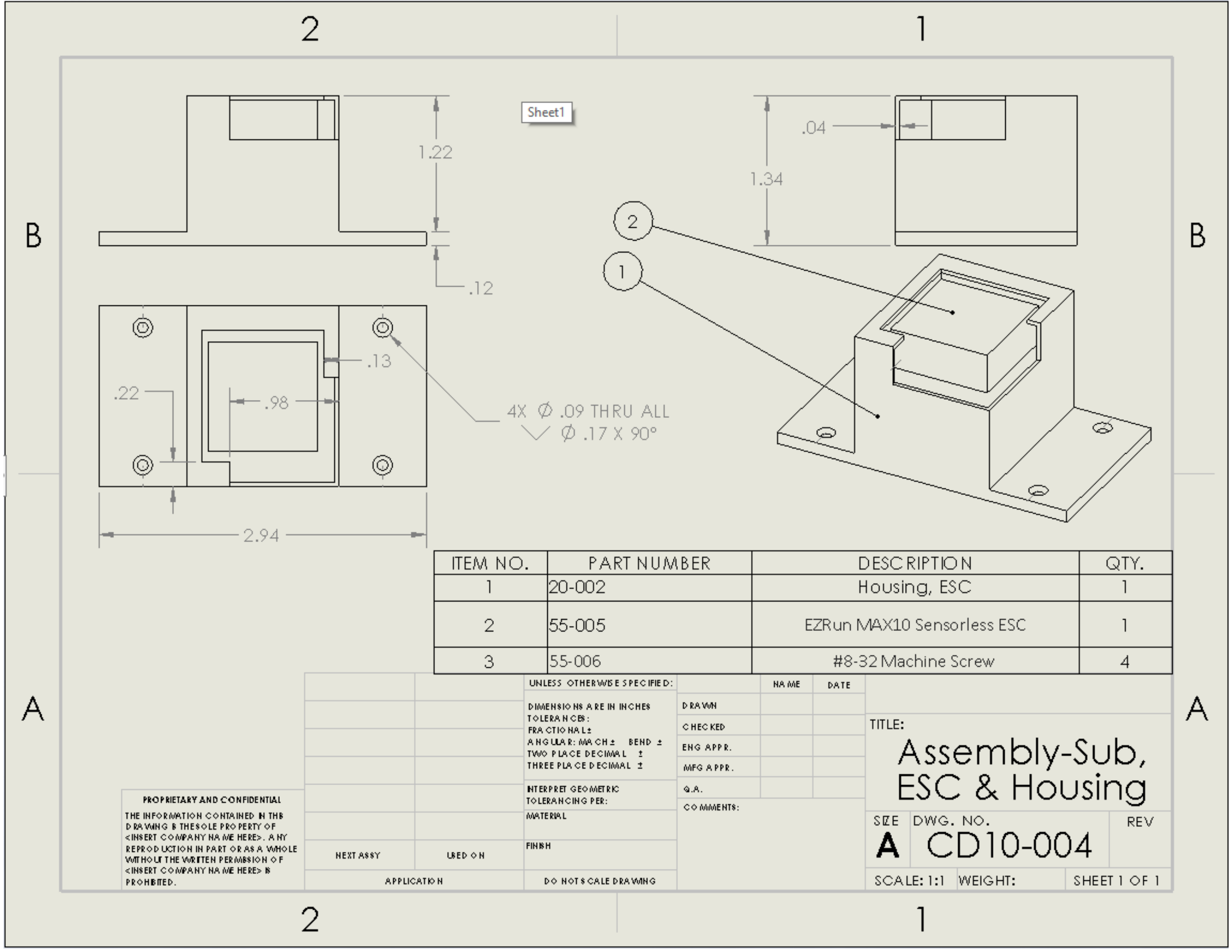
Appendix B06 – CD10-004- ESC & Housing Sub-Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-002	Housing, ESC	1
2	55-005	EZRun MAX10 Sensorless ESC	1
3	55-006	#8-32 Machine Screw	4

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY

USED ON

APPLICATION

PROPRIETARY AND CONFIDENTIAL

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TITLE:
Assembly-Sub,
ESC & Housing

SIZE
A

DWG. NO.
CD10-004

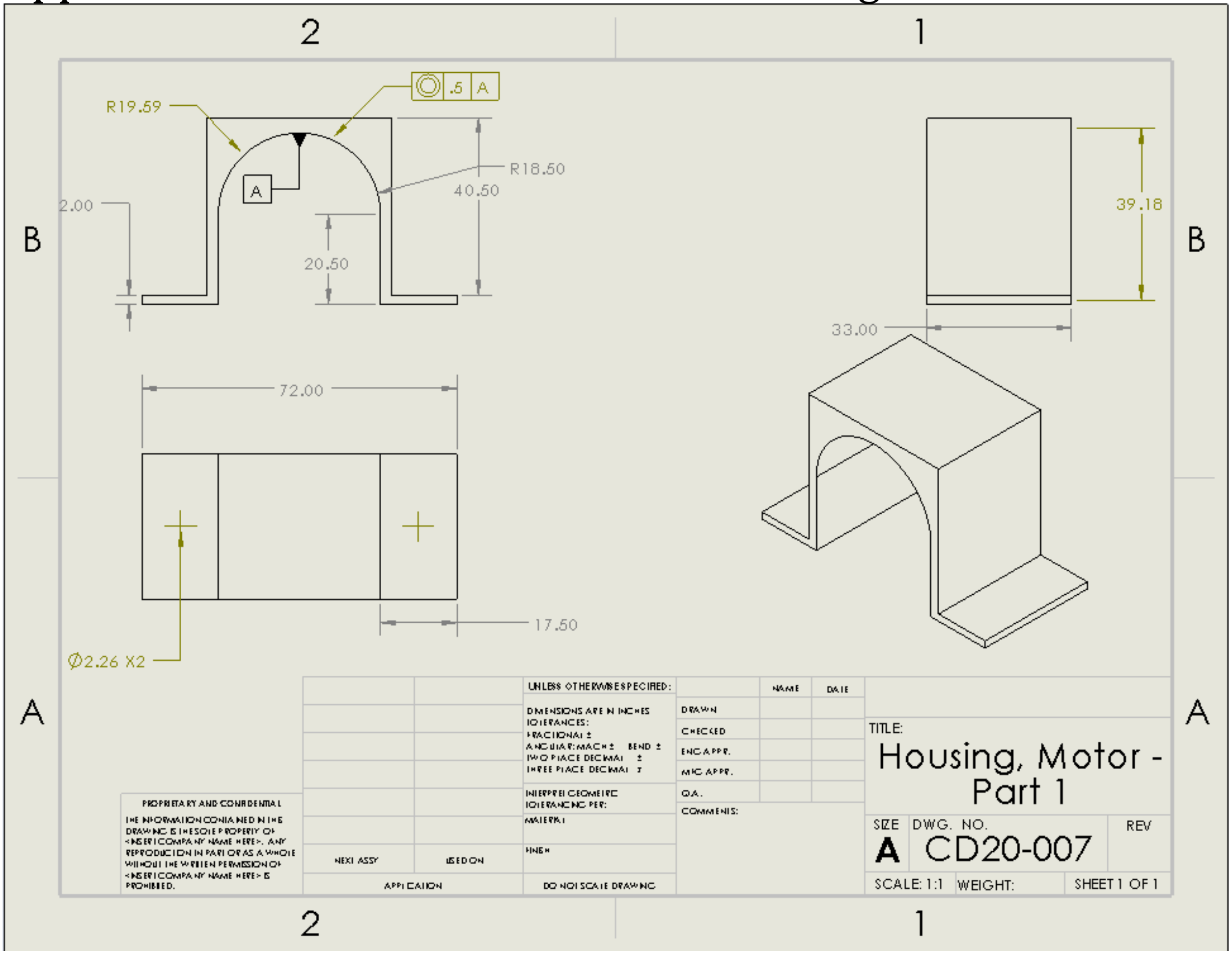
REV

SCALE: 1:1

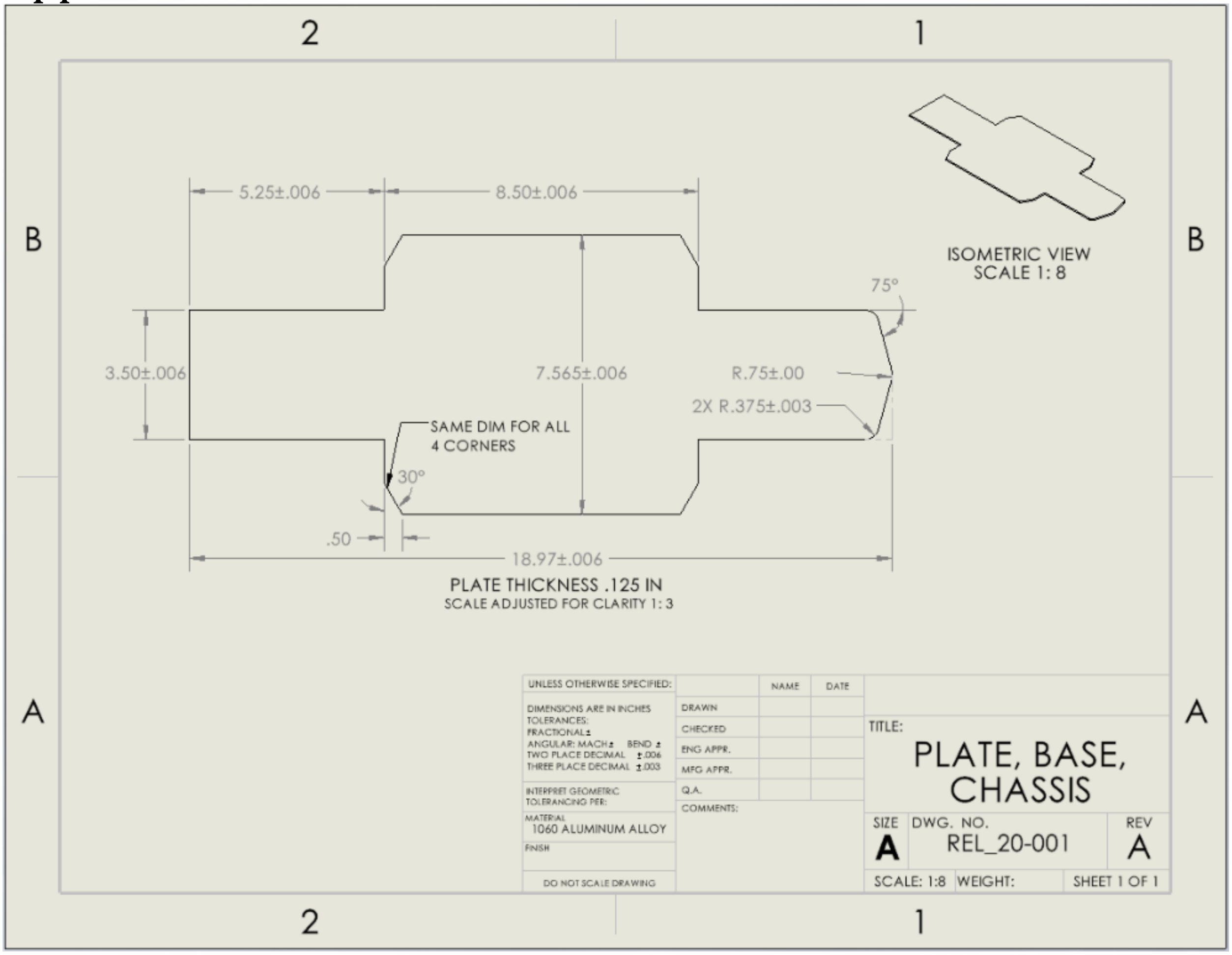
WEIGHT:

SHEET 1 OF 1

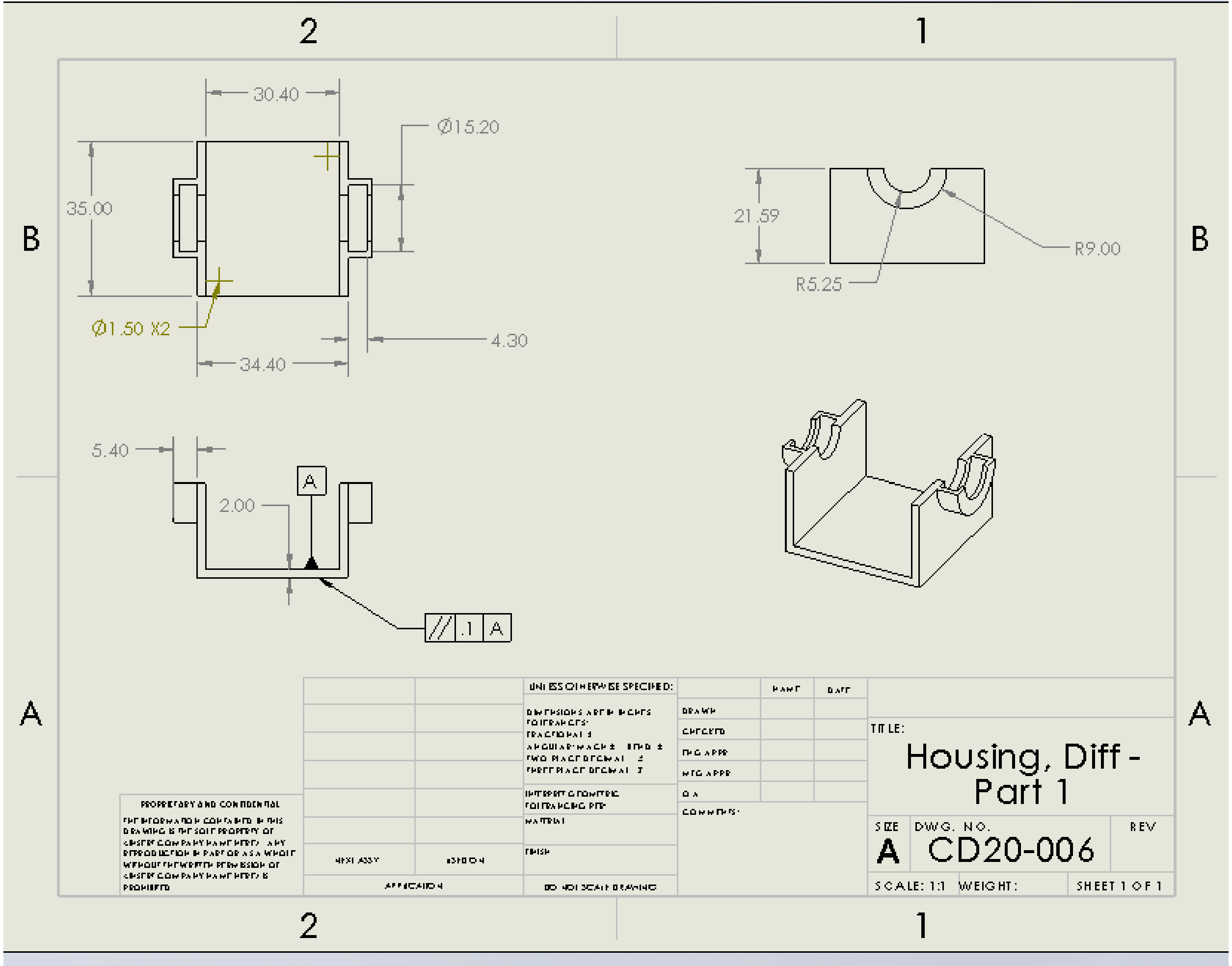
Appendix B07 – CD20-007 – Motor Housing Part 1



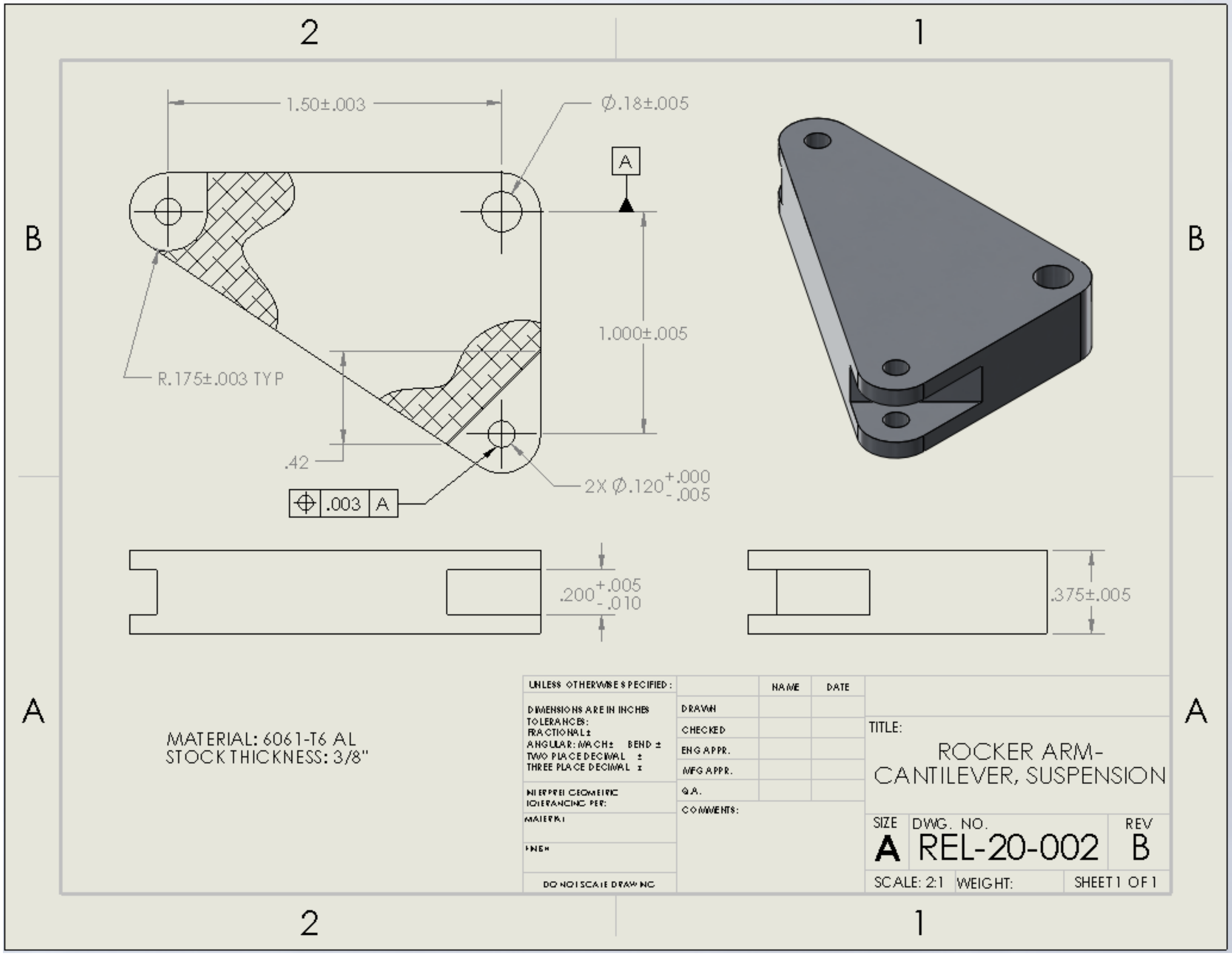
Appendix B – REL_20-001 - Chassis Base Plate



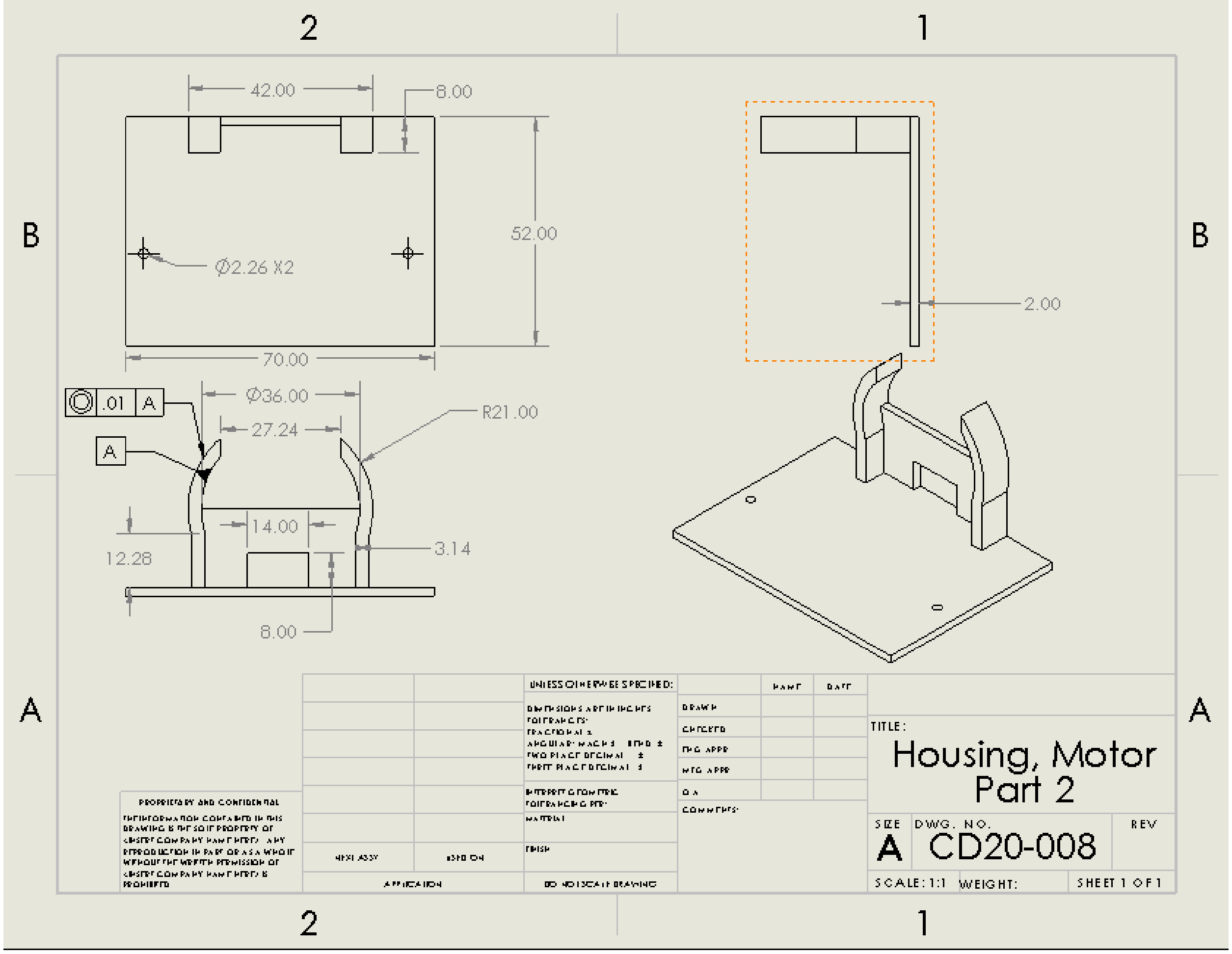
Appendix B08 – CD20-006- Differential Housing



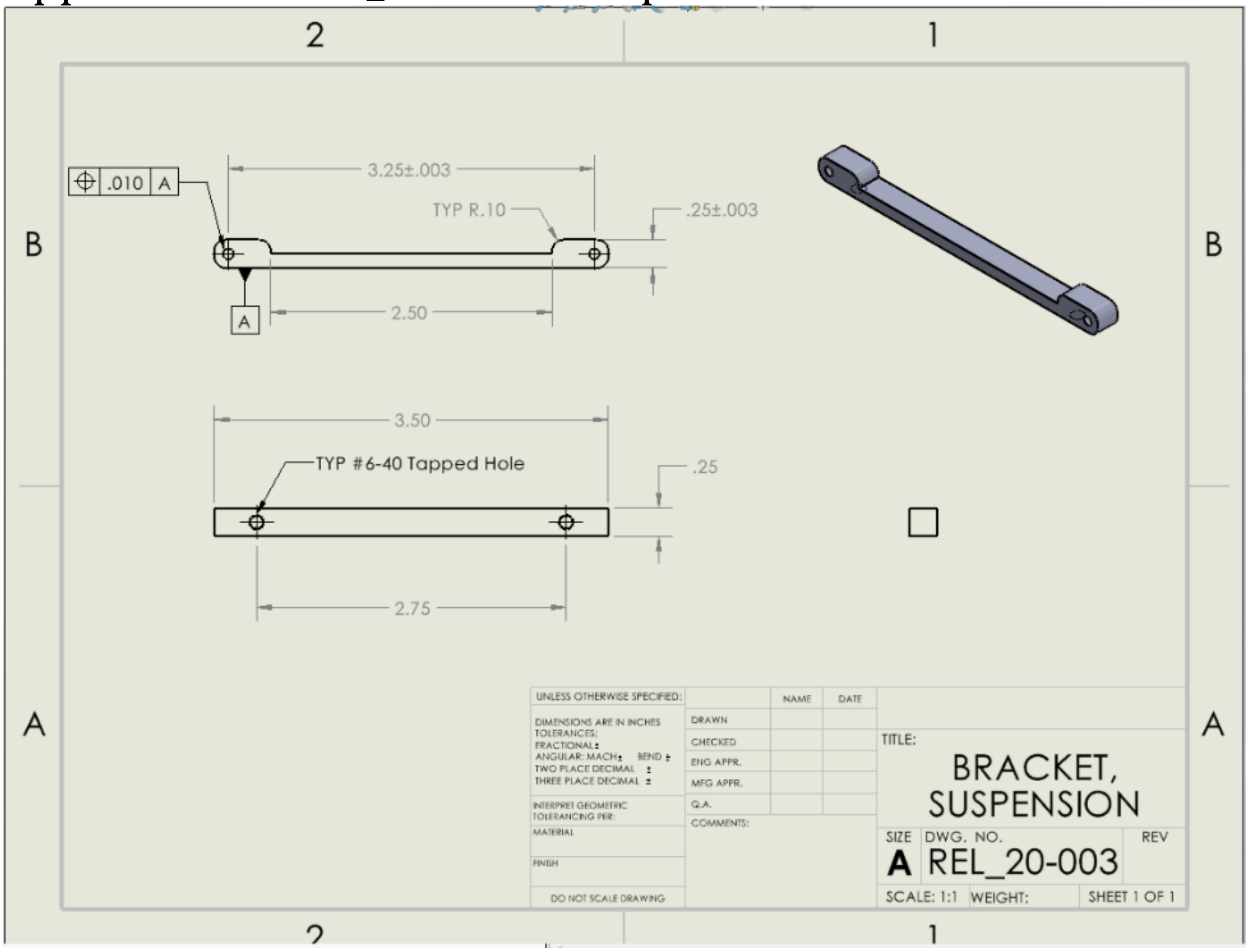
Appendix B – REL_20-002 - Rocker Arm



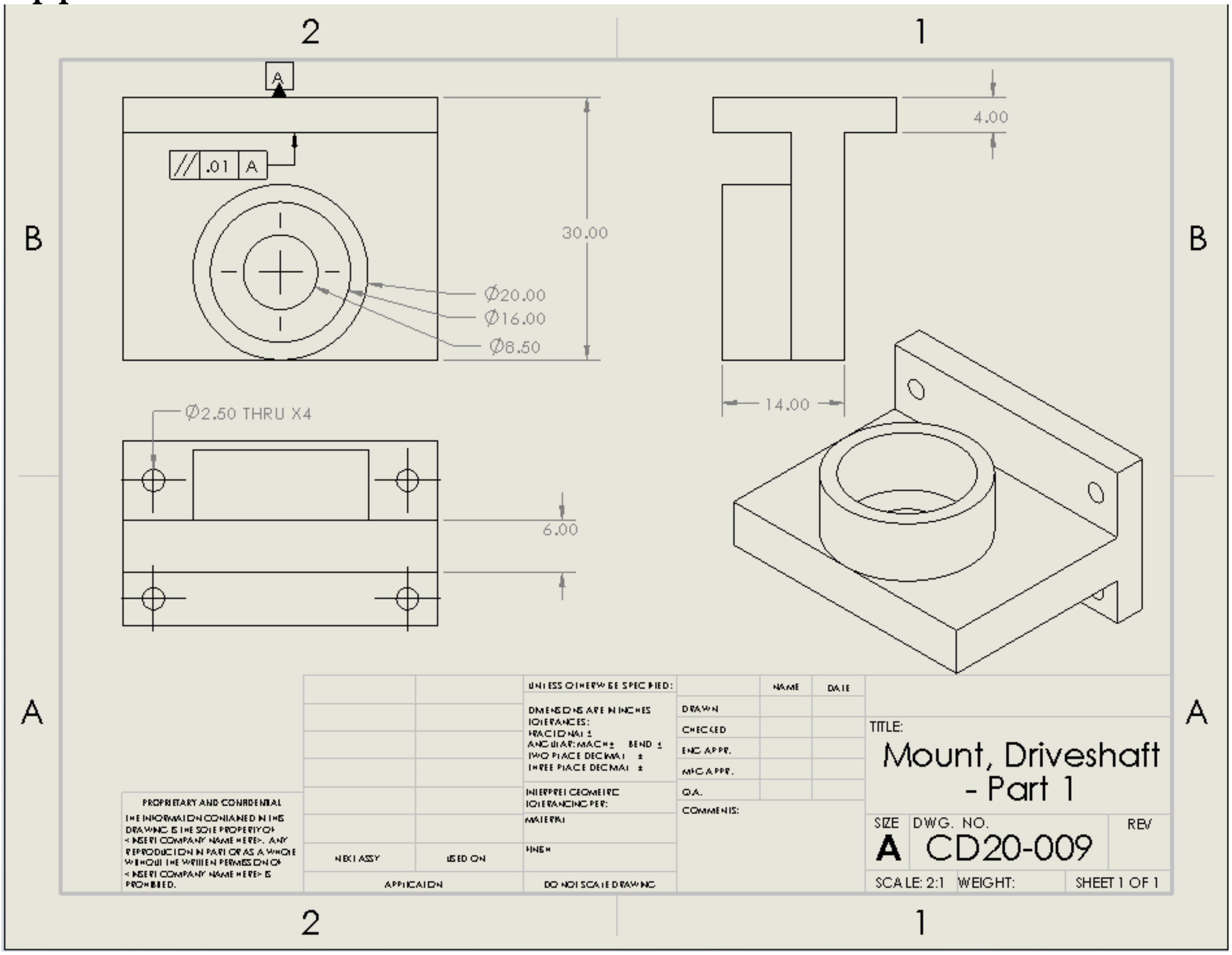
Appendix B09 –CD20-008- Motor Housing Part 2



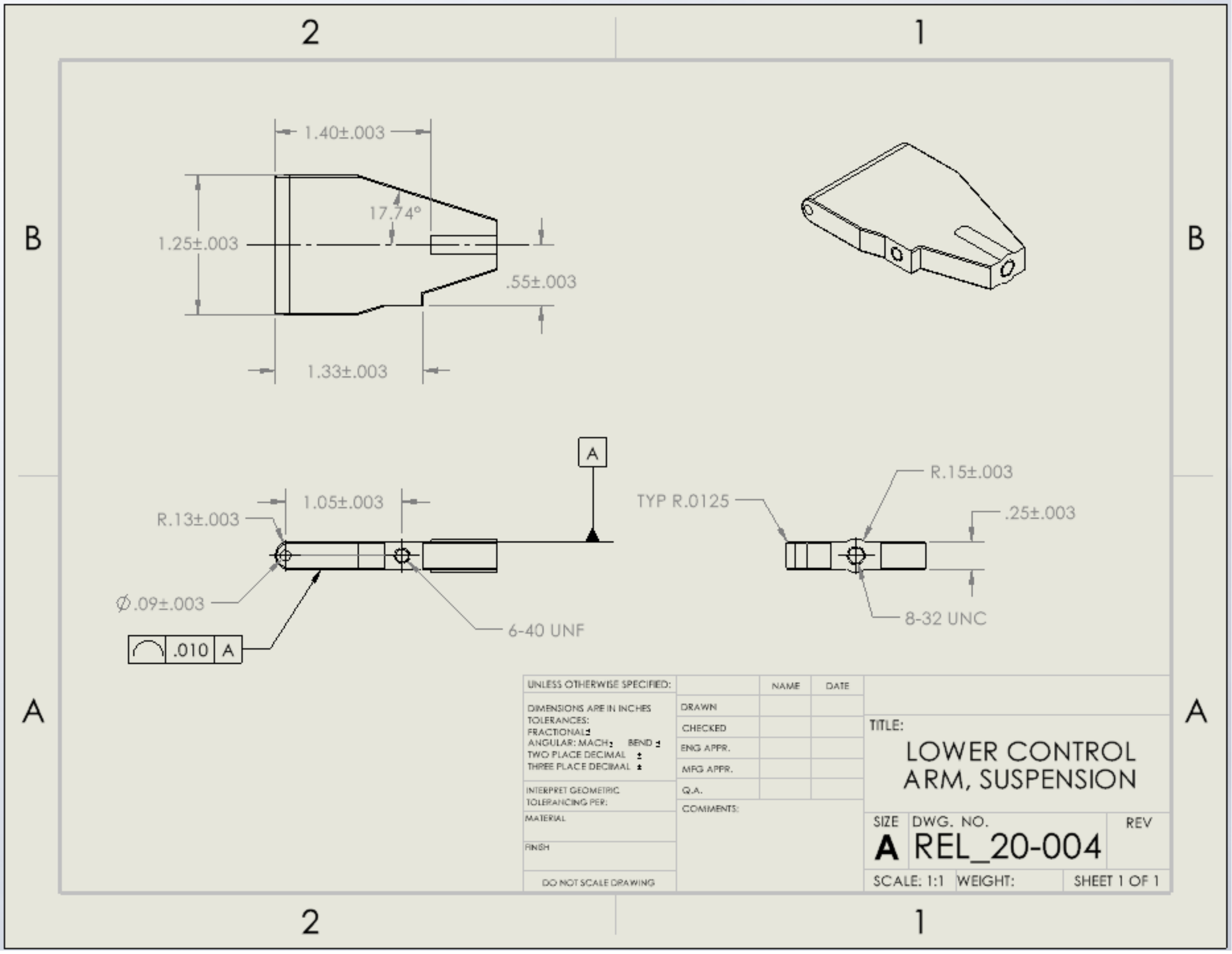
Appendix B – REL_20-003 - Suspension Bracket



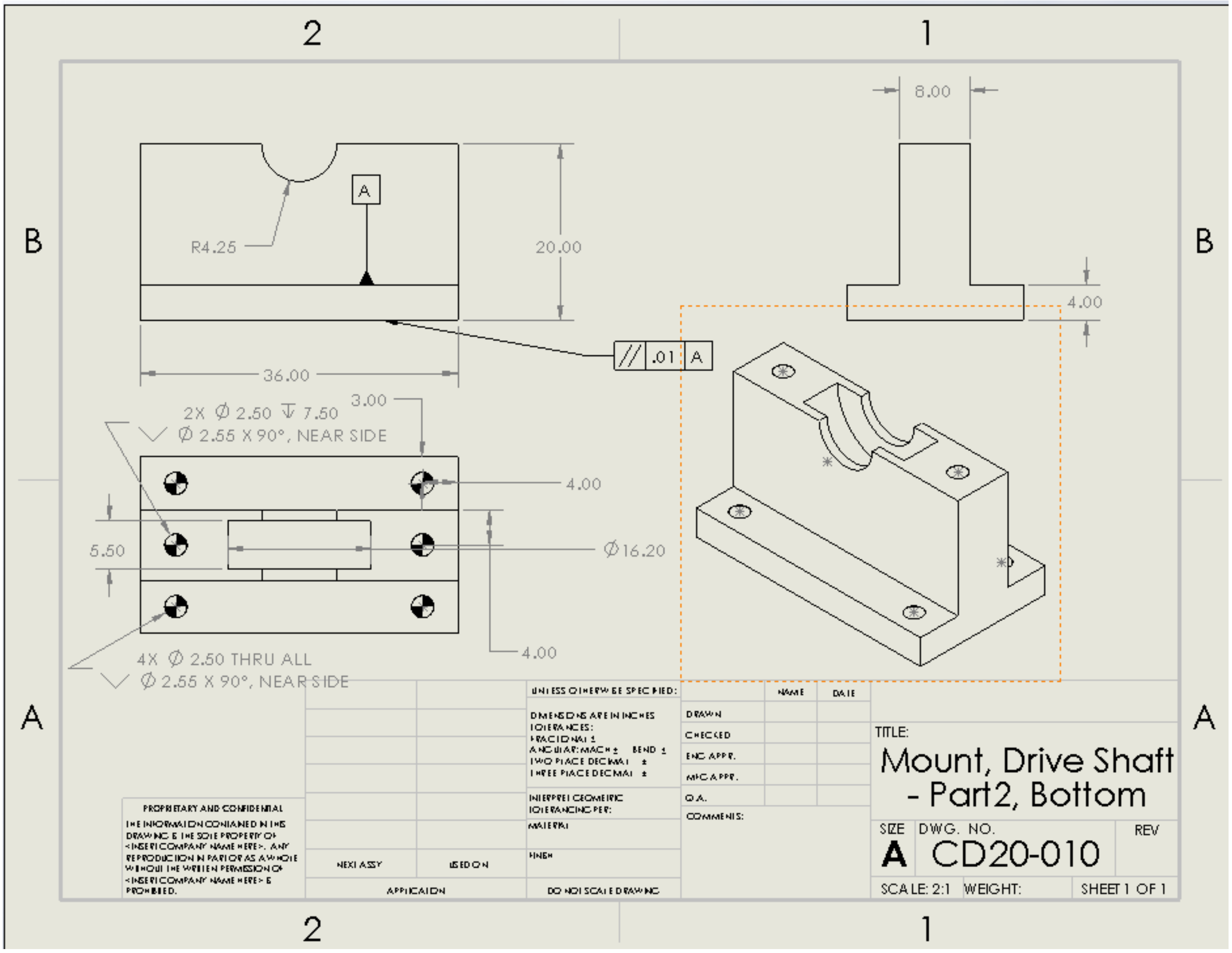
Appendix B10 –CD20-009-Driveshaft Mount Part 1



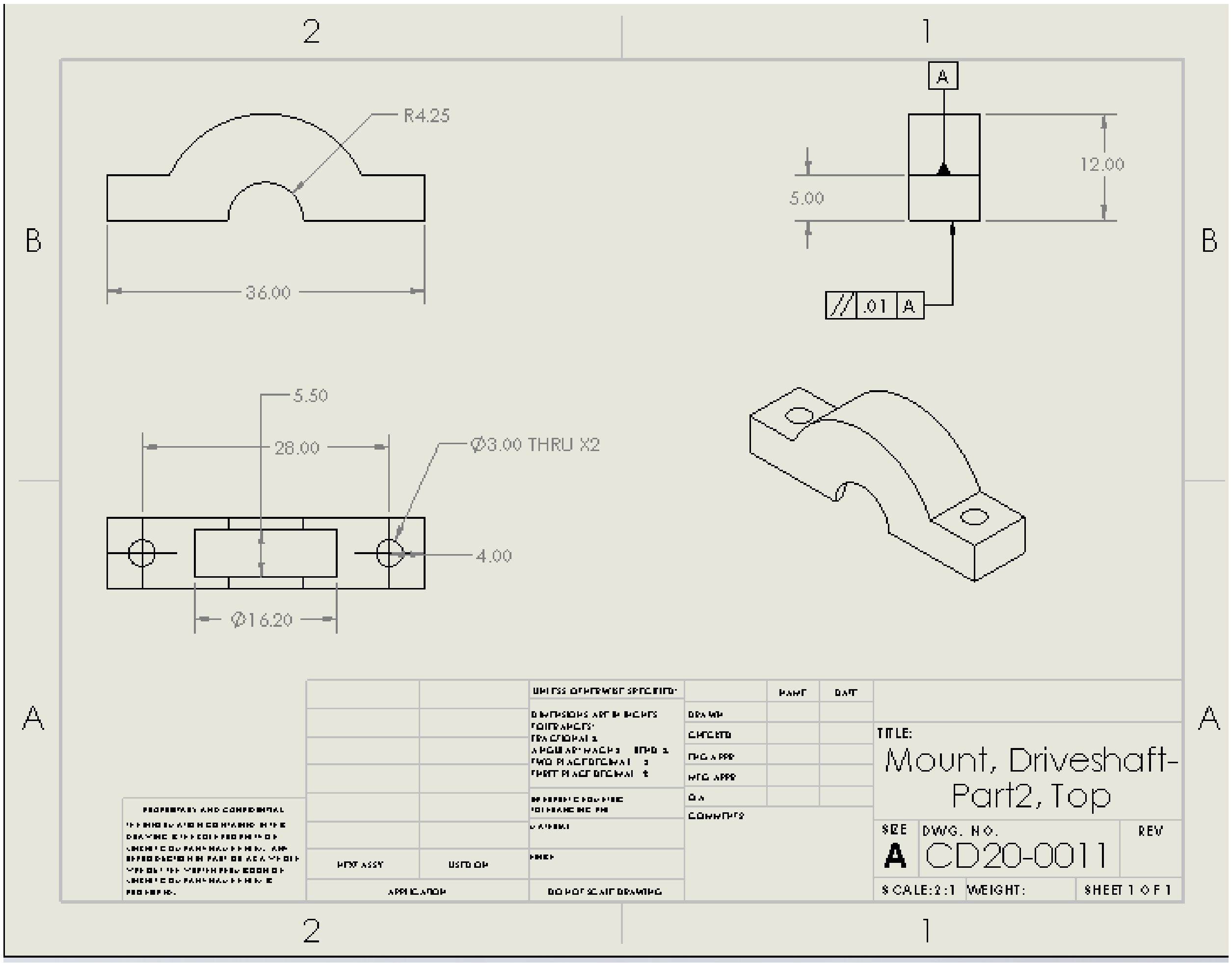
Appendix B – REL_20-004 - Lower Control Arm



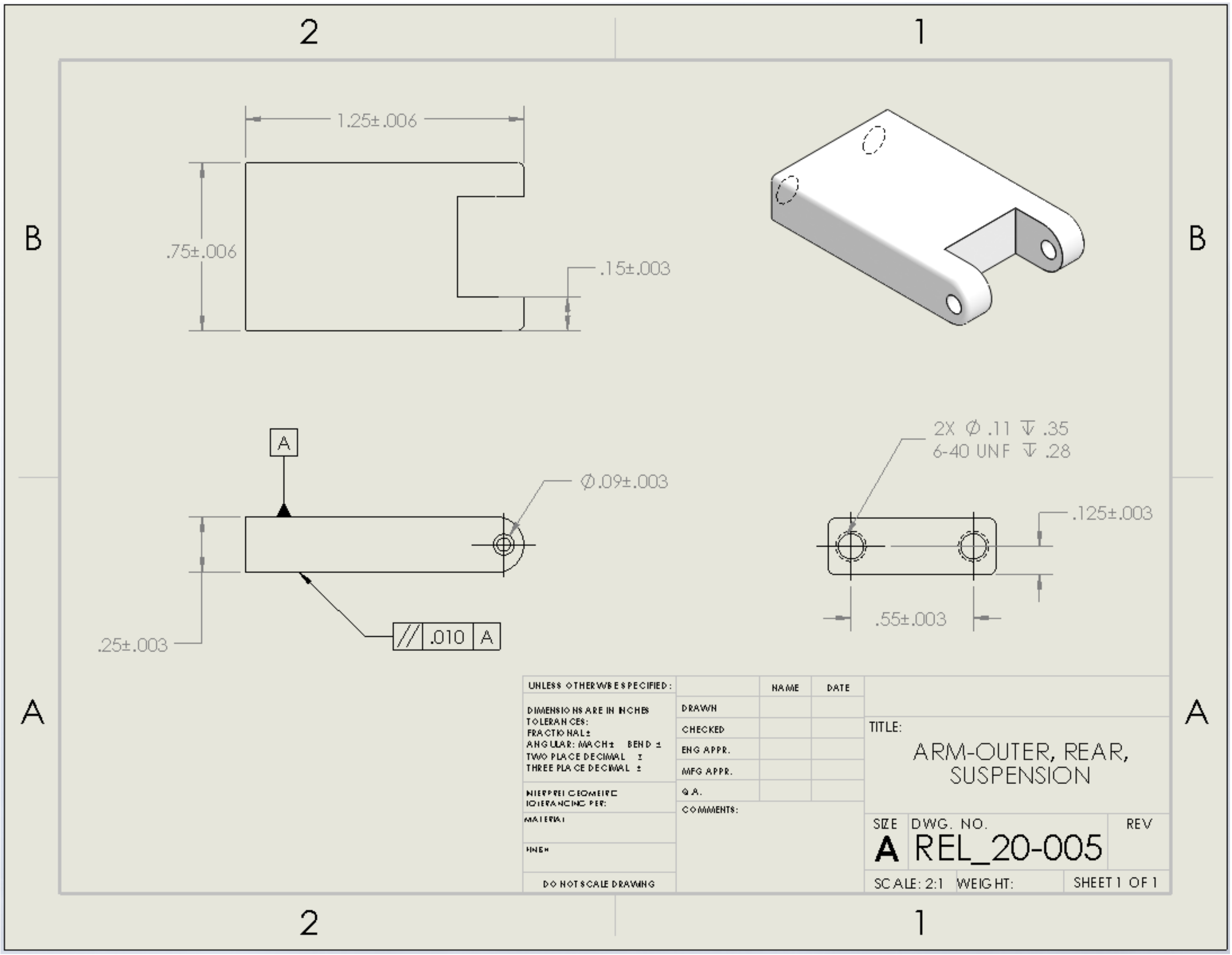
Appendix B11 –CD20-010-Driveshaft Mount Part 2, Bottom



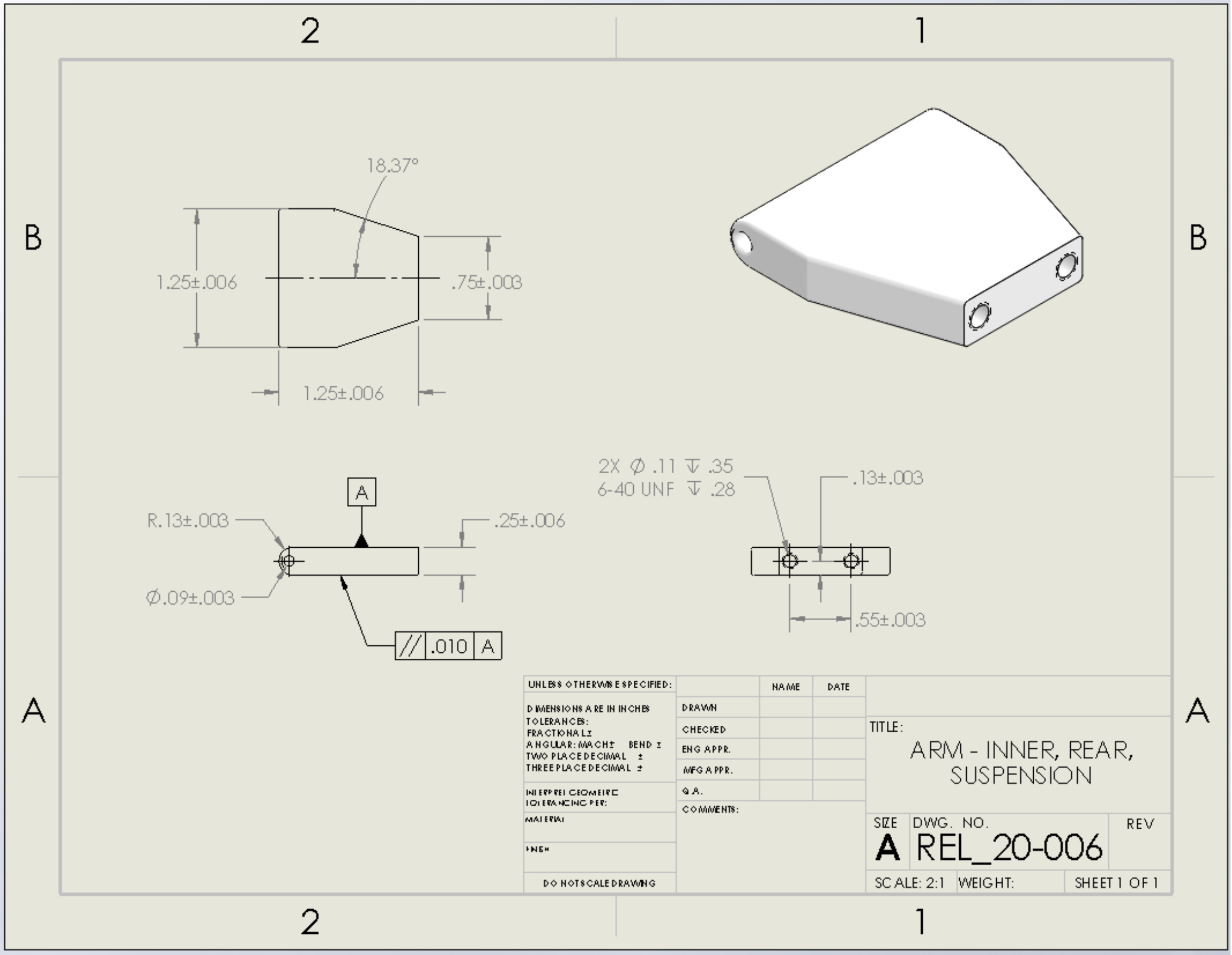
Appendix B11 –CD20-011- Driveshaft Mount Part 2, Top



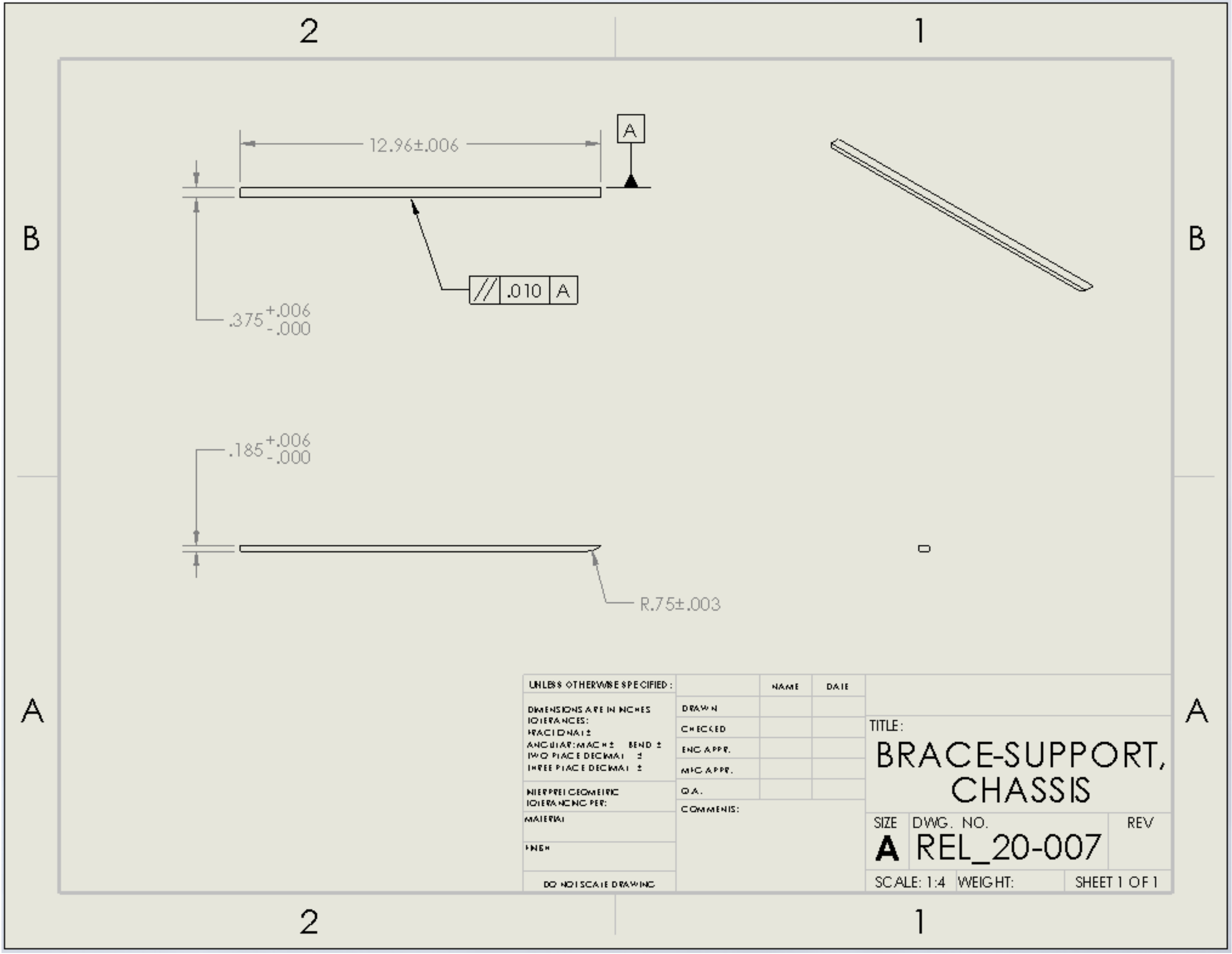
Appendix B – REL_20-005 - Rear Outer LCA


2
1
B
A
1.25±.006
.75±.006
.15±.003
A
Ø.09±.003
.25±.003
// .010 A
2X Ø .11 ↧ .35
6-40 UNF ↧ .28
.125±.003
.55±.003
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
ARM-OUTER, REAR,
SUSPENSION
SIZE
A
DWG. NO.
REL_20-005
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

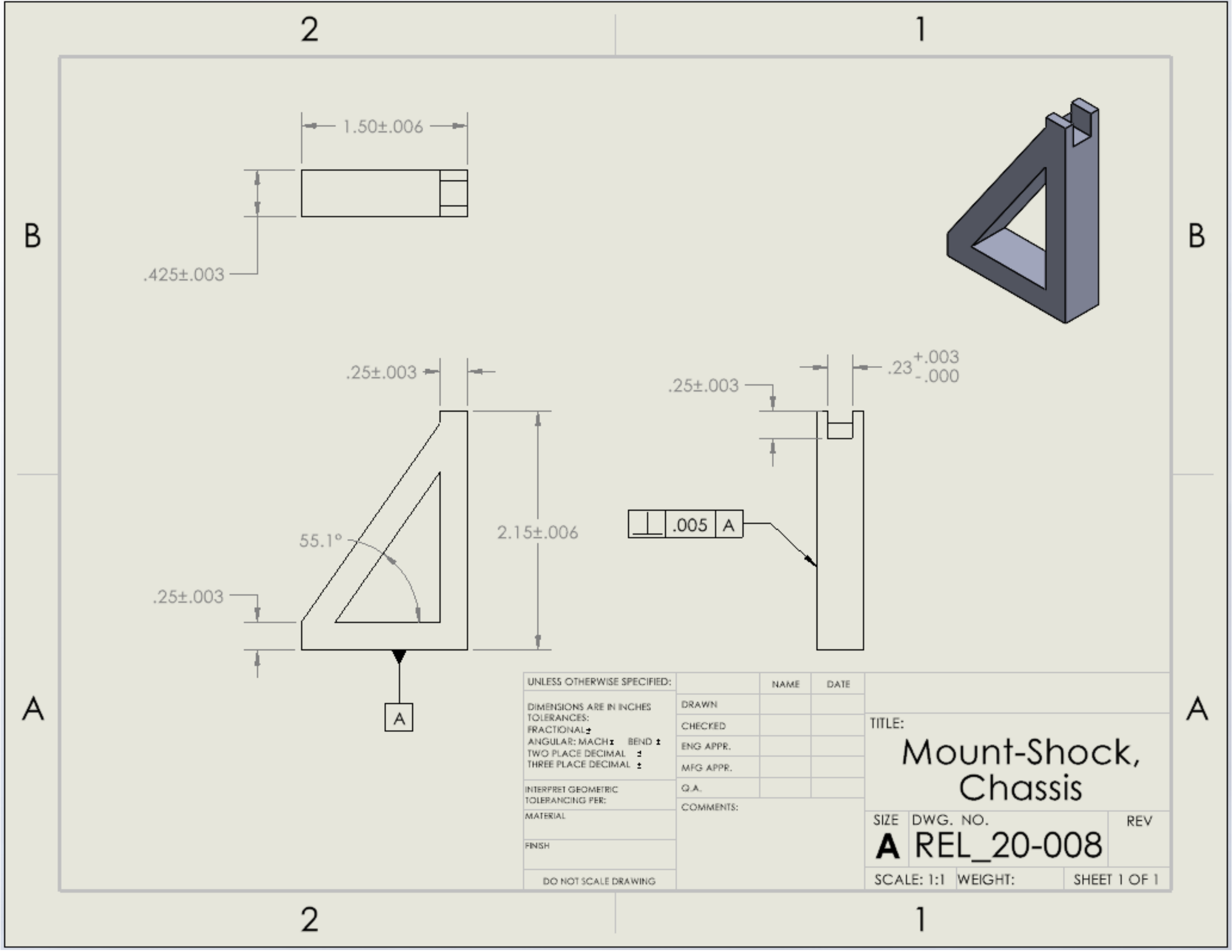
Appendix B – REL_20-006 - Rear Inner LCA



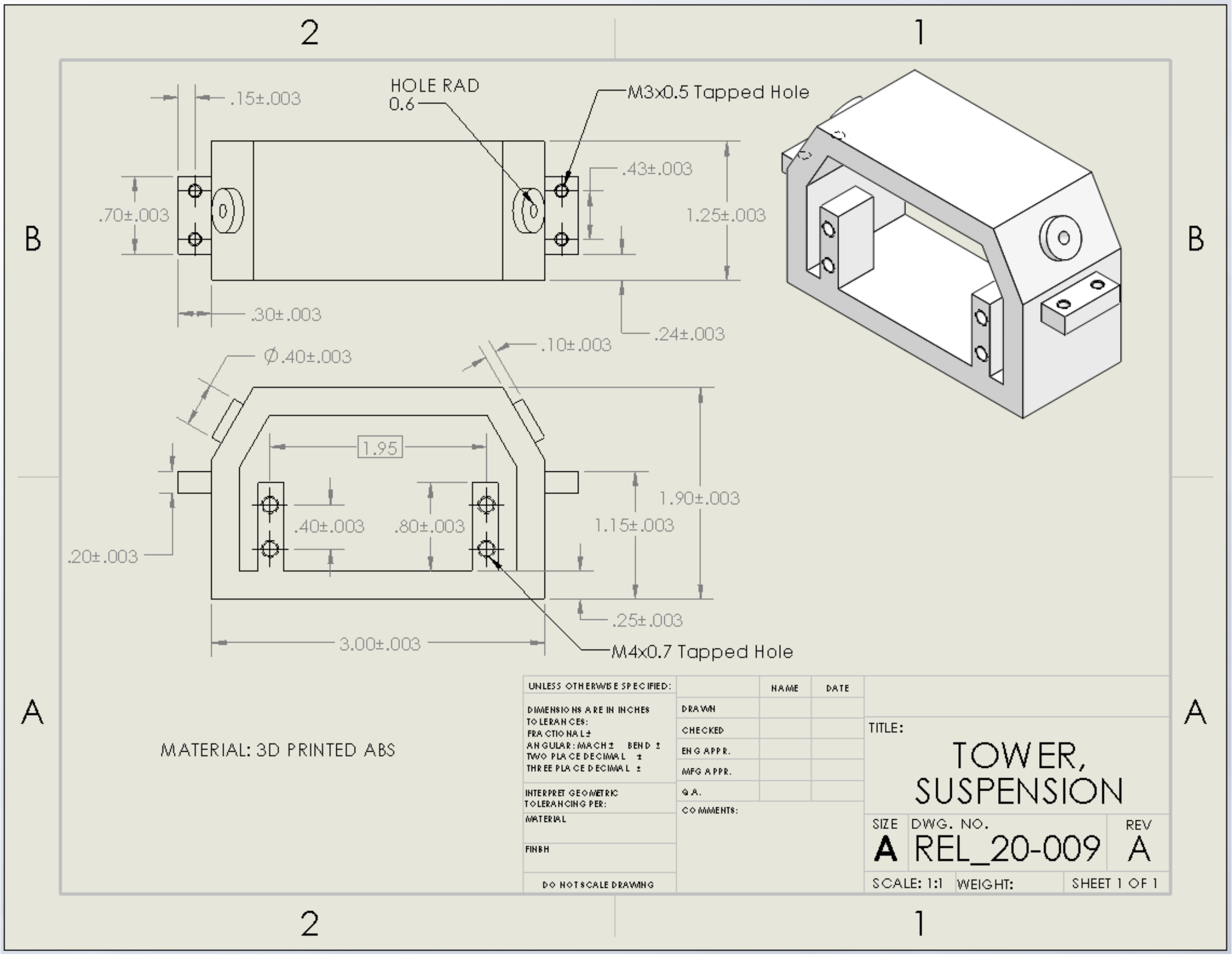
Appendix B – REL_20-007 - Chassis Support Brace



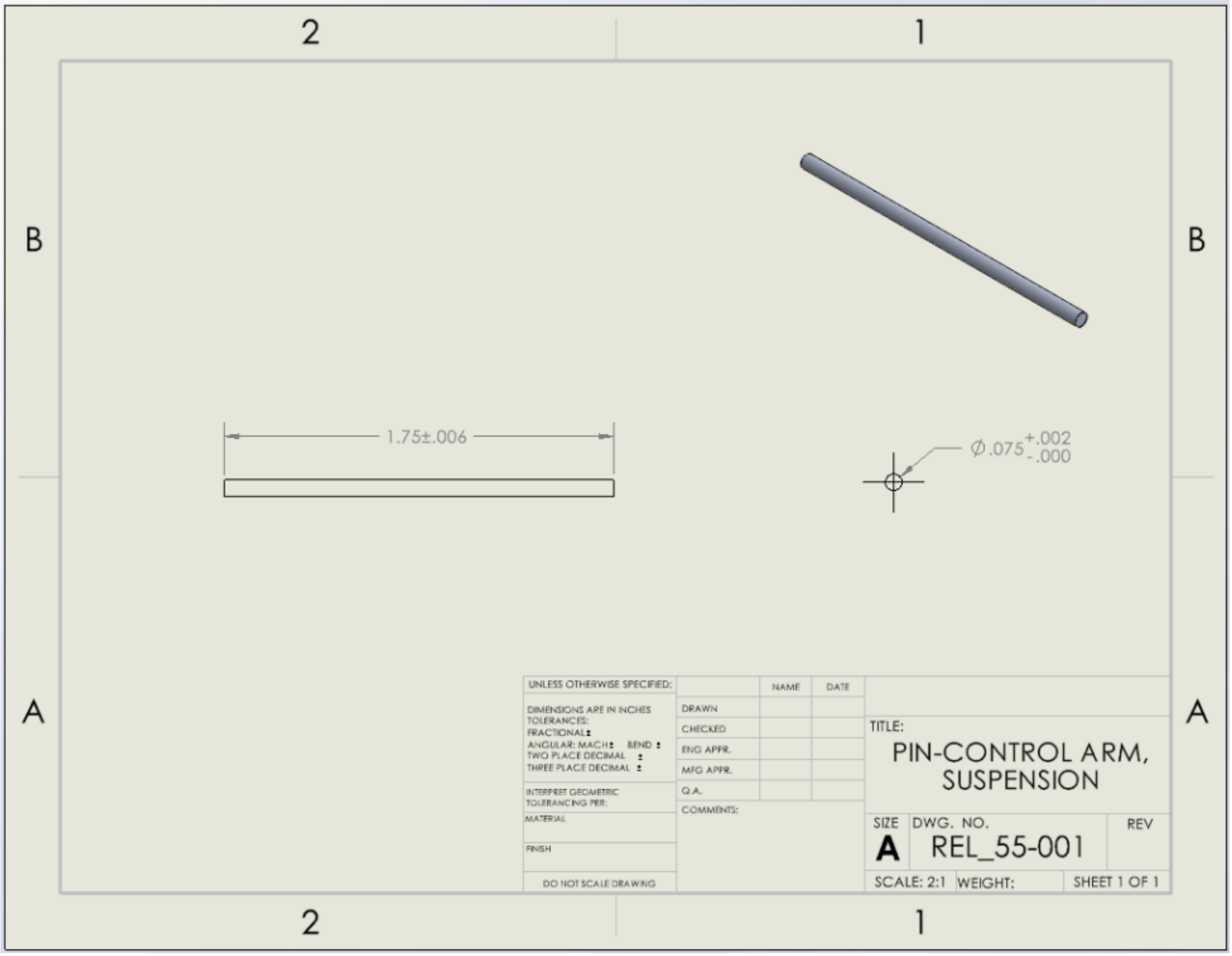
Appendix B – REL_20-008 -Shock Mount



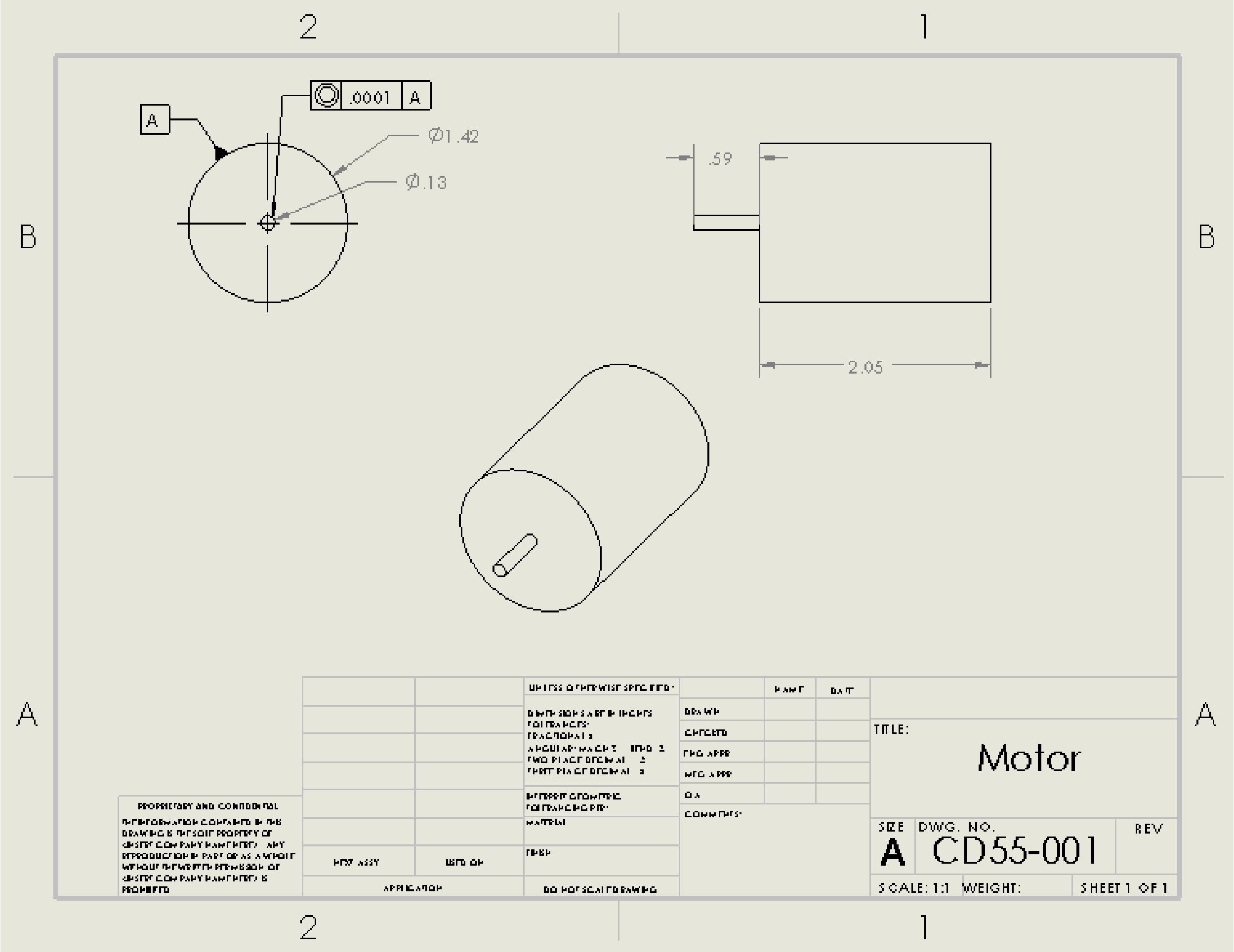
Appendix B – REL_20-009 -Shock Tower



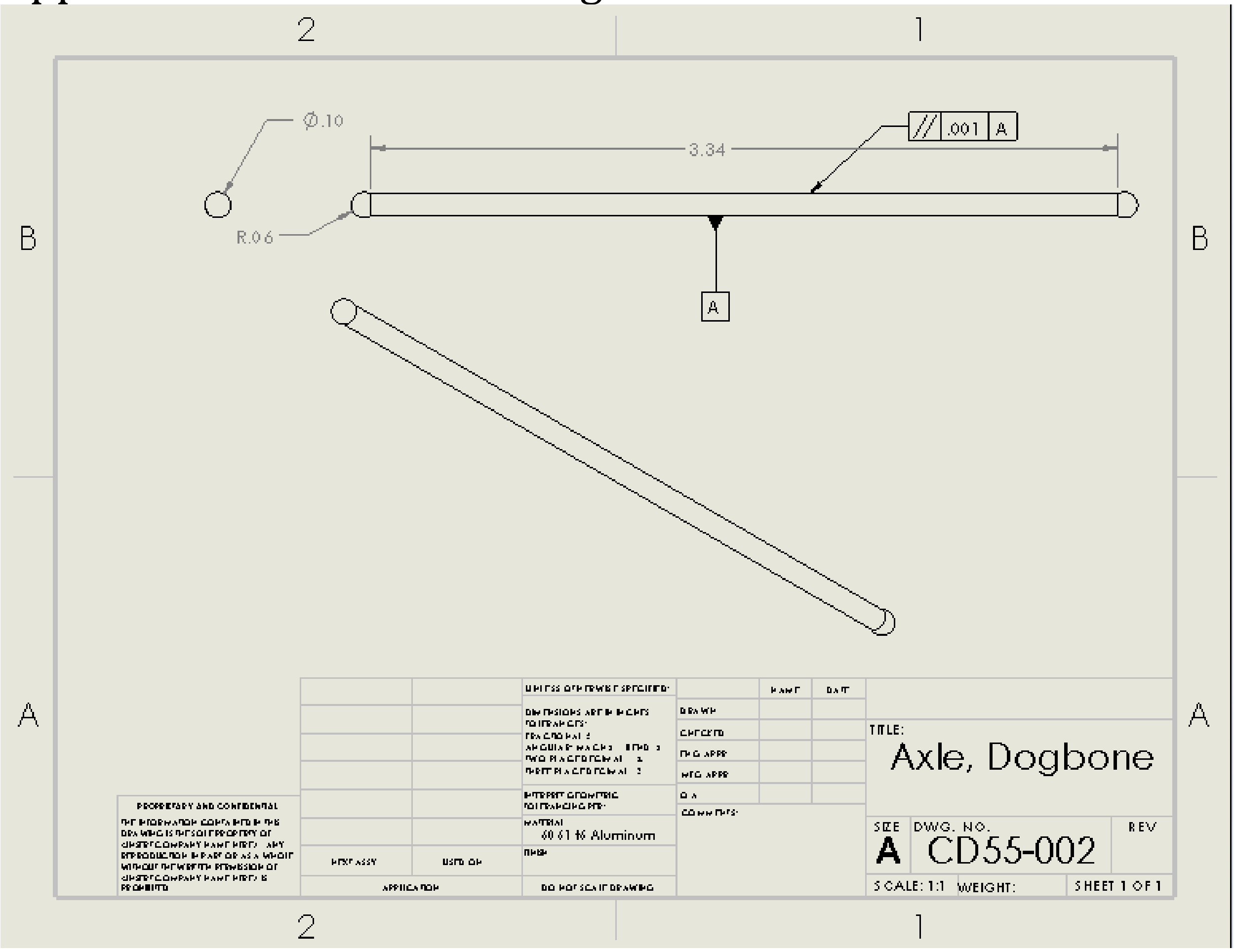
Appendix B– REL_55-001 - LCA Pin



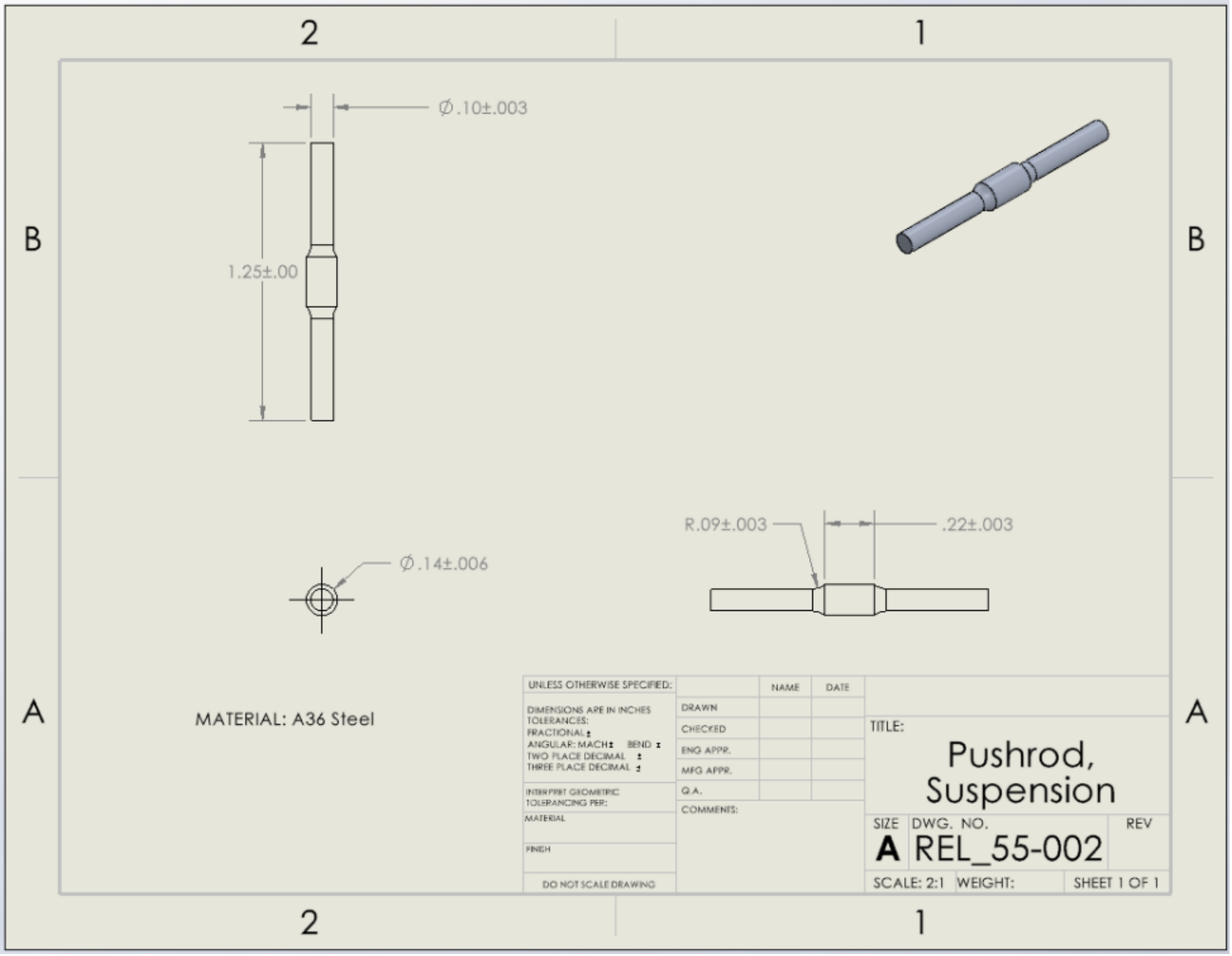
Appendix B12 –CD55-001- Motor



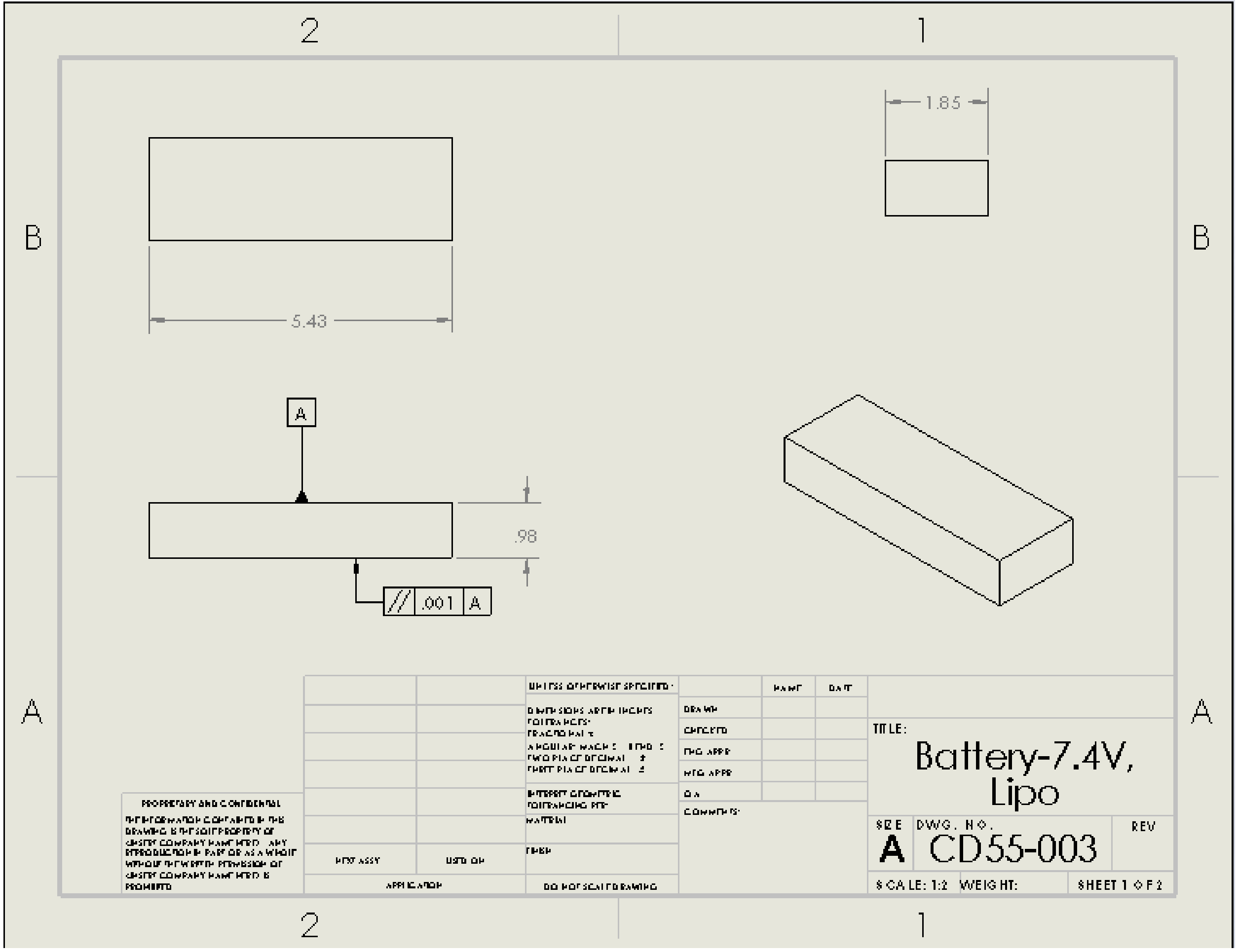
Appendix B13-CD55-002-Dogbone Axle



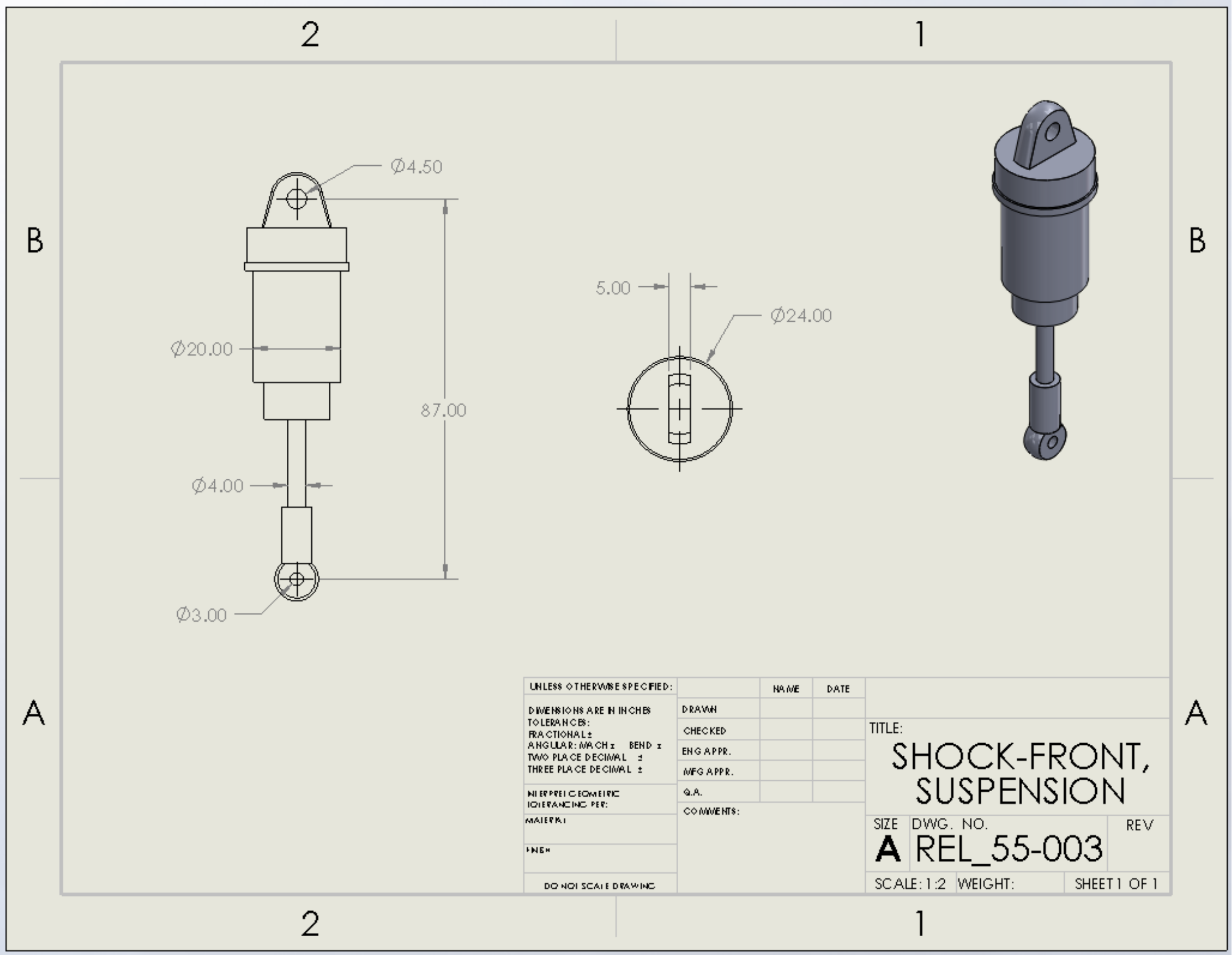
Appendix B – REL_55-002 -Suspension Pushrod



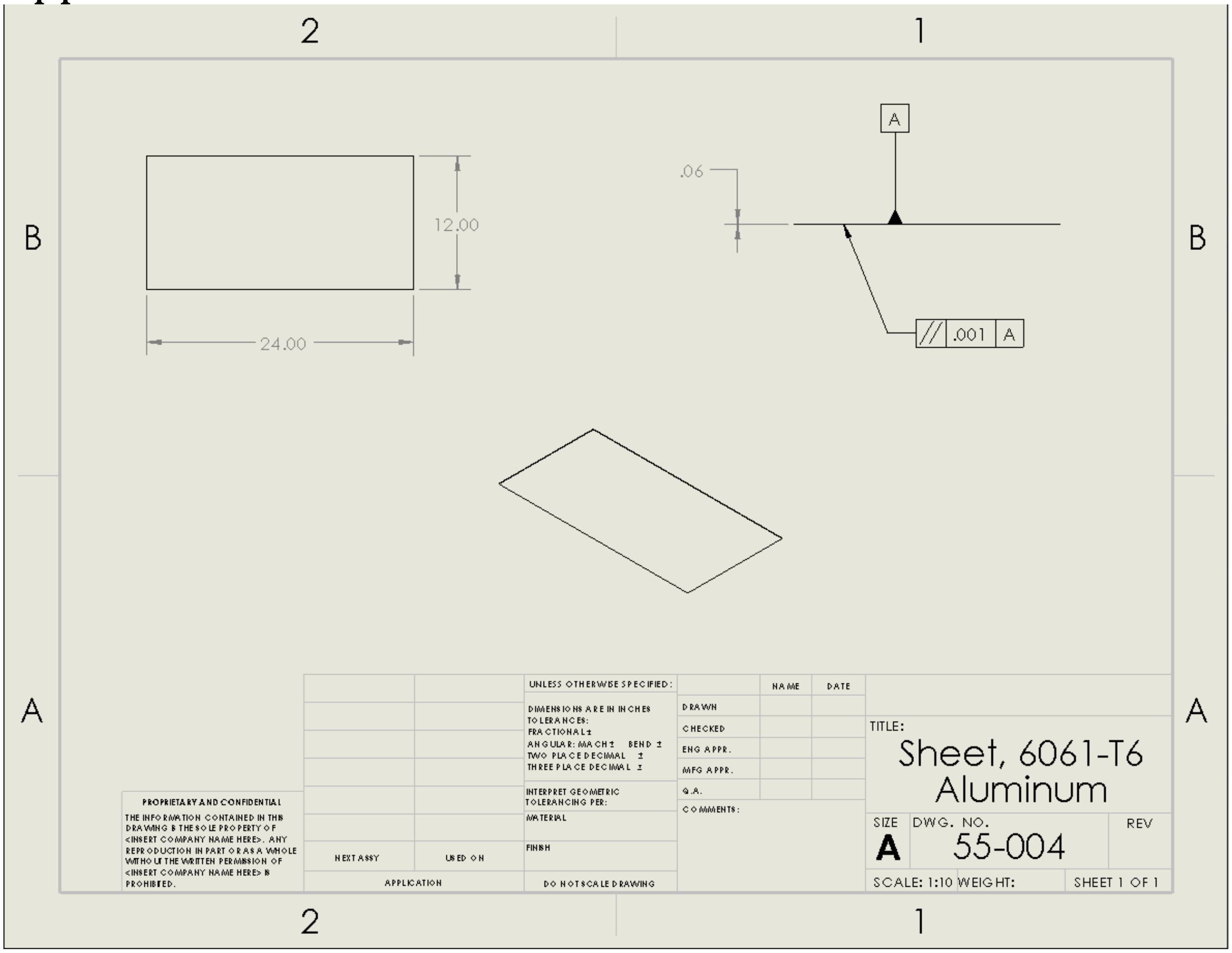
Appendix B14 –CD55-003- 7.4V, Lipo Battery



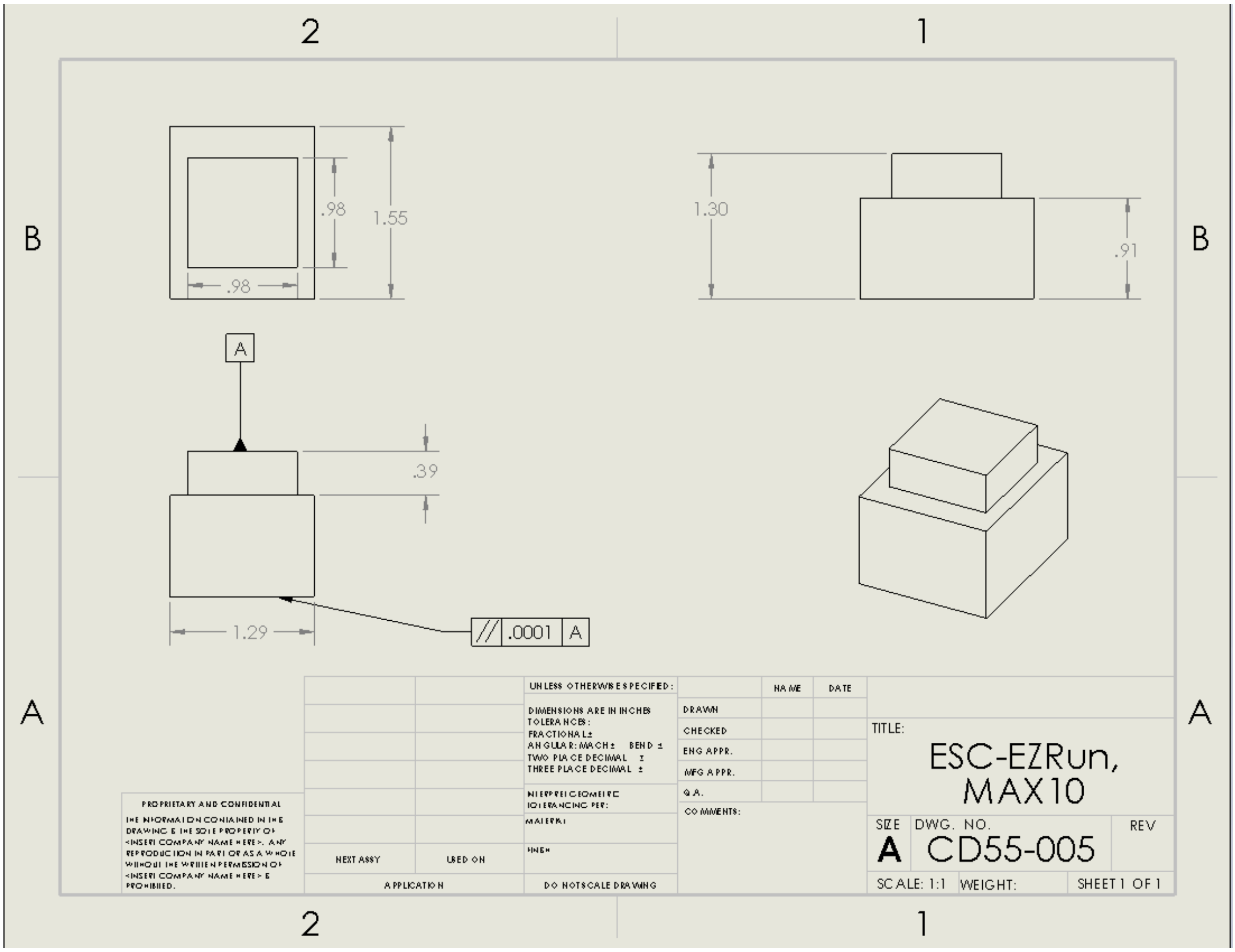
Appendix B – REL_55-003 – REL_55-004 – Front/Rear Shock



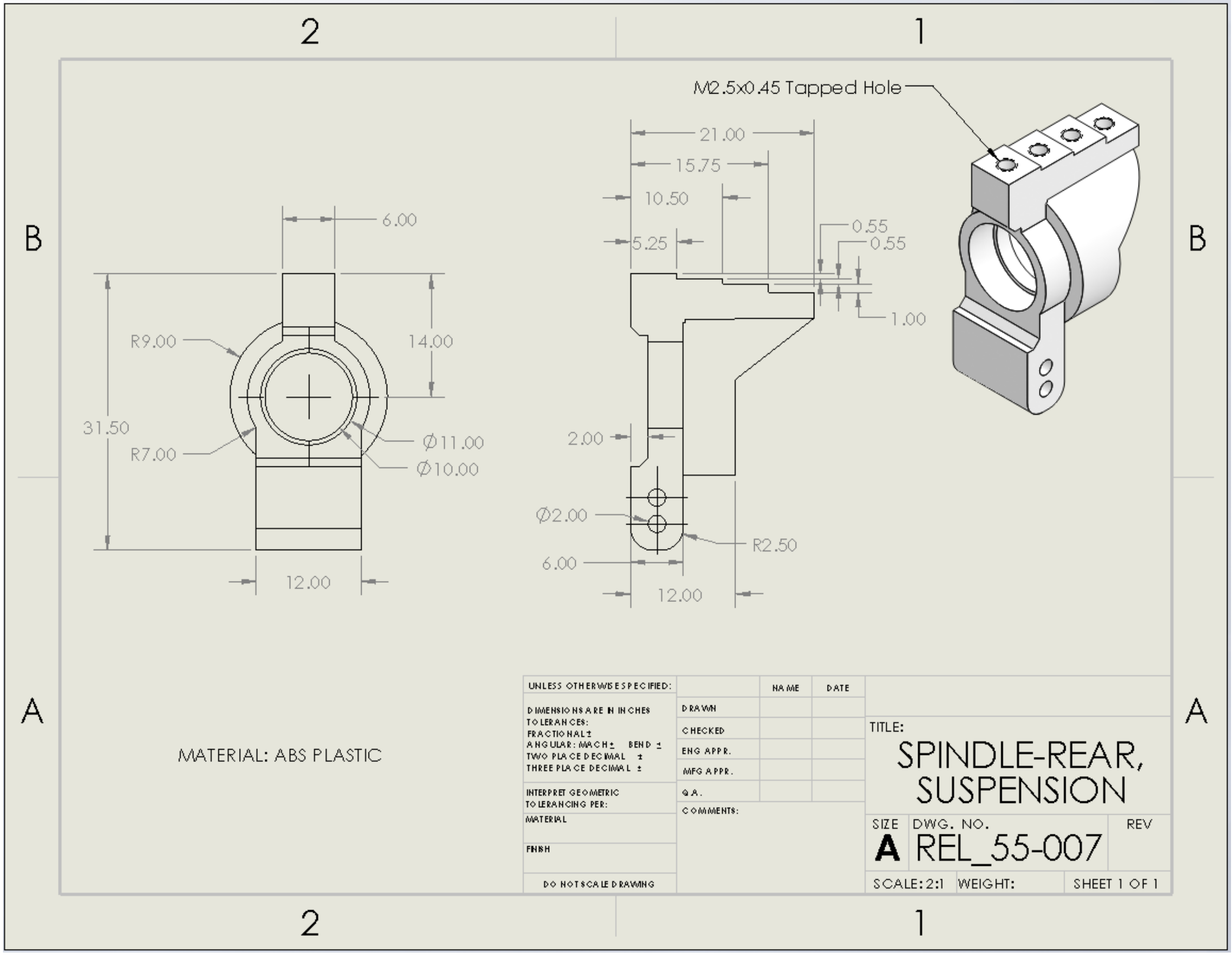
Appendix B15 –CD55-004- 6061-T6 Aluminum Sheet



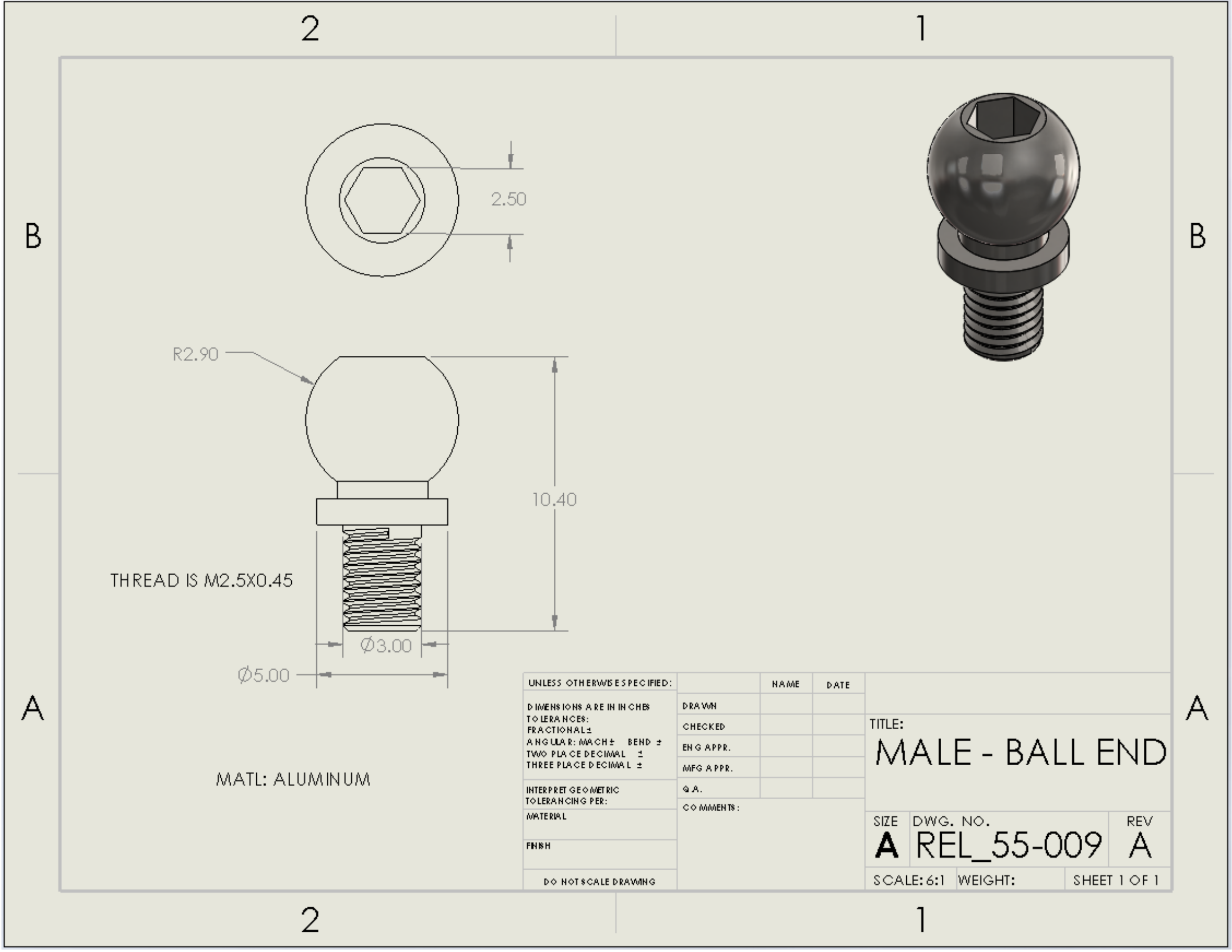
Appendix B16 –CD55-005- EZRun MAX10 Sensorless ESC



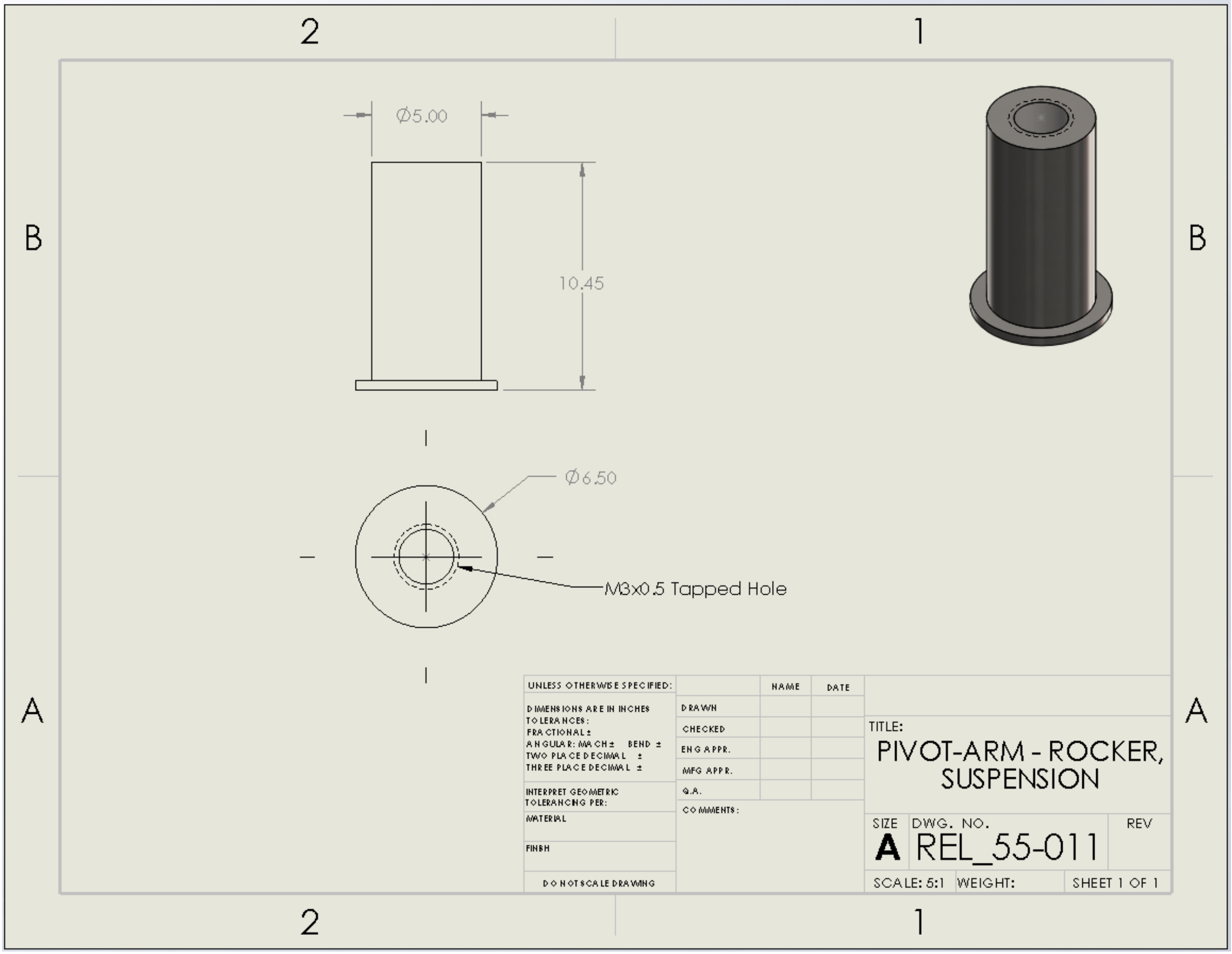
Appendix B – REL_55-007 – Rear Spindle



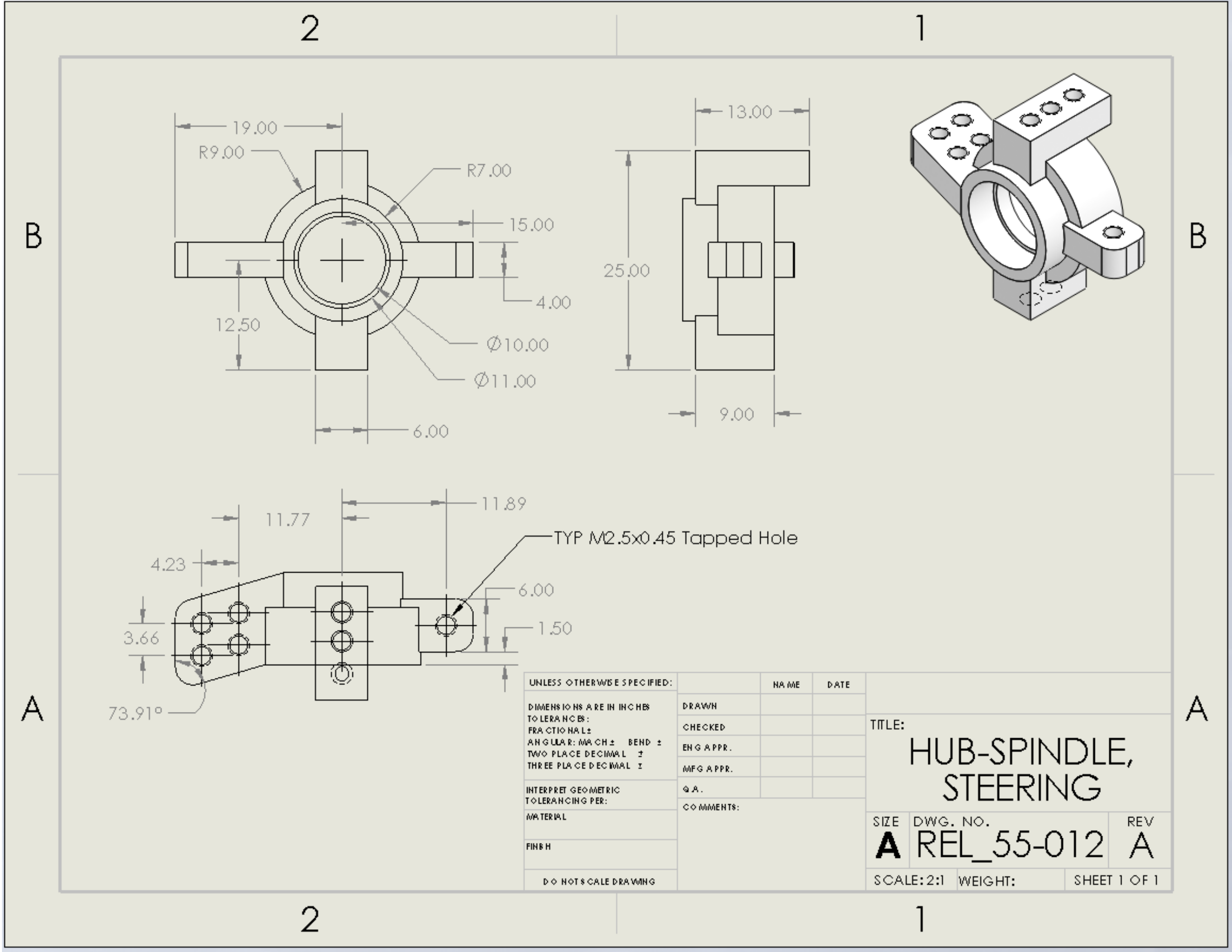
Appendix B – REL_55-009 – Male Ball End



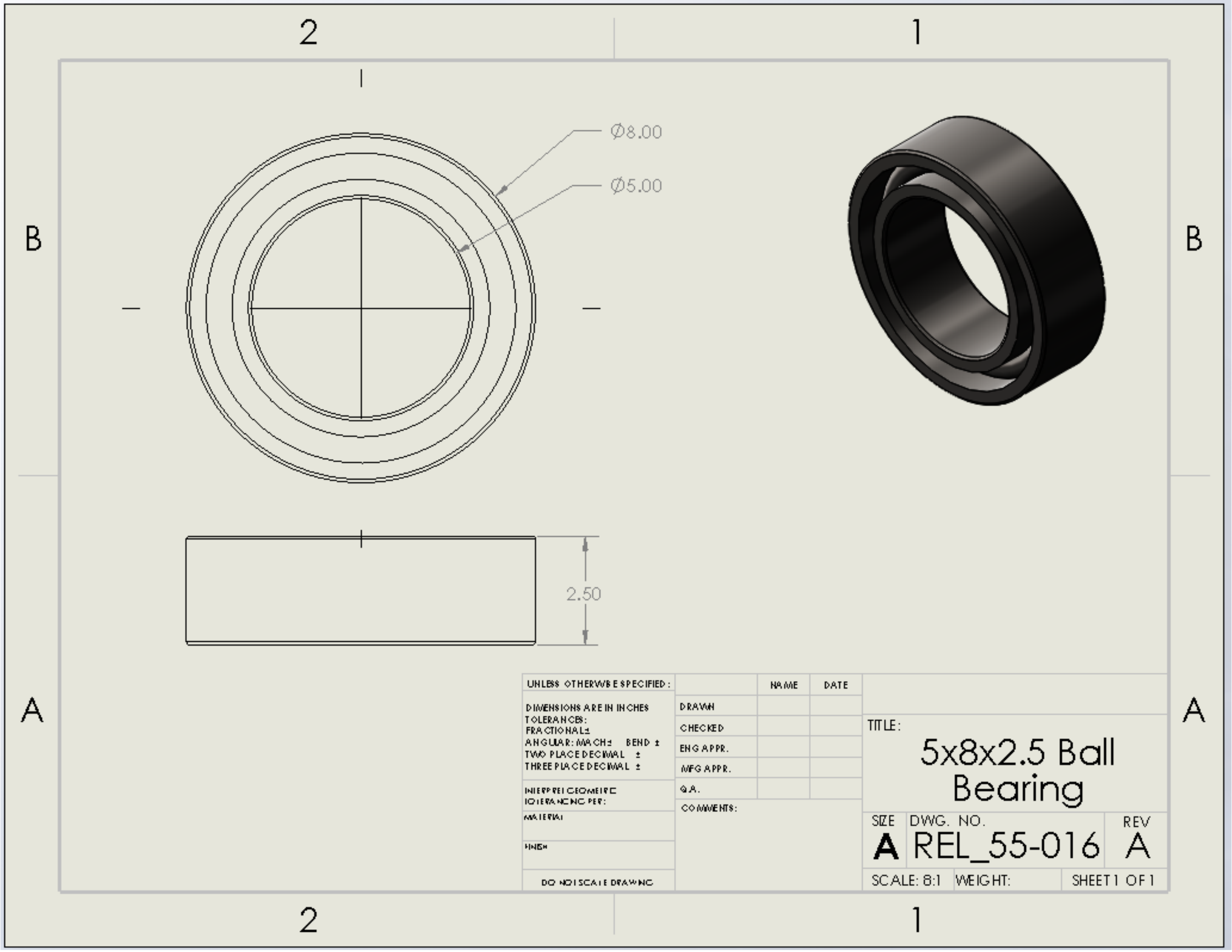
Appendix B – REL_55-011 – Rocker Arm Pivot



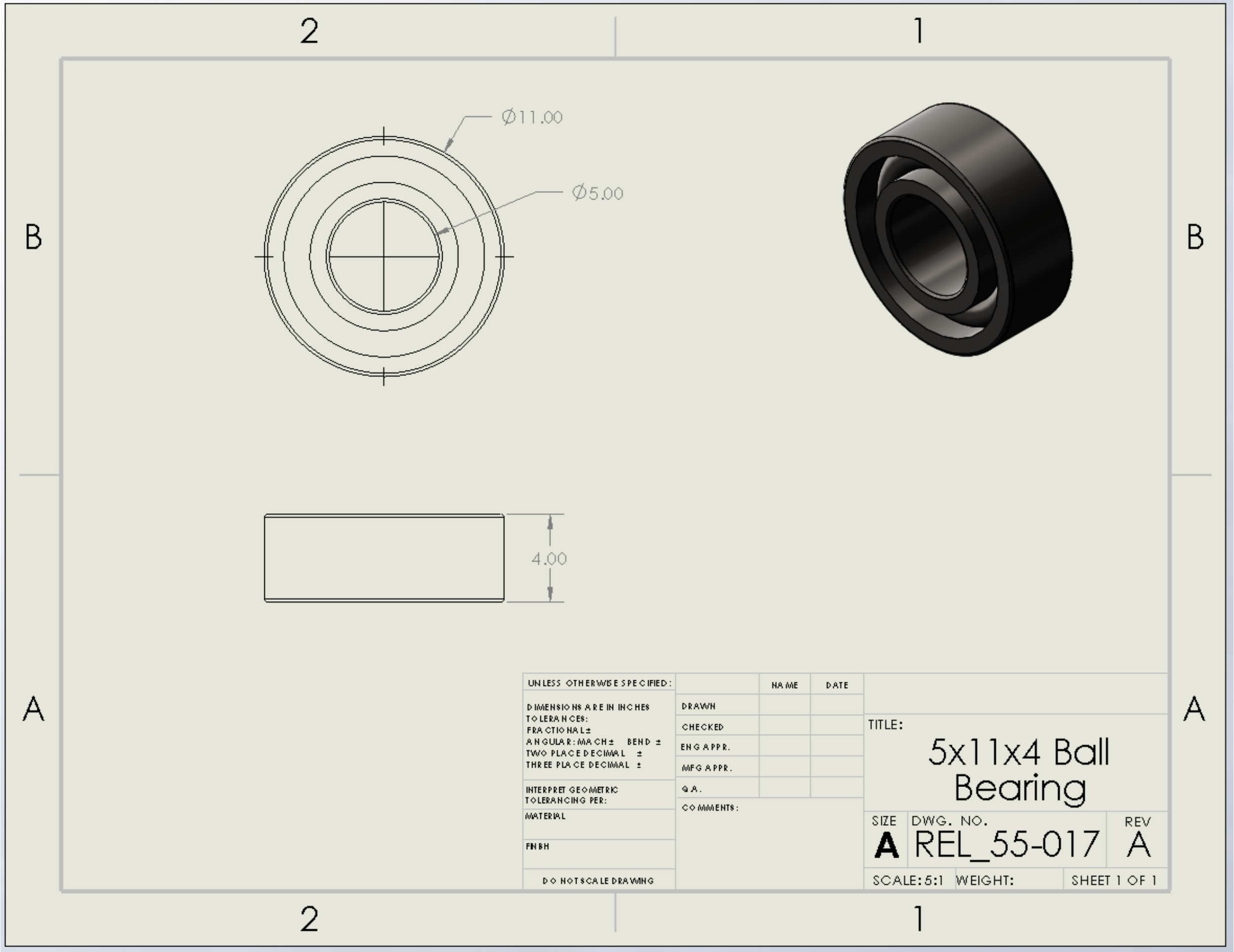
Appendix B – REL_55-012 – Front Spindle Hub



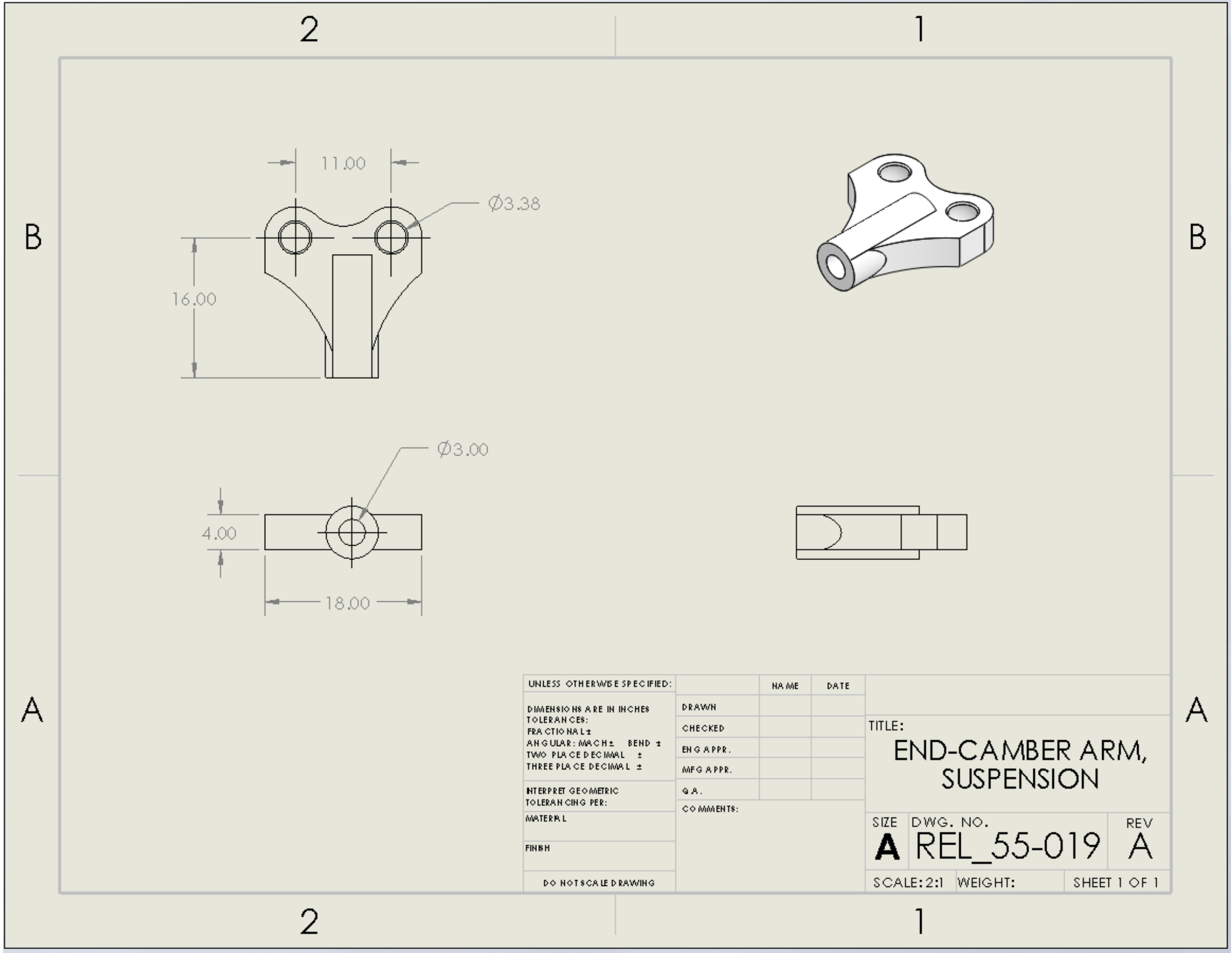
Appendix B – REL_55-016 – 5x8x2.5 Bearing



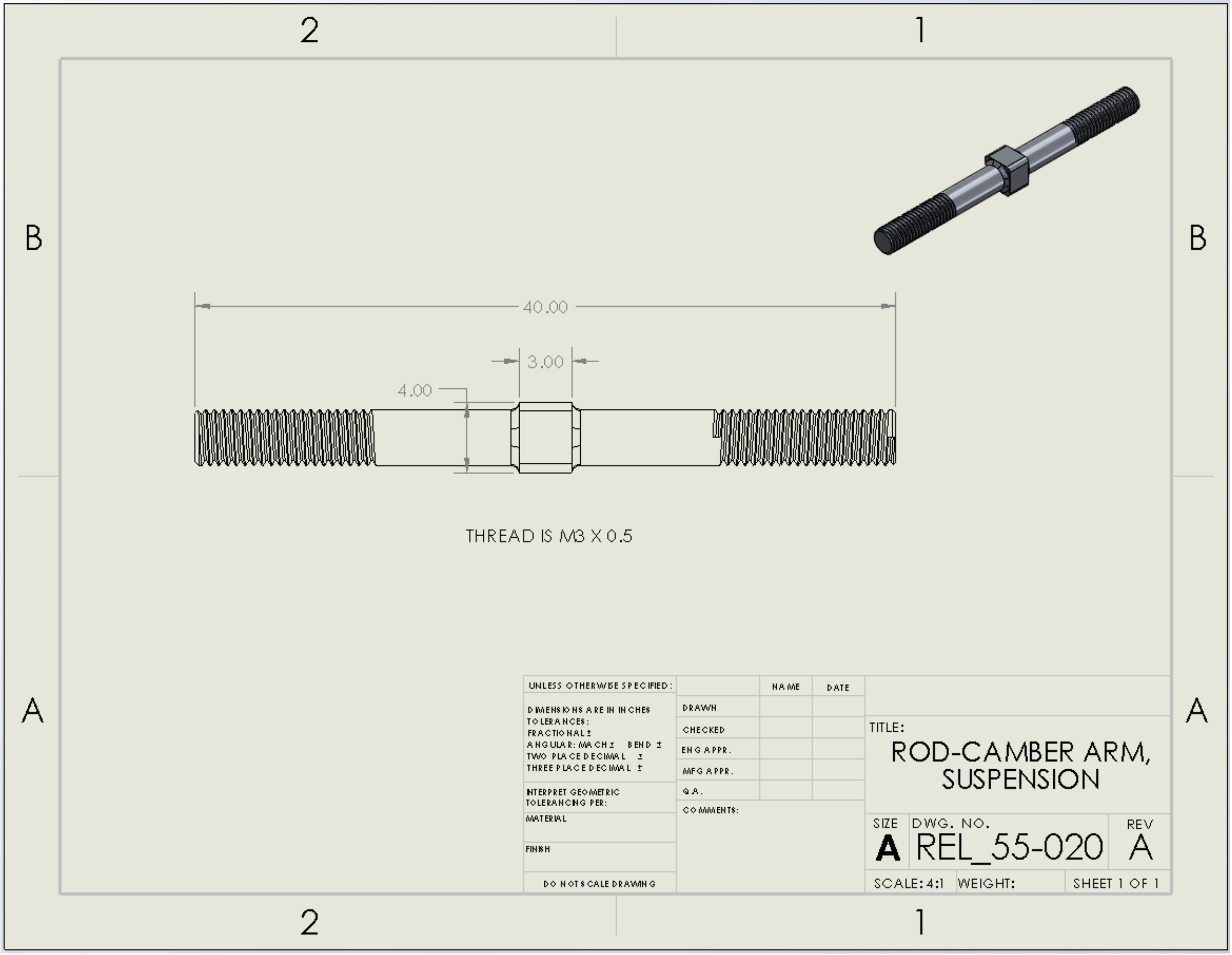
Appendix B – REL_55-017 – 5x11x4 Bearing



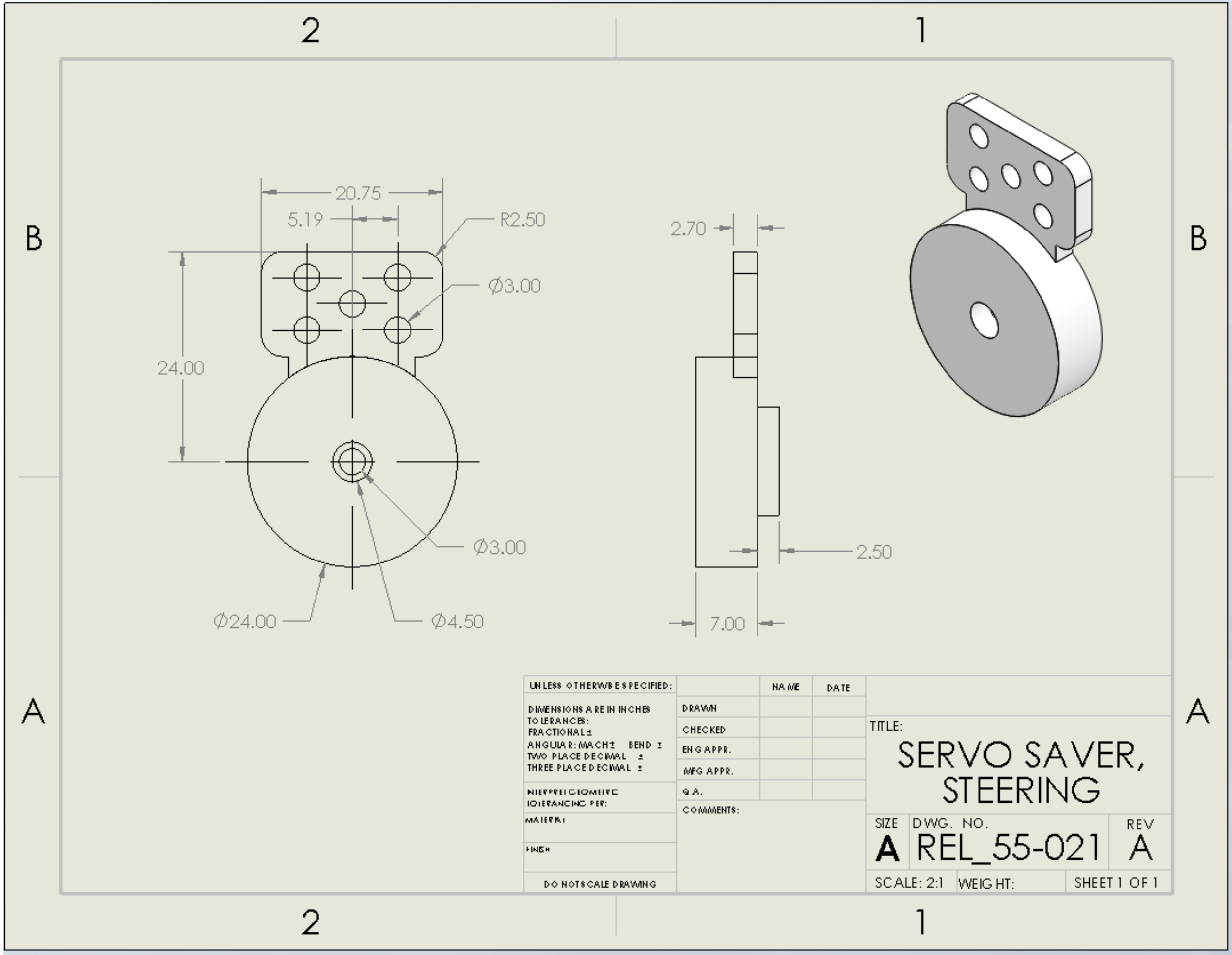
Appendix B – REL_55-019 – Camber Arm End



Appendix B – REL_55-020 – Camber Arm Turnbuckle



Appendix B – REL_55-021 – Servo Saver



APPENDIX C – CD Parts List and Costs

Table C1. Parts List

Part Number	Qty	Part Description	Source	Cost	Disposition
CD20-001	1	Housing, Motor	OnlineMetals	Included in cost of Aluminum sheet	Not yet fabricated
CD20-004	1	Housing-Part 1, Diff	OnlineMetals	$0.00	Fabricated
CD20-005	1	Housing-Part 2, Diff	Hogue Hall 3d Printer	$0.00	Fabricated
CD20-006	1	Differential Parts	Supergdrift	$40.00	Acquired
CD55-001	1	Brushless ESC/3652SL Motor	Hoppywing	$119.99	Acquired
CD55-002	1	Team Associated CVA Bone (2)	Amain Hobbies	$15.00	Acquired
CD55-003	2	Zeee 2S Lipo Battery 7.4V 5200mAh 100C	Amazon	$45.99	Acquired
CD55-004	1	36”x 12”x 1/16” 6061-T6 Aluminum Sheet	OnlineMetals	$49.99	Acquired
CD55-005	1	EZRun MAX10 Sensorless ESC	Hobbywing	Included in cost of motor	Acquired

APPENDIX C1 – REL Parts List and Costs

Fig. 1

Part Number	Qty	Part Description	Source	Cost	Disposition
20-001	1	Chassis Plate	Metal Supermarket	Incl. in cost of material	Acquired
20-002	1	Rocker Arm	Metal Supermarket	Incl. in cost of material	Acquired
20-003	1	CWU 3D printer, ABS Filament	CWU Hogue Tech	$.50/hr.	Not Ordered
20-004	1	CWU 3D printer, ABS Filament	CWU Hogue Tech	$.50/hr.	Not Ordered
20-005	1	CWU 3D Printer, ABS Filament	CWU Hogue Tech	$.50/hr.	Not Ordered
20-006	1	CWU 3D Printer, ABS Filament	CWU Hogue Tech	$.50/hr.	Not Ordered
20-007	1	CWU 3D Printer, ABS Filament	CWU Hogue Tech	$.50/hr.	Not Ordered
20-008	1	CWU 3D Printer, ABS Filament	CWU Hogue Tech	$.50/hr.	Not Ordered
20-009	1	CWU 3D Printer, ABS Filament	CWU Hogue Tech	$.50/hr.	Not Ordered
55-001	4	Suspension Shaft/Pin	AmainHobbies.com	$9.98	Not Ordered
55-002	2	Mild Steel Pushrods (Comes as pair)	AmainHobbies.com	-	Acquired
55-003	2	Front Shocks, 6061-T6 Aluminum	AmainHobbies.com	$79.99	Acquired
55-004	2	Rear Shocks, 6061-T6 Aluminum	AmainHobbies.com	$79.99	Acquired
55-005	2	Front Wheels (pair comes with rubber non-belted tires)	AmainHobbies.com	$33.99	Acquired
55-006	2	Rear Wheels (pair comes with rubber non-belted tires)	AmainHobbies.com	$33.99	Acquired
55-007	2	Plastic Rear Spindles (pair)	AmainHobbies.com	-	Acquired
55-008	1	Female ABS Ball Ends (Set)	AmainHobbies.com	-	Acquired
55-009	1	Male Steel Ball Ends (Set)	AmainHobbies.com	-	Acquired

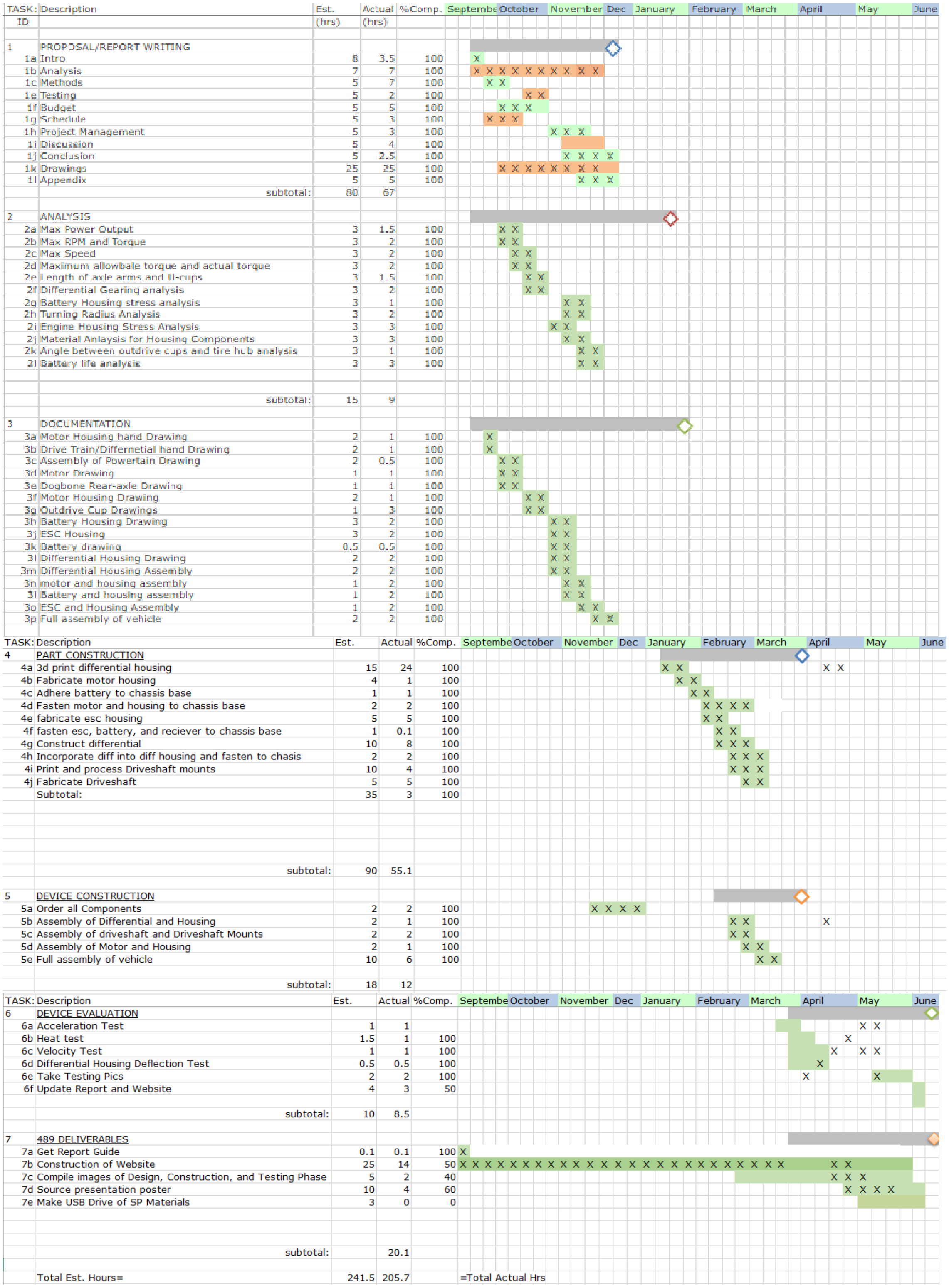
55-010	2	Hardened Steel Threaded Rod	AmainHobbies.com		Not Ordered
55-011	4	Rocker Pivot	SuperGdrift.com	$5.99	Acquired
55-012	1	Plastic Front Spindles (Pair)	AmainHobbies.com	-	Acquired
55-013	2	Spindle Shaft/Pin	AmainHobbies.com	$5.99	Not Ordered
55-014	4	Heavy Duty Springs	AmainHobbies.com	$15.78	Acquired
55-015	2	Front 2WD Axles (pair)	AmainHobbies.com	$7.99	Acquired
55-016	8	5x8x2.5mm Bearings	AmainHobbies.com	$9.98	Acquired
55-017	2	5x11x4mm Bearings	AmainHobbies.com	$3.50	Acquired
55-018	2	10x15x4mm Bearings	AmainHobbies.com	$3.99	Acquired
55-019	4	Camber Arm End	RCmart.com	-	Acquired
55-020	4	Camber Arm Turnbuckle	RCmart.com	-	Acquired
55-021	1	Servo Saver	HobbytownUSA	$4.00	Acquired
55-022	1	6061-T6 Aluminum Sheet Stock, 1/8”	Metal Supermarket	$33.82	Acquired
55-023	1	6061-T6 Aluminum Flat Bar, 3/8”	Metal Supermarket	$4.69	Acquired
55-024	4	Wheel Hub	AmainHobbies.com	-	Not Ordered
55-025	1	Stainless Steel Screw Set	AmainHobbies.com	$30.00	Not Ordered
55-026	1	Shock Fluid	HobbytownUSA	$5.99	Acquired

APPENDIX D – Budget

Table D1. Project Budget.

Item	Qty	Description	Cost
Parts	20	Total parts cost (Taxes/shipping)	$350
Labor Hrs.	400	Total labor cost	$6,000

APPENDIX E - Schedule

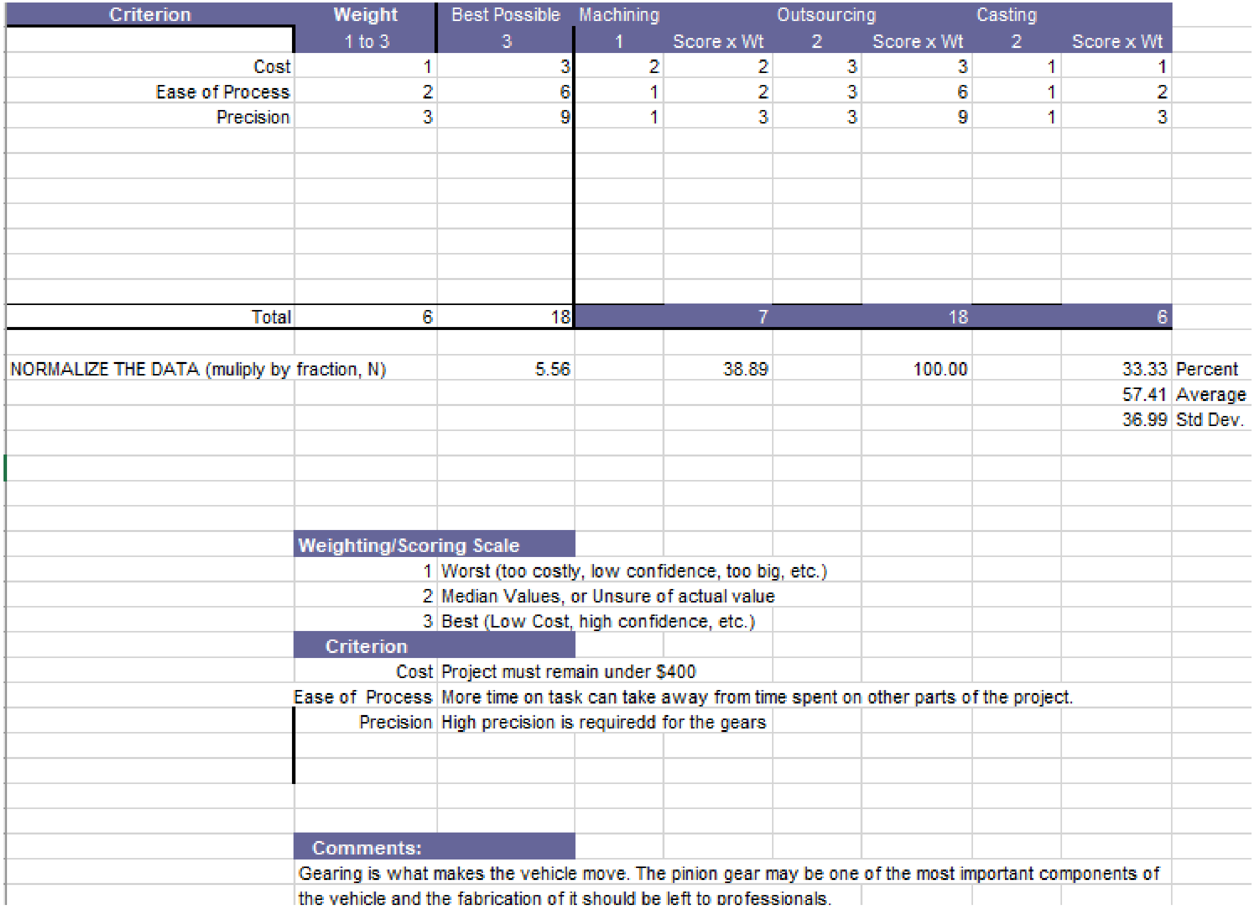


TASK: ID	Description	Est. (hrs)	Actual (hrs)	%Comp.
1	PROPOSAL/REPORT WRITING			
1a	Intro	8	3.5	100
1b	Analysis	7	7	100
1c	Methods	5	7	100
1e	Testing	5	2	100
1f	Budget	5	5	100
1g	Schedule	5	3	100
1h	Project Management	5	3	100
1i	Discussion	5	4	100
1j	Conclusion	5	2.5	100
1k	Drawings	25	25	100
1l	Appendix	5	5	100
	subtotal:	80	67	
2	ANALYSIS			
2a	Max Power Output	3	1.5	100
2b	Max RPM and Torque	3	2	100
2c	Max Speed	3	2	100
2d	Maximum allowbale torque and actual torque	3	2	100
2e	Length of axle arms and U-cups	3	1.5	100
2f	Differential Gearing analysis	3	2	100
2g	Battery Housing stress analysis	3	1	100
2h	Turning Radius Analysis	3	2	100
2i	Engine Housing Stress Analysis	3	3	100
2j	Material Anlaysis for Housing Components	3	3	100
2k	Angle between outdrive cups and tire hub analysis	3	1	100
2l	Battery life analysis	3	3	100
	subtotal:	15	9	
3	DOCUMENTATION			
3a	Motor Housing hand Drawing	2	1	100
3b	Drive Train/Differnetial hand Drawing	2	1	100
3c	Assembly of Powertain Drawing	2	0.5	100
3d	Motor Drawing	1	1	100
3e	Dogbone Rear-axle Drawing	1	1	100
3f	Motor Housing Drawing	2	1	100
3g	Outdrive Cup Drawings	1	3	100
3h	Battery Housing Drawing	3	2	100
3j	ESC Housing	3	2	100
3k	Battery drawing	0.5	0.5	100
3l	Differential Housing Drawing	2	2	100
3m	Differential Housing Assembly	2	2	100
3n	motor and housing assembly	1	2	100
3l	Battery and housing assembly	1	2	100
3o	ESC and Housing Assembly	1	2	100
3p	Full assembly of vehicle	2	2	100
TASK:	Description	Est.	Actual	%Comp.
4	PART CONSTRUCTION			
4a	3d print differential housing	15	24	100
4b	Fabricate motor housing	4	1	100
4c	Adhere battery to chassis base	1	1	100
4d	Fasten motor and housing to chassis base	2	2	100
4e	fabricate esc housing	5	5	100
4f	fasten esc, battery, and reciever to chassis base	1	0.1	100
4g	Construct differential	10	8	100
4h	Incorporate diff into diff housing and fasten to chasis	2	2	100
4i	Print and process Driveshaft mounts	10	4	100
4j	Fabricate Driveshaft	5	5	100
	Subtotal:	35	3	100
	subtotal:	90	55.1	
5	DEVICE CONSTRUCTION			
5a	Order all Components	2	2	100
5b	Assembly of Differential and Housing	2	1	100
5c	Assembly of driveshaft and Driveshaft Mounts	2	2	100
5d	Assembly of Motor and Housing	2	1	100
5e	Full assembly of vehicle	10	6	100
	subtotal:	18	12	
TASK:	Description	Est.	Actual	%Comp.
6	DEVICE EVALUATION			
6a	Acceleration Test	1	1	
6b	Heat test	1.5	1	100
6c	Velocity Test	1	1	100
6d	Differential Housing Deflection Test	0.5	0.5	100
6e	Take Testing Pics	2	2	100
6f	Update Report and Website	4	3	50
	subtotal:	10	8.5	
7	489 DELIVERABLES			
7a	Get Report Guide	0.1	0.1	100
7b	Construction of Website	25	14	50
7c	Compile images of Design, Construction, and Testing Phase	5	2	40
7d	Source presentation poster	10	4	60
7e	Make USB Drive of SP Materials	3	0	0
	subtotal:		20.1	
	Total Est. Hours=	241.5	205.7	

Figure E1. Project Gantt Chart.

APPENDIX F – Expertise and Resources

Table F1. Decision Matrix for process of obtaining the pinion gear for the motor.



Criterion	Weight	Best Possible	Machining		Outsourcing		Casting		
	1 to 3	3	1	Score x Wt	2	Score x Wt	2	Score x Wt	
Cost	1	3	2	2	3	3	1	1	
Ease of Process	2	6	1	2	3	6	1	2	
Precision	3	9	1	3	3	9	1	3	
Total	6	18		7		18		6	
NORMALIZE THE DATA (muliply by fraction, N)		5.56		38.89		100.00		33.33	Percent
								57.41	Average
								36.99	Std Dev.

Weighting/Scoring Scale

1	Worst (too costly, low confidence, too big, etc.)
2	Median Values, or Unsure of actual value
3	Best (Low Cost, high confidence, etc.)

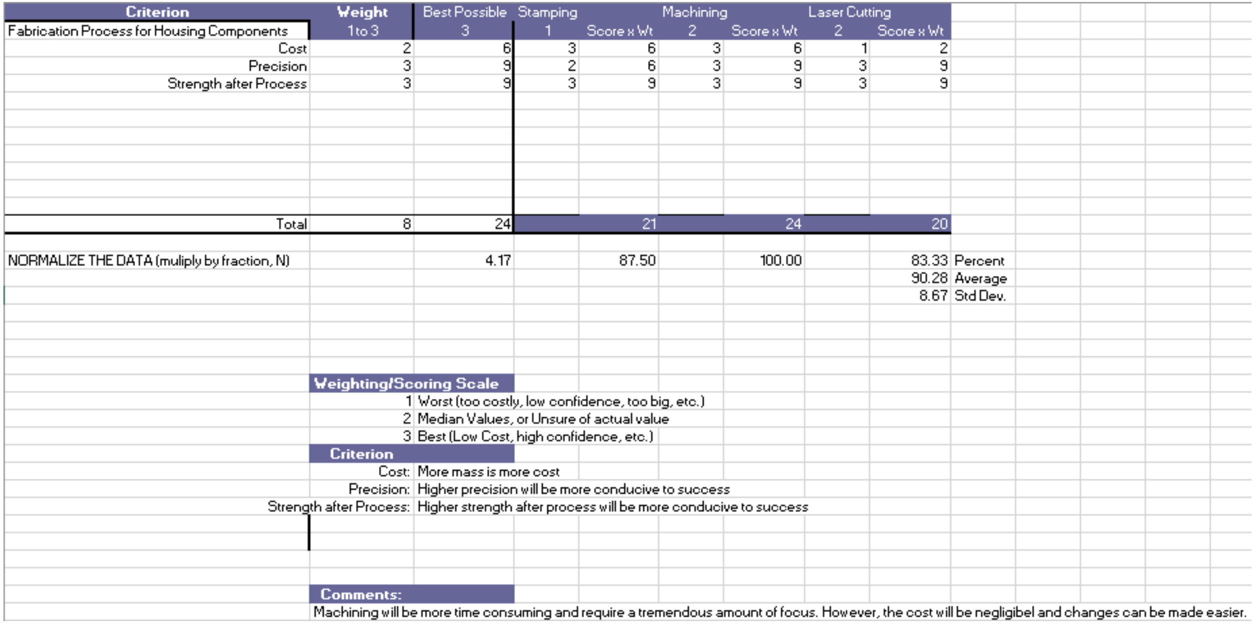
Criterion

Cost	Project must remain under $400
Ease of Process	More time on task can take away from time spent on other parts of the project.
Precision	High precision is requiredd for the gears

Comments:

Gearing is what makes the vehicle move. The pinion gear may be one of the most important components of the vehicle and the fabrication of it should be left to professionals.

Table F2. Decision Matrix for the fabrication process of the housing components.



Criterion	Weight	Best Possible	Stamping		Machining		Laser Cutting		
Fabrication Process for Housing Components	1to 3	3	1	Score x Wt	2	Score x Wt	2	Score x Wt	
Cost	2	6	3	6	3	6	1	2	
Precision	3	9	2	6	3	9	3	9	
Strength after Process	3	9	3	9	3	9	3	9	
Total	8	24		21		24		20	
NORMALIZE THE DATA (muliply by fraction, N)		4.17		87.50		100.00		83.33	Percent
								90.28	Average
								8.67	Std Dev.

Weighting/Scoring Scale

1	Worst (too costly, low confidence, too big, etc.)
2	Median Values, or Unsure of actual value
3	Best (Low Cost, high confidence, etc.)

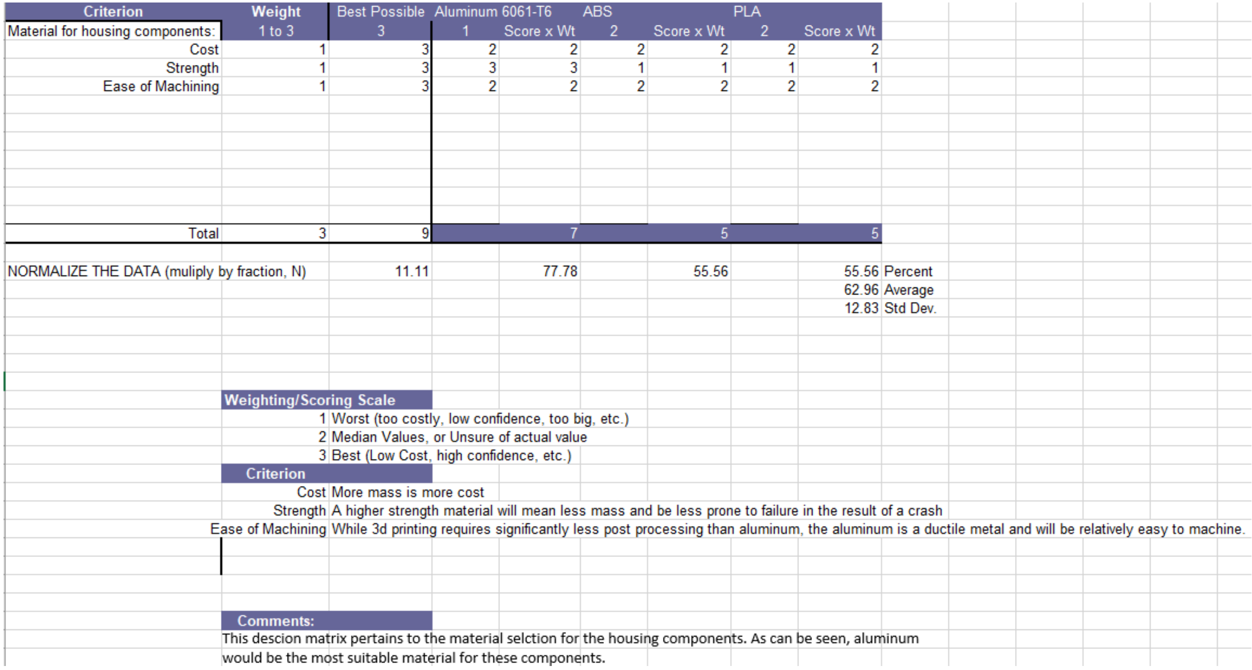
Criterion

Cost:	More mass is more cost
Precision:	Higher precision will be more conducive to success
Strength after Process:	Higher strength after process will be more conducive to success

Comments:

Machining will be more time consuming and require a tremendous amount of focus. However, the cost will be negligibel and changes can be made easier.

Table F3. Decision Matrix for the material of the housing components.



Criterion	Weight	Best Possible	Aluminum 6061-T6		ABS		PLA		
Material for housing components:	1 to 3	3	1	Score x Wt	2	Score x Wt	2	Score x Wt	
Cost	1	3	2	2	2	2	2	2	
Strength	1	3	3	3	1	1	1	1	
Ease of Machining	1	3	2	2	2	2	2	2	
Total	3	9		7		5		5	
NORMALIZE THE DATA (muliply by fraction, N)		11.11		77.78		55.56		55.56	Percent
								62.96	Average
								12.83	Std Dev.

Weighting/Scoring Scale	
1	Worst (too costly, low confidence, too big, etc.)
2	Median Values, or Unsure of actual value
3	Best (Low Cost, high confidence, etc.)
Criterion	
Cost	More mass is more cost
Strength	A higher strength material will mean less mass and be less prone to failure in the result of a crash
Ease of Machining	While 3d printing requires significantly less post processing than aluminum, the aluminum is a ductile metal and will be relatively easy to machine.

Comments:

This descion matrix pertains to the material selction for the housing components. As can be seen, aluminum would be the most suitable material for these components.

APPENDIX G – Testing Report

Appendix G1 (Maximum Speed Test)

Introduction

Requirement #1 stipulates that the vehicle must achieve, at minimum, 20 mph. Based on the calculations done in analysis #3 in appendix A-03, the predicted maximum speed was 30 mph. The data will be collected via a speedometer app on a phone that will be adhered to the chassis of the vehicle.

Method/Approach

As stated in the introduction, the speed data will be recorded via a speedometer app on the engineers phone that is then secured to the chassis of the vehicle. Also required will be a measuring tape and blue masking tape to measure and mark a 100ft straight-away. The speed data captured on the phone will be input directly into a spreadsheet to document the data. The speedometer app that is employed for this test is very precise. Before testing, the engineering team tested the speedometer app in a vehicle where the speed data was compared to what the vehicle's speedometer showed. Due to there being no discrepancy, the engineering team is very confident in the precision of the app.

Test Procedure

- **Overview:** The maximum acceleration of the vehicle will be measured in this test. This will be measured by using a speedometer app on the engineer's phone.
- **Location:** This test will take place on the walkway that runs diagonal to the southeast corner of the Hogue Technology Building.
- **Time/Duration:** The Test will take place in the middle of the day and require approximately 20 minutes to complete.
- **Risks:** There are multiple risks associated with this test, the most prominent of which being the vehicle crashing. There are multiple sensitive components that could be severely damaged in the case of a crash. To mitigate this risk, the engineering team selected a long and level section of walkway that is clear of obstacles on either side. This risk will be further mitigated by looking for and clearing any debris along the walkway. One of the potential risks associated with the location of the test is that the walkway is frequently used by students and pedestrians traversing campus. The engineering team will employ two strategies to mitigate this risk. The strategy entails doing the test in the middle of an hour where foot traffic is lower because students are in class. The second strategy entails having one member of the engineering team standing at the far end of the straight away that the vehicle will traverse. Their responsibility will be to look for pedestrians that could interfere with the testing and signal to the vehicle operator when it is safe to initiate the testing.

Test Procedure:

1. Collect the R/C vehicle, controller, measuring tape, masking tape and phone with the downloaded speedometer app.

2. Go to the specified walkway. Traverse the length of it (from the Music Building to the Hogue Technology Building) to ensure that the walkway is clear of debris.
3. Mark out 100ft with the measuring tape and masking tape. This will preferably be the section that has grass and bark dust on either side. It runs from the bicycle garage closest to the music building to the southwest until it becomes adjacent to the parking lot. This should allow for more than ample space for the marked 50ft distance.
4. Remove the body of the vehicle, initiate the speedometer app on the phone and wedge the phone between the battery and suspension towers. This will thoroughly secure the phone. The battery placement can be adjusted due to its Velcro adhesive to fit any size phone.
5. Fasten the vehicle body back onto the chassis and place the vehicle at the marked starting point. The starting point will be the marked point closest to the apron of the Hogue technology building, and the vehicle will be driven towards the point closest to the Music Building.
6. The engineer that is not operating the vehicle must stand towards the point the vehicle will be driving to ensure that no pedestrians will interfere and it is safe to initiate the test.
7. Once the engineer that is operating the vehicle receives the all clear, they will press the power button on the chassis of the vehicle to provide power to all drivetrain components
8. The operator will then fully engage the throttle and drive straight towards the other marked point.
9. Once the vehicle has passed the far marked point, they may disengage the throttle and initiate steering inputs if the vehicle is at risk of collision when coasting.
10. Once the vehicle has come to a stop, the engineer not operating the vehicle will remove the body from the chassis, remove the phone, stop the accelerometer app, and email the data file to themselves.
11. Steps 4-10 will be repeated two more times for a total of three trials.

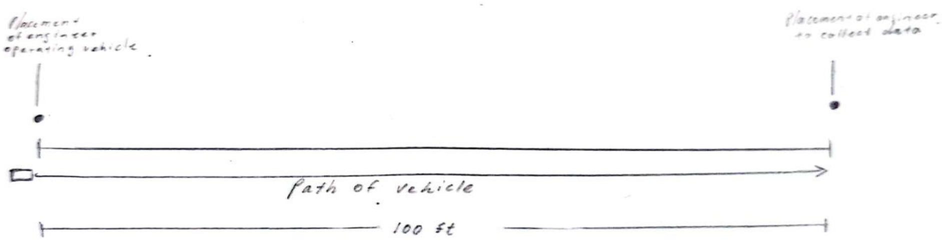


Figure G1.1: Testing setup for the maximum speed test

- **Discussion:** The original attempt for the maximum speed test ended immediately in failure. Due to not calculating the minimum diameter of the driveshaft, it experienced a torsional shear failure. Once this was resolved, the testing went smoothly and all three trials resulted in successful data collection. This is a product of a simple, yet thorough test procedure. The accuracy and precision of the collected data cannot be disputed.

Deliverables
Results:

Appendix G1.1 – Procedure Checklist

☐ Collect the R/C vehicle, controller, measuring tape, masking tape and phone with the downloaded speedometer app.
☐ Go to the specified walkway. Traverse the length of it (from the Music Building to the Hogue Technology Building) to ensure that the walkway is clear of debris.
☐ Mark out 100ft with the measuring tape and masking tape. This will preferably be the section that has grass and bark dust on either side. It runs from the bicycle garage closest to the music building to the southwest until it becomes adjacent to the parking lot. This should allow for more than ample space for the marked 50ft distance.
☐ Remove the body of the vehicle, initiate the speedometer app on the phone and wedge the phone between the battery and suspension towers. This will thoroughly secure the phone. The battery placement can be adjusted due to its Velcro adhesive to fit any size phone.
☐ Fasten the vehicle body back onto the chassis and place the vehicle at the marked starting point. The starting point will be the marked point closest to the apron of the Hogue technology building, and the vehicle will be driven towards the point closest to the Music Building.
☐ The engineer that is not operating the vehicle must stand towards the point the vehicle will be driving to ensure that no pedestrians will interfere and it is safe to initiate the test.
☐ Once the engineer that is operating the vehicle receives the all clear, they will press the power button on the chassis of the vehicle to provide power to all drivetrain components
☐ The operator will then fully engage the throttle and drive straight towards the other marked point.
☐ Once the vehicle has passed the far marked point, they may disengage the throttle and initiate steering inputs if the vehicle is at risk of collision when coasting.
☐ Once the vehicle has come to a stop, the engineer not operating the vehicle will remove the body from the chassis, remove the phone, stop the accelerometer app, and email the data file to themselves.
☐ Steps 4-10 will be repeated two more times for a total of three trials.

Appendix G1.2 – Data Forms

Appendix G1.3 – Raw Data

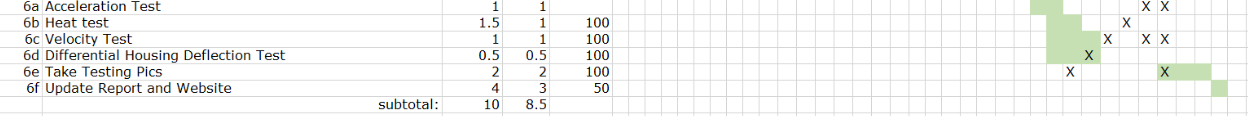
N/A. Data input immediately into table in Appendix G1.4.

Appendix G1.4 – Evaluation Sheet

Table G1.1. Collected data from the maximum acceleration test.

Trial #	Maximum Speed (mph)	Distance Traveled (ft)
1	19	100
2	20	100
3	20	100

Appendix G1.5 – Schedule (Testing)



TASK:	Description	Est.	Actual	%Comp.
6	DEVICE EVALUATION			
6a	Acceleration Test	1	1	
6b	Heat test	1.5	1	100
6c	Velocity Test	1	1	100
6d	Differential Housing Deflection Test	0.5	0.5	100
6e	Take Testing Pics	2	2	100
6f	Update Report and Website	4	3	50
	subtotal:	10	8.5	

Figure G1.2. The testing schedule including task 6c, the maximum speed test.

Appendix G2 (Maximum Acceleration Test)

Introduction

Requirement #3 stipulated that the vehicle must achieve a minimum acceleration of 5ft/s^2. Based on the calculations done in analysis #12 in appendix A-12, the vehicle will achieve an acceleration of approximately 6.8 ft/s^2. Data will be collected via a linear accelerometer app on the engineer’s phone that will be adhered to the chassis of the vehicle.

Method/Approach

As stated in the introduction, the acceleration data will be recorded via a linear accelerometer app on the engineer’s phone that is then secured to the chassis of the vehicle. Also required will be a measuring tape and blue masking tape to measure and mark a 50ft straight-away. The acceleration data captured on the phone will be saved as an .xls file and emailed to the engineer. The relevant data will then be taken from the file and input into a more succinct table.

Test Procedure

- **Overview:** The maximum acceleration of the vehicle will be measured in this test. This will be measured by using a linear accelerometer app on the engineer's phone.
- **Location:** This test will take place on the walkway that runs diagonal to the southeast corner of the Hogue Technology Building.
- **Time/Duration:** The Test will take place in the middle of the day and require approximately 20 minutes to complete.
- **Risks:** There are multiple risks associated with this test, the most prominent of which being the vehicle crashing. There are multiple sensitive components that could be severely damaged in the case of a crash. To mitigate this risk, the engineering team

selected a long and level section of walkway that is clear of obstacles on either side. This risk will be further mitigated by looking for and clearing any debris along the walkway. One of the potential risks associated with the location of the test is that the walkway is frequently used by students and pedestrians traversing campus. The engineering team will employ two strategies to mitigate this risk. The strategy entails doing the test in the middle of an hour where foot traffic is lower because students are in class. The second strategy entails having one member of the engineering team standing at the far end of the straight away that the vehicle will traverse. Their responsibility will be to look for pedestrians that could interfere with the testing and signal to the vehicle operator when it is safe to initiate the testing.

Test Procedure:

1. Collect the R/C vehicle, controller, measuring tape, masking tape and phone with the downloaded linear accelerometer app.
2. Go to the specified walkway. Traverse the length of it (from the Music Building to the Hogue Technology Building) to ensure that the walkway is clear of debris.
3. Mark out 50ft with the measuring tape and masking tape. This will preferably be the section that has grass and bark dust on either side. It runs from the bicycle garage closest to the music building to the southwest until it becomes adjacent to the parking lot. This should allow for more than ample space for the marked 50ft distance.
4. Remove the body of the vehicle, initiate the accelerometer app on the phone and wedge the phone between the battery and suspension towers. This will thoroughly secure the phone. The battery placement can be adjusted due to its Velcro adhesive to fit any size phone.
5. Fasten the vehicle body back onto the chassis and place the vehicle at the marked starting point. The starting point will be the marked point closest to the apron of the Hogue technology building, and the vehicle will be driven towards the point closest to the Music Building.
6. The engineer that is not operating the vehicle must stand towards the point the vehicle will be driving to ensure that no pedestrians will interfere, and it is safe to initiate the test.
7. Once the engineer that is operating the vehicle receives an all clear, they will press the power button on the chassis of the vehicle to provide power to all drivetrain components
8. The operator will then fully engage the throttle and drive straight towards the other marked point.
9. Once the vehicle has passed the far marked point, they may disengage the throttle and initiate steering inputs if the vehicle is at risk of collision when coasting.
10. Once the vehicle has come to a stop, the engineer not operating the vehicle will remove the body from the chassis, remove the phone, stop the accelerometer app, and email the data file to themselves.
11. Steps 4-10 will be repeated two more times for a total of three trials.

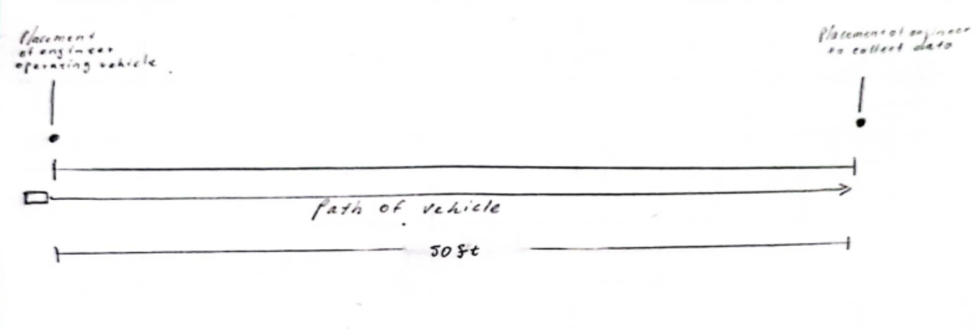


Figure G2.1: Testing setup for the maximum acceleration test

- **Discussion:** This test went very smoothly due to the simple yet thorough procedure. All trials were completed within the predicted time frame with no issues encountered. The data file was a bit cluttered due to the length of time in which the app was running. If the team were to perform this test again, they would try to expedite the portion in which the app is running to reduce the clutter in the data file. Outside of this very minor issue, the test was very successful in that the engineering team collected usable and accurate data in a quick and simple fashion.

Deliverables

Results: The values produced by the testing exceeded that minimum acceleration requirement of 5 m/s^2 by approximately 38%. More importantly the test values matched up almost perfectly with the values produced by the preliminary acceleration calculations.

Appendix G2.1 – Procedure Checklist

☐ Collect the R/C vehicle, controller, measuring tape, masking tape and phone with the downloaded linear accelerometer app.

☐ Go to the specified walkway. Traverse the length of it (from the Music Building to the Hogue Technology Building) to ensure that the walkway is clear of debris.

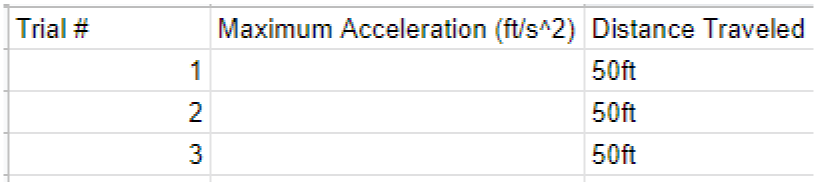
☐ Mark out 50ft with the measuring tape and masking tape. This will preferably be the section that has grass and bark dust on either side. It runs from the bicycle garage closest to the music building to the southwest until it becomes adjacent to the parking lot. This should allow for more than ample space for the marked 50ft distance.

☐ Remove the body of the vehicle, initiate the accelerometer app on the phone and wedge the phone between the battery and suspension towers. This will thoroughly secure the phone. The battery placement can be adjusted due to its Velcro adhesive to fit any size phone.

☐ Fasten the vehicle body back onto the chassis and place the vehicle at the marked starting point. The starting point will be the marked point closest to the apron of the Hogue technology building, and the vehicle will be driven towards the point closest to the Music Building.
☐ The engineer that is not operating the vehicle must stand towards the point the vehicle will be driving to ensure that no pedestrians will interfere, and it is safe to initiate the test.
☐ Once the engineer that is operating the vehicle receives an all clear, they will press the power button on the chassis of the vehicle to provide power to all drivetrain components
☐ The operator will then fully engage the throttle and drive straight towards the other marked point.
☐ Once the vehicle has passed the far marked point, they may disengage the throttle and initiate steering inputs if the vehicle is at risk of collision when coasting.
☐ Once the vehicle has come to a stop, the engineer not operating the vehicle will remove the body from the chassis, remove the phone, stop the accelerometer app, and email the data file to themselves.
☐ Steps 4-10 will be repeated two more times for a total of three trials.

Appendix G2.2 – Data Forms

Table G2.1: The data form for the maximum acceleration test

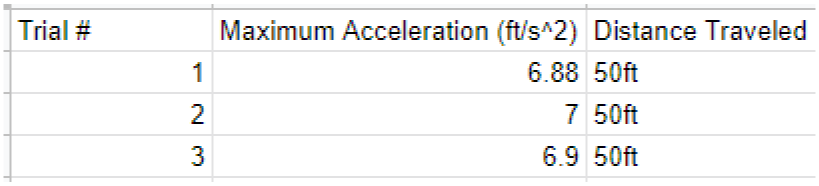


Trial #	Maximum Acceleration (ft/s^2)	Distance Traveled
1		50ft
2		50ft
3		50ft

Appendix G2.3 – Raw Data

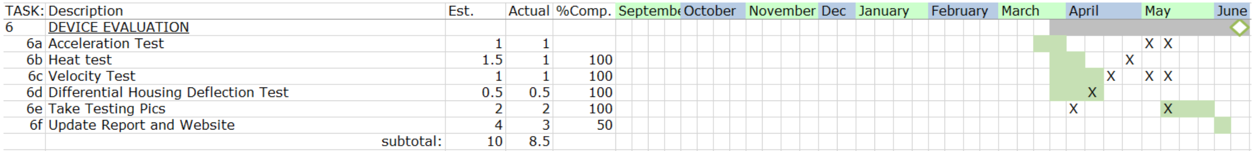
Appendix G2.4 – Evaluation Sheet

Table G2.2: Collected data from the maximum acceleration Test



Trial #	Maximum Acceleration (ft/s^2)	Distance Traveled
1	6.88	50ft
2	7	50ft
3	6.9	50ft

Appendix G2.5 – Schedule (Testing)



TASK:	Description	Est.	Actual	%Comp.	Septembe	October	November	Dec	January	February	March	April	May	June
6	DEVICE EVALUATION													
6a	Acceleration Test	1	1										X X	
6b	Heat test	1.5	1	100								X		
6c	Velocity Test	1	1	100								X	X X	
6d	Differential Housing Deflection Test	0.5	0.5	100								X		
6e	Take Testing Pics	2	2	100								X	X	
6f	Update Report and Website	4	3	50										
	subtotal:	10	8.5											

Figure G1.2. The testing schedule including task 6c, the maximum speed test.

Appendix G3 (Temperature Test)

Introduction

Requirement #9 stipulated that none of the drivetrain components will exceed a temperature that will jeopardize their adherence to the chassis of the vehicle. Due to the complexity of the temperature calculations and several other incalculable factors, there is no analysis related to this test. It is instead based on the temperature limit of the materials adhering the components to the chassis. This test involves measuring the ambient temperature of the battery, electronic speed controller, and motor. Then running the vehicle at full power for 90 seconds and measuring the temperature of those components again. The temperature will be measured with a temperature gun.

Method/Approach

This test involves propping the vehicle up so that its wheels do not contact the ground. The justification for this decision was as follows; any procedure that involved that vehicle moving would involve variation from trial to trial. This would be due to inconsistent speeds from the vehicle operator not being able to exactly replicate the initial trial. Additionally, it would be unrealistic to plan on operating the vehicle at full power for more than a few seconds at a time when there are obstacles to avoid. The last justification for this decision would be the consistent temperature indoors allowing for little variation in the ambient temperature of the drivetrain components. As stated in the introduction, the ambient temperature of each component will be measured with a temperature gun. Following this, the vehicle will be run at full power for 90 seconds, after which the temperature of each component will be measured again. This data will be input directly into a spreadsheet and compared to the temperature limits of the adhering materials for those components.

Test Procedure

- Overview: The maximum temperature of the battery, electronic speed controller, and motor will be measured after running the vehicle at full power for 90 seconds. The temperature will be measured with a temperature gun.
- Location: This test will take place on a workbench in the Hogue Hall machine shop.
- Time/Duration: This test will take approximately 30 minutes to complete.
- Risks: There are a limited number of risks associated with this test, but most relate to the drivetrain hardware, which could be serious. The biggest risk is causing damage to the gearing or driveshaft by running the vehicle for so long at full throttle. Because there is limited load on the drivetrain (the vehicle is stationary, wheels not in contact with the ground), the engineer performing this test does not believe that gear damage will occur

though there is still a nonzero chance. Another risk is that one of the electronic components (ESC, Battery, Motor) will overheat and become damaged. Though this is highly unlikely, it is still a possibility.

Test Procedure:

1. Collect the R/C vehicle, controller, temp gun, phone (for stopwatch), and the metal bricks available in the machine shop.
2. On a level workbench, place the metal bricks in two stacks of two, approximately 8 inches apart.
3. Remove the body from the chassis of the vehicle.
4. Place the vehicle on the metal bricks so that the wheels are fully suspended and not in contact with the bricks or the table.
5. Measure and record the ambient temperature of the battery, ESC, and motor with the temp gun and input into the premade excel table.
6. Turn the vehicle on via the power button on the chassis.
7. Start the timer and fully engage the throttle on the controller at the same time.
8. After 90 seconds, stop the timer and disengage the throttle.
9. At approximately 4 inches, use the temp gun to measure the temperature of the battery, ESC, and motor. After taking the temperature of each component, input the data directly into the premade excel sheet.
10. Do not initiate the next trial until the components reach the original ambient temperature that was measured. This may take consistent measurement over the course of 3-5 minutes.
11. Once the original ambient temperature is reached for all components, repeat steps 5-10 two more times for a total of three trials.

Figure G3.1. The testing setup for the heat test

Deliverables

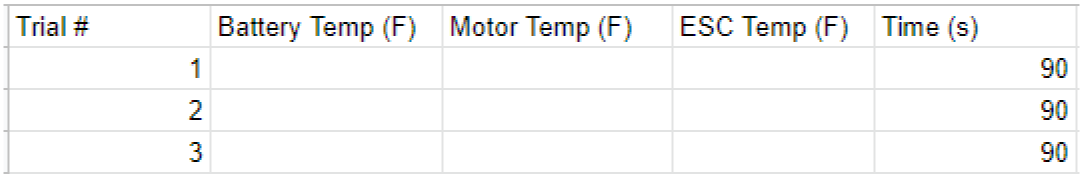
Results: Over the course of three trials, the temperature of all three components (Battery, ESC, Motor) did not exceed a temperature that would cause damage or failure to the materials that are adhering them to the chassis. In fact, the engineering team was taken aback by how little the temperature increased for each component. The maximum temperature achieved was 76.2 degrees Fahrenheit. This is 44.7% of the maximum allowable temperature. The engineering team reached the conclusion that any of these components would need to suffer a catastrophic failure to even come close to the temperature limits

Appendix G3.1 – Procedure Checklist

☐ Collect the R/C vehicle, controller, temp gun, phone (for stopwatch), and the metal bricks available in the machine shop.
☐ On a level workbench, place the metal bricks in two stacks of two, approximately 8 inches apart.
☐ Remove the body from the chassis of the vehicle.
☐ Place the vehicle on the metal bricks so that the wheels are fully suspended and not in contact with the bricks or the table.
☐ Measure and record the ambient temperature of the battery, ESC, and motor with the temp gun and input into the premade excel table.
☐ Turn the vehicle on via the power button on the chassis.
☐ Start the timer and fully engage the throttle on the controller at the same time.
☐ After 90 seconds, stop the timer and disengage the throttle.
☐ At approximately 4 inches, use the temp gun to measure the temperature of the battery, ESC, and motor. After taking the temperature of each component, input the data directly into the premade excel sheet.
☐ Do not initiate the next trial until the components reach the original ambient temperature that was measured. This may take consistent measurement over the course of 3-5 minutes.
☐ Once the original ambient temperature is reached for all components, repeat steps 5-10 two more times for a total of three trials.

Appendix G3.2 – Data Forms

Table G3.1: The data form for the heat test



Trial #	Battery Temp (F)	Motor Temp (F)	ESC Temp (F)	Time (s)
1				90
2				90
3				90

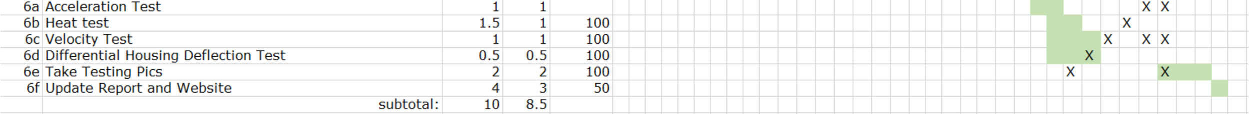
Appendix G3.3 – Raw Data

Appendix G3.4 – Evaluation Sheet

Table G3.2: Collected temperature data from testing

Trial #	Battery Temp (F)	Motor Temp (F)	ESC Temp (F)	Time (s)
1	71.2	75.6	72.3	90
2	70.2	76.1	72.5	90
3	70.5	76.2	73.6	90

Appendix G3.5 – Schedule (Testing)



TASK:	Description	Est.	Actual	%Comp.
6	DEVICE EVALUATION			
6a	Acceleration Test	1	1	
6b	Heat test	1.5	1	100
6c	Velocity Test	1	1	100
6d	Differential Housing Deflection Test	0.5	0.5	100
6e	Take Testing Pics	2	2	100
6f	Update Report and Website	4	3	50
	subtotal:	10	8.5	

Figure G3.2. The testing schedule including task 6b, the heat test.

APPENDIX H – Resume