# RC Baja Car

By

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# ABSTRACT

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# 1. INTRODUCTION

## a. Description
This project was chosen to create a vehicle capable of competing in the CWU ASME R/C Baja competition. The project detailed in this proposal will use statics, dynamics, mechanics of materials, and physics calculations to develop an optimal solution for the baja competition. This competition consists of 2 events that include the Slalom-and-Sprint as well as the Baja Competition. This R/C baja car seeks to create a low-cost, radio-controlled vehicle that can compete with success. The following project proposal will include documentation for the design and manufacturing for the drivetrain and chassis of the R/C Baja competition car.

## b. Motivation
This project was undertaken with the intention of creating a platform to learn how dynamics apply to vehicles, using this knowledge to develop skills related to R/C inspection and survey tools.

## c. Function Statement
For the RC Baja car, the chassis is the support for sub-assembly attachments, as for the Drivetrain, the drivetrain provides torque to the system for motion.

## d. Requirements
The Baja RC Car will have the following specifications by the end of the project deadline:

1. Drivetrain assembly must be capable of sustained operation (for 2 minutes) at 20 mph without reaching point of failure.
2. Chassis must deflect less than .6 inches from 15 mph head-on impact.
3. Vehicle weight must be less than 10 pounds.
4. Drivetrain must be able to achieve a maximum speed of 30 mph
5. Drivetrain must be able to provide a minimum 0.2 Nm of torque to the wheels during initial acceleration.
6. Chassis must deflect less than .1 inches from normal due to weight of sub-assemblies.
7. Drivetrain sub-assemblies must be able to deflect from normal .2 inches due to impacts of 15 mph without yielding.
8. Drivetrain must be able to achieve a speed of 10 mph in under 10 seconds
9. Chassis must be capable of withstanding 20-40 Hz vibrations at a speed of 15-20 mph.
10. Drivetrain must be capable of providing torque to climb a 45$^{\circ}$ ramp.
11. The R/C car must have a drag force lower than 120 lbf when at speeds between 10 mph and 30 mph.

## e. Engineering Merit

This project will include calculations using formulas learned from the CWU Mechanical Engineering Technology Program. These calculations include Static calculations for forces acting on the chassis as well as the forces acting on the drivetrain, Dynamics calculations to determine forces acting on the system during impacts, and formulas from mechanics of materials for calculating stresses induced during operation, and physics calculations to determine the torque requirements for achieving minimum and maximum speeds for the success in the competition.

## f. Scope of Effort

The scope of this proposal will only include drawing for the design and manufacturing of the Drivetrain and the chassis of the vehicle. All other parts and assemblies will be completed by either the designers' team or purchased through outside means.

## g. Success Criteria

The success of the project is determined by how well the R/C vehicle performs during testing and whether the vehicle completes the racing challenges set by the competition board, ie. Slalom-and-Sprint and the Baja competition. The vehicle is to be evaluated based on requirements set by both team members prior to manufacturing. This Project would be deemed successful if the vehicle achieved 2nd place during the Baja competition and achieved a Salam-and-Sprint time of under 7 seconds.

## h. Stakeholders

The Stakeholders of this project are as follows:

- Alex Amadio. Team member, designer, and builder.
- Federico Berrospe. Team member, designer, and builder.
- Charles Pringle, Mentor and Instructor.
- John Choi, Mentor and Instructor.
- CWU MET department, providing lab space for manufacturing and prototyping.
- Susan Donahue, donor of the Walter R. Kaminski Memorial scholarship, scholarship granted to Mechanical Engineering students for senior project funding.

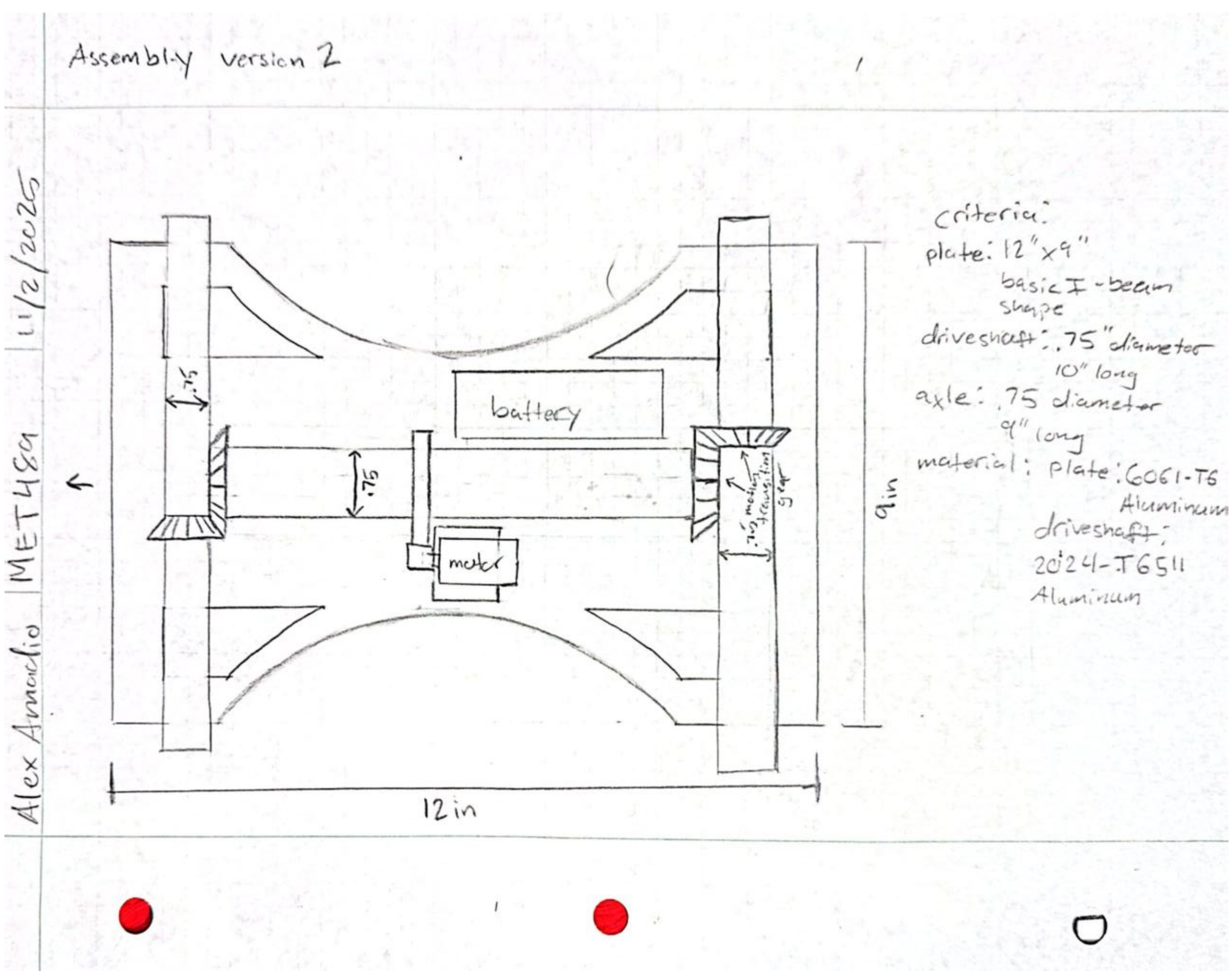
# 2. DESIGN & ANALYSIS

## a. Approach: Proposed Solution

The problem this project seeks to solve is the need for an R/C car capable of completing the CWU ASME R/C Baja Competition. A decision matrix was utilized to gain a better understanding of what type of design is best suited to solve this problem. As detailed in Appendix F, the design matrix shows that an all-wheel drive drivetrain is best suited for this type of competition. During initial brainstorming sessions with partner and peers, it was suggested to use a belt system for the drivetrain as well as a 2-motor configuration, this was later scrapped as it violates the rules and regulations of the R/C Baja competition.

## b. Design Description

The current design uses a single central drive shaft that is connected to both the front and rear axle. These are connected using a canted gear that fitted to the shaft of both. These gears will likely be covered by a housing unit, to prevent gears from wearing faster than designed from rocks, dirt, or other debris. The motor will use a similar canted gear system to rotate the central drive shaft; however, the motor will go through a gear reduction as to not shear the pinion gear in the motor, or the gears on the way to the drive shaft.



## c. Benchmark

This project is benchmarked on an R/C competition car that is commercially available and is sold by TENSSENX, an outdoorsman accessory online retailer. This commercially available vehicle advertises a top speed of 40 mph, a chassis made from aluminum, and a total weight of 1.2 pounds. All these advertisements are within the criteria for success and the requirements set for this project, with the top speed being lower than the benchmarked model.

## d. Performance Predictions

Based on calculations done, the R/C car's drivetrain is predicted to provide enough torque to achieve a maximum speed of 30 mph, while maintaining an operational speed of 20 mph. the R/C car is predicted to be able to achieve 2$^{nd}$ place in the Baja competition, and a time of 7 seconds in the slalom-and-sprint.

## e. Description of Analysis

The analysis done for this project was completed using formula from the CWU MET statics, to gain an understanding of what the weight on the wheel will be. This understanding allows for a better understanding of what types of wheels are needed to hold the R/C car off the ground. Mechanicals of materials formula are used to better understand what the deflection of the chassis and the drivetrain due to components as well as impacts while at speeds of 15 – 20 mph. Physics and dynamics equations are used to find what the value of torque is acting on the drivetrain during operation, as well as during a cold start. Physics, dynamics, and Mechanical design calculations will also be performed to assess how much torque needs to be produced by the motor to climb a 45-degree ramp. Statics calculations will be used to create Free Body Diagrams to determine the forces on the wheels, through this calculation the proper wheel size can be determined.

## f. Scope of Testing and Evaluation

The R/C car will be tested and evaluated for whether it was successful by how it performs during testing in the spring as well as during the R/C Baja Competition held by the CWU ASME chapter. The scope of the testing done for this is by how well the car can handle sharp turns while speeding up and slowing down the motor RPM during the Slalom. The car will also be tested on how well it can go from 0 – 10 mph during the Sprint section of the competition. Finally, the R/C car's drivetrain and chassis will be tested on how well it can handle rough terrain and sudden drops and jumps, during the Baja competition. Testing prior to this will be down to test its ability to climb a 45-degree ramp and how well it performs on subsequent impact.

## g. Analysis

The requirements for this project will be met through the manufacturing and selection of components. The manufactured parts are designed using formulas learned through the CWU MET undergraduate program. The engineering merit of this project is to be exemplified using the CWU: RADD (Requirements, Analysis, Design Parameters, and Documentation) metric. Some of the requirements found in section 1d were calculated using Plate deflection analysis, speed-torque relationship formulas, and Finite Element Analysis. Detailed below are analysis performed to understand what is to be manufactured to achieve requirements found in section 1d.

### i. Analysis 1 – Structural Deflection and Weight on Wheels

This analysis is being conducted to satisfy design requirement 1.d.6, for the deflection on the chassis due to component weight. After calculations found in appendix A01, the chassis will deflect 0.00004 inches due to the weight of components. While the weight that the wheels experience is .3286 pounds on each of the front wheels and .3481 pounds on each of the rear wheels. The documentation for this analysis can be found in Appendix A01.

### ii. Analysis 2 – Torsional Shear, angle of rotation due to torque, Driveshaft Diameter and Critical Speed Frequency

This analysis was conducted to determine the shear affecting the driveshaft, and the angle of rotation caused by the motor. The torque used for this calculation came from the minimum torque requirements defined in section 1.d.5 compared to the manufacturer's specifications. This analysis also looked at whether the chosen diameter for the drive shaft would break at maximum required speed as defined by Requirement 1.d.4. The shear value was calculated to be 576 lb*in with the angle of twist being 0.0004 degrees. This signifies that the drive shaft will not shear at due to torque from the motor. The drive shaft diameter is .25 inches, with the critical speed being 403513 RPM, this means that the drive shaft would need to spin at 403513 RPM before breaking or bending due to rotation. The critical frequency is 754225 Hz; this signifies that the drive shaft will break after experiencing vibration at the calculated frequency. The documentation for this analysis can be found in Appendix A02.

### iii. Analysis 3 – Chassis Deflection due to 15 mph impact

This analysis was conducted to understand how the chassis design would deflect due to a head-on impact going 15 mph. Using deflection of a beam and the Euler's buckling equation. It was found that if the vehicle weighs 3 pounds or less, the chassis will experience a defection of .599 inches. This analysis satisfies the requirements found in section 1.d.2, however the value is extremely close to being out of spec. The vehicle would need to weigh less than 3 pounds to have this value see a reduction. The documentation for this analysis can be found in Appendix A03.

### iV. Analysis 4 – Actual RPM and Gear Reduction

This analysis was conducted to gain an understanding of what RPM is coming from the chosen motor and how that RPM gets transferred to the Drivetrain. This was calculated using torque equations and an assumption of the motor's efficiency. The gear ratio was found using the gear ratio equation. Based on calculations found in Appendix A04, the motor transfers an RPM of 14592 RPM with a motor efficiency of 80%. This is an appropriate estimation of the motor efficiency as this encompasses if the motor is made poorly. For the gear reduction needed to get the RPM required for a maximum speed of 30 MPH, with 4-inch diameter tires, would be a minimum of a 5-to-1 gear reduction. This means that for every 5 rotations from the motor the drivetrain would rotate once. This analysis was conducted to satisfy requirements found in 1.D.4. The documentation for this analysis can be found in Appendix A04.

### V. Analysis 5 – Motor Power and Friction on wheels

This analysis was conducted to find the power that is generated from the motor during an incline this also looks at how much friction is needed from the wheels to propel up a 45-degree incline ramp. Based on calculations found in Appendix A05, with the use kinematics the friction force that was found is 68.31 pounds, and using power equations the power from the motor was found to be 1556.2 horsepower to go up a 45-degree incline. This satisfies the requirement 10 found in section 1.d. This motor power value is used during later analysis. The documentation for this analysis can be found in Appendix A05.

### Vi. Analysis 6 – Damage Factor and Number of Cycles over time

This analysis was conducted to determine if the driveshaft can run continuously over a 2-minute span. This is found as a requirement in section 1.d.1. Using the power from the motor found during Analysis_05, as well as specs from chosen components, the damage factor was found. The damage factor is a ratio between the number of cycles of operation over the number of cycles the part can handle before yielding. Based on calculations found in Appendix A06 as well as standard tables for 2024 Aluminum for number of cycles when related to stress, the number of cycles the drive shaft can handle before yielding is 14000 cycles with the number of cycles over 2 minutes is 5826. This puts the damage factor at .441, this is less than 1 meaning the shaft will not yield during the operational 2 minutes. However, this details 2 minutes at 35 mph, whereas the requirement states that the driveshaft is operation over 2 minutes at 20 mph. This is lower than the calculation for 35 mph, this means that there is less stress affecting the drive shaft at 20 mph, thus significantly increasing the number of cycles before yielding. The documentation for this analysis can be found in Appendix A06.

### Vii. Analysis 7 – Deflection of Driveshaft during a 15-mph impact

This analysis was conducted to gain a better understanding of the forcing acting on the driveshaft during a 15-mph impact. This satisfies the requirement 1d_7, that states that the drivetrain must not deflection more than .2 inches during impact. Based on calculations found in Appendix A07, it was found that the drive shaft deflects exactly .2 inches during impact. While this does satisfy the 1d-7 requirement, this doesn't fully account for a safety factor. The documentation for this analysis can be found in Appendix A07.

### Viii. Analysis 8 – Chassis vibration at 15 mph

This analysis was conducted to understand what kind of vibration is affecting the chassis while at operational speeds. Found in section 1d-9, the requirement states that the chassis needs to withstand a frequency of 20-40 Hz. After completing analysis 8, calculations found in Appendix A08, it was found that the chassis experiences a frequency of 36 Hz on gravel. This is at the higher end of the frequency range which indicates that the car will vibrate more than needed. This vibration value, however, don't consider suspension from the shocks these values will likely be 5-7 Hz lower with the consideration of shocks. This analysis satisfies requirement 1d-9. The documentation for this analysis can be found in Appendix A08.

### Viiii. Analysis 9 – Motor torque needed for acceleration.

This analysis was conducted to understand what the minimum torque that's needed to get to 10 mph within 10 seconds, as stated as a requirement in section 1.d.8. Based on calculations found in Appendix A09, the minimum torque that is needed is 3.538 Nm or about 2.61 lbf. This is significantly under the torque that the motor can produce based on manufacturer's specifications. Based on these calculations and the specifications from the vendor, the motor is judged to be able to produce the minimum torque to be able to accelerate the R/C car to 10 mph within 10 seconds. This analysis satisfies requirement 1.d.8 for being able to reach 10 mph in 10 seconds. The documentation for this analysis can be found in Appendix A09.

### X. Analysis 10 - Frag Force at operational speeds

This analysis was conducted to gain a better understanding of the drag force that is affecting the R/C car at different operational speeds. Based on calculations found in Appendix A10, the drag force was found to be 12.33 lbf at 10 mph, 49.34 lbf at 20 mph, and 111.03 lbf at 30 mph. these values are under the acceptable maximum value detailed as a part of requirement 1.d.11. This indicates that with the assumption that the height of the car is 5 inches with the height added by the components, then requirement 1.d.11, for drag values being lower than 120 lbf, is satisfied. The documentation for this analysis can be found in Appendix A10.

## h. Device: Parts, Shapes, and Conformation

The design for the car was chosen after completing different analysis of various aspects of the requirements. These aspects use a curved profile to prevent stress concentration from accumulating around joints. The chassis uses a 1-foot-long narrow body to prevent deflection due to components. The chassis uses a safety factor of 1.5, while the drivetrain has a safety factor of 2.

## i. Device Assembly

The car uses a selected motor and battery to drive a student-built drivetrain to allow for locomotion, while an entirely student-built chassis provides the support for the entire project to come together. The chassis uses an aluminum frame with points to connect straps for vital components, like the motor housing and battery. The drivetrain uses a shaft with angled gears to convert rotational motion 90 degrees to the axles, to provide torque to the wheels at the same time.

## j. Technical Risk Analysis

Some technical risk associated with this project would be around whether the gears for the drivetrain are properly tempered, this would cause a problem during operation if the gear's teeth sheared off rendering the car undrivable. Another technical risk would be around whether the motor has a bad magnet or the motor pinion was bad, this would make the pinion more brittle and susceptible to failure or the magnet would generate the torque needed for the R/C car. The last technical problem would be with the battery, such as if the battery wasn't able to hold a charge or didn't have the advertised voltage output for the motor.

## k. Failure Mode Analysis

During operation, the chassis experiences load caused by the weight of component sitting atop the chassis, this was found to not be an issue in analysis01. The drivetrain is more likely to fail during operation. The drivetrain experiences dynamic loads from rotational forces, maximum shear stress generated due to torque from the motor

## l. Operation Limits and Safety

For the R/C car, there is a level of safety concern around the drivetrain as this involves objects rotating at high RPMs. If not covered adequately then the drivetrain has a chance for clothing or hair to get caught. This is mitigated by covers that are situated around major gear hubs and around the driveshaft. The covers around gears are to reduce the chance of pinching to occur.

# 3. METHODS & CONSTRUCTION

## a. Methods

This project was designed at CWU to complete the Baja R/C competition at the end of the year. While it is designed at CWU the manufacturing utilizes a mix of machines the student has access to. These machines include a mix of CNC and laser cutting methods for metal components as well as 3D Printing for plastic components. These methods were chosen based on careful consideration using a decision matrix.

### i. Process Decisions

The decision matrix used to determine the best possible construction methods are detailed in Appendix F. This decision matrix in Appendix F02, detail mixing laser cutting and CNC methods will produce the best results for all metal components; these components include the chassis and the drive train. As for the Plastic components, Appendix F03 shows that 3D printing is the best choice for this application as it has the best adherence to tolerance as well as availability of the materials. Material selection for the chassis as detailed in Appendix F04, was chosen based on analysis seen in 2g as well as throughout Appendix A. The best possible material was considered from different 3D printed materials as well as aluminum, and Aluminum was chosen for its ideal strength cost and weight.

The laser cut parts will be using an xtools metal fabricator, these parts include the chassis frame and the bearing mounts. A CNC lathe will be utilized to manufacture the driveshaft and the axle components. Finally, 3D printing using a Bambu H2D/X1 carbon will be utilized to fabricate the non-structural components such as the motor mounts, the battery holder, and the covers. One of the main issues that was found during the construction of this project was that this is the first time that some of these tools were being turned on. Due to this a lot of calibration was needed to be done to be able to effectively use the tool to cut to tolerance. This calibration was the only thing that really impeded the construction timeline. Other complications that were noticed during manufacturing was that the frame itself was not perfectly symmetrical. This was noticed after manufacturing for the first time and was needed to be recut.

Another thing that was noticed was after completing the 3D Printing process for AA-20-010, It was noted that the way that the part was initially produced could be redesigned to better optimize how the cover is attached to the chassis frame to better increase stability and make it easier to attach and remove for maintenance. Aside from AA-20-001 not being symmetrical, another complication that needed to be addressed is that the plate needed to be longer to better accommodate the motor being larger than initially estimated, an estimation was used as the product manufacturer did not put the dimensions on the website when purchasing the required part, due to this the frame needed to be extended and as such the analysis associated with AA-20-001 needed to be updated to make sure the frame will continue to perform to requirements in 1d.

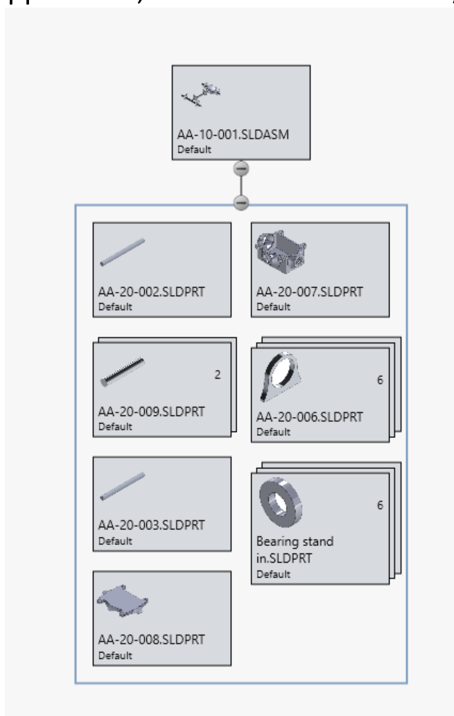
## b. Construction

### i. Description

The construction of the project will be done in multiple parts that correspond to designed parts found in appendix B. Many of these parts will be assembled into subassemblies, such as the front axle assembly, the rear axle differential assembly, and the motor-battery chassis assembly. Gears for each of these assemblies are a purchased part that has been detailed in appendix C. Many of these parts are made from 6061-T6511 Aluminum metal with fixture mounts being made from ABS/PLA plastic. When time is not an issue, parts will be made at the student's personal workshop. However, if time is an issue, then the parts will be made here at CWU. This being the case, however, 3D printed parts will always be made by the student personal 3D printer due to the student having a better understanding of the slicing program needed. As mentioned previously the construction took place in multiple parts, the first part is the purchasing of components like the motor and battery, the second part is the construction of the chassis subassembly to provide a stable platform for the rest of the car to mount to, the third part is the construction of the drivetrain subassembly this will connect to the chassis subassembly to provide locomotion, the final part is the final assembly with the project partners' subassemblies so that the final assembly is a complete and working prototype.

### ii. Drawing Tree, Drawing ID's

The following is a subassembly used for the drivetrain of the R/C Baja car. A larger and more full drawing tree can be found in appendix B; this details the entire R/C Baja Car.




### iii. Parts

Fall: to manufacture parts found in appendix B, there were 3 main manufacturing processes that were utilized to build the subassemblies. The first main process is a laser cutting that will use a MetalFab 1200W laser cutter. This is used for the chassis body (AA-20-001) and the bearing mounts (AA-20-006). The next process is the use of a CNC lathe for use on the drive shaft (AA-20-002) and axles (AA-20-003). The CNC lathe is used to keep the shaft and axles as close to circular as possible. The final process group makes use of 3D printing to build the mount components, the battery mount (AA-20-005) and the motor mount (AA-20-004). This process utilizes a Bambu Labs H2D printer to print in ABS/ASA plastic.

Winter:

### iv. Manufacturing Issues

Fall: there are a couple of potential risks that can be foreseeable prior to manufacturing. One of the potential risks is learning how to utilize the CNC lathe as well as the laser cutter. Both machines are devices that the student has access to but had never utilized until this project. Another potential risk is the possibility of a print failure while 3D printing. While Bambu labs has a reputation for having a much lower failure rate than competitors, there is always a possibility of a failure, such as if the nozzle temperature is too low for the material or if the print bed needed to be heated

Winter:

v. Discussion of Assembly

# 4. TESTING

## a. Introduction

The main testing approach will be the R/C Baja Competition held at the end of the year for the CWU ASME chapter. This, however, has multiple race requirements that R/C cars must be able to complete. These include the slalom-and-sprint and the Baja competition. Students will test the R/C cars capabilities on mock tracks as well as on gravel and dirt roads, these tests will simulate the track conditions for the competition. Based on calculations and speed limits set by gear ratios, the R/C car is predicted to perform well during the sprint tests. The car is also predicted to perform well during the Baja portion as values like the natural frequency are calculated for a gravel road.

Outside of the Baja competition testing, the R/C car will undergo various tests that are related to the requirement found in section 1d. Based on calculations found in Appendix A, the car is predicted to perform to specification during the testing methods.

## b. Method/Approach

To test the predictions made for the performance of the car, there will be various testing done. A maximum speed test will be used to find requirement 1d-4, this will require a stopwatch and 100 feet of flat land this will determine if the car can reach the maximum specified speed. During the speed test, there will also be an acceleration test that uses the same set-up to determine how long it takes to reach a specified speed, a purchased accelerometer will be used to determine the speeds. A crash test will be used to determine the reliability of the car for requirement 1d-2 and 7, this test will be the most destructive test that the car will undergo and will involve getting the car to 15 mph, determine using the accelerometer, then running into a concrete wall. Data will be collected based on pictures taken with a cellphone camera before the test and after the test, to determine how much deflection the R/C car experiences. A scale will be used to determine the final weight of the car found in 1d-3. Lastly a student-made wooden ramp with a 45-degree incline will be used to determine how well the car can handle inclined surfaces found in 1d-10. The data collected will be how far up the ramp the car goes before slipping, the test would be determined successful if the car makes it up the ramp. This ramp will be made the week prior to the test being completed to allow for adhesive to dry.

## c. Test Process

## d. Deliverables

# 5. BUDGET

## a. Parts

Parts are to be procured by one of 3 methods, either made in house, purchased from online retailer/warehouse, and made using student's personal workshop. Parts with longer lead times such as the motor and battery are to be ordered during early winter quarter and stored with the rest of the manufactured parts. Parts 20-002 and 20-003 are to be made in house using the CWU machine shop and Part 20-001 and 20-004 are to be made using a laser cutting process at student's personal workshop.

## b. Outsourcing

Outsourcing will not be a necessary cost as the student's workshop has the capabilities to perform all processes outside of the need to purchase raw materials and advanced electronic components.

## c. Labor

Student's personal hourly rate is $12/hour as this is the rate for personal or school projects. This estimate is based on the students' estimation of capabilities.

## d. Estimated Total Project Cost

This project is estimated to cost about $800; this estimation includes project partner estimates. Much of the cost is detailed in Appendix C as the motor and battery are a significant portion of the cost. Labor is the second most expensive portion making up about $300 of the estimated cost.

## e. Funding Source

This project is funded by the Kaminski Scholarship Foundation, as well as funding from students' personal funds.

## f. Winter Updates

fa: During winter Quarter, there was a major redesign of both the drive train and the chassis. Due to this redesign, there was no longer a need to manufacture the rear axles as these now needed to be purchased. This was updated in Appendix C and D. Additionally; there was a larger cost that was due to mistakes and recuts for the chassis frame. Due to these recuts, the cost of making the chassis frame was higher than expected.

fb: There were no issues with outsourcing as outsourcing was not used to make any part of this project. All Parts are either made by 3D-Printing on in-house printers or cut by machines owned by the student.

fc: Labor costs are accurate with the Gantt Chart in Appendix E.

fd: As this update was done during winter quarter there are no costs that needed to be addressed due to testing. The electronics test done to ensure component compatibility resulted in a successful test. This was the only test that was done during winter quarter that could have resulted in a need to change the costs or budget for new electronics.

fe: There is no change in funding from scholarships, however there was a change that the student needed to purchase parts out of pocket

# g. Spring Updates

ga:
gb:
gc:
gd:
ge:

# 6. SCHEDULE

## a. Design

Fall:

This section sees major headway made on the proposal of the project. Analysis is performed to gain a better understanding of what needs to be manufactured and how the Baja Car performs throughout testing. This performance analysis extends to the performance of the Car during the ASME CWU Baja Competition. There were many scheduling conflicts as the component selection for the car took more time than originally expected, this caused some errors to appear during analysis as the weight of certain calculations was slightly off. This was corrected as the component selection was finalized. Time estimates can be found in the provided Gantt chart, found in Appendix E; these time estimates were based on current ability and comprehension. The estimates themselves are close to the indicated values with some analysis taking slightly more or less time, usually by half a day.

Winter:

During this time, the design was fully finalized and ready for construction to start. Few major design changes occur to reflect current tooling availability. Throughout this project, from fall quarter to spring quarter, the estimated time investment comes out to about 100 hours for the design, conception, and analysis of the R/C car during all quarters. For the winter quarter, the estimated time is about 80 hours. This is for the construction, prototyping, and revision of any parts. Lastly for spring quarter, this is estimated to be about 20 hours. This estimation is significantly lower than the other quarters as much of this quarter revolves around testing the car, the competition, and the presentation of the final car to the CWU MET faculty as well as to the SOURCE judges and onlookers. It was found during winter quarter that the design was not completed to be manufactured. A week was dedicated to fixing the design so that I can be best used for offroad applications. This design change was a major flaw that required a large setback in the manufacturing timeline. The design was supposed to be completed and ready for construction by the end of fall quarter, but due to these redesigns, the final design was completed 2/6/2026.

## b. Construction

Fall:

Construction is fully planned out as to not have delays. These plans include the time for CNC components and parts that are milled on an engine lathe. These plans also include shipment dates and arrival times for purchased parts, such as the motor and the battery.

Winter:
During winter quarter, the construction of the R/C car will begin. This includes the use of engine lathes for the driveshaft to get within tolerance for roundness, the use of CNC machinery to get the dimensions for the chassis within tolerance. Construction is going smoothly when the student could get into the workshop to manufacture parts. There were parts that needed to be manufactured more than once due to poor planning on manufacturing method. For the laser cutting, it took longer than expected to set up the laser cutter as the ambient temperature was lower than normal, thus creating a sub-optimal air compressor environment. This environment made some of the parts come out with more slag than expected. This slag made the post-processing time longer. For the 3D-printed parts, there were a couple of print failures that occurred after several hours of print time. This was a major problem as these print failures directly led to loss of money as well as time. This was solved over time as the part that failed was edited to make for better design. The use of the lathe made for easy construction of the driveshaft. Originally Task 4c in the Gantt chart in Appendix E was supposed to only take about 1 hour, this task ended up taking 4 hours due to needing a redesign as well as the laser not cutting the first time resulting in multiple cutting passes. As for Task 4b, this part is the motor housing which was not measured correctly. This part needs 1 hour to fully print, but due to this mismeasurement, the print will need to be reprinted which will add to manufacturing time.

## c. Testing

Fall:
The testing for the R/C car is done to test the requirements found in section 1d. The scheduling for these tests is found in Appendix E in the testing section of the Gantt chart.
Spring: These tests will include crash tests for the drivetrain and chassis, Acceleration tests for the drivetrain, as well as any other tests needed for the suspension and steering of the vehicle.

# 7. PROJECT MANAGEMENT

Throughout this project there were many risks that were undertaken in order to ensure the successful completion of this project. While much of the risk is undertaken during the project, from financial, human, physical, and software resources. There is a level of risk associated with completing the project, this risk comes in the form of losing money to purchased components as the student documenting this proposal chose not to keep the R/C upon completion, it will go to the students' project partner.

## a. Human Resources

For the successful completion of this project, there will be many people aside from the Student and the Student's project partner. This includes Professor Charles Pringle, Doctor John Choi, and other CWU MET students and Facility. For project assistance, the student's father, Lou Amadio, will be asked to assist as this individual is the primary owner of many of the machines there are planned to be utilized. The risks with receiving outside assistance are that individuals may not understand the scope of the project and assistance may not be helpful to the completion of the project. Another risk that may come up is scheduling conflicts may occur. The risks will be managed by asking a few days, about 3-4 days, in advance if the students' father is available to keep the workshop open. This advanced notice will be needed for the student as well as the student must commute to the workshop to make use of the resources.

## b. Physical Resources

As mentioned prior, there are many machines that are being planned on being used. These include access to a 3D printer (Bambu Labs H2D), A CO2 laser cutter, an all-in-one CNC machine, an all-in-one Lathe, Drill Presses, Engine Lathes, and a metal bender. As many of these machines that are accessible to the student, there is a risk associated with many of these machines, and that is that they are owned by the students' father, therefore meaning that the student may not have access to these machines without prior permission and scheduling. Other physical resources are raw materials such as aluminum sheets and aluminum rods; the risks associated with these items are whether the vendor has it in stock or lead times. Should the risks with physical resources become a hinderance to the success of the project, then the fall back will the resources and facilities provided by the CWU MET department.

## c. Soft Resources

Unlike with physical resources, there are not as many software resources being used. The primary use of software is GitHubs' Jekyll (JECK-uhl) program and Virtual Studio Code (VScode). These programs are employed to code and develop the required webpage deliverable. The biggest risk with this method of webpage development is that troubleshooting must be done by the student. This troubleshooting may incur missed deadlines leading to a delay is schedule. Another piece of software that is being employed is the R/C controller board/program as this is used to be able to control the R/C Baja Car and is vital to the success of the project. The risks with this piece of hard/software are that because it is vital it is also prone to breaking during use or shorting due to contamination. For designing components and drawing tree found in Appendix B, SolidWorks 2025 was utilized. The risks involved with this program are crashes delaying the design of components and assemblies. Useless saved extensively, there isn't a fix for this type of risk as a crash could occur at any point during the design process.

## d. Financial Resources

The project sponsor is committed to providing monetary support for components that cannot be manufactured by the student. This support extends to raw materials, electronics, and tires. The students will also be using their own funds to finance the project should the project go over budget at any point throughout senior year.

# 8. DISCUSSION

## a. Design

Throughout fall quarter, analysis was carried out to get a better understanding of the design parameters that needed to be met or the car to perform to specifications outlined in section 1.

Throughout the fall quarter, the design underwent 2 major redesigns. The first redesign detailed an update to the drive shaft and axles. Based on initial analysis, the driveshaft and axles needed to be .25 inches in diameter to withstand the rotational forces that are acting on the parts. However, later analysis of the lifetime cycles decided that a drive shaft of .25 inches diameter would not be enough to prevent failure. Thus, an increase in diameter was needed. The increase went from .25 inches to .75 inches for the part to withstand a minimum operational time of 2 minutes.

The second major redesign during fall quarter was going back through every part and updating each model to reflect a current process method. This includes updating the battery mount as this part was originally being laser cut and bent from aluminum but after careful consideration, it was decided to 3D Print it from PLA instead. The other redesign is to the bear mount, the cover, and the frame as all the parts originally had no fixture holes to be able to connect everything to the frame.

The last major redesign was to the placement of the drivetrain and the cover; the cover needs to be able to cover all parts and subassemblies. This action is to reduce the drag experienced by the car, hopefully reducing the work needed by the motor to reach specified speeds. The other major redesign was to the placement of the drivetrain system. Initially, this system was to be placed on the underside of the frame to give it enough ground clearance, however this was changed to the top side of the frame because the differential housing was too big for the chosen wheels.

Some risks that needed to be overcome during the design process were that some of the programs being used were crashing, not allowing the proctors to view the webpage after turning it in. The fix that was found for this was to sit down for multiple hours figuring out where the codebase broke, turning out the codebase broke from a single dependency not being updated.

## b. Construction

Throughout winter quarter, it was noted that manufacturing the car would be the easiest step of the process. This, however, was the wrong assumption.

During winter quarter the student didn't like how the chassis was originally designed causing a need to completely redesign the chassis frame/body. This setback then raised some concern about the dimensions of the motor; the inclusion of the motor also caused the project to become out of budget. Due to both the chassis redesign and the budget, a new motor was sought out.

The reason for the chassis redesign is because the original design did not allow for enough clearance for the wheels and suspension to move during operation, which is a basic function for an off-road R/C Car, this was overlooked during the initial design phase.

The redesign of the chassis frames also caused a need to redesign the drivetrain subassembly. Due to this the rear suspension also needed to be redesigned to accommodate, this is done by the project partner. This redesign was started because of overlooking the need for the car to bounce, the original design did not account for this.

During the construction phase of the project, the original parts were produced using a laser cutter, the convenience of having access to a laser allowed for more complex shapes to be produced is relatively short amount of time. This allowed for a short manufacturing timeframe. In addition to laser cutting, the inclusion of 3D-printed parts in materials like PLA or PETG allow for complex shapes that have similar or better stability and strength to cast plastic or vacuum formed plastic.

Something that wasn't helpful with the construction of the project is that the project is being manufactured during winter quarter. During these months, it is significantly more difficult to keep the laser cutter warm enough that the compressed air, that is used for the cutting environment, won't freeze. This freezing leads to an increase in the amount of slag that get produced on the part that's being cut. This slag also is a result of trying to cut metal that is too large for the machine to handle. Due to the slag build up it increases the production time when removing this slag.

## c. Testing

# 9. CONCLUSION

## a. Design

This project serves as the Capstone project for the CWU MET program. The project chosen was an R/C car that is to compete in the ASME CWU chapter Baja Competition. This proposal details the design, construction, and testing of the Chassis and drivetrain components. These components serve a specific purpose to the success of the R/C Baja car, the chassis is the support for sub-assembly attachments, as for the Drivetrain, the drivetrain provides torque to the system for motion. The analysis chosen for these components was chosen based on the design requirements in section 1-d, these analyses include deflection across the chassis, the required torque and gear reduction to reach a specific speed, and the torsional shear that is acting on the driveshaft. The analysis contributes to the success of the project, by providing the minimum requirements for the purchased parts and constructed components. These analyses were performed using formulas learned through the CWU MET program such as statics formulas for determining the deflection on the chassis, dynamics to understand the forces acting on the car during impacts, and physics to understand the minimum acceleration for launching. Resources needed for this project to be successful are easily accessible by way of the student personal workshop as well as through online venders who provide access to commonly used metals and 3D-printing materials. To determine whether is project was a successful senior project or not the car will undergo a series of testing that was defined by the student, such as a crash test, acceleration test, max speed test, and an endurance test. The car will also compete in the ASME CWU Baja competition that is held during the spring quarter and it will determined to be successful if the car finishes the race in 2$^{nd}$ place during the Baja competition and 7 seconds or less in the Slalom-and-Sprint race.

## b. Construction

## c. Testing

# 10. ACKNOWLEDGEMENTS

# References

# APPENDIX A - Analysis

## Appendix A01 – Structural Deflection & Weight on Wheels

Alex Amadio | ME 484 | 10/6/2025 | 1/3

Analysis 01: structural

given: $D_{alum} = 2.7 g/cm^3$ (based on inital assumeptions subject to change)

battery weight: 196g

weight of 1 motor: 0.48lb → 0.218 Kg

find: force on wheels (end points)

deflection due to

assume: equillibrum

perfect square plate

equal Distrabution of components

method: static/moment equatiions

Navier's Double-Sine Expansion

Rayleigh–Ritz single term worked estimate

solution:

$$w(x,y) = \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} W_{mn} \sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$$

$$W_{mn} = \frac{Q_{mn}}{D\left(\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2\right)^2}$$

$$W_{max} = \frac{q_{eq}}{D\pi^4\left(\frac{1}{a^2}+\frac{1}{b^2}\right)^2}$$

bending strain energy

$$U = \frac{D}{2}\int_0^a\int_0^b (\nabla^2 w)^2\,dx\,dy$$

$$U = D\frac{\pi^4}{8}\left(\frac{1}{a^2}+\frac{1}{b^2}\right)abW^2$$

work done by load

$$V = \int_0^a\int_0^b q\,w\,dx\,dy = qW\frac{ab}{4}$$

$$W_{max} = \frac{q_{eq}}{D\pi^4\left(\frac{1}{a^2}+\frac{1}{b^2}\right)^2}$$

$$q_{eq} = \frac{P_c + 2P}{ab}$$

$P_c$ = weight from battery

$P$ = weight from motors

$a = 12$

$$D = \frac{Et^2}{12(1-v^2)}$$

E = young's modulus

t = thickness

v = poisson's ratio

# Appendix A01 – Structural Deflection & Weight on Wheels Cont. (2)



Solution cont.:

$$\omega_{max} = \frac{q_{eq}}{D\pi^4\left(\frac{1}{a^2}+\frac{1}{b^2}\right)^2}$$

$$q_{eq} = \frac{P_c + 2p}{ab}$$

$$D = \frac{Et^2}{12(1-V)^2}$$

$V = 0.33$ (Aluminum 6061-T6)

$E = 69\,GPa \rightarrow 69.0\times10^9$

$a = 12'' \times 0.0254 \rightarrow .3048m$

$b = 9'' \times 0.0254 \rightarrow .2286$

$t = .0125'' \times .0254 \rightarrow 0.0003175m$

$P_c = .196\,Kg \cdot 9.81 = 1.92276N$

$p = .218 \cdot 9.81 = 2.13858N$

$$D = \frac{(69.0\times10^9 Pa)(.0003175m)^2}{12(1-0.33)^2} = 1291.24$$

$$q_{eq} = \frac{P_c \times ((2)(p))}{.3048 \cdot .2286} = 118.03$$

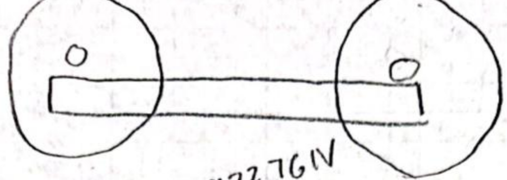
$$\omega_{max} = \frac{118.03}{(1291.24)\pi^4\left(\frac{1}{.3048^2}+\frac{1}{.2286^2}\right)^2} = 0.00000105\ m \rightarrow 0.0000413in$$

$\boxed{\text{the chassis will deflect 0.0000413 in due to weight of proposed components at 1/8 thickness}}$

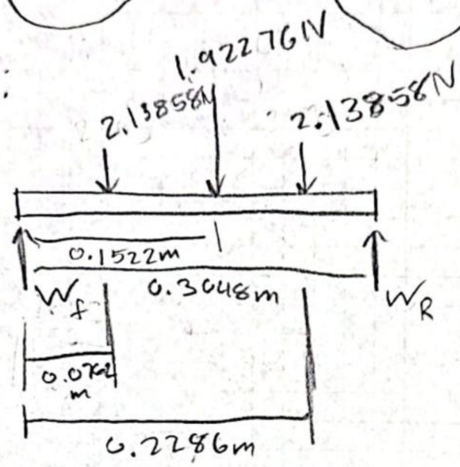
Alex Amadio | MET 489 | 10/6/2025 | 3/3

solution cont.:

*not to scale



FBD:




$\Sigma F_X = 0 = N/A$

$\Sigma F_Y = 0 = W_f + W_R - 2.13858 - 1.92276 - 2.13858$

$\Sigma M_{W_f} = 0 = (2.13858N)(0.0762m) + (1.92276N)(0.1522m) + (2.13858N)(.2286m) - (WR)(.3046m)$

$W_R = \frac{.9445Nm}{.3048m} = -3.0987N$

$W_R = 3.0987N \times 0.22481 lbs$ $\boxed{W_R = 0.6966 lbs/2}$

$0 = W_f + 3.0987 - (2)(2.13858) - 1.92276$

$W_F = 3.10122N \to 0.22481 lbs$ $\boxed{W_F = 0.697 lbs/2}$

the wheels currently experience 0.3486 lbs on both of the front wheels and 0.348 lbs on both back wheels

# Appendix A02 – Torsional Shear, angle of rotation due to torque, Driveshaft Diameter and Critical Speed Frequency

Alex Amadio | MET 489 | 10/12/2025 | 1/2

Analysis 02:

given: $\rho = 0.0975 \text{ lb/in}^3$ $\quad G = 11.5 \times 10^6 \text{ psi}$

$L = 10 \text{ in}$

$E = 10 \times 10^6 \text{ psi}$

$T = .1475 \text{ lb/ft}$ (from motor specs) $\rightarrow 1.77 \text{ lb/in}$

find: - shear stress on drivtrain before gear-reduction

- Drivetrain diameter to withstand 30MPH

assume: 3in Ø wheels

gear reduction down to a torque of 1.77 lb/in

method: shear stress analysis

critiacal speed analysis

Solution:

$$\tau = \frac{Tr}{J}$$

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

$$N_{cr} = (4.76 \times 10^6)\frac{r}{L^2}\sqrt{\frac{E}{\rho}}$$

$r = .125 \text{ in}$

$$N_{cr} = (4.76 \times 10^6)\frac{.125}{10^2}\sqrt{\frac{10 \times 10^6}{0.0975}}$$

$N_{cr} = 6025.7992 \text{ RPM}$ $\quad f_{cr} = \frac{N_{op}}{60} = 75.3225 \text{ Hz}$

$N_{op} = .75(N_{cr}) = 4519.3494 \text{ RPM}$

$\frac{N_{op} \cdot 3}{336} = 40.3513 \text{ MPh}$

this means the drive shaft with a diameter of .25 inch will not fail at 30mph with a critical frequency of 75.3225 Hz

# Appendix A02 – Torsional Shear, angle of rotation due to torque, Driveshaft Diameter and Critical Speed Frequency Cont. (2)

Alex Amadio MET489 10/12/2025 2/2

solution cont.

$$\tau = \frac{Tr}{J} = \frac{1.77(.125)}{J} = 576 \text{ lb in}$$

$$\phi = \frac{TL}{JG} = \frac{1.77(10\text{in})}{J\,G} = 0.0004024°$$

$$J = \frac{\pi r^4}{2} = \frac{\pi(.125)^4}{2} = 0.0003832495 \text{in}^4$$

# Appendix A03 – Chassis deflection due to 15 mph impact

Alex Amadio | MET489 | 10/14/2025 | 1/1

find: deflection due to head-on impact

given: $V = 15$ mph

$m \approx 3$ pounds (based on estimates)

$b = 5.2$ in (based on drawing in appendix B06)

$t = .125$ in

$\nu = .33$ (for Aluminum)

$L = 12$ in

$E = 10 \times 10^6$ psi

$\varnothing = .25$ in

assume: perfectly elastic collision

method: Kinetic energy

Deflection

solution:

$$\delta_{max} = \sqrt{\frac{mv^2}{K_{bend}}} = \sqrt{\frac{(3)(15^2)}{1880.79}} = 0.599\text{ in}$$

$$K_{bend} = \frac{48EI}{L^3} = \frac{48(10\times10^6)(0.006770833)}{12^3} = 1880.79$$

$$I = \frac{bt^3}{12} = \frac{5.2(.125)^3}{12} = .006770833\text{ in}^4$$

$$F_{max} = K\delta = (1880.79)(.599) = 1126.74\text{ lb}$$

at a speed of 15 mph the car will deflect .599 inches with a peak impact force of 1126.74 pounds

# Appendix A04 – Drivetrain RPM and Motor-Drivetrain Gear Ratio

Alex Amadio | MET489 | 10/14/2025 | 1/1

given: voltage: 7.6V (from Battery specs)
KV = 2400 (from motor specs)
wheel Ø = 4in

find: RPM and required gear ratio

assume: no slipping between gears
80% efficiency

method: RPM calculations

Solution:

$$RPM = (KV)(V)(\eta) = (2400)(7.6)(.80) = \boxed{14592\ RPM}$$

$$MPh = \frac{RPM \times (C \times 60\left[\frac{min}{hour}\right])}{12\left[\frac{in}{foot}\right] \times 5280\left[\frac{feet}{mile}\right]} = \frac{(14592)(12.57)(60)}{(12)(5280)} = 173.7\ mph$$

$$C = \pi Ø = \pi(4) = 12.57\,in$$

173.7 mph with no gear reduction

gear reduction for target speed of 30 mph

$$G = \frac{N_{motor}(\pi Ø)}{1056\ V_{target}} = \frac{14592(\pi(4))}{1056(30)} = 5.7$$

gear reduction for target speed of 35 mph

$$G = \frac{14592(4\pi)}{1056(35)} = 5$$

$\boxed{G = 5 \text{ with safety in mind}}$

# Appendix A05 – Motor Power and Friction on Wheels at an Incline

Alex Amadio | MET489 | 10/26/2025 | 1/1

Given: $N = 2400$ RPM  $i = 5$

$\varnothing_{\text{Diameter}} = 3\text{in}$  $g = 32.2\ \text{ft/s}^2$

$45°$ incline  $m = 3$ pounds

find: motor power and friction on wheels

assume: constant torque

$\eta = 80\%$

method: $P = T\omega$

$T = F_{drive} \times r$

Solution:

$$\omega = \frac{2\pi N}{60} = \frac{2\pi(2400)}{60} = 251.\ \text{rad/sec}$$

$$T = \frac{F_{drive} \times r}{(i)(\eta)} = \frac{(68.3)(.375)}{(5)(.8)} = 6.2$$

$$F_{drive} = mg \cdot \sin\varnothing = 3(32.2)(\sin 45) = 68.3\ \text{lb}$$

$\boxed{\text{the wheels need to generate 68.3 lb of friction}}$

$$P = 6.2 \times 251.0 = 1556.2\ \text{hp}$$

$\boxed{P_{motor} = 1556.2\ \text{hp to go up a } 45° \text{ incline}}$

# Appendix A06 – Damage Factor and Number of Cycles Over Time

Alex Amadio | MET 489 | 10/26/2025 | 1/2

given: RPM = 14592/5 = 2918.4

$\rho_{alum} = 2.7\ g/cm^3 \Rightarrow .0975\ lb/in^3$

$A = .0491\ in^2$

$L = 10\ in$

$r = .375\ in$

$\varnothing = .75$

$P_{motor} = 490.71$

find: The damage factor

assume: perfect horizonal shaft

Doubling Driveshaft Diameter

methods: Miner's Rule

Torsional shear (recalculation)

bending moment

Fig. 5-10

Solution:

$$\omega = \frac{2\pi(2918.4)}{60} = 305.61\ rad/s$$

$$\omega_c = \rho A r \omega^2 = .284(.442)(.375)(305.61)^2 = 4396.5$$

$$M_{max} = \frac{\omega_c L^2}{8} = \frac{4396.54(10)^2}{8} = 54956.24$$

$$\sigma_b = \frac{54956(.375)}{I} = 468164.24$$

$$I = \frac{\pi(.375)^4}{4} = .0155$$

$$T = \frac{5252 \cdot 1556.2}{14592} = 524.19$$

# Appendix A06 – Damage Factor and Number of Cycles Over Time Cont. (2)

Alex Amadio | MET 484 - | 10/27/2025 | 2/2

$\tau = \frac{Tc}{J} = \frac{356.4(.375)}{J} = 6320.62$ (off from previous calculation but within parameters)

$\sigma_{eq} = \sqrt{468164.24^2 + 3(14521.2)^2}$

$\sigma_{eq} = 468292.227$ psi -> 47 ksi

$J = \frac{\pi(.375)^4}{2} = 0.0311$

$D = \frac{N}{N_i} = \frac{5826 \text{ (revolution over 2 minutes)}}{14000 \text{ (Fig 5-10)}}$

$N = 2913 \times 2 = 5826$

$D = .416 << 1$

# Appendix A07 – Deflection of Driveshaft at 15 mph Impact

Alex Amadio | MET 489 | 11/2/2025 | 1/2

given: $d = .75$ inches   $V = 15$ mph

$E = 10\times10^6$ psi (2024-T6511 Aluminum)

$L = 10''$

$K = 1.0$ (Pinned-pinned)

find: deflection on drive shaft during 15 mph head

assume: perfectly elastic collision

pinned-pinned.

simply supported beam

method: Euler critical buckling load

slender ness ratio

Kinetic energy

simply supported

solution:

$$\tau = \frac{L}{\sqrt{\frac{I}{A}}} = \frac{10}{\sqrt{\frac{.015532}{.44179}}} = 53.3 < 100$$

$$I = \frac{\pi(.75)^4}{64} = 0.015532 \text{ in}^4$$

$$A = \pi(.375)^2 = 0.44179 \text{ in}^2$$

$$P_{cr} = \frac{\pi^2 E I}{(KL)^2} = 15329.47 \text{ psi} \rightarrow 15.33 \text{ Ksi}$$

$$F = \frac{\frac{1}{2} m V^2}{\delta} = \frac{\frac{1}{2}(3)(15)^2}{.2} = 1687$$

# Appendix A07 – Deflection of Driveshaft at 15 mph Impact Cont. (2)

Alex Amadio | MET489 | 11/2/2025 | 2/2

solution cont.

$$\delta_{max} = \frac{1687(10)^3}{48(10\times10^6)(I)} = 0.2 \text{ inches}$$

$$\boxed{\delta = 0.2 \text{ inches}}$$

$1687 < 15329$

the driveshaft will not buckle more than 0.2 inches at 15mph

# Appendix A08 – Chassis Vibration at 15 mph

Alex Amadio | MET 489 | 11/2/2025 | 1/2

Given: $V = 15\text{ mph} \rightarrow 6.7056\text{ m/s}$

$d_{wheel} = 4\text{ in} \rightarrow 0.1016\text{ m}$  $\zeta \approx .1$

$b = 9\text{ in} \rightarrow .2286\text{ m}$  $A_{rd} = 0.001$

$t = .125\text{ in} \rightarrow 0.003175\text{ m}$  $A_{gravel} = 0.003$

$L = 12\text{ in} \rightarrow 0.3048\text{ m}$

$E = 71\text{ GPa} \rightarrow 71\times10^{9}\text{ Pa}$

$m = 3\text{ pounds} \rightarrow 1.360777\text{ Kg}$

find: can the chassis withstand 10-30 Hz at 15mph

assume: Basic oil-filled shock

method: excitation frequency
- chassis stiffness
- Natural frequency
- transmissibility
- response Amplitude

Solution:

$$f_{wheel} = \frac{V}{\pi d} = \frac{6.7056}{\pi(0.1016)} = 21.01\text{ Hz}$$

$$I = \frac{bt^3}{12} = \frac{.2286(.003175)^3}{12} = 6.097\times10^{-10}$$

$$K = \frac{48(71\times10^{9})(6.097\times10^{-10})}{(.3048)^3} = 73378.85$$

$$f_n = \frac{1}{2\pi}\sqrt{\frac{73378.85}{1.360777}} = \boxed{36.96\text{ Hz}}$$

# Appendix A08 – Chassis Vibration at 15 mph Cont. (2)

Alex Amadio | MET 489 | 11/2/2025 | 2/2

Solution. cont.

$$r = \frac{f_{wheel}}{f_n} = \frac{21.01\,Hz}{36.96\,Hz} = 0.57$$

$$T(r) = \sqrt{\frac{1+(2\zeta r)^2}{(1-r^2)^2+(2\zeta r)^2}} = \sqrt{\frac{1+(2(.1)(.57))^2}{(1-(.57)^2)^2+(2(.1)(.57))^2}}$$

$T(r) = 1.47$

displacment amplitude

road

$X_{response} = A_{road} \cdot T(r) = (.001) \cdot 1.47 = 0.0015\,m$

gravel

$X_{response} = A_{gravel} \cdot T(r) = (.003)(1.47 = 0.0044\,m$

# Appendix A09 – Motor Torque Needed for Acceleration

Alex Amadio | MET 489 | 11/9/2025 | 1/1

Given: $D = 4in$

$t = 10$ seconds

$V = 10mph \rightarrow \frac{10560}{\pi(4)} = 840$ RPM

$P_{motor} = 1556.2$ hp

$a = 12in \rightarrow .3048m$

$b = 9in \rightarrow .2286m$

$m = 3lbs \rightarrow 1.36kg$

find: how much torque from motor is needed to reach 10 mph in 10 seconds

assume: no slip

method:

$$\omega_f = RPM \times \frac{2\pi}{60}$$

$$T = I\alpha$$

Solution:

$$\omega_f = 840(RPM) \times \frac{2\pi}{60} = 87.96 \text{ rad/s}$$

$$\alpha = \frac{87.96 \text{ rad/s}}{10 \text{ sec}} = 8.796 \text{ rad/s}^2$$

$$I = \frac{m(a^2+b^2)}{12} = \frac{1.36(.3048^2 + .2286^2)}{12} = 0.0165$$

$$T = I\alpha = 0.0165 \times 8.796 = 0.145134 \text{ Nm}$$

$$\omega_{motor} = 87.96 \times 5 = 439.80 \text{ rad/s}$$

$$T_{motor} = \frac{1556.2}{439.80} = \boxed{3.538 \text{ Nm}}$$

motor needs 3.538 Nm to reach 10mph in 10 seconds

# Appendix A10 – Drag Forces on the Car

Alex Amadio | MET 489 | 11/9/2025 | 1

Given: $C_d = 0.4$

$\rho = 0.07647\ lb/ft^3$

$A = 9\ in \times 5\ in = 45\ in^2 \rightarrow 3.75\ feet^2$

$V_1 = 10\ mph \rightarrow 14.66\ ft/s$

$V_2 = 20\ mph \rightarrow 29.33\ ft/s$

$V_3 = 30\ mph \rightarrow 44.00\ ft/s$

find: drag forces

assume: 5 in height with height of components

method: drag forc equation

solution:

10 mph:

$$F_d = \frac{1}{2}\rho C_d A V^2$$

$$F_d = \frac{1}{2}(.07647)(.4)(3.75)(14.66)^2$$

$$\boxed{f_d = 12.33\ lbf}$$

20 mph

$$F_d = \frac{1}{2}(.07647)(.4)(3.75)(29.33)^2$$

$$\boxed{F_d = 49.34\ lbf}$$

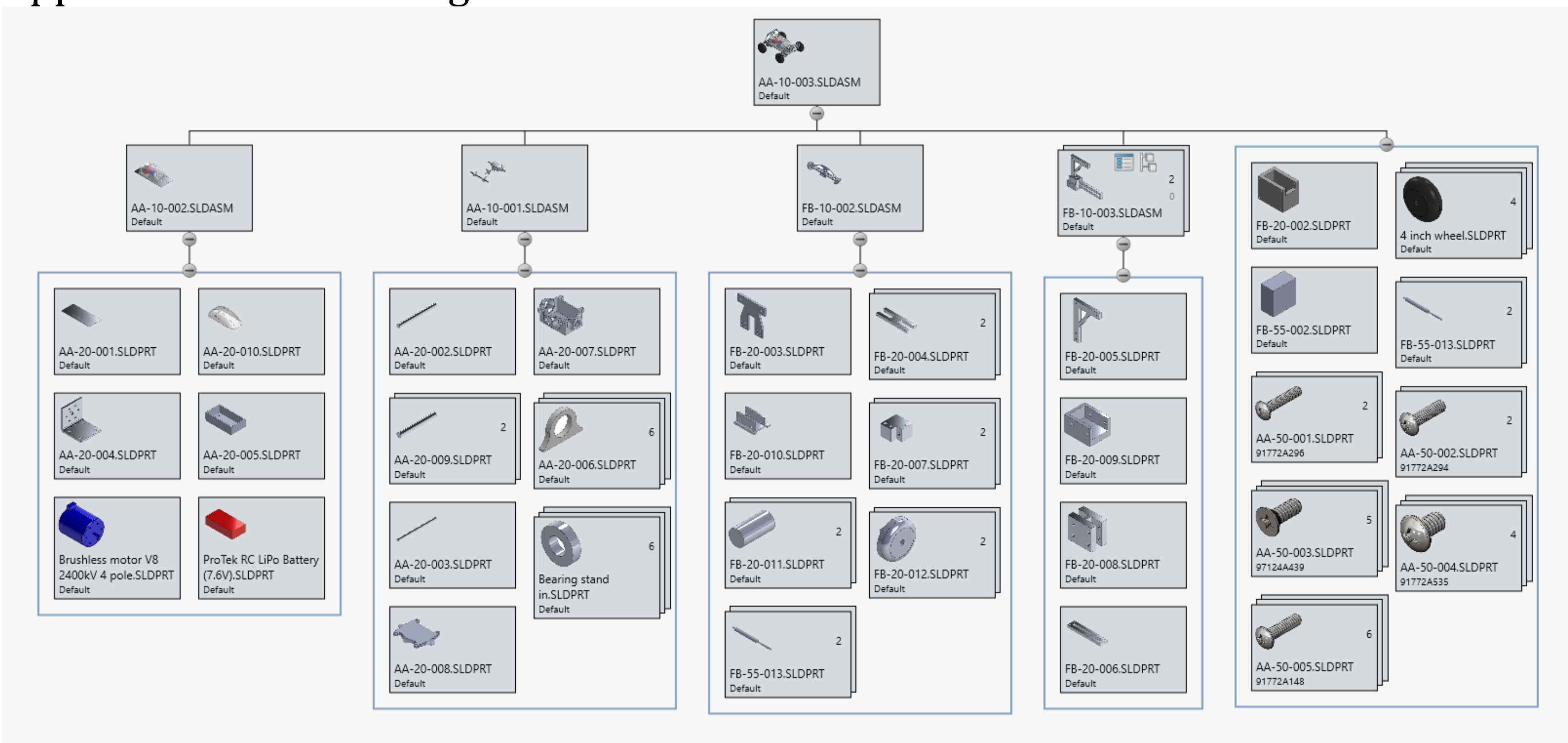
30 mph =

$$F_d = \frac{1}{2}(.07647)(.4)(3.75)(44)^2$$

$$\boxed{F_d = 111.03\ lbf}$$

# APPENDIX B - Drawings

## Appendix B01 – Drawing Tree

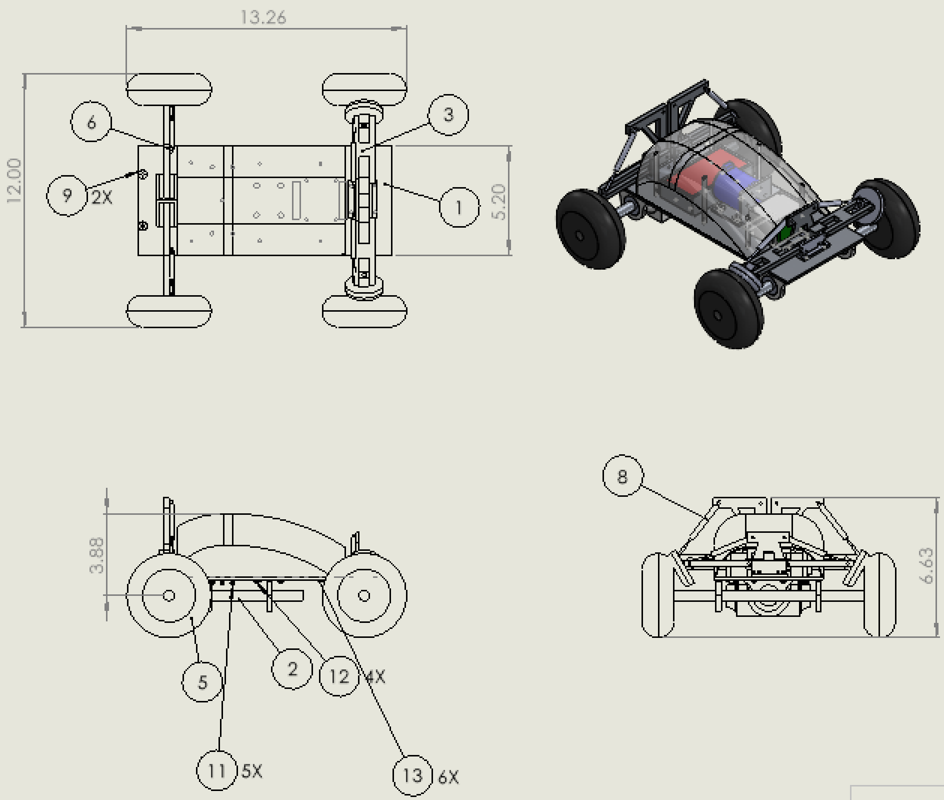


# Appendix B02 – Drawing Index

Table B02. Drawing Index

| **Drawing Assignment Num.** | **Drawing #(s)** | **Date submitted** |
|---|---|---|
| Upload: DWG 1 | AA-20-001 | 10/15/2025 |
| Upload: DWG 2 | AA-20-002 | 10/21/2025 |
| Upload: DWG 3 | AA-20-003 | 10/29/2025 |
| Upload: DWG 4 | AA-20-004 | 10/29/2025 |
| Upload: DWG 5 | AA-20-005 | 11/5/2025 |
| Upload: DWG 6 | AA-20-006 | 11/5/2025 |
| Upload: DWG 7 | AA-20-007 | 11/12/2025 |
| Upload: DWG 8 | AA-20-008 | 11/12/2025 |
| Upload: DWG 9 | AA-20-009 | 11/19/2025 |
| Upload: DWG 10 | AA-20-010 | 11/19/2025 |
| Upload: Subassembly 1 | AA-10-001 | 11/19/2025 |
| Upload: Subassembly 2 | AA-10-002 | 12/5/2025 |
| Upload: Top assembly | AA-10-003 | 12/5/2025 |

# Appendix B03 – AA-10-003 – Top Assembly




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | AA-10-002 | Drivetrain | 1 |
| 2 | AA-10-001 | Chassis | 1 |
| 3 | FB-10-002 | Front Shock Tower | 1 |
| 4 | FB-20-002 | Servo Housing | 1 |
| 5 | AA-55-004 | 4 inch Wheels | 4 |
| 6 | FB-10-003 | Rear Shock Tower | 2 |
| 7 | FB-55-002 | Front Shock | 1 |
| 8 | FB-55-013 | Rear Shock | 2 |
| 9 | AA-50-001 | Passivated 18-8 Stainless Steel Pan Head Phillips Screw | 2 |
| 10 | AA-50-002 | Passivated 18-8 Stainless Steel Pan Head Phillips Screw | 2 |
| 11 | AA-50-003 | Aluminum Phillips Flat Head Screws | 5 |
| 12 | AA-50-004 | Passivated 18-8 Stainless Steel Pan Head Phillips Screw | 4 |
| 13 | AA-50-005 | Passivated 18-8 Stainless Steel Pan Head Phillips Screw | 6 |

PROPRIETARY AND CONFIDENTIAL
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NEXT ASSY | USED ON
APPLICATION

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

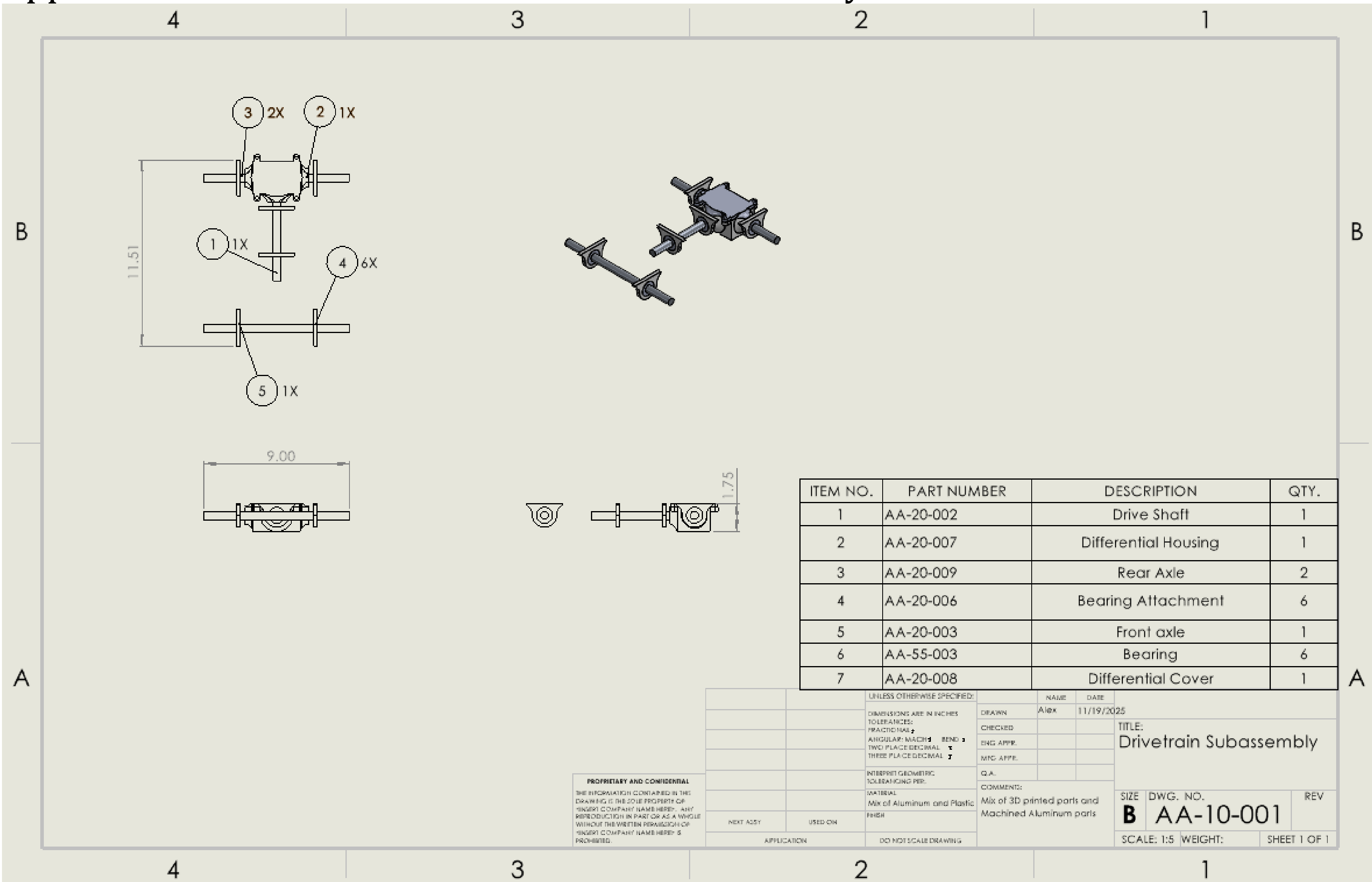
| | NAME | DATE |
|---|---|---|
| DRAWN | Alex | 12/5/2025 |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |
| COMMENTS: | | |

TITLE: Tron RC Car

SIZE B | DWG. NO. AA-10-003 | REV

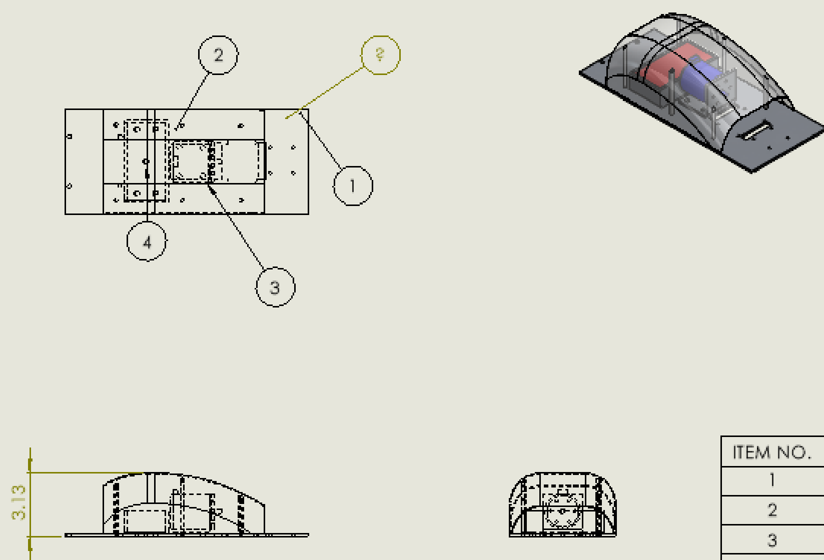
SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

# Appendix B04 –AA-10-001 – Drivetrain subassembly




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | AA-20-002 | Drive Shaft | 1 |
| 2 | AA-20-007 | Differential Housing | 1 |
| 3 | AA-20-009 | Rear Axle | 2 |
| 4 | AA-20-006 | Bearing Attachment | 6 |
| 5 | AA-20-003 | Front axle | 1 |
| 6 | AA-55-003 | Bearing | 6 |
| 7 | AA-20-008 | Differential Cover | 1 |

# Appendix B05 –AA-10-002 – Chassis subassembly




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | AA-20-001 | Chassis Body | 1 |
| 2 | AA-20-010 | Chassis Cover | 1 |
| 3 | AA-20-004 | Motor Mount | 1 |
| 4 | AA-20-005 | Battery Mount | 1 |
| 5 | AA-55-001 | Motor | 1 |
| 6 | AA-55-002 | Battery | 1 |

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

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
mix of Plastic and Aluminum
FINISH
NEXT ASSY | USED ON
APPLICATION
DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | Alex | 11/19/2025 |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:
holes for fixtures need to be placed and the cover needs to be cut into

TITLE:
Chassis Assembly

SIZE B DWG. NO. AA-10-002 REV
SCALE: 1:5 WEIGHT: SHEET 1 OF 1

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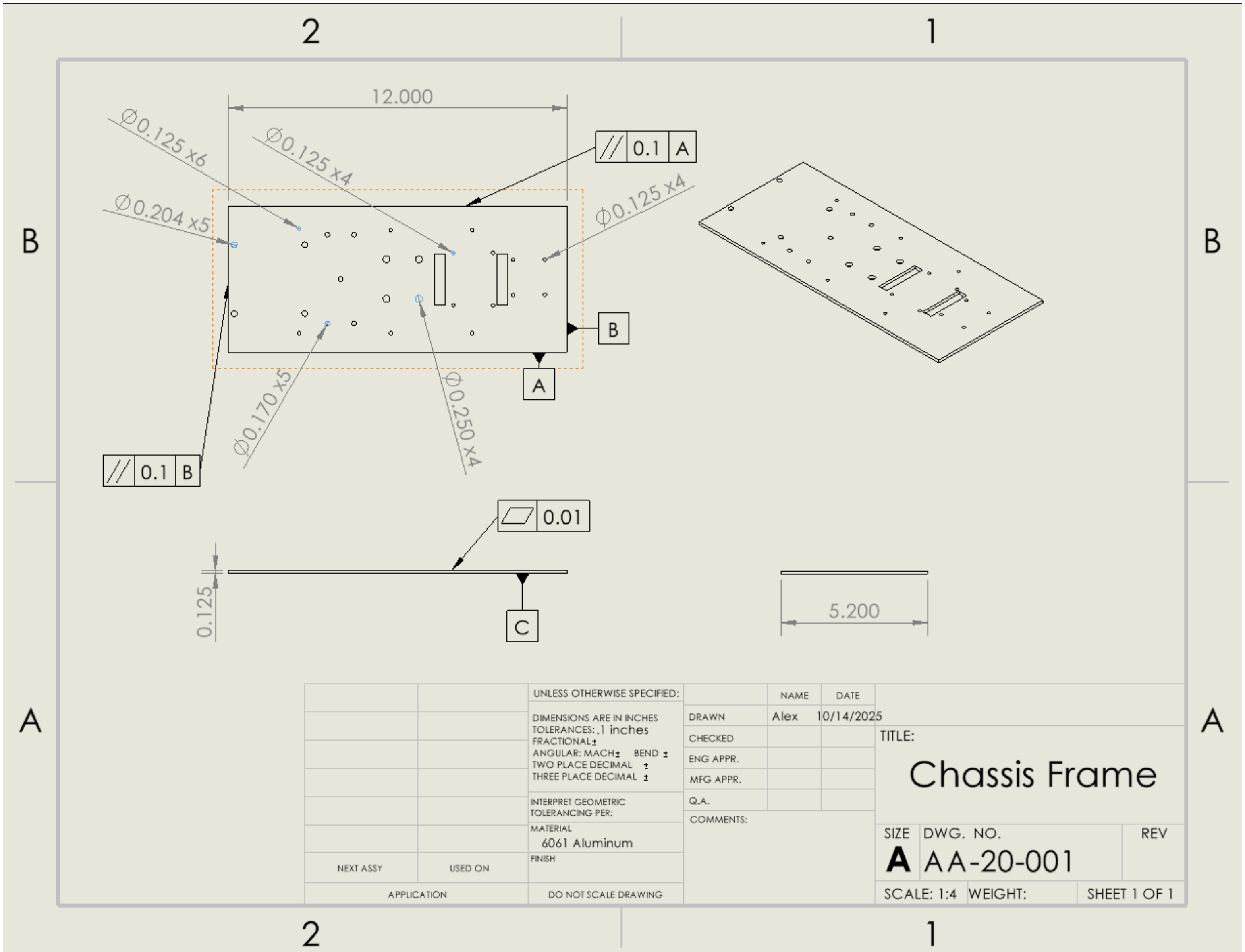
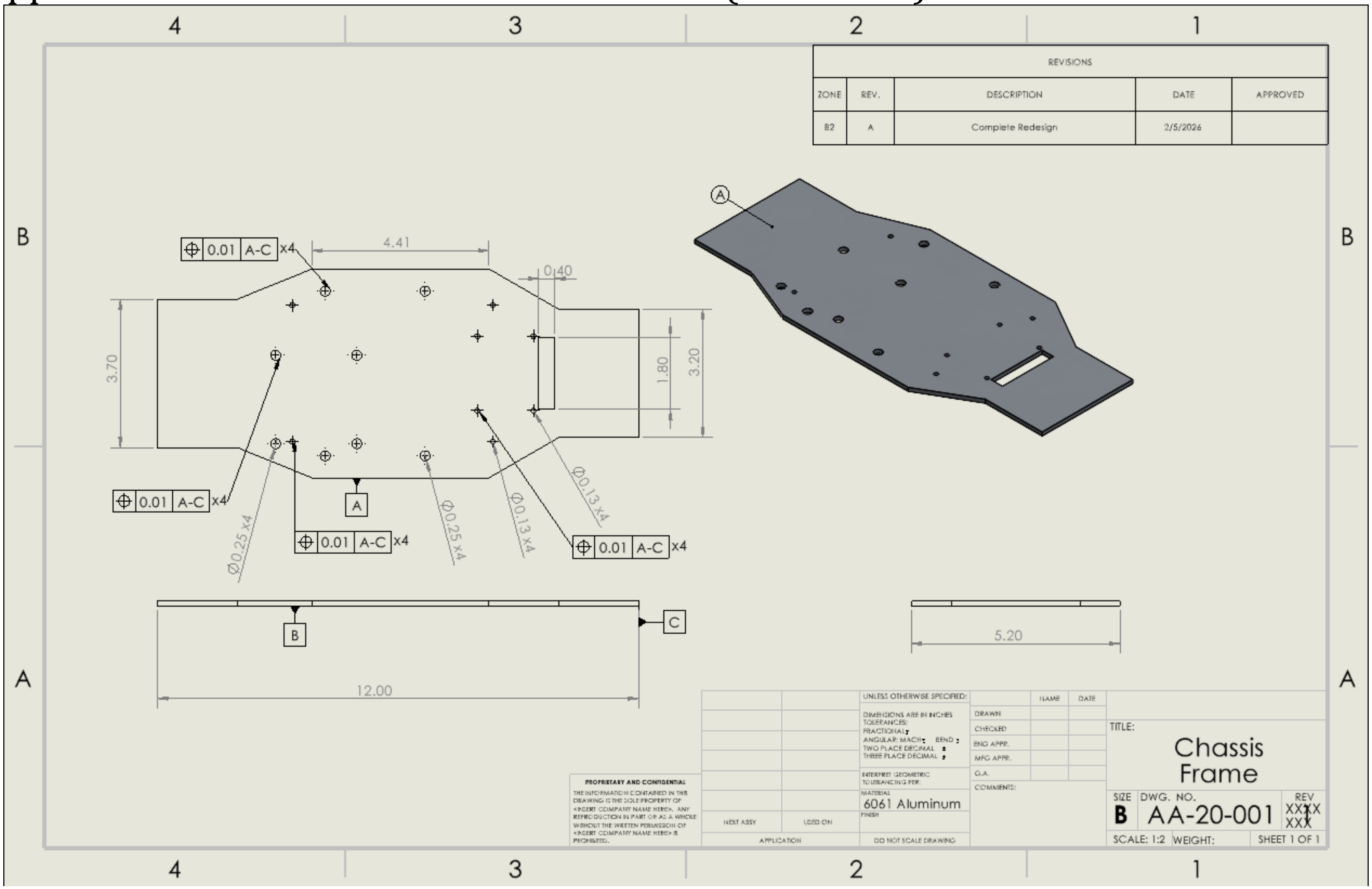
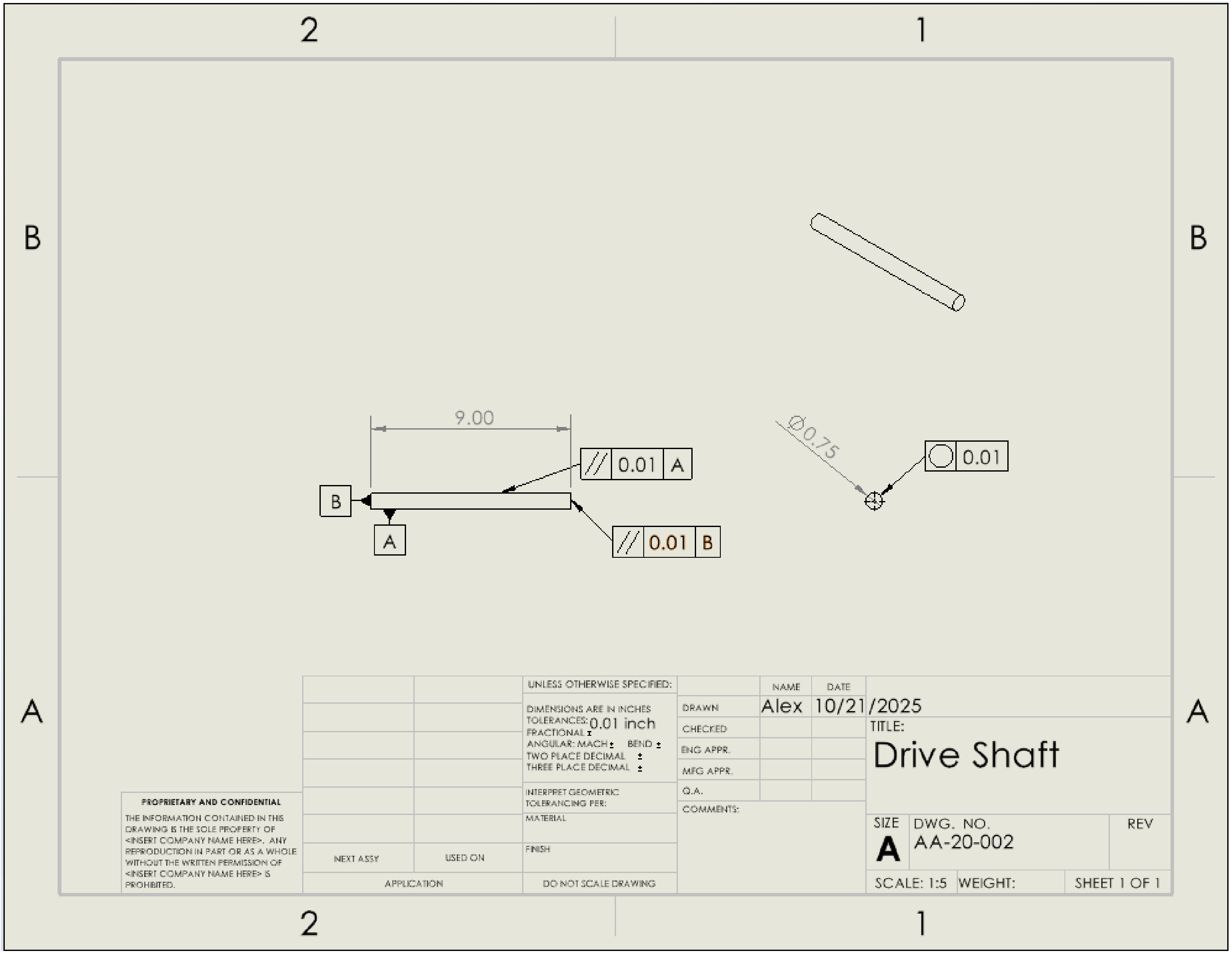
# Appendix B06 – AA-20-001 – Chassis Frame



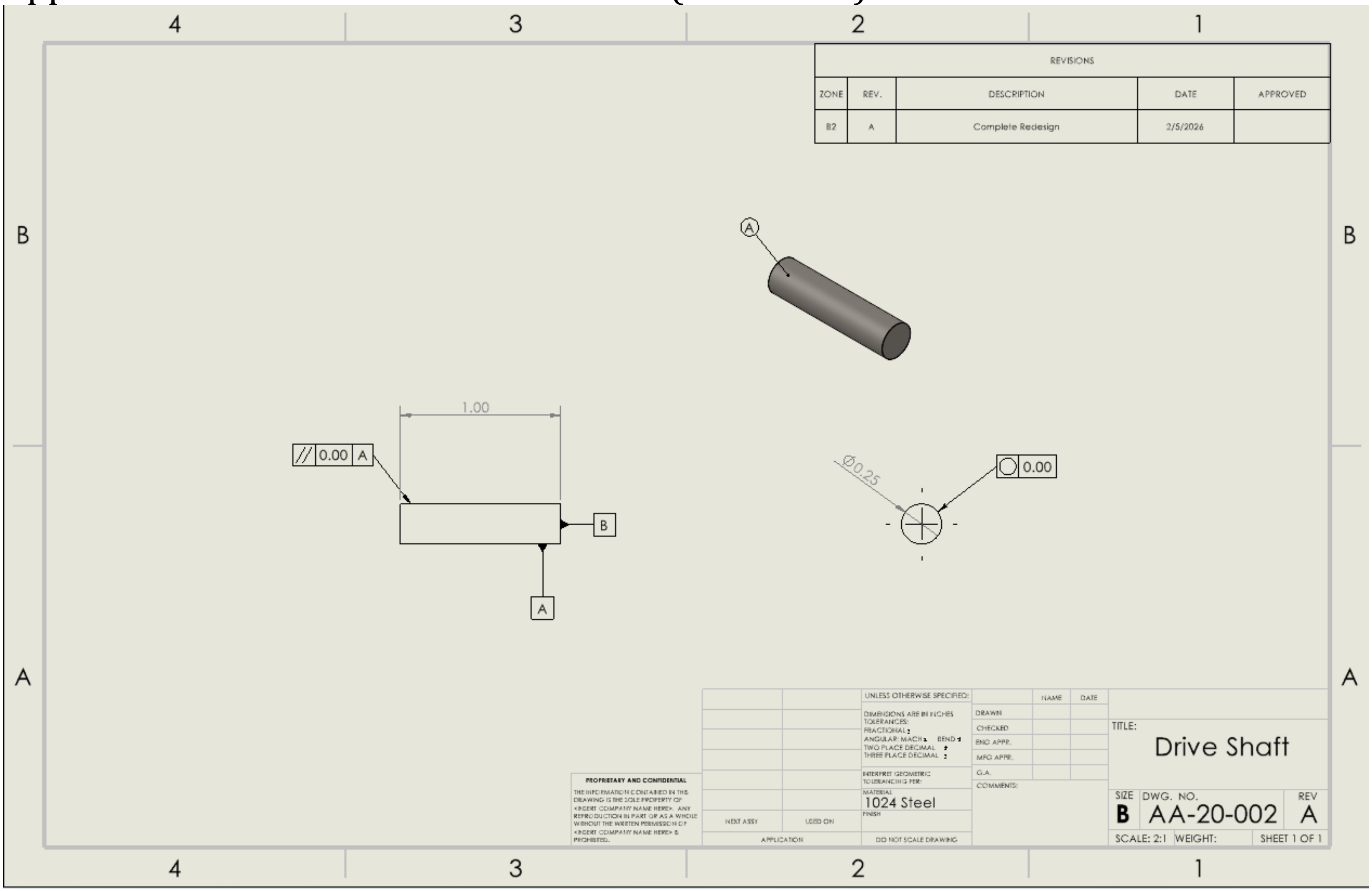
## Appendix B07 – AA-20-001 – Chassis Frame (Revision 1)



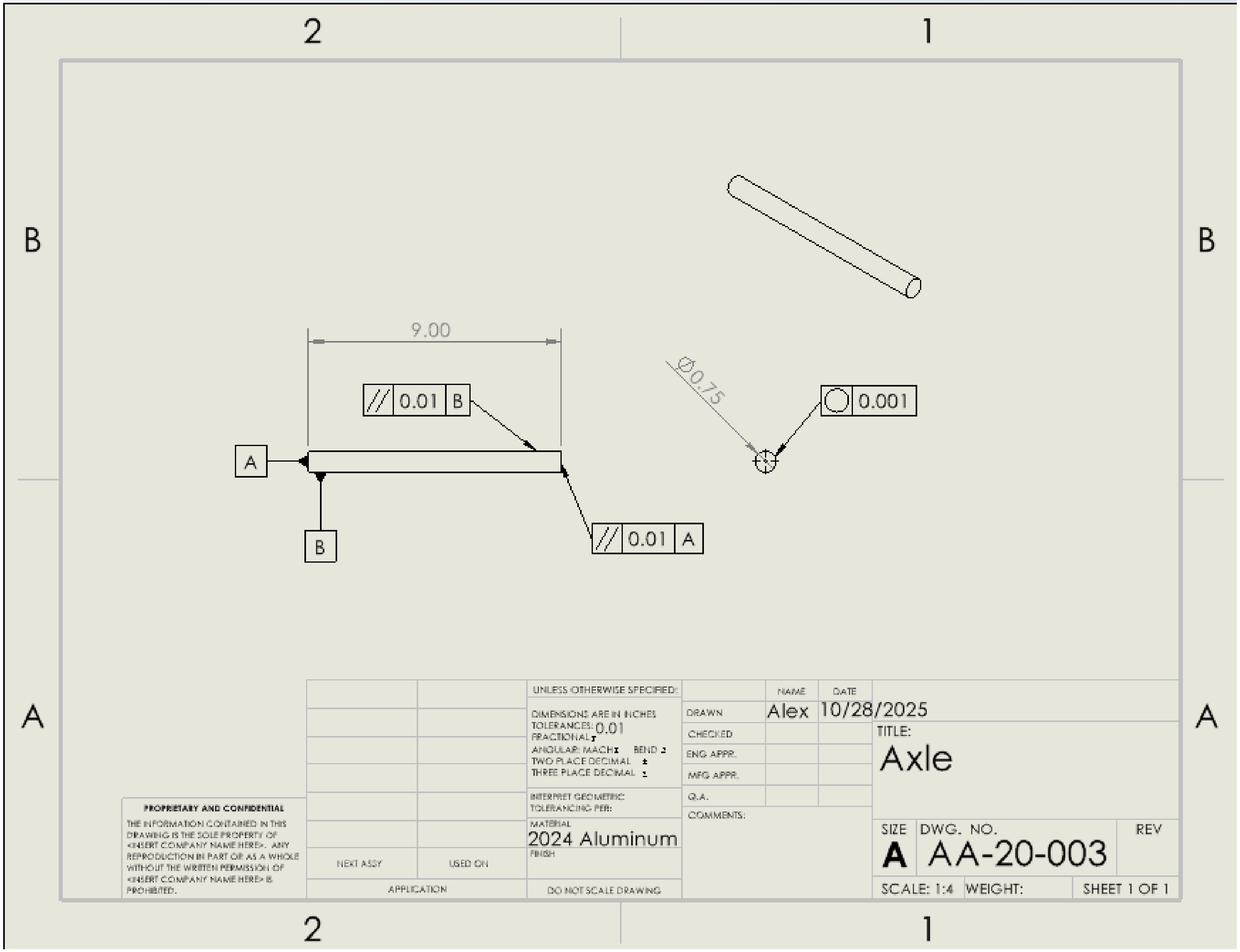
# Appendix B08 – AA-20-002 – Drive Shaft



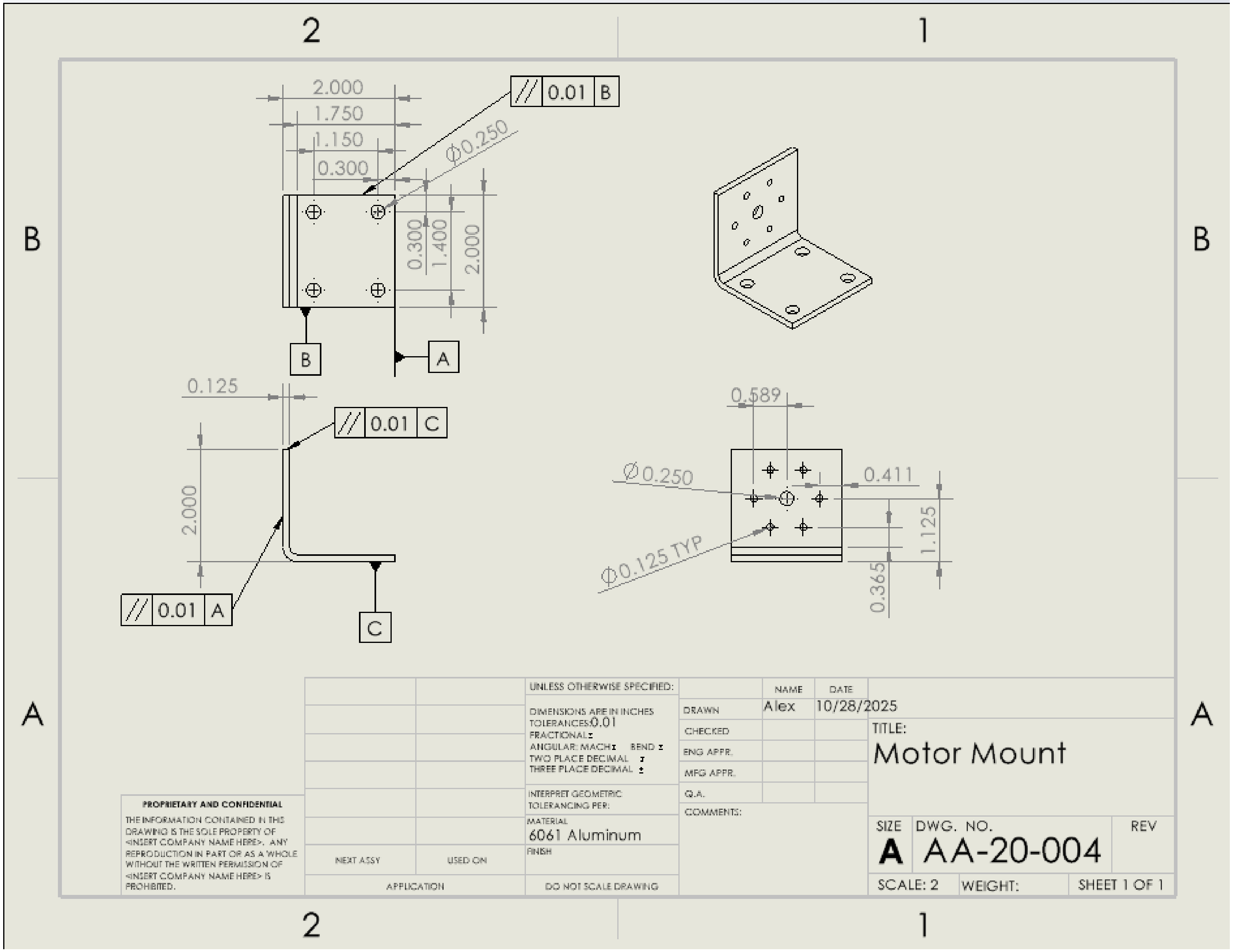
# Appendix B09 – AA-20-002 – Drive Shaft (Revision 1)



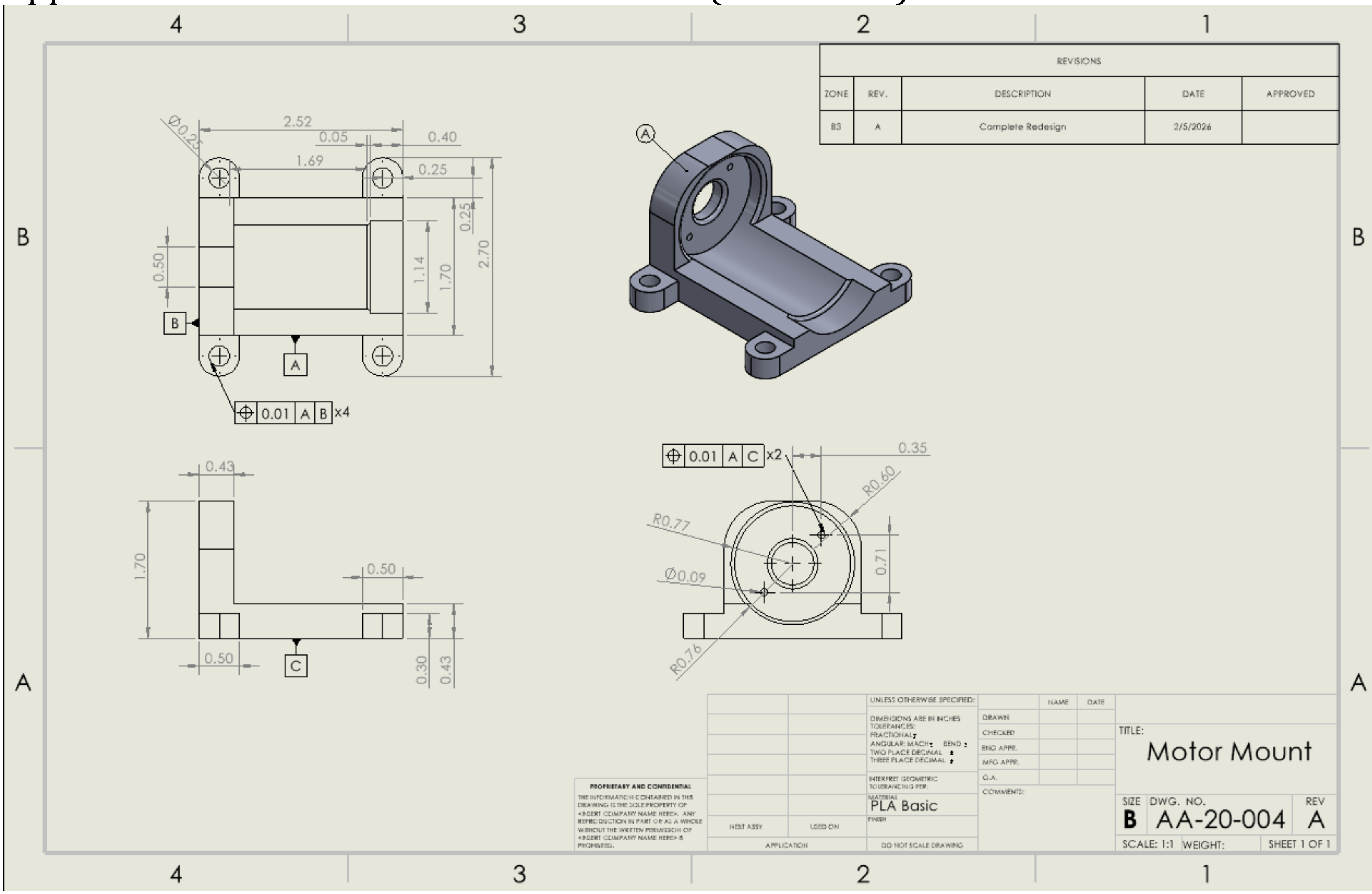
# Appendix B10 – AA-20-003 – Axle



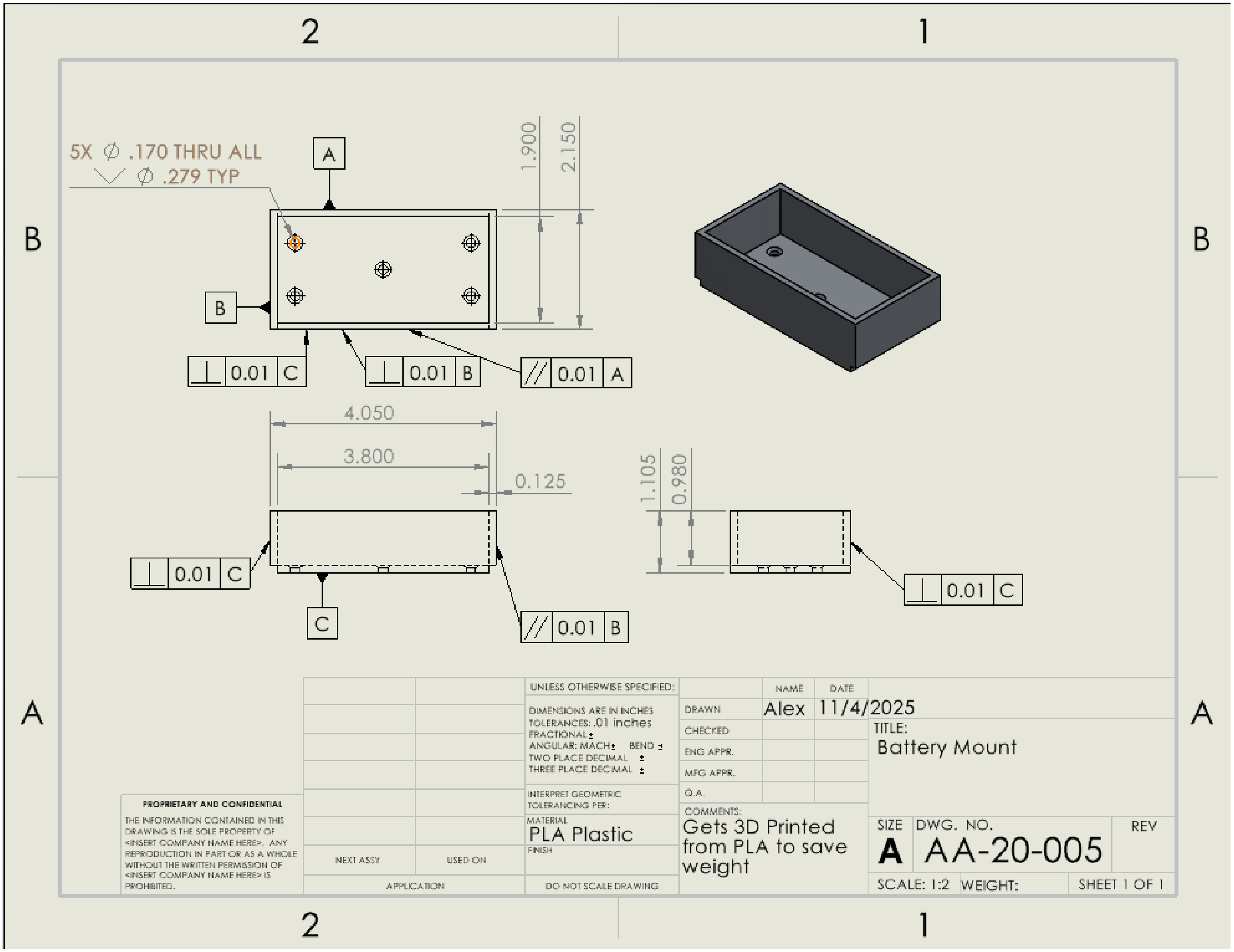
## Appendix B11 – AA-20-004 – Motor Mount



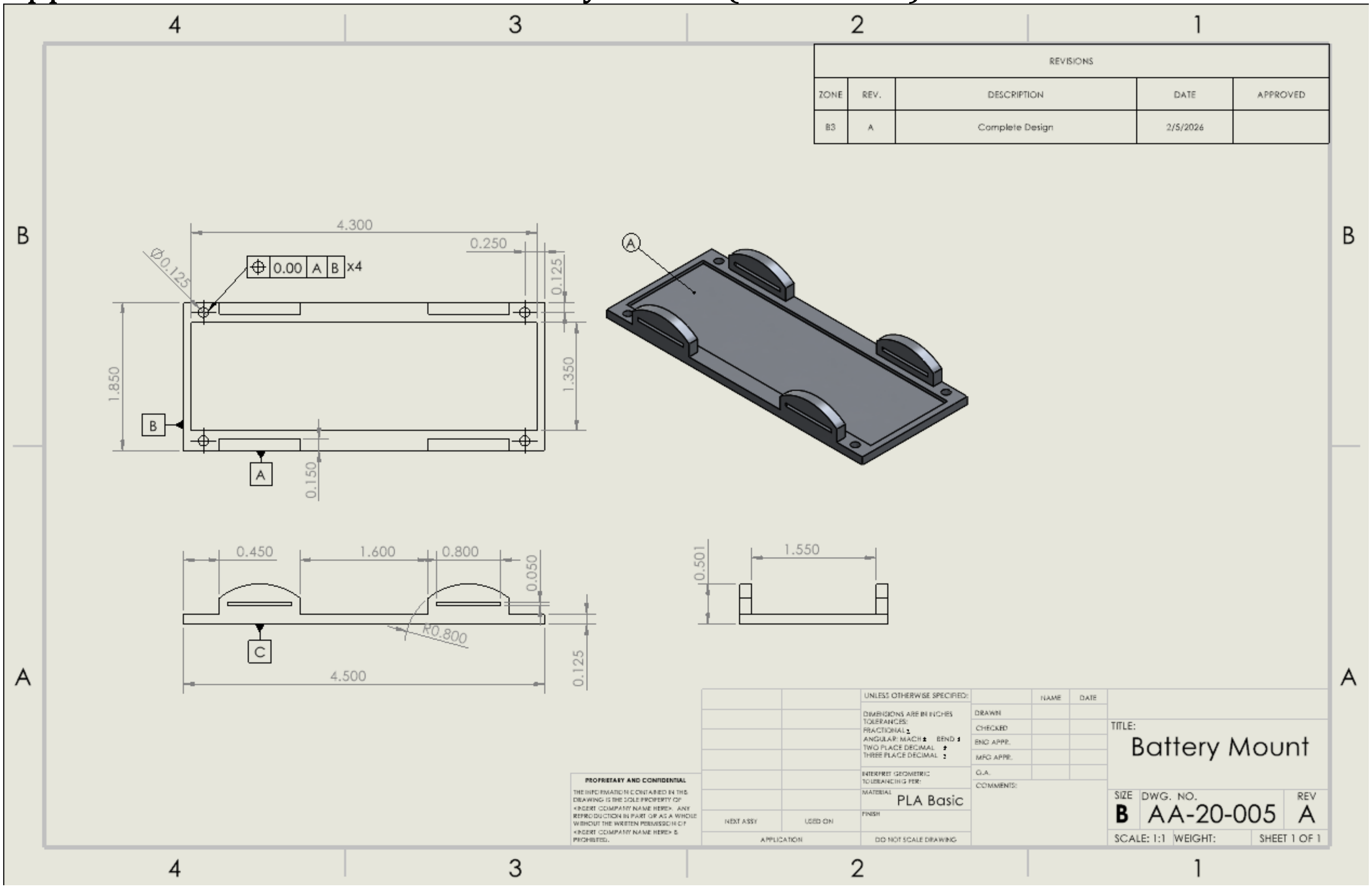
## Appendix B12 – AA-20-004 – Motor Mount (Revision A)



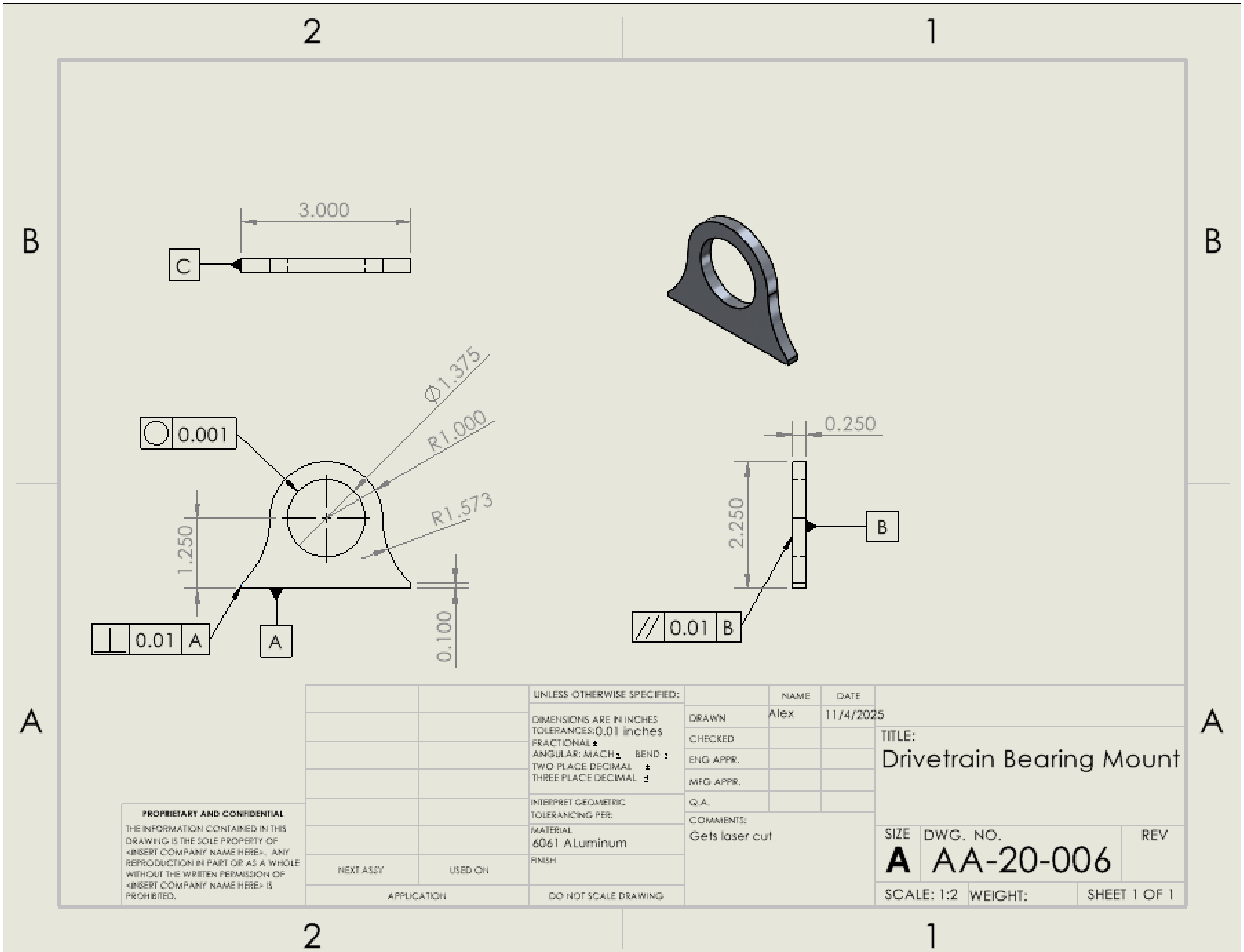
# Appendix B13 – AA-20-005 – Battery Mount



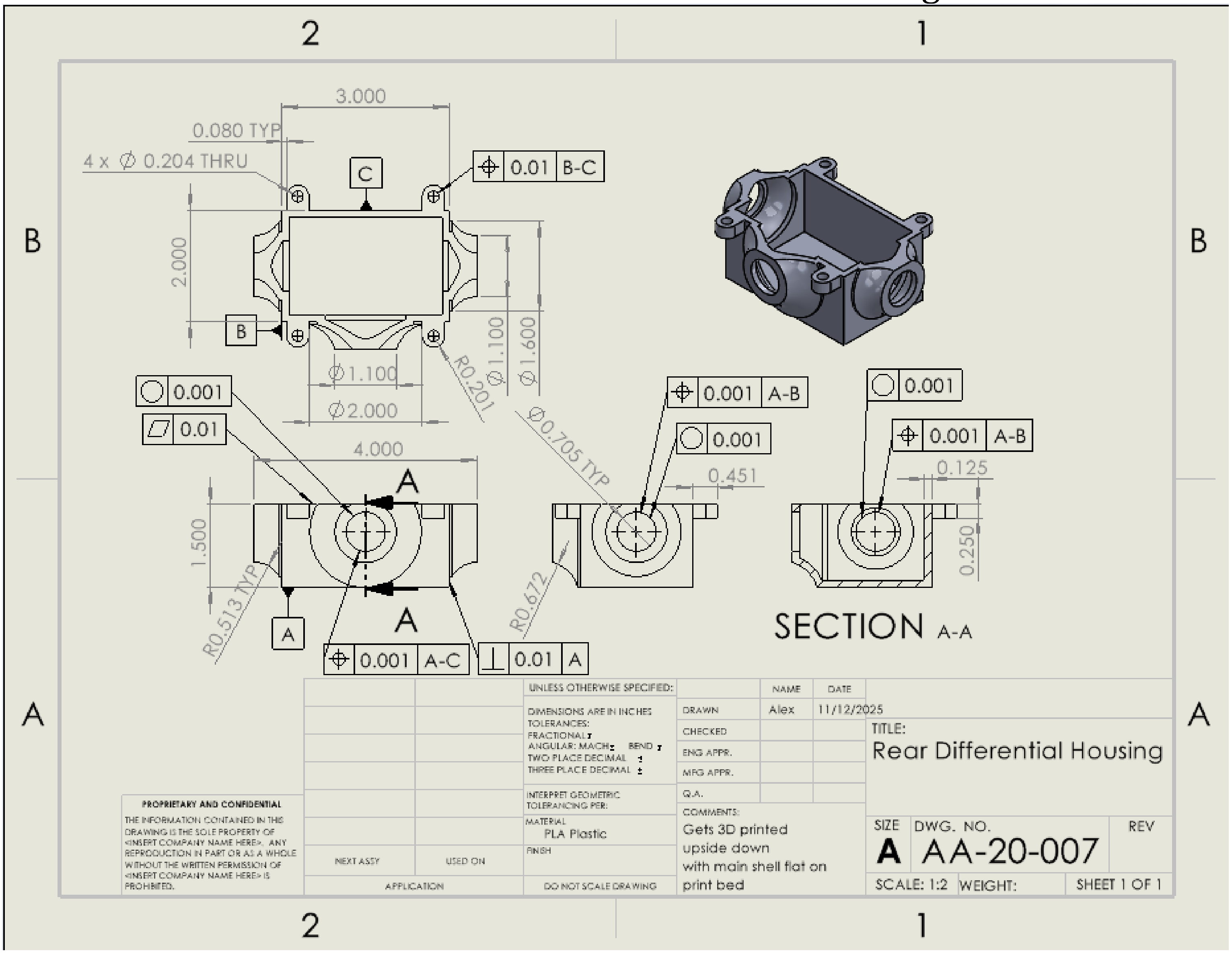
# Appendix B14 – AA-20-005 – Battery Mount (Revision 1)



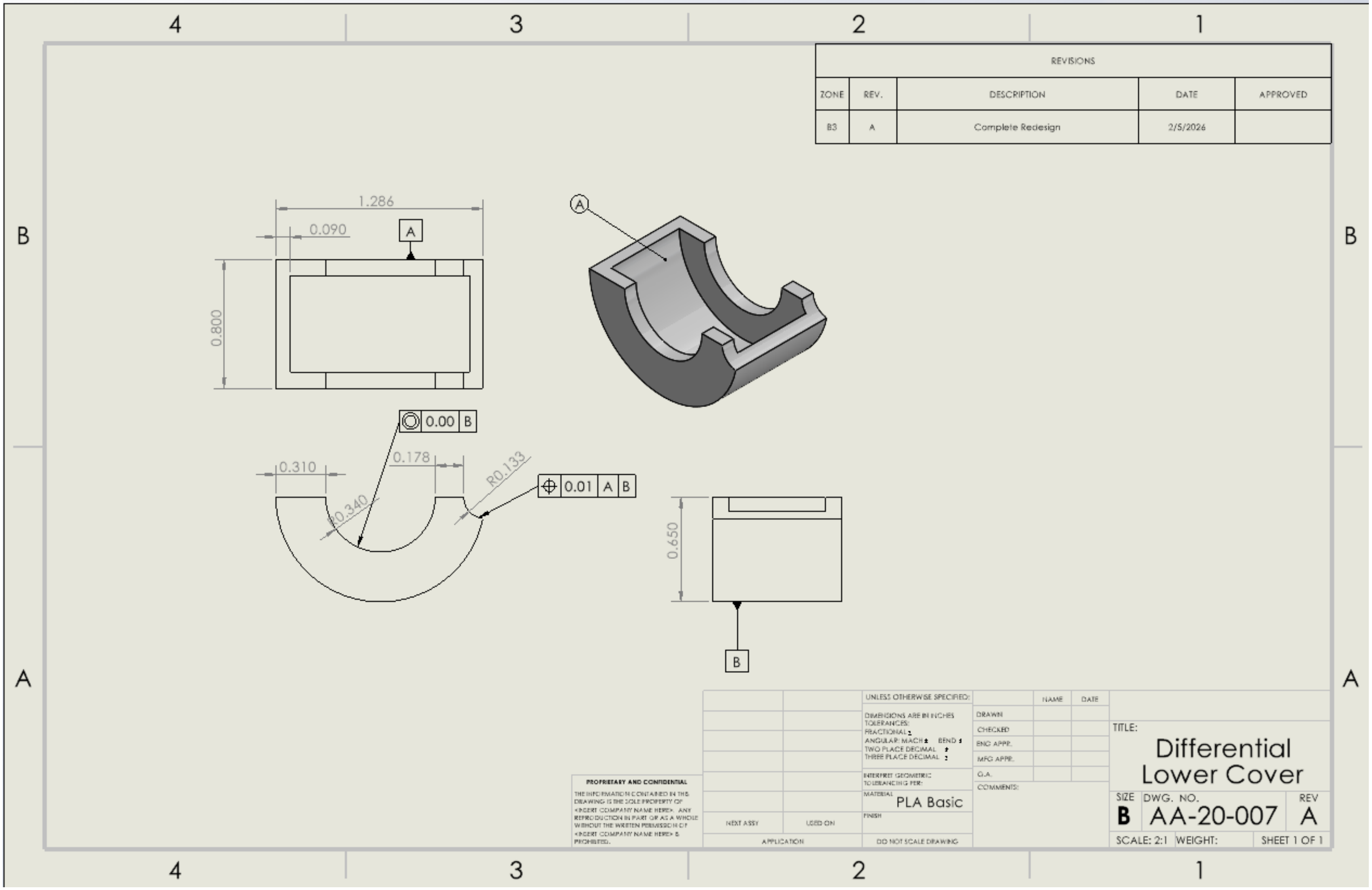
# Appendix B16 – AA-20-006 – Drivetrain Bearing Mount



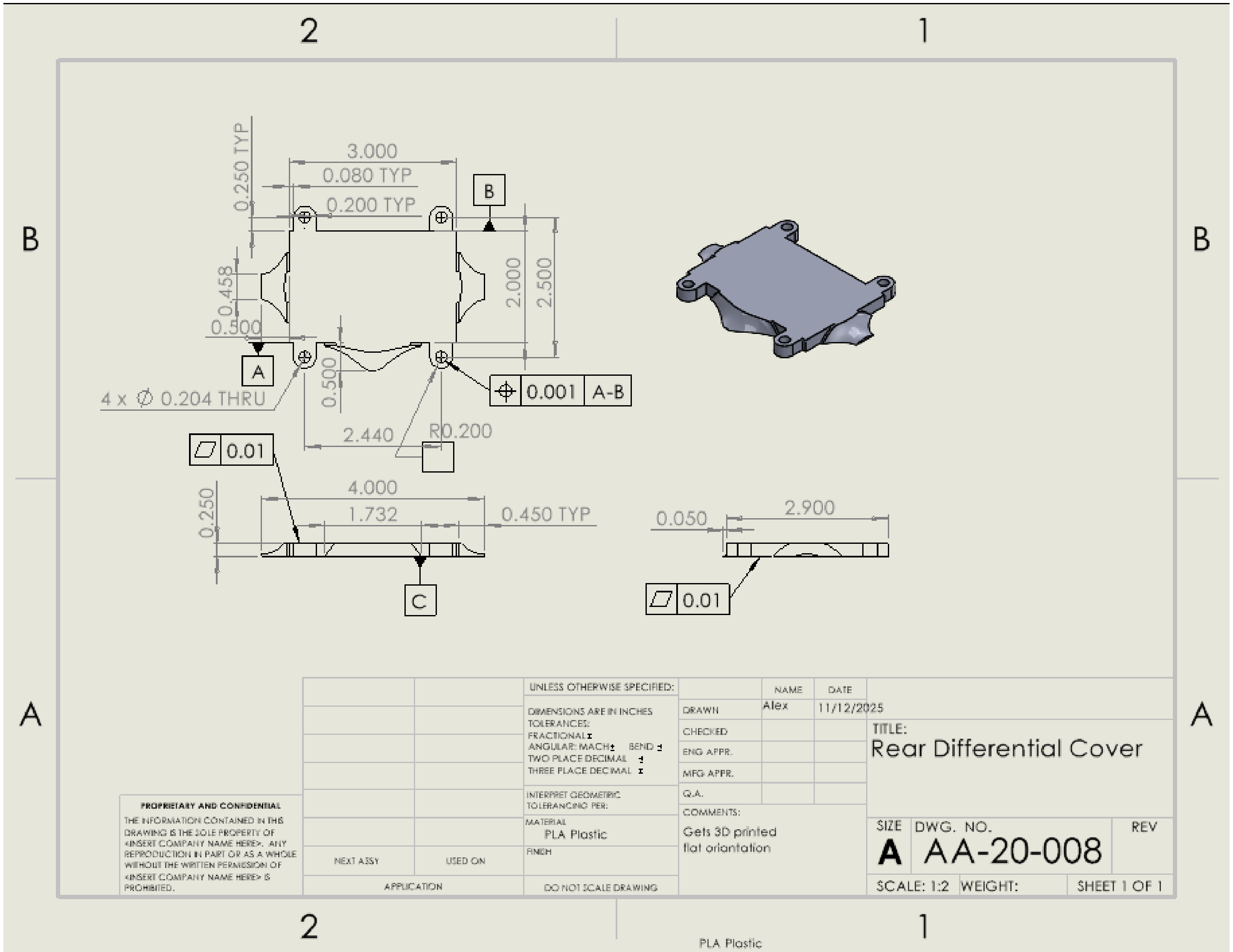
# Appendix B17 – AA-20-007 – Rear Differential Lower Housing



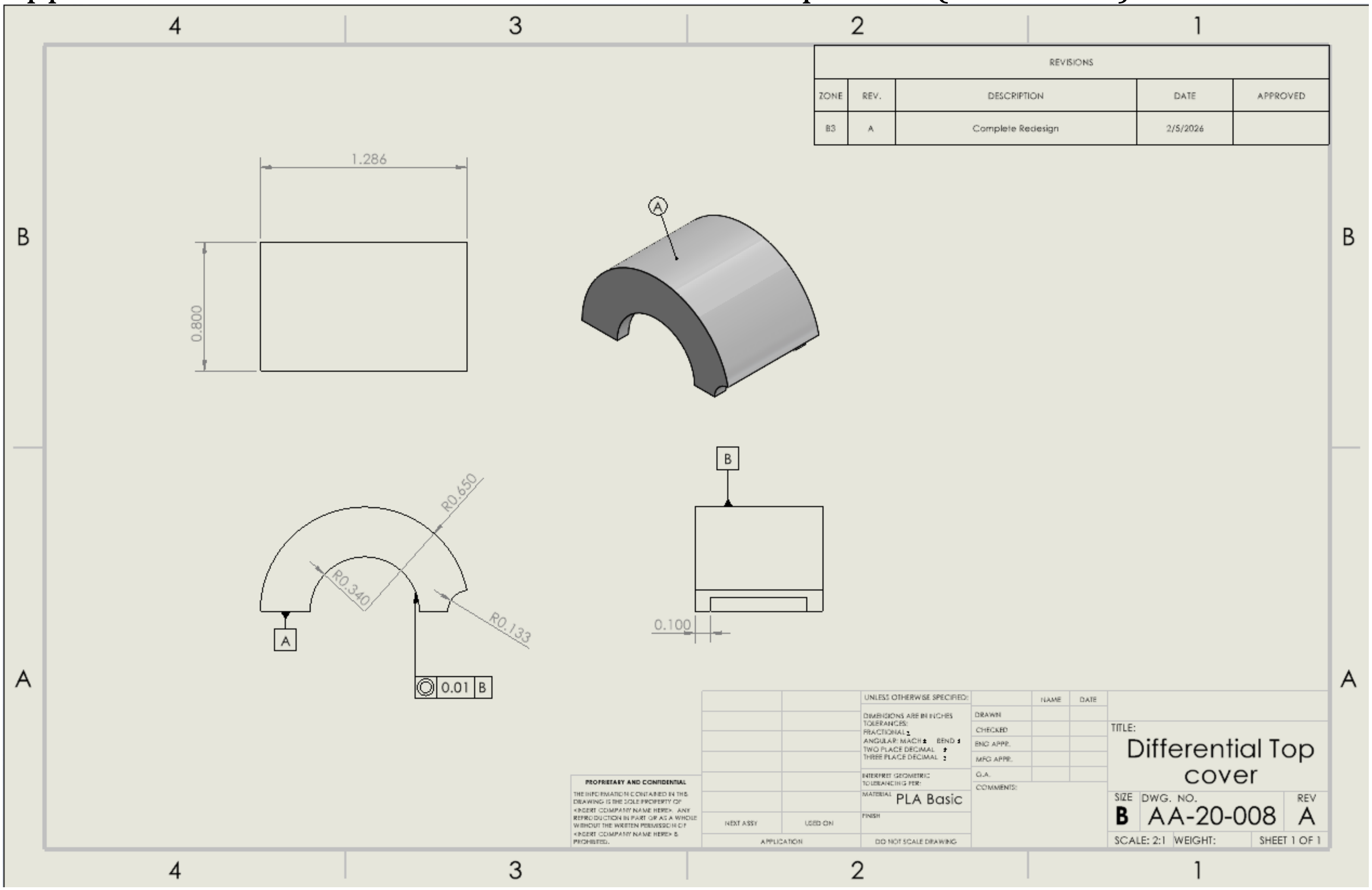
# Appendix B18 – AA-20-007 – Rear Differential Lower Housing (Revision 1)



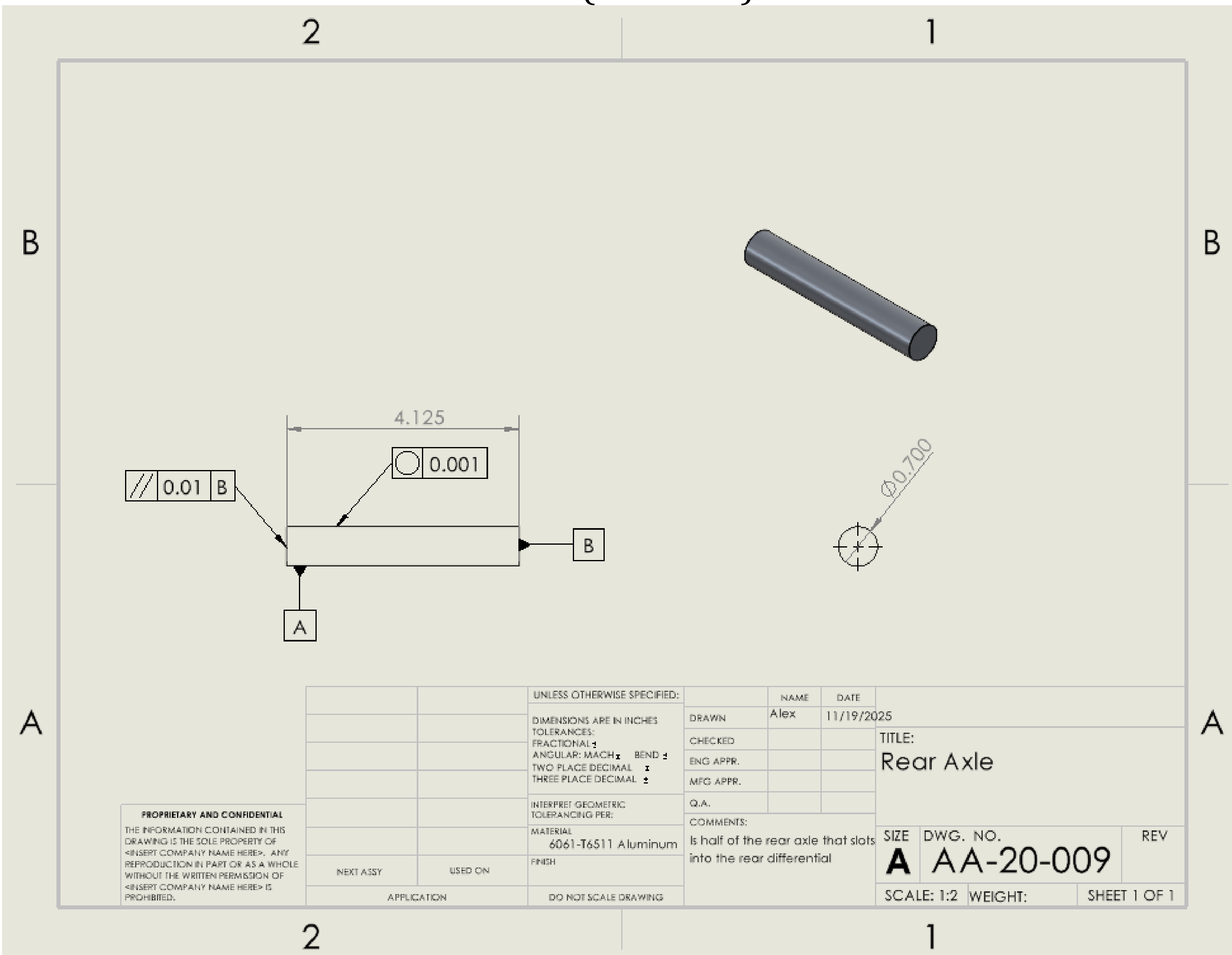
## Appendix B19 – AA-20-008 – Rear Differential Cover



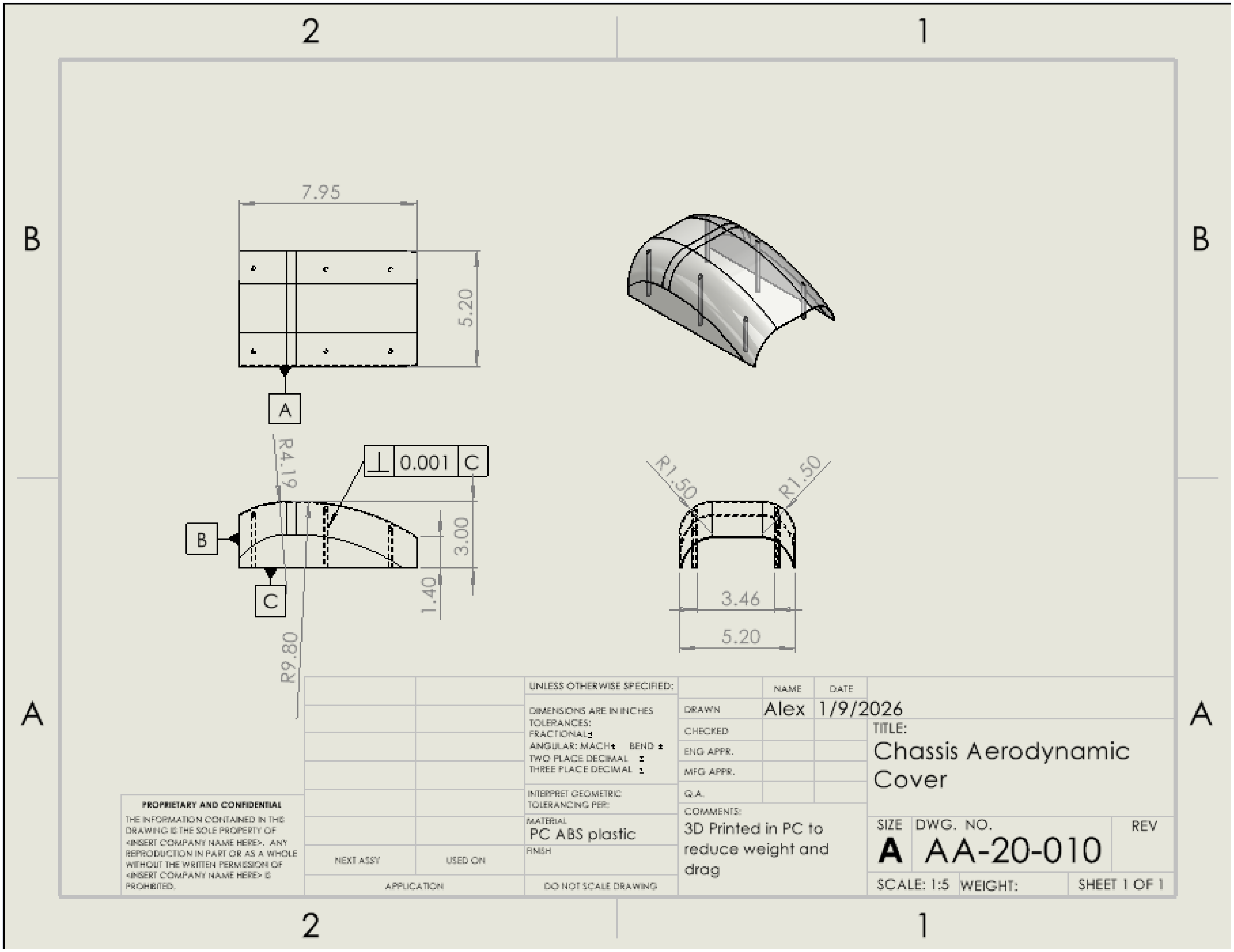
# Appendix B20 – AA-20-008 – Rear Differential Top Cover (Revision 1)



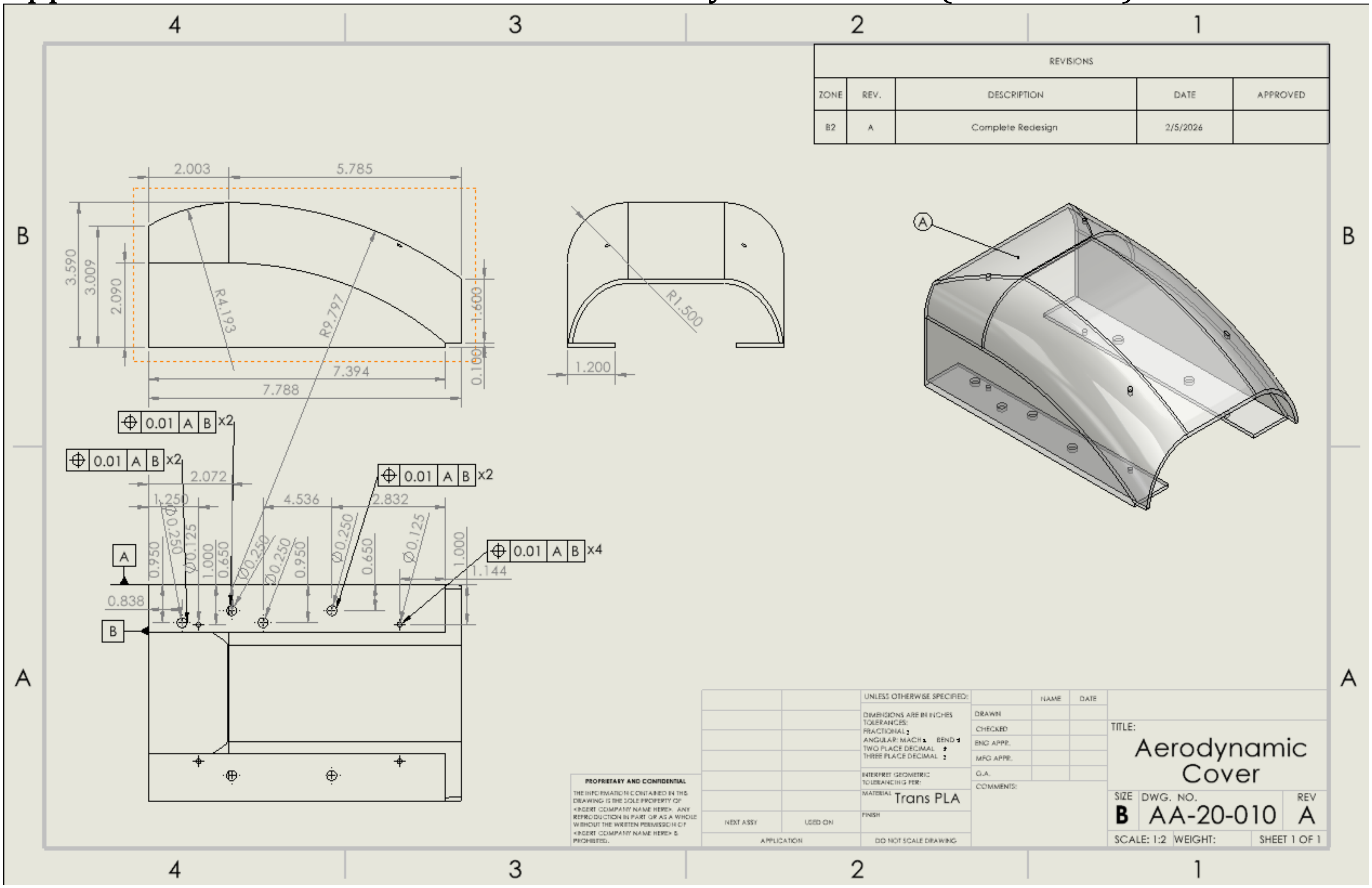
# Appendix B21 – AA-20-009 – Rear Axle (Obsolete)



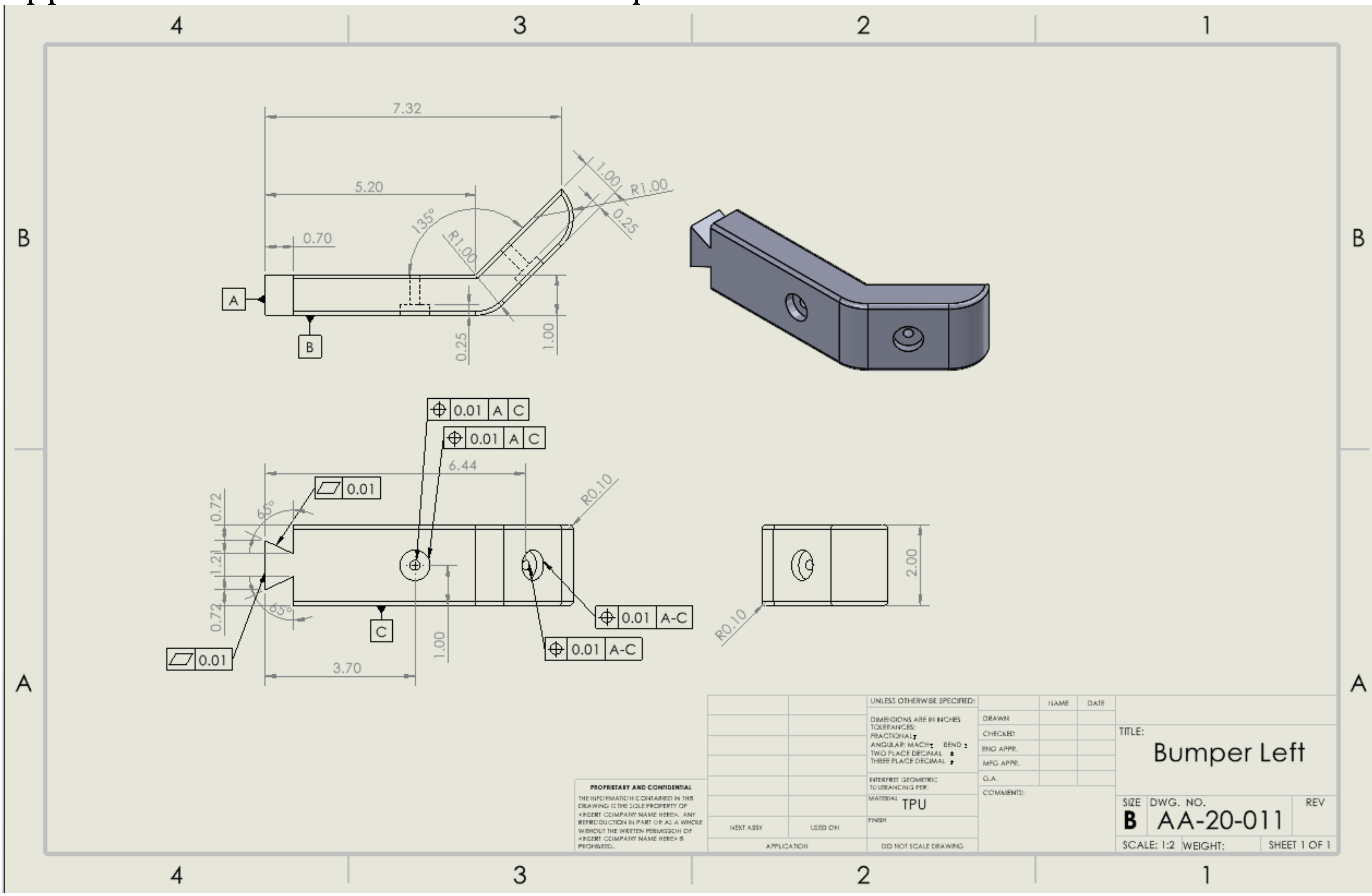
# Appendix B21 – AA-20-010 – Chassis Aerodynamic Cover



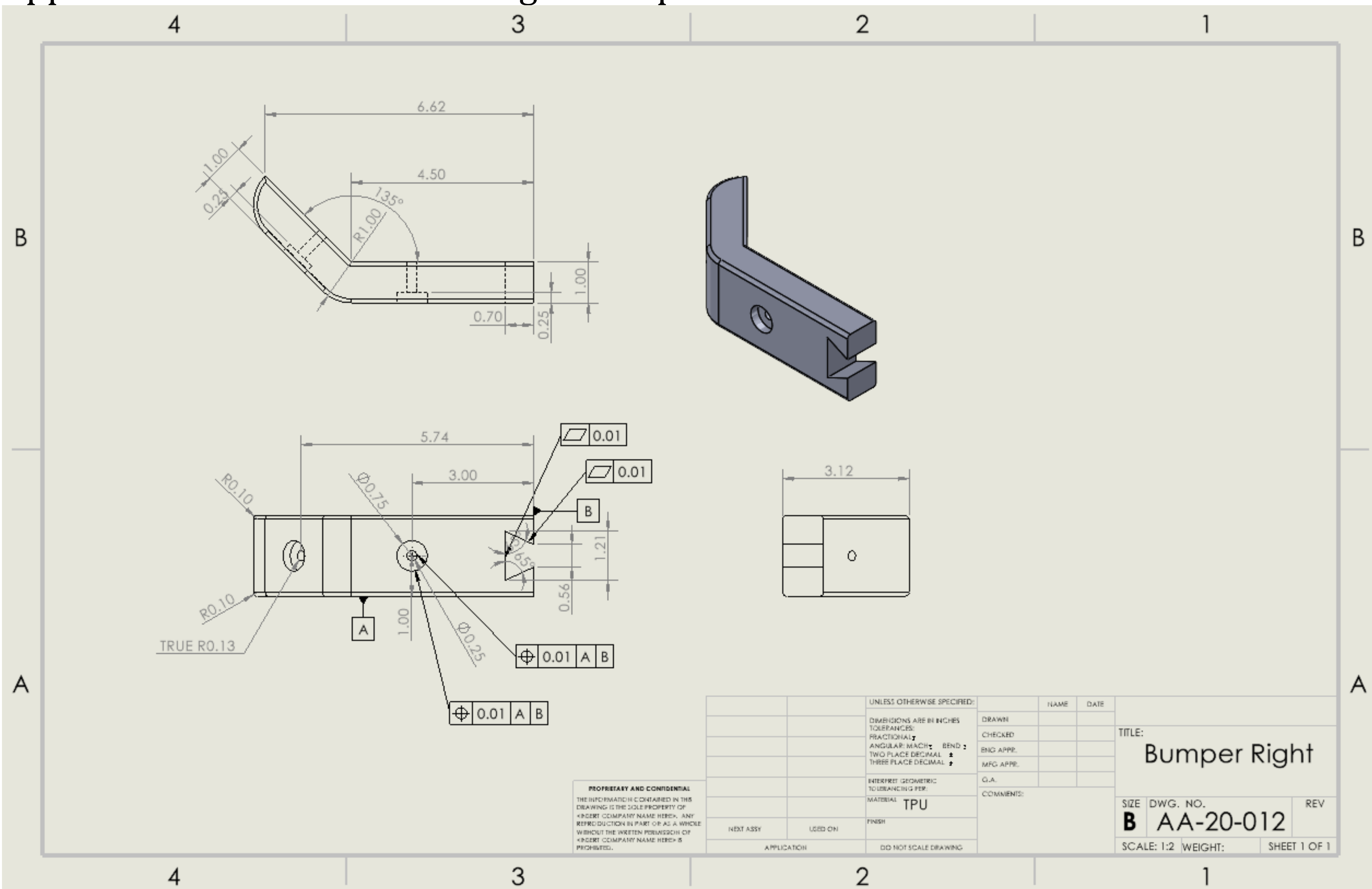
# Appendix B22 – AA-20-010 – Chassis Aerodynamic Cover (Revision 1)



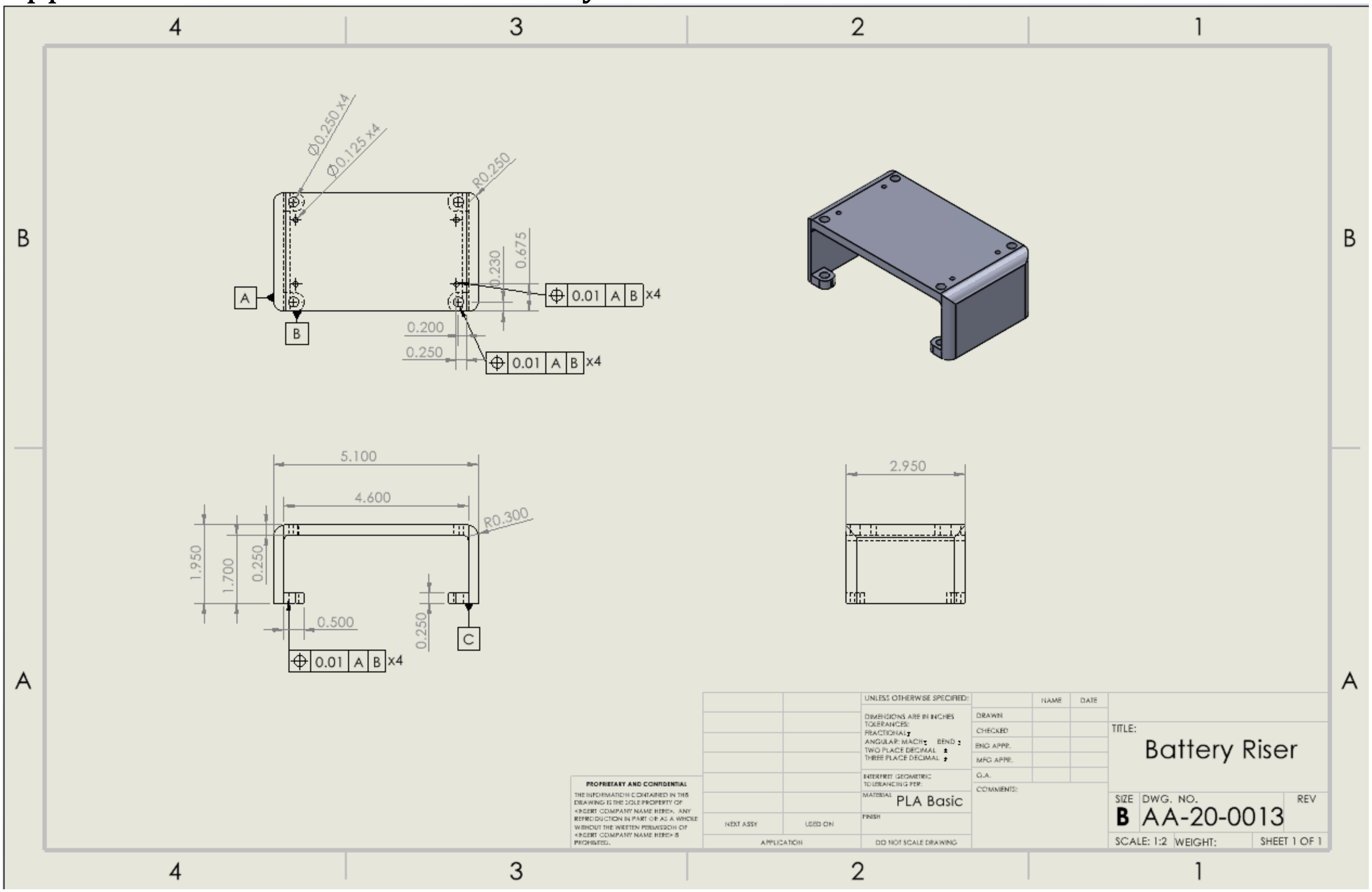
# Appendix B23 – AA-20-011 – Left Bumper



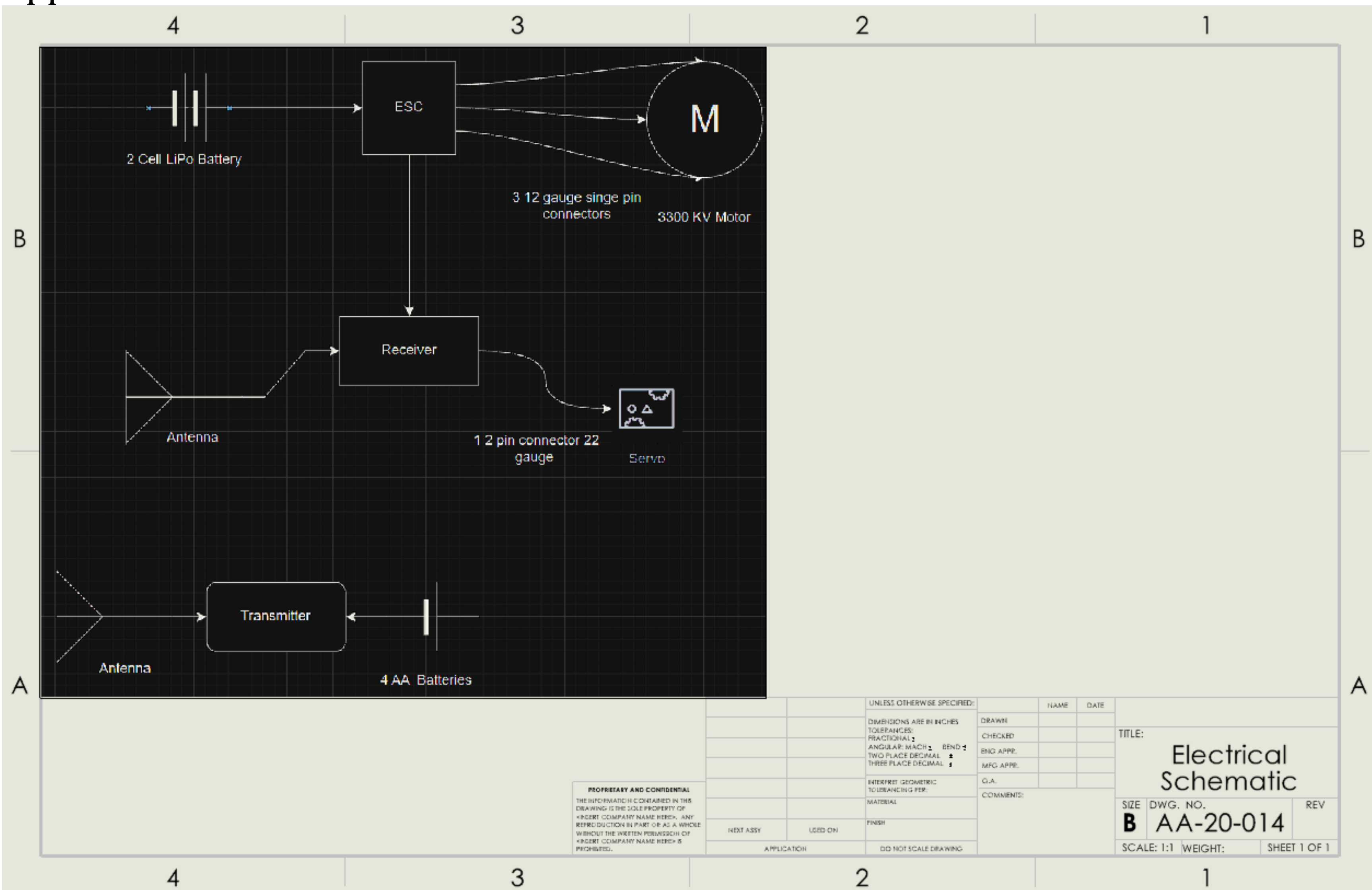
## Appendix B24 – AA-20-012 – Right Bumper



## Appendix B25 – AA-20-013 – Battery Riser



# Appendix B26 – AA-20-014 – Electrical Schematic



# APPENDIX C – Parts List and Costs

Table C1. Parts List

| Part Number | Qty | Part Description | Source | Cost | Disposition |
|---|---|---|---|---|---|
| 20-001 | 1 | Chassis Frame | Made in house | ~$10* | To be made 1/12/2026 |
| 20-002 | 1 | Driveshaft | Made in house | ~$6* | To be made 1/19/2026 |
| 20-003 | 2 | Rear Axle | Traxxas | $10 | To be made 1/19/2026 |
| 20-004 | 1 | Motor Housing | Made in house | $8.59** | To be made 1/6/2026 |
| 20-005 | 1 | Battery Housing | Made in house | $3.29** | Made 1/31/2026 |
| 20-007 | 1 | Differential lower housing | Made in house | $2.19** | Made 1/31/2026 |
| 20-008 | 1 | Differential top cover | Made in house | $2.19** | Made 2/7/2026 |
| 20-010 | 1 | Aerodynamic cover | Made in house | $15.27** | Made 2/5/2026 |
| 20-011 | 1 | Left Bumper | Made in house | $14.31** | Made 2/1/2026 |
| 20-012 | 1 | Right Bumper | Made in house | $14.31** | Made 2/1/2026 |
| 20-013 | 1 | Battery Riser | Made in house | $5.27** | Made 1/31/2026 |
| 55-001 | 1 | Brushless BL-2s 3300 KV motor + ESC | Traxxas | $99.99 | To be ordered during winter quarter |
| 55-003 | 5 | Pinion and Spur Gears for Drive Train | Traxxas | $30 | To be order during winter quarter |
| | | | Cost Total: | $ 221.41 | |
| | | | Total Parts: | 18 | |

Notes:
*: about the price of metal used
**: The cost of Filament used

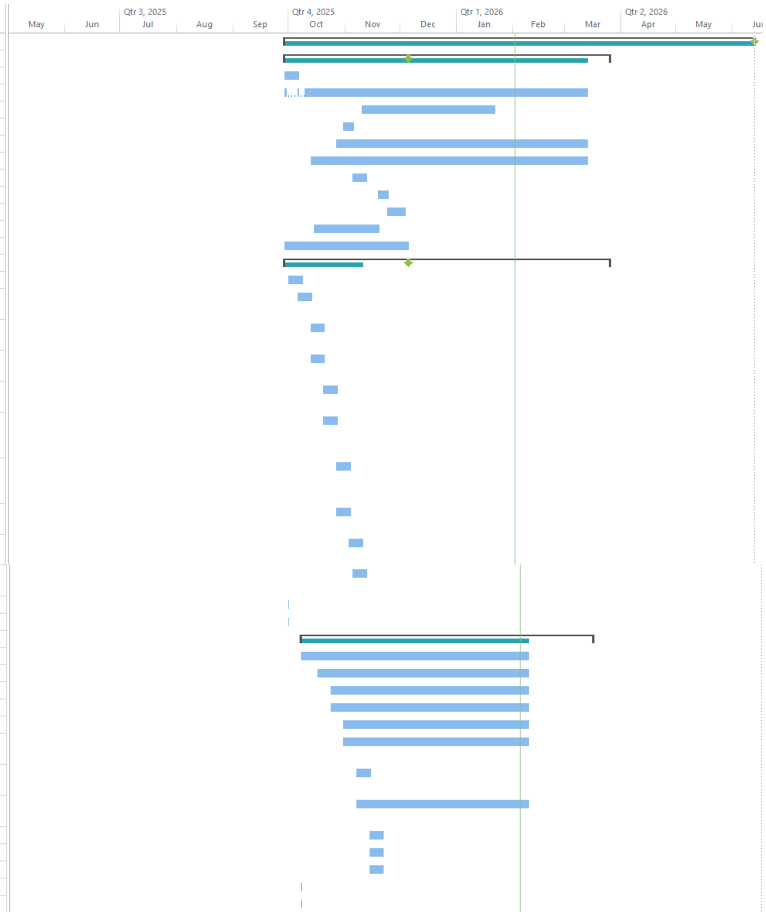
# APPENDIX D – Budget

Table D1. Project Budget.

| Item | Qty | Description | Cost |
| --- | --- | --- | --- |
| .125inx2ftx2ft 6061-T6 Aluminum | 1 | From Metalsdepot.com<br>Used for part 20-001 and 20-004 | $110.84 |
| ¾inx36ft Aluminum Round Bar 2024-T351 | 1 | From Oninemetals.com<br>Used for part 20-002 and 20-003 | $37.23 |
| Brushless BL-2s 3300 KV motor + ESC | 1 | Traxxas | $99.99 |
| Partner Budget | 5 | List of purchased budget items from R/C Baja project partner | $192.49 |
| | | | Total: $440.55 |
| | | | |
| Manufacturing Labor | 4 hours | Spent on manufacturing | $48 |
| Partner Labor | 7 hours | Spent on manufacturing | $200 |
| | | | Total: $248 |

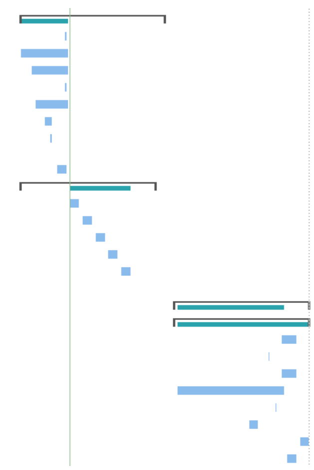
# APPENDIX E - Schedule

| Task ID | Task Name | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|
| | **Senior Project** | **185 days?** | **Mon 9/29/25** | **Fri 6/12/26** | |
| **1** | **PROPOSAL/REPORT WRITING** | **128 days?** | **Mon 9/29/25** | **Wed 3/25/26** | |
| 1a | Intro | 6 days? | Mon 9/29/25 | Mon 10/6/25 | |
| 1b | Analysis | 113 days | Mon 9/29/25 | Fri 3/13/26 | |
| 1c | Methods | 53 days? | Mon 11/10/2! | Wed 1/21/26 | |
| 1d | Testing | 4 days? | Fri 10/31/25 | Wed 11/5/25 | |
| 1e | Budget | 100 days? | Mon 10/27/2! | Fri 3/13/26 | |
| 1f | Schedule | 110 days? | Mon 10/13/2! | Fri 3/13/26 | |
| 1g | Project Management | 6 days? | Wed 11/5/25 | Wed 11/12/2! | |
| 1h | Discussion | 4 days? | Wed 11/19/2! | Mon 11/24/2! | |
| 1i | Conclusion | 8 days? | Mon 11/24/2! | Wed 12/3/25 | |
| 1j | Drawings | 26 days? | Wed 10/15/2! | Wed 11/19/2! | |
| 1k | Appendix | 50 days? | Mon 9/29/25 | Fri 12/5/25 | |
| **2** | **ANALYSIS** | **128 days?** | **Mon 9/29/25** | **Wed 3/25/26** | |
| 2a | Analysis01 Chassis Structural | 48 hrs? | Wed 10/1/25 | Wed 10/8/25 | |
| 2b | Analysis02 Drivetrain Torsional Shear | 48 hrs? | Mon 10/6/25 | Mon 10/13/25 | |
| 2c | Analysis03 Chassis Impact Deflection | 48 hrs? | Mon 10/13/25 | Mon 10/20/25 | |
| 2d | Analysis04 Drivetrain actual RPM and gear ratio | 48 hrs? | Mon 10/13/25 | Mon 10/20/25 | |
| 2e | Analysis05 Motor Power and Friction on Wheels | 48 hrs? | Mon 10/20/25 | Mon 10/27/25 | |
| 2f | Analysis06 Damage Factor and Number of Cycles Over Time | 48 hrs? | Mon 10/20/25 | Mon 10/27/25 | |
| 2g | Analysis07 Drivetrain Driveshaft deflection during 15mph impact | 48 hrs? | Mon 10/27/25 | Mon 11/3/25 | |
| 2h | Analysis08 Chassis vibration at 15 mph | 48 hrs? | Mon 10/27/25 | Mon 11/3/25 | |
| 2i | Analysis09 Drivetrain acceleration | 48 hrs? | Mon 11/3/25 | Mon 11/10/25 | |
| 2j | Analysis10 Chassis Drag Forces | 48 hrs? | Mon 11/3/25 | Mon 11/10/25 | |
| 2k | | 1 hr? | Mon 9/29/25 | Mon 9/29/25 | |
| 2l | | 1 hr? | Mon 9/29/25 | Mon 9/29/25 | |
| **3** | **DOCUMENTATION** | **115 days?** | **Mon 10/6/25** | **Fri 3/13/26** | |
| 3a | Designed Part Chassis body | 720 hrs? | Mon 10/6/25 | Fri 2/6/26 | |
| 3b | Purchased Part Motor | 664 hrs? | Wed 10/15/2! | Fri 2/6/26 | |
| 3c | Designed Part Driveshaft | 624 hrs? | Wed 10/22/2! | Fri 2/6/26 | |
| 3d | Designed Part Axle | 624 hrs? | Wed 10/22/2! | Fri 2/6/26 | |
| 3e | Designed Part Motor Mount | 584 hrs? | Wed 10/29/2! | Fri 2/6/26 | |
| 3f | Designed Part Battery Housing | 584 hrs? | Wed 10/29/25 | Fri 2/6/26 | |
| 3g | Designed Part Drivetrain bear mount | 48 hrs? | Wed 11/5/25 | Wed 11/12/25 | |
| 3h | Designed Part Rear Differenetial housing | 544 hrs? | Wed 11/5/25 | Fri 2/6/26 | |
| 3i | Subassembly Drivetrain | 48 hrs? | Wed 11/12/2! | Wed 11/19/2! | |
| 3j | Subassembly Chassis | 48 hrs? | Wed 11/12/2! | Wed 11/19/2! | |
| 3k | Top Assembly | 48 hrs? | Wed 11/12/2! | Wed 11/19/2! | |
| 3l | Purchased Part Battery | 1 hr? | Mon 10/6/25 | Mon 10/6/25 | |
| 3m | Purchased Part Tire | 1 hr? | Mon 10/6/25 | Mon 10/6/25 | |



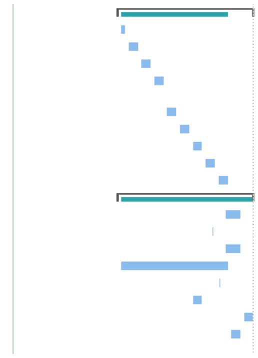

Fall Quarter Gantt Chart

| Task ID | Task Name | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|
| **4** | **PART MANUFACTURING** | **57 days?** | **Tue 1/6/26** | **Wed 3/25/26** | |
| 4a | Buy Motor | 1 day | Fri 1/30/26 | Fri 1/30/26 | |
| 4b | Make Motor Housing | 19 days? | Tue 1/6/26 | Sat 1/31/26 | |
| 4c | Make Chassis Body | 15 days? | Mon 1/12/26 | Sat 1/31/26 | |
| 4d | Buy Battery | 1 day? | Fri 1/30/26 | Fri 1/30/26 | |
| 4e | Make Battery Housing | 13 days? | Wed 1/14/26 | Sat 1/31/26 | |
| 4f | Make Driveshaft | 4 days? | Mon 1/19/26 | Thu 1/22/26 | |
| 4g | Update Website construction section | 1 day? | Thu 1/22/26 | Thu 1/22/26 | |
| 4h | Manufacture Plan | 5 days? | Mon 1/26/26 | Fri 1/30/26 | |
| **5** | **DEVICE MANUFACTURING** | **54 days?** | **Tue 1/6/26** | **Fri 3/20/26** | |
| 5a | Assemble Sub LL | 5 days? | Mon 2/2/26 | Fri 2/6/26 | |
| 5b | Assemble Sub RR | 5 days? | Mon 2/9/26 | Fri 2/13/26 | |
| 5c | Assemble Sub FF | 5 days? | Mon 2/16/26 | Fri 2/20/26 | |
| 5d | Assemble | 5 days? | Mon 2/23/26 | Fri 2/27/26 | |
| 5e | Take Device Pictures | 5 days? | Mon 3/2/26 | Fri 3/6/26 | |
| 5f | Working Device On The Desk | | | | |
| **6** | **DEVICE EVALUATION** | **54 days?** | **Tue 3/31/26** | **Fri 6/12/26** | |
| **7** | **DELIVERABLES** | **54 days?** | **Tue 3/31/26** | **Fri 6/12/26** | |
| 7a | Web Page/Design | 48 hrs? | Fri 5/29/26 | Fri 6/5/26 | |
| 7b | SOURCE | 2 hrs? | Thu 5/21/26 | Thu 5/21/26 | |
| 7c | Create Presentation | 48 hrs? | Fri 5/29/26 | Fri 6/5/26 | |
| 7d | Test reports | 336 hrs? | Thu 4/2/26 | Fri 5/29/26 | |
| 7e | Update Website | 1 hr? | Mon 5/25/26 | Mon 5/25/26 | |
| 7f | Make USB Drive | 40 hrs? | Mon 5/11/26 | Fri 5/15/26 | |
| 7g | Final Presentation | 40 hrs? | Mon 6/8/26 | Fri 6/12/26 | |
| 7h | Final Report Submission | 40 hrs? | Mon 6/1/26 | Fri 6/5/26 | |



Winter Quarter

| | | | | | |
|---|---|---|---|---|---|
| **6** | **DEVICE EVALUATION** | **54 days?** | **Tue 3/31/26** | **Fri 6/12/26** | |
| 6a | Deflection Test | 2 days? | Thu 4/2/26 | Fri 4/3/26 | |
| 6b | Acceleration Testing | 5 days? | Mon 4/6/26 | Fri 4/10/26 | |
| 6c | Friction Testing | 5 days? | Mon 4/13/26 | Fri 4/17/26 | |
| 6d | Sudden stop and Start Testing | 5 days? | Mon 4/20/26 | Fri 4/24/26 | |
| 6e | | 5 days? | Mon 4/27/26 | Fri 5/1/26 | |
| 6f | | 5 days? | Mon 5/4/26 | Fri 5/8/26 | |
| 6g | | 5 days? | Mon 5/11/26 | Fri 5/15/26 | |
| 6h | | 5 days? | Mon 5/18/26 | Fri 5/22/26 | |
| 6i | Take Device Photos | 5 days? | Mon 5/25/26 | Fri 5/29/26 | |
| **7** | **DELIVERABLES** | **54 days?** | **Tue 3/31/26** | **Fri 6/12/26** | |
| 7a | Web Page/Design | 48 hrs? | Fri 5/29/26 | Fri 6/5/26 | |
| 7b | SOURCE | 2 hrs? | Thu 5/21/26 | Thu 5/21/26 | |
| 7c | Create Presentation | 48 hrs? | Fri 5/29/26 | Fri 6/5/26 | |
| 7d | Test reports | 336 hrs? | Thu 4/2/26 | Fri 5/29/26 | |
| 7e | Update Website | 1 hr? | Mon 5/25/26 | Mon 5/25/26 | |
| 7f | Make USB Drive | 40 hrs? | Mon 5/11/26 | Fri 5/15/26 | |
| 7g | Final Presentation | 40 hrs? | Mon 6/8/26 | Fri 6/12/26 | |
| 7h | Final Report Submission | 40 hrs? | Mon 6/1/26 | Fri 6/5/26 | |



Spring Quarter

# APPENDIX F – Expertise and Resources

## Appendix F01 – Drivetrain Decision Matrix

| Criterion | Weight 1 to 3 | Best Possible 3 | Front Wheel | Score x Wt | Rear Wheel | Score x Wt | All Wheel | Score x Wt | |
|---|---|---|---|---|---|---|---|---|---|
| Cost | 2 | 6 | 1 | 2 | 3 | 6 | 2 | 4 | |
| Weight | 3 | 9 | 2 | 6 | 2 | 6 | 1 | 3 | |
| Manufacturability | 3 | 9 | 2 | 6 | 3 | 9 | 2 | 6 | |
| Drivetrain Impact Resistance | 1 | 3 | 2 | 2 | 3 | 3 | 2 | 2 | |
| Chassis Impact Resistance | 2 | 6 | 2 | 4 | 2 | 4 | 1 | 2 | |
| Drivetrain Speed | 3 | 9 | 1 | 3 | 2 | 6 | 1 | 3 | |
| Controlability | 3 | 9 | 2 | 6 | 2 | 6 | 3 | 9 | |
| Total | 17 | 51 | | 29 | | 40 | | 29 | |
| NORMALIZE THE DATA (muliply by fraction, N) | | 1.96 | | 56.9 | | 78.4 | | 56.9 | Percent |
| Decide if Bias is Good or Bad | Good Bias: | Standard Deviation is two or more digits | | | Good? Then done. | | | 64.1 | Average |
| | Poor Bias: | Standard Deviation is one or less digits | | | Poor? Change something!!! | | | 12 | Std Dev. |

**Weighting/Scoring Scale**

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

**Criterion**

| | |
|---|---|
| Cost | This includes material costs and the costs for components |
| Weight | This includes the the weight of the chassis and the drivetrain |
| Manufacturability | This includes how difficult it will be to manufacture the subassemblies |
| Drivetrain Impact Resistance | This includes how the drive train will react to sudden impacts |
| Chassis Impact resistance | This includes how the chassis will react to sudden impacts |
| Drivetrain Speed | This includes how the drive train will be able to accelerate and sustain speeds over all terrains |
| Controlability | This includes how difficult it will be to steer will be with troque forces acting on with or against the direction of motion |

**Comments:**

For the cost this was put as a 2 as this signifies a lower cost requirement.
For the Weight criterion, this was set at a 3 as this criterion is significant to the design requirements
For Manufacturing, this is set at a 3, as the manufacturing of this project should be achievable within 10 weeks
For Drivetrain Impact Resistance, this is set at a 1 as this criterion isn't as important as other criterion however is still worth considering as it is involed in the design requirements
For Chassis impact resistance, this is set for a 2 because it is more important to take into consideration than the drivetrain impact resistance, this is because this needs to not fail during impacts
for Drivetrain speed, this is set for a 3, this is because the drivetrain must be able to deliver enough torque to speed up quickly during the sprint competition.
for Controlability, this is also set for a 3 as this is important for speeding up and slowing down for tight turns for the slalom competition.

## Appendix F02 – Metal Construction Method Decision Matrix

| Criterion | Weight 1 to 3 | Best Possible 3 | Laser Cut | Score x Wt | CNC | Score x Wt | Mix of Both | Score x Wt | |
|---|---|---|---|---|---|---|---|---|---|
| Cost | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | |
| Weight | 2 | 6 | 2 | 4 | 1 | 2 | 2 | 4 | |
| Able to get to spec | 3 | 9 | 3 | 9 | 2 | 6 | 3 | 9 | |
| Postprocessing | 3 | 9 | 1 | 3 | 2 | 6 | 2 | 6 | |
| Time Spent on manufacturing | 2 | 6 | 2 | 4 | 1 | 2 | 2 | 4 | |
| Total | 11 | 33 | | 21 | | 17 | | 25 | |
| NORMALIZE THE DATA (muliply by fraction, N) | | 3.03 | | 63.6 | | 51.5 | | 75.8 | Percent |
| Decide if Bias is Good or Bad | Good Bias: | Standard Deviation is two or more digits | | | | Good? Then done. | | 63.6 | Average |
| | Poor Bias: | Standard Deviation is one or less digits | | | | Poor? Change something!!! | | 12 | Std Dev. |
| | | 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 | Cost of Manufacturing |
| Weight | weight of moving material around the workshop |
| Able to get to spec | How close the student can get to tolerance |
| post proccessing | Confidence level in the indicated failure location |
| Time spent on manufacturing | Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs |

# Appendix F03 – Plastic Construction Method Decision Matrix

| Criterion | Weight | Best Possible | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 to 3 | 3 | 3D printing | Score x Wt | Vaccum | Score x Wt | Heat mold | Score x Wt |
| Cost | 1 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| Weight | 2 | 6 | 3 | 6 | 2 | 4 | 2 | 4 |
| Percision of Tolerance | 3 | 9 | 3 | 9 | 1 | 3 | 1 | 3 |
| Machine Availabilty | 2 | 6 | 3 | 6 | 1 | 2 | 1 | 2 |
| Material Availability | 3 | 9 | 2 | 6 | 1 | 3 | 1 | 3 |
| Total | 11 | 33 | | 29 | | 14 | | 14 |
| NORMALIZE THE DATA (muliply by fraction, N) | | 3.03 | | 87.9 | | 42.4 | | 42.4 Percent |

| | | | | |
|---|---|---|---|---|
| Decide if Bias is Good or Bad | Good Bias: | Standard Deviation is two or more digits | Good? Then done. | 57.6 Average |
| | Poor Bias: | Standard Deviation is one or less digits | Poor? Change something!!! | 26 Std Dev. |
| | | 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 | The cost of Materials |
| Weight | Weight of the materials |
| Percision of Tolerances | How well does the plastic accomadated tolerances |
| Machine Availabilty | How Availabile the machince is |
| Material Availabilty | How easy is the material aquired |

# Appendix F04 – Chassis Material Selection Decision Matrix

| Criterion | Weight | Best Possible | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 to 3 | 3 | Aluminum | Score x Wt | PLA | Score x Wt | ABS | Score x Wt |
| cost | 2 | 6 | 1 | 2 | 2 | 4 | 1 | 2 |
| Weight | 3 | 9 | 2 | 6 | 2 | 6 | 2 | 6 |
| Availability | 2 | 6 | 3 | 6 | 1 | 2 | 1 | 2 |
| Strength | 3 | 9 | 3 | 9 | 2 | 6 | 3 | 9 |
| Torsional Resistance | 3 | 9 | 2 | 6 | 1 | 3 | 1 | 3 |
| Total | 13 | 39 | | 29 | | 21 | | 22 |
| NORMALIZE THE DATA (muliply by fraction, N) | | 2.56 | | 74.4 | | 53.8 | | 56.4 Percent |

| | | | | |
|---|---|---|---|---|
| Decide if Bias is Good or Bad | Good Bias: | Standard Deviation is two or more digits | Good? Then done. | 61.5 Average |
| | Poor Bias: | Standard Deviation is one or less digits | Poor? Change something!!! | 11 Std Dev. |

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

| Criterion | |
|---|---|
| Cost | More mass is more cost |
| Weight | The car needs to be under a specfic weight |
| Availabilty | How easy is it to aquire the material |
| Srength | how likely is it to bend or break |
| Torsional resistance | how likely is it to bend or break when twisted |

**Comments:**

Done for the Chassis

# APPENDIX G – Testing Report

## Appendix G1 (Replace with test title here)

Introduction

Method/Approach

Test Procedure

Deliverables

## Appendix G1.1 – Procedure Checklist

## Appendix G1.2 – Data Forms

## Appendix G1.3 – Raw Data

## Appendix G1.4 – Evaluation Sheet

## Appendix G1.5 – Schedule (Testing)

# Appendix G2 (Replace with test title here)

Introduction

Method/Approach

Test Procedure

Deliverables

# Appendix G2.1 – Procedure Checklist

# Appendix G2.2 – Data Forms

# Appendix G2.3 – Raw Data

# Appendix G2.4 – Evaluation Sheet

# Appendix G2.5 – Schedule (Testing)

# Appendix G3 (Replace with test title here)

Introduction

Method/Approach

Test Procedure

Deliverables

# Appendix G3.1 – Procedure Checklist

# Appendix G3.2 – Data Forms

# Appendix G3.3 – Raw Data

# Appendix G3.4 – Evaluation Sheet

# Appendix G3.5 – Schedule (Testing)

# APPENDIX H – Resume

# ALEX AMADIO

| alex.amadio@outlook.com

## Objective

I am looking to gain experience for a career with a Mechanical engineering background.

## Skills & Abilities

Abilities

- Flexibility for complex situations
- On-the-spot learning
- Problem solving in creative and cost-effective ways.

Skills

- 5+ years' experience in 3D modeling in AutoCAD Fusion 360
- SolidWorks Associate Certified
- 5+ years' experience 3D printing
- Project cost analysis
- Public Speaking

## Experience

June 2021-september 2021

Courtesy Clerk, *Safeway*

· Worked to help customer satisfaction, and bagging for cashiers.

September 2021-december 2021

Deli Clerk, *Safeway*

· Helped with housekeeping in House Deli, with primary job in cooking in the morning.

June 2022 – September 2022

Deli Clerk, *Safeway*

· Helped with housekeeping in House Deli, with primary job producing products and customer satisfaction.

June 2025 – August 2025

Mechanical Engineering Intern, *H.F. Hauff*

June 2021-
september 2021

Courtesy Clerk, *Safeway*

· Worked to help customer satisfaction, and bagging for cashiers.

· Helped with designing the frame of a project to compete with competitors' products. This work used SolidWorks to confirm calculations

# Education

Dates From-
Current

Mechanical Engineering Technology, Ellensburg, *Central Washington University*

| Classes | Proficiency |
|---|---|
| Computer Aided Design | Solidworks Associate Certification |
| Project Cost Analysis | Proficient |
| Statics | Proficient |
| Machining | Proficient |
| Lean Manufacturing | Proficient |