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ASME RC Baja Car Drivetrain

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Drivetrain for
Radio-Controlled Baja Car

By

Gizan Gando
Team Member: Chesna Kern

ABSTRACT

Abstract/Artists Statement:

The purpose of the RC Baja Car is to compete in the American Society of Mechanical Engineers (ASME) competition, a series of events to prove the vehicle's functionality. This series of events includes the Slalom, Drag, and Baja races. The Slalom is a test of the steering capability of the car. The Drag is a test of the acceleration of the car in a straight line. Lastly, the Baja puts all factors together in a race to test every component of the car. This project is about building an RC car that can function under these conditions and hit maximum performance capabilities. This report describes the analysis, design, construction, and testing evaluation of the drivetrain and steering systems of the car. Chesna Kern was responsible for the chassis and suspension portion; together, this makes a complete system. The drivetrain was built with two different gear ratio systems for the idea of being able to get high speed and get high torque. The steering was constructed with a high ratio servo and Lego pieces for easy change and adjustability. Using lightweight material was one of the most critical aspects of building, so most car parts used ABS and acrylic plastic to keep the weight low. The resulting car reached speeds of 25 mph, an acceleration of 10 ft/s^2, a turning radius of 35 degrees, and all weight under 5 pounds. These were the critical factors that the car needed so that the event runs could be successful.

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1. INTRODUCTION

a. Description

The Radio-Controlled Baja car can be used in a contest, recreation, or sporting event. The end goal of this project would be to compete in an ASME Radio-Controlled Baja car competition. This proposal will be a recording of designing, creating, and building a drivetrain system connected to a chassis. The Radio-Controlled Baja car at the end of the project will move forward, backward, and turn while driving.

b. Motivation

A need for a device to enter an ASME Radio-Controlled Baja car yearly contest would run an obstacle course and time trails. Also, to use basic fundamental engineering principles and skills learned in classes these past years to design the car's components. Building most of this car from scratch and buying the necessary parts will also help gain knowledge on how to use the engineering process in a real-life application.

c. Function Statement

The Radio-Controlled Baja Car will convert electrical power from a battery to the drivetrain in two directions. The Radio-Controlled Baja Car also will be able to turn while in motion.

d. Requirements

The Radio-Controlled Baja Car must meet the minimum ASME Baja car requirements:

- The motor must be ROAR Racing compliant.
- Radio Controlled Baja Car must have a steering angle of at least 60 degrees.
- Driveshaft must withstand torque produced by the motor.
- A 7.2 voltage battery must power radio Controlled Baja car.

Radio-Controlled Baja Car personal requirements:

- The drivetrain must be no higher than 4 inches from the chassis plate.
- The drivetrain must be able to withstand being dropped from 1.5 feet.
- Radio Controlled Baja Car must at least reach a velocity of 25 mph.
- Radio Controlled Baja Car must be able to go up to 30^o incline without backtracking.
- Radio Controlled Baja Car must complete the slalom-and sprint race under 2.5 mins.
- The cost of parts for the Baja car should be limited to $400.

e. Engineering Merit

The project will require a gear analysis with the differential. Stress, strain, and bending analysis will be done on the driveshafts while the drives are in motion. Stress and strain analysis on the steering mechanism determine the max amount of force that can be applied.

f. Scope of Effort

This portion of the project will only cover the Radio-Controlled Baja Car's drivetrain system and steering assembly. The other half of the project, which is the chassis and suspensions, will be developed by Chesna Kern.

g. Success Criteria

This project's success depends on the Radio-Controlled Baja Car's performance by meeting all the requirements listed above. Also, the Radio-Controlled Baja Car will complete the Slalom-and-Sprint courses listed in the ASME Radio-Controlled Baja Car competition rule book.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

The approach for this design was to start with getting to the max rotational out speed from the motor shaft and figure out to transfer that to the rear axle to get the max speed the car needs. For that get, a need drive ratio and design the gear box. Then from the gear box got to the housing and connecting components to help make the drivetrain.

b. Design Description

This car drive train had two main components which is to power the rear axle and steer the front axle. For the powering, the back axle there is the transmission in a form of a gear box and the differential, which help reduce the motor power and help get a higher torque. For the steering there is a servo motor to help pivot the wheel in the right orientation. Also, a major design factor is creating a shifting gear box that would be able to have two different speeds at a given time.

c. Benchmark

The Radio cantor car that then projects is being based on is Axial RC Jeep Wrangler. This car was chosen because of the highlevel of detail and can be usede in many different terrains. Just has a lot of images to reference off when design the Radio-Controlled Baja car.

d. Performance Predictions

The main goal for the performance of the drivetrain is that the car drives smoothly at a constant speed. Shown in Appendix A.1, for the car to be able to go up to 30MPH. Also being able to easily go up a 45 ramp without out falling back down.

e. Description of Analysis

First to determine the car to have a constant drive speed shown in Appendix A.1. Then was to figure out a good second ratio for the car to go up the ramp in Appendix A.2. In Appendix A.3 the two different drive ratios are combined to be put in a dual-shifting gearbox for the motor. Moving on to the car's shafts using the power and angular velocity calculated in Appendix A.4. With those torque values, analyses can be done to determine the forces on the shafts and bearings calculated in Appendix A.5. To find design parameters for the shafts, an analysis can be done to determine a minimum diameter when designing with a specific material which is calculated in Appendix A.6. With these shafts, a key width and depth can be chosen so an analysis can be done to determine the minimum length and stresses of the key, calculated in Appendix A.7. In Appendix A.8, an analysis is done to determine the distance and angle between the two offset shafts. Using figuring out the need angles for turn radius in Appendix A.9. Looking at force, angular acceleration, linear acceleration of rear wheels in Appendix A.10.

f. Scope of Testing and Evaluation

The main evaluation of the car came during the ASME RC Baja competition, as the success criteria defined in the introduction depend on the car completing all events of the competition. In addition to the competition, the car was running it speed to Evaluate how fast the car top speed can reach. A ramp test was also performed to ensure the car would be able to complete the off course event. Lastly a differntal test was made to look at that it was working and would help the turning radius which would help the slalom event.

g. Analysis

i. Analysis 1

For the required speed of 30 MPH an analysis on a turn ratio is needed that would reduce the shaft speed of 28800 RPM running at 5.4V to 2536 RPM. In the Appendix A.1.1, the first calculation was to figure out the maximum RPM for the 4000 KV motor and could produce 28800 RPM. Calculating max speed from a conversation of the wheels being ~ 101 mm and got the 2536 RPM. Found the max drive ratio to be 11:1, but that was too high of a ratio, so if the voltage was lower down to 5.4V so there some leeway factor of $\frac{3}{4}$ to be able to reach 30 MPH and not having to use the full battery power. So, the drive ratio lower would be 9:1. Next in the Appendix A.1.2, differential ratio was pick for gear parts found on the R/C website and so the transmission ratio got calculate as 4:1.

ii. Analysis 2

For the design required for the car to go up a 45-degree ramp. Drew out the force that would be applied on the car going up the ramp on Appendix A.2.1. Following by need torque on the back-drive wheel, to the need toque on back axel. Next solved the torque that is being cause on the differential Appendix A.2.2 and reduce factor to the need gear ratio. Then found the motor solve for the horsepower and then from that then the torque. Lastly compared the two last torques to get a ratio that the gear box needs to be able to reduce to go up the ramp. The required torque will be achieved with a 12:1 ratio.

iii. Analysis 3

For the previous two analysis figure out a way to design a gear box too run two different speeds at the same time with a shifter. So, in Appendix A.3.1 was drawing out the four different stages that were needed to transfer the different ratios. Then from that try to pick gear teeth ratio that where standards so it will be easy to design and make. Appendix A.3.2 shows the sum of what the overall gear box design will be.

iv. Analysis 4

Doing the first stage of the gear box and scaling the gear in the right size to fit to the motor and to the gear box Appendix A.4.1. Then finding which hex axel material that should be use for the gears that could with withstand the torsion of the motor Appendix A.4.2.

v. Analysis 5

The car back axle torque was already found (Analysis 2). It was essential to compare the maximum allowable torque to the torque produced to ensure the limit is not reach, which would fail the axle. Also, to keep weight to a minimum is the project's priority; Aluminum 6061-T6 was the choice for the axle material. Which help find the rear axle length of 12.4 and having a mass of 17.25 grams.

vi. Analysis 6

Looking at the force being apply on the wheel when moving at high speed which is 8.4lbs. Then using that to help find the need angular acceleration and linear acceleration that the wheel can get. There was an assumption that the car will be able to get top speed in under five seconds. So, the angular acceleration is 95 rad/s^2 and the linear acceleration is 4.85 m/s^2.

vii. Analysis 7

Figuring out what the car mount turn radius and angle which will be need later for how much the servo motor needs to move so that the steering will move correctly. First found the mount angle from center which was 7.4 degrees. Then add a 90 degree to the 7.4 to get the mount angle for axel which is 97.4 degree. The with the axel degree use to find the turning radius which is 4.58 ft which make sense from (Analysis 6).

viii. Analysis 8

This looked at what the need length for the beams at the steering point need to be from the servo. After the calculations, the left side need to be 0.45 inches long and the right need to be 2.45 inches.

ix. Analysis 9

The front wheels needed to pivot so there must be a pin that connected to the wheel plate. Used the weight, tire width, and distance from the wheel to the pin to find the torque of pin. Then found the torque is 11.24 kg*cm. Which was checked with the torque of the servo which is less and will work.

x. Analysis 10

Calculated what the need distance the wheel pivot plate to the wheel so that it will be able to fully pivot without the wheel hit the plate. Found that the distance needs to be at least 2.85 inches.

xi. Analysis 11

Found what the need distance the support beam for the steering and the servo. It was calculated that the distance needs to be 2.75 inches.

xii. Analysis 12

For the shifter on the gear box to work there need to be a pivoting arm that can pull the shifting inner axle in and out. Needed to find what the distance that arm need to be so that the servo can pull the axle and d-shifter can move. It was found that the length needs to be 2.65 inches.

h. Device: Parts, Shapes, and Conformation

i. Drawing B.1

One of the cover plates for the differential housing (Front).

ii. Drawing B.2

The other cover plates for the differential housing (Back).

iii. Drawing B.3

A gear for the differential that will match for the Lego gears. The gear has the match Lego teeth of 40 and attach at the bottom of the gear box.

iv. Drawing B.6-B.11

The side part for the shell of the Gear box.

iv. Drawing B.12-B.17

The connecting part for the shell of the Gear box.

vi. Drawing B.19

The servo holder for the front steering of the car.

i. Device Assembly

First, it started with the build of the differential, then connects to the gearbox. Then moved on to mounting to the chassis plate and then add the needed motor and mounts to the gearbox. It then attached the steering pivots to the chassis and the servo to the car. Then attached the axels and joint, and lastly, the wheel and hub to the end of the axels.

j. Technical Risk Analysis

The main problem faced in the analysis was that the 3D print part could take the force that the car will be under. What is the percent density that the part needs to be printed and the amount of tolerance there can be in the prints.

k. Failure Mode Analysis

The failure was mostly looked at where the components might break in the gearbox, which might be the tooth of a gear or the axle's bending stress.

l. Operation Limits and Safety

Most of the build will be done on a 3D printer, which will be supervised by a professor or lab technician,

3. METHODS & CONSTRUCTION

a. Methods

Previous years of the student from the Mechanical Engineering Technology program building Radio-Controlled Baja Cars conceived this project's idea. The analysis, design, manufacturing, and testing are completed within the CWU campus's restraints and Central's Hogue building capabilities. Also following the constraints of the ASME Radio-Controlled Baja Car Contest Rules. There was a lot of hardship this building quarter and having to reschedule and apart from new circumstances. There was less time to create custom parts, and the car built had to rely on pre-made parts.

i. Process Decisions

Most of the made part was a 3D printer and laser cutter because it will be easier to change and adapt to the building process. For 3D printing, parts can have small tolerances in the design. The 3D printer has also changed over the past years. There can be stronger plastic composites like nylon and more detailed parts with resin, making the analysis much more comfortable because fewer uncontrolled variables need to be calculated. For 3D parts, there is a faster turnaround in redesign because there is less human error and there is less waiting time for new parts to arrive.

For all the other flat car parts, the laser cutter was used. It is much faster than a human to cut out a plate and drill out holes in the correct position. There is less room for error and creates tighter tolerances. The only limiting factor is the types of plastic that are allowed on the laser cutter. The most robust plastic that is permitted is acrylic, so that is what was pick for parts.

Looking at the RC Baja car's standard electrical controller, there are only two ports connected: the drive motor and the steering servo motor. The RC Baja car design needs another port to allow another independently controlled servo motor for the shifter in the drive gearbox. So, a solution found is to use an Arduino UNO for all the motors' logic board. It can also easily be programmed for the motors and adapt for a power toggle needed. It was also able to program in a primary controller and create a personal button map. It makes the project more easily adaptable and can change through the building process.

With a pandemic taking effect on this build quarter and having the school be shut down for two whole weeks. It changed the building process instead of making parts for the gearbox, drive, steering, and electrical wiring components. I first worked on doing the electrical components' wiring because it did not require any part of the car to build a feature yet. The shift of schedule affected the amount of time that parts could be built. There was a redesign to use more off-the-shelf components with less time to make parts on campus. That way, the project can be finished by the build quarter deadline.

Replacing the 3D printing gear with Lego gear was made mainly because the tooth on the 3D printing gear was not printing in their tolerance that it needs to be, which causes many backlashes and would fail under stress the gearbox needs to be. So a redesign and change need to happen so in the end, the gearbox could work. Two decisions could be made: to redesign and CAD new gear to print out again or to use Lego gear that where already owned. Looking at the timeline, it seems wise to go with the Lego gear because there is no need to check if they will work after the 3D printing process. The Lego gear would help make the project more defined and finish with the project. Also, since the Lego gear is already its own, this project does not have to spend any more money developing new gears and helping the project be within its budget.

b. Construction

i. Description

The driving and steering half of the car project contains 23 parts and 4 sub-assemblies; most of them are 3D printed and laser cut. The rest of the main parts that are not custom manufactured are secondhand use or a connecting part like a screw or a nut that is a stander part to be bought.

ii. Drawing Tree, Drawing ID's

In Appendix B1, a drawing tree is available showing the process from full assembly to preliminary parts.

iii. Parts

In Appendix C, a parts list is available with all the parts needed to build the full assembly and the price for that component.

v. Manufacturing Issues

The first major issue was the pressing times presented; it made it harder to access all the Central Washington University campus's technology resources. Especially try to access the Hogue engineering building with its 3D prints, laser cutter, and other machine tools. Also, meeting in-person was much harder to do with taking more health safety pre-caution before meeting and had fewer places to meet.

With the pandemic, the school was shut down for a full two weeks of the winter quarter—it is pushing the schedule of creating part back and having to redesign relying on off-shelf parts. The choice made to have the end goal function car by the need end time.

With having most of the part 3D printer, there is less error for having a part fitting together, and there was lower tolerance on parts. If a problem was raised in the building's build, it was straightforward to redesign or reside the model part and reprint, so the turnaround for the rebuild was fast. The significant part that was not 3D printed, like the motor, battery, controller, etc., are secondhand use and had some ware with it, and some adjustments had to be made to make sure they fit and function correctly.

There was a problem with printing out the gearbox shell. After three try to print out the shell out, it just keeps failing in the middle of the print. The main issue was that the part was large and had a lot of gaps. In turn, there needs to be a lot of support in the print, and support in the middle leads the printer to mess up more. Also, since the print is large, it needs a lot of filament to print, and one of the times the roll ran out during the printing causes it to fail. Try to print this anywhere else would cost a lot considerably. The design solutions were splitting the shell into different components then will be attached back together.

vi. Discussion of Assembly

Most of the parts were 3D printed and laser cut to fit together easily. First started with making the differential and made sure that there was enough lubrication to move smoothly. Then the differential went inside the gearbox and placed all the axles and gears. Then mounted the motor and shifter to the gearbox. Then moved on to the build of the steering sub-assembly and made sure that it can move the chassis pivots entirely turn to the right and left the right degree. They bolted-down all the parts down and add axles and joints throughout the car to connect everything.

The needed electrical components were placed in lasted, mostly Velcro down. The battery mount was strapped in, and the battery was strapped in. The Arduino board connected the ESC motor controller, the two servos, and the wireless reviver. Then a controller was modified to fit in the Arduino board and wireless transmitter. There was a lot of soldering involved in making the election connections. Lastly, coding was made in the main Arduino program.

4. TESTING

a. Introduction

The main tests for the Radio-Controlled Baja car were determined from previous RC Baja Car projects. The speed and acceleration of the car can be tested for accuracy from calculations. The test was done on a smooth and off-road surface.

b. Method/Approach

The vehicle's speed can be calculated by the time and the distance. . Also, the turning radius was tested and needed to be in a 3ft radius. The car was given a pass/fail if it could go up a 30-degree incline ramp. Lastly, the car differential was given a pass/fail if it could still drive if a wheel were being held.

c. Test Procedure

A lot of space was needed for this testing procedure, so different areas around Central Washington University Hogue Building locations were used. Since various types of surfaces will affect the friction to the wheels, which will change the speed and acceleration, testing will take place on three different surfaces. The test will require the surfaces of smooth concrete, rough concrete, and off-road. The smooth concrete surface will be tested inside Hogue Hall. The unfinished surface will be tested on the concrete walkway outside of Hogue Hall. The off-road surface will be tested on the grass yard beside Hogue. Each testing surface will require a minimum of three trial runs with the vehicle. If more distance is needed, the location of testing is subjected to change.

The equipment required for this test will be a tape measure, stopwatch, and a way to mark the set distance. In the acceleration test, the compression of the suspension or "squat" of the vehicle was watched. When the car is pursuing high speeds and maximum torque when leaving the starting line, the squat must be minimalized and not allow the car to bottom out on the ground.

The distance was measured by measuring out the distance then marking down lines onto the surface. A stopwatch application on the phone was used to measure time.

The first test that was done was the maximum speed test. The speed of the vehicle can be calculated by recording the following data:

- Total distance traveled, **x**
- Amount of time for the car to reach total distance, **t**

$$\textbf{velocity} = \frac{\boldsymbol{distance}\ (\boldsymbol{X})}{\boldsymbol{time}\ (\boldsymbol{t})}$$

The second test was the turn test. A 3-foot radius circle was tape on the floor. If the car could turn around inside the circle, it was given a pass, and if it could not, a fail was given.

The third test was the ramp test. Two plywood boards (4ft x 8ft) were placed side by side; a 4ft high block was placed under one side to create a ramp that will have a 30-degree incline. The car was given a passed or failed depending on if it made it up the ramp without stopping or going back.

The fourth test was to test out the differential. First, to support the vehicle so that the rear wheels are suspended. Then put in a fully charged battery and turn on the remote and receiver. Slowly trim throttle up to half power. While wearing gloves, steadily apply pressure to one of the rear wheels' sides to stop rotating within three seconds. Hold the wheel for six seconds after it has stopped spinning, then release the wheel. Repeat the holding wheel steps while alternating between the two rear wheels for a total of 60 seconds. Lastly, verify that the car can still move the grounds at minimum speed without the wheel slipping.

Important factors that were considered during testing:

- Battery voltage must be maintained at the same voltage for each run, reducing the lack of power in the trial runs.
- The vehicle must travel in a straight line to be considered an applicable trial run.
- The weather may affect the outcome of testing, so testing can only happen on dry days.

If the chassis plate contacts the ground, suspension modifications will have to be made. Some ways to fix this problem include adding bump stops to the suspension, increasing spring stiffness, adjusting damping in shocks, or raising ride heights. All these components have kept the vehicle from dragging on the floor and slowing the vehicle's speed.

d. Deliverables

Max speed and acceleration will be compared to the predicted value. The ability to handle off-road terrain will also be evaluated to see how much difference is made. Gave the car a passed or failed based on the success of climb up the ramp. Also, pictures and videos were taken for the recording of the data. The behavior of the suspension components and steering was also noted. If used for a competition, one of the essential factors will be how the car can steer and withstand jumps. Redesigns will be made if any test is failed until a design that satisfies all four tests are achieved.

The max speed test had a predicted result of reaching an average speed of 20 MPH. But the reached result was the car got an average speed of 5 MPH, which is below what was predicted. The slow speed was probably from the car going through much wear and tear before doing this testing session. The main problem found was the main differential gear was striped a lot. After doing the drop test for the chassis test, it seems the gearbox competition where lose. Which also gave the ability for gear to be misaligned. These factors affect the result of the speed test having slow speeds.

The max speed was tested again with a few changes to the gearbox—the main changes being the differential gear to a modified lego gear instead of a 3D printed one. Also, glue down the gearbox point, so it was not that loose anymore. Then from previous knowledge of the last test and new calculations, lower the speed prediction to a more reasonable speed of 10MPH. After having the five main trails, the average speed was 10.88MPH, which is a pass of meeting the requirement of getting 10MPH.

5. BUDGET

a. Parts

The parts for this project have been purchased and manufactured. Some parts are readily available for purchase and, due to time constraints, were more efficiently purchased than manufactured in-house. Other parts have been manufactured due to the required parameters of the dimensions needed.

All the parts required for this system are as listed and can be seen in Appendix C.

The cost varied throughout the design because of changes during the building quarter. Since it was planned to have 80% of the custom-made components, making the cost cheaper, the school's shutdown had restricted custom parts to using more off-shelf parts, which causes spending more parts.

One significant area change of part was swap where 3D print gears for the gearbox were changed to Lego gears. This choice was made because they were already owned and would save money on making them on the 3D printer and time because they were already made. Another change was making the custom electric components to be more accessible on the drive's electric part.

As of February 12th, 2021, all 12 components that planned to be bought have been purchased. The pieces bought all match what the model needed, and the measurement matched what the product describes them to be.

There have been a few redesigns in the project to affect a lot of the car. But all the parts have been arriving on time, and the parts that still need to be 3D printed will not take that might time to change. We will finish the project on March 27th with the planned budget estimated in the design quarter.

During April, testing began, and some errors arrive at the project car. So there had to be a rehaul of the gearbox, and new parts had to be reprinted. But since there was remained filament for the 3D printer, the budget was not affected.

As of the end of May, the overall project was done, and the project was kept under budget.

b. Outsourcing

Most of the part will be plastic, and 3D printed thought the help of Mr. Kern's school printer. The remaining components will be purchased through Amazon. The rest will be manufacture by Gizan and Chesna in their homes or on the Central Washington University campus.

c. Labor

For the whole project, the 3D printer took 45 hours to print all the components for the project. That includes all the prototypes and different versions of parts. The parts were ordered, and it took ten days for parts and components purchased on Amazon to come to Ellensburg. The rest of the car labor will be with time from Gizan and Chesna putting the car together for free.

d. Estimated Total Project Cost

The total cost of the project should cost under $400. Look at Appendix C for the cost breakdown for the drive train of the car cost. The Drive Train cost was estimated to be under a budget of $200. The final cost of building the drive train and steering project was $198.27, which fit under the given account, which half of the components were already owned. The overall car cost was $356.89, which was under the max limit of how much the project should cost.

e. Funding Source

The cost of this project is supported by out-of-pocket money from Gizan Gando & Chesna Kern. Also, from spare car donation part from Central Washington University Mechanical Engineering Technology department.

6. Schedule

a. Design

The schedule for this project was estimated during the design phase, before the start of any construction or ordering of necessary parts. Within the design portion of the project, the deadlines are listed below. The time involved with the design was estimated accurately based on screen time and time in class.

Design section (a-f)

- 10/02/2020

Analysis:

- Analysis 1: 09/25/2020
- Analysis 2: 10/02/2020
- Analysis 3: 10/09/2020
- Analysis 4: 10/09/2020
- Analysis 5: 10/16/2020
- Analysis 6: 10/16/2020
- Analysis 7:10/23/2020
- Analysis 8: 10/16/2020
- Analysis 9: 10/30/2020
- Analysis 10: 10/30/2020
- Analysis 11:11/06/2020
- Analysis 12: 11/06/2020

Drawings:

- Part 1 Drawing: 10/09/2020
- Part 2 Drawing: 10/16/2020
- Part 3 Drawing: 10/23/2020
- Part 4 Drawing: 10/30/2020
- Part 5 Drawing: 11/6/2020
- Assembly Drawing: 11/13/2020

b. Construction

After finishing the design part of the schedule, a continuation was made for this project construction phase. Within the project's construction portion, the deadlines are listed below—the time involved with the estimated accurately based on building time and time in class.

Timeline Marks:

- Design Finalized: January 15th, 2021
- Manufactured Check 1: January 20th, 2021 (at least two parts made for final design)

- All parts ordered/produced and delivered: January 25th, 2021
- Manufactured Check 2: February 3rd, 2021 (four more parts made for final design)
- 3D prints of all parts: February 21st, 2021
- Adjustments and last parts printed: March 1st, 2021
- RC Car assembled and ready for testing: March 5th, 2021

To assemble this project, 18 different 3-D parts are needed, consisting of 28 pieces. There are also 42 purchased parts that a few need to be modified.

A scheduling issue that was run into was not being able to any lab space, which included a 3-D printer for two weeks. This caused the project to be slightly behind those parts in progress. It also totally flipped the original way the project should run. First, made the control system and getting all the electric components functional. Once access was allowed on campus, the part-making began. Changes had to be made to the Gantt Chart during Construction, but that got the project back on schedule and allowed the device to be assembled.

Redesigns also had an impact on the schedule. The original proposed design and analysis were not expected to work precisely as planned. Which interments that more time had to go into the redesign and to modify. If the project did not shift to using more off-shelf parts, then it would not have been finished by the end date. One of the parts that were changed was Lego gear instead of making personal 3-D printed gears. It was the main change because the 3D printer could not get in the tolerance need. They were also changing to make control system from buying one off-shelf and making a personal controller for the RC car.

c. Testing

After finishing the building part of the schedule, a continuation was made for this project testing phase. Within the project's testing portion and project submission, the deadlines are listed below—the time involved with the estimated accurately based on building time and time in class.

Timeline Marks:

- Written Test Procedure: April 2nd, 2021
- Start testing: April 5th, 2021
- Test Demo Report TDR 1: April 14th, 2021
- ASME RC Baja car competition: April 23rd, 2021
- Test Demo Report TDR 2: April 28th, 2021
- SOURCE Poster Final Draft: April 28th, 2021
- SOURCE Poster Submission: April 30th, 2021
- Testing Report: May 10th, 2021
- Presentation Video: May 24th, 2021

During the beginning testing phase, the car was not fully working under the testing condition that it was being put under. So the overall schedule was shifted to allow for some modified tweaks to the car. The first TDR saw a failure to the car as there was a problem with the car's transmission and need a whole rechange. But by the second TDR, the speed test was redone, it was given a pass. The other test was conducted and where given result according.

Overall the limitation to this project was time. If there was more time, there could be more modifications and changes to the design and build of the car after the first round of testing. But there could only be so much done for a year of this project.

7. Project Management

a. Human Resources
Dr.Choi and Dr. Pringle gave a steady flow of knowledge and resource during the project's duration. Which included help in the analysis solving, the contact for resources on the project, the break down of what was expect at the end of the project. Chesna Kern had an equal share of the project and many more risks were associated with her involvement. If she was not able to manage his time well, deliverables for the drive train that need information from the chassis could have been late, not to mention the actual building of the project where the car would not have been able to fit together and have functionablity.

b. Physical Resources
During the designing The computer lab in Houge 120 was used a lot to design in the fall.

To successfully complete the project, the team needed access to a 3d printer and a laser cutter, both of which were available in Hogue hall, but high demand for the 3d printers caused the team to move manufacturing to other locations. The risks associated with this include access and time.

Access was limited from the school by the ongoing COVID-19 pandemic and complicated by the team's work schedule. This preventing the team from accessing the 3d printers and laser cutter needed to produce parts. The 3d printers also take a significant amount of time to print, so all parts needed to be printed as early as possible to avoid a time crunch on printing. The laser cutter also presented a physical resources problem in that a maximum of two chassis plates could have been cut from the sheet of acrylic the team bought initially

c. Soft Resources
All the design was made on Solidworks software. The writing of this project was done on Microsoft Office Word. The templates of the project were provided in the senior project class of the CWU MET program. Risks associated with these as project schedule updates could have been lost if Word crashed with the large file or it becoming corrupted,. Also with SolidWorks crashed the assembly and/or parts could be lost. SolidWorks did crash a few times, but only a few easily repeatable updates were lost. The best way to prevent these issues was to keep multiple copies and always turn on autosave.

d. Financial Resources

The entire budget was out of pocket for the team (Gizan and Chesna), so if the project went over budget, the team had to pay more. The risk of going over budget was low as the most expensive part of the chassis (the wheels) were donated.

8. DISCUSSION

a. Design

The Radio Control Baja car drivetrain goal was to find a way to transfer power from the motor to the rear wheels in the most efficient manner while still allowing maximum power and optimized for torque output. It was essential to making sure all the components worked together in an assembly during the design process. Basing the design on a standard R/C Car and other CWU MET students' past cars, power transmittal's central idea was a geared rear-wheel drive.

The main design factor in designing the Radio Control Baja car's drivetrain was determining the proper gearing ratios between the motor, axles, and differential. When starting the design, an assumption was made that the need max speed was 30 mph, so a 9:1 ratio was determined. But that ratio was not enough torque for the car to go up a 45-degree ramp, so a second gear ratio was determined to be 12:1 so that the vehicle could go up the ramp. In the end, the design has a gearbox that has a shifter that can change between these gear ratios. It can be fast when it needs to be and have torque when it needs to be.

Another essential aspect of the drivetrain design was the type of material being used for the drivetrain. The main plan was to use 3D printing to be too quickly revised when needed for the next step of making the RC Baja Car. 3D printing will also help put the whole assembly together because it designs all the parts harmoniously and printing with tighter tolerances. Also, a spare part can be made in just a couple of hours, rather than waiting for the order part to manufacture parts by hand. Plastic components will also help keep the drivetrain weight in the range of less than10lb. The parts that will be printed are gears, shifter, shifter axle, motor holder, gearbox shell, steering arms, pivot points, servo motor mounts, holding clips, and more depending on redesign during the duration of the other period of this project.

b. Construction

At the beginning of the first two weeks of the construction period, there were some restrictions to access 3D printers and other machines to make the parts. In turn, shifted and rearranged the project's whole construction phase schedule. The original plan was first to create the full-function gearbox, move to the steering parts, and then add the motors plus electric components. But since that process could not be excused in that order, building electrical components and testing out the motors were done first because it did not require any part to be made yet. Then when the campus opens up started to work on the other components.

A stander radio-control car remote only has space to hook up an electronic speed control (ESC) for the drive motor and a port for the steering servo motor. Brought the problem of need a port to control the gear box's shifting servo. It was decided to make a custom drive controller instead so that any extra need electric components that need to be added could be added. After some quick research, the cheapest and fastest way to build a custom electric board was to use an Arduino board and a wireless controller. The process was relatively easy; first, wires were connected to all the components: battery, ESC, motor, and servo, to the board. Then moved on to program the board to test that all the components could run off the board. Some challenges were to figure out the output number for power and angle rotation for motor and servo. A programming map for the controller was then made to give value based on the button's position to transfer the power to the motor or angle position on a servo dependent on the button. Then connect an antenna to the controller and the board to be controlled off the computer.

Once there was access given to the 3D printing, the first batch of prints was made on all the parts needed. All the parts that had to design in the design phased fail during the first printing. All the components that had more detail: gears, pivot points, and servo brackets failed. Different materials like PLA, ABS, and resin were tested, and none could produce the right part within the tolerance need. Multiple runs were also tried, but the result was consultation. The first option was to make the part out of other machines like a laser cutter or CNC machine from a piece of plastic. Calls were made, and research was done, but the time constraint of trying to get it done and making sure it worked by the time deadline had a considerable risk. So, moved on to use Lego part like gear and pins to use and incorporate them into the design. This decision was made because there were already Legos in-hand, and there is high certainty that it will yield needed results. Then from choosing those gear, a new gearbox was a redesign from the ground up.

The first iteration of the redesign gearbox was one whole piece, but it failed after printing it three times. The main root of the problem was that it was too intricate and required many support material in the middle. The 3D printer that was used had a problem switching between building and support. This printing way also causes it to be so much work to remove the support material if it finishes all the way. The redesign was made for the box was to slice it up and reassemble it with a few screws. After weeks of working with the 3D printer and getting a more successful print that fit the tolerance given and did not fail, then it was time to assembly the gearboxes.

The steering was made in Lego because it needed to be easily adaptive to rebuild during this period. This component was the hardest to design because it also is dependent on how the chassis is built, which is not part of this project. In the end, the design did call for a 3D print mount that could hold up the servo for the steering, but the rest was Lego parts. Communicate with the team to change the pivot arm on the chassis to incorporate the Lego axle to build on.

During the gearbox construction, the motor shaft adapters made from 3D printed ABS keep stripping and falling out of place. A quick solution was made with limited time, which was that a brass gear made more RC was stripped down to make like a motor coupling—then tapped one side to attach the need Lego gear.

During the last two weeks of the quarter had a lot of meeting up with the team to make sure that everything was getting incorporated correct and checking that everything was functional before the March 10th working device deadline.

c. Testing

The first test that the RC Baja car went under was the speed test, which had a predicted requirement of reaching a top speed of 20MPH. But after running the first few trials, the car performance did not reach the expectation that it needs to be. The car only reaches a speed of around 5MPH. A problem that arose was that the car went through some wear and tore before testing. When the gearbox looked again, there was a problem between the pinion gear and the differential gear. So replacements were made, and another test happens, but the problem arose again. The differential gear was 3D printed out of ABS, which cause to be a lot of weak points in the teeth. Then, switch out to using a modified Lego gear to fit where the differential gear was 3D. There have been fewer teeth breaking, which is a real improvement.

The other partner of this project underwent drop testing. Tested the car up to 2ft off the ground test, which looked at if it would later survive an obstacle course. But this test results in a fail also bring the chassis plate to snap. Lucky most of the parts for the car are modular, so switching and changing parts was a breeze. During the car's repair process, the gearbox was looked at, and found out the box was very loose, attached to the base plate. The screw attachment must have broken during the drop test, which entails that the gear would start to misalign and strip teeth. The repair was made to fix the screw attachment, but the box keeps falling apart. So the quick backup solution was to use plastic glue to bond the base plate to the box. The downside is that the gearbox can't be fully taken apart, which means repair might take longer because there is less access point now. But the gearbox is now fully operational and able to run.

After a few more test runs, a problem started to arise in the pinon gear. The gear teeth kept on bending and breaking off. So a redesign of the gearbox was needed for the car to survive all the speed and running tests. The main focus of the redesign gearbox was to make room for the eight tooth pinion gear to be a tweety-four tooth pinion gear. The change will help reduce tooth stress on each tooth, helping cause less bending and breakage. The new redesign was changed to a single fix ratio instead of the original switch speed ratio, which failed during testing. The finished product was with a more compact single-speed gearbox, with a bigger pinion gear with more teeth so that the gear toque can be more disputed.

When the redesign where done, the test continued. The speed test was reconducted, and it could not reach the minimum requirement of 10 MPH. During the testing, the car only reached half its potentiation max speed, and this was because there was something that was making the front wheel of the car jam up and stop spinning and turning the car uncontrollably. So this meant the car did not reach the minimum requirement and was given a fail. The car was able to be successful during the ramp test to get up a ramp around a 20-degree slope. The differential was also tested and was successfully working like it was designed.

9. CONCLUSION

This project was to design, build, and test an RC car for the ASME club's annual RC Baja competition, which consists of sprint, slalom, and obstacle course events. This project's success depended upon the car's ability to finish all three events. The team decided that speed, durability, and simplicity were the keys to completing these events. Speed was primarily dependent upon the design of the drivetrain, which was based on the function. But also having a chassis and suspension need to be light to help make the car fast, but this was out of my project scope. There were many versions of the gearbox to help it perform more effectively, stronger, and more straightforward with each iteration. Also, the same with the steering block went through many design changes. These changes were quickly many under quick time change with being to 3D print or laser cut significant of our parts. With the adjustment, the car becomes lighter, which help also makes the car faster. Durability was the focus of the gearbox and steering design too. The bearings were used in the gearbox to stand up to an impact at the speeds the gearbox would be under the predicted top speed of thirty mph. The axel was also analyzed to determine if they would make it through the stress and strain the car would endure. Still, every part used simple shapes for ease of manufacture and analysis. Most parts were either used in multiple locations or were based on the same design and modified for different positions.

10. ACKNOWLEDGEMENTS

Project help from professor Dr.Pringle and Dr.Choi for supporting this project by mentoring both the principal engineer and drivetrain engineer for the project.
Manufactionn help with 3D printing and laser cutting from Mr.Kern.
My project partner Chesna Kern
Thank you to the CWU ASME club for donating the wheels for the project car.

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APPENDIX A - Analysis

Appendix A.1.1 – ***Speed and ratio Calculation page 1***

Gizan Gondo | MET 494 A.1 | 9/25/20 | 1/2

Design Requirement: max speed ≥ 30 mph

GIVEN:

- ↳ Motor ⇒ have at least 4000 KV rating (brushless)
- ↳ Battery = high voltage of 7.2V
- ↳ Tire size = OD ≈ 4 in ⇒ 101 mm

FIND: The need gear ratio from the motor to the wheel

Assume: ↳ Neglect all loses with in the drive train system
↳ Constant max RPM

METHOD: ↳ Solve max motor RPM
↳ Solve for max speed to RPM
↳ Solve for Max Drive Ratio
↳ Solve for using only 3/4 of max motor ⇒ 5.4 V_{max}

SOLUTION:

↳ Motor RPM

$$RPM_{max} = \text{motor KV} \times \text{max voltage} = 4000 \frac{RPM}{V} \times 7.2V = \boxed{28{,}800\ RPM}$$

↳ Max Speed → RPM

$$1\ Rev = \pi(OD) \Rightarrow \pi(101mm) = \boxed{317.30mm}$$

$$\left(\frac{30\ miles}{1\ hr}\right)\left(\frac{1609.34m}{1\ miles}\right)\left(\frac{1000\ mm}{1\ m}\right)\left(\frac{1\ Rev}{317.30mm}\right)\left(\frac{1\ hr}{60\ min}\right) = \boxed{2{,}535.98\ RPM}$$

↳ Max Drive Ratio

$$Ratio = \frac{\text{Max motor RPM}}{\text{Wheel RPM}} = \frac{28{,}800\ RPM}{2{,}535.98\ RPM} = \boxed{11:1}\ \text{max}$$

↳ Drive Ratio lower to (3/4 ⇒ 5.4V)

$$Ratio = \frac{(3/4)(\text{Max motor RPM})}{\text{Wheel RPM}} = \frac{21{,}600.00\ RPM}{2{,}535.98\ RPM} = 8.51 \Rightarrow \boxed{9:1}$$

Appendix A.1.2 – *Speed and Ratio Calculation page 2*

Gizen Gudo | MET 489 A.1 | 9/25/20 | 2/2

GIVEN:

Motor → Wheel Ratio = 9:1 for 30mph

Differention Ratio = 2.5:1

FIND: The need Transmission Ratio

ASSUME: Neglect all loses from friction

METHOD: ↳ Use Trasmission Ratio!

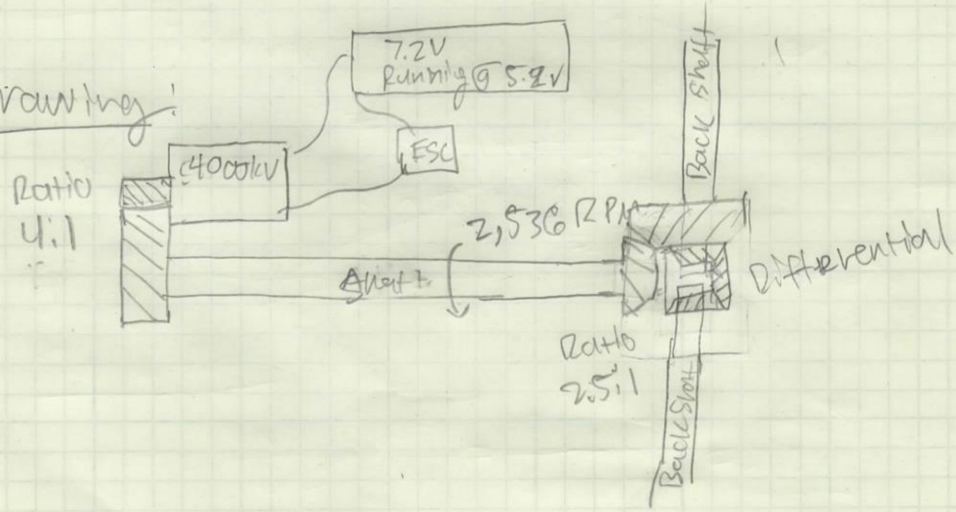
SOLUTION:

$$\text{Transmission Ratio} = \frac{\text{Final Drive Ratio}}{\text{Differential ratio}}$$

$$\text{transmission Ratio} = \frac{9:1}{2.5:1}$$

Transmission Ratio = 3.6:1 ⇒ **4:1**

Drawing!



Appendix A.2.1 – ***Needed drive ratio to going up a ramp page 1***

Gizen Gando | MET 489A A.2 10/01/2020 1/2

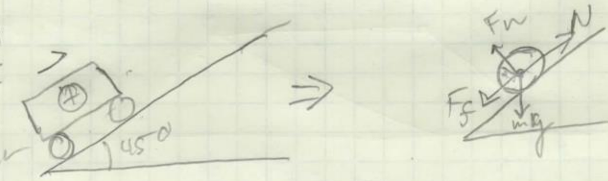
GIVEN: ↳ car > 16 lbs ⇒ 7.2575 kg (Website of engineering tool box) for rubber
↳ Tires ≠ 8 4in μ_k = avg. 0.7
↳ Speed = 30 mph ⇒ 13.41 m/s

$T = F * r$ FIND: Need Torque to go a feet a 45° ramp

Assumption: weight of Car is in the center
↳ The μ_k is an average rubber value

Method: FBD, work on sum of torque to get drive ratio

Solution:



horse power ↓

$P = \bar{F} \times \bar{v}$

$P = mg\cos\theta \cdot \mu \cdot v$

$P = (7.2575\,kg)(9.81\,m/s^2) \times (\cos 45°) \times (13.41\,m/s)$

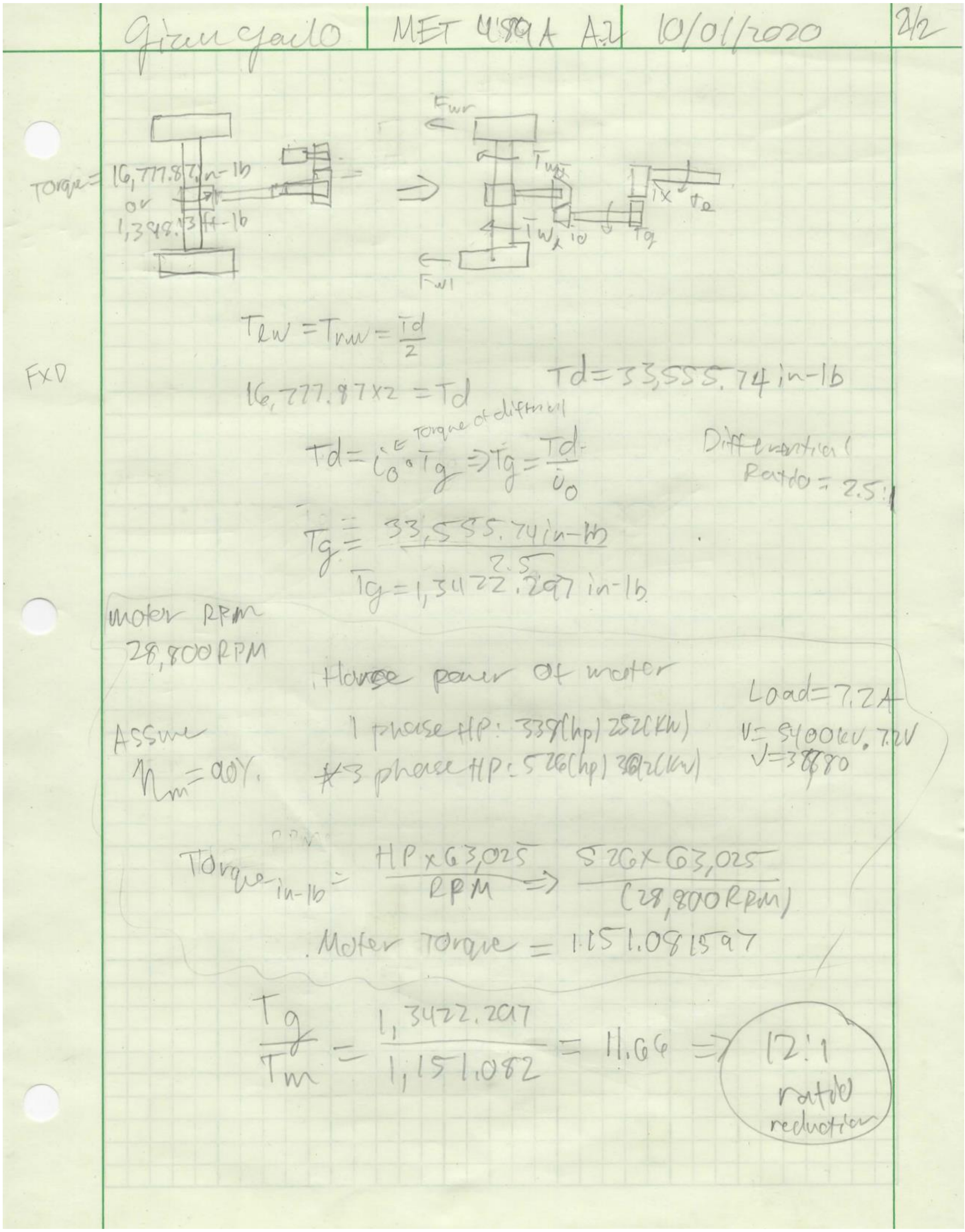
$HP = 675.1027\,HP$

$$\text{Torque in-lb} = \frac{P \times 63{,}025}{RPM} \Rightarrow \frac{675.10\,HP \times 63{,}025}{2{,}535.98\,RPM} = 16{,}777.87\ \text{in-lb}$$

(found in previous analysis)

$$\text{Torque ft-lb} = \frac{P \times 5{,}252}{RPM} \Rightarrow \frac{675.10\,HP \times 5{,}252}{2{,}535.98\,RPM} = 1{,}398.14\ \text{ft-lb}$$

Appendix A.2.2 – ***Needed drive ratio to going up a ramp page*** **2**



Girun Gaclo | MET 4?9A A2 | 10/01/2020 | 2/2

$T_{lw} = T_{rw} = \frac{T_d}{2}$

FxD

$16{,}777.87 \times 2 = T_d$ $\quad T_d = 33{,}555.74$ in-lb

$T_d = i_0 \cdot T_g \Rightarrow T_g = \frac{T_d}{i_0}$ (Torque of differential)

Differential Ratio = 2.5:1

$T_g = \frac{33{,}555.74 \text{ in-lb}}{2.5}$

$T_g = 1{,}3422.297$ in-lb

motor RPM
28,800 RPM

Horse power of motor

Load = 7.2A

Assume
$\eta_m = 90\%$

1 phase HP: 339(hp) 252(kW)
3 phase HP: 526(hp) 392(kW)

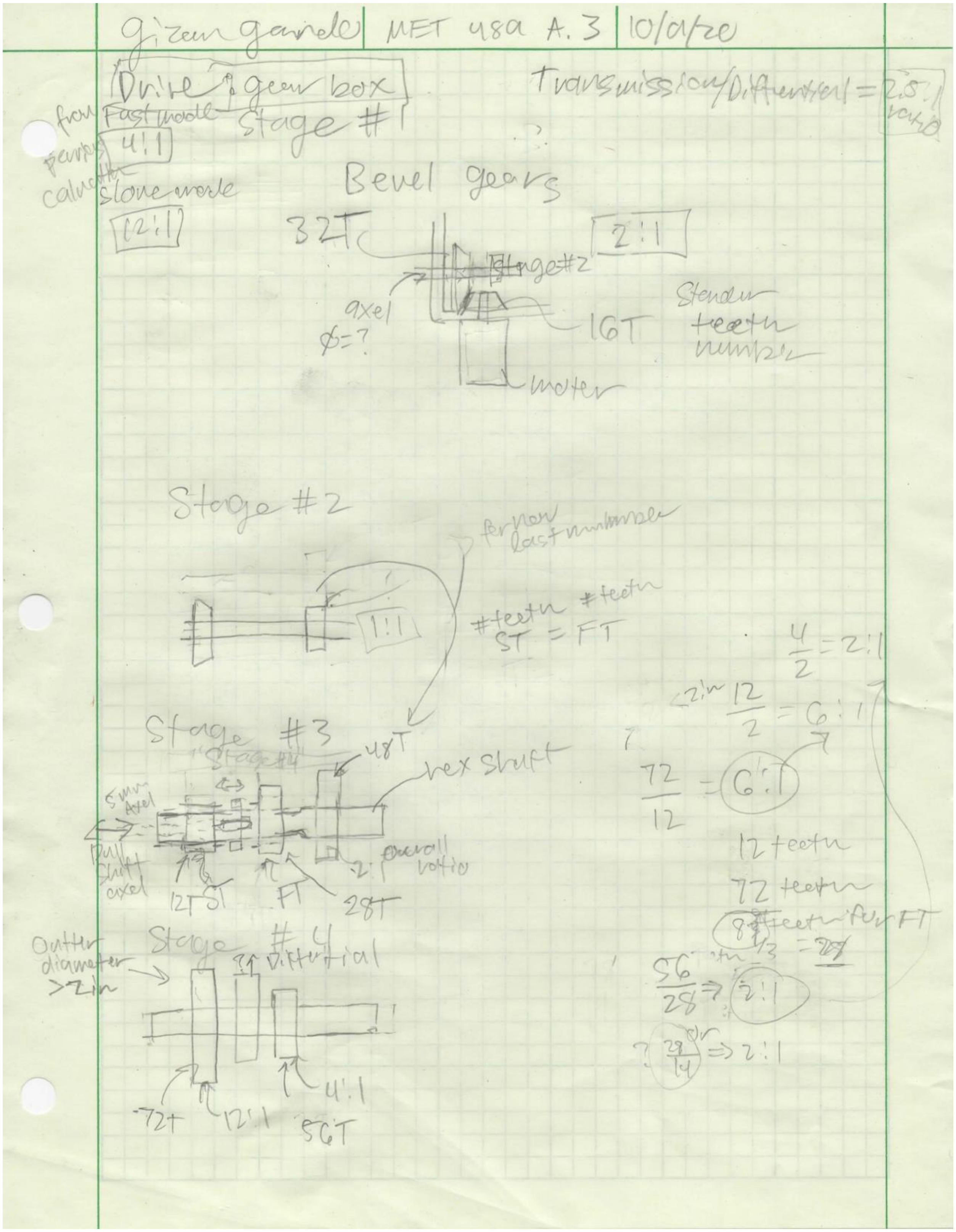
V = 5400kV, 7.2V
V = 38880

$\text{Torque}_{in\text{-}lb} = \frac{HP \times 63{,}025}{RPM} \Rightarrow \frac{526 \times 63{,}025}{(28{,}800 \text{ RPM})}$

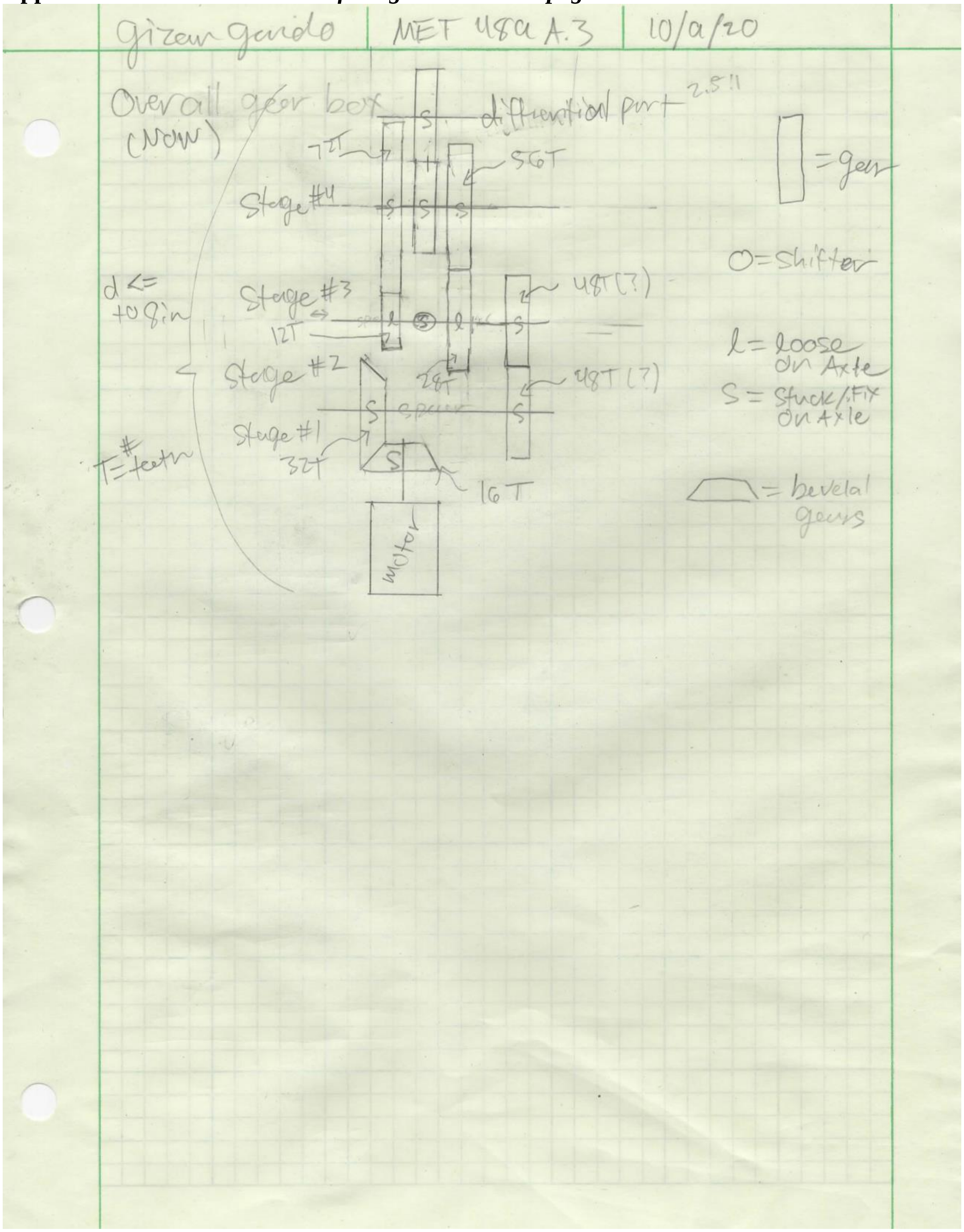
Motor Torque = 1,151.081597

$\frac{T_g}{T_m} = \frac{1{,}3422.297}{1{,}151.082} = 11.66 \Rightarrow$ 12:1 ratio reduction

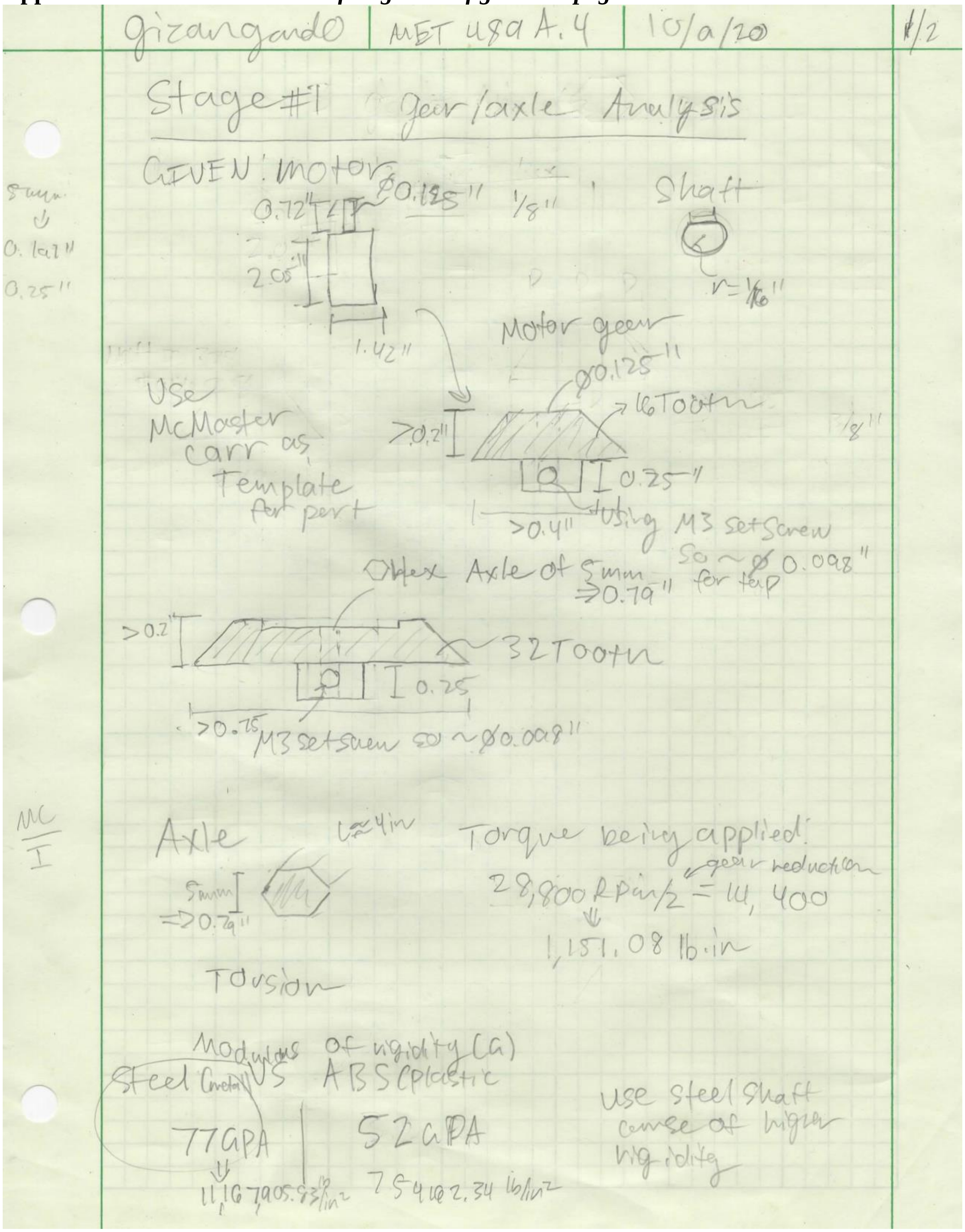
Appendix A.3.1 – ***Calculations of the gear box ratios page 1***



Appendix A.3.2 – ***Calculations of the gear box ratios page 2***



Appendix A.4.1 – ***Calculations of stage one of gear box page 1***



Appendix A.4.2 – ***Calculations of stage one of gear box page 2***

given grade | MET 484 A.4

Stage #1

Axle cont.

Maximum shear stress (τ_{max} : 12,608.93 psi

HP required : 34.52 HP < 526 HP ✓

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

$I = 0.06 D^4$

$I = 0.06 (0.197)^4$

0.197"

$\tau (I \cdot t) = V$

$V = (12{,}608.93\ psi)(9.037 \cdot 10^{-5}\ in^4)(0.0985\ in)$ lb·in

$V = .11.222$

Shear factor of steel 0.6

0.11 ≤ 0.6 ✓ (so steel will not break under the high torque)

steel

Appendix A.5.1 – ***Finding Axle size and mass page 2***

Gizem gado | MET 489 | 10/16/20

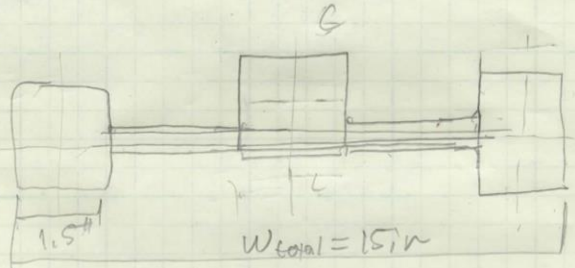
GIVEN: Tire width = ~1.5 in
Tire O.D. = ~4 in
Allowable width = ~15 in

FIND: Solve for axle length, diameter, and mass

ASSUME: Material will be Homogeneous

METHOD: 1) Draw diagram of rear end
2) Solve length of axle
3) Solve allowable diameter of axle.
4) Find material and density
5) calculate mass of axle

Solution:



$W_{t}/2 = 7.5 in$

Length $- (W \times 2) = 15 in - (1.5 \times 2) = 12 in$
Axle length to inside face of wheel = 12 in

Needed length to pin hub = 0.2 in
Axle length = $12 in + (0.2 in \times 2) = 12.4 in$

diameter of Axle to be 5 mm hex ~ 0.2 in
$d_{axle} = 0.2 in$

Appendix A.5.2 – ***Finding Axle size and mass page 2***

Gicean Grido | MET 489 | 10/16/20

material = 6061 Aluminum 5mm O.D.

ρ 6061-Alum = 2.7 g/cm^3

Yeild Strength = 35,000 psi (McMaster-Carr) Sucess!

Volume of the axle:

$V = \pi r^2 \times h = \pi (0.1\text{in})^2 \times 12.4\text{in}$

Volume of axle = 0.39 in^3

mass of axle:

mass = density x volume

0.39 in^3 ⇒ 6.39

2.7 g/cm^3 x 6.39 cm^3

mass of axle = ~17.25 g

Appendix A.6.1 – ***Finding Acceleration page 1***

Gizen gade | MET 98a | 10/16/20

GIVEN: Wheel radius = ~2in ⇒ 0.051m
Torque = 16.78 in·lb or
mass of wheel = 120 grams
Rev of rear axle = 4,535 RPM

FIND: ↳ Force applied by wheel
↳ Angular acceleration of wheel
↳ linear acceleration of wheel

Assume: constant torque and RPM
Mass of wheel is equal for all wheels
Final velocity is reached in 5 sec

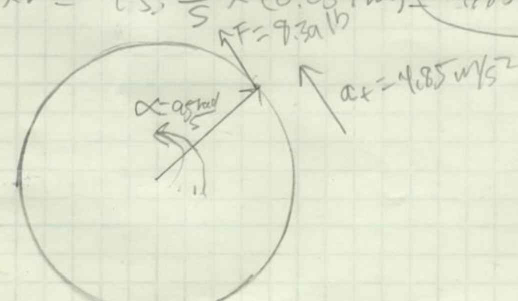
METHOD 1) Solve for force
2) Solve for angular acceleration
3) Solve for linear acceleration

Solution: $\tau = rF\sin\theta \Rightarrow F = \frac{\tau}{r}$

$$F = \frac{16.78\,in\cdot lb}{2\,in.} = \boxed{9.39\,lb}$$

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{4{,}535\,\frac{rev}{min} \times \frac{2\pi\,rad}{1\,rev} \times \frac{1\,min}{60\,sec}}{5\,s} = \boxed{95\,\frac{rad}{s^2}}$$

$$a_t = \alpha \times r = 95\,\frac{rad}{s} \times (0.051\,m) = 4.85\,m/s^2$$



Appendix A.7.1 –*Turning radius and angle page 1*

Giancarlo | MET489 | 10/23/2020 | 1/2

A.7

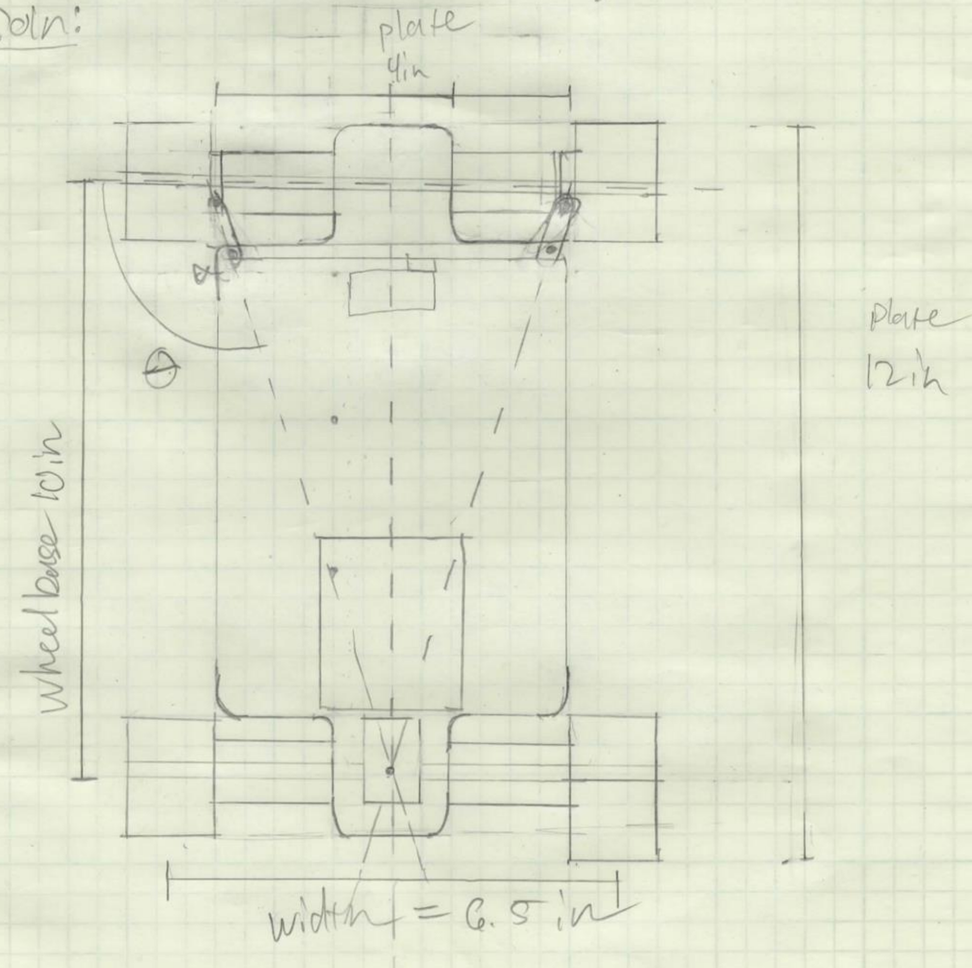
GIVEN: Wheel base = 10in
width = 6.5 in

FIND: Turning Radius & steering mount angle

ASSUME: It does not slip when it is turning

METHOD: a) Draw out the car
b) solve for α – for the mount angle from car
c) solve for θ – for the mount angle from axle
d) solve for r – turning radius

Soln:



Appendix A.7.2 – ***Turning radius and angle page 2***

Gizen Gudo | MET 489 | 10/23/2020 | 2/2

A.7 ↳ Solve for α:

$$\alpha = \tan^{-1}\left(\frac{\left(\frac{W}{2}\right)}{L}\right)$$

$$\alpha = \tan^{-1}\left(\frac{\left(\frac{6.5}{2}\right)}{10\,in}\right)$$

$$\alpha = 7.4^\circ$$

↳ Solve for wanting angle

$$\theta = 90^\circ + \alpha$$

$$\theta = 90^\circ + 7.4^\circ$$

$$\theta = 97.4^\circ$$

↳ Solve for r – turning radius

$$r = \frac{W}{\tan(\alpha)} + \frac{L}{2}$$

$$r = \frac{6.5}{\tan(7.4)} + \frac{10}{2}$$

$$r = 55.0\,in \Rightarrow 4.58\,ft$$

Appendix A.8.1 – ***Length for steering page 1***

Giran Gudo | MET 480 | 10/23/2020 | 1/1

A.8

GIVEN: width of body = 7.5 in
width of wheel center = 4.5 in
Tire width = 1.5 in
mount hub = 0.8 in
steering ratio = 1 in

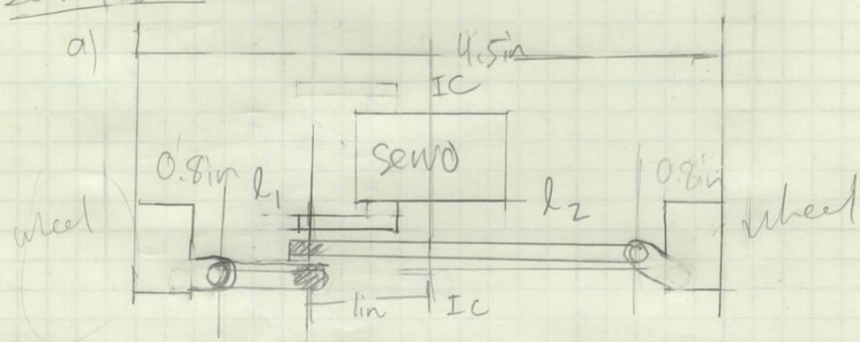
FIND: solve for total the rod length (include the rod-ends)
Solve for threaded rod length

ASSUME: Servo will be place in center
zero angle of the rods

METHOD: a) draw out the steering system
b) solve l_1 - for left side
c) solve l_2 - for right side

Solution:

a)



b) left side length

$$l_1 = \left(\frac{4.5}{2}\right) - 0.8\,in - 1\,in$$

$$l_1 = 0.45\,in$$

c) right side length

$$l_2 = \left(\frac{4.5}{2}\right) - 0.8\,in + 1\,in$$

$$l_2 = 2.45\,in$$

Appendix A.9.1 – ***Length for steering page 1***

Jizou Gundo | MET 4991 | 10/30/2020 | 1/1

A.9

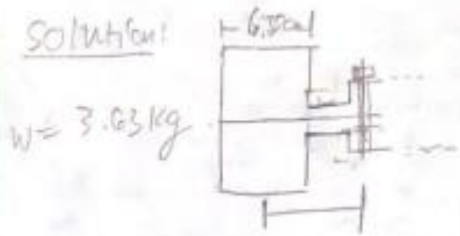
GIVEN: weight = 8 lbs ⇒ 3.63 kg
Tire width = 2.5 in ⇒ 6.35 cm
Center of tire to pin: 1.5 in ⇒ 3.81 cm
Torque must be less than = 21.22 kg/cm

FIND: Torque @ the pin

Assume: $\mu = 0.7$
weight ratio of car is 50/50.

METHOD: . Solve Torque

Solution:



$$\text{Torque} = w\mu\sqrt{\frac{B^2}{8} + b^2}$$

$$= (3.63\,kg)(0.7)\sqrt{\frac{(6.35)^2}{8} + (3.81\,cm)^2}$$

$$= 11.24\ kg \cdot cm$$

$\text{Torque}_{pin} < \text{Torque}_{servo}$ ✓

Appendix A.10.1 – *Length for steering page 1*

Giem Grandle | MET 480 | 10/30/2020 | 1/1

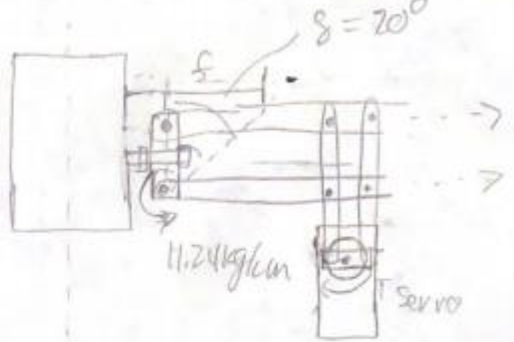
A.10 GIVEN: T at the Pin, $T_{servo} = (0.4)T_{@ Pin}$, $d = 2in \Rightarrow 5.8cm$

FIND: Steering Arm length (f)

Assume: weight ratio for car is 50/50

Method: Solve for Torque of servo

Solution:



$\left(\frac{T}{f}\right) = \left(\frac{T_{servo}}{\left(\frac{d}{2}\right)}\right)$

$\left(\frac{T}{f}\right) = \left(\frac{T(0.4)}{\left(\frac{d}{2}\right)}\right)$

$f = \frac{\left(\frac{d}{2}\right)}{0.4}$

$f = \left(\frac{\left(\frac{d}{2}\right)(T)}{T(0.4)}\right)$

$f = \frac{\left(\frac{5.8cm}{2}\right)}{0.4}$

$f = 7.25$ cm

2.84in

Appendix A.11.1 – ***Length for pivoting beam page 1***

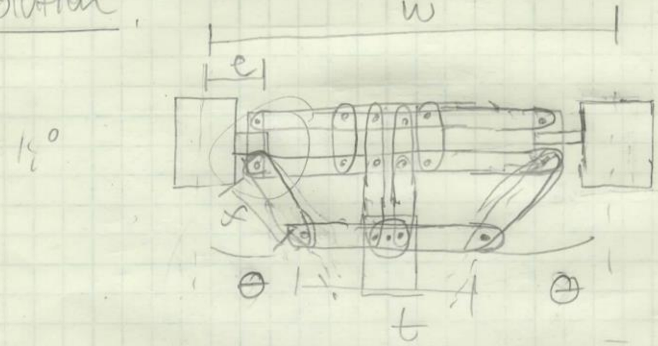
Gizem Guido | MET 489 | 11/6/2020 | 1/1

A.11

GIVEN: $\theta = 18°$ $e = 2.40\text{ cm}$
$w = 16.15\text{ cm}$ $f = 7.25\text{ cm}$

Find: length of pivoting support beam

Solution:



$$t = w - \left[(2e) + \left(\frac{2f}{\sin(\theta)}\right)\right]$$

$$t = (16.15\text{ cm}) - \left[(2(2.40)) + (2(7.25)(\sin(18°))\right]$$

$t = 6.87\text{ cm}$
or
2.75 in

Appendix A.12.1 – ***Length for shifter page 1***

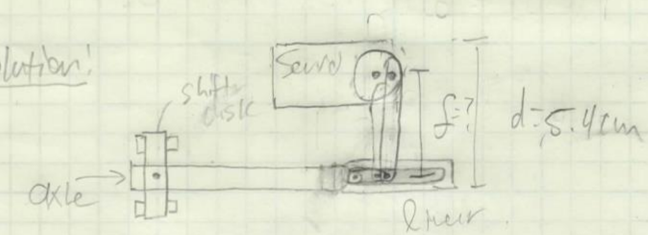
Gizen Grado | MET 489 | 11/6/2020 | 1/1

A.12

GIVEN: Torque of servo = 250 ft·lb

FIND: The pivoting length (f) for shifting gears

Solution:



$$\left(\frac{T}{f}\right) = \left(\frac{T_{servo}}{\left(\frac{d}{2}\right)}\right)$$

$$\left(\frac{T}{f}\right) = \left(\frac{\text{Tan}(0.4)}{\frac{d}{2}}\right)$$

$$f = \left(\frac{\left(\frac{d}{2}\right)(T)}{(T)(0.4)}\right)$$

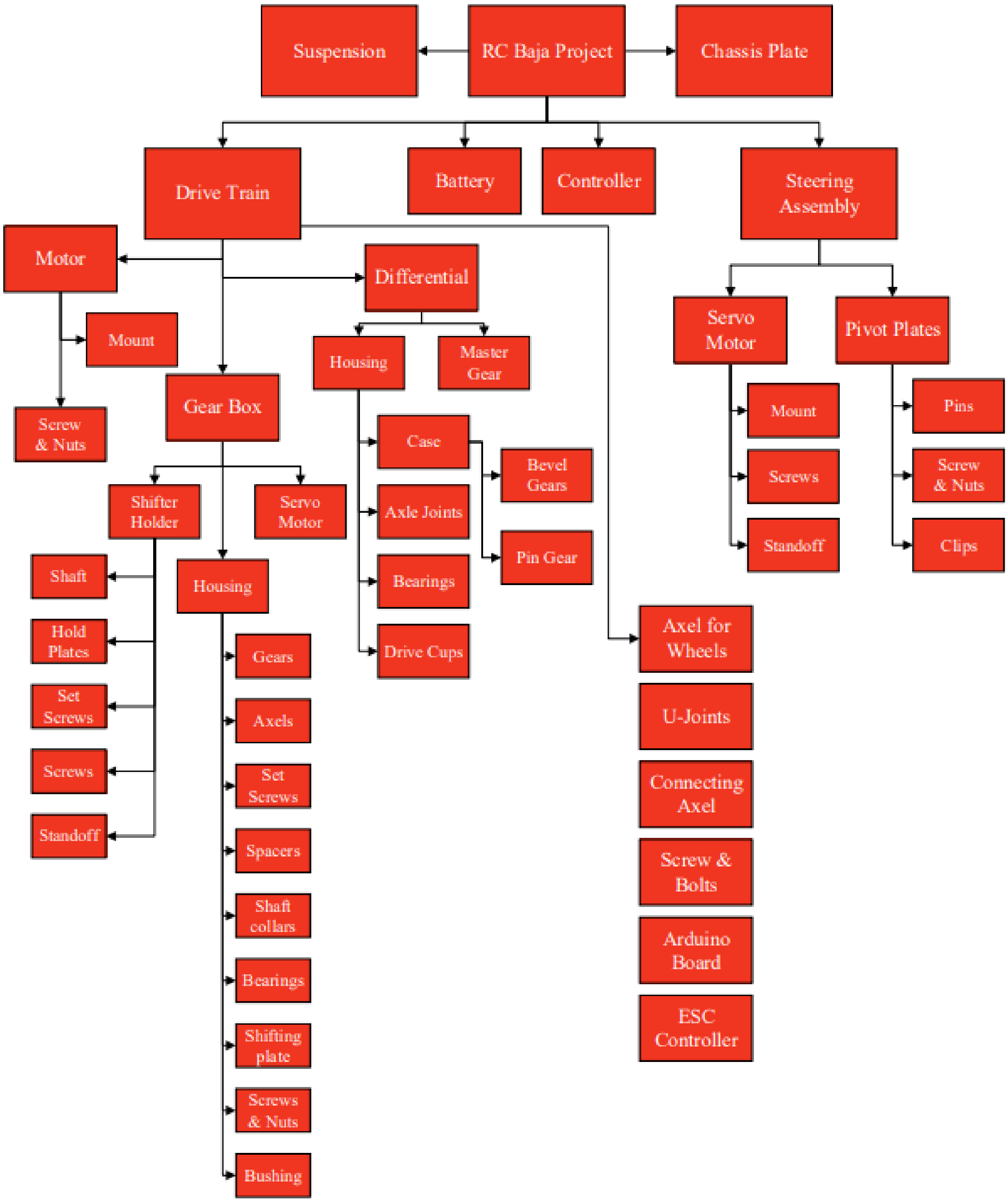
$$f = \frac{\left(\frac{d}{2}\right)}{0.4}$$

$$f = \frac{\left(\frac{5.4}{2}\right)}{0.4}$$

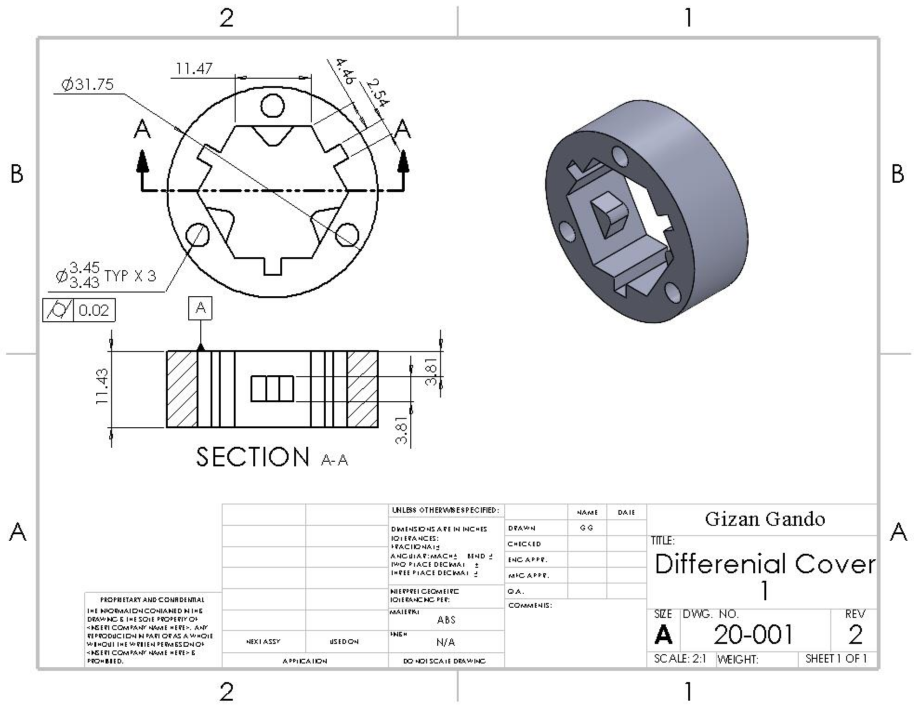
$$f = 6.75cm$$

APPENDIX B - Drawings

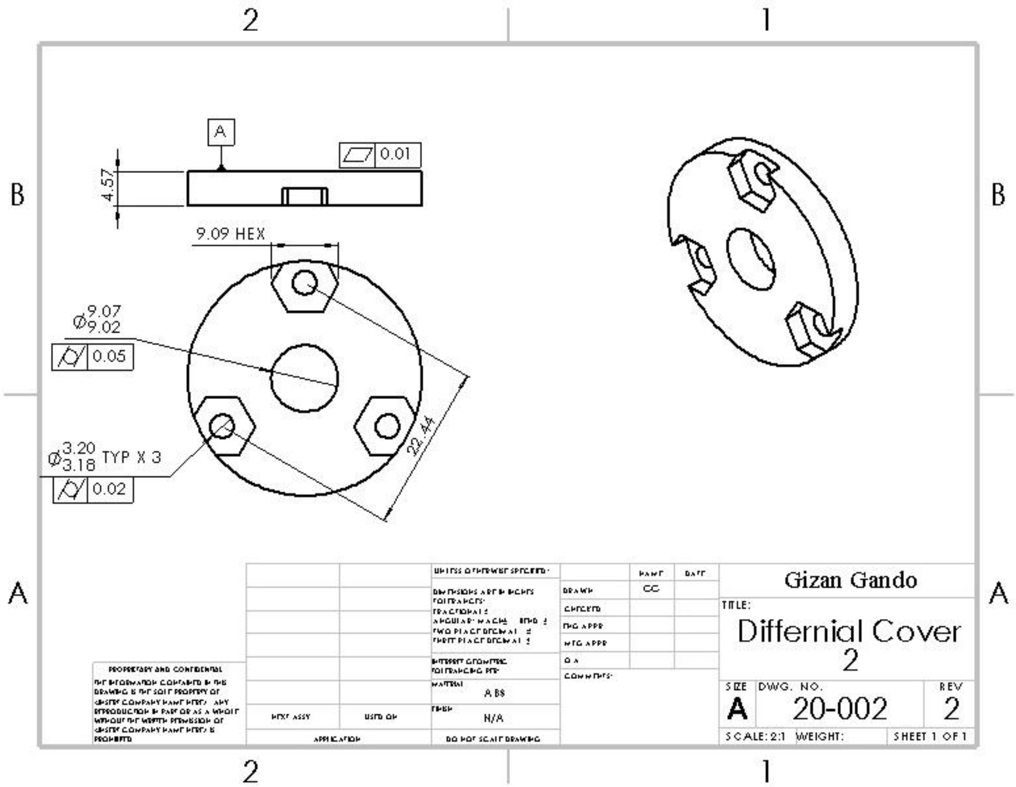
Appendix B.1 – Drawing Tree



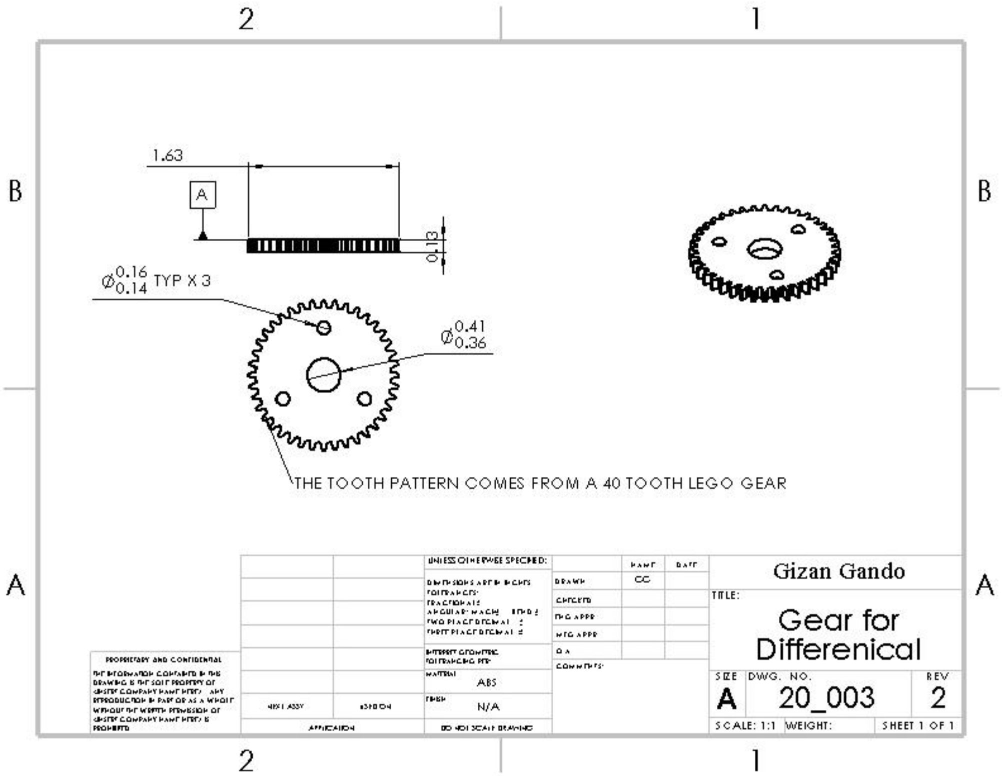
Appendix B.2 DIFFERNICAL COVER 1



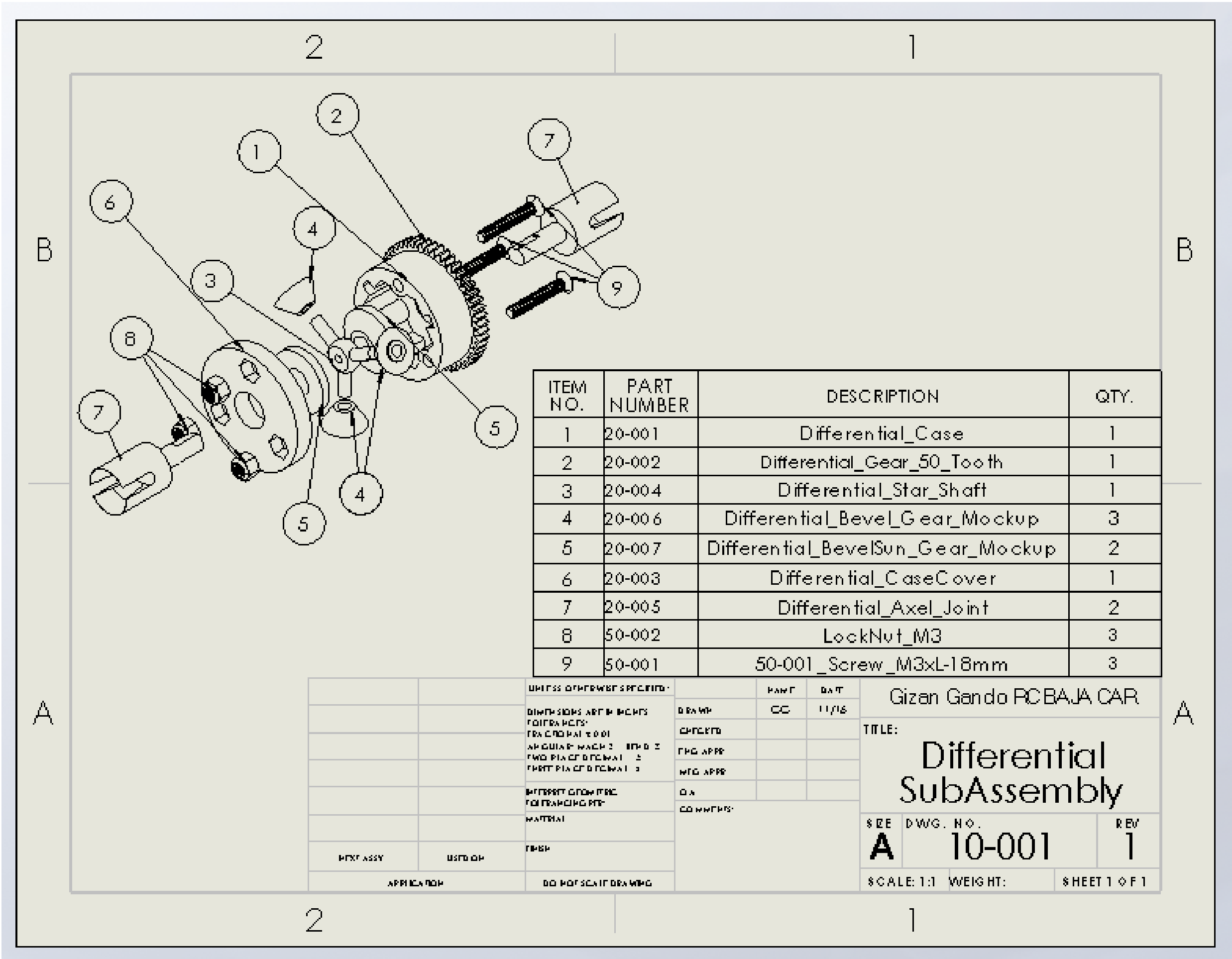
Appendix B.3 DIFFERNICAL COVER 2



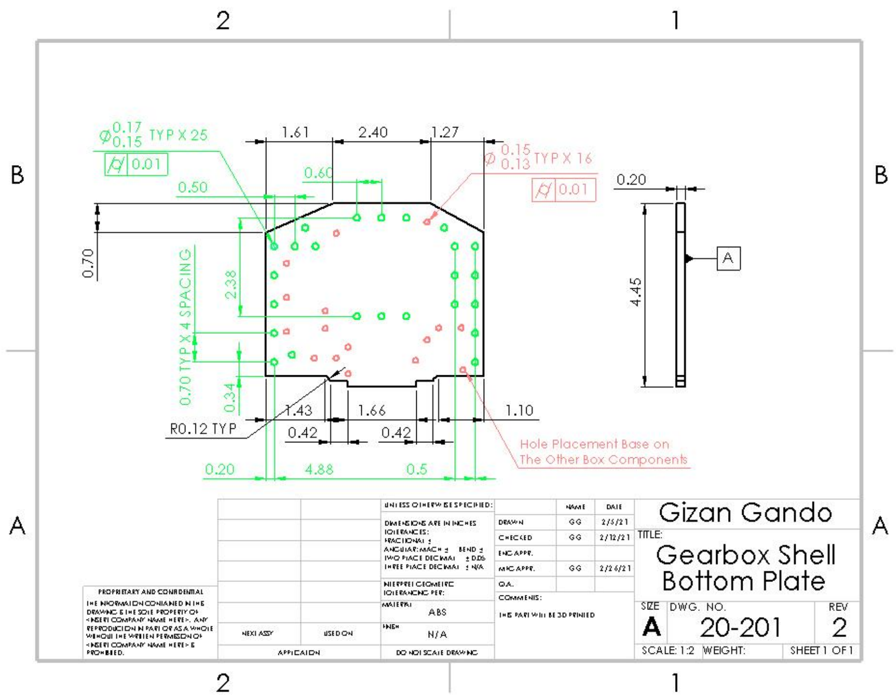
Appendix B.4 GEAR FOR DIFFERNICAL



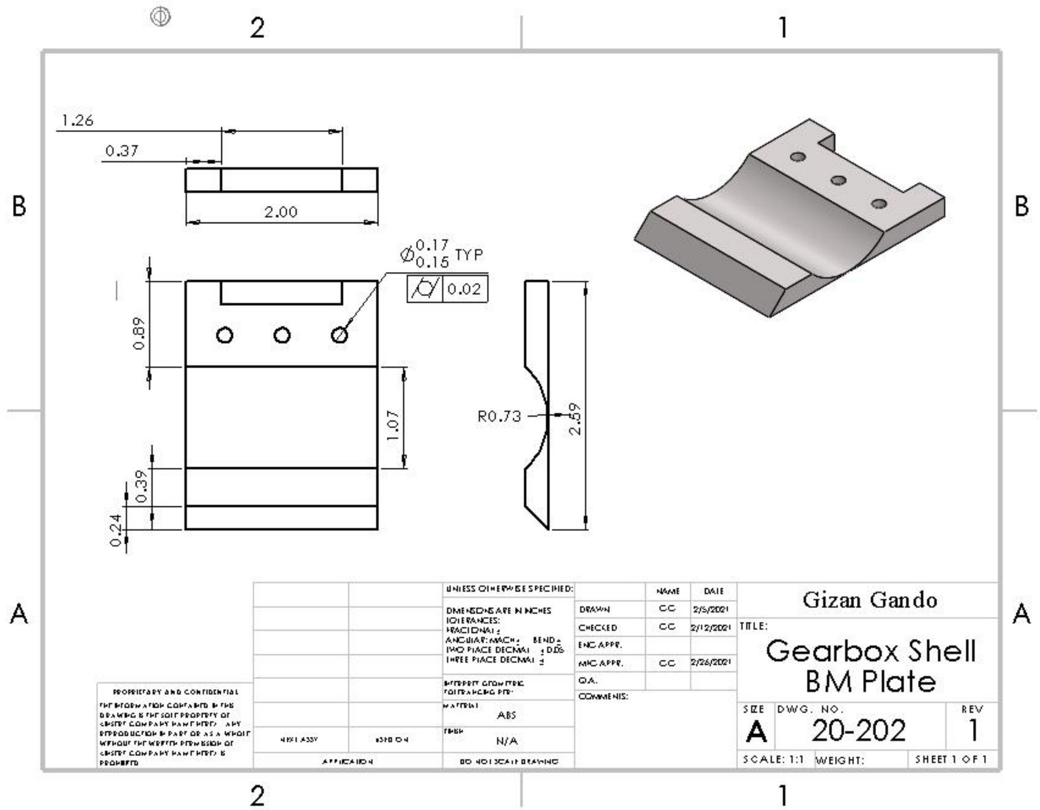
Appendix B.5 ASSEMBLY OF DIFFERNICAL



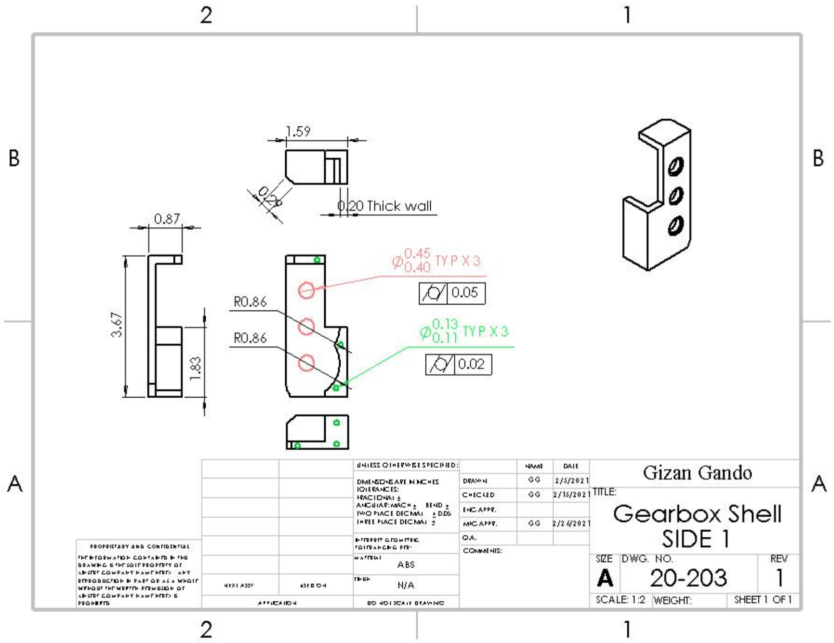
Appendix B.6 Gearbox Shell Bottom Plate Verion 2



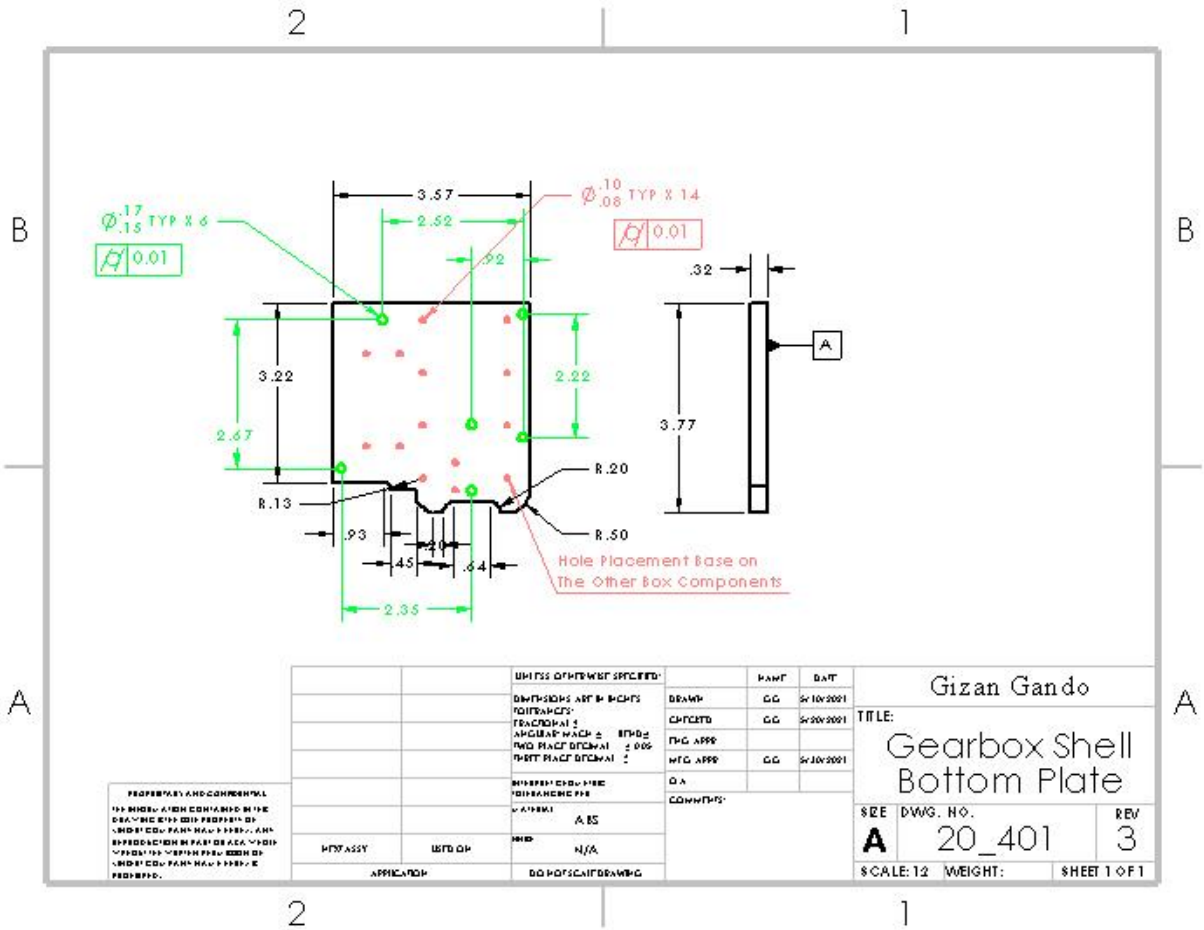
Appendix B.7 Gearbox Shell BM Plate Version 2



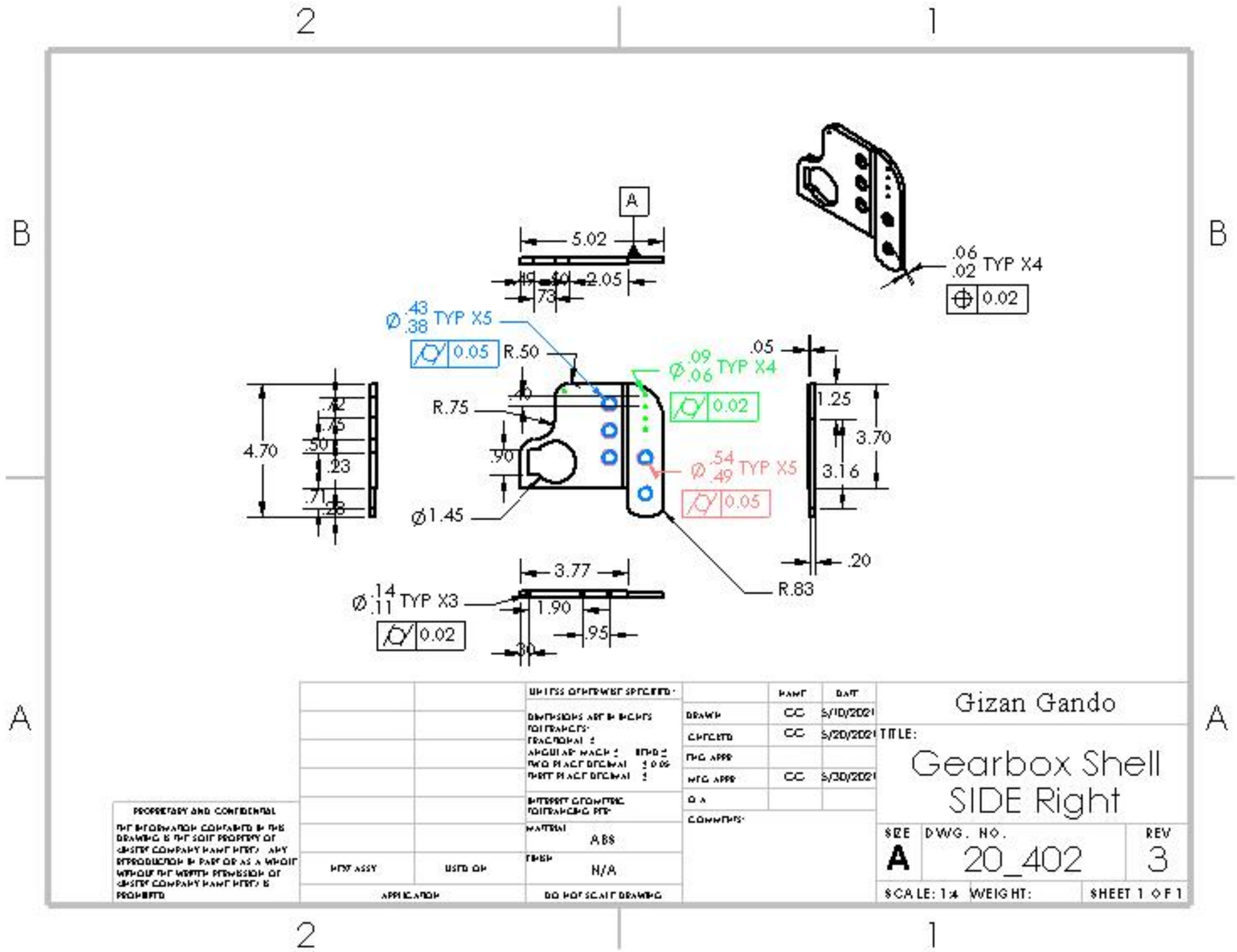
Appendix B.8 Gearbox Shell SIDE 1 Version 2



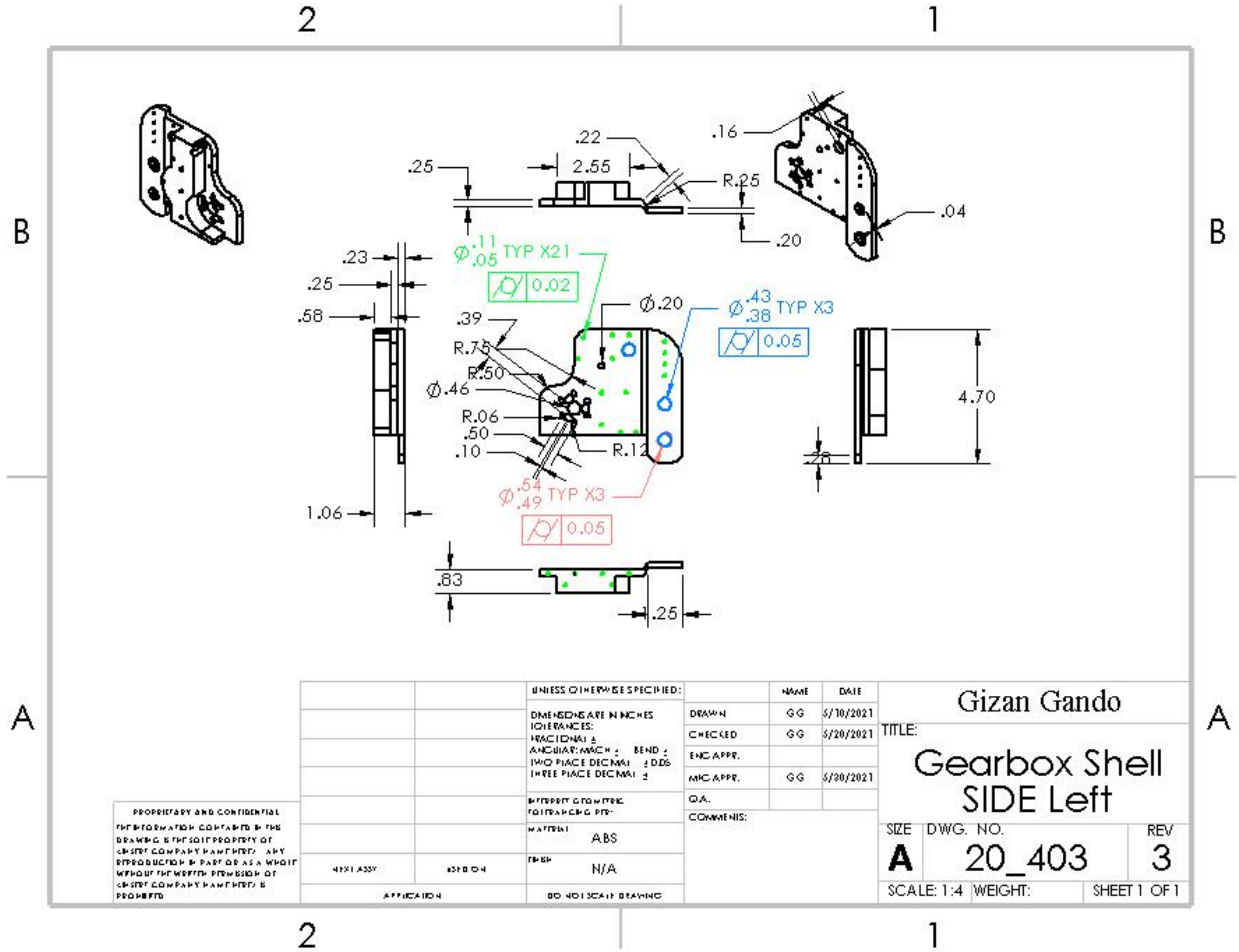
Appendix B.9 Gearbox Shell Bottom Plate Verion 3



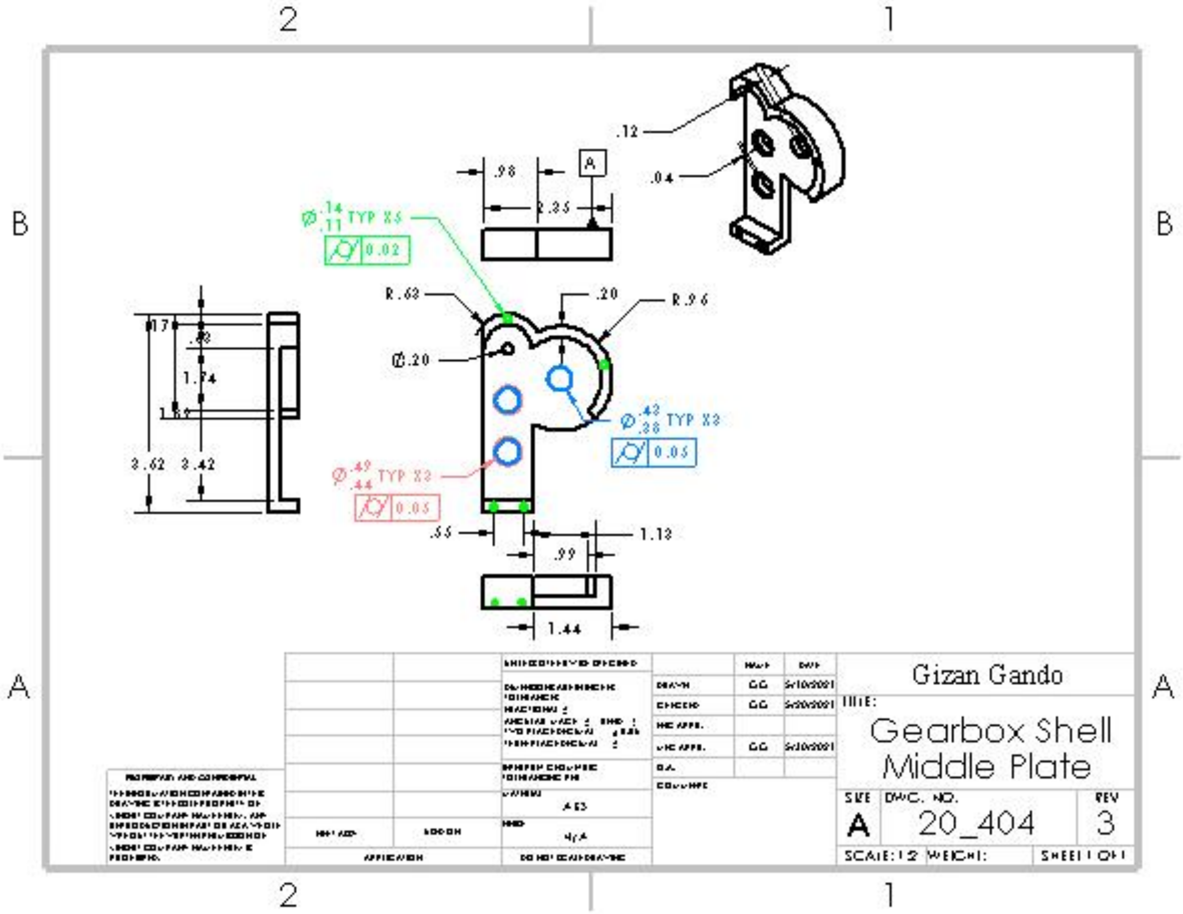
Appendix B.10 Gearbox Shell Right Side Version 3



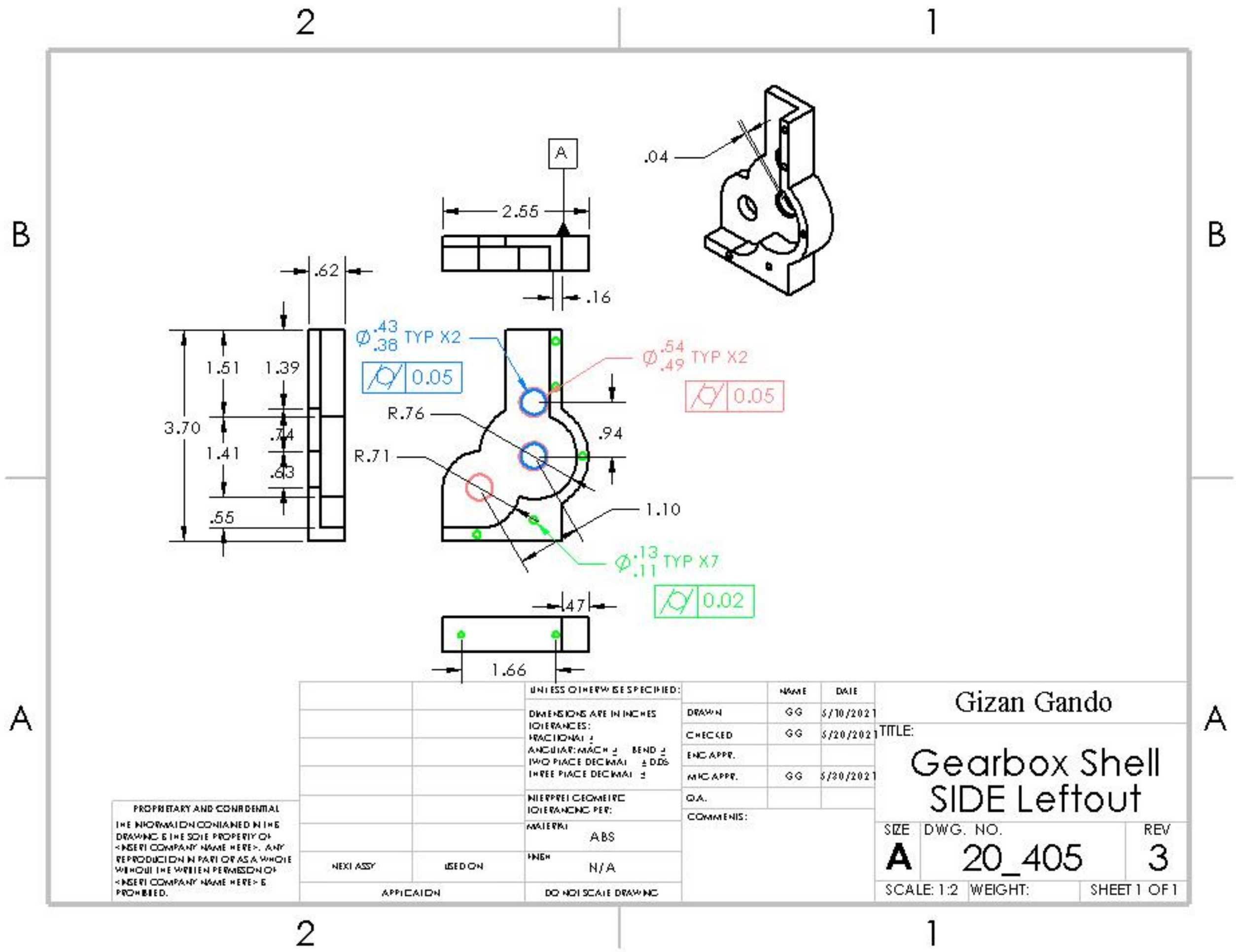
Appendix B.11 Gearbox Shell Left Sside Version 3



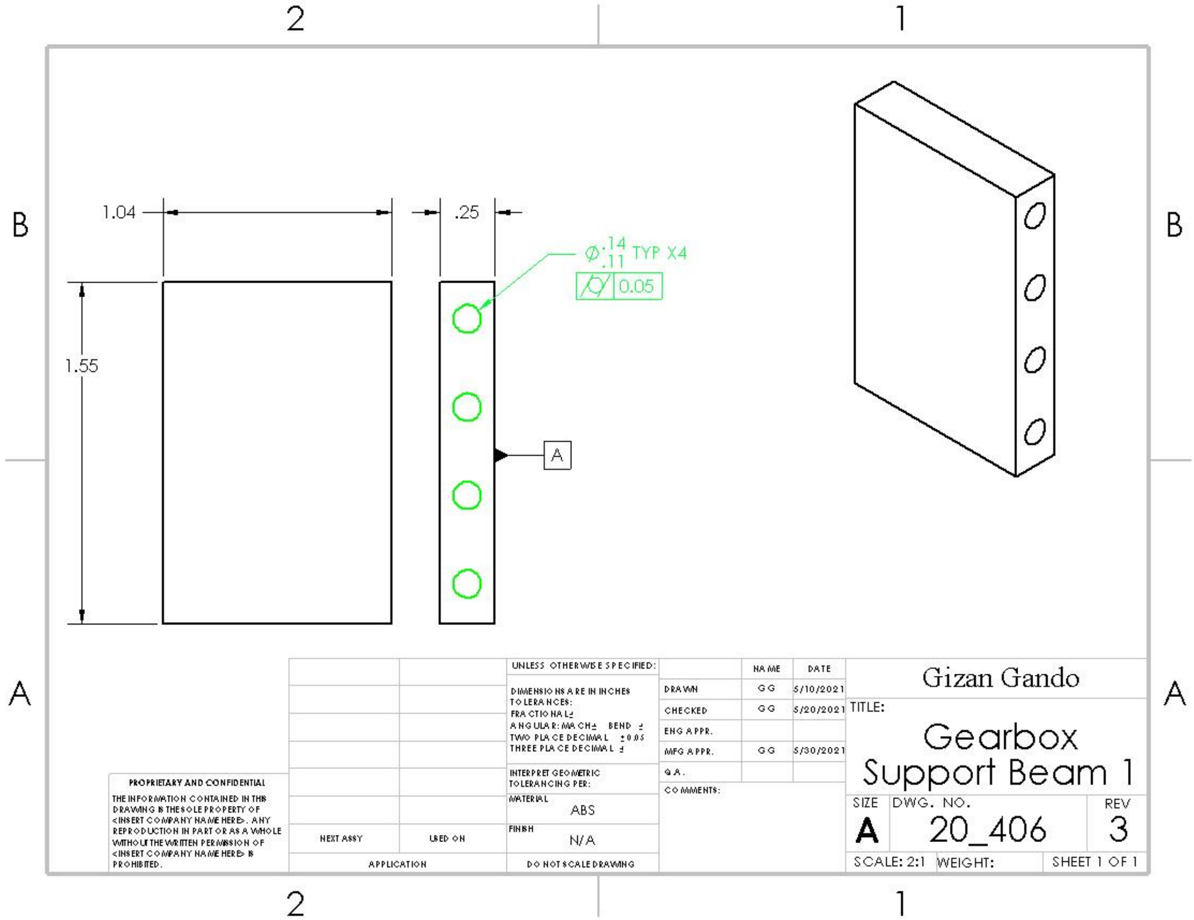
Appendix B.12 Gearbox Shell Middle Plate Version 3



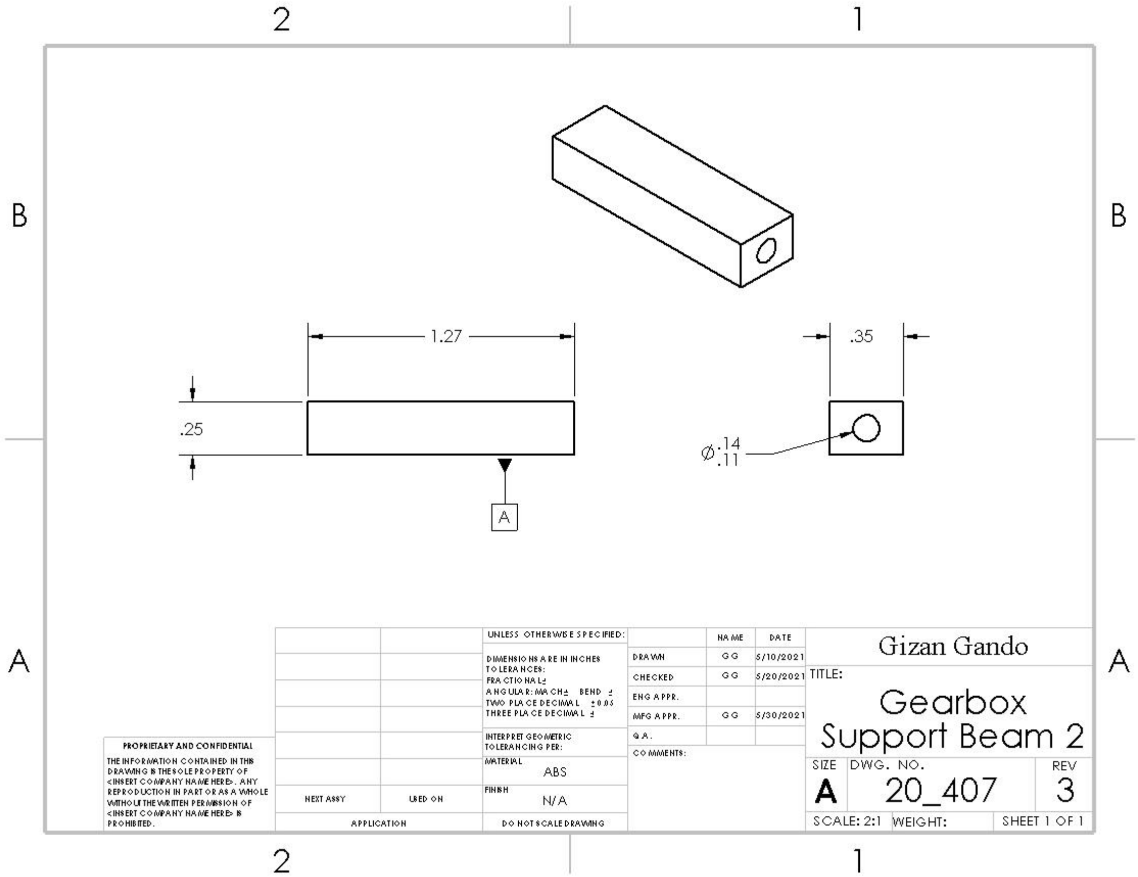
Appendix B.13 Gearbox Shell Left Side Outter Version 3



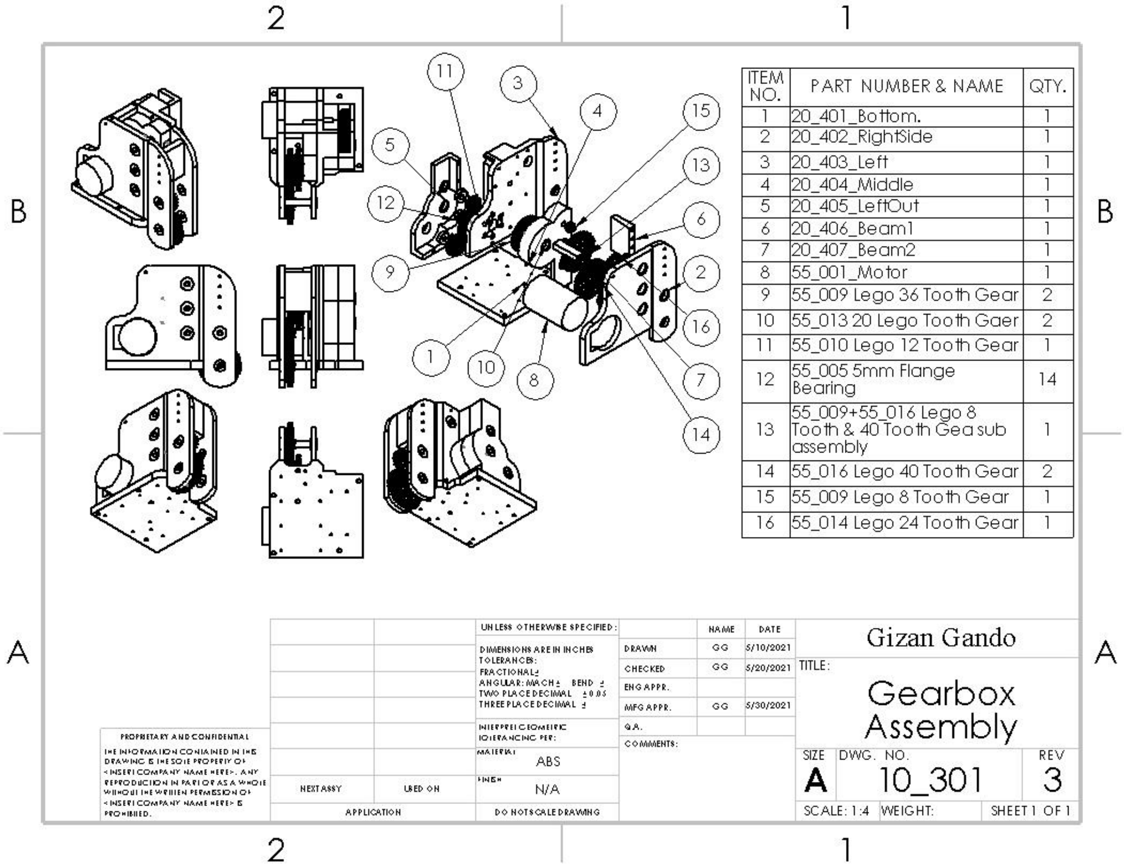
Appendix B.14 Gearbox Shell Connector Beam 1 Version 3



Appendix B.15 Gearbox Shell Connector Beam 2 Version 3

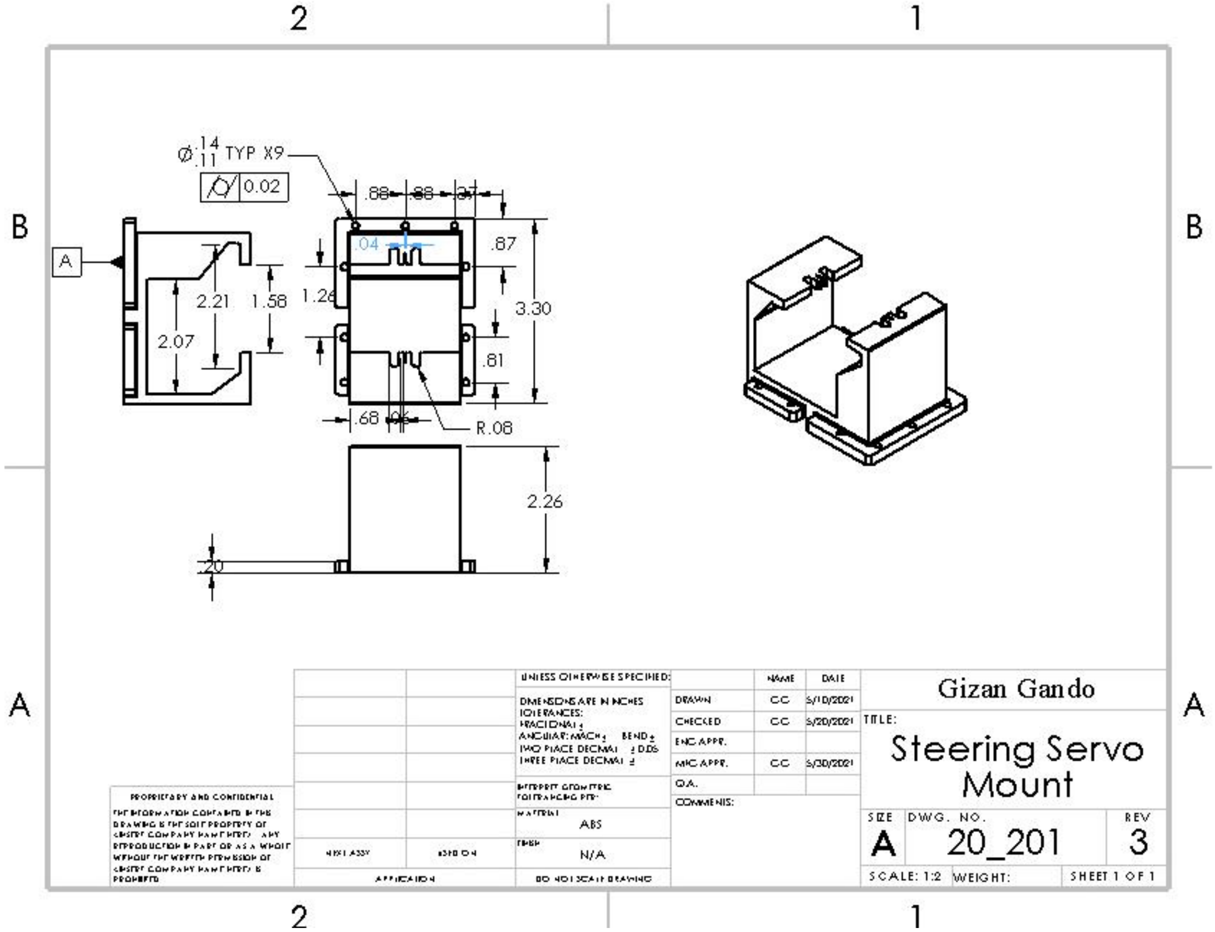


Appendix B.16 Gear Box Assembly Version 3

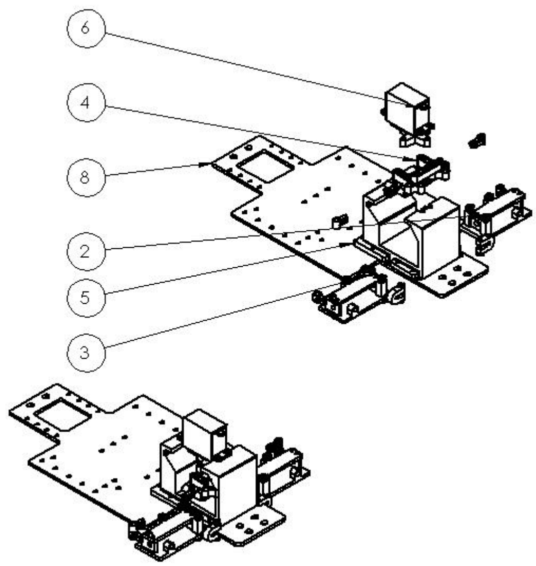


ITEM NO.	PART NUMBER & NAME	QTY.
1	20_401_Bottom.	1
2	20_402_RightSide	1
3	20_403_Left	1
4	20_404_Middle	1
5	20_405_LeftOut	1
6	20_406_Beam1	1
7	20_407_Beam2	1
8	55_001_Motor	1
9	55_009 Lego 36 Tooth Gear	2
10	55_013 20 Lego Tooth Gaer	2
11	55_010 Lego 12 Tooth Gear	1
12	55_005 5mm Flange Bearing	14
13	55_009+55_016 Lego 8 Tooth & 40 Tooth Gea sub assembly	1
14	55_016 Lego 40 Tooth Gear	2
15	55_009 Lego 8 Tooth Gear	1
16	55_014 Lego 24 Tooth Gear	1

Appendix B.17 Steering Servo Mount



Appendix B.18 Steering Assembly



ITEM NO.	PART NUMBER & NAME	QTY.
2	10-006 Right Arm with Lego Steering plate (KERN +)	1
3	10-007 Left Arm with Lego Steering plate (KERN +)	1
4	55-018 + 55-019 +55-021 + 55-023 Lego Parts SUB-ASSEMBLY	1
5	20-201 Steering Servo Mount	1
6	55-004 Servo Motor	1
8	20-001 Plate (GIVEN FROM KERN)	1

	NAME	DATE
DRAWN	GG	5/10/2021
CHECKED	GG	5/20/2021
ENG APPR.		
MFG APPR.	GG	5/30/2021
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL ABS
FINISH N/A
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.

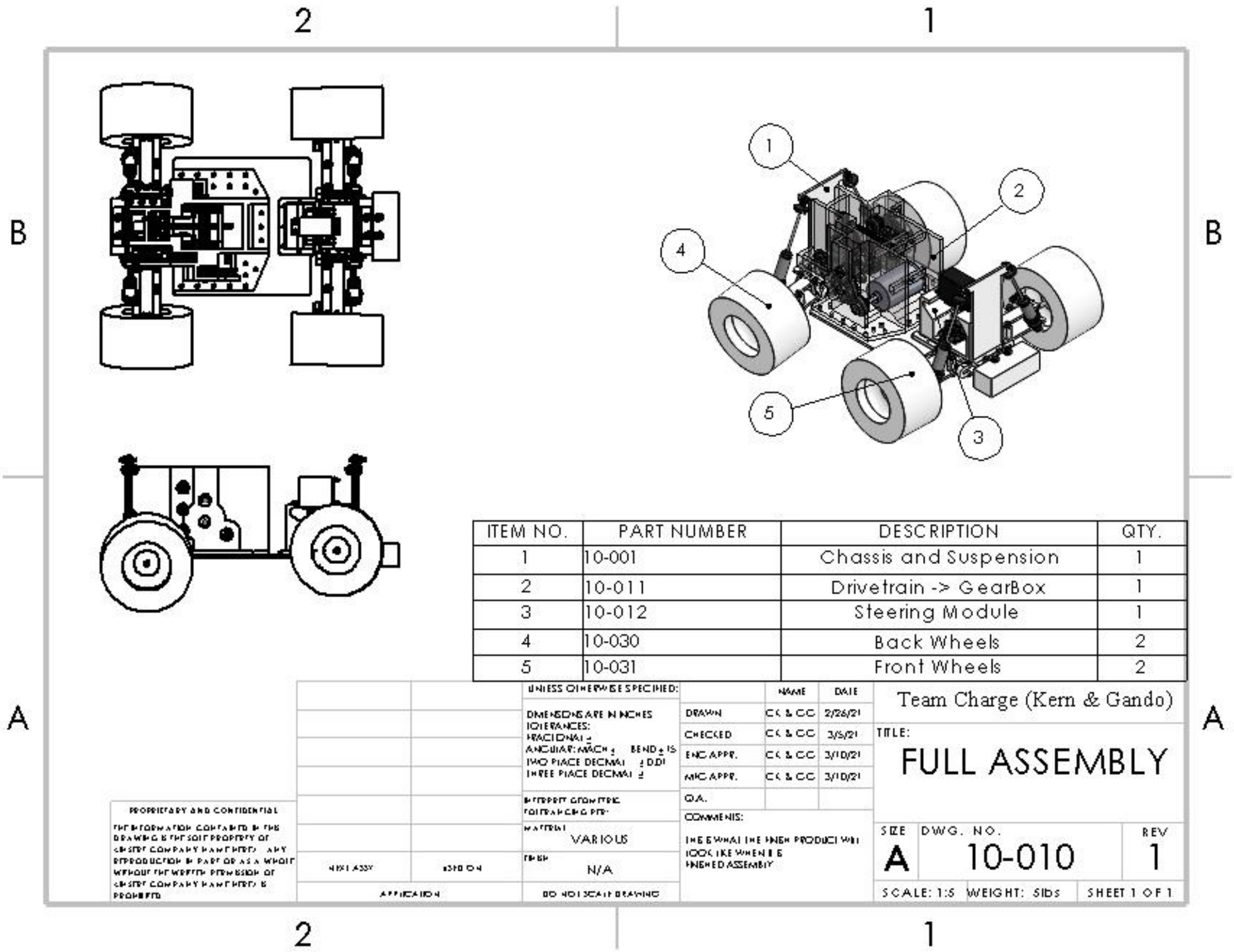
Gizan Gando

TITLE: Steering Assembly

SIZE A | DWG. NO. 10-302 | REV 3

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

Appendix B.19 FULL ASSEMBLY OF RC BAJA CAR Version 2



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	10-001	Chassis and Suspension	1
2	10-011	Drivetrain -> GearBox	1
3	10-012	Steering Module	1
4	10-030	Back Wheels	2
5	10-031	Front Wheels	2

APPENDI55X C - Parts List and Costs

Part Number	Qty	Part Description	Source	Cost	Disposition
55-001	1	Venom Red 540 6.5T Brushless Motor (13011)	Vennom-Group	$35	2nd Hand
55-002	1	Hobbywing Ezrun 60A Brushless ESC	www.rcmart.com/ (Model: MAX10)	$10	2nd Hand
55-003	1	6-Cell Sub-C Stick Pack NiMh 7.2V Battery	Borrowing from MET Department	$0	Borrowed
55-004	2	HS-311 Servo Motor 180° Rotation	www.servocity.com (SKU: 31311S)	$0	Already Owned
55-005	2	Arduino Nano v3.0 like board	Amazon - ELEGOO	$11	Ordered
55-006	2	NRF24L01 Wireless Transceiver Module + Antenna for Arduino	Amazon - Aideepen	$9	Ordered
55-007	N/A	Miscellaneous Wire, Solder & Connectors	Self-Supply from Electronic stores		Already Owned
50-001	N/A	#6-32 screws at various lengths	Self-Supply from Hardware stores	$0	Already Owned
50-002	N/A	#6-32 screws at various lengths	Self-Supply from Hardware stores	$0	Already Owned
50-003	20	Flanged Ball Bearing 5mm ID X 5 X 11 (F685ZZ)	Amazon - Uxcell	$20	Ordered
50-004	10	Flanged Ball Bearing 3mm ID X 4 X 10 (F623ZZ)	Amazon - Uxcell	$10	Ordered
50-005	10	100 X 5mm Rod Stainless Shaft	Amazon - RilexAwhile	$13	Ordered
50-006	10	100 X 3mm Rod Stainless Shaft	Amazon - Sutemribor	$12	Ordered
50-007	20	5mm Shaft Collar	Amazon - nineone	$20	Ordered
50-008	10	3mm Shaft Collar	Amazon - Sutemribor	$6	Ordered
50-009	4	5mm ID U Joint Coupler (L23XD11)	Amazon - Uxcell	$10	Ordered
50-010	18	Motor Screws M3	Amazon – Redcat Traxxas	$1	Ordered
50-011	30	M2 Flat Head Screws	Amazon - Hilitchi	$3	Ordered
50-012	30	M2 Knurled Threaded Insert, Brass	Amazon - Hilitchi	$3	Ordered
50-013	4	4 inch Dia. Treaded Tires	Borrowing from MET Department	$0	Borrowed
20-001	1	Steering Mount (ABS)	School Printer	$3.50	Printed

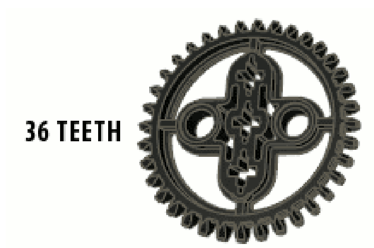
20-202	1	Servo Motor Mount to Lego Axle (ABS)	School Printer	$0.25	Printed
20-003	1	Gear shell box (ABS)	School Printer	$12	Printed
20-004	1	Motor shaft to Lego Axle	School Printer	$0.10	Printed
20-005	2	5mm shaft to the differential	School Printer	$0.10	Printed
20-006	1	Differential Container	School Printer	$1.50	Printed
20-007	30 each	Various Spacers “3mm, 5mm, & Lego Axle” ID (ABS)	School Printer	$2.50	Printed
55-008	Pack	Differential Gears	Amazon - SunMade	$4	Order
55-009	3	Lego 8 teeth Gear	Lego	$0	Already Owned
55-010	2	Lego 12 teeth Gear	Lego	$0	Already Owned
55-011	1	Lego 16 teeth Gear	Lego	$0	Already Owned
55-012	2	Lego 16 teeth Gear w/ shift	Lego	$0	Already Owned
55-013	3	Lego 20 teeth Gear	Lego	$0	Already Owned
55-014	6	Lego 24 teeth Gear	Lego	$0	Already Owned
55-015.	3	Lego 36 teeth Gear	Lego	$0	Already Owned
55-016	2	Lego 40 teeth Gear	Lego	$0	Already Owned
55-017	N/A	Various Lego Axle	Lego	$0	Already Owned
55-018	N/A	Various Lego Angle Connectors	Lego	$0	Already Owned
55-019	N/A	Various Lego Pins	Lego	$0	Already Owned
55-021	N/A	Various Lego Pins	Lego	$0	Already Owned
55-022	N/A	Various Lego Axle Spacers	Lego	$0	Already Owned
55-023	N/A	Various Lego Axle Connectors	Lego	$0	Already Owned

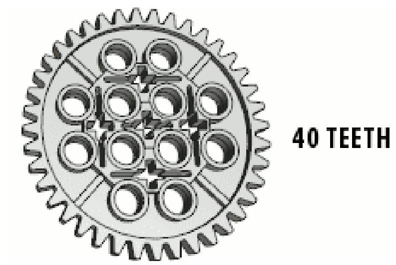
COLOR SECTIONS

GREEN = GEAR BOX & DRIVE
PURPLE= DIFFERENTIAL
RED = STEERING
ORANGE = (STEERING) + (GEAR BOX & DRIVE) SHARE
BLUE = ELECTRONICS + CONTROLLER
GOLD = MISC. SHARE IN ALL CATAGORIES

TYPES OF LEGO GEAR USE ON PROJECT

Special
Shifting Type





APPENDIX D - Budget

Overall Drive Project Budget

Item	Description	Cost
Gear Box & Drive	(1) 3D Printer Shell, Axles, Legos Gears, Spacers, Hubs, Shaft Collars, Bearings, & Fasteners	$110
Differential	(1) 3D Printer Encloser with Gear Head, Printer 5mm shaft connectors and Steel Gears	$7
Steering System	(1) 3D Printer Mount & Lego Beams + Connectors.	$5
Electronics + Controller System	(1) Drive Motor, (2) Servo Motors, (1) NiMh 7.2V Battery, (2) Arduino Uno Boards, (2) Transceiver, & Miscellaneous wire + Connectors	$85
Fasteners	ALL MISC. SCREWS & NUTS	$7
MISC.	All other that where not accounted	$4
	TOTAL COST	$198

*Overall budget: $400 | Personal budget: $200

APPENDIX E – Schedule

Schedule E.1 Fall: Design

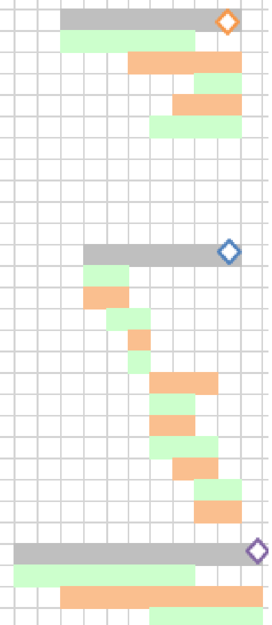
PROJECT TITLE: Radio Controlled Baja Car Drive Train

Principal Investigator.: Gizan Gando

TASK: ID	Description	Duration Est. (hrs)	Actua (hrs)	%Con	September	October	November	Dec	January	February	March	April	May	June
1	Proposal*													
1a	Outline	3	0											
1b	Intro	3	4											
1c	Methods	4	0											
1d	Analysis	5	0											
1e	Discussion	4	0											
1f	Parts and Budget	3	0											
1g	Drawings	4	1											
1h	Schedule	3	0.5											
1i	Summary & Appx	3	0											
	subtotal:	32	5.5											
2	Website													
2a	Basic Layout	2	5											
2b	Sketches	1	1											
2c	Introduction	2	0.5											
2d	Analysis	4	1											
2e	Finalize Design	4	0											
	subtotal:	13	7.5											
3	Analysis													
3a	Introduction	2	4											
3b	Drive Ratio	1	2.5											
3c	Torque Ratio	1.5	0.5											
3d	Gear Box	2	4											
3e	Box stage #1	2	3											
3f	Box stage #2	2	0											
3g	Box stage #3	2	0											
3h	Box stage #4	2	0											
3i	Steering Radius	2	0											
3j	Transmistion pressure	4	0											
	subtotal:	18.5	10											
4	Documentation													
4a	Part 1 Motor Bevel Gear	2	3											
4b	Part 2 Bevel Gear drawing	2	3											
4c	Subassembly TBD	0	0											
4d	Part 3 TBD drawing	0	0											
4e	Part 4 TBD drawing	0	0											
4f	Subassembly TBD	0	0											
4g	Part 5 TBD drawing	0	0											
4h	Part 6 TBD drawing	0	0											
4i	Subassembly TBD	0	0											
4j	Device TBD drawing	0	0											
4k	Kinematic Check	0	0											
4l	ANSIY14.5 Compl	0	0											
4m	Make Object Files	0	0											
	subtotal:	4	6											

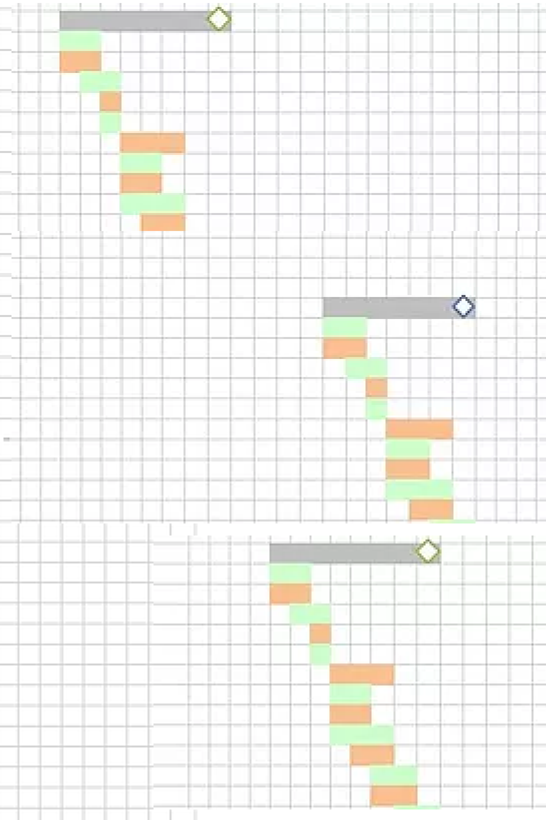
Schedule E.2 Winter: Build

	subtotal:	0	10
	Device Construct		
5a	Assemble CONTROL SYSTE	5	10
5b	Assemble Sub GEAR BOX	15	30
5c	Assemble Sub STEERING	8	10
5d	Assemble ELECTRONICS	2	4
	subtotal:	100	200
	Part Construction		
6a	Buy Screws	0.5	1
6b	Buy Screws	0.5	1
6c	Buy Axle	0.5	1
6d	Buy Shaft Collers	0.5	1
6e	Buy Motor	0.5	1
6f	Buy Screws	0.5	1
6d	Buy Shaft Collers	0.5	1
6e	Buy Motor	0.5	1
6f	Buy Screws	0.5	1
6g	Take Part Pictures	0.5	1
	subtotal:	5	10
7	Proposal Mods		
7a	Modified Overall Design for m	10	60
7b	Update Website	10	15
7c	Take Part Pictures	0.5	1
	Crit Des Review*	20	75
	subtotal:		



Schedule E.3 Spring: Test

9	Device Evaluation		
9a	Editing testing report	10	15
9b	Speed Test Procedure	1	2
9c	Speed Test	2	2
9d	Turn Radius Test Procedure	1	2
9e	Turn Radius Test	2	2
9f	Ramp Test Procedure	1	2
9g	Ramp Test	2	2
9h	Diff Test Procedure	1	2
9i	Diff Test	2	2
	subtotal:	22	31
10a	489 Deliverables		
10b	Get Report Guide	15	20
10c	Make Rep Outline	20	20
10d	Write Report	14	20
10e	Make Slide Outline	15	20
10f	Create Presentation	20	20
10g	Make CD Deliv. List	16	20
10h	Write 495 CD parts	21	20
10i	Update Website	30	20
10h	Project CD*	25	20
	Update Website	176	180
	subtotal:		
12	489 Edit		
12a	Redesign	20	20
12b	Get Report Guide	20	20
12c	Make Rep Outline	20	20
12d	Write Report	20	20
12e	Make Slide Outline	20	20
12f	Create Presentation	20	20
12g	Make CD Deliv. List	20	20
12h	Write 495 CD parts	20	20
12u	Update Website	20	20
	Project CD*	20	20
	subtotal:	200	200



APPENDIX F – Expertise and Resources

Pprofessor Dr.Pringle and Dr.Choi for teaching.
Manufactionn help with 3D printing and laser cutting from Mr.Kern.

APPENDIX G – Testing Report

Speed Test

PASS/FAIL: **PASS**
(MIN. 10 MPH)
Predicted from the experience of using the car
Lower from the original guess of "20 MPH" because it did not account for loss before and redesign of the gearbox on the car.

Speed Test

Trial	Run 5m Time (sec)	Speed (m/s)	Overall (MPH)
1	0.95	5.26	
2	1.02	4.90	
3	1.13	4.42	
4	0.92	5.43	
5	1.18	4.28	
Avg.	2.63	4.86	10.88 **(PASSED)**

Ramp Test

(MIN. 20 degress)
Step one (11.5 degrees): **(PASSED)**
Step two (23.2 degrees): **(PASSED)**

Differntal Test

Held wheel for at least 15 second
on each back wheel: **(PASSED)**

APPENDIX H – Resume

Gizan G. Gando

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Phone (206) 356 8053
Address
Seattle, WA 98108

Objective

A mechanical engineering student desiring a position in the theme park industry that innovative and manufactures advanced technology for rides and attractions.

Education

Central Washington University, Ellensburg, WA — *Expected June 2021*
Bachelor of Science, **Mechanical Engineering Technology & Robotics and Automation**

Related Experience

Wild Waves, Federal Way WA — *June 2019 To October 2019*
Ride Operator
- Trained to operate coasters, dodgems, drop towers, pendulum and tracked rides
- Recognized for best ride operator on the month of August
- Collaborated with team members to manage ride safety in the theme park

Multimodal Education Center, Ellensburg WA — *September 2018 to June 2019*
Student Attendant
- Guided students & staff how to use laptops, tablets, cameras, and sound equipment
- Operated laser cutter, 3D printers, and VR headset for customers
- Collected customer data using Microsoft Access, Excel, Outlook

Microsoft, Redmond WA — *July 2017 to August 2017*
Intern in Learning and Readiness
- Developed Java and Python tutorial videos published on Edx.org
- Explored and talked to multipe Microsoft team and employees
- Tested out new products and put my input on there material

FIRST Robotics FRC & FRC, Seattle WA — *June 2012 To June 2017*
Member of TEAM XBOT #488
- Designed, built, and engineered a robot in 6 weeks for a yearly competition
- Collaborated with 20 other student & 25 adult mentors
- Connected with Microsoft research labs to access their laser cutter, CNC, lathe, water jet, and other shop tools
- Learned how to design with SolidWorks, Inventor, MS Visio, and AutoCAD

Academic Achievements

Gained a SOLIDWORKS Certification — *June 2018*
- Mechanical Design at the level of Associate

Skills Level

●●●○○	MATLAB	●●●○○	LabVIEW	●●●●○	Mathematics
●●●●○	AutoCAD	●●●●○	Microsoft Office	●●●●●	Creative
●●●●○	Inventor	●●●○○	Basic Coding	●●●○○	Organization
●●●●●	SolidWorks	●●●●●	Basic Machining	●●●●○	Communication

**The scale is out of five dots, with one being poor on the skill and five being strong on the skill.*