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PC RC Baja: Steering and Drivetrain

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ABSTRACT

Students participating in the American Society of Mechanical Engineers (ASME) RC Baja competition are expected to work in teams of two to create an RC car from their own design to compete in a race and off-roading competition, as well as meeting the requirement of holding a top speed of at least 15mph. The students of team PC RC Baja used various methods to create the parts necessary for a functional RC car. Parts such as the gearbox and differential-box were 3D printed to incorporate their complex designs, and because they're used as housing and not expected to withstand substantial load. Other parts such as the multiple drive shafts, shock towers, and chassis were machined from aluminum and steel, because they are expected to withstand substantial load and provide torque for the RC car. Finally, many parts were purchased for various reasons, such as the motor, servo, and motor controller and RC remote because of their complexity and importance. Other parts like the gears, shocks, and tires were purchased because the students simply didn't have enough time to create these parts on time. The RC car is functional and ready for testing. The RC car has an 8:1 gear ratio and has a top speed of 30mph.

Keywords: RC Car, Steering, Drivetrain

Contents

1. INTRODUCTION

a. Description

Students must create a remote-controlled vehicle of their own design to compete in the RC Baja competition. In a combination of engineering, robotics, and machining, a Baja RC car will be constructed to meet specific criteria and requirements. In this competition, the vehicle is expected to survive a drop test, impact test, and compete in the dash, slalom, and Baja races.

b. Motivation

This project was motivated by the need to complete a senior project and a desire to learn more about vehicles and their function. The students have the desire to create a better RC vehicle than past RC Baja groups, while preparing themselves for a possible future career in the automotive field. The purpose of this project is to test the student's current knowledge of engineering, simulate a team environment to prepare them for future work, and encourage them to learn more about an area of their desire.

c. Function Statement

The drivetrain will provide locomotion for the RC Baja and the steering provides control for the chassis.

d. Requirements

The requirements of the Baja vehicle are:

1. The Baja Car must be able to reach a minimum top speed of 15mph.
2. The overall turn radius must not exceed 5 feet.
3. The RC vehicle must run on a single motor.
4. The RC vehicle must only use a single propulsion battery-pack.
5. The battery used must last 20 minutes before needing to be replaced/recharged while maintaining full motor RPM.
6. The differential must be able to withstand accelerating to top speed (assumed 15mph) in 5 seconds.
7. Motor must output a minimum of 400W and generate at least 1lb*in of torque.
8. Minimum gear ratio is recommended to be 8:1.
9. The drive shaft must have a minimum factor of safety of 5.
10. The Baja car must be able to drive up an incline with a height of 5ft and angle of 30°.

e. Engineering Merit

The student will use their knowledge of robotics to program a controller, Basic Electronics to wire various equipment, knowledge of gear trains and mechanical design to create an axil and differential, Statics to understand the output power needed to propel the vehicle, and Mechanics of Materials to ensure materials used will not break under various stresses and strains the vehicle may encounter.

f. Scope of Effort

The student is expected to program the controller, create a drivetrain to propel the vehicle, and create a steering mechanism that will allow the vehicle to maneuver the Baja Course. Additional expectations are for the student to create a neat and orderly wiring system that will allow the team to easily access various vehicle components for possible maintenance.

g. Success Criteria

The RC car moves and can change direction. The RC car meets all requirements and completes the three RC Baja challenges.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

Students are expected to create and design a remote-controlled car to compete in various race challenges. To begin the analysis, the students brainstormed possible designs for their vehicle and this section of the project is dedicated to the steering and drivetrain. Firstly, the student looked at different tires to determine which would be the most useful between hollow tires, normal tires, and sand tires. Next, the student brainstormed drive location between front and rear wheel drive. Finally, the student had to decide what type of drivetrain would be used between motor to axil or motor to differential to axil. The decision matrix can be found in Appendix F (Table F1).

b. Design Description

The student decided that the best design going forward would be a rear wheel drive, with sand tires in the rear and hollow tires in the front, and with the motor to differential to axil drivetrain.

c. Benchmark

For tires, the student valued off road driving traction and shock absorption to be the most important design factor. For drive location, manufacturability was decided to be the most important factor to make production easier on the student. Finally for drivetrain, shock absorption and the ability to lift the chassis was the most important factor to ensure a successful drop test.

d. Performance Predictions

The top speed of the vehicle is predicted to be 20mph, which should mean the 60ft sprint time is less than 5 seconds. The turn radius of the vehicle should be approximately 5ft.

e. Description of Analysis

The analysis for drive train and steering will draw from knowledge about basic electronics, motor output, geartrains, steering, and turn radius to get a baseline understanding of what to expect from various drivetrain and steering components. The analysis for steering and drivetrain will touch on motor RPM output, max speed, gear ratios, angle of turn, and turn radius.

f. Scope of Testing and Evaluation

Testing can be done using either laser gates or hand stopwatch to test for top speed. Turn radius testing can be performed by setting up a tape measure against the vehicle and setting the vehicle perpendicular to the tape measure and forced to drive in a half or full circle.

g. Analysis

Using the RADD (Requirements, Analysis, Design Parameters, Documentation) method developed at CWU the student will exemplify the engineering merit of the project. The requirements

i. Analysis 1

The motor output requirement the chosen motor must meet is a minimum actual output of 400W. To calculate this, the student used basic electricity principals and used to power equation which multiplies current and voltage to calculate power output. Then the student uses the efficiency equation to calculate the actual power output the motor produces, which was calculated at 444W. This value is greater than the requirement as shown in Appendix A-1.

ii. Analysis 2

The motor requirement approached in Analysis 2 is the motor torque to be at least 1.0 lb*in. To calculate the torque of the motor, the student must initially solve for the rpm the motor produces, which was calculated at 28,800rpm. Then the student can calculate the torque of the motor using the torque equation and conversions to get a lb*in value, which was calculated at 1.3lb*in. This value satisfies the motor torque requirement as shown in Appendix A-2.

iii. Analysis 3

The top speed requirement the student stives to reach is a minimum top speed of 15mph. To calculate the theoretical top speed of the RC car the student also accounted for the recommended gear ratio requirement of 8:1 to calculate the rpm that the wheels will be spinning at. Then the student calculated the circumference of the wheel to understand the distance traveled for every revolution of the wheel. Finally, the student calculated top speed using the velocity equation and converted rpm to mph to get a top speed of 51mph, as shown in Appendix A-3.

iv. Analysis 4

The requirement approached in Analysis 4 is the recommended gear ratio to be 8:1. The student has a prechosen differential to axil bevel gear values of 38T/13T bevels, so the student now needs to find gear values for the gear box to meet the 8:1 gear ratio. It was determined that the closest and most practical teeth values for the gear train would be 31T/18T and 32T/20T. This calculated the gear ratio to be very close to the required 8:1 gear ratio at a gear ratio of 8.05:1, which fulfills the gear ratio requirement, as shown in Appendix A-4.

v. Analysis 5

The requirement factor of safety for the drive shaft the student desires is a ratio of 5:1. The student first calculated the yield strength of shear and max torque of an 8mm 6061 T-6 Aluminum drive shaft to then solve for its factor of safety. The student determined the yield strength in shear to be 138MPa and max torque of 13.87Nm which gave a factor of safety for the drive shaft of 94. The student determined that an 8mm 6061 T-6 Aluminum drive shaft would be sufficient in for the design of the drive shaft, as shown in Appendix A-5.

vi. Analysis 6

The requirement for turn radius of the vehicle must be less than 5ft and will be a 3-part analysis to solve minimum turn angle, minimum wheel deflection, and minimum servo deflection. Analysis 6 tackles the first of these needed analysis by calculating minimum turn angle using the wheelbase width of 14in and assuming the turn radius as the minimum required 5ft. The calculated turn angle for the RC car was 13.5° as shown in Appendix A-6.

vii. Analysis 7

Analysis 7 tackles the second of three needed turn radius analysis and will focus on the minimum wheel deflection to achieve a 13.5° turn angle. The student used the law of sines to calculate for the minimum deflection using the 13.5° turn angle and 1in as the spindle radius. With this information, the minimum deflection needed to achieve a turn angle of 13.5° is .233in, which will be important to calculating the minimum turn angle of the servo horn to achieve the minimum turn radius. This analysis can be viewed in Appendix A-7.

viii. Analysis 8

This is the final of a three-part analysis for the minimum turn radius of 5ft and will focus on the minimum angle of turn the servo horn to achieve a 13.5° minimum turn angle. To solve for this, the student used the law of cosines for an isosceles triangle with the three given sides being .5in, .5in, and .233in. Using the law of cosines for an isosceles triangle the student was able to calculate for a minimum servo horn turn angle of 26.95°, which satisfies the minimum turn radius of 5ft. This analysis can be viewed in Appendix A-8.

ix. Analysis 9

The requirement for the RC car as a whole and per the RC Baja rules is that the vehicle must only run on a single battery and motor. In addition, the student requires that the RC car must run at a constant motor output for at least 20 minutes. In this analysis the student used the motor output from Analysis 1 to determine the amount of energy a battery must store in order to fulfill this requirement. The constant motor output wattage was multiplied by 20 minutes and converted seconds to minutes to determine the minimum power needed for the RC car to run at constant motor output of 592kW, as shown in Appendix A-9.

x. Analysis 10

The student requires that the RC car accelerate to top speed within 5 seconds. The student not only calculated for the minimum acceleration to achieve top speed within 5 seconds, but also accounted for how to test for this and how much room will be needed to set up the test. First, the acceleration equation was used to calculate the minimum acceleration of 4.4ft/sec^2 then the student used the acceleration to solve for the distance of 55ft needed to reach top speed, as shown in Appendix A-10.

xi. Analysis 11

The requirement for the car is to complete the RC Baja competition, in which there are inclines, so the requirement for the RC car is to drive up an incline of 5ft tall and 30° incline angle. The analysis uses the requirement of the top speed to be 15mph to calculate whether the RC car can reach the top. The student calculated the Potential Energy needed to reach the top of the slope of 1610 lb*ft^2/s^2 and the final velocity after the RC car at the top of the slope is 8.68mph, as shown in Appendix A-11.

xii. Analysis 12

Analysis 12 goes back to the gear ratio requirement of 8:1 and uses the answer from Analysis 4 to recalculate the top speed of the RC car. To calculate top speed the drive rpm was first calculated using the 8.05:1 gear ratio from Analysis 4, which came out to be 3577.6rpm. The top speed for the actual gear ratio came out to be 50.7mph, which is only .3mph slower than originally calculated in Analysis 3. This analysis can be viewed in Appendix A-12.

h. Device: Parts, Shapes, and Conformation

As steering and drivetrain, many of the parts created did not have to support load and were mainly designed for securing equipment to the chassis. However, the drive axil, steering rod, and differential shaft were all designed well over the design safety factor of 5 as the gears, bevels, and screws that will be put on these parts already require these shafts to be thick enough to support larger loads than required.

i. Device Assembly

An RC Baja car will be assembled to complete the RC Baja competition and fulfill the student's requirements. The Baja car will only have a single motor that will be able to provide an output power of 400W and a torque of 1lb*in and propel the car to a top speed of 15mph and accelerate to that speed within five seconds. The car will also only have a single battery that will provide the motor with enough energy to run the motor at a constant speed for 20 minutes. The car will be steered by a single servo with a horn attachment that will be able to provide the car with a turn radius less than 5ft. Finally, the drive shaft must have a safety factor of at least 5 and house a recommended gear ratio of 8:1.

j. Technical Risk Analysis

The students will be optimizing the RC car for speed, as the Baja competition is a series of races. The RC car is required to have a gear ratio of 8:1, however, the students chose a bigger set of RC wheels to combat the low gear ratio. The car is also made to support and absorb impact from both the impact and drop tests to protect the chassis. The largest of the technical risks will be programming the controller, motor control, and servo to optimize their use. The student does not have background programming controllers or motor controllers, so some extra time will be needed to learn and create the program. However, despite these technical risks the students still expect to finish the project construction on time.

k. Failure Mode Analysis

As the steering and drive train, there is much less failure analysis needed than the chassis and suspension. The main focus for the failure analysis in the steering and drivetrain section is the torsional shear of the drivetrain, the stress on the steering shaft, and the current flowing from the battery to the motor and servo. The drivetrain shaft was calculated to have a safety factor well above the required safety factor of 5 (Appendix A-5), the steering shaft was designed with respect to the shear it will encounter, and the energy and voltage needing to be provided by the battery was calculated and accounted for.

l. Operation Limits and Safety

The RC car limits accounted for are with respect to all the components used in the car, any other weight or unnecessary outside stress caused to the Baja car run the risk of failure if these stresses are excessive. The Baja car is designed for specific impact tests, so it is built to withstand some outside forces acting upon the car. However, students should be wary of any outside factors that may cause damage to the car.

3. METHODS & CONSTRUCTION

a. Methods

This RC Baja project was brainstormed, analyzed, and designed at CWU. The student had to work within the constraints of the university resources and tools/labs made available to the student by the school. The processes the student intends to use for the creation of parts will be 3D printing, lathe, and laser printing various parts according to their complexity and necessity. The student is to create a solution to the RC Baja competition of their own design and through their own funding. The decision as to how parts will be manufactured will be discussed in the section below. The student has created decision matrixes discussing why each manufacturing process was chosen for the various parts needing to be created. The decision matrixes can be viewed in Appendix F.

i. Process Decisions

The decision matrixes discuss the different manufacturing processes and various 3D printing materials that could be used in the creation of these parts. There are three different matrixes, the first discusses the 3D printing materials, the second discusses the shaft creation process, and the third discusses the steering rod machining process.

In the first decision matrix (Table F2) the student decides between using ABS, PLA, or PETG plastic for printer filament. The decision was close between ABS and PETG as they were clearly better options than PLA, since they are more weather resistant and cheaper options. However, ABS is the cheapest and most readily available to the student and has a higher temperature resistance than PETG, which made it the clear choice over PETG. So, the student will use ABS plastic for 3D printing.

In the second decision matrix (Table F3) the student chooses how to create or gather shafts for the drivetrain. The choices the student chose between were lathing a single shaft to different sizes, ordering different sized shafts, or casting different sized shafts. In this decision matrix, there was a clear choice being to lathe a single shaft to different sizes. However, to illustrate the decision-making process, the most important criteria in this decision was cost and manufacturability. Ordering separate shafts would have been the most ineffective and costly way to solve this problem, which made it the least desirable. Casting would have been the most efficient and time effective, however, the student does not have a background in casting and casting would be more expensive than lathing. So, the clear choice was for the student to lathe the shafts to the desired lengths and diameters from a single shaft, since the student is most comfortable with this process, even though casting would be more efficient.

Finally, the last decision matrix (Table F4) displays the student's choice in machining the steering rod. This decision presented much of the same problems that the previous decision matrix had, however, in this case the decision was closer than in the previous. The problem encountered in this decision matrix along with the previous is that the final product would be the same, which caused many of the scores to be similar. However, the student changed a criterion to help solidify the decision for this matrix, the criterion added was time to produce. This criterion along with manufacturability were the most important in separating laser printing from CNCing the steering rod, since laser printing is faster and has a finer finish.

b. Construction

i. Description

The device itself will be built in sections, there are five total sub-assemblies for the steering and drivetrain portion alone. Along with, seven 3D printed parts, three machined parts, and several parts needing to be purchased. The 3D printed parts will need to be top priority, as they will take the most time to create. Then, the purchased parts will need to be ordered either over break or as soon as the students return from break. Next, once material is gathered, the student will need to machine a few parts and account for the dimensions needed for a successful assembly. Finally, the student will assemble the drivetrain through sub-assembly fashion first, then an overall construction when all sub-assemblies are created.

ii. Drawing Tree, Drawing ID's

The drawing tree can be viewed in Appendix B-1 and will be referenced to extensively in this section. The drawing tree is a hierarchal table of construction, the lower on the tree, the more specific the part. The second lowest section of the drawing tree contains the sub-assemblies, and each sub-assembly has parts in the lowest section of the drawing tree associated with that sub-assembly. The sub-assemblies were organized by which parts will be used to create those sub-assemblies when constructed and how they will be put together when the full construction rolls around. For example, the differential is a separate sub-assembly from the drivetrain, because the differential will need to be constructed prior to the drivetrain sub-assembly construction. Moreover, the bevels are not included in the differential sub-assembly, because the differential will go through the differential box before the bevel could be added to the differential shaft. So, in simpler terms, the sub-assemblies were organized in order of construction sequence and part association.

iii. Parts

The parts list can be viewed in Appendix C and will be referenced to extensively in this section. The parts are grouped into two groupings; however, this may become three sections in the future if any purchased parts need to be modified, but so far there are no modified parts used in the construction of this project. These two groupings are created parts, signified with a naming convention of 20-###, and purchased parts, signified with a naming convention of 55-###. The created parts will either be 3D printed or machined, based on if they will need to support any significant load. Most of the parts created do not support any significant load and are used as custom fasteners for key instruments, such as the motor mounts and servo mount (Appendix B-8-13). However, there are parts that do support load, such as the shafts connected to the drivetrain and the servo shaft, and these parts will be machined to be able to support these loads (Appendix B-14-17). The remaining of these parts will need to be purchased from outside vendors. Most of the parts purchased will be purchased through Amazon, for ease of access and because they are generally cheaper to buy through Amazon. And the rest of the parts will be purchased from other RC vendors or local hardware stores. Within each row in the parts list, it describes quantity of each part needed and where they will be purchased from, along with the price associated with the part.

iv. Manufacturing Issues

The main risk associated with most of the parts will be the time needed to create the parts. Most of the parts are being 3D printed, and the 3D printer takes a long time to print parts, on average the 3D printer prints at a speed of 1.5g/hour. Another variable is the customization factor, the student is well versed in the machine shop, however, the 3D printer provides a wider ability for customization. The student chose to 3D print parts because of the accessibility to the 3D printer and the ABS plastic material the printer uses to print parts. Moreover, 3D printing is the cheapest option when it comes to part creation, so the pros outweighed the cons in this particular instance.

v. Discussion of Assembly

The student began the motor assembly, as the first assembly to be completed. However, with the parts originally created for the motor assembly, the motor would not be able to generate torque across the drivetrain. So, the student created a new custom part that incorporated the screw pattern on the front face of the motor. This will allow the motor to transmit torque across the driveshaft while mounted to the chassis. A problem encountered during this assembly was the design of the new part, the student rushed to complete the part and forgot to add a hole for the drive shaft on the motor. So, the student drilled a hole big enough for the driveshaft, as well as, the chamfered section closest to the motor.

4. TESTING

a. Introduction

For the RC Baja project, the main test is the Baja competition, which includes the sprint, slalom, and Baja courses. But aside from these tests there are other tests that could be run to get a better understanding of the RC car's capabilities. For the steering and drivetrain perspective, these tests include a top speed test, turn radius test, and an incline test. The team predicts to finish in the top half of competitors in the RC Baja competition. The team predicts a top speed of about 50mph (Appendix A-3), a turn radius of less than 5ft (Appendix A-6), and the ability to scale a 5ft height 30° incline (Appendix A-11).

b. Method/Approach

The RC Baja competition is a timed event of three courses, which will most likely be timed by judges/officials. All the students would need for this event is their completed RC car and controller. For the top speed test, students will need two laser gates and a tape measure to set the distance of the laser gates. To test turn radius, students will need a tape measure. Lastly, the front impact test is a pass/fail test, so no special equipment is needed other than a hard wall and room to accelerate to top speed.

c. Test Process

To test the RC Baja competition, students are expected to compete and complete each course of the competition with their RC car, which will be timed for speed of completion. The top speed and turn radius test can be tested in the Interdisciplinary Lab where there is plenty of room and the ground is flat. For the top speed specifically, a track will be set up with a start and finish line and laser gates set 1 meter apart at the back end of the track and connected to a computer to collect data. For the turn radius test, a 5ft circle will be drawn or taped out and the car must keep its front wheel within the circle for success to be considered. Finally, the front impact test will be tested right outside of Hogue against the wall of the building.

d. Deliverables

All data will be video recorded on phones and any hard data, such as times, will be recorded in either the student's engineering notebook or electronically via Excel sheet. This data will be used later to be inputted into testing papers for submittal and videos uploaded to the student's website for proper documentation of results.

5. BUDGET

a. Parts

The cost of parts is separated into two separate cost totals, which are the cost for 3D printed parts and cost of purchased parts. This can be viewed in Appendix C (Table C1). 3D printed parts are custom parts created by the student to add to the project and will be made of ABS plastic with the MET 3D printer. The purchased parts will be ordered and gathered next quarter for the construction of the RC Baja car. Finally, there are a few machined parts in which the cost will be considered as ordered parts, as the material must be ordered.

The larger cost items were purchased online in groups by order of importance. The motor combo, servo, and battery were purchased first since they were the most important and required proper dimensioning to fit onto the chassis. The total of the first group of parts all together totaled around $141, including shipping and taxes. The second group of parts was the wheels and the bevels for the differential. These parts were also important for shaft sizing throughout the driveshaft and totaled around $37, including shipping and taxes. Finally, the last two groups of parts will be the remaining online ordered parts, which include the gears and differential yoke, and the last group will be any additional fasteners needing to be purchased. The total budget for the project was spent and the students only went a dollar over their expected budget total.

In the testing phase, during spring, the students encountered many problems in which parts needed to be replaced for sturdier parts or parts needing to be reprinted. The repurchased parts were the gears to change the material from a lighter aluminum to a sturdier cold rolled steel and the battery, as the battery originally purchased was defective. The parts needing to be reprinted were the differential box and the gearbox, however, the student was not charged for any of the 3D print reprints. Additionally, there is a part in which the students added that was not a part of the original design, and that would be the bearings for the gearbox. The gearbox encountered an issue of melting from the friction of the shafts, so the students added bearings to eliminate this issue. The total for all these parts being repurchased was approximately $80 for a new battery, gear set, and bevel.

b. Outsourcing

All assemblies and processes are currently planned on being completed by the students, however, if need be, the student will draw from the contingency fund for outsourcing.

c. Labor

The student accounts for cost of labor in the total budget of the project, even though the student will not be paid for work on this project. This is to simulate an industry standard like project proposal that will include labor costs. So, the student used the national every level engineering wage of $28/hr for 12hr/week, accounting for 6hrs in class and 6 hours out of class, and for 10weeks/quarter for three quarters. This amounted to a total cost of labor for a project of this magnitude to be $10,080.

d. Estimated Total Project Cost

There are a few major project cost totals being 3D printed parts, ordered parts, labor costs, equipment/space fees and the contingency fund. The 3D printed part cost is very cheap as the cost of filament is $20/kg and the student only plans on using around 200-250g worth of filament. For ordered parts, the students have set aside $200 for each side of the project for both steering and drivetrain, as well as chassis and suspension. Parts cost also considers taxes, shipping, and handling fees for the parts being ordered. Labor cost is considered, however, the students will not be paid for this project, it is used more as a theoretical project cost that would normally be considered, and so reflected in the final budget. Next, the equipment and space fees were combined, as the student pays lab fees for Central Washington University which covers both equipment and lab space. Finally, the student has set aside $100 more as a contingency fund, just in case the student must reorder parts or needs to purchase a better part. All these totals amount to a total estimated project cost of $10,510, however, taking away the labor cost would amount to an actual budget of $410 for the steering and drivetrain. The project budget can be viewed in Appendix D (Table D1).

The student will end up spending more money than originally calculated for the project. There was an increase in funding for 3D printed parts, once the student learned of the cost of 3D printing from $5 to $25. Moreover, the student did not factor the cost of some items needed for the completion of the RC Baja car, like the controller. However, the cost may not be associated with the steering and drivetrain and might be covered by the student's teammate to include with the chassis and suspension total. However, the price for the steering and drivetrain was undercalculated, so the student will have to use some reserve funds.

e. Funding Source

This project will be supported and financed by the students themselves.

6. Schedule

a. Design

The fall quarter schedule covers the project proposal, analysis, and documentation tasks for the RC Baja project, which is annotated in the Gantt chart as sections 1-3. The project schedule is constrained by the MET 489 course work and the Gantt chart can be viewed in Appendix E (Figure E1). The student fell behind due to unforeseen circumstances causing him to take time away from school and the project. The student slowly caught up to being on schedule by focusing on single missing or late tasks each week while still keeping up with the current progression of assignments for each week.

b. Construction

The winter quarter covers the construction of RC parts and construction of the RC car itself for the RC Baja project, which is annotated as section 4-5 of the Gantt chart (Figure E1). The student will be 3D printing most of the parts created, however, the shafts and steering rod will be machined, because they need to be stronger than 3D printed parts. After all the parts are made and gathered, the student will start constructing the RC car and sub-assemblies. The goal of winter quarter is to complete the construction of the RC car. The progression of winter stayed on schedule for a majority of the quarter with a few hiccups along the way. A majority of those hiccups were waiting for parts to be shipped to measure important dimensions needed for custom parts to be created then waiting on those custom parts to be 3D printed. The manufacturing process took the longest to complete due to the shear number of parts needing to be either machined or 3D printed.

c. Testing

The spring quarter covers the RC Baja project testing, deliverables, and competition, which is annotated as section 5-7 in the Gantt chart (Figure E1). The student will be testing the RC car to determine whether the car meets the project requirements the student created for the Baja car. Along with this, the student must participate and compete in the RC Baja competition, which will take place on the third Saturday of April. Then, the student must finalize the project website with videos and results from the test data recorded. Finally, the student will submit all the gather and organize the test results to be submitted as a final project deliverable at the end of the quarter. The student fell behind in testing due to many of the parts needing dimension updates or needing to be recreated due to either breaking or not functioning optimally. The student fixed these issues by changing the material of the parts that broke to stronger materials, and adjusting the sizing on parts that did not function optimally. A majority of these problems were located in either the differential or gearbox, because of the difficulty found in making the torque streamline through the entire drivetrain.

7. Project Management

With any project comes risk, for the RC Baja project the most important risk will be in the financial resources and human resources. This is due to the students needing to purchase their own parts, since there is no project sponsor. The project is also dependent on two students to complete, so they must be able to find time to work together to achieve a successful product. The students must use their project management skills to control the risks by scheduling and setting boundaries in which they plan to uphold. This project will succeed due to the availability of appropriate technical expertise and resources that the students have access to.

a. Human Resources

The principal engineer will provide expertise in steering and drivetrain of for the RC Baja car and their resume can be viewed in Appendix H. The second principal engineer is the student's partner who will provide expertise in chassis and suspension. The associated risk to a group project is that student's will not be able to work together throughout the entire project and will only have a limited time to work together. However, the access and communication between partners is eases some of the burden from not being able to work together the whole time.

b. Physical Resources

This project will require many tools and machines for the completion of the project. These tools and machines include, but may not be limited to: 3D printer, belt sander, screw drivers, drills, allen wrenches, plyers, tables, and lab facilities. The risk associated with the use of these tools is that most belong to the school, so the students will have to be in Hogue Hall to use these tools and machines. So, access and available time will be limited for the use of these tools and machines for not only this reason, but also because many students will also be working on their projects simultaneously. This may make the project run longer than it should, however, to combat this, the students can use their own resources at home, when possible, to stay on track.

c. Soft Resources

The students use software programs such as Solidworks and Microsoft Office to create parts and develop their project. These programs are subject to updates, computer crashes, and software malfunction through the data transfer between devices. The students, however, have access to all software at home, so access is readily available to them. But some students have trouble due to the possibility of running a different version of the program at home compared to when they are in Hogue, which may corrupt files.

d. Financial Resources

The students are responsible for any purchases they make and are reliant upon themselves for providing funds. However, the equipment is supplied by the school in which the students may use to complete their project. If the students go over budget, it is on them to cover the cost of whatever they may need, but students can combat this by using parts from previous projects if available.

8. DISCUSSION

a. Design

The quarter began with the student finding a partner to participate in the RC Baja senior project with. The student originally preferred to do the chassis and suspension, however, due to the circumstances and due to the current level of knowledge of the students, it was decided that the drivetrain and steering was the best challenge for the student to pursue. This is because, the student had more knowledge in the realm of electronics and programming that would be important for completing the steering and drivetrain when constructing the car.

As the quarter went on, the student encountered a death in the family, which caused the student to take time away from school and fall behind in work. So, the whole quarter, the student was forced to play catch up and was always a couple steps behind of where the project should be. However, the student was able to get the help necessary to keep up with the constant work the project demanded.

Then around week 5-6 the student was informed that the analyses had to be related to the requirements, which was unknown to many of the students prior. So, the student was forced to redo and edit a majority of the analyses the student had already solved to relate to the requirements the RC car must meet. At this point, eight analyses were already made and solved, but after hearing this the student had to omit two analyses and edit the remaining six.

Around this same time the student was deciding which parts to use in the steering system and originally chose to design a steering system that connected the servo to a gear rack. However, the student and partner decided to use a servo and servo horn system to control the steering for the RC car, because it would save space and fit on the chassis.

b. Construction

The first couple of weeks the student began ordering the essential RC parts, which included the motor, battery, servo, and wheels. These parts are essential to the RC car, while also being the parts that determine the dimensions of gear boxes and shaft sizes. So, the student will need these parts to begin designing the shafts for the drivetrain and choose the correct gears that will fit the shafts.

Once the student was confident in the dimensions of the motor and wheels, the student began 3D printing parts to fit the given dimensions. The motor mount was the first of which to be printed, next will be the differential box, then the gear box when the student is confident in the sizing of the gears being used. This should happen early on in the quarter beginning within the first few weeks and should finish by week 5 to give enough time to assemble the RC car.

The next step will be lathing the shafts for the drivetrain to the correct sizes. There will be more than a single dimension for the entire drivetrain, as the diameter for the differential is different than that of the diameter of the motor shaft and the wheels. This will happen in weeks 5-7 when the student attains the gears, differential yoke, and the wheels. The student had trouble machining the driveshaft not having considered the small dimensions would encounter significant bending while being lathed. To combat this problem, the student decided to cut a rod a few inches longer than necessary, then cut the size needed after completing the lathe.

Once all these parts are created, purchased, and gathered, the student will begin assembling the RC Baja car. This should begin in week 8 and run till the very end of the quarter where it will be completed. Finally, once the majority of the RC Baja car is completed the student will have to laser print or plasma cut the steering rod to complete the assembly.

To keep the assembly as smooth running as possible, the student allowed the group partner to assemble the chassis first, then all of the drivetrain and steering assemblies were added to the chassis. This was also a very necessary process in order to place the mounting holes in the correct position on the chassis in order for everything to fit properly on the chassis. Meanwhile, the student is assembling the drivetrain parts in the order they appear in Section B to mount these sub-assemblies together when being mounted to the chassis.

c. Testing

Spring quarter began with the students adjusting and improving on the design constructed in the winter. The main focus for improvement was the drivetrain, because while preparing for the functionality presentation, the gears in the gearbox stripped and the bevel on the axil broke. So, the student switched out the aluminum gears for cold rolled steel gears for more durability. The change in gears also meant the student had to redesign the gearbox to incorporate the change of sizing for the gears, however, the gear ratio stayed the same. The bevel was swapped out and a part was designed to attach to the bevel and mount to the axil, to better provide torque from the differential to the axil. These redesigns took a while to print, which caused a lot of time to be spent making these necessary adjustments. The RC car is now competition ready after these adjustments, and the students expect a good showing at RC Baja.

The student then tested the turn radius test first, as it was the simplest to set up and required the least amount of strain on the RC car, because the students wanted to ensure a functioning car for the RC Baja competition. The measurements for this test were turn diameter, turn radius, and deviation from the starting position. The student then used the turn radius and measured the wheelbase to calculate the turn angle in an Excel document. The student kept test results in the engineering notebook for the project, for ease of access and later entered data collected into a singular Excel file that all the test results were kept in.

The student then tested the wattage and torque output of the RC car. This required the RC car to be suspended off the ground and ran at full speed to get the most accurate calculations. Unfortunately, the student did not have a means of measuring wattage or torque output directly, so the student had to use a digital multimeter to measure the voltage and current to calculate power in watts. Then using the calculated wattage output, the student also calculated torque output, similar to what was done in Analysis 1 and 2 (Appendix A-1 and A-2).

While the student waited on parts to be 3D printed and redesigned, the student took the time to record the construction of the RC Baja car, because the construction was unable to be recorded last quarter due to time restraints. These videos along with pictures of the construction were then uploaded to the student’s senior project website.

The gearbox-to-differential shaft sheared off during the RC Baja competition, so the student had to machine a new shaft. In this iteration, the student decided to machine the shaft out of a steel screw, because the previous shaft bent too easily. The screw was lathed close to the diameter needed, then filed down to a small enough diameter for the gear to easily go onto the shaft. Finally, the student grinded down two flats on the greater diameter to fit into the differential and drilled a hole through the flat to fit a pin into and filed a single flat onto the lesser diameter to fasten the gear to the shaft.

An additional critique added to the gearbox design, was the student purchased bearings to minimize friction against the plastic gearbox, which was causing the gearbox to melt. So, the student incorporated the outer diameter of the bearing into the gearbox to alleviate friction from the gearbox. This change called for a reprint of the gearbox to incorporate these design changes, and the middle wall still carries the same shaft diameters, the outer walls carry the diameter of the bearings.

9. CONCLUSION

This project is to create an RC Baja car to compete in the RC Baja competition. The RC Baja project steering and drivetrain is designed to provide locomotion and maneuverability to the chassis. The student has provided analysis to describe the capability of the RC Baja car and chose parts that will exceed the requirement expectations. The student used gear train analysis, mechanical design, and physics to determine the RC car's top speed. The top speed is documented to exceed expectation by a substantial margin, as the required top speed is 15mph compared to the documented speed of 50.7mph. Which will not only allow the car to complete a majority if not all the obstacles the Baja race will provide but allow the RC car to be a serious competitor in the competition. Similarly, student used mechanics of materials and strengths of materials to determine a factor of safety for the drive shaft. The factor of safety requirement will be exceeded by a significant margin, as it is only required that the drive shaft factor of safety be 5, but the documented factor of safety is 94 meaning the drivetrain is in no danger of fracturing or failing (Analysis in Appendix A). The student has compiled a parts list that is within budget for the project, and the student is given the resources needed to complete the project through the use of space and equipment provided by Central Washington University. The RC Baja car is now fully designed and ready for construction.

10. ACKNOWLEDGEMENTS

Special thanks to key mentors, Professor Pringle and Dr. Choi, for advice and assistance to the students in the creation of this project. The professors mentored the principal engineer throughout the duration of the project and could not be thanked enough for their contributions to the success of the RC Baja project.

References

Project advisors and contributors:

- Professor Pringle: Project Instructor
- Dr. Choi: Project Instructor
- Professor Berkshire: Project Mentor/Shop specialist
- Caden Foster: Project Partner

APPENDIX A - Analysis

Appendix A-1 – Motor Output

Pablo Ruelas	MET 489	October 9, 2021	1/12

Analysis 1: Motor Output

Given: Requirement - Motor output ≥ 400W

Onyx Brushless Motor 4000 Kv : 3.5mm Bullet

$K_{v\,rated}$ = 4000Kv

Idle current = 1.5A

Max continuous current = 70A

Avg Voltage = 7.2V

Output = 290W

Find: Actual Power of motor

Actual Power output

Assume: η_{motor} = 90%

Method: 1) $P = IV$

2) $\eta = \frac{P_{actual}}{P_{theoretical}}$

Solution

Power from Motor:

$P = IV$

$P = (70A - 1.5A)(7.2V)$

$\boxed{P_{motor} = 493.2W}$

Actual Power Output

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

$P_{actual} = \eta \cdot P_{motor} = (.90)(493.2W)$

$\boxed{P_{actual} = 444W}$

tolerance: ±5W

Appendix A-2 – Motor Torque

Pablo Ruelas | MET 489 | October 8, 2021 | 2/12

Analysis 2: Motor Torque

Given: Requirement – Motor Torque ≥ 1.0 lb·in
Onyx Brushless Motor 4000Kv: 3.5mm Bullet
Avg Voltage = 7.2V
P_{total} = 444 W
K_v = 4000 Kv

Find: Motor RPM
torque of Motor

Assume: Neglect loss of energy to system

Method: 1) Solve for RPM
2) Solve for torque

Solution:

RPM of Motor

$$RPM = K_v \cdot Voltage = (4000 K_v)(7.2V)$$

$$\boxed{RPM = 28{,}800 \text{ rpm}}$$

tolerance ± 5%

Torque from Motor

$$\tau_{motor} = \frac{P}{RPM} = \frac{444\,W}{28{,}800\,rpm}\left(\frac{1\,rev}{2\pi}\right)\left(\frac{60\,sec}{1\,min}\right)\left(\frac{1\,J}{1\,W}\right)\left(\frac{1\,N{\cdot}m}{1\,J}\right)\left(\frac{8.85\,lb{\cdot}in}{1\,N{\cdot}m}\right)$$

$$\boxed{\tau_{motor} = 1.30 \text{ lb·in}}$$

tolerance ± .05 lb·in

Appendix A-3 – Top Speed

Pablo Ruelas	MET 489	October 8, 2021	3/12

Analysis 3: Top Speed

Given: Requirement – Top Speed ≥ 15 mph
Requirement – Gear Ratio = 8:1
Onyx Brushless Motor 4000 Kv : 3.5 mm Bullet
1:10 Monster Truck Tires
RPM = 28,800 rpm
OD tire = 4.76 in

Find: Wheel RPM
Top Speed

Assume: Recommended gear ratio 8:1
Neglect loss of energy to system
Constant RPM
Neglect friction / drag / weight

Method: 1) RPM to Wheels
2) Distance per rev
3) Top Speed

Solution:

RPM to Wheels

$$RPM_{out} = \frac{RPM_{in}}{\text{Gear Ratio}} = \frac{28{,}800\ rpm}{8} \Rightarrow \boxed{RPM_{out} = 3600\ rpm}$$

tolerance: ± 5%

Distance per Rev

$$1\ rev = \pi d = \pi (4.76\ in)$$

$$1\ rev = 14.95\ in \left(\frac{1\ ft}{12\ in}\right)\left(\frac{1\ mi}{5280\ ft}\right) \Rightarrow \boxed{1\ rev = 236 \times 10^{-6}\ mi}$$

tolerance ± 5%

Top Speed

$$V_{max} = \frac{\Delta x}{\Delta t} = \frac{(3{,}600\ rev)(236 \times 10^{-6}\ mi)}{1\ min}\left(\frac{60\ min}{1\ hr}\right)$$

$$\boxed{V_{max} = 51\ mph}$$

tolerance: ± 5 mph

Appendix A-4 – Gear Train

Pablo Ruelas	MET 484	October 13, 2021	4/16

Analysis 4: Gear Train

Given: Bevel Gear 38T/13T : AXIC 0395

$N_{B1} = 13T$

$N_{B2} = 38T$

Requirement – Gear Ratio = 8:1

Find: Gear Ratios

Gear Teeth Numbers

Assume: All Gears 20 DP

Neglect loss of energy to system / Gear Slips

Assume 2 Ratios in Gear Box

Method: 1) VR Differential

2) VR Gear Box

3) Number of Teeth possibilities

Solution:

VR Differential

$$VR = \frac{N_G}{N_P} = \frac{N_{B2}}{N_{B1}} = \frac{38T}{13T} \Rightarrow \boxed{VR_{Dif} = 2.92}$$ tolerance ± .05

VR Gear Box

$$TV = 8 = (VR_{GB})(VR_{Dif})$$

$$VR_{GB} = \frac{TV}{VR_{Dif}} = \frac{8}{2.92}$$

$\boxed{VR_{GB} = 2.74}$ tolerance: ± .05

Number of Teeth Possibilities

$$VR_{GB} = 2.74 = \left(\frac{N_G}{N_P}\right)\left(\frac{N_G}{N_P}\right) = \left(\frac{N_G}{N_P}\right)^2$$

$$\left(\frac{N_G}{N_P}\right) = 1.66$$

Option 1: (31T/18T)(32T/20T) = 2.76 (2.92) = 8.05

Option 2: (37T/22T)(36T/22T) = 2.76(2.92) = 8.04

Option 3: (42T/24T)(39T/25T) = 2.73(2.92) = 7.98

tolerance: ± 5%

Appendix A-5 – Drive Shaft Factor of Safety

Pablo Ruelas | MET 489 | October 26, 2021 | 5/12

Analysis 5: Drive Shaft Factor of Safety

Given: Requirement – F.S ≥ 5
6061-T6 Aluminum
Diameter of Shaft = 8mm
$\tau_{motor} = 1.30$ lb·in

Find: Yield Strength in Shear
Factor of Safety

Assume: $\sigma_{yield} = 276$ MPa (Mat-web)
Homogenous Material
Solid Shaft

Method: 1) Convert τ to N·m
2) Yield Strength in Shear
3) Max torque
4) F.S

Solution:

Convert to Nm

$$1.30\,\text{lb in}\left(\frac{1\,\text{Nm}}{8.85\,\text{lb in}}\right) = \boxed{.147\,\text{Nm}}$$ tolerance: ± 5%

Yield Strength in Shear

$$S_{ys} = S_y/2 = 276\,\text{MPa}/2 \Rightarrow \boxed{S_{ys} = 138\,\text{MPa}}$$ tolerance: ± 5MPa

Max Torque

$$\tau_{max} = \frac{T}{Z_p} \qquad \text{Appendix 1, p.782} \qquad Z_p = \frac{\pi D^3}{16}$$

$$T = \tau_{max}\left(\frac{\pi D^3}{16}\right)$$

$$T = (138\times10^6\,\text{Pa})\left(\frac{\pi(.008)^3}{16}\right)$$

$$\boxed{T = 13.87\,\text{Nm}}$$ tolerance: ± 5%

Factor of Safety

$$F.S = \frac{T_{max}}{T_{actual}} = \frac{13.87\,\text{Nm}}{.147\,\text{Nm}}$$

$$\boxed{F.S = 94}$$ tolerance: ±5%

Appendix A-6 – Turn Angle

Pablo Ruelas	MET 489	November 4, 2021	6/12

Analysis 6: Turn Angle

Given: Requirement – Turn Radius < 5ft
MG995 RC Servo
Wheel Base = 14 in
Maximum Turn Radius = 5ft or 60 in

Find: Turn Angle of Front Wheels

Assume: Neglect Slippage
Rear wheel drive / Front wheel steering
Flat ground

Method: 1) Turn Radius
2) Min Turn Angle

Solution:

Turn Radius

$$R = \frac{WB}{\sin(TR)}$$

$$\sin(TA) = \frac{WB}{R}$$

$$TA = \sin^{-1}\left(\frac{14in}{60in}\right)$$

Min Turn Angle = 13.5° Tolerance ± 1°

Appendix A-7 – Wheel Deflection

Pablo Ruelas	MET 489	November 22, 2021	7/12

Analysis 7: Wheel Deflection

Given: Requirement - Turn Radius < 5ft
Losi Super Baja Rey Front Spindle Set
PAR-20-010 Rod-Steering
Minimum deflection = 13.5°

Find: Minimum Wheel Deflection

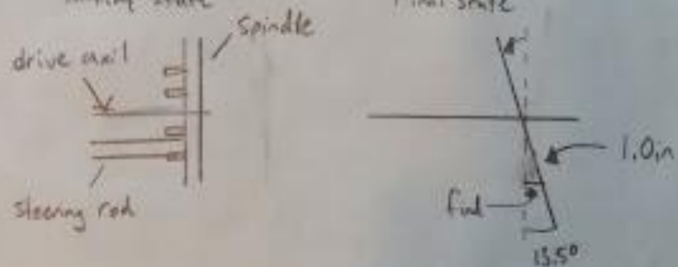
Assume: Distance from center of Spindle to Steering Rod
$r = 1.0$ in
Neglect slip

Method: 1) Picture
2) Deflection

Solution:

Picture:

initial state / Final state



Deflection

$$\sin\theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$\sin(13.5^\circ) = \frac{\text{Minimum Deflection}}{1.0\text{in}}$$

$$(1.0\text{in})\sin(13.5^\circ) = \text{Minimum Deflection}$$

Minimum Deflection = .233 in

tolerance: ± 5%

Appendix A-8 – Servo Horn Deflection

Pablo Ruelas | MET 489 | November 22, 2021 | 8/12

Analysis 8: Servo Horn Deflection

Given: Requirement – Turn Radius < 5ft
MG995 RC Servo
Max angle of twist = 180°
PAR-55-012 Servo-Horn
Minimum wheel Deflection = .233 in (From Analysis 7)

Find: Minimum deflection Angle

Assume: $r_{su} = .5$, Radius of center to Steering Rod
Neglect Slip
Start position of steering rods; starting with respect to the positive x-axis, = π/4 + 3π/4

Method: 1) Picture
2) Angle of Deflection

Solution:

Picture

Starting Position

Minimum Deflection Position

Drawing

Solve for θ
using the law of cosines
for an isosceles triangle

$$\theta = \cos^{-1}\left(1 - \frac{c^2}{2a^2}\right)$$

$$\theta = \cos^{-1}\left(1 - \frac{(.233\text{in})^2}{2(.5\text{in})^2}\right)$$

θ = 26.95° minimum Servo Horn Deflection

tolerance: ± .5°

Appendix A-9 – Motor Power Usage

Pablo Ruelas	MET 489	November 24, 2021	9/12

Analysis 9: Motor Power Usage

Given: Requirement - Battery Life > 20 min
Onyx Brushless Motor 4000 Kv
OVONIC 11.1V 2200mAh 3S 25c Lipo Battery
Avg Voltage = 7.2V
P_{motor} = 493.2W (Analysis 1)

Find: Total Wattage the battery needs to store to last 20minutes

Assume: Constant Motor Output
Neglect loss of energy
Perfect System
20minutes

Method: 1) Motor Power Usage in 20min

Solution:

Motor Power Usage

1W = 1J/s

$$\frac{1J}{1s} \times \left(\frac{60s}{1min}\right) \times 20\ min$$

= 1200 J

Min Power Needed

493.2 W (1200)

Min Power = 591840W or 592kW tolerance: ± 5%

Requirement - Run on single motor

Requirement - Run on single battery

Appendix A-10 – RC Acceleration

Pablo Ruelas | MET 489 | November 24, 2021 | 10/12

Analysis 10: RC Acceleration

Given: Requirement - Accelerate to top speed <5s
Onyx Brushless Motor 4000 Kv
Requirement - RC car < 10lbs (per Caden Foster)
RC Monster Truck Type Tires
V_f = 15mph , V_i = 0mph

Find: Minimum Acceleration
Distance needed to reach top speed

Assume: t = 5s (Requirement)
Neglect loss of energy
Constant Acceleration
Perfect System

Method: 1) Min Acceleration
2) Distance needed to reach top speed

Solution:

Min Acceleration

$$a = \frac{\Delta v}{\Delta t} \qquad \frac{15mi}{1hr} \times \left(\frac{1hr}{60min}\right)\left(\frac{1min}{60sec}\right)\left(\frac{5280ft}{1mi}\right) = 22ft/s$$

$$a = \frac{22\ ft/s}{5s}$$

$$\boxed{a = 4.4\ ft/sec^2}$$ tolerance ± 5%

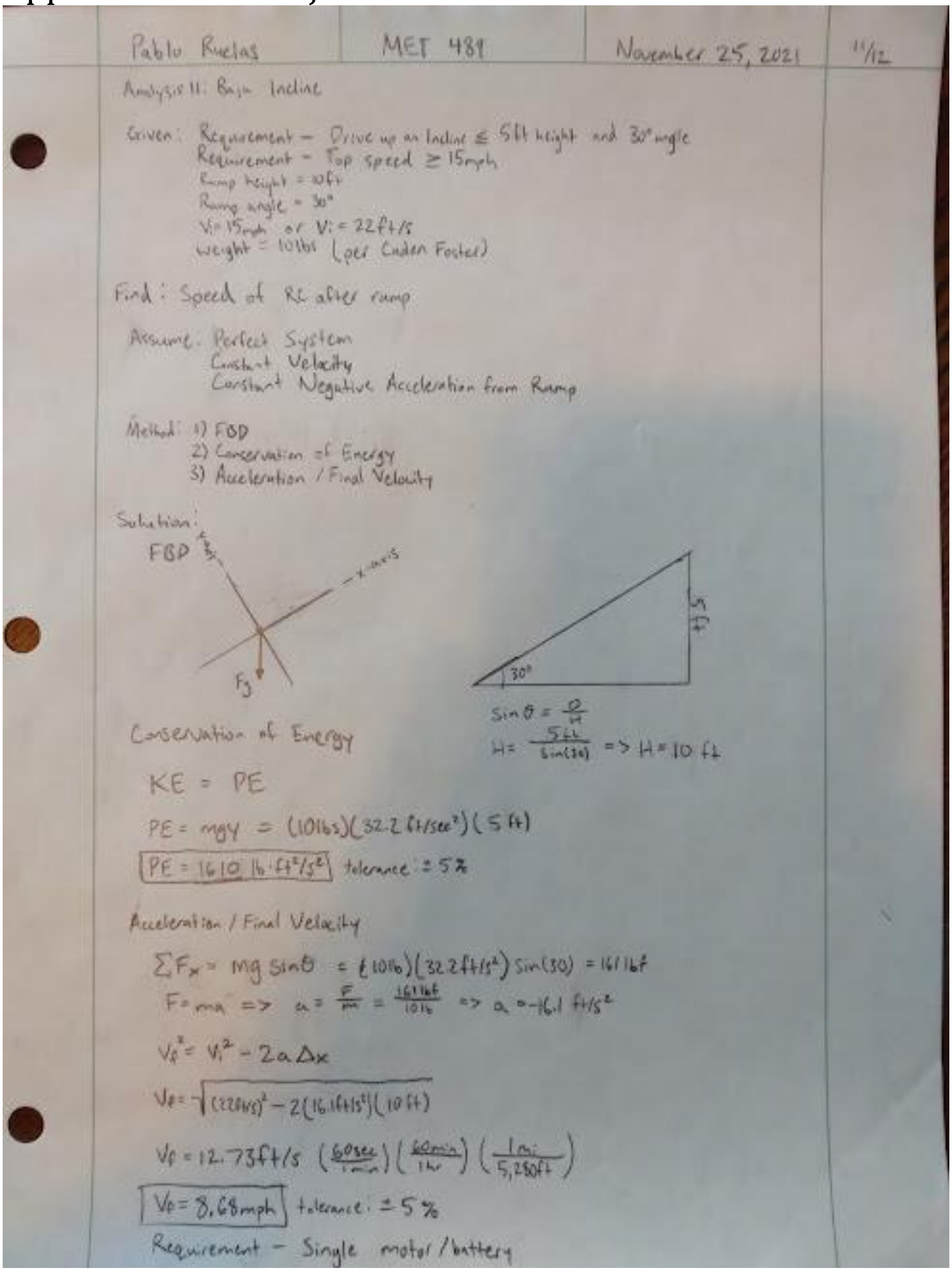
Distance Covered

$$\Delta x = \cancel{V_0 t}^{\,0} + \frac{1}{2}at^2$$

$$\Delta x = \frac{1}{2}(4.4ft/sec^2)(5sec)^2$$

$$\boxed{\Delta x = 55\ ft}$$ tolerance ± 5ft

Appendix A-11 – Baja Incline



Pablo Ruelas | MET 489 | November 25, 2021 | 11/12

Analysis 11: Baja Incline

Given: Requirement – Drive up an Incline ≤ 5ft height and 30° angle
Requirement – Top speed ≥ 15mph
Ramp height = 10ft
Ramp angle = 30°
V_i = 15mph or V_i = 22ft/s
weight = 10lbs (per Caden Foster)

Find: Speed of RC after ramp

Assume: Perfect System
Constant Velocity
Constant Negative Acceleration from Ramp

Method: 1) FBD
2) Conservation of Energy
3) Acceleration / Final Velocity

Solution:

FBD

$\sin\theta = \frac{O}{H}$

$H = \frac{5ft}{\sin(30)} \Rightarrow H = 10\ ft$

Conservation of Energy

KE = PE

$PE = mgy = (10lbs)(32.2\ ft/sec^2)(5\ ft)$

$\boxed{PE = 1610\ lb \cdot ft^2/s^2}$ tolerance: ± 5%

Acceleration / Final Velocity

$\sum F_x = mg\sin\theta = (10lb)(32.2ft/s^2)\sin(30) = 161\ lbf$

$F = ma \Rightarrow a = \frac{F}{m} = \frac{161\ lbf}{10lb} \Rightarrow a = -16.1\ ft/s^2$

$V_f^2 = V_i^2 - 2a\Delta x$

$V_f = \sqrt{(22ft/s)^2 - 2(16.1ft/s^2)(10\ ft)}$

$V_f = 12.73ft/s \left(\frac{60sec}{1min}\right)\left(\frac{60min}{1hr}\right)\left(\frac{1mi}{5{,}280ft}\right)$

$\boxed{V_f = 8.68mph}$ tolerance: ± 5%

Requirement – Single motor / battery

Appendix A-12 – Adjusted Top Speed

Pablo Ruelas | MET 489 | November 25, 2021 | 12/12

Analysis 12: Adjusted Top Speed

Given: Requirement – Top Speed ≥ 15 mph
Requirement – Gear Ratio ≈ 8:1
Requirement – Single motor/battery
Gear Ratio = 8.05 (Analysis 4)

Find: Top Speed

Assume: Neglect Slip
All Gears 20DP
Neglect loss of energy to system
1 rev = 236×10^{-6} mi (Analysis 3)

Method: 1) RPM to Wheels
2) Top Speed

Solution:

RPM to Wheels

$$RPM_{out} = \frac{RPM_{in}}{\text{Gear Ratio}} = \frac{28{,}800\ RPM}{8.05}$$

$$\boxed{RPM_{out} = 3577.6\ rpm}$$ tolerance: ±5%

Top Speed

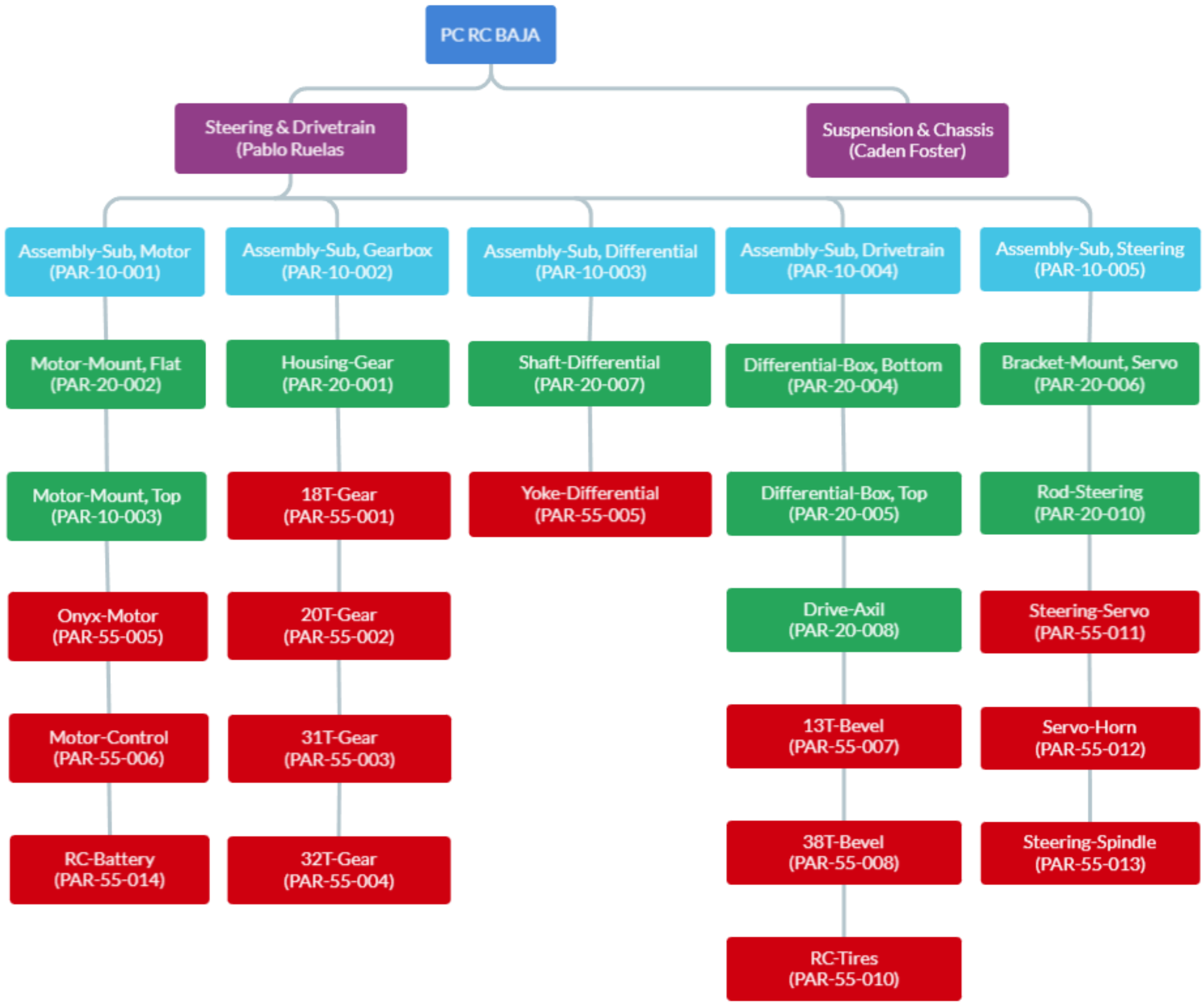
$$V_{max} = \frac{\Delta x}{\Delta t} = \frac{(3577.6\ rev)(236 \times 10^{-6}\ mi)}{1\ min}\left(\frac{60\ min}{1\ hr}\right)$$

$$\boxed{V_{max} = 50.7\ mph}$$

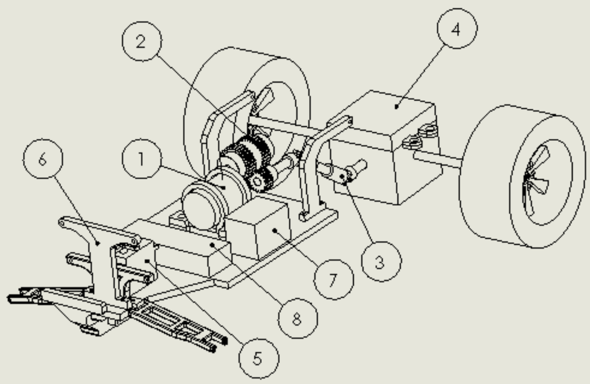
tolerance: ± 5 mph

APPENDIX B - Drawings

Appendix B-1 – Drawing Tree



Appendix B-2 – Assembly Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PAR-10-001	Assembly-Sub, Motor	1
2	PAR-10-002	Assembly-Sub, Gearbox	1
3	PAR-10-003	Assembly-Sub, Differential	1
4	PAR-10-004	Assembly-Sub, Drivetrain	1
5	PAR-10-005	Assembly-Sub, Steering	1
6	CMF-10-001	Assembly-Sub, Front	1
7	PAR-55-006	Controller-Motor	1
8	PAR-55-014	RC-Battery	1

	NAME	DATE
DRAWN	PAR	12/3/21
CHECKED	CMF	12/3/21
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Baja-Assembly

SIZE A | DWG. NO. PAR-10-007 | REV

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

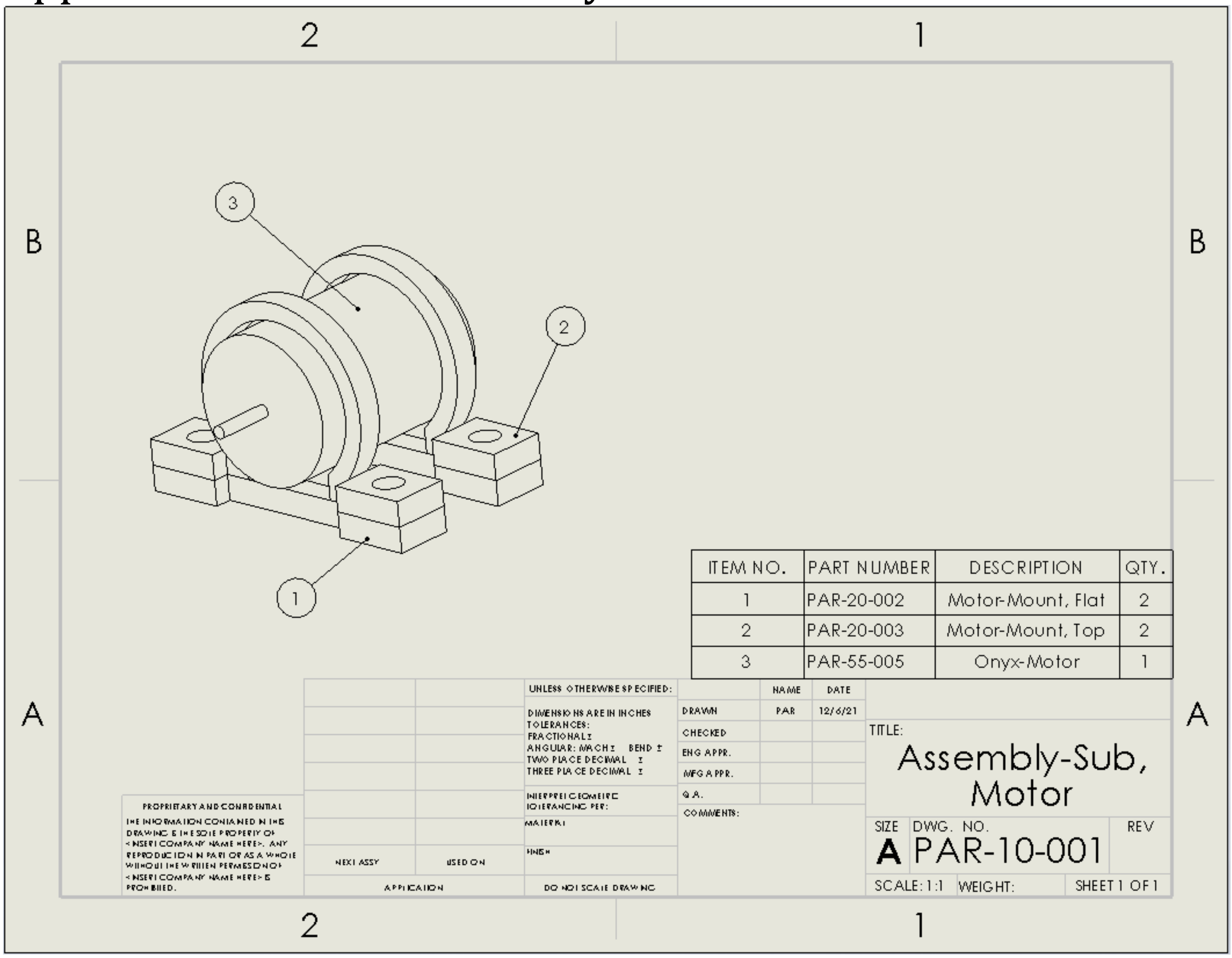
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

NEXT ASSY | USED ON
APPLICATION

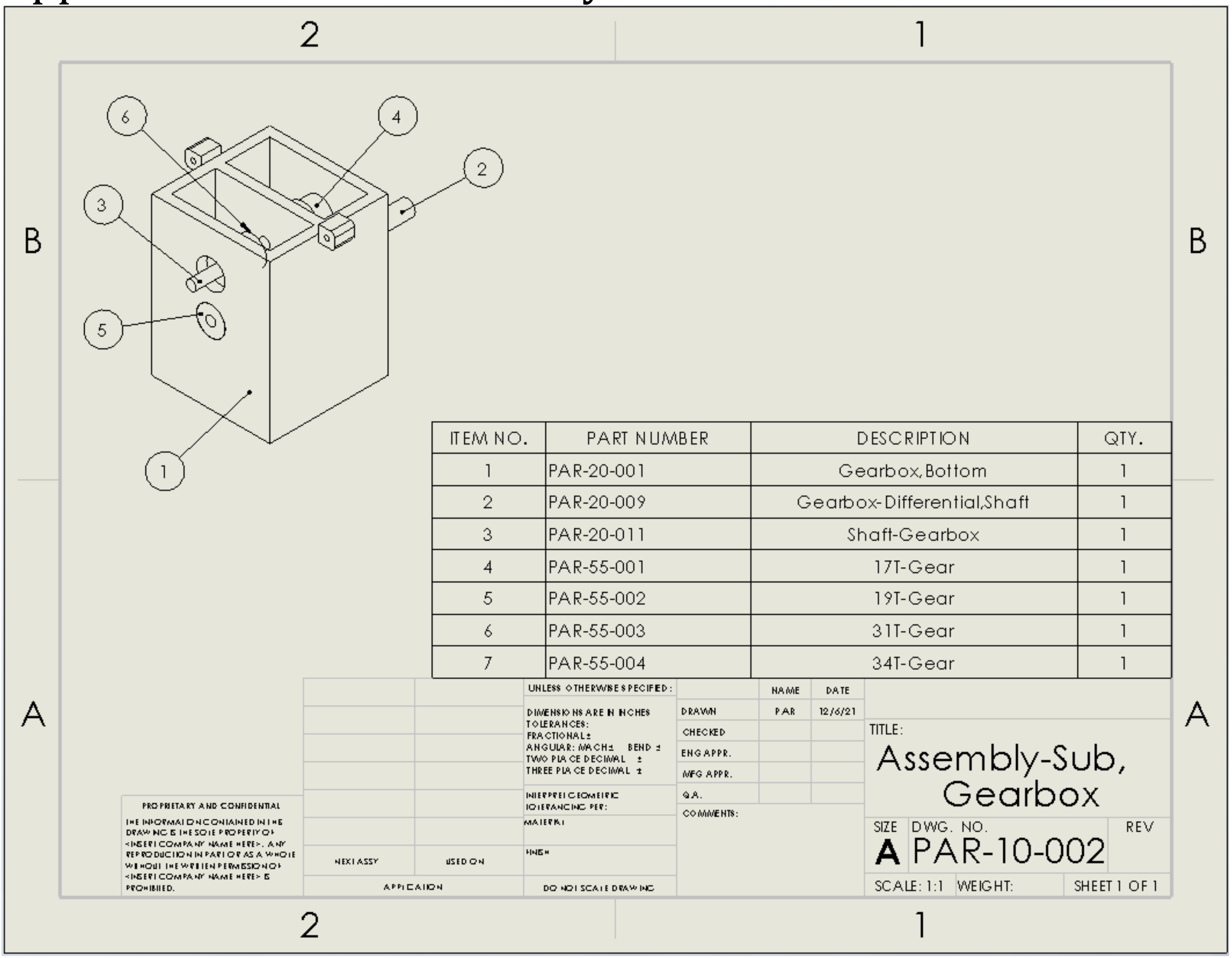
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

Appendix B-3 – Sub-Assembly Motor



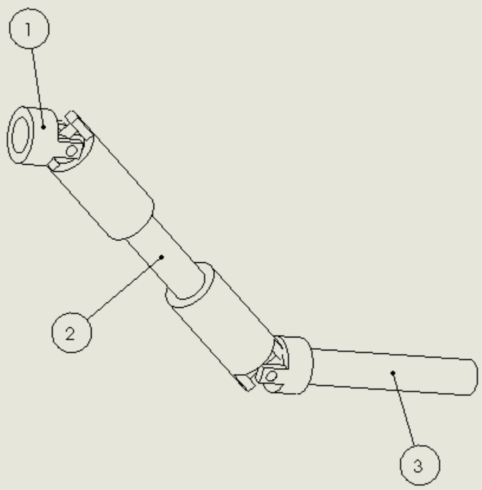
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PAR-20-002	Motor-Mount, Flat	2
2	PAR-20-003	Motor-Mount, Top	2
3	PAR-55-005	Onyx-Motor	1

Appendix B-4 – Sub-Assembly Gearbox



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PAR-20-001	Gearbox, Bottom	1
2	PAR-20-009	Gearbox-Differential, Shaft	1
3	PAR-20-011	Shaft-Gearbox	1
4	PAR-55-001	17T-Gear	1
5	PAR-55-002	19T-Gear	1
6	PAR-55-003	31T-Gear	1
7	PAR-55-004	34T-Gear	1

Appendix B-5 – Sub-Assembly Differential



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PAR-10-006	Assembly-Sub, Yoke	2
2	PAR-20-007	Shaft-Differential	1
3	PAR-20-011	Gearbox-Shaft	1

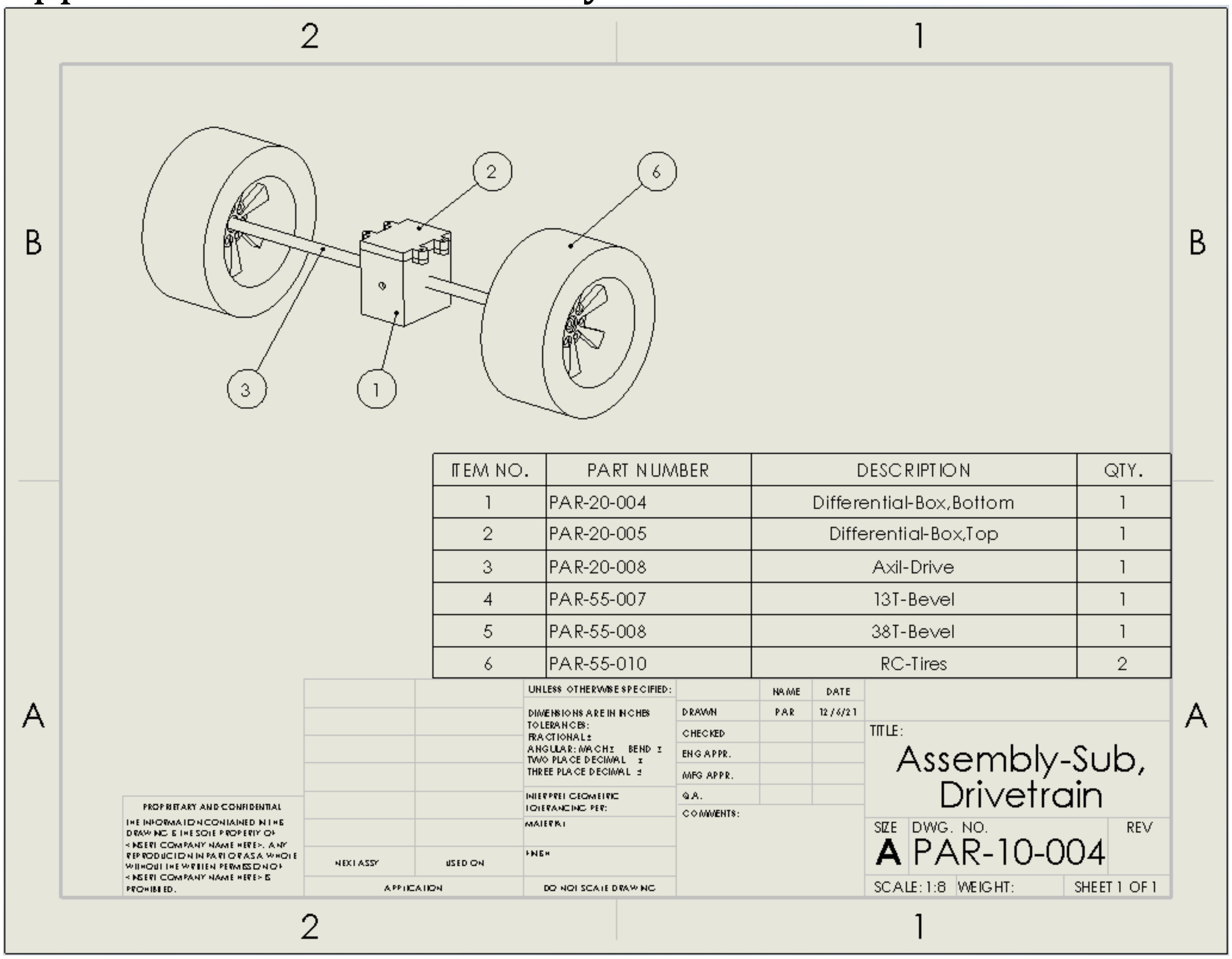
	NAME	DATE
DRAWN	PAR	12/6/21
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

TITLE: Assembly-Sub, Differential

SIZE A DWG. NO. PAR-10-003 REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

Appendix B-6 – Sub-Assembly Drivetrain

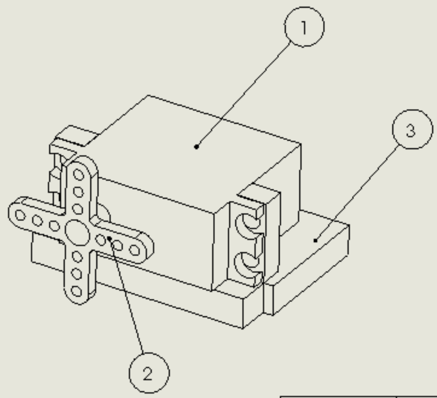


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PAR-20-004	Differential-Box,Bottom	1
2	PAR-20-005	Differential-Box,Top	1
3	PAR-20-008	Axil-Drive	1
4	PAR-55-007	13T-Bevel	1
5	PAR-55-008	38T-Bevel	1
6	PAR-55-010	RC-Tires	2

Appendix B-7 – Sub-Assembly Steering

2 1

B B



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PAR-55-011	Steering-Servo	1
2	PAR-55-012	Servo-Horn	1
3	PAR-20-006	Servo, Mount	1

A A

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	PAR	12/6/21
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE: Assembly-Sub, Steering

SIZE A DWG. NO. PAR-10-005 REV

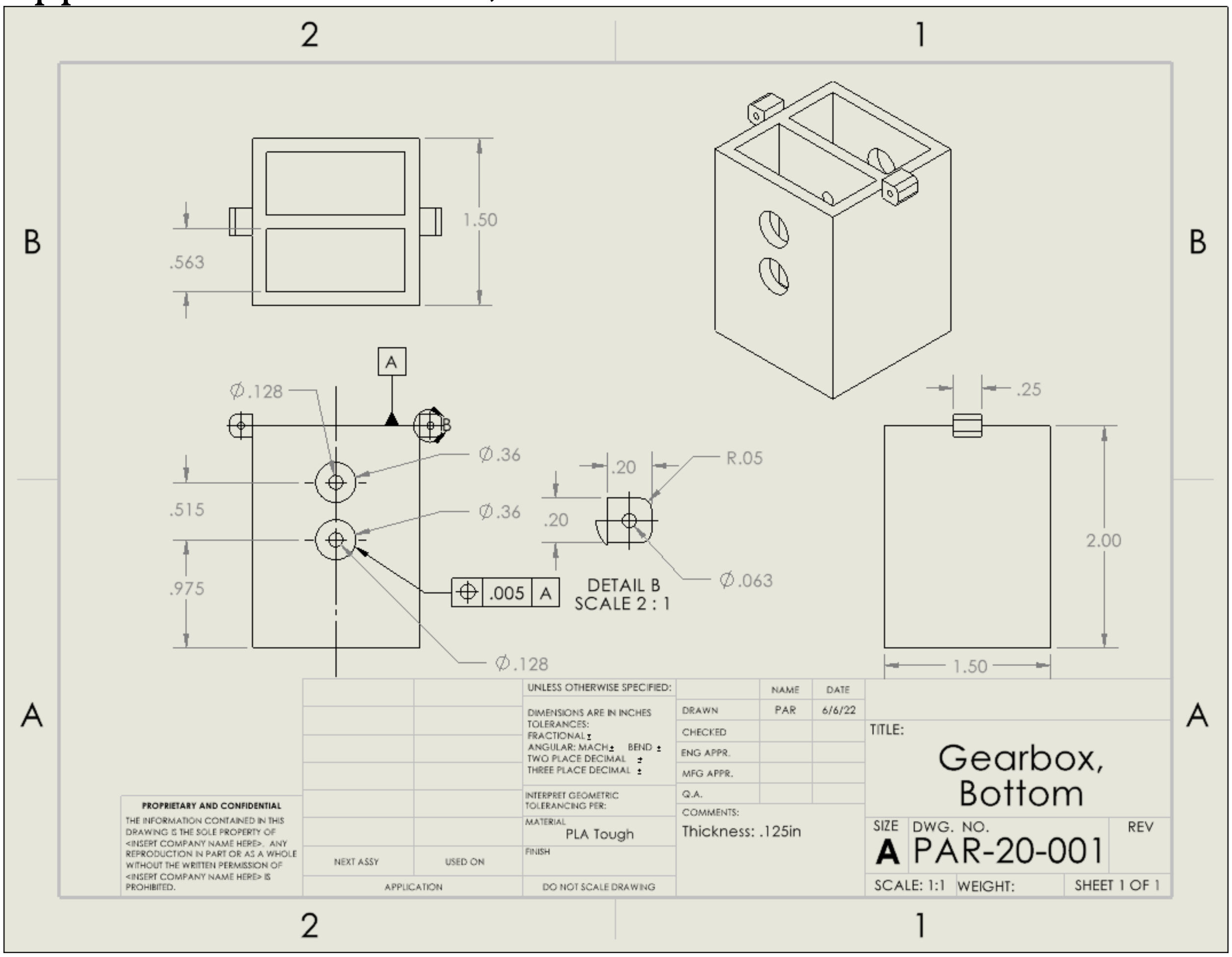
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

NEXT ASSY USED ON
APPLICATION

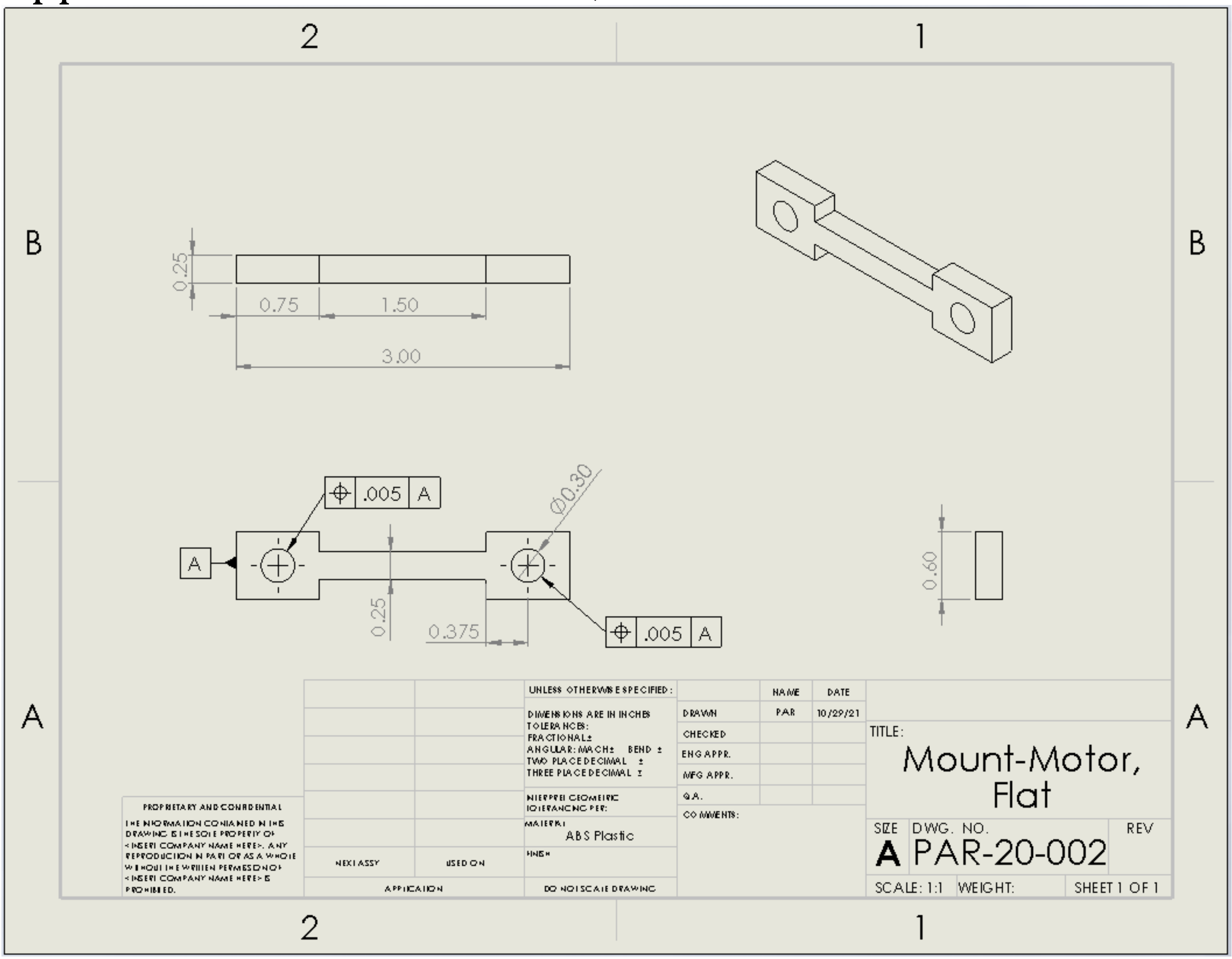
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

2 1

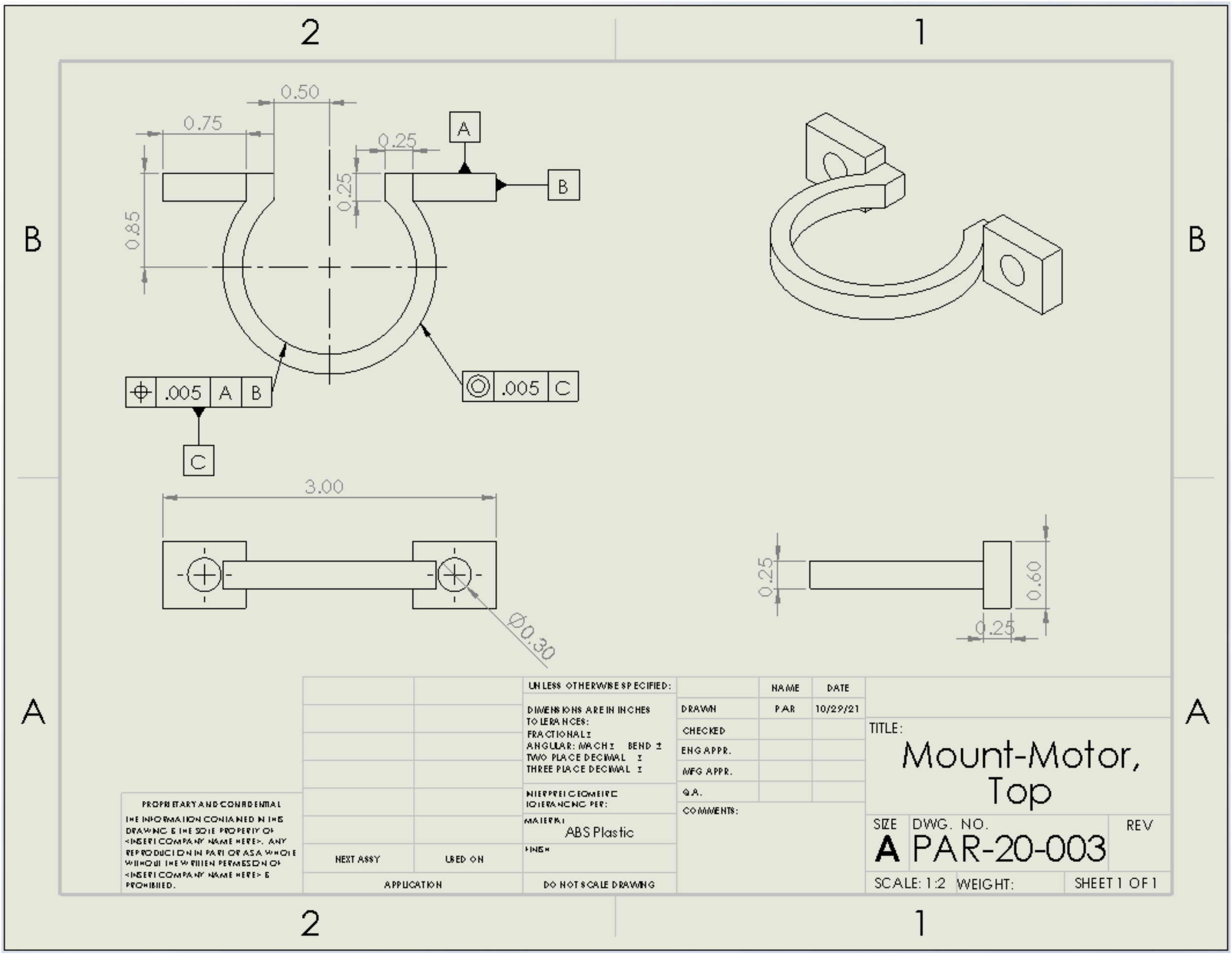
Appendix B-8 – Gearbox, Bottom



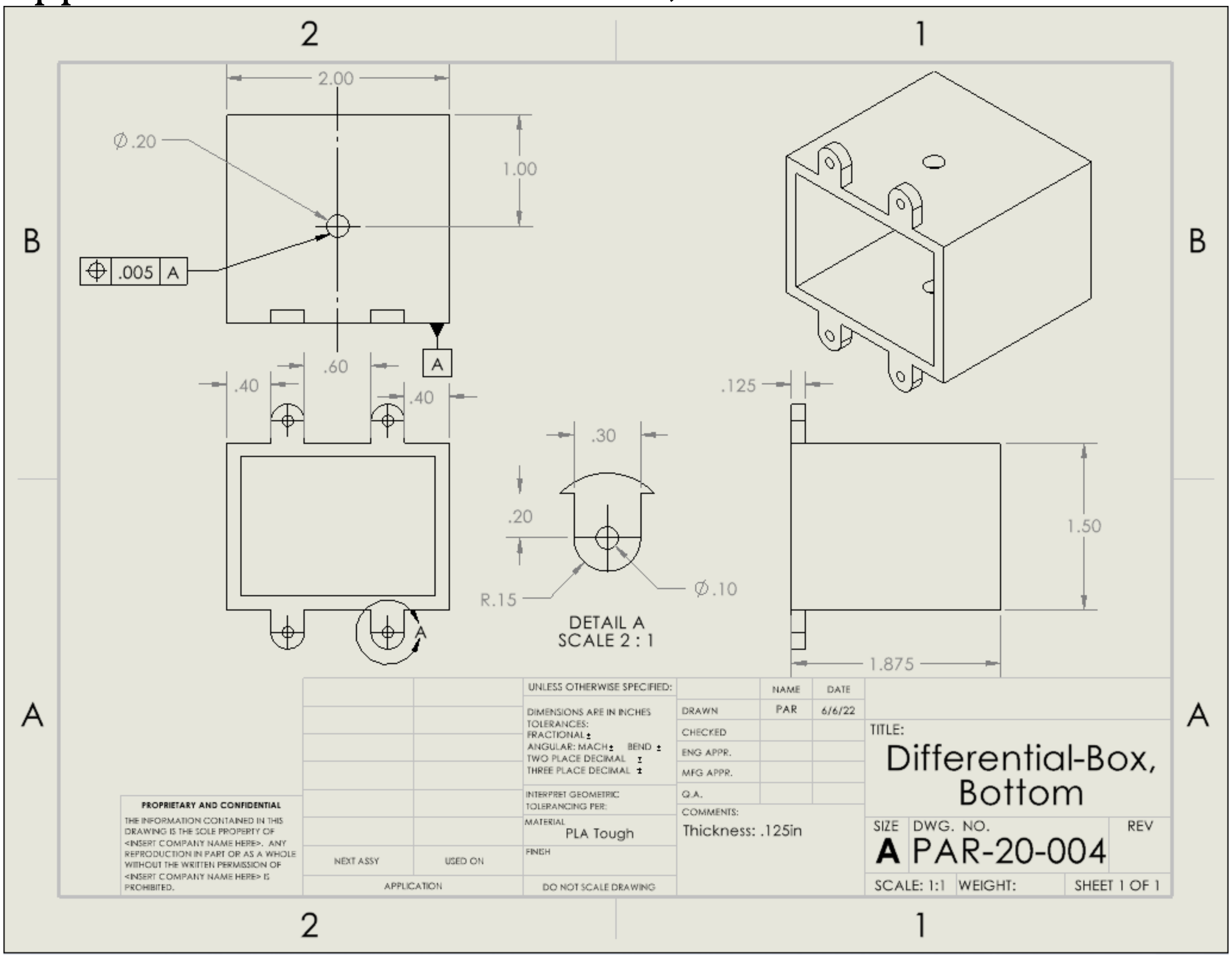
Appendix B-9 – Mount-Motor, Flat



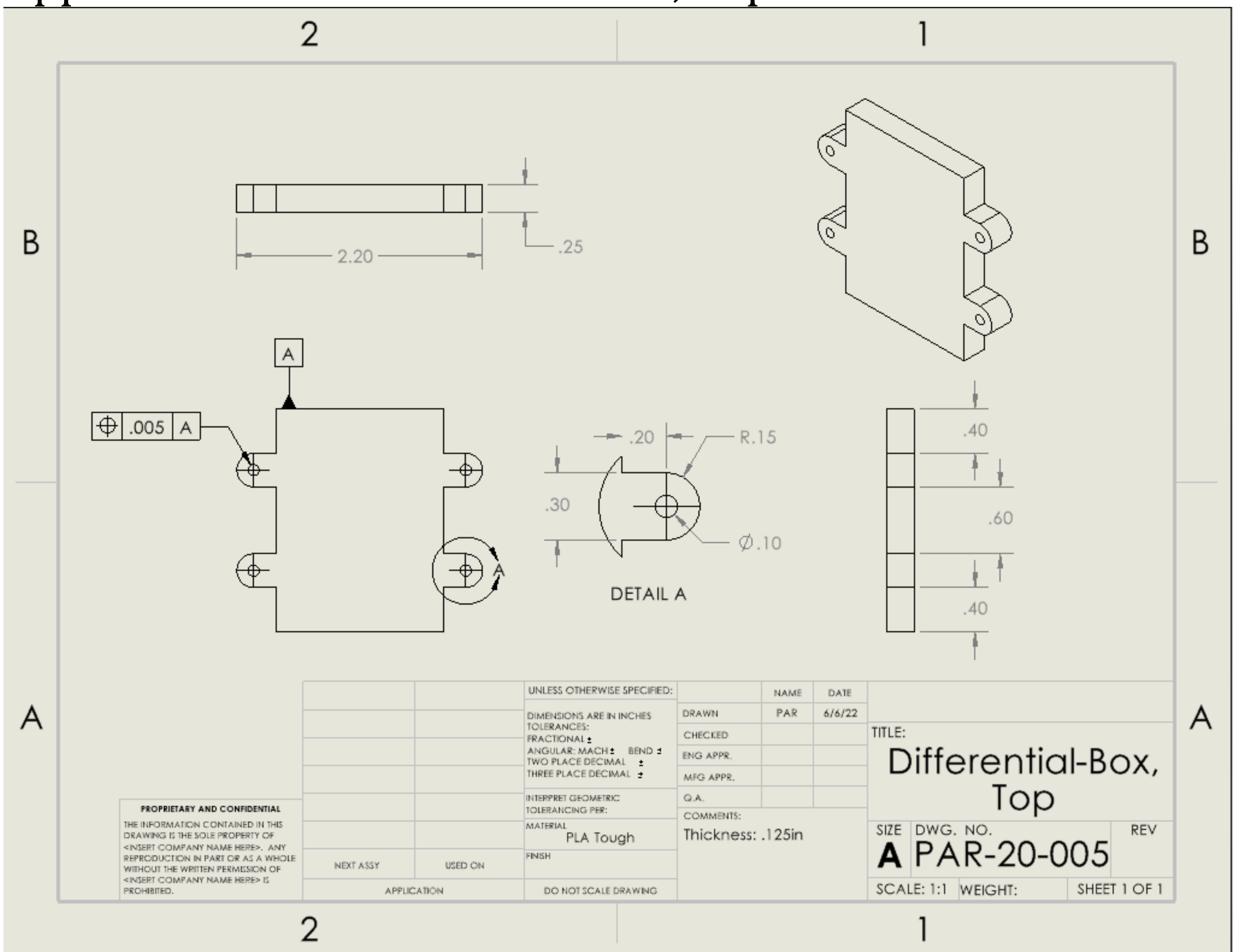
Appendix B-10 – Mount-Motor, Top



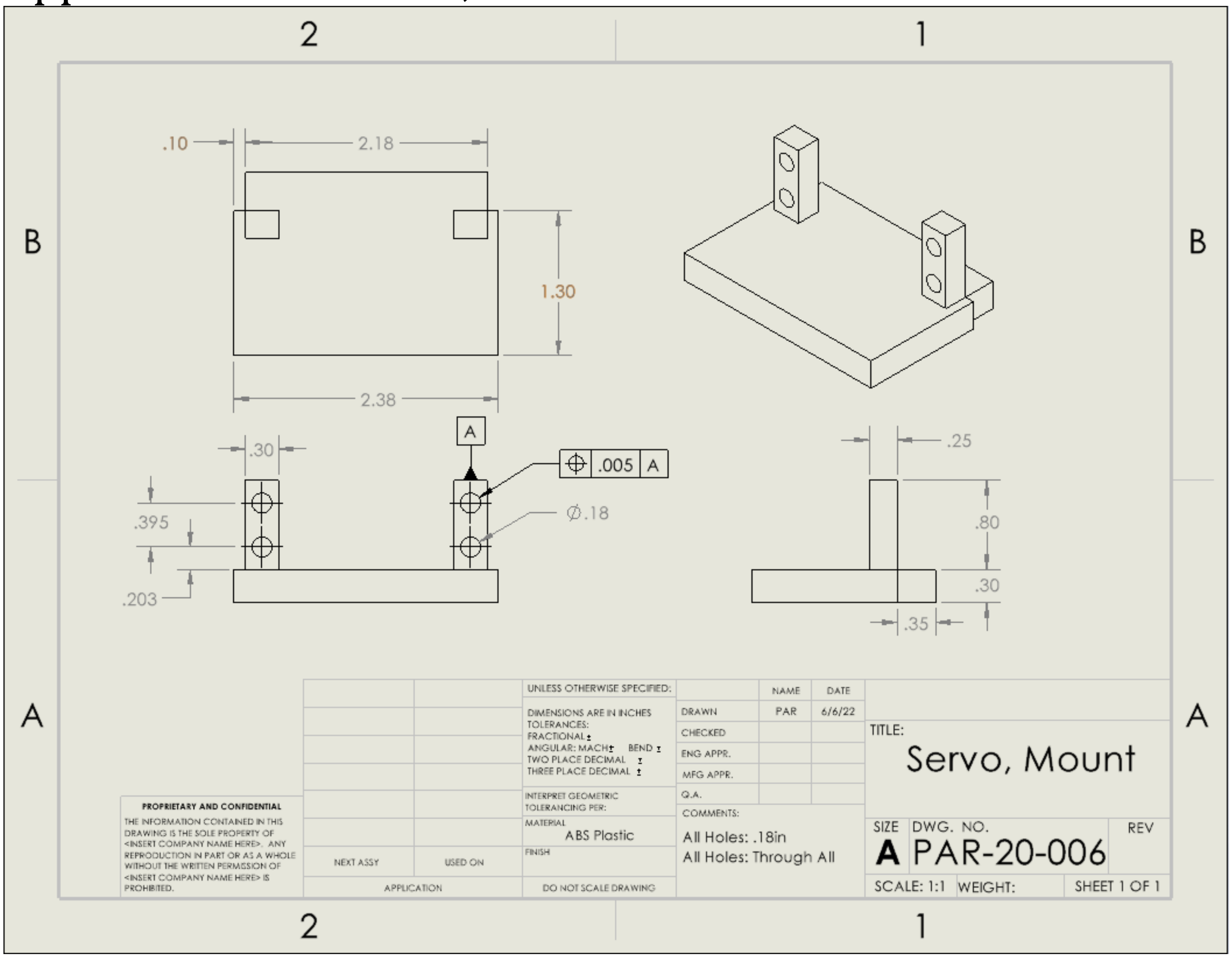
Appendix B-11 – Differential-Box, Bottom



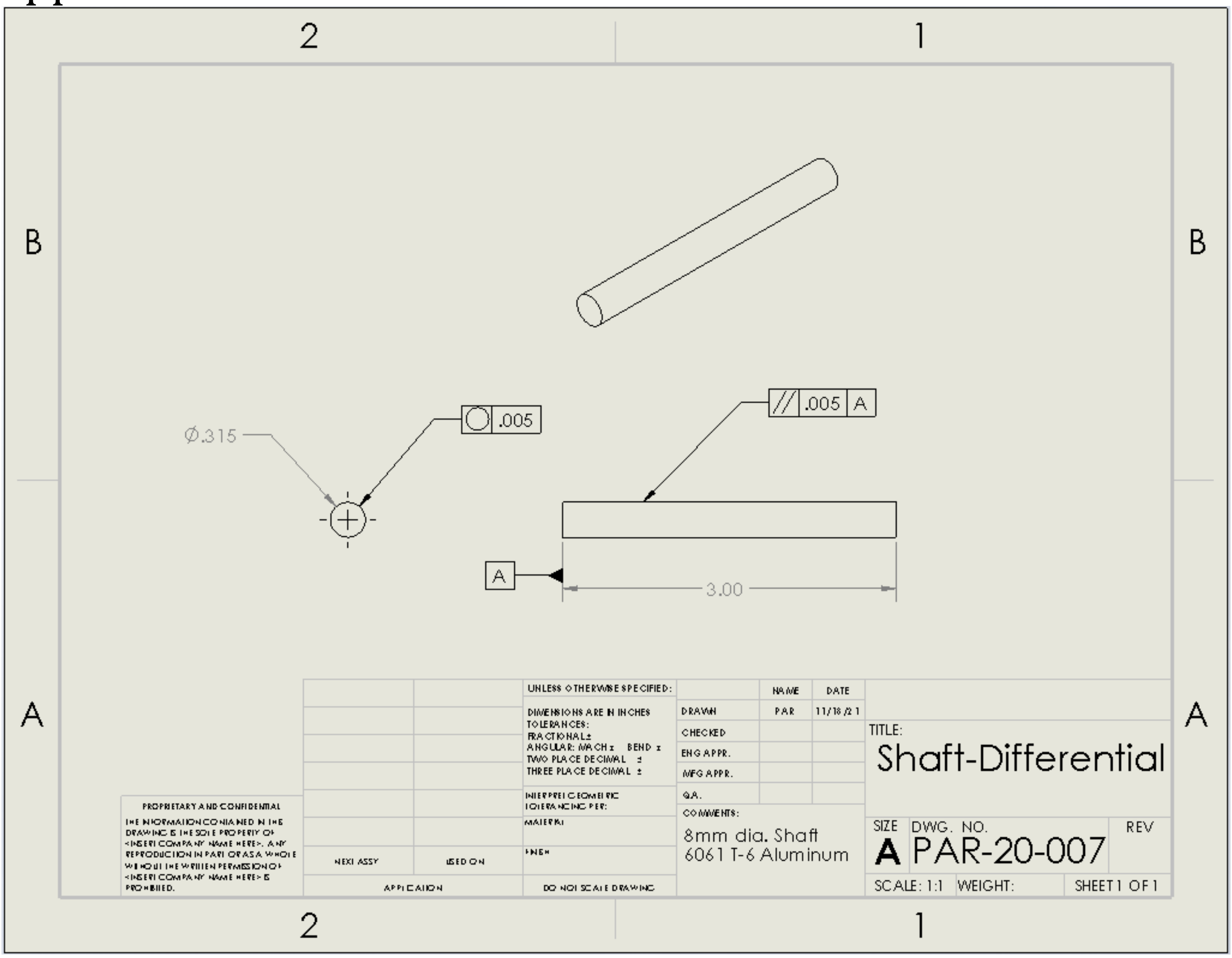
Appendix B-12 – Differential-Box, Top



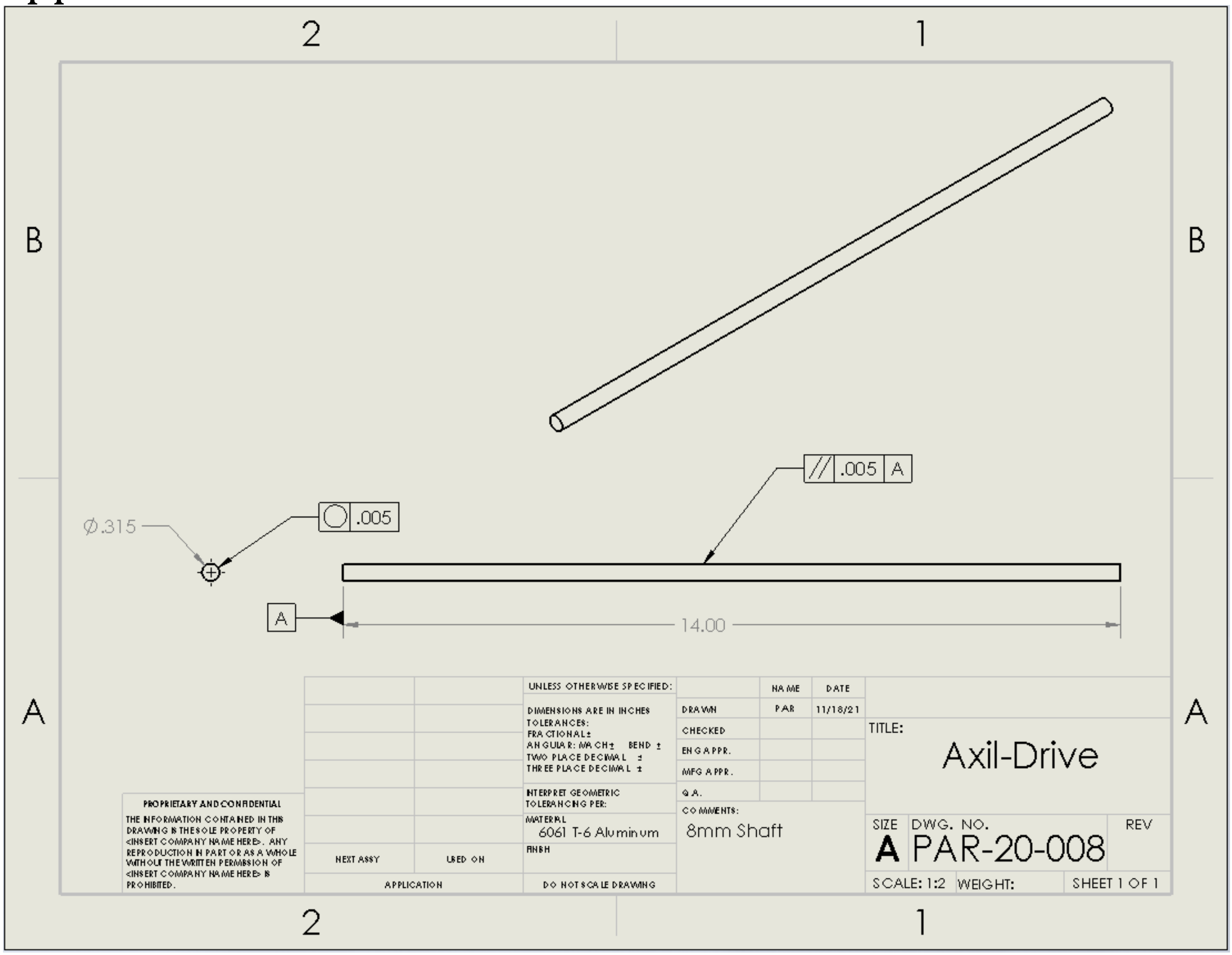
Appendix B-13 – Servo, Mount



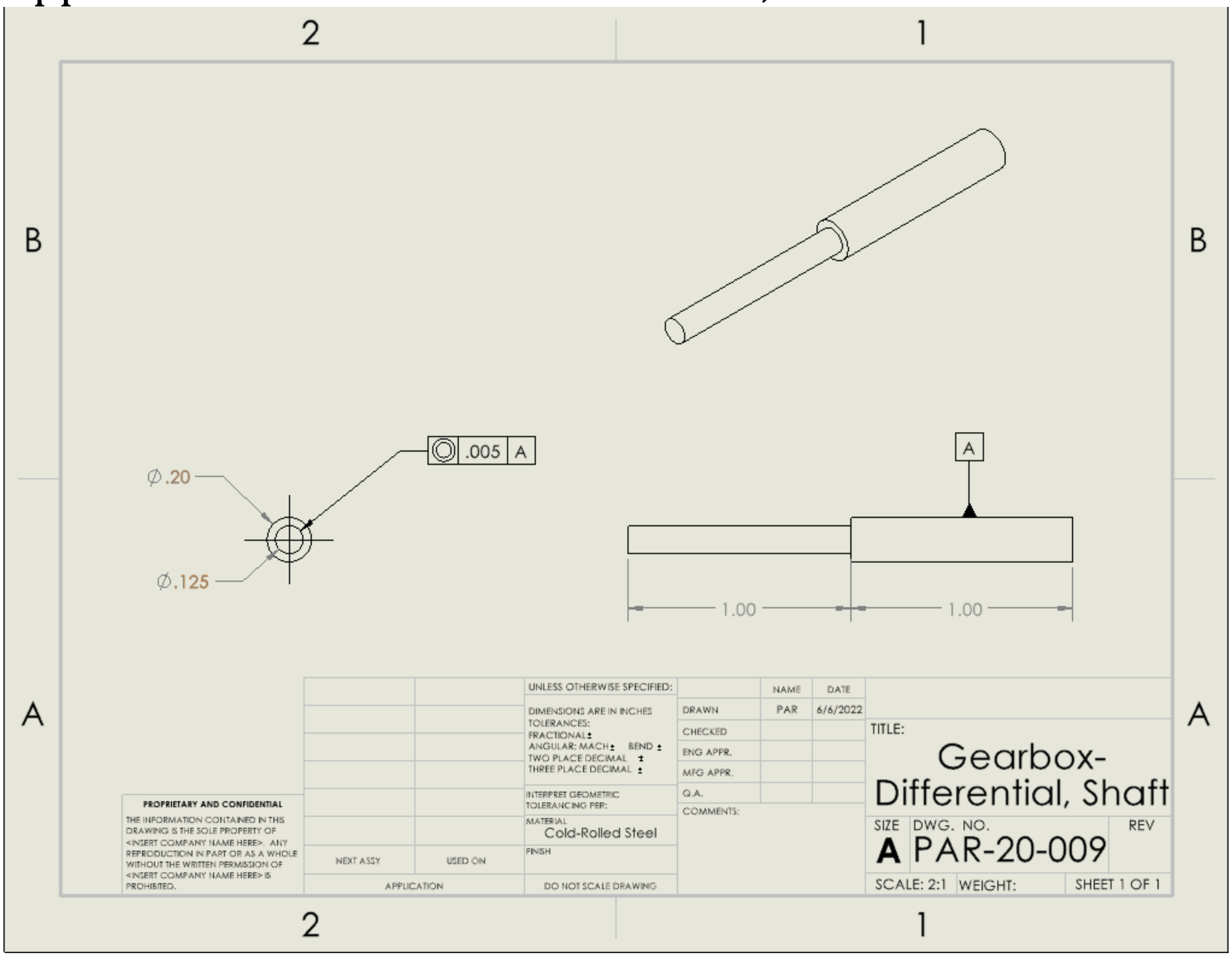
Appendix B-14 – Shaft-Differential



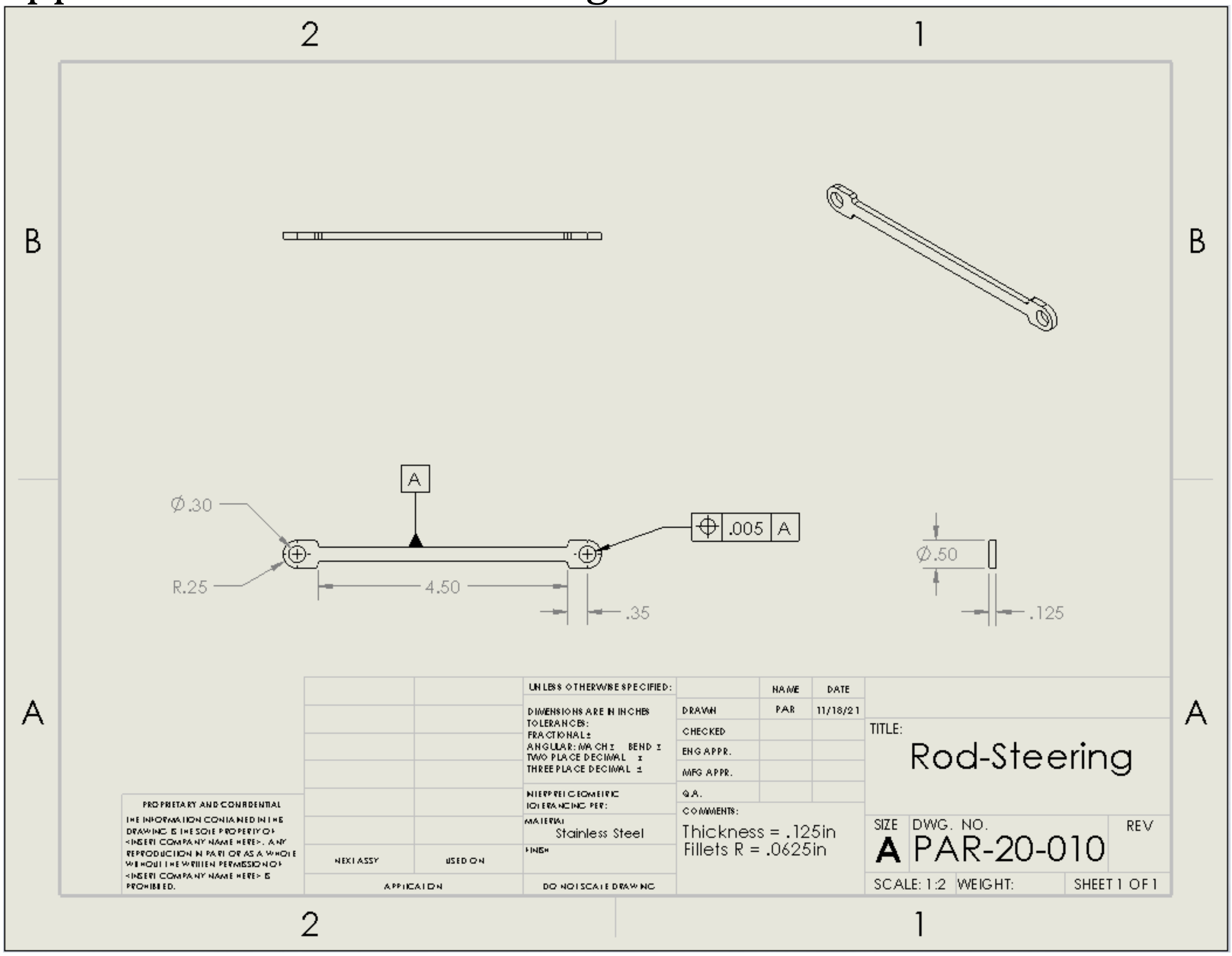
Appendix B-15 – Axil-Drive



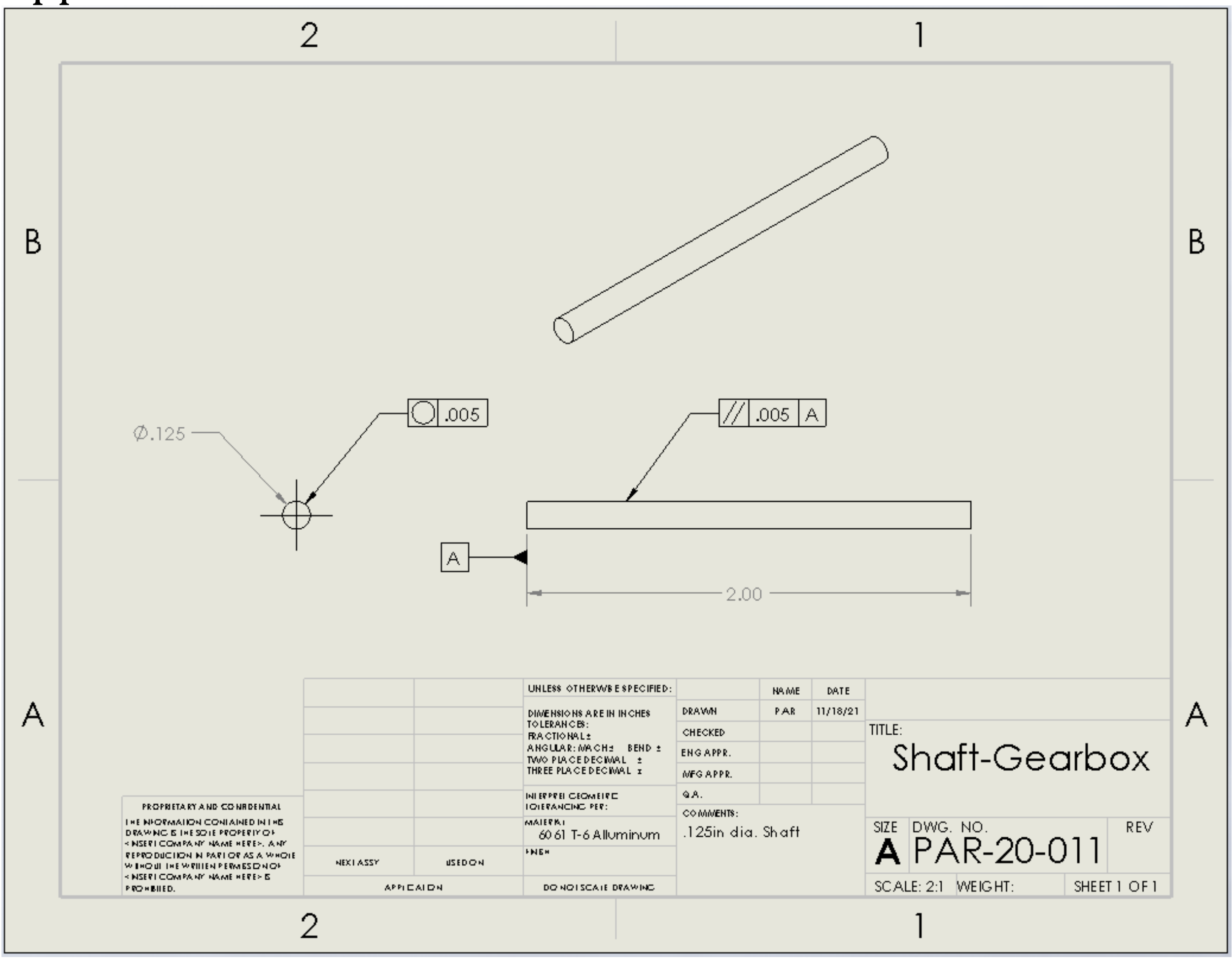
Appendix B-16 – Gearbox-Differential, Shaft



Appendix B-17 – Rod-Steering



Appendix B-18 – Shaft-Gearbox



APPENDIX C – Parts List and Costs

Table C1. Parts List

Part #	Qty	Part Description	Source	Cost	Disposition
20-001	1	Gearbox	Pablo Ruelas	$6	3D Print
20-002	2	Motor-Mount,Flat	Pablo Ruelas	$5	3D Print
20-003	1	Motor-Mount,Top	Pablo Ruelas	^^^	3D Print
20-004	1	Dif-Box,Bottom	Pablo Ruelas	$17	3D Print
20-005	1	Dif-Box,Top	Pablo Ruelas	^^^	3D Print
20-006	1	Servo-Mount	Pablo Ruelas	$4	3D Print
20-007	1	Shaft-Differential	Pablo Ruelas	Donated	Lathe/File
20-008	1	Drive-Axil	Pablo Ruelas	Donated	Lathe/File
20-009	2	Steering-Rod	Pablo Ruelas	Donated	Band Saw
20-010	1	Motor-Mount,Front	Pablo Ruelas	Donated	3D Print
55-001	1	17T-Gear	Amazon	$27	Unaltered
55-002	1	19T-Gear	(with 55-001)	^^^	Unaltered
55-003	1	30T-Gear	(with 55-001)	^^^	Unaltered
55-004	1	34T-Gear	(with 55-001)	^^^	Unaltered
55-005	1	Onyx-Motor	Amazon	$87	Unaltered
55-006	1	Motor-Control	(with 55-005)	^^^	Unaltered
55-007	1	13T-Bevel	Jerrols	$16	Unaltered
55-008	1	38T-Bevel	(with 55-007)	^^^	Unaltered
55-009	2	Yoke-Differential	Amazon	$11	Unaltered
55-010	4	RC-Tires	Amazon	$23	Unaltered
55-011	1	Steering-Servo	Amazon	$27	Unaltered
55-012	1	Servo-Horn	(with 55-011)	^^^	Unaltered
55-013	2	Steering-Spindle	Amain Hobbies	$10	Unaltered
55-014	1	RC-Battery	Jerrols	$44	Unaltered
55-015	3	Bearing	Ranch & Home	$50	Unaltered

APPENDIX D – Budget

Table D1. Project Budget.

Item	Qty	Description	Cost	Actual
3D Printed Parts	8	Time/Materials cost 3D printing	$25	$32
Total Labor Costs	12hr/w	National entry avg. $28/hr	$10,080	$8,988
Equipment/Space	1	MET labs fees	$105	$105
Total for Parts	1	Cost+Shipping+Handling+Taxes	$200	$200
Contingency Fund	1	Backup Funds	$100	$95
		Project Total	$10,510	$9,420

APPENDIX E – Schedule

Figure E1: Project Gantt Chart

SCHEDULE FOR SENIOR PROJECT:

PROJECT TITLE: Pablo/Caden RC Baja
Principal Investigator.: Pablo Ruelas

TASK: ID	Description	Duration Est. (hrs)	Actual (hrs)	%Con
1	PROPOSAL/REPORT WRITING			
1a	Intro	10	8	
1b	Analysis	30	32	
1c	Methods	10	9	
1e	Testing	3	5	
1f	Budget	10	8	
1g	Schedule	8	1	
1h	Project Management	8	2	
1i	Discussion	6	12	
1j	Conclusion	4	5	
1k	Drawings	48	36	
1l	Appendix	6	3	
	subtotal:	143	121	
2	ANALYSIS			
2a	Analysis 1: Motor Output	2	2	
2b	Analysis 2: Motor Torque	2	2	
2c	Analysis 3: Top Speed	2	3	
2d	Analysis 4: Gear Train	2	2	
2e	Analysis 5: Drive Shaft F.S	2	3	
2f	Analysis 6: Turn Angle	2	4	
2g	Analysis 7: Wheel Deflection	2	2	
2h	Analysis 8: Servo Horn Deflection	2	2	
2i	Analysis 9: Motor Power Usage	2	2	
2j	Analysis 10: RC Accelleration	2	2	
2k	Analysis 11: Baja Incline	2	2	
2l	Analysis 12: Adjusted Top Speed	2	2	
	subtotal:	24	28	
3	DOCUMENTATION			
3a	Part 1: Gear Box	3	2	
3b	Part 2: Motor Mount Flat	3	4	
3c	Part 3: Motor Mount Top	3	3	
3d	Part 4: Differential Box, Bottom	3	1	
3e	Part 5: Differential Box, Top	3	1	
3f	Part 6: Bracket-Mount, Servo	3	3	
3g	Part 7: Shaft-Differential	3	2	
3h	Part 8: Axil-Drive	3	2	
3i	Part 9: Nut-Hexhead, 5-40	3	2	
3j	Part 10: Rod Steering	3	2	
3k	Assembly-Sub, Motor	3	1	
3l	Assembly-Sub, Gearbox	3	2	
3m	Assembly-Sub, Differential	3	3	
3n	Assembly-Sub, Drivetrain	3	1	
3o	Assembly-Sub, Steering	3	1	
3p	Baja-Assembly	3	3	
	subtotal:	48	33	
4	PART CONSTRUCTION			
4a	Buy Motor Parts	1	1	
4b	3D Print Motor Parts	6	6	
4c	Buy Gear Box Parts	1	1	
4d	3D Print Gear Box	2	3	
4e	Buy Differential/Drive Parts	1	2	
4f	Machine Differential/Drive Shafts	5	10	
4g	Buy Steering Parts	1	1	
4h	Machine Steering Parts	5	2	
4i	Gather Screws, Nuts, Fastners	3	3	
4j	Website: Part Construction	20	7	
4k	MDR Sheets	15	6	
	subtotal:	60	42	
5	DEVICE CONSTRUCTION			
5a	Assemble Motor	10	6	
5b	Assemble Gear Box	10	18	
5c	Assemble Differential	5	5	
5d	Assemble Drivetrain	10	10	
5e	Assemble Steering System	20	10	
5f	Website: Device Construction	20	6	
	subtotal:	75	55	
6	DEVICE EVALUATION			
6a	List Requirements	2	2	
6b	Design Test Environments	5	2	
6c	Obtain Resources	3	1	
6d	Create Test Sheets	10	8	
6e	Test RC Car	20	2	
6f	Video Record Tests	5		
6g	Take Testing Pictures	5		
6h	Record Testing Data	10	2	
6i	Website: Evaluation	30	8	
6j	Finalize Project Document	30	6	
	subtotal:	120	31	
7	489 DELIVERABLES			
7a	Report Guide	20		
7b	Create Presentation Outline	10		
7c	RC BAJA	5	5	
7d	Create Powerpoint	10	6	
7e	Presentation Practice	10		
7f	Project Flashdrive Portfolio	10		
7e	Test Report	10		
7f	Website: Finalize	20		
7g	Project Presentation	5		
	subtotal:	100	11	
	Total Est. Hours=	570	321	=Total Actual Hrs
Labor$	28	15960	8988	

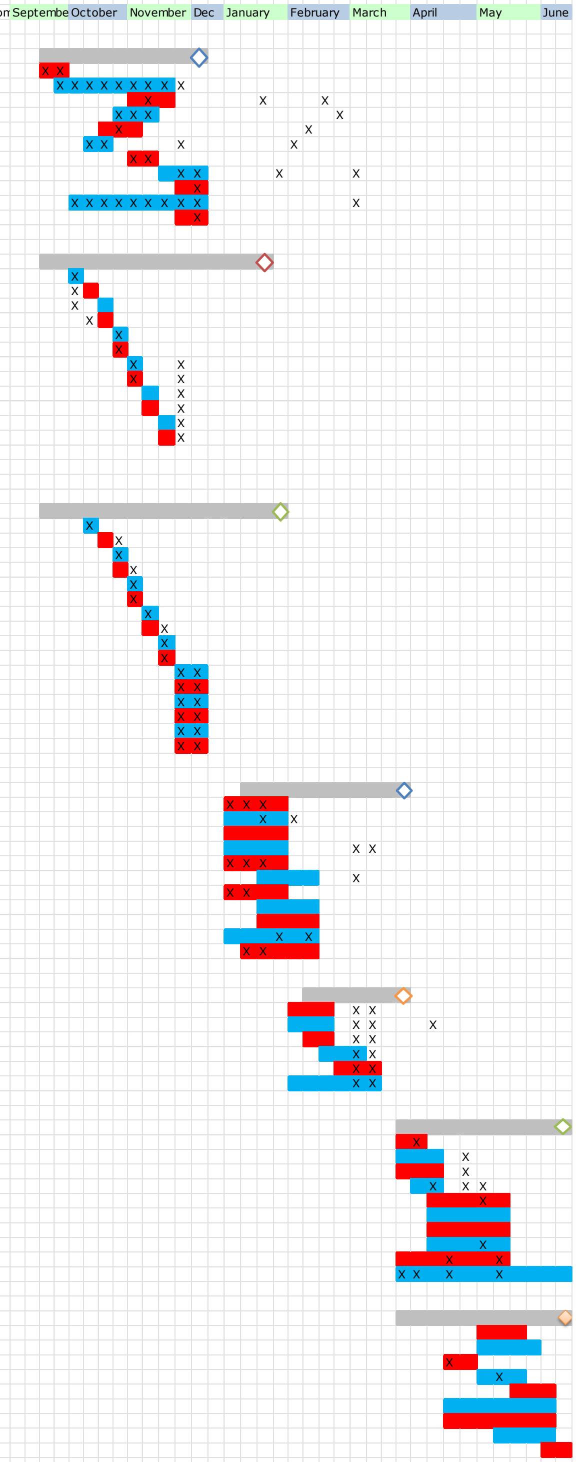
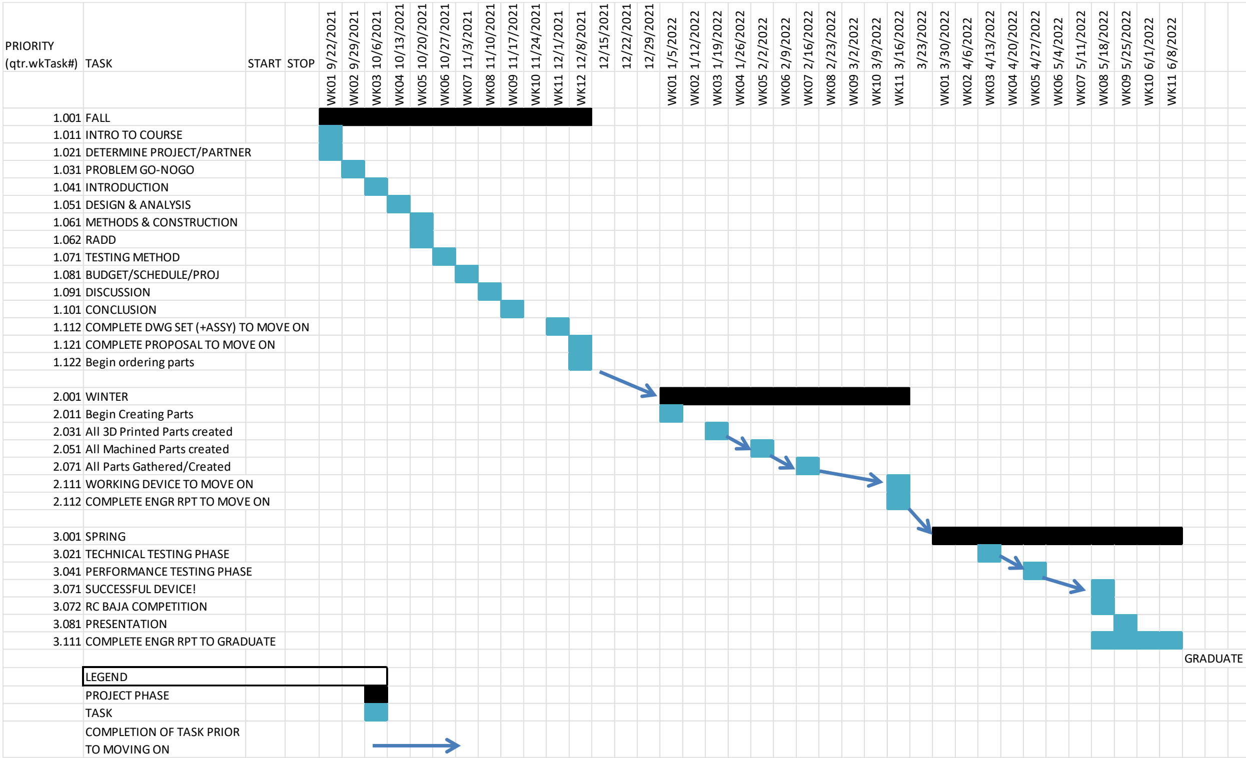


Figure E2: Project Milestones



APPENDIX F – Expertise and Resources

Table F1: Design Matrix

Criterion	Weight	Best Possible	Tire 1: Hollow		Tire 2: Normal		Tire 3: Sand Tires		Front Wheel Drive		Rear Wheel Drive		Motor/Axil		Motor/Dif./Axil		
	1 to 3	3	1	Score x Wt	2	Score x Wt	2	Score x Wt	2	Score x Wt	2	Score x Wt	2	Score x Wt	2	Score x Wt	
Cost	3	9	2	6	3	9	2	6	2	6	2	6	3	9	2	6	
Weight	2	6	3	6	2	4	2	4	2	4	3	6	3	6	3	6	
Prediction precision	2	6	3	6	2	4	3	6	2	4	2	4	1	2	3	6	
Confidence in failure location	1	3	3	3	2	2	2	2	2	2	2	2	1	1	3	3	
Prismatic vs non prismatic	2	6	3	6	2	4	3	6	2	4	3	6	3	6	2	4	
Manufacturability/Aquireability	3	9	2	6	3	9	3	9	2	6	3	9	3	9	3	9	
Total	13	39		33		32		33		26		33		33		34	
NORMALIZE THE DATA (muliply by fraction, N)		2.56		84.62		82.05		84.62		66.66667		84.61538		84.61538		87.17949	Percent
																83.76	Average
																6.94	Std Dev.

Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits	Good? Then you're done.
	Poor Bias:	Standard Deviation is one or less digits	Poor? Then change something!!!
		You can change the criteria, weighting, or the projects themselves…	

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
Weight	Light weight scores better on the success equation
Prediction precision	Are the engineers calculations sufficient and correct?
Confidence -failure loc	Confidence level in the indicated failure location
Prismatic vs non prismatic	Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs
Manufacturability/Aquireability	Is it simple to produce? Are there multiple process for a single component? How easy will it be to aquire the necessary parts?

Comments:

For the tires, students decided to try something different and favored tires that would give them better off road traction and shock absorbtion, so students decided to use the sand tires in the rear and hollow tires in the front to achieve both.

For drive, students decided that a rear wheel drive system would allow for a more ease of manufacturing and would locate the weight of the vehicle in a more desired location than the front wheel drive.

The decision between Motor/Axil drivetrain and Motor/Dif./Axil drivetrain was more difficult, but inevitably the students chose the Motor/Dif./ Axil drivetrain, because it would allow the students to lift the chassis and absorb more shock.

Table F2: Decision Matrix, 3D Printed Parts

Criterion	Weight	Best Possible	ABS Plastic		PLA Plastic		PETG Plastic	
	1 to 3	3	1	Score x Wt	2	Score x Wt	3	Score x Wt
Cost	3	9	3	9	1	3	2	6
Weight	2	6	2	4	1	2	3	6
Prediction precision	1	3	3	3	2	2	1	1
Weather Resistant	3	9	3	9	1	3	2	6
Prismatic vs non prismatic	2	6	2	4	2	4	3	6
Manufacturability	2	6	3	6	2	4	3	6
Total	13	39		35		18		31

NORMALIZE THE DATA (muliply by fraction, N)	2.56	89.74	46.15	79.49
				71.79 Average
				22.79 Std Dev.

Decide if Bias is Good or Bad

Good Bias: Standard Deviation is two or more digits — Good? Then you're done.

Poor Bias: Standard Deviation is one or less digits — Poor? Then change something!!!

You can change the criteria, weighting, or the projects themselves...

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
Weight	Light weight scores better on the success equation
Prediction precision	Are the engineers calculations sufficient and correct?
Weather Resistant	Does the material stay in correct form in different temperatures and weather conditions?
Prismatic vs non prismatic	Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:

PETG and ABS plastic ended rather close together, however I favored weather resistance and cost.
This tilted the results to favor ABS over PETG, since ABS was both cheaper and had a higher temperature softening point.
Moreover, ABS plastic is the filament material that the school has readily available,
which means PETG would not need to be ordered.

Table F3: Decision Matrix, Drivetrain Shafts

Criterion	Weight	Best Possible	Lathe a Single Shaft		Order Separate Shafts		Cast Shafts	
	1 to 3	3	1	Score x Wt	2	Score x Wt	3	Score x Wt
Cost	3	9	3	9	1	3	1	3
Weight	2	6	2	4	2	4	2	4
Prediction precision	1	3	2	2	2	2	2	2
Confidence in failure location	1	3	2	2	2	2	2	2
Prismatic vs non prismatic	1	3	2	2	3	3	3	3
Manufacturability	3	9	3	9	2	6	3	9
Total	11	33		28		20		23

NORMALIZE THE DATA (muliply by fraction, N)		3.03		84.85		60.61		69.70	Percent
								71.72	Average
								12.25	Std Dev.
Decide if Bias is Good or Bad		Good Bias:	Standard Deviation is two or more digits				Good? Then you're done.		
		Poor Bias:	Standard Deviation is one or less digits				Poor? Then change something!!!		
			You can change the criteria, weighting, or the projects themselves…						

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
Weight	Light weight scores better on the success equation
Prediction precision	Are the engineers calculations sufficient and correct?
Confidence -failure loc	Confidence level in the indicated failure location
Prismatic vs non prismatic	Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:

Many criteria in this decision matrix is ranked the same, as the end goal would be same in each of these situations.
This means, the most important criteria in this situation is cost and manufacturability.
This greatly favored Lathing a single shaft, since it is the cheapest and easiest solution to manufacture.

Table F4: Decision Matrix, Steering Rod

Criterion	Weight	Best Possible	CNC		Laser Print		Milling	
	1 to 3	3	1	Score x Wt	2	Score x Wt	3	Score x Wt
Cost	1	3	2	2	2	2	2	2
Weight	2	6	3	6	2	4	3	6
Prediction precision	1	3	2	2	2	2	2	2
Time to produce	3	9	2	6	3	9	1	3
Prismatic vs non prismatic	2	6	2	4	3	6	2	4
Manufacturability	3	9	3	9	3	9	2	6
Total	12	36		29		32		23

NORMALIZE THE DATA (muliply by fraction, N)	2.78	80.56	88.89	63.89	Percent
				77.78	Average
				12.73	Std Dev.

Decide if Bias is Good or Bad

Good Bias:	Standard Deviation is two or more digits	Good? Then you're done.
Poor Bias:	Standard Deviation is one or less digits	Poor? Then change something!!!
	You can change the criteria, weighting, or the projects themselves…	

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
Weight	Light weight scores better on the success equation
Prediction precision	Are the engineers calculations sufficient and correct?
Time to produce	How long will this take to create? Is it going to take a lot of attention to create?
Prismatic vs non prismatic	Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:

Many criteria in this decision matrix is ranked the same, as the end goal would be same in each of these situations.
This means, the most important criteria in this situation is time to produce and manufacturability.
This slightly favored laser printing over CNCing, since it faster.
But, what put laser printing over the edge was the finer finish possible through laser printing.

APPENDIX G – Testing Report

Appendix G1 – Turn Radius Test

Introduction:

The turn radius test was based on the requirement that the turn radius not exceed 5 feet. In this test, the main parameter will be turn diameter after turning 180° in feet. The predicted result of this requirement, as seen in Appendix A6-8, is a turn radius of 5 feet. The data will be collected by using a tape measure and aligning the front inside tire to the tape measure set up the test.

Method/Approach:

To test the turn radius, the student will need a tape measure, the RC car and its remote, a phone, and at least two people. The second person will be used to take pictures and video record the test taking process. There will be two parts to this test, the turn radius portion, and the turn deviation portion. The turn radius test will require the car to turn 180° to measure the turn diameter, and the turn deviation will require a 360° turn to measure the distance from the start location. The car will be run at as low speed as possible to ensure the best test results and that the car is getting as much grip on the test surface as possible. Using Excel, the student will then calculate turn radius and tire deflection using the turn diameter and create a table to hold all the results.

Test Procedure:

The student began by setting up the turn radius test in the fluke lab in Hogue Hall and the test setup, completion, and take down should only take an hour. There are no safety concerns, however, students stayed clear of the RC car and wore safety glasses. The testing procedure is as follows:

1. Student first gathered materials and laid the measuring tape out stretching at least 25ft.
2. The student then set the inside front tire on the 0ft mark.
    a. A second student then began recording the test session using a phone.
3. The student then turned the tires to max turn deflection using the remote, then pulled the trigger slowly until the car began to move slowly to begin acceleration.
4. The student stopped the test once the car passed the measuring tape the first time and released the trigger. The car was now facing the opposite direction from the start position.
5. The student then recorded the distance using the same wheel, front inside wheel, and reset the car.
6. Steps 2-5 were repeated for the same direction for at least three tests.
7. When the car was reset after the third test it was then set up to face the opposite direction to test the turn in the opposite direction and steps 2-5 were repeated for this direction as well.
8. The RC car was then moved to a centralized location on the tape measure, about the 10-foot mark aligned with the inside tire, then tires were turned to max deflection and the trigger was pulled to allow slow acceleration.
9. Once the car turned a full 360°, the student measured the distance the car traveled from the original starting point using the inside front tire.

10. Steps 8-9 were repeated for a total of at least three tests.
11. The student then turned the tires in the opposite direction to measure deviation in the opposite direction, and steps 8-9 were repeated for at least three tests.
12. The students then compiled all the collected data for submission and the materials used were gathered and put away properly.

Deliverables:

Turn Radius Test				
	Turn Diameter (ft)	Turn Radius (ft)	Deviation (ft)	Tire Deflection Angle (°)
Trail 1 (Left)	8.188	4.094	0.281	51.646
Trail 2 (Left)	8.375	4.188	1.094	50.553
Trail 3 (Left)	8.896	4.448	-0.667	47.734
Average (Left)	8.486	4.243	0.236	49.978
Trail 1 (Right)	4.166	2.083	0.000	94.596
Trail 2 (Right)	4.125	2.063	0.042	95.371
Trail 3 (Right)	4.313	2.157	0.063	91.911
Average (Right)	4.201	2.101	0.035	93.959
			Wheel Base (ft):	1.208

Appendix G2 – Battery Output Test

Introduction:

The battery output test was based on the requirements that the wattage output exceed 400W and the torque output to the motor exceed 1.0lb*in of torque. In this test, the main parameter was the given voltage of the battery and the current outputted by the battery when running at top speed. The predicted result of this requirement, as seen in Appendix A1-2, is a wattage output of 444W and 1.3lb*in of torque. The data will be collected using a clip multimeter to measure the current output based on the electromagnetic field it creates around the battery wires, while the RC car is suspended off the ground.

Method/Approach:

To test the power output, the student will need a box to suspend the RC car, the RC car and its remote, and a clip multimeter. The student will first suspend the RC car off the ground using the box, then attach the clip multimeter around the positive wire to measure current being provided through the system. The student will then run the car at maximum output and record the highest number displayed on the digital multimeter. Using Excel, the student will then calculate turn radius and torque similar to how it was calculated in Analysis 1 and 2.

Test Procedure:

The student began by setting up the power output test in the EET Lab in Hogue Hall and the test setup, completion, and take down should take no longer than two hours. There are no safety concerns, however, safety glasses were worn. The testing procedure is as follows:

1. The student gathered all materials and began test setup at an open desk.
2. Using the box, the student suspended the RC car making sure the chassis was centered on the box so that the RC car was not in danger of slipping off.
3. The student then clipped the clip multimeter around the positive, red, wire and turned the multimeter on.
4. Then the student turned on both the remote control and the RC car.

5. Testing began by applying pressure to the acceleration trigger until max deflection, max power, was reached and the highest number of Amps (A) was recorded for the test.
6. The trigger was then released and the car was given a 30 second break before the next test could be run.
7. Steps 5-6 were repeated for a total of 3 tests.
8. Wattage and torque were then calculated by using the equations used in Analysis 1 and 2 respectively.

Deliverables:

Battery Output Test				
	Voltage Out (V)	Current Out (A)	Wattage (W)	Torque (lb*in)
Trail 1	7.4	6.8	420.912	1.202
Trail 2	7.4	6.1	425.574	1.215
Trail 3	7.4	7.0	419.580	1.198
Average	7.4	6.633	422.022	1.205

Appendix G3 – Top Speed Test

Introduction:

The top speed test was based on the top speed requirement that the car at least run at a top speed of 15mph. In this test, the main parameter measured was the time it took for the RC car to run 20ft worth of track after a 25ft length of acceleration. The predicted result of this requirement, as seen in Appendix A-12, is a top speed of 50.7mph. The data will be collected using a tape measure to mark distance of the track and a stopwatch to measure time.

Method/Approach:

To test the top speed, the student will need tape, a tape measure, a stopwatch, the RC car and its remote, a phone, and at least two people. The second person will be used to start and stop the stopwatch accordingly and record video of the testing process. The student marked a 0ft starting line, then measured 25ft from the starting line and marked the end of the acceleration zone, then 20ft more or 45ft total for the finish line. The car will be allowed to accelerate in the first 25ft to accelerate to top speed. Then, once the car passes the 25ft mark, the car will be timed from the 25ft mark to the finish line to calculate for top speed. Using Excel, the student will first solve for top speed in ft/s then convert to top speed in mph and solve for the average acceleration in the 25ft in ft/s^2.

Test Procedure:

The student began by setting up the top speed test on the patio outside the fluke lab right outside Hogue Hall and the test setup, completion, and take down should take no more than two hours. The only safety concern is the RC car running into the timer; however, the student stood a good distance off to the side to ensure that the student was not in the path of the RC car during its test. The testing procedure is as follows:

1. Student first gathered materials for the top speed test then headed to the Fluke Lab patio outside Hogue Hall.
2. The student then marked a 0ft starting line using the tape. Then the student measured 25ft from the starting line and marked the 25ft mark using tape. Finally, the student measured 20ft more or a total of 45ft from the start line using the tape for the finish line.

3. The student and the timer then got into position and the car was placed so that the front wheels were just behind the starting line.
4. The remote and RC car were then turned on.
5. The driver then counted down from three to signal to the timer when the test should begin and on “GO” the driver started applying pressure to the trigger until full speed was achieved.
    a. The driver should reach full speed by the time the RC car reaches the 25ft mark.
    b. The timer starts the stop watch once the front of the car reaches the 25ft mark and stopped when the front of the car reaches the finish line.
6. Once the RC car passed the finish line, the driver then decelerated the car to a stop by slowly letting go of the acceleration trigger.
7. The car was then reset for another test, with the front wheels just behind the starting line.
8. Steps 5-7 were then repeated for a total of 3 tests.
9. Results were compiled to an Excel data table and top speed was calculated using the travel distance of 20ft and time recorded for each test.

Deliverables:

Top Speed Test				
	Time (seconds)	Top Speed (ft/s)	Top Speed (mph)	Acceleration (ft/s^2)
Trail 1	1.2	16.667	24.444	5.556
Trail 2	1.4	14.286	20.952	4.082
Trail 3	1.26	15.873	23.280	5.039
Average	1.287	15.608	22.892	4.892
	Velo Distance (ft):	20	Accel Distance (ft):	25

APPENDIX H – Resume

Pablo Ruelas

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EXPERIENCE

AnoDelivery, Ellensburg, WA— *Driver*

March 2020 - Present

Driving/delivering food, communicating with customers, and app fluency

CWU Dining Services, Ellensburg, WA— *Student employee*

October 2019 - March 2020

Prepping, register, serving, opening, closing, and cooking on the flat top

EDUCATION

Central Washington University, Ellensburg, WA

September 2018 - PRESENT

GPA: 2.9, Junior (C.O. 2022), Major: Mechanical Engineering Tech.

Kalani High School, Honolulu, HI

August 2016 - May 2018

GPA: 3.6, AB Honor Roll 16-18, AP US History, AP Physics, AP World History, Calculus, Engineering Leadership (Class of 2018).

VOLUNTEER EXPERIENCE

Team 3008 Magma Robotics, Kalani High School

Places varied on island, 100+ hrs community service

Outreach events and community service events such as: volunteering at robotics competitions, craft fairs, robot demos, beach clean up, etc.

Catholic Campus Ministry, CWU

Retreats and community service, 40+ hrs community service

Retreat lead, community service

Qualifications

Solidworks/CAD —Autodesk and Solidworks

Robotics — *Design, build, and intro level programming*

Programming — *Labview, Lego EV3, Visual Studio, and Studio 5000*

SKILLS

- Fluent in multiple CADing softwares
- I work well with others and learn to work to a common goal through sports and marching band
- Prior job experience and robotics have taught me teamwork & communication

AWARDS

STEM, CTE, and Academic Honors STEM: 4 years science and math 1 year stem capstone (private research and project class), CTE: 2 years engineering or business background classes, Academic: 4 APs & 3.0 GPA

Science fair best in category best in Mechanical Engineering category in district science fair

All Tournament baseball award for being one of the best performers in the district tournament (2015-16 season)

Hustle Award received for giving my full effort during all games and practices (baseball 2016 season)

LANGUAGES

English (Fluent), Spanish (Beginner)