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RC BAJA: STEERING and SUSPENSION

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ABSTRACT

Students attending Central Washington University teamed up to manufacture an RC car to compete against peers in the RC Baja competition events as a senior project. The project was split between the two individuals, Rogelio was responsible for the steering and suspension, while Roberto was responsible for the chassis and drivetrain. The team collaborated to brainstorm ideas that would fit the requirements applied.

The RC was built with 3D printed parts and designed using engineering methods such as mechanics of materials, dynamics, and statics to successfully compete in the BAJA events and meet requirements. Before it was ready for competition, the RC underwent various tests, and the team was able to gather data to compare it to the calculated data. The slalom competition and straight-line sprint race reflected the performance of the RC's drivetrain, suspension, and steering as it worked in unison with the chassis. The final competition put the entire project to the test against the rest of the competitors.

The suspension was expected to compress 0.5," but it only compressed 0.25." The steering radius was expected to be 4 feet, but it was recorded as 6 feet. In addition, the steering range was expected to be 60 degrees and the team recorded 70 degrees of range. The 3D printed components were required to not bend more than 0.1" and they were recorded to bend 0.07". Instruments and manufactured jigs were used to take measurements.

Keywords: RC, suspension, drivetrain, 3D printed

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Time: ... 148

The test was conducted on 4/22/24 from 10:00AM to 11:00PM in the Fluke lab inside of Hogue Hall. There were 10 minutes of acquiring equipment and setting up before testing. After testing, 10 minutes were dedicated to gathering data and cleaning up. 148
Place: 148
Fluke lab Inside Hogue Hall, Central Washington University campus in Ellensburg, WA. . 148
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A risk while performing this test is motor overheating. Due to it being a brushed motor it runs hotter than a brushless motor. This could cause an issue with the drivetrain's 3D printed gears warping and being deemed useless. If that were the case the test could not be conducted because it requires the RC to be drivable. The next risk would be inaccurately placing the RC in the same place, not allowing consistent measurements. Another risk would be the RC not being able to move. The Final risk would be the battery being drained on the RC or the RC controller. This would postpone the test. 148
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1) Arrive to the fluke lab with the following materials: safety glasses, Rc device fully charged, Rc controller with fully charged batteries, measuring tape, blue tape, straight edge149
2) Using an existing straight edge from the floor of the fluke lab, set a 2-foot marker along the edge. This is the starting line. 149
3) Using another straight edge set a 2-foot blue tape marker perpendicular to the first marker on the left side. The setup should look like Figure G6. 149
4) Bring the RC over to the starting line. 149
5) Turn the ESC on to power the RC using the on/off switch 149
6) Turn the RC controller on using the on/off switch 149
7) When the transmitter and receiver are confirmed to be connected make sure the wheels spin in reverse. 149
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Time: 156
The test was conducted on 5/6/24 from 10:00AM to 10:30PM in the Fluke lab inside of Hogue Hall. There were 5 minutes of acquiring equipment and setting up before testing. After testing, 3 minutes were dedicated to gathering data and cleaning up. 156
Place: 156
Fluke lab Inside Hogue Hall, Central Washington University campus in Ellensburg, WA. . 156
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1. INTRODUCTION

a. Description

The problem that will be in fronted and attempted to solve will be the ability of the RC Baja to robustly pass the testing and compete under the ASME RC Baja competition requirements. The requirements will be a challenge in design work, manufacturing, and testing. The challenge is to build a robust remote battery-controlled RC. The design, manufacturing, and testing phases will separate into Fall, Winter, and Spring quarters. Firstly, the fall quarter will be designing and doing analysis to confirm whether the components will fail the set requirements. During the Winter quarter, the RC will be constructed according to the manufacturing processes for each part to build the final project. Finally, in Spring quarter the RC will be put to the test to determine whether the analyses were correct under the chosen requirements. Revision of the analyses and Iteration of the test processes will guarantee success in the project. The Issues that will be challenged will be method of mounting and what stresses would be experienced when experiencing sudden impact from a 2 ft drop (req 1d-6). The analyses would determine if the part were to fail under the given conditions. A solution will be engineered via SolidWorks modeling and utilizing an additive manufacturing method of 3D printing as much as possible to cut down on costs and analyses to back up the information. The other portion of the RC BAJA is being conducted on the chassis and drivetrain.

b. Motivation

The motivation to complete this project is personal and is seen to challenge one self's skills and knowledge of forces to create a qualifying RC Baja car.

c. Function Statement

The steering provides the RC with directional control of a 60-degree range and the suspension absorbs irregularities in the terrain and keeps the vehicle stable.

d. Requirements

1. Wheels turn 60 degrees without interference.
2. RC Baja must be able to have 1.5” of clearance for suspension.
3. Must have suspension travel of 1”.
4. RC should not exceed 10lbs.
5. RC uses M4 standard fittings.
6. RC should not deflect more than 0.1” at a 2ft drop test more than once.
7. The RC can go 30 mph max.
8. Can withstand an impact at 30 mph.
9. Components must not deflect more than 0.1.”
10. Suspension must support 10 lbs.
11. Must have less than 4-foot turning radius.
12. E6000 Adhesive will not fail from a 2ft drop.

e. Engineering Merit

The ASME RC Baja competition rules and challenges determine the required components used to attempt a successful RC Baja. To choose, the components is up to the team and what parts will meet their requirements listed above in 1d. The components were analyzed with methods of engineering learned in statics, dynamics, and mechanics of materials. An example that could be used to analyze a component of the RC is shear stress in the control arms and steering rods. Additionally, a deflection problem can be used as an analysis for the tie rods.

f. Scope of Effort

Effort will be made to choose the best steering and suspension components and style to fit the needs of the RC Baja chassis and requirements. By the end of the year a functional RC Baja car will be ready to test. Fall quarter will be used to do analyses and a proposal.

g. Success Criteria

A robust successful RC Baja will complete all three challenges without breaking. Will still be able to work after the tests.

h. Stakeholders

The stakeholders are Professor Pringle, Dr. Choi, and the team leading the project because it will be funded and dependent on them.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

The problem confronted with this project will be the application of the suspension and steering controls. The alternative idea was to construct a low-profile car, but it must be designed for the requirements made. Thus, the idea was to rework the initial design and implement a larger body that would fit the requirements and fit the final competition events. The second alternative design was based on the Razer off road vehicles, but it was not chosen. See the figure below in Appendix F for matrix decision.

Matrix Decision of design ideas for RC Baja car-

Criterion	Weight 1 to 3	Best Possible 3	Gear Drivetrain Design	Score x Wt	Belt Drivetrain Design	Score x Wt	Off Road Design	Score x Wt	
Cost	1	3	3	3	2	2	1	1	
Weight	3	9	2	6	3	9	1	3	
Prediction precision	2	6	2	4	1	2	1	2	
Confidence -failure loc	2	6	2	4	2	4	1	2	
Prismatic vs non prismatic	3	9	2	6	1	3	1	3	
Manufacturability	2	6	3	6	3	6	1	2	
Total	13	39		29		26		13	
NORMALIZE THE DATA (muliply by fraction, N)		2.56		74.4		66.7		33.3	Percent

Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits	Good? Then done.	58.1 Average
	Poor Bias:	Standard Deviation is one or less digits	Poor? Change something!!!	22 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	More mass is more cost
Weight	Light weight scores better on the success equation
Prediction precision	Are the engineers calculations sufficient and correct?
Confidence -failure loc	Confidence level in the indicated failure location
Prismatic vs non prismatic	Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:

The gear drivetrain design scored the highest out of the three because it showed the best possibilities of being produced with minimal cost and manufacturability. The off road design scored the least because of its size it would cost more to produce. As for belt drivetrain desing it was similar to the alt gear drivetrain , but it has additional components that would affect cost of manufacturing and create a complication of space availability in the drivetrain.

Figure 2.1- Matrix decision of design ideas

b. Design Description

The design chosen implies that the chassis will be lifted and not a low-profile setup. The design is meant to allow the suspension to travel 1" but allow for 2" of clearance. This is used as a preventative measure that will protect the chassis and components from damage. Knowing how much force the RC Baja will experience, the suspension components can be chosen at a selection that suits it best. Further analysis will need to be done to correct for any bending of the components.

Sketch ideas of rc baja-

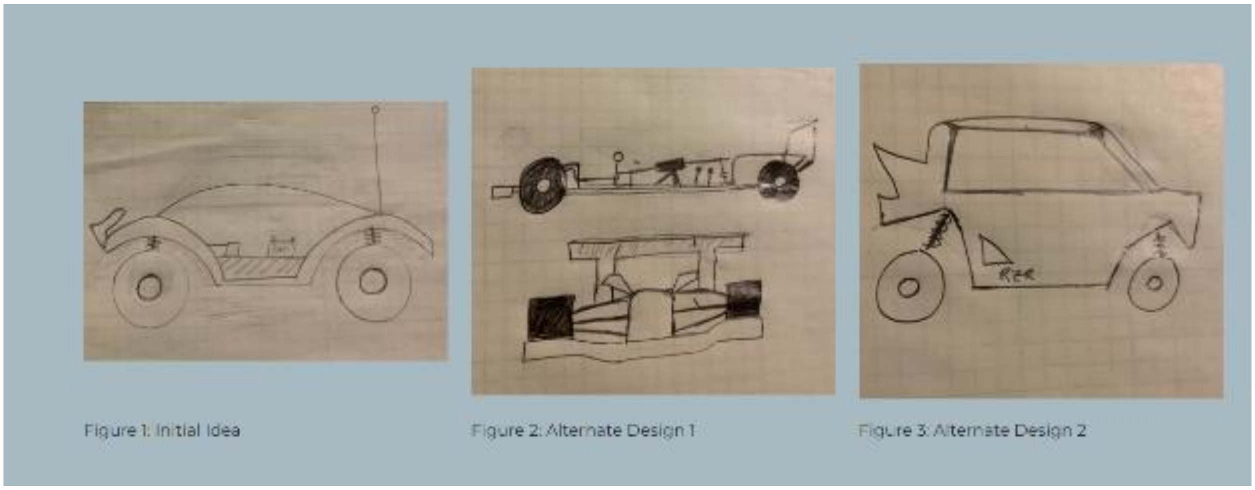

Figure 2.2- Sketches of design ideas

c. Benchmark

In comparison to retail RC cars, a frequent problem in RC cars is the steering not leading the car in a straight path. This problem can be overcome by replacing servos if they are damaged or tune the suspension components. In addition, allowing for several options of mounting and adjustments, the steering and suspension can be tuned. This can be done by adjusting camber, caster, and toe. Additionally, when an RC car is driving fast on uneven terrain, the suspension experiences bumps that need to be absorbed through the shock and the rest of the chassis so that the RC does not bounce and get thrown off course.

d. Performance Predictions

The shocks will experience a force of about 100lbf if the entire vehicle were assumed to weigh 5 lbm. The shocks will be chosen to withstand this force and fit the requirement of allowing 1” of suspension travel while not deflecting the members by more than 0.1” as well.

e. Description of Analysis

A drop test analysis was conducted for the first analysis. In the first analysis, it was assumed the car to not exert more than 10lbf. A combination of statics and physics was used to find the force of 67.7lbf acting on the springs if dropped from 2ft onto flat ground. In analysis #2, the goal is to find the k factor of the spring compressing 1” (req 1d- 3). Using statics, physics and the answer from the previous analysis, the spring force of 67.7lbf set equal to the spring reaction force equation and calculated for the k factor. Similarly, using mechanics of materials and statics to find the right cross section of a shock tower that will withstand the force of 67.7lbf from a 2 ft drop (drop test spring event requirement). In analysis 4, only mechanics of materials were used to find the minimum bolt size made of grade 1 steel to withstand 5lbf. A safety factor of 8.5 was applied and a 4mm bolt was used to mount components wherever it can be used. In analysis 5, simple geometry and a FBD were used to find the turning radius of the RC and its range of steering based on the track width and wheelbase. In analysis 6, the engineering merit used was statics and mechanics of materials, specifically using sum of force and moments, then using the bending stress equation to find out if the lower control arm will exceed the max bending stress. In analysis 7, the rear shock tower is required to not deflect more than 0.1" (req 1d-6) and not exceed the max bending stress for PLA+. Analysis 8 was done on the torque applied to the steering rod pin at the knuckles. Simple physics and algebra were used to find the torque on the pin. Analysis 9 and 10 were done with the exact process to find a cross section that will not deflect more than 0.1" (req 1d-6) and will not exceed the max bending stress for PLA+. The correct cross section will determine if it breaks or not. The 11th analysis uses the bending stress from mechanics of materials and shear to find a cross section that would withstand a 2ft drop. In analysis 12, the deflection equation using mechanics of materials and statics engineering merit reveals a cross section that will not deflect more than 0.1" (req 1d-6). Mechanics of material deflection equations are used to determine deflections of the members under the expected loads/forces they will be experiencing. Also, statics has been used for finding the force that will be loaded onto the springs at each corner from a 2ft drop. In addition, an impact test can be done to determine the force that will be applied when making an impact at 30mph head on (req 1d-8). Finally, the steering angle can be determined with a gauge that is accurately illustrated to test the turning angle of the front wheels.

f. Scope of Testing and Evaluation

Testing for angle of steering components can be done using paper and correctly illustrated lines of degrees to represent the range of motion of the wheels. A marker is placed at the center of the wheel, and it is turned till it locks either direction. The range is then found using simple math addition. While conducting this test, the wheels must not interfere with any other component of the RC BAJA. Under its own weight and additional loading from the drop test, the control arms must operate as predicted by allowing for 1" of travel and must not deviate more than 0.1" using the deflection equation.

g. Analysis

i. Analysis 1 – Force acting on the shock from a 2.13ft drop

The problem being solved in this situation is the force acting on the suspension point attached to the lower control arm after being dropped from 2.13ft (Req. 1d-6). The problem is solved by setting potential energy equal to force acting on a spring. The equation results in a value of about 60lb and uses this value to find the force reaction on the point of the suspension shock. The analysis is done by finding forces in the x & y direction and taking the moment of the end of the arm where the tire is experiencing the force from the impact on the ground. This relates to the requirement of withstanding the impact force of the floor when dropped from 2.13ft. See Figure A01 in Appendix A01 for analysis.

ii. Analysis 2 – Suspension travel

In this analysis, the problem was to find the k factor of a 4" spring that won't contract more than 1", when using the force value of the previous analysis as it is the force that the RC will be experiencing if assuming the RC weighs 5lbs and is dropped from 2 ft (spring event requirement). The k value was determined to be 5760.4 lbm/s^2. This relates to the suspension travel requirement and drop test requirement. See Figure A02 in Appendix A02 for analysis.

iii. Analysis 3 – Width and deflection of sectioned shock tower
In this analysis, the problem was to find width and deflection of sectioned shock tower. Using previous data from the drop test analysis, forces acting on the shock tower must not exceed the amount of stress the material can resist under the selected dimensions. This analysis shows the selected dimensions would allow for failure under the load it would experience. The sectioned portion was assumed to be a rectangle with a length of 4.3" and made of PLA+ 3d printer filament. A second deflection and bending stress analysis determines the cross section of .75" and .5" is okay to use. See figure A03.1 and A03.2 in Appendix A03 for analysis.

iv. Analysis 4 – Hardware size
In this analysis, the problem was to find the correct hardware size that is closest to standard that will hold the shock tower in place. The material being steel and has a yield stress of 36ksi. It is assumed that the force the bolts will be experiencing will be 5lb shear force in single shear scenario. Thus, the shear force equation is applied to find the diameter of the hole. A size factor of 8.5 applied to the resultant determines a 4mm bolt is adequate for the material of choice and force that it will experience. See figure A04 in Appendix A04 for analysis.

v. Analysis 5 – Steering angle and turning radius.
This analysis is related to the requirement of a 4-foot turning radius and allowing for 60 degrees of angle without interference (req. 1d-1 & 1d-11). Utilizing the dimensions of the track width and the wheelbase, the steering angle is calculated using an arctangent equation and setting the respective values in place. The result of this being 71.6 degrees. Using the steering angle estimation, the turning radius is calculated by subtracting 71.6 and 90 from 180 to get the unknown angle of 18.4 degrees. Then using the tangent formula, the length of the turning radius is 30" inches. See figure A05 in Appendix A05 for analysis.

vi. Analysis 6 – Lower control arm
The problem in this analysis is the deflection and stress requirement needed for the drop test (Req. 1d-6). The analysis began with a guess for the cross section to see if it would withstand the force applied without exceeding 0.1" of deflection. Results revealed it would have deflected 0.64." Nest, bending stress was calculated, but the value exceeded the max yield stress on the PLA+ material under those dimensions. A new cross section was calculated by setting the base of the cross section to be 0.3" in the bending stress equation. This produced a 0.5" height value that was verified to deflect only 0.06" and bending stress less than the max yield stress for the material. See figure A06 in Appendix A06 for analysis.

vii. Analysis 7 – Rear tower shock
The problem in this analysis is the deflection and stress requirement needed for the drop test (Req. 1d-6). The analysis began with a cross section of 1x0.75in to see if it would withstand the force applied without exceeding 0.1" of deflection or yielding. Results revealed the first arm

would have deflected 0.0077” and experienced 919.84psi, well under the yield stress of 10733psi. The deflection showed it was well under the required deflection of 0.1,” as listed under 1d-6. Next the second arm had a cross section of 1x0.98in. Results showed the arm would deflect 0.00356” and have 538.7psi acting on it. Both arms are to be experiencing less than the required maximum deflection and should not surpass the yield point according to the material properties. See Figure A07.1 and A07.2 in Appendix A07 for analysis.

viii. Analysis 8 – Torque applied on steering pin

The problem in this analysis is the torque applied on the steering pin on the steering rod (Req. 1d-1). The analysis is done assuming the “mu” factor is 0.5 and the force of the RC car is 5lbf. The mass would then be 0.16lbm. Also, assuming the space between the center of the tire and pin is 1.7in. Finally, the tire width being 4.06in. According to the calculations, the torque applied to the pin would be 0.18lb-in. The torque applied to the steering pin is assumed that nothing will be interfering with the actions because the RC must always be able to turn its wheels. See Figure A08 in Appendix A08 for analysis.

IX. Analysis 9 – Impact analysis on upper control arm

This analysis begins with the force of the impact when the RC is going at its max speed of 30mph given as 4382.4lb force. The requirement for the RC is that it must reach 30mph and withstand an impact at 30mph (req 1d-7, 1d-8). The control arm is assumed to have the material properties of PLA+ filament. The yield point of PLA+ is 10733ksi and the modulus of elasticity is 484.426ksi. Firstly, the reaction forces were calculated and the moment of the load about point A was found. The moment value was used to calculate a stress of 2.208ksi, much less than the yield point of 10733ksi. Changes to cross section are not necessary with this analysis because the value of the bending stress is less than the max. The analysis shows that requirement 1d-8 is met, and the RC will not deform because it will not surpass the max bending stress. See Figure A09 in Appendix A09 for calculations.

X. Analysis 10 – Stress analysis on rear lower control arm

The problem in this analysis is to find the bending stress of the lower control arm from a 2ft drop as required in 1d-6. In addition, the RC must not exceed 10lb (req. 1d-4). The part is to be printed out of PLA+ so that the Modulus of elasticity and yield point are given as 494.426ksi and 10733ksi. The impact force from the drop is given as 67.77lb. The reaction forces are calculated in sections and the max moments are graphed in the shear moment diagram. The moments are used to calculate the bending stress applied and are experiencing less than the max bending stress of 10733ksi. The first member experiences 12412.5psi and the second member experiences 1424.6psi. Also, shear stress was calculated as 173.8psi and 150.6psi. According to the analysis, the control arm should not deform from a 2ft drop (req 1d-6) because it will not reach the max bending stress of 10733ksi. See Figure A10.1 and A10.2 in Appendix A10 for calculations.

XI. Analysis 11 – Front upper control arm deflection analysis

The problem in this analysis is to find the deflection of the front upper control arm from a 2ft drop as required in 1d-8. The part is to be printed out of PLA+ so that the Modulus of elasticity and length are given as 484.4ksi and 3.95”. Also, it is to not exceed a deflection greater than 0.1.” The Impact force on the arm with the first set of cross section dimensions of .25” x 0.4” was deflecting 1.5”, assuming it acts directly on the member. Modifications to the dimensions of the cross section were made till an adequate dimension would not deflect more than 0.1.” According to the new dimension from the analysis, the lower control arm should only deflect up to 0.096.” Because it deflects less than the required 0.1” (Req 1d-8) that means the new cross section is 0.6” x 0.75”. See Figure A11 in Appendix A11 for calculations.

XII. Analysis 12 – Front lower control arm deflection analysis

The problem in this analysis is to find the deflection of the front lower control arm from a 30mph impact as required in 1d-8. The part is to be printed out of PLA+ so that the Modulus of elasticity and length are given as 484.4ksi and 1.96”. Also, it is to not exceed a deflection greater than 0.1.” The Impact force on the arm with the first set of cross section dimensions of .25” x 0.4” was deflecting 0.264”, assuming it acts directly on the member. Modifications to the dimensions of the cross section were made till an adequate dimension would not deflect more than 0.1.” According to the new dimension from the analysis, the lower control arm should only deflect up to 0.084.” Because it deflects less than the required 0.1” (Req 1d-8) that means the new cross section is 0.4” x 0.5”. See Figure A12 in Appendix A12 for calculations.

h. Device: Parts, Shapes, and Conformation

A 3d printer and PLA+ are used as much as possible for all suspension and steering components for this project and all components that are designed must be 3d printable. The suspension shocks are designed to be at a 45-degree angle to have forces act in the x and y. When dropped on a flat even surface, the forces in the x component would theoretically cancel each other out and the suspension would be experiencing forces only in the y component. The reason for designing the suspension orientation at 45 degrees is to minimize forces acting on the tower in one single direction. Distributing the load in different directions would enhance its resistance to break. The shock towers are designed to absorb the load delivered from the shocks reacting from a 2ft drop but also mount the upper control arm from the wheels. In addition, the part will be printed with holes at the bottom that will be used for mounting onto the chassis with threaded inserts and hardware. A shear stress analysis on the bolts determined a 4mm bolt with an 8.5 safety factor applied is adequate to mount the shock tower to the chassis. As for the lower control arms, they are designed to be mounted to the chassis and must adhere to the requirements in 1d. The servo motor is to be mounted at the front and designed to fit in a mount that will keep it from falling off while operating. All 3d printed components are to the 0.05 intolerance unless otherwise specified. The design of the RC must meet the requirements listed in 1d, but also be practical to manufacture and capable of being printed on 3d printers.

Simply, the project must be easily repeatable with succeeding requirements. In analysis 2, kinematics was used to find the pound mass of the RC when experiencing a 2ft drop, then finding the k factor. The RC's requirements influenced the design and choices of components, purchased and manufactured in-house.

i. Device Assembly

The RC assembly will consist of the chassis, lower & upper control arms, shocks, steering, drive train, and other miscellaneous parts. The suspension style used in the RC is double wishbone, which incorporates mounting the shock to the lower control arm and the tower. The chassis would allow for mounting the steering, suspension components like the shock towers and control arms. Additionally, it will be mounting the propulsion system, servo, electronics, and battery also. The drivetrain and steering components will work together to allow for drivability and controls of the steering to complete the drop test, drag race, and impact testing in spring. The completion of the tests would prove the analysis of the components chosen and the robustness of the RC.

j. Technical Risk Analysis

A risk in successfully creating the RC BAJA would be getting the RC to receive signal from the controller and accurately represent the full steering range of the wheels. The RC must receive signals from the controller to be successful as described in the function statement. Learning to connect the devices via signals would require further investigating into how it works and what to do for it to work accurately.

k. Failure Mode Analysis

A failure mode that might arise from the design in the suspension will be fatigue due to stress on the mounting points of the components. Most of the failure may come from the mounting of the suspension shocks because those will be experiencing most of the impact force when dropped and driven into a wall as listed in the requirements.

l. Operation Limits and Safety

Operate in flat open areas to avoid damage to RC and/or injury to self. Make sure RC battery is charged to avoid damaging battery from discharge.

3. METHODS & CONSTRUCTION

a. Methods

The primary method of manufacturing would be on personal 3D printers, using PLA+ because it is not heavy, and inexpensive. Also, it has a high impact resistance and is durable. The other forms of manufacturing explored such as CNC machining and laser cutting are not applicable to this project with the requirements of weighing less than 10lbs because the material plays a crucial role in the weight of the RC (Req 1d-6). In addition, the availability of the other methods would require assistance in the machine shop and outreach. To reduce dependency and not interrupt workflow, 3D printing is an extremely helpful method because the printer does it by itself, other forms would require the attendance of one or more people and a longer setup for the processes. See Appendix F for decision matrixes on material selection and manufacturing methods.

i. Process Decisions

The options of manufacturing explored are CNC machining, 3D printing, laser cutting. The most feasible option out of these options is 3D printing primarily because of the availability. A personal 3D printer is utilized to print the components instead of using the other variations of manufacturing methods. This additive form of manufacturing is better because the CNC machine would require the help of a qualified person and a longer setup. Also, the laser cutter would need to be operated by someone qualified. A 3D printer is much easier because it does not require the help of a qualified individual and would be available to the team at any time needed. In addition, the cost of printing is much lower than CNC machining and laser cutting. See Figure F02 in Appendix F for decision matrix.

A few other options of manufacturing methods were explored. The methods being casting, welding, and stamping. The cost of stamping was found to be the least expensive out of the three methods, but a downside to this is that stamping is done with flat sheets and with the use of a die to press the part. In addition, stamping would need to be an outreach method because it is not as easily available. This form of manufacturing is not applicable and for many other reasons it was not chosen. The other forms of manufacturing also are not suitable for the project because it would be difficult to weld without experience and if cast, it would take more than one attempt to get a good casting of the part. Then, the part will need to be finished afterwards. Ultimately leaving stamping to be the best decision of these three methods, but not suitable for the project due to availability and how challenging it is to manufacture. See Figure F03 in Appendix F for decision matrix.

The materials listed to be selected are PLA, PLA+ and aluminum 6061. Although Aluminum is found to be the best option when it comes to yield strength, it is the least desirable because of its cost in comparison to PLA and PLA+. The cost of aluminum is much higher than PLA and PLA+, making it not a desirable choice of material because keeping costs down as much as possible is more desirable. Also, it is found that PLA+ is much more dense than regular PLA and aluminum. A bending stress and deflection analysis on the rear shock tower based on a 2ft drop requirement revealed PLA+ is suitable for the application and helpful in maintaining weight under 10lb (Req. 1d-6 & 1d-10). For these reasons, the PLA+ filament is a better choice of material. See Figure F04 in Appendix F for decision matrix. See Figure A07.1 and A07.2 in Appendix A for analysis on bending stress and deflection of rear shock tower.

The method of 3D printing was the most accessible and cheapest form of constructing the RC Baja. The accessibility of 3D printing is much more achievable thanks to the advancement of technology. For this reason, it makes it possible to print physical parts from a model like on SOLIDWORKS. Other such methods of construction are not as easily available. Aside from availability, the 3D printer can create parts while the team is busy. With other methods of construction, it would not be possible to leave the machine to do the work if the process involved a machine because it would need to be monitored at all times, except when 3D printing, the printer needs to be monitored for the first few layers before leaving it. Issues that would have arisen from machining instead of 3D printing would be mistakes made in machining would be costly in comparison to 3D printing. The issues that are addressed while 3D printing is done to correct the hole diameter sizes and dimensions of features. This is done by tuning the printer slicer settings and live tuning the printer for better quality. Threaded inserts are added into the parts to fasten them together during assembly. A soldering iron is used to heat the threaded insert and plastic on the inside of the hole. A small amount of pressure vertically down is used to direct the insert in the correct position.

Fully 3D printed components were not viable for assembling. This meant redesigning the RC control arms for better forms of fastening together. Ball joint ends were the best option. For the upper control arms to accept the ball joint ends, M3 hardware was designed to fit inside the end of the control arm. The hardware was then bonded in place using JBWELD plastic bonder. This certain product is a smart choice because it works well bonding metal to plastic and plastic to plastic. In addition, the team added threaded inserts to help assemble and disassemble the RC without damaging the plastic. This would preserve the part longer than originally because the hardware was threaded into the plastic.

Once assembled, the RC was discovered to be too low for the team’s clearance requirement. In attempt to increase clearance, the RC had its front lower control arms swapped and flipped upside down. A soldering iron was used to modify the lower control arms slightly to fit the shocks in their intended place. This method was not originally considered from the start but will be used to help redesign the height of the RC to meet the team’s requirement.

Initially, the team was going to purchase the steering rods, but changes made to the chassis and suspension also changed the way the budget was spent. The budget went over the limit of 500. This is because the parts that are CNC machined metal make up most of the budget. In efforts to not exceed the budget further, the steering rods were 3D printed and test fitted. The change in height of the RC stretches the steering rods together causing the wheels to have a positive toe (inward) so it must be redesigned to straighten the wheels out.

b. Construction

i. Description

The RC is to be constructed by attaching the components to the main chassis. The 3D printed components that are made in-house consist of the main chassis, the upper and lower control arms for all four wheels, shock towers, servo mount, motor mount, and axle mount. The rest of the components such as batteries, motors, shocks, servo, steering rack, hardware, axle, and axle ends are purchased parts. The chassis is to be the first step in assembling the RC and can begin mounting the shock towers and control arms. Next the wheel knuckles and wheels can be installed. Shocks, motor, battery, electronics, and axle can be installed with adequate hardware.

ii. Drawing Tree, Drawing ID's

The assembly of the RC is done by attaching all components to the chassis or another modeled part. The RC consists of 2 sub-assemblies and one main assembly. The front subassembly consists of the mounting of the front shock tower and the parts that attach to the tower. The rear subassembly consists of the mounting of the rear shock tower and the parts that attach to the tower. See Appendix B01 for larger image.

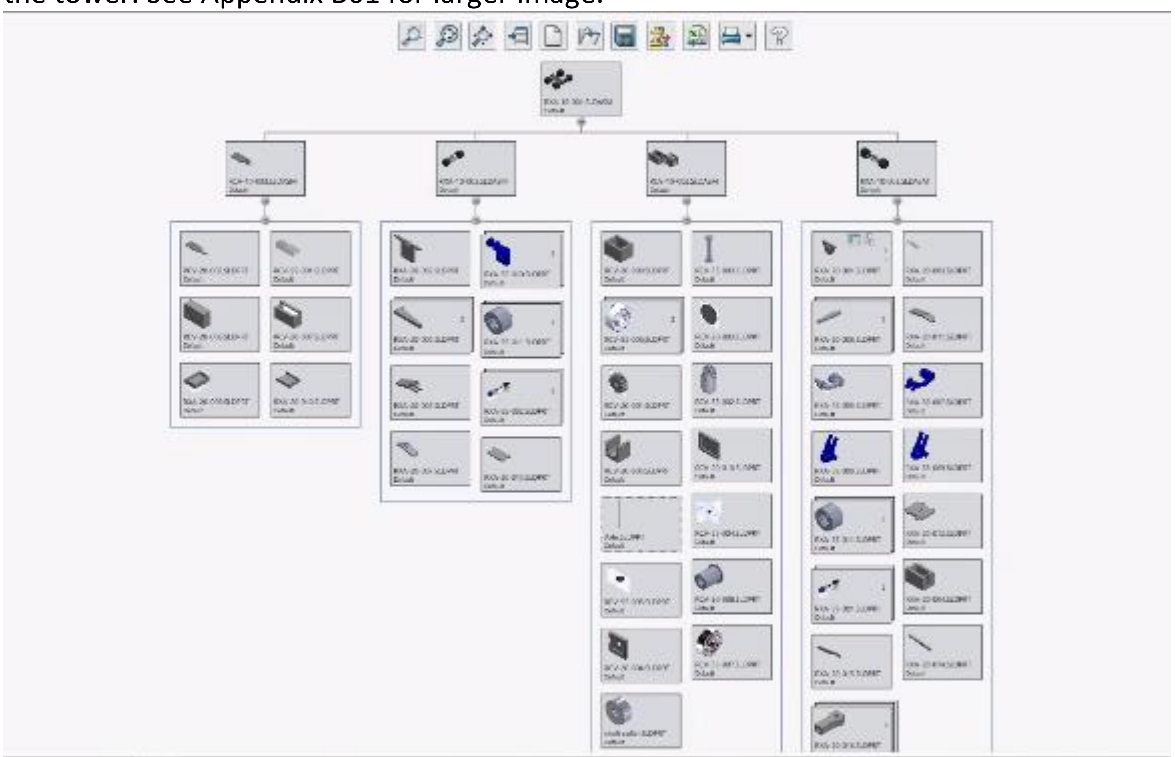

Figure bii- Treehouse of drawings from Appendix B01.

iii. Parts

Fall: The only process of additive manufacturing is 3D printing. Most of the RC is 3d printed to reduce cost and weight. For example, the front and rear shock towers (RXA-20-001 &RXA-20-002) are the biggest 3d printed component of the RC and would require the most time to print.

Thus, it would be the biggest cost for the project if machined out of aluminum. The second process group is from purchased parts like the 4-piece shocks (RXA-55-001). The last process group is for purchased parts requiring modifications. The axle is one component that is purchased but will require modifications to it (RXA-55-009). A keyway will need to be machined to mount the gear to prevent the gear from spinning and allowing it to drive the axle. All parts can be found in Appendix C.

Winter: Between Fall and Winter quarter, the suspension underwent a complete redesign, and so parts were different than before. As the team assembled the RC, purchased parts, and manufactured parts required modifications. The modifications to purchased parts were related to the drive train. The team added heated inserts to the RC to make it easier to assemble and disassemble without damaging plastic threads. Also, the front lower control arms were swapped and flipped upside down to experiment with height clearance. There have not been any changes to the purchased parts on the suspension of the RC. Instead of purchasing the steering rods, they were manufactured with the 3D printer. This saves the team cost and time on shipping. This way the RC steering can be made to fit custom to the RC and tested for functionality.

iv. Manufacturing Issues

Fall: For fall quarter manufacturing issues such as failed prints from slicer settings or adhesion issues could arise if the PLA+ is contaminated with too much humidity. This would require a dehumidifier to prevent the issue or the purchase of a new filament roll. Also, there could be issues in finding help using machines when modifying the axle for a keyway.

Winter: Over the break a personal printer had issues with heating up, which required replacement of parts and lots of troubleshooting. Once everything was working as it should be, it needed to be calibrated to print functional parts for the RC. After the printer was calibrated and tested, the RC parts have not had issues with manufacturing. The only issues would be stemming from design issues. For example, the front control arms were redesigned to accept ball joint ends. The 3D printed parts are always at risk of misprinting or something wrong happening with the printer. This can be minimized as much as possible by running tests on the printer and supervising the progress as it prints. There has been an issue of edges over extruding from their dimensions, but this is not much of an issue because the tolerances do not need to be exact. Also, randomly the printers can have crashing issues that affect the time it takes to manufacture a part and even times would lead to layer shifting when resuming the print. This could be an issue that stems from the G-code or Firmware version of the printer.

v. Discussion of Assembly

The RC is held together by fasteners and the use of threaded inserts on the components. The chassis itself does not have threaded inserts, but the components that mount to it do. That being the components are being clamped in place on the chassis from either side. Since the chassis could not be printed as one piece, it was split in half. The sub-assemblies that make up the RC are RXA-10-002, RXA-10-003, RCV-10-002, and RCV-10-003. The first issue arose when the wheel hubs were not compatible with the dog bone axle and axle ends that were purchased before assembling. A new set of axle ends were purchased and fit correctly in place. The new axle ends did not come with fasteners, so the old fasteners from the old axle ends were used to tighten the axles. The front lower control arms were swapped and flipped upside down to experiment with the height of the RC. This raised the RC to 0.93in and only required small modifications to the lower control arms. It was necessary to melt around the mounting slot for the shock to allow it to be mounted in place. Some components were printed before finding out the threaded inserts were not the same diameter as the manufacturer listed them. This meant the holes that were supposed to have threaded inserts were the incorrect size and needed to be redesigned and reprinted to the correct size of the threaded inserts. The RC would compare to a retail RC that can have directional control and wheel alignment. This could improve steering deviation and suspension control when driving over obstacles. While it is only rear wheel drive, it should have a higher top speed and slower acceleration in comparison to a 4-wheel drive RC. The cost of a retail RC is different from the team's RC in that the wheels and wheel hubs are outsourced parts that were the most expensive to purchase. The size of the RC was meant to be a 1:8 RC with a wheelbase of about 20 inches and a track width of 13 to 15 inches. The team's RC was measured to have a wheelbase of 11.5 inches and a track width of 18 inches.

4. TESTING

a. Introduction

In this section of the proposal, it will introduce the testing processes that will be conducted to evaluate the RC overall and the components that make it a complete system. The main tests consist of the drop test from 2 feet, a turning radius test, and a steering angle test. Multiple trials of these tests will need to be recorded to have consistent values. These tests are specific to the steering and suspension of the RC. The results will help determine the performance the RC will reflect in the BAJA competition drag race, slalom, and Baja. The obstacle course is yet to be determined, but it will be done as a class effort to set up.

b. Method/Approach

The three main competition events will be the drop test that requires the RC to be dropped from a height of 2ft. The next tests will be the acceleration tests and front impact test. A camera will be used to video the drop and impact on the suspension system of the RC. With the use of sensors, the deflection can be measured to ensure its components will not exceed the requirement value of 0.1” (req 1d-6). The test is done using a measuring stick to measure the drop height of each trial and then finding an average value of the results. Equipment needed to do the drop test besides the measuring stick is the complete RC weighing less than 10lbs, a slow-motion camera to video the deflection, and sensors to measure deflection. The impact test will be done by driving the RC at full speed towards a wall to test its impact resistance for multiple trials. The analysis of the frontal impact demonstrates the RC will not experience any permanent deformation. The equipment required for this test will be the completed RC, a wall of choice with open space, a slow-motion camera, sensors to measure deflection, and a speed sensor. The acceleration test will be a drag event in competition with other RC Baja cars where all RC cars will be lined up at the start and will accelerate to the finish line trying to beat the others before they finish. The obstacle test will be organized by the entire class and the only requirement to pass the test is that it will complete the obstacle course without issues. A RC requirement that may help in the obstacle course will be that the RC requires a clearance of 2” (req 1d-2). Also, a steering angle test will be done on the wheels. It will require a protractor to be set up under the center of the front wheels with accurate increments marked. The RC is then controlled to fully lock the wheels to the left and right. The RC should have a steering angle of 60 degrees as required in 1d-1.

As the tests were developed, the first test was done on a 2-foot drop test. The materials needed to change also with the development of the procedure. The RC was required to withstand the impact of the 2- foot drop and deflect no more than 0.1”. This requirement was partially impossible because the RC would always deflect more than 0.1,” but the RC would survive the impact after some changes. The front lower control arms initially had 3d printed ball joint ends because they provided stiffness to the turning but were too weak and the 3d printed threads would not hold. CNC machined aluminum ball joint ends were used and withstood the impact from 2 feet every time consistently. The predicted value was estimated to be 1.4 inches of deflection and the RC bottomed out at 1.5 inches of deflection in the front view and less in the side view. See Appendix G1 for full drop test.

The next test was conducted on the turning radius. The turning radius test was slightly changed due to the motor having complications not wanting to drive forward. The issue could stem from the motor because its orientation of rotation is CCW. To resolve this issue the RC was tested in reverse. This could affect the results, but it was a change that was necessary or else the test could not be conducted. The test had no issues besides the RC not moving forward, but it was compensated by driving it reverse. See Appendix G2 for full drop test.

The steering angle test is the final test for the RC. The RC had a range of 60 degrees. This was soon found to be a difficult value to reach because the RC knuckles would interfere with the ball joint ends on the front lower control arms, which limited the steering range of the RC. Initially, the team decided to use a jig, but a protractor was purchased to accurately measure the steering angle. This is an improvement to the test because if a constructed jig was made, the RC can have issues due to human error. See Appendix G3 for full drop test.

c. Test Process

The RC must be able to withstand 10lbs according to section 1d and will be measured using a scale. The RC's components should be able to deflect no more than 0.1" from a 2-foot drop. This is completed by marking 2ft on the wall from the floor and 4 feet from the wall to set the camera up. Any object can be used to prop the phone to face the RC. Thus, a flat area with enough room to place the phone 4 feet away and a wall tall enough to mark 2 feet with blue tape is needed.

The RC must also have a 4-foot turning radius that requires a measuring tape. In the turning radius test, the required equipment is needed to conduct the test. In addition to this, the location is as well required because the RC has a 4.31 foot turning radius. The Fluke Lab has adequate floor space and flatness for the turning radius. In section 1d the RC was required to have a turning radius less than 4 feet and based on the dimensions of the RC it was predicted to be 2 feet, but the test demonstrated otherwise.

The RC's steering range was initially required to be 60 degrees according to section 1d and will be tested using a protractor with accurate markings. The RC is turned left and right, taking measurements of each wheel as the trails are done. For this test, the RC can be tested anywhere the RC can fully lock the steering both ways, but the Fluke lab was chosen because the tape sticks best to that floor.

d. Deliverables

The RC will have tabulated data with labeled tables for the specific tests and a description of how the tests were performed. The tests will be conducted as same as possible each time to reduce errors in the data. Also, photos and videos will be recorded during testing. The RC will be tested for its top speed on a flat surface and then tested on the success of withstanding an impact at full speed. This will be done by calculating the strain from the force impact and comparing it to the material properties of PLA+. This will be a priority along with the deviation of the RC. Next, the RC will be recorded in slomo to determine if it will deflect more than 0.1" according to the analyses. The steering range is tested with a protractor like how alignments on vehicles are performed, but on paper. The steering radius will be tested using a measuring tape.

The test performed is the 2ft drop test. It is set up along a wall with blue tape marking 2 feet from the floor where the RC will be dropped and 4 feet from the wall where the slow-motion camera is set up. The tape measurer is placed visibly in front of the camera and the RC is dropped and recorded each trial. The drop test requirements for the RC were that it must be from 2 ft and survive the impact. Initially, the requirement is that the RC should not deflect more than 0.1" based on a cantilever deflection equation, but the team did not first take into consideration that the Instron would be best for that test. This was apparent when the deflection values were not close to the predicted value. A predicted value of 0.86in calculated from a conservation of energy equation best represents the test because it involves a load over a brief time instead of a static load. The goal of the test is to perform 12 successful trials and record each deflection measurement on a slow-motion camera. The measured deflection value is then compared to the predicted value calculated using conservation of energy instead of the deflection cantilever equation. The k value is an average value over the length of 1" and works for an appropriate assumption. The predicted value of 0.86in best fits this test because it is found assuming the entire RC deflects together, while the 0.1" deflection is only meant for individual components which is best represented on the Instron. The equation used set m*g*h equal to .5kx^ (2) and calculated for the displacement of the spring. This tells how much the RC device had deflected from its equilibrium state after the 2ft drop. Using a tape measurer, the front view demonstrated an average deflection of 3.8cm (about 1.5 inches), while the side view demonstrated an average deflection of 2.63 cm which is a little over an inch. The displacement average value of 3.795 cm from the front view and 3.14cm from the side view are compared to the predicted value of 0.86in. Comparing the values will determine if the k value is the most inaccurate variable in the equation because the size of the springs is different in the front from the back, so the k values are too. Also, the fact the RC slams the front section and that the shocks do not have oil in them can be a reason the impact force is seen much higher in the front section than the predicted 14lbf. The front section of the RC resulted to have deflected the most and presumably due to many other factors such as, user error, 3d print orientation, infill %, and infill pattern. The issues that arose while testing came from the control arm 3d printed ball joint ends breaking off due to too much tensile stress while deflecting that it would rip the threads out of the plastic ball joints. To resolve this issue 6061 aluminum ball joint ends replaced the 3d printed ones because the plastic ones were too weak. Finally, the RC is not able to fall flat because its weight is not uniform and is resolved by attempting to drop as flat as possible to have impact on all wheels at the same time. See Appendix G1 for testing of a 2-foot drop.

This next test was on the turning radius of the RC device. The materials used are blue tape, a straight edge, safety glasses, measuring tape, the RC device, the RC controller, paper, and a writing utensil. The test was setup by placing 2 ft of blue tape along an existing straight edge on the floor in the Fluke Lab in Hogue Hall. Another 2 feet of blue tape were placed perpendicular at the end of the first strip of tape. The RC was placed with the rear wheels in the front because the RC's motor is only capable of moving the RC in reverse due to the motor's orientation spinning CCW. This was a change that had to be made to the test because the RC suddenly would not drive forward. The procedure was updated to include that the RC would be placed with the rear wheels on the starting line instead of the front wheels as first expected. The predicted value of 2 feet was calculated using a turning radius equation and the test determined the RC would have a turning radius of 4.31 feet on average. The turning radius of the RC was much more than predicted and it could be due to the size of the wheels creating wheel tilt angle. See Appendix G2 for testing of turning radius.

The final test was on the steering angle of the RC. The RC was predicted to have a steering range of 25.4 degrees. The materials used in this test were blue tape, safety glasses, a protractor, the RC device, the RC controller, paper, and a writing utensil. The RC steering test was set up in the Fluke Lab in Hogue Hall but can be conducted anywhere the RC is able to full lock both ways. The protractor is placed on the ground and taped in place so that it does not move. The RC's left wheel is placed on top of the protractor pivot point and turned left and right. Measurements on the protractor are taken when turning left and to the right. The same is done for the right wheel. The values are recorded on the table and summed to determine a full steering range. The RC steered at most 29 degrees to the left and 35 degrees to the right between both wheels steering the same direction. The lower control arms incorporate ball joint ends that would interfere with the steering range, which could be the reason for the substantial difference in steering between the left turn and the right turn. Human error can be present also because the 7-inch wheels create wheel tilt and makes reading the increments on the protractor a challenge to read accurately. Values are rounded to the next nearest whole degree. See appendix G3 for testing of the steering angle.

5. BUDGET

This RC project will be supervised to not be interrupted or exceed budget. The risk of any delay or fall back can be managed by planning out the schedule and including extra time in the schedule for any uncertainties. If following through with this can be done, risks of falling behind can be brought to a minimum and stay on schedule. In addition, taking note of the costs of every component bought can help keep track of the total amount of money spent on the project so far. Constantly keeping this value updated for every purchase made will help manage how much will be spent. Most components that can be easily manufactured will be 3D printed with PLA+ to reduce costs. Although parts will be 3D printed, the cost of 3D printing will be estimated using an average cost.

a. Parts

The main components of the RC that will take up most of the budget are the shocks, steering, battery, and motor. If possible, all parts are found on Amazon for easy availability and free shipping, otherwise the part will be noted where it was found. For example, just like the motor bought from hobbyking.com (Appendix C). The biggest cost so far is the transmitter and receiver valued at $39.96, listed as Part number RXA-55-006 in Appendix C. Smaller components such as adapters and electrical connectors are less significant costs that are needed to be considered besides the major components like the shocks. See Appendix C for budget list and all part numbers.

b. Outsourcing

All parts will be made in-house to help lower costs of labor, travel, shipping, processing, and operations. The only operations expected to be used are the use of a personal 3D printer. The benefit of outsourcing is that it would be fewer processes that need to be done for the team, but in contrast it would mean more of a cost.

c. Labor

Labor costs for the 3D printer are calculated as such: Eq1- [(The cost of the filament) * (weight of the print in grams)]/1000. The rest of labor can be estimated as it relates to its process.

d. Estimated Total Project Cost

The total cost of purchased parts should be no more than $300 with taxes and shipping included. As stated above most parts will be purchased from Amazon to take advantage of free shipping and availability of parts. The labor is estimated based on the mass of the 3d print model and calculated using the equation above (Eq1).

e. Funding Source

The cost of this project is funded by Roberto Vieyra and Rogelio Arroyos. Also, materials donated by CWU (Central Washington University).

f. Winter Updates

5a: The highest cost so far has been the knuckles for the RC car. The knuckles cost $86.39. The knuckles and current axle ends were not going to work as expected and a new set of axle ends were found to fit. RXA-55-006 to RXA-55-010 are the knuckles that need the new axle ends to fit properly in place. The price of axles is significantly higher for the new set of axles, which would push the budget even further than originally. Methods used to resolve cost issues were improvising with 3D printed components as much as possible and minimizing the amount of the budget going towards shipping of purchased parts.

5b: For outsourcing, the team did not purchase any manufactured components. The components are all made in-house using personal 3D printers to escalate the process of printing in comparison to using CWU 3D printers. The printers only required calibration to work independently with minimal supervision.

5c: Labor costs are determined by the amount of filament used for each part. See Appendix D for printer filament cost for 3D printed parts.

5d: The estimated total project costs for the Fall quarter were set at $500, but currently have exceeded the budget cap because of fasteners and incompatible parts. To find parts as cheaply as possible, the parts were bought from Amazon using prime to save money on shipping. If this were not the case, the budget would have been exceeded sooner.

5e: The project is funded by the team leading the project and donated parts from CWU.

g. Spring Updates

5a: The cost of the RC was much higher than the initially set budget of $500. This is due to the team struggling to get the brushed motor to work. The team struggled with overheating and not enough torque. The team broke two ESCs because the brushed motor drew too much current for the ESCs to handle. Fans were purchased to try to control the motor's heat. When the first ESC broke, the receiver was also broken and so a new receiver and transmitter needed to be purchased and arrived as soon as possible. The RC motor was swapped to a brushless motor to achieve the torque necessary to get the RC to roll from a stop. To convert to a brushless motor, the team needed to purchase a brushless 1980KV motor and a high rated amp ESC meant for brushless motors. If the team did not attempt to make the brushed motor work for the RC and instead chose a brushless motor, the budget would be much less because the team would not have had the heating and power issues in the first place.

The design changes that affected the price changes were the gearbox and the chassis. The team split the chassis to fit on the build plate for the 3D printer and glued together with E6000 glue. The gearbox was updated to include more material that functions in stabilizing the axle.

The entire project cost the team $830.59. This counts for the parts that were not used like the UBEC because the team switched to a brushless motor and the brushless ESC purchased has an integrated UBEC that delivers enough power to the servo. It also accounts for the tax and delivery of the parts. See Appendix D for full budget.

5b: When purchasing parts or hardware online, the RC would be out of commission for testing and the team would have no other choice but to wait until the part arrives on time or sooner than expected. Usually, the parts would arrive within a week of purchasing and the team would get to working on the RC as soon as possible to troubleshoot any of the previous issues. The team was fortunate enough to save on delivery because the team chose to order most of the parts from Amazon to take advantage of the free delivery on parts that are eligible for prime shipping. At times parts would entirely not show up. For that reason, the team would not get to finish on time due to lost packages or packages arriving late.

5c: The only labor calculated for the project was the printer manufacturing of the 3D printed parts. See Appendix D for labor cost. For the reason the team was able to use personal printers for construction, the labor was free, but calculated based on the weight of the print and the cost of the roll. The use of personal 3D printers made it easier for the team to remanufacture parts instead of setting the part with another classmate's part or waiting until the current print is finished.

5d: Much of the budget was taken up by the purchased parts from the wheels to the knuckles and the charger for the battery. These are a few of the many parts that make up most of the cost. The cost of the unused parts makes up a substantial portion of the overall cost too. Labor for manufacturing is cheap because the personal printers are available free to use at any time, but it is still considered as if the team paid for the component, without shipping and taxes. Luckily, any parts that were 3D printed can be easily remanufactured, so the total project cost is not affected much by this. The mistakes made during 3D printing are not significant cost to the budget because the part can be reprinted. The parts that were not used turned out to cost $162.7, which affected the budget a lot, but this includes the hardware and necessary parts to complete the RC. The purchased parts, which are all parts 55-xxx and 50-xxx, cost the team $745.43. This could have been reduced by purchasing cheaper wheel knuckles and wheels. In addition, if the team would have not attempted to use a brushed motor in the first place, it would have reduced the likelihood of breaking the budget of $500. Since the team has implemented a brushless motor, it was a huge improvement in performance and heat management. See Appendix D for budget.

5e: The project is funded by the team leading the project and donated materials from CWU. The project was over the $500 budget so additional funds were spent.

6. SCHEDULE

a. Design

Fall: There are plenty of possibilities of schedule risks when designing the RC. Time is a schedule risk because delivery of components can take a while and even finding the desired part is time consuming and a setback for the project. For example, some of the analyses have been corrected because a physical part is not present to take accurate dimensions of. In addition, this prevents further work from being completed when a part is dependent on another part. Task 1a was estimated to take 7 hours, but only 0.5 hours has been invested so far. The project has fallen behind a bit due to design changes between the initial analysis of the drop impact and the updated analysis. The project got back on track by correcting the analysis and updating the others dependent on the initial calculations. To see the schedule, see Appendix E.

Winter: The project fell behind at the beginning, but the team got back on track. When the chassis was still not at its final design, all the components needed to be redesigned to fit the chassis. This meant more time was spent modeling and updating for better designs. The lower control arms and upper control arms were substantial changes made to the suspension because the original parts were not going to work with the updated chassis. It was estimated to have taken 4 hours to model each control arm, and the actual time varied at most 0.5 hours from the estimated time because the first design was rough, and it was used as test fitment. Except for the lower control arms because they were mirrored and so it made it easy to model quickly. See Task numbers 3a, 3g, 3h, 3i, 3j, 3k, in schedule. In addition, a method of mounting the lower control arms was to create separate parts that will be threaded under the chassis and place to mount the lower control arms. See Task numbers 3x and 3y in schedule. Fine tuning of parts was also taken care of to simplify drawings further. Once all parts were redesigned for small fixes along the way, it should be able to assemble. To see the schedule, see Appendix E.

b. Construction

Fall: Schedule risks can arise in the construction of the RC. For instance, the parts could be in hand, but the components would not meet up as expected. This could be due to the intended part# the component was meant to replace. Some of the parts used are replacement parts for a toy RC can be deemed a risk if used on something it was not intended to be used on. The risks of using 3D printed components can stem from software crashing, modeling issues, file corruption, slicing errors, and printing issues. The risks of using 3D printed material can arise if the material has been exposed to open air and has too much moisture content, ruining the print quality. When assembling, the risks of parts not fitting as they should, would be a problem if inaccurately printed. See Appendix E for Gantt chart.

Winter: During manufacturing of the parts, the issue of a bad thermistor arose on a personal printer which meant the parts could not be printed ahead of time as expected. However, this problem was resolved during the first two weeks of the winter quarter. The risks with manufacturing the first few parts on printer that was having issues were if the part was going to print properly or fail due to printer issues when replacing the thermistors and updating firmware.

To prevent such a problem, the team leading the project calibrated the printer and accounted for corrections at 9 locations across the bed of the printer to achieve adequate layer adhesion between layers for large pieces. This improved accuracy in the printer and quality in parts manufactured.

The parts were estimated to have taken longer to print because the team was expecting to use a higher infill percentage for the bigger pieces, but it was not necessary because the materials properties were strong enough for the application. The estimated times are assuming all components were printed separately, but most were printed together for time's sake. For example, see Task 4e, 4f, and 4a. These tasks are estimated to have taken 4,5, and, 7 hours of time, but issues with steering were discovered with the design and a second prototype with ball joint ends was quickly modeled. Manufacturing the part over again meant the time had doubled than expected and because there are two of the same upper control arms in the front, it was counted in for actual time as well. To see the schedule, see Appendix E.

c. Testing

Fall: The sub assembly of the suspension and steering are essential to the testing of the impact and drop test of the RC car. The risks that can come up when testing the RC are that it is possible the components that are not as easily available can break. The components experiencing loads in the impact and drop tests are at the highest risk of breaking. This would set the project back and would need replacement parts to get back on track. See Appendix E for Gantt chart.

Spring: While testing the RC during the 2-foot drop, the RC experiences sudden forces from the impact causing the RC to break components. The first part to break were the threads in the initially 3d printed ball joint ends. The team replaced the 3D printed ball joint ends with the aluminum ball joint ends and the issue was resolved. The shock towers started to break after swapping the ball joint ends. The threaded inserts on the part did not fail, but the plastic that was melted around the threaded insert did. The entire shock tower was lifted from its place, while the threaded inserts remained in place. The RC required reprinting of the rear shock tower and fixing the front shock tower because the front shock tower was not as bad. When the test was conducted again for a real attempt, the team glued the shock towers in place using E6000 to prevent the same issue from happening again. This test was the most time consuming due to the pieces needing to be replaced. The test was attempted on two separate days. The RC broke on the first day. The successful test took 3 hours to complete because the RC needed repairs. See Appendix E for schedule of Gantt chart.

Testing of the turning radius was conducted without issue, but there were issues with getting it ready for testing. This delayed the testing date at first, but when it was resolved, it was conducted as soon as possible to meet deadlines. The issues were that the RC did not have enough torque from the motor to get it rolling from a stop. The RC needed to have the drivetrain modified from a 9:1 to a 12:1 ratio. This took time from the team to change out the gear and modify the motor placement because the center distance changes when the number of teeth on the gears change too. Changes to the procedure were necessary because for whatever reason, the RC was not able to drive forward, so the RC was driven in reverse. This is the original orientation for the brushed motor. After testing, the RC also had a new motor to replace the brushed motor. This helped manage the heat more and prevent as much warping since a brushed motor runs much hotter. Once the drivetrain modifications were made, the RC had no issue during testing. The only risk at the time was that the brushed motor would get hot and melt the 3D printed gears. This was not much of a problem because only 5 trails were recorded. The issues changed the original schedule of the test, but it gave more time to modify the procedure to fit better. See Appendix E for Gantt chart.

During the testing of the steering angle. There were initially issues with the protractor moving underneath the steering wheel. The issue was resolved by taping it down with blue tape. A few strips on both sides and on the straight edge were added. It was enough to hold down the protractor so that it would not move under the wheel while turning. While not an issue, the large wheels tilt more as the wheels are turned from equilibrium to full lock. The wheel tilt made it tricky to get an accurate measurement of the turning angle. This issue in the test can be resolved by getting smaller wheels because they will not tilt like the wheels currently on the RC device. The test did not take long to complete because only a few trials were recorded. The test only took 0.5 hour to complete measurements See Appendix E for Gantt chart

7. PROJECT MANAGEMENT

This engineering project is at risk of allocation of bought parts. The limited number of parts that can be used on the design of the RC makes it difficult to progress through the completion. In addition, the correct dimensions of the parts must also match the design. This makes it increasingly difficult because the parts do not always include dimensions, so further research is needed. This can be overcome by specifically searching for parts with the required dimensions online and if not possible, the parts will be acquired through another manner. Those methods being 3D printing and machining. This risk will be managed by keeping a list of the parts that need attention, the ones needing the most placed atop. The project will succeed in completion due to availability of parts and manufacturing methods.

a. Human Resources

The project is managed and foreseen by Rogelio Arroyos and Roberto Vieyra. Rogelio oversaw the steering and suspension of the RC, while Roberto worked on the chassis and drivetrain. See Appendix H for Rogelio's resume. The risks associated with being managed by two people is the availability of time. This is managed by setting times to meet.

b. Physical Resources

The physical resources required for the successful completion of the RC project are the utilization of the 3D printer, solder iron, and glue. The risks associated with the physical resources is the available time to print and slicing settings. This will affect the project because slicer settings determine the time it takes to print a part and how it was printed. The risks can be minimized by exploring the slicer settings and knowing what settings will be suitable for the application.

c. Soft Resources

The Cura STL file slicer and SOLIDWORKS 2023 are the main programs used for the project's completion. Without these programs, the project would need to be done differently. The risks associated with these programs are that the programs would have unplanned updates. Also access to these needs to be always available to not delay the project. Software crashes are also a significant risk and can be overcome by saving progress frequently. The other risks can be avoided by updating programs and making sure access to these applications is available.

d. Financial Resources

The project sponsors are Rogelio Arroyos and Roberto Vieyra. Most of the equipment is provided from personal tools, such as the 3D printer. If the budget is exceeded, better choices of parts could have been made to keep the budget below the maximum amount.

8. DISCUSSION

a. Design

The RC Baja car underwent several changes throughout fall due to availability of parts, risks, and design challenges faced. While attempting to meet deadlines, the parts were necessary to find and acquire because they are used to make accurate drawings. The 3d printed RC parts that are compatible with the purchased parts will be created from PLA+. Moreover, the RC must meet all the listed requirements in Section 1d (req 1d-1 to 1d-11).

The first drawings of the front and rear shock tower were redesigned multiple times to be simple and have mounting locations for the upper control arms and shocks. The parts needed to be reduced because it would be too much material to produce. Also, the parts were changed to have the mounting holes at the bottom, this would help maximize the space on the chassis for other components to fit. The front and rear shock towers are required to not deflect more than 0.1" according to requirements under Section 1d (1d-6), so changes were made to keep the requirement valid. Similarly, all the control arms were designed twice and are expected to be revised further to correct fitment. The deflection requirement of 0.1" is also applied to these components (1d-6). Many design changes were made to fit components, but also include function as intended. For example, attempts at 3D printing a drive gear and spur gear revealed a gear too large to mount that would have issues with transferring power so, bevel gears were the next best choice. The bevel gears were chosen to save space on the chassis and deliver power as intended. Printing the bevel gears was unsuccessful due to the complex geometry of the parts and size constraints. The printer failed each attempt at printing the bevel gears no matter what orientation it was printed on. After these two attempts, the plan changed to outsource the specified bevel gears from a manufacturer.

The RC is always at risk of components not fitting as expected so changes to one part will mean changes to an additional part. Once the purchased wheels arrived, measurements revealed fitting the wheels required redesigning of the control arms, which must not deflect more than 0.1." What is at risk in this instance is redesigning of the control arms may cause the requirement to be invalid if the new cross section or length are not appropriate. This will then cause a domino effect on the rest of the modeled parts it attaches to. Another risk associated with this is fasteners or hardware not fitting onto the purchased parts, so modifications or purchasing of new parts are solutions around this.

The initial choice of a spur and driver gear was unsuccessful because of the size of the gear required from the teeth count analysis. The unsuccessful attempt at printing the bevel gears could come from the precision of the nozzle of the 3D printer, flow rate, heat, retraction distance between layers, speed, or a combination of them all. This could be improved by spending time changing the settings and running tests. Attempts were successful in modifying placement of control arms and reducing the size of the shock towers because they were over engineered for the forces it will be withstanding.

Mostly all parts were redesigned to fit the new parts that were purchased. The lower control arms were redesigned to raise the ground clearance to 1.75" from 0.93." In addition, the rear upper control arms and the steering rods were redesigned to have ball joints implemented with M3 hardware like the front upper control arms.

b. Construction

The team did not change their method of construction or process but did change the design of some components to fit the components on the chassis (RCV-20-002). The chassis was lengthened and thinned so the components mounted in their original place needed to be adjusted to fit the new length and thickness of the chassis (RCV-20-002). This change in design led to the redesign of the lower control arms (RXA-20-003, RXA-20-005, RXA-20-007, RXA-20-011), upper control arms (RXA-20-006, RXA-20-008), shock towers(RXA-20-001, RXA-20-002), and creation of the mounts for the lower control arms (RXA-20-012, RXA-20-013). The issue when the chassis was redesigned was that the lower control arms would not have a place to mount into if the chassis were thinner than needed so a new part was modeled to mount the lower control arms to the chassis. This meant mounts needed to be made to attach to the chassis and the lower control arms together. While addressing this issue the model had many issues when assembling in SOLIDWORKS because it would attempt to keep other mates true at the same time. To get around this without affecting the other mates the team opted to fix the components in place instead of mating. See Appendix B for parts and assemblies in the treehouse.

Some risks needed to overcome were the risk of the printer malfunctioning during printing. Many examples of a malfunction would be if the printer accidentally crashed into the part, nozzle clogging, poor print quality, and thermal runaway. Assuring the printer is up to date with firmware and passes all calibration tests will mitigate the chances of the printer malfunctioning. Doing regular calibrations when expecting to use the printer constantly is a good habit as it would prevent the printer from crashing into the printed part and help with quality control. Over the winter break, a personal printer was subject to thermal runaway causing the thermistors in the heat bed and hot end extruder to go bad because of too much current being driven to the sensors. This required replacement of the parts and iteratively calibrating the printer until the first layer calibration at all points of the bed are tuned to the desired quality.

The things that were most successful in manufacturing were the diameter of the holes being just the right size to add heated inserts with a soldering iron. This is good because some components need threaded inserts added to allow assembly of the parts. The components that require modification are the front and rear lower control arms (RXA-20-003, RXA-20-005, RXA-20-007, RXA-20-011). These components had threaded inserts installed and held in with M3 hardware. This method of attaching the LCAs was more effective than just threading the screws into plastic because the components would be removed and installed various times. Some of the parts needed to be reprinted to accommodate wiring and the threaded inserts. For example, the servo motor mount (RXA-20-004) needed to be remodeled to allow fitting of the servo motor without interference from the wires. The holes including threaded inserts needed redesigning to fit correctly when adding them because before the holes were too large due to manufacturer putting the wrong diameter. For the fact the team has not received all ordered parts, it leaves the team to do what they must do to meet deadlines and adjust the part later when the component is in hand.

Some parts were modeled to exact measurements, which meant tight tolerances in joining parts and this would require slight modifications to the parts. For example, the rear lower control arms were dimensioned to the exact width of the knuckle and so it required filing. A new addition to the RC was the implementation of ball joints to the rear upper control arms with M3 hardware fixed using JBWeld plastic bond.

c. Testing

During testing, the issues that arose related to the RC were that the 3d printed ball joint ends on the front lower control arms would shear off the threads because the PLA+ material was too weak to withstand the tensile force experienced when dropped from 2ft. This issue was resolved by replacing the 3D printed ball joint ends with 6061 aluminum ball joint ends. After changing the components, the RC deflected to an average of 3.7 cm in the front view and deflected 3.14 cm in the side view. The RC's weight is not uniform so when it was dropped the RC wheels did not contact the ground all at once, instead the front section was slammed down because due to human error the RC was not dropped so that the wheels hit all at once. If the RC were uniform in weight, the RC would have a better chance landing on all four wheels. In addition, the initial predicted value was not suited for this test because the test does not assume the components are simply supported. A new predicted value was calculated that was much more representative than the last, but there were still issues because the calculations assumed the RC was able to rebound to its initial height when that is not the case. Therefore, the calculations needed to be redone considering the coefficient of restitution and other related energy losses. A slight change to the procedure was needed when the tape measurer was not able to be readable from the back of the RC, so it was moved to the front and changes were made accordingly. Although the test predictions did not accurately represent the test results, the RC showed it was able to withstand the 2ft drop repeatedly through the 12 trials. The test can be improved if further dynamics assumptions in the analysis were considered. The deflection equation predicted 1.4 in or 3.6 cm, while the RC showed it deflected 3.7 cm in the front and deflected 3.14 cm. The issues discussed are factors that play a key role in the RC's deflection from the 2-foot drop and can be mitigated by paying more attention to these areas. It was also necessary to know if the adhesive E6000 glue would fail.

Between testing, the teams experimented with the RC's motor because the initial motor would not produce enough torque for the RC to move from a stop. The drive train was modified and so testing deadlines would be a motivation to complete the drivetrain modifications. Once changed from a 6:1 to a 9:1 ratio, it performed better in acceleration from the start. This would affect the turning radius test results for the RC because before the RC did not have enough torque to get it moving from a stop and accelerating around a turn. The test was performed with the 9:1 ratio and did not have issues with the RC device performing the test. The initially installed brushed motor did not work when rotating CW, which makes the RC move forward. To work around this issue, the RC was placed with the rear wheels on the starting line and driven in reverse. The simple things to improve this would require modifications to the RC's control arms and size of wheels. The procedure was updated for the modifications to the motor not being able to spin CW. Once the motor was swapped from a brushed to a brushless motor, it was an overall vast improvement in torque and acceleration at lower rpms. In addition, to performance gains, the motor does not overheat as easily. It was apparent that the RC did not reach the requirement of under 4 feet of turning radius and a predicted turning radius of 2 feet. The test showed an average value of 4.31 ft in turning radius. The deliverables in this test are to test the turning radius and its ability to turn full lock to make tight turns during the competitions. This will determine how well the RC will perform and will reflect its overall placement on the scoring board. See table G5 in Appendix G2.4 for results of the turning radius test.

In the final test of the steering angle, the RC was not experiencing any issues related to the test. The RC demonstrated a turning angle of 29 degrees at most to the left and 35 degrees at most to the right. The predicted value of 25.7 degrees was exceeded and that can be due to the wheel tilt of the 7-inch wheels causing inaccuracy in the angle. The requirement of 60 degrees was not reached because the design of the lower control arms would interfere with the knuckles, limiting it from turning more. The RC steering angle results can be improved if the team redesigned the suspension components and purchased smaller wheels, even possibly changing the steering knuckles.

9. CONCLUSION

a. Design

The entire project is on the creation and construction of the RC BAJA that will be used in the senior RC BAJA competitions in Spring. The necessary resources to construct this RC project are purchased by the students leading the project and acquired from selected companies (ex. Esun, Ultimaker). The modeled components are 3d printed in-house to reduce cost of printing but will be considering the cost by weight of the print. All the printing should be easy-going and only dependent on the time to print, quality and modeling. This project was done on the steering and suspension of the RC, partnered with Roberto Vieyra, who is responsible for the chassis and drivetrain. The steering provides the user of the RC with directional control of a 60-degree range (req 1d-1) and the suspension absorbs irregularities in the terrain to keep the vehicle stable.

The RC is required to withstand a drop from 2ft as listed in 1d-6. In analysis #1, the RC chassis was assumed to be 5lbm and made of PLA+. The RC is required to weigh no more than 10lbs as listed in requirement 1d-4 & 1d-10. When dropped from 2ft, the reaction at all four wheels would be 31.95lbf. This value was then used to find the force reaction of 67.7lbf along the shock. The methods used in this analysis consisted of spring force, sum of forces, and sum of moments to find 67.7lbf. Knowing that the RC will be experiencing 67.7lbf to the shock towers, means the shock towers must be the right dimensions to also not deflect 0.1" (req 1d-9).

The 67.7lbf is commonly used throughout the analyses because it is the reaction force acting onto the shock towers. For example, 67.7lbf was used in analysis #3 to determine a cross section that would not deflect more than 0.1" (req 1d-9) and will not exceed its max bending stress of 10732.8 psi. Using the bending stress equation and deflection equations, the analysis revealed the initial cross section will deflect greater than 0.1," so a new cross section of .75" x .5" determined a deflection of 0.029" and bending stress of 6592 psi.

In analysis #9, a front impact analysis at 30 mph is done to determine if the control arm will deform and deflect more than 0.1" (req 1d-8 & 1d-9). Using the given material properties of PLA+ and the impact force of 4382.4lbf, this information is used to find the deflection and bending stress of the control arm. Sum of the forces and sum of the moments were used to find reactions on the control arm from the impact and then used in the bending stress equation to find the stress it experiences. When comparing the max and calculated value of bending stress, the control arm experiences a stress of 2208ksi while the max bending stress is 10733ksi. The part is to deflect only .00013" when bending around the y-axis.

The RC analyses adhere to requirements listed in section 1d, including using engineering merit to conclude. The RC requires a 3d printer to build the chassis and components that mount to it. The resources are found readily online and printed with personal printers. The design is ready when components are finalized in their positions on the CAD assembly. When revised and checked multiple times for interferences, the parts would be ready to print and then assembling would be the last thing before testing. For the RC to be successful, it must meet the requirements listed in section 1d, pass the testing phase, and complete the spring competition event without breaking.

b. Construction

The team's goal was to manufacture a mostly 3D printed RC monster truck with the design requirements listed in section 1d. The team wanted to build an AWD RC, but for simplicity the team decided to do 2WD. The RC has implemented a double wishbone style suspension system. The steering will also only be controlling the two front wheels, but the team did consider adding a 4-Wheel steering system. Adding more would have only made the RC bigger and heavier than it is now and can potentially disqualify it for an event.

The lower control arms underwent 4 designs and manufactured 3 over the winter quarter. The Upper control arms were designed 3 times and manufactured 2 times. The rest of the components were redesigned up to 3 times, but no less than 2 times. The final designs were not ready to be printed until the team was satisfied with the placement and fitment of the component. The front lower control arms were too stiff using the initial design when steering, then were too loose with the purchased ball joint ends because the hardware had no place to thread into. To resolve the issue, printed manufactured ball joint ends were used in place, demonstrated desired results, and had a place to thread into to hold the components together.

The team avoided making any permanent modifications to purchased components as much as possible, but only modifications to purchase components are related to the drivetrain. The suspension and steering were made of 3D printed PLA+ and hardware held together with threaded inserts installed using a soldering iron. Also, a JBWeld plastic- to-metal bonder was used to secure the M3 hardware permanently in place. Where spacers could not be used, nuts were threaded on to space out components.

In the end, the team made a presentable prototype of the RC with functioning forward, reverse, and directional control. Although very tedious and frustrating designing and manufacturing, it is satisfying to see it work.

c. Testing

10. ACKNOWLEDGEMENTS

Professor Charles Pringle and Professor John Choi mentored and guided the project. With their help, the project was overseen by someone who has experience in the industry and knows what to expect in a proposal for a project. Furthermore, they assisted and got more involved as the project progressed. In addition, Professor Furman helped provide advice on improving the contact between the spur gear and pinion gear. The team struggled the most with this because the 3D printed gears stripped each other.

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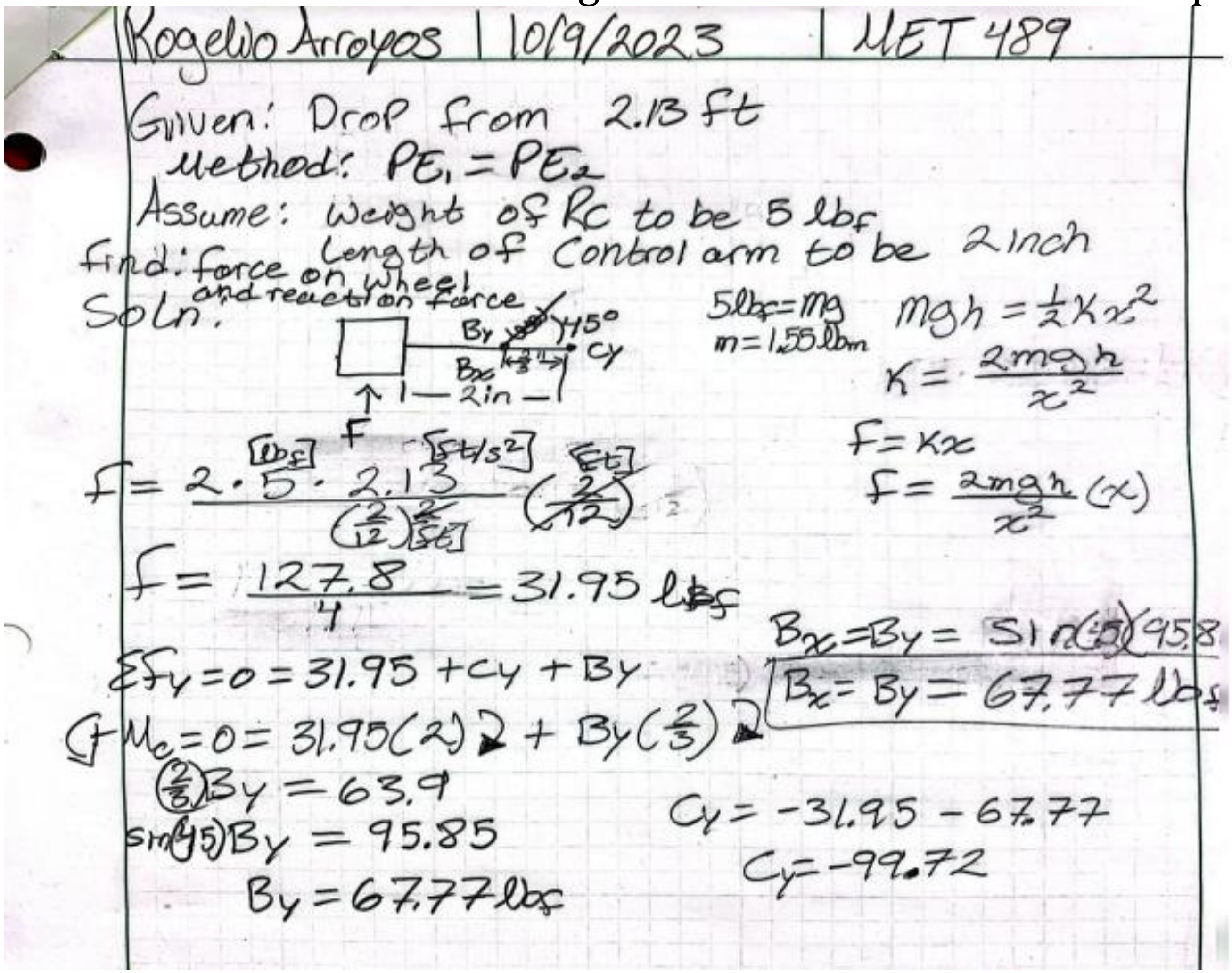
APPENDIX A01– Force acting on the shock from a 2.13ft drop


Rogelio Arroyos | 10/9/2023 | MET 489

Given: Drop from 2.13 ft

Method: $PE_1 = PE_2$

Assume: Weight of RC to be 5 lbf

Length of Control arm to be 2 inch

Find: force on wheel and reaction force

Soln:

$5\,lbf = mg$

$m = 1.55\,lbm$

$mgh = \frac{1}{2}Kx^2$

$K = \frac{2mgh}{x^2}$

$F = Kx$

$F = \frac{2mgh}{x^2}(x)$

$F = \frac{2 \cdot 5 \cdot 2.13}{(\frac{2}{12})^2}\left(\frac{2}{12}\right)$ [lbf] [ft/s²] [ft]

$F = \frac{127.8}{4} = 31.95\,lbf$

$\Sigma F_y = 0 = 31.95 + C_y + B_y$

$\Sigma M_c = 0 = 31.95(2) + B_y(\frac{2}{3})$

$(\frac{2}{3})B_y = 63.9$

$\sin(45)B_y = 95.85$

$B_y = 67.77\,lbf$

$B_x = B_y = \sin(45)(95.85)$

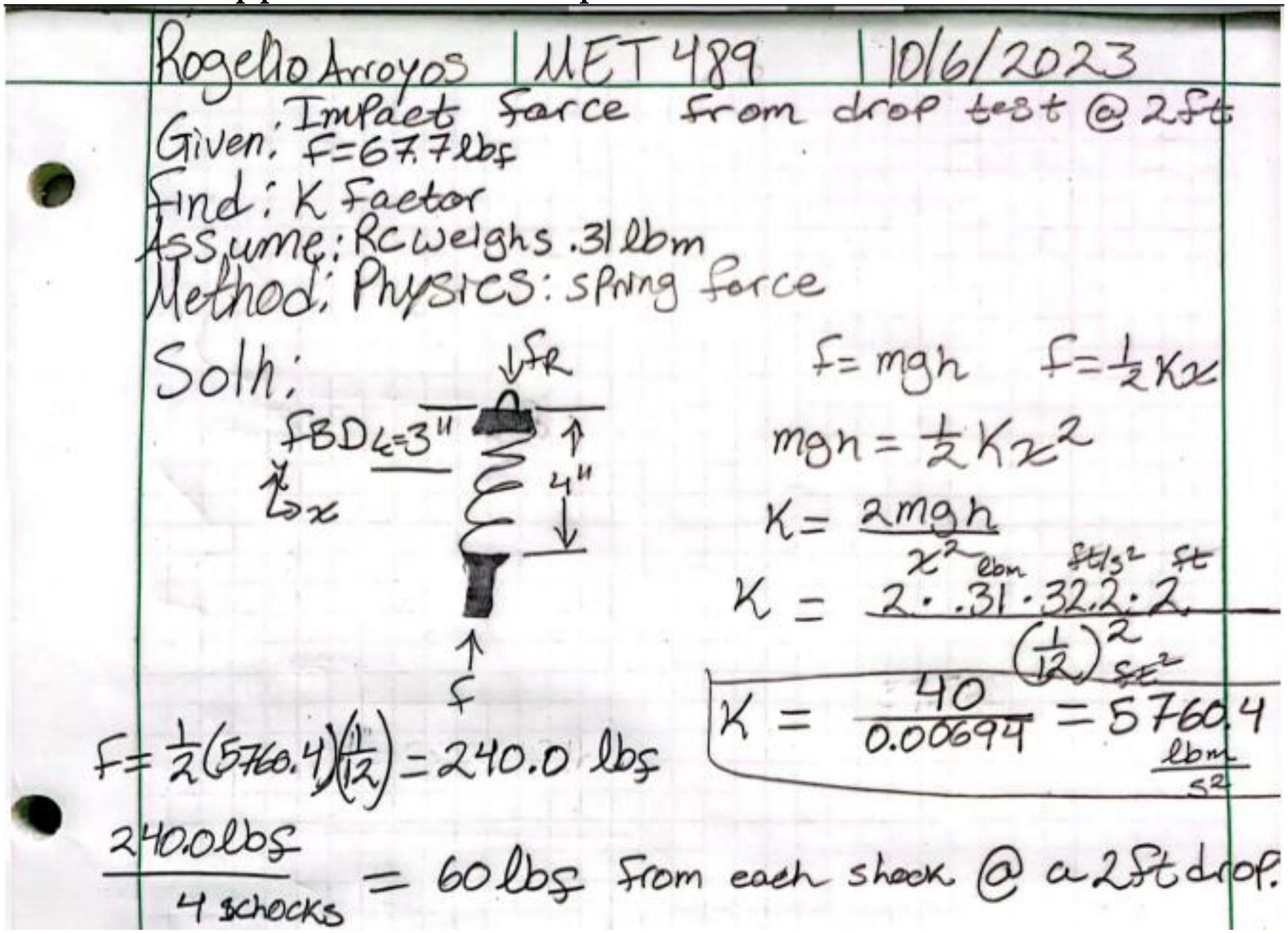
$B_x = B_y = 67.77\,lbf$

$C_y = -31.95 - 67.77$

$C_y = -99.72$

Figure A01- Analysis of force acting on the wheel from a 2.13ft and the reaction forces of that load on the shock lower mount location.

Appendix A02 – Suspension travel and K factor



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Given: Impact force from drop test @ 2ft
$F = 67.7\ lbf$

Find: K Factor

Assume: RC weighs .31 lbm

Method: Physics: spring force

Soln:

FBD L=3" 4"

$F = mgh \quad F = \frac{1}{2}Kx$

$mgh = \frac{1}{2}Kx^2$

$K = \frac{2mgh}{x^2}$

$K = \frac{2 \cdot .31 \cdot 32.2 \cdot 2}{\left(\frac{1}{12}\right)^2}$

$K = \frac{40}{0.00694} = 5760.4\ \frac{lbm}{s^2}$

$F = \frac{1}{2}(5760.4)\left(\frac{1}{12}\right) = 240.0\ lbf$

$\frac{240.0\ lbf}{4\ shocks} = 60\ lbf$ from each shock @ a 2ft drop.

Figure A02- Analysis of suspension travel and required k factor of a 4” spring that does not compress more than 1”.

Appendix A03 – Finding width and deflection of sectioned shock tower

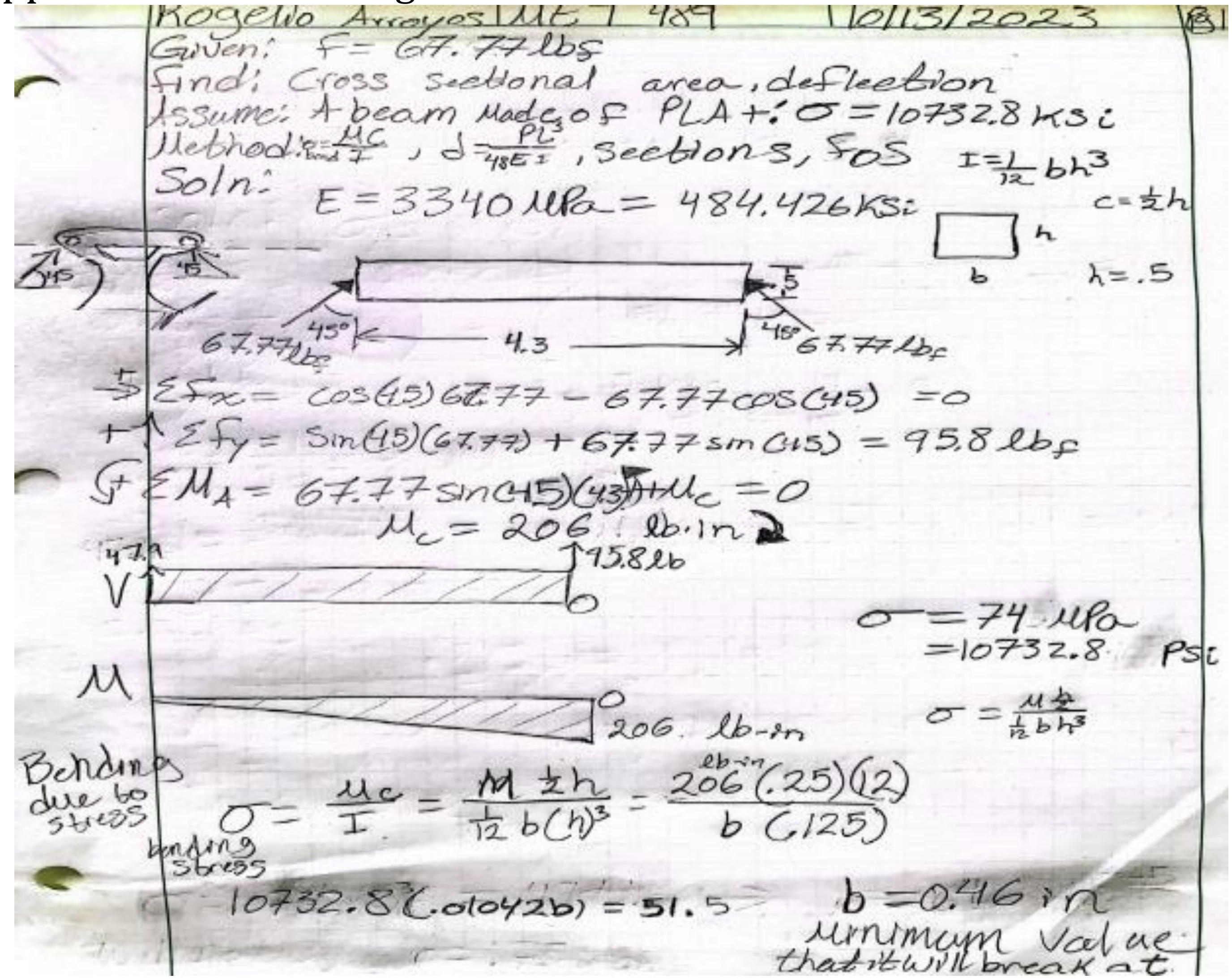
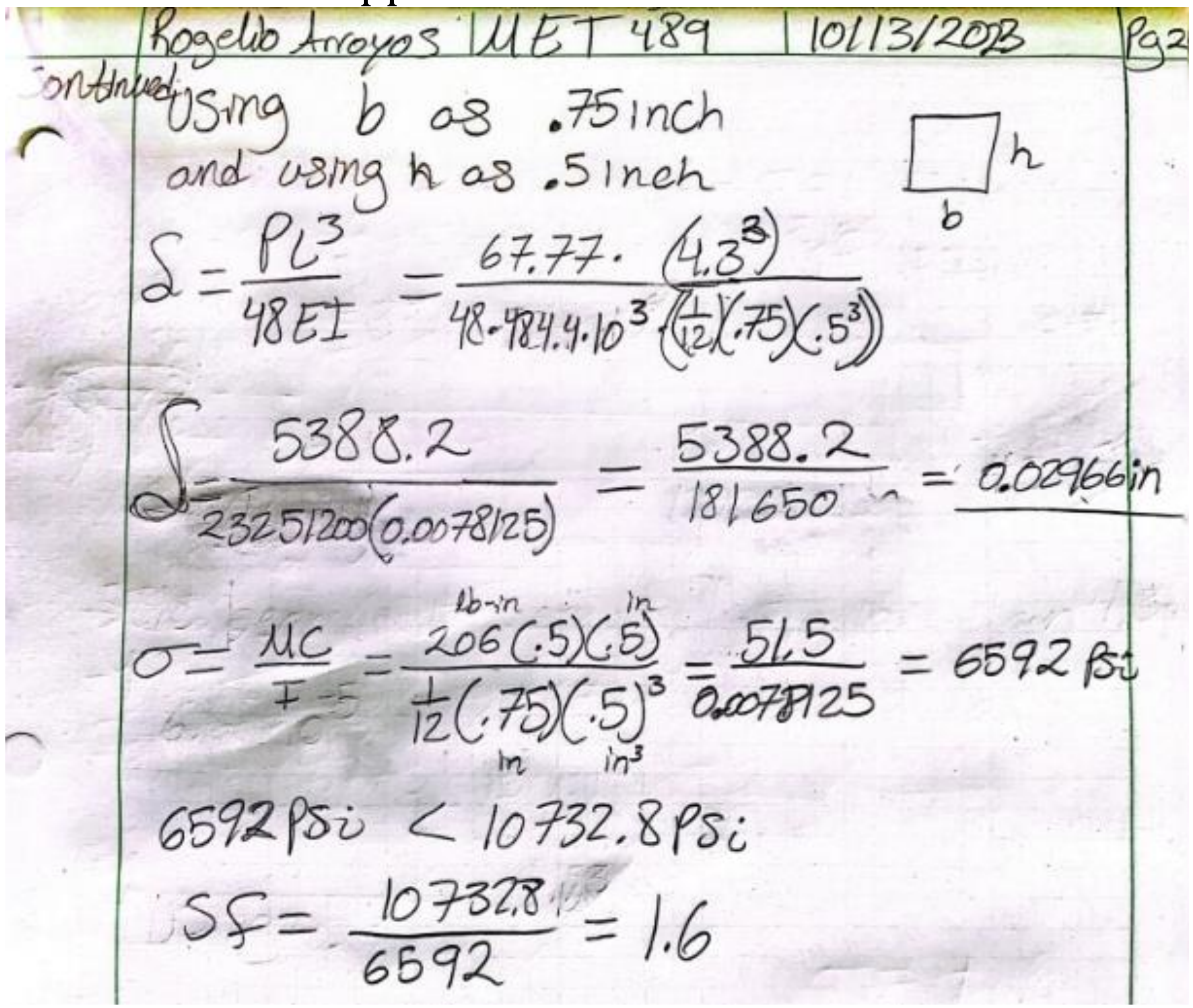


Figure A03.1- This analysis is done to find the cross section of the shock tower.

Appendix A03 – Continued



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Continued: using b as .75 inch
and using h as .5 inch

$$\delta = \frac{PL^3}{48EI} = \frac{67.77 \cdot (4.3^3)}{48 \cdot 484.4 \cdot 10^3 \left(\left(\frac{1}{12}\right)(.75)(.5^3)\right)}$$

$$\delta = \frac{5388.2}{23251200(0.0078125)} = \frac{5388.2}{181650} = 0.02966 \text{ in}$$

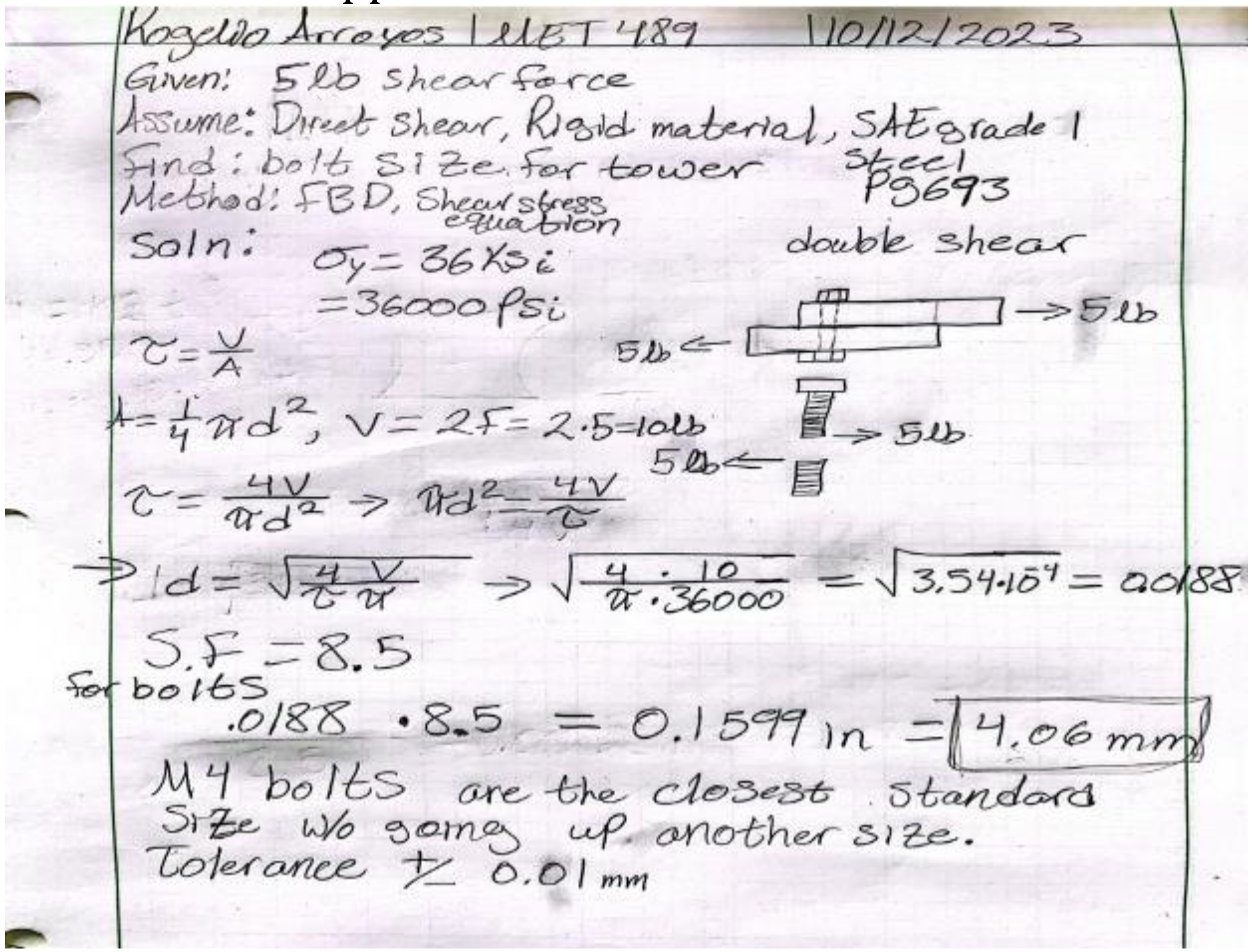
$$\sigma = \frac{Mc}{I} = \frac{206(.5)(.5)}{\frac{1}{12}(.75)(.5)^3} = \frac{51.5}{0.0078125} = 6592 \text{ psi}$$

6592 psi < 10732.8 psi

$$SF = \frac{10732.8}{6592} = 1.6$$

Figure A03.2- continuation of figure A03 to find deflection.

Appendix A04 – Hardware size



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Given: 5 lb shear force

Assume: Direct shear, Rigid material, SAE grade 1 steel pg 693

Find: bolt size for tower

Method: FBD, Shear stress equation

Soln: $\sigma_y = 36\ ksi$ $= 36000\ psi$

double shear

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

$A = \frac{1}{4}\pi d^2$, $V = 2F = 2 \cdot 5 = 10\ lb$

$\tau = \frac{4V}{\pi d^2} \rightarrow \pi d^2 = \frac{4V}{\tau}$

$\rightarrow d = \sqrt{\frac{4V}{\tau \pi}} \rightarrow \sqrt{\frac{4 \cdot 10}{\pi \cdot 36000}} = \sqrt{3.54 \cdot 10^{-4}} = 0.0188$

S.F = 8.5 for bolts

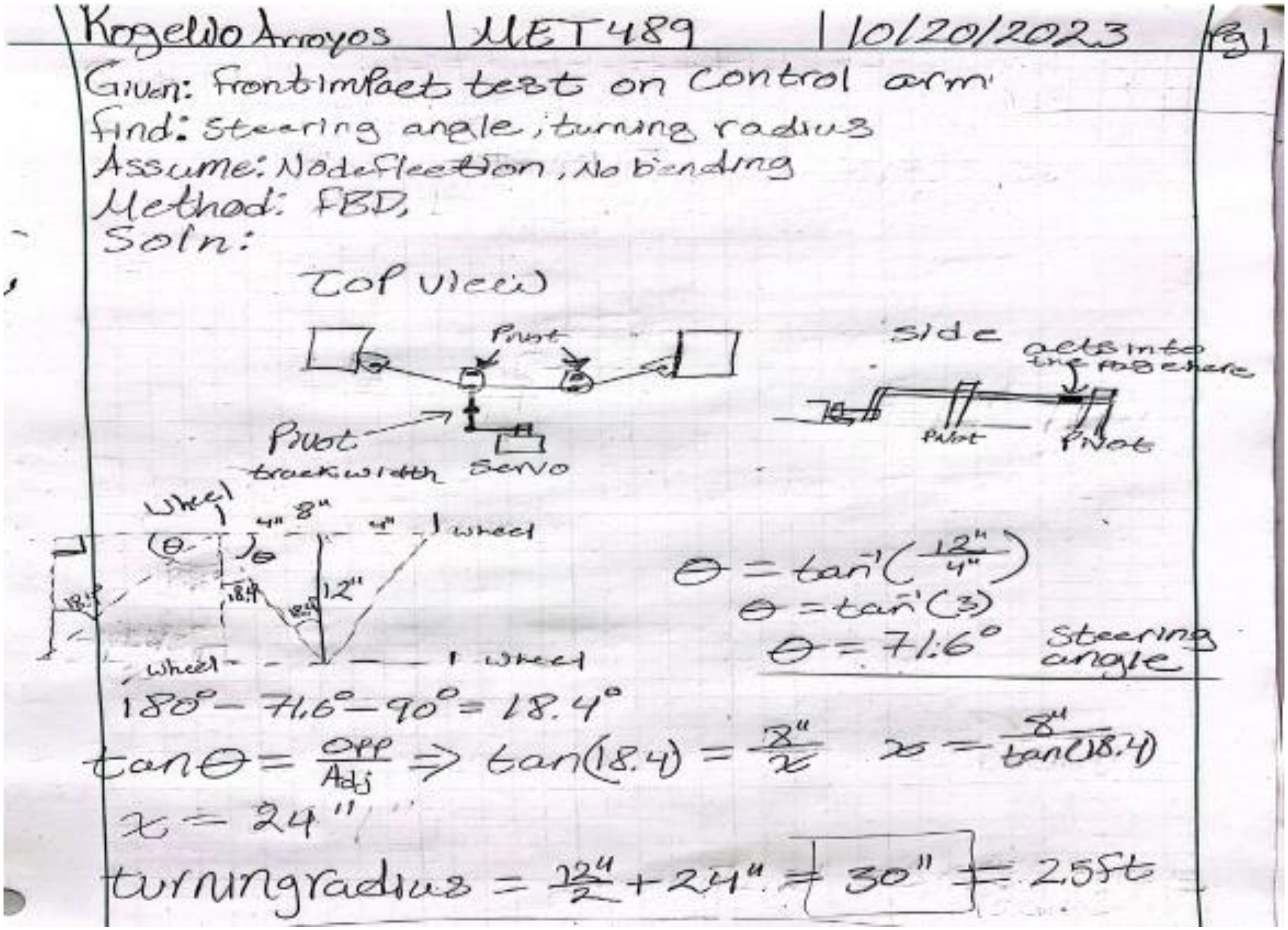
$.0188 \cdot 8.5 = 0.1599\ in = 4.06\ mm$

M4 bolts are the closest standard size w/o going up another size.

Tolerance +/- 0.01 mm

Figure A04- Analysis done on figuring out what the bolt size should be to hold the shock tower to the chassis.

Appendix A05 – Steering angle and turning radius



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Given: front impact test on control arm

Find: steering angle, turning radius

Assume: No deflection, No bending

Method: FBD

Soln:

$\theta = \tan^{-1}\left(\frac{12''}{4''}\right)$

$\theta = \tan^{-1}(3)$

$\theta = 71.6°$ Steering angle

$180° - 71.6° - 90° = 18.4°$

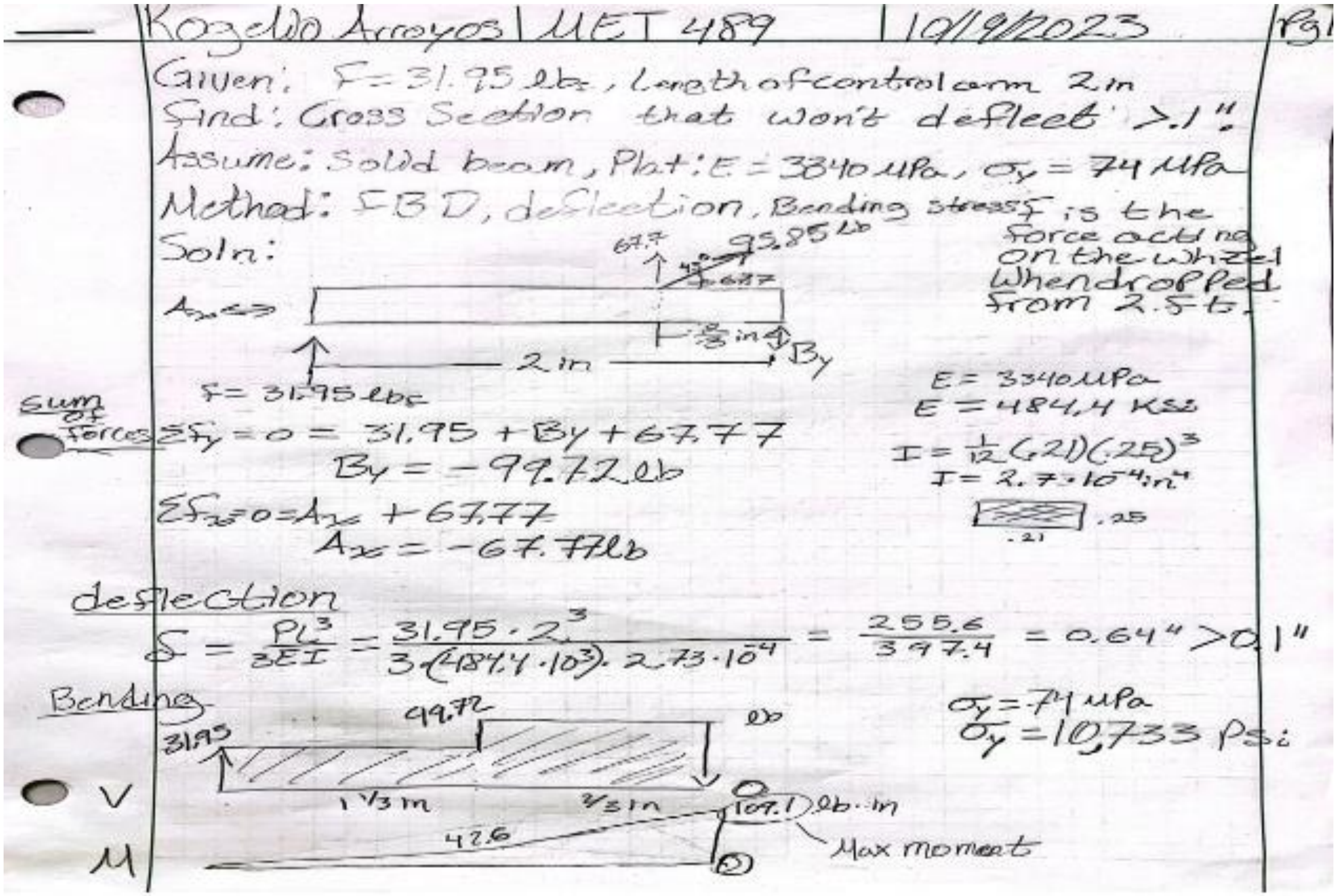
$\tan\theta = \frac{Opp}{Adj} \Rightarrow \tan(18.4) = \frac{8''}{x}$ $\quad x = \frac{8''}{\tan(18.4)}$

$x = 24''$

turning radius $= \frac{12''}{2} + 24'' = 30'' = 2.5ft$

Figure A05- Analysis of the steering angle of the RC and as well as the turning radius.

Appendix A06 – Lower control arm



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Given: F = 31.95 lbs, Length of control arm 2 in

Find: Cross Section that won't deflect > .1"

Assume: Solid beam, Plat: E = 3340 MPa, σ_y = 74 MPa

Method: FBD, deflection, Bending stress F is the force acting on the wheel when dropped from 2.5 ft.

Soln:

sum of forces $\Sigma F_y = 0 = 31.95 + B_y + 67.77$

$B_y = -99.72$ lb

$\Sigma F_x = 0 = A_x + 67.77$

$A_x = -67.77$ lb

E = 3340 MPa

E = 484.4 ksi

$I = \frac{1}{12}(.21)(.25)^3$

$I = 2.7 \cdot 10^{-4}$ in⁴

deflection

$\delta = \frac{PL^3}{3EI} = \frac{31.95 \cdot 2^3}{3(484.4 \cdot 10^3) \cdot 2.73 \cdot 10^{-4}} = \frac{255.6}{397.4} = 0.64" > 0.1"$

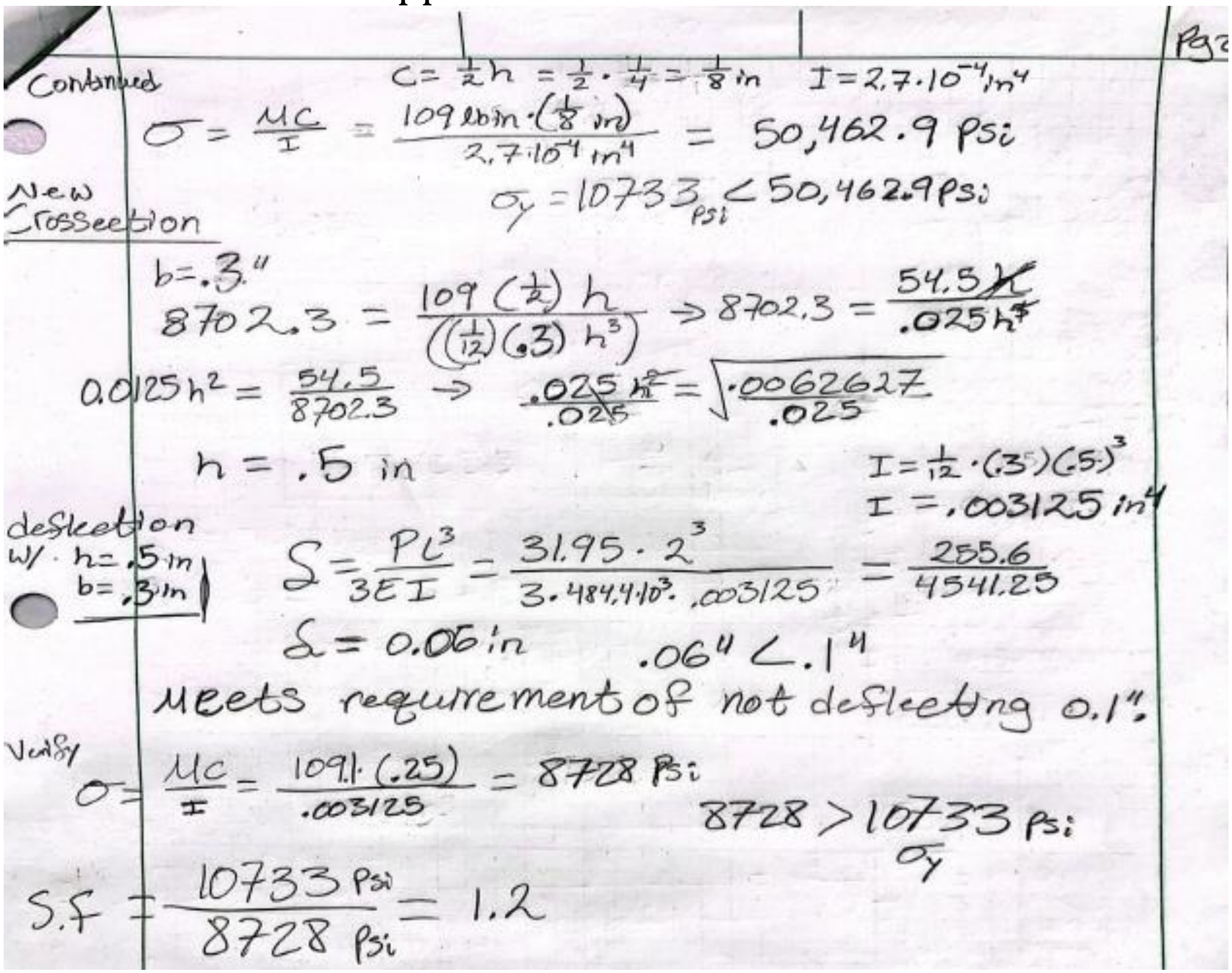
Bending

σ_y = 74 MPa

σ_y = 10,733 Psi

Figure A06.1- Analysis of the lower control arm assuming it to be a solid beam.

Appendix A06 – Continued



Continued

$c = \frac{1}{2}h = \frac{1}{2}\cdot\frac{1}{4} = \frac{1}{8}\,in \qquad I = 2.7\cdot10^{-4}\,in^4$

$\sigma = \frac{Mc}{I} = \frac{109\,lbin\cdot(\frac{1}{8}\,in)}{2.7\cdot10^{-4}\,in^4} = 50{,}462.9\ psi$

New Crossection

$\sigma_y = 10733_{psi} < 50{,}462.9\,psi$

$b = .3''$

$8702.3 = \frac{109\,(\frac{1}{2})\,h}{((\frac{1}{12})(.3)\,h^3)} \rightarrow 8702.3 = \frac{54.5}{.025h^2}$

$0.0125h^2 = \frac{54.5}{8702.3} \rightarrow \frac{.025\,h^2}{.025} = \sqrt{\frac{.0062627}{.025}}$

$h = .5\ in$

$I = \frac{1}{12}\cdot(.3)(.5)^3$

$I = .003125\ in^4$

deflection w/ h = .5 in, b = .3 in

$\delta = \frac{PL^3}{3EI} = \frac{31.95\cdot2^3}{3\cdot484.4\cdot10^3\cdot.003125} = \frac{255.6}{4541.25}$

$\delta = 0.06\,in \qquad .06'' < .1''$

Meets requirement of not deflecting 0.1".

Verify

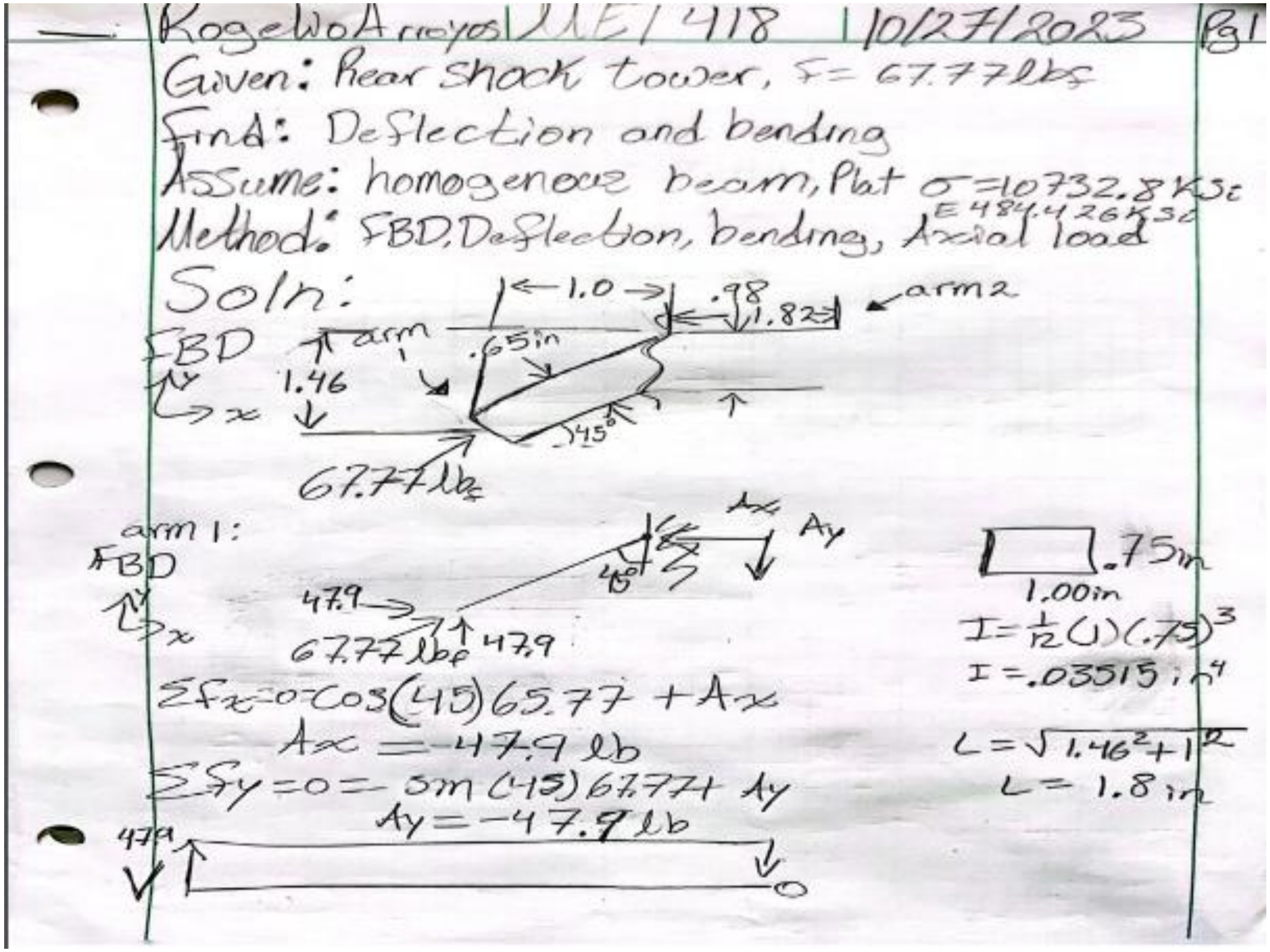
$\sigma = \frac{Mc}{I} = \frac{109.1\cdot(.25)}{.003125} = 8728\ psi$

$8728 > 10733\ psi\ (\sigma_y)$

$S.F = \frac{10733\,psi}{8728\,psi} = 1.2$

Figure A06.2- Continuation of Figure

Appendix A07 – Rear tower shock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Given: Rear shock tower, F = 67.77 lbs

Find: Deflection and bending

Assume: homogeneous beam, Flat σ = 10732.8 ksi, E 484.426 ksi

Method: FBD, Deflection, bending, Axial load

Soln:

$I = \frac{1}{12}(1)(.75)^3$

$I = .03515\ in^4$

$\Sigma F_x = 0 = \cos(45)\,65.77 + A_x$

$A_x = -47.9\ lb$

$\Sigma F_y = 0 = \sin(45)\,67.77 + A_y$

$A_y = -47.9\ lb$

$L = \sqrt{1.46^2 + 1^2}$

$L = 1.8\ in$

Figure A07.1- Rear tower shock analysis.

Appendix A07 – Continued

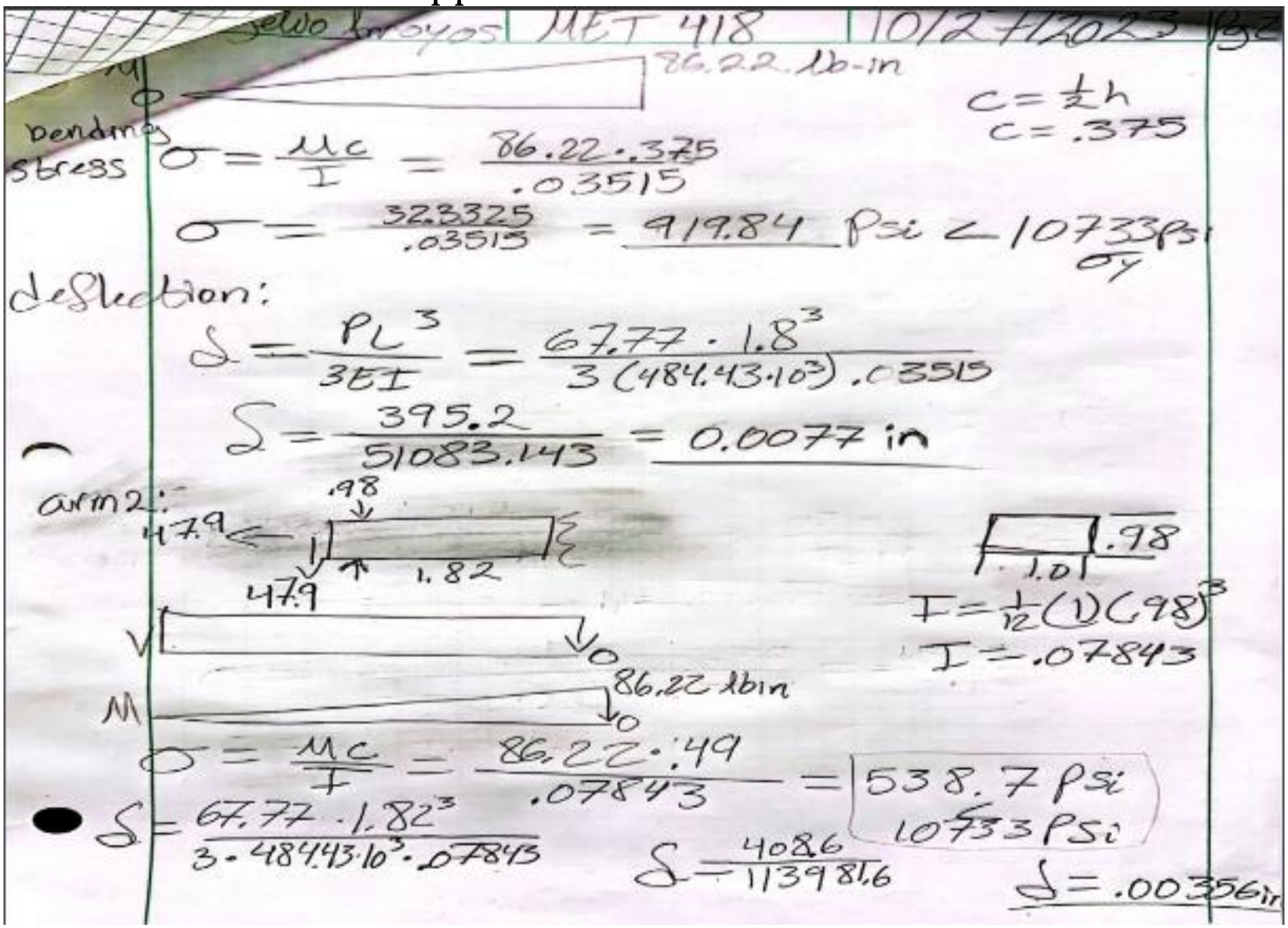
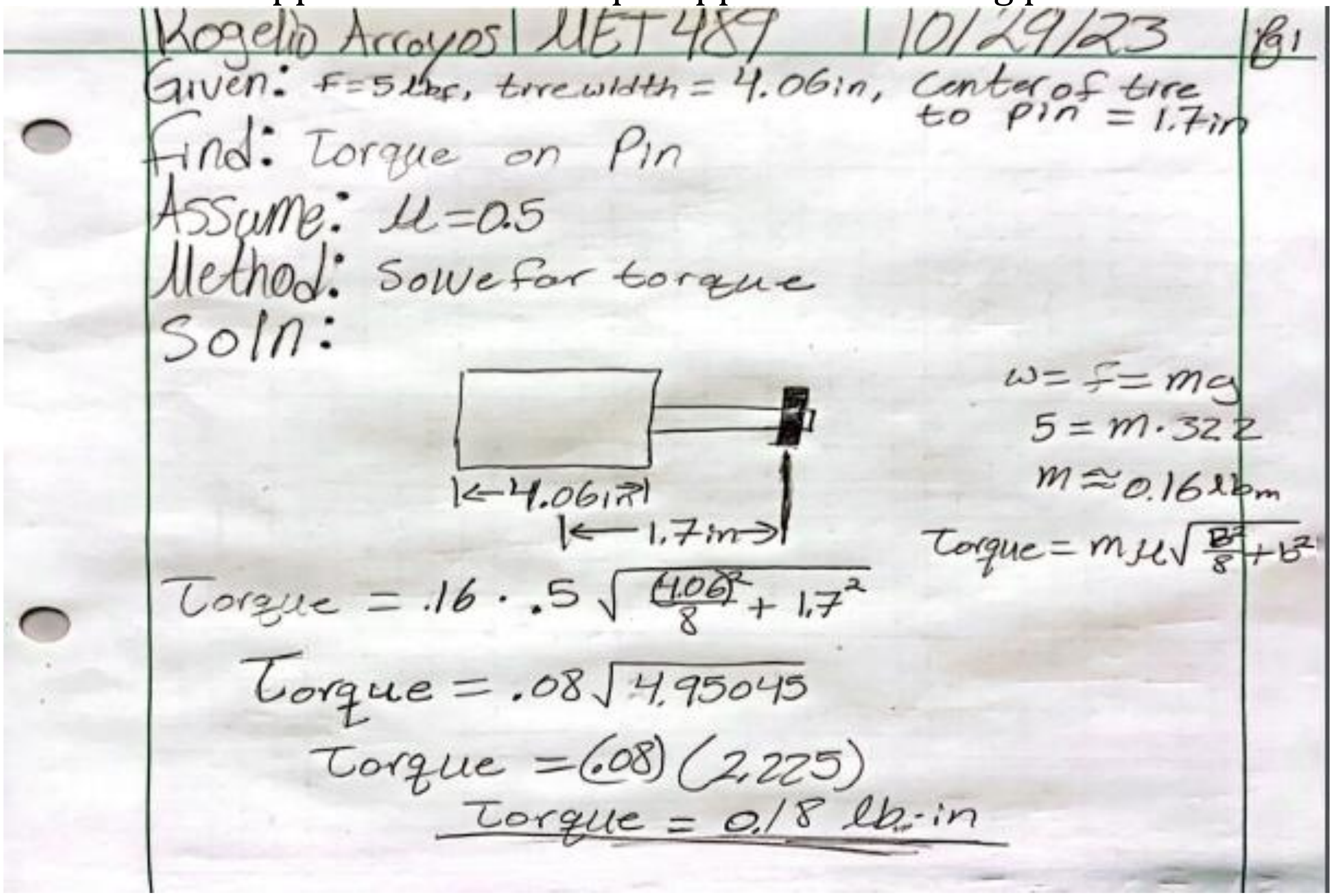


Figure A07.2- Continuation of Figure A07.1.

Appendix A08 – Torque applied on steering pin.



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Given: F = 5 lbf, tire width = 4.06 in, Center of tire to pin = 1.7 in

Find: Torque on Pin

Assume: $\mu = 0.5$

Method: Solve for torque

Soln:

$|\leftarrow 4.06 \text{ in} \rightarrow|$

$|\leftarrow 1.7 \text{ in} \rightarrow|$

$w = f = mg$

$5 = m \cdot 32.2$

$m \approx 0.16 \text{ lb}_m$

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

$$\text{Torque} = .16 \cdot .5 \sqrt{\frac{(4.06)^2}{8} + 1.7^2}$$

$$\text{Torque} = .08 \sqrt{4.95045}$$

$$\text{Torque} = (.08)(2.225)$$

$$\underline{\text{Torque} = 0.18 \text{ lb-in}}$$

Figure A08- Torque analysis on steering pin.

Appendix A09 – Impact analysis on upper control arm

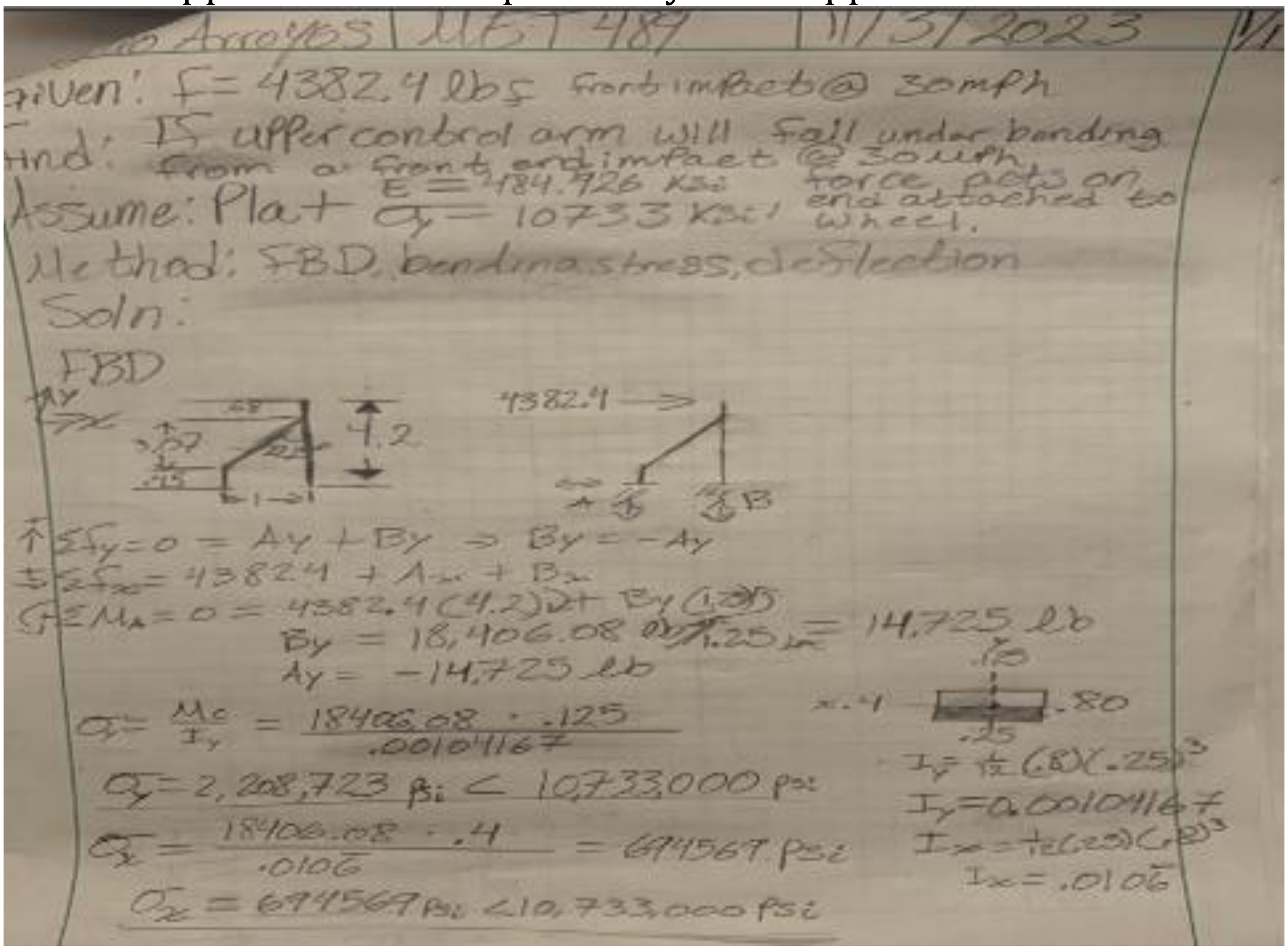
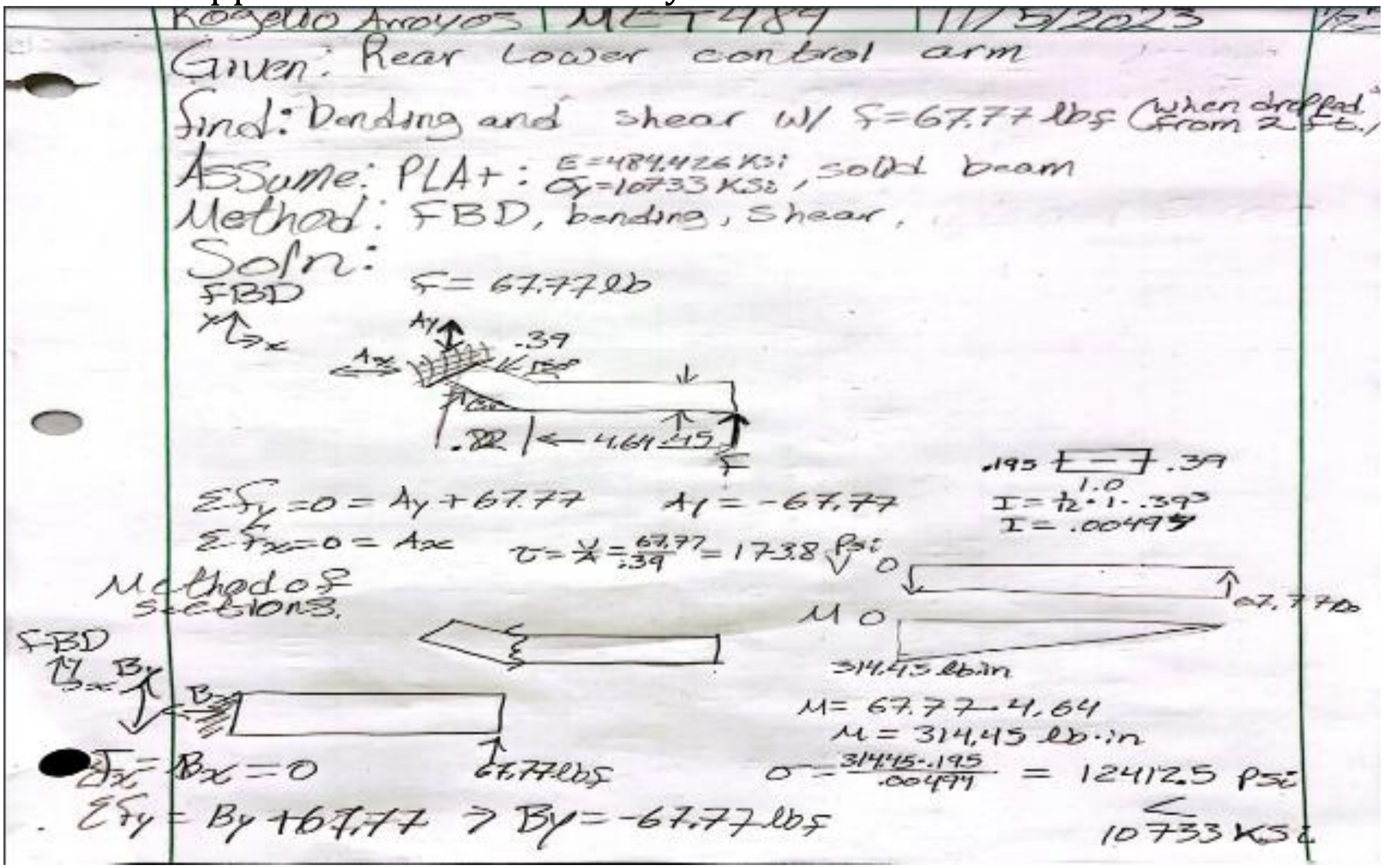


Figure A09- Impact analysis based on force of the RC hitting a wall at full speed.

Appendix A10 – Stress analysis on rear lower control arm



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Given: Rear Lower control arm

Find: Bending and shear w/ F=67.77 lbs (when dropped from 2 ft.)

Assume: PLA+ : E=484,426 KSI, σ_y=10733 KSI, solid beam

Method: FBD, bending, Shear,

Soln:

FBD F= 67.77 lb

.39 .22 4.64 .15

.195 .39 1.0

$\Sigma F_y = 0 = A_y + 67.77$ $A_y = -67.77$

$\Sigma F_x = 0 = A_x$

$I = \frac{1}{12} \cdot 1 \cdot .39^3$

$I = .00494$

$\tau = \frac{V}{A} = \frac{67.77}{.39} = 173.8$ psi

Method of Sections,

V 0 67.77 lb

M 0 314.45 lb.in

FBD B_y B_x

$\Sigma F_x = B_x = 0$ 67.77 lbs

$\Sigma F_y = B_y + 67.77 \Rightarrow B_y = -67.77$ lbs

$M = 67.77 \cdot 4.64$

$M = 314.45$ lb$\cdot$in

$\sigma = \frac{314.45 \cdot .195}{.00494} = 12412.5$ psi $\leq$ 10733 KSI

Figure A10.1- Drop test analysis on the rear lower control arm.

Appendix A10 – Continued

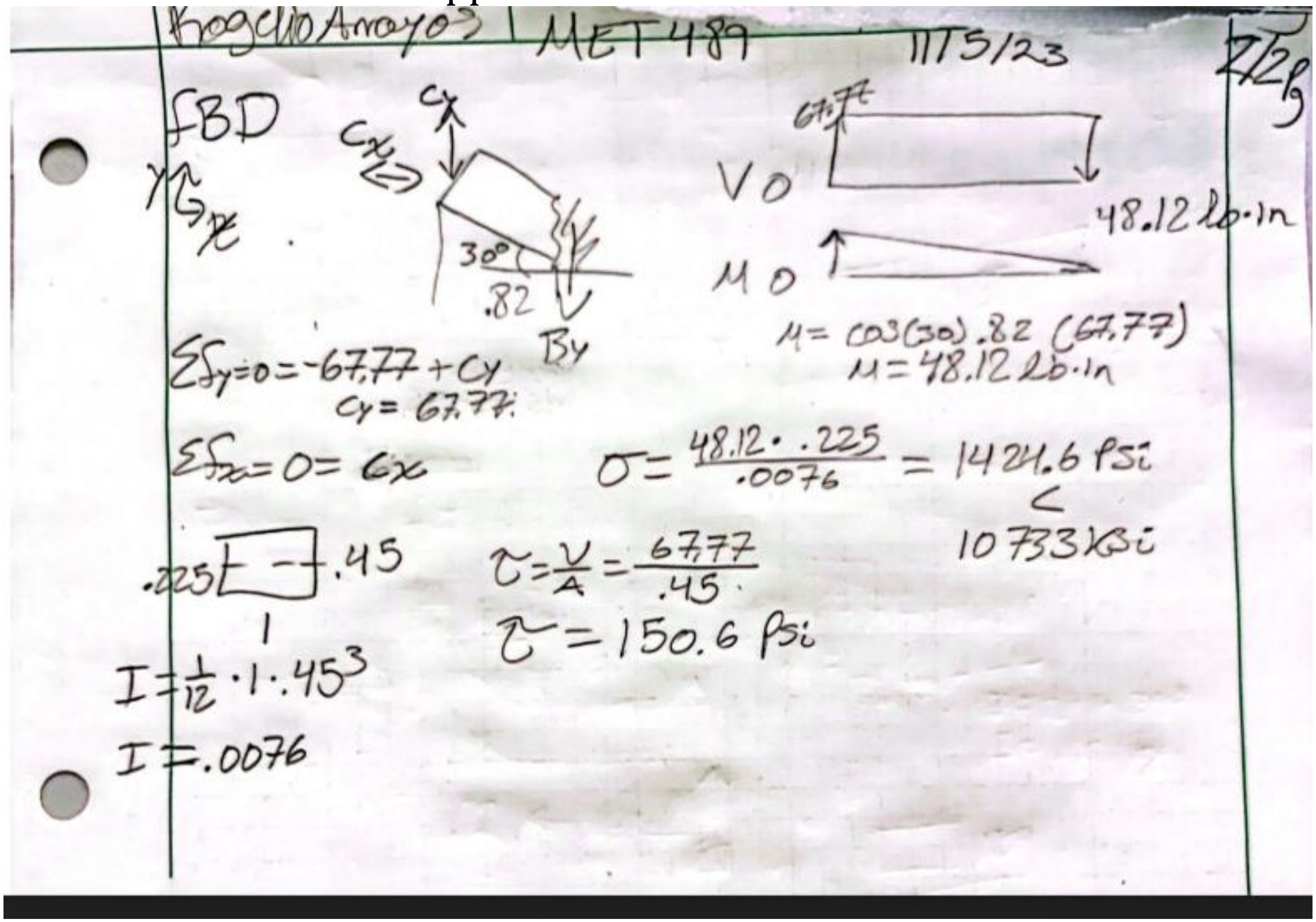
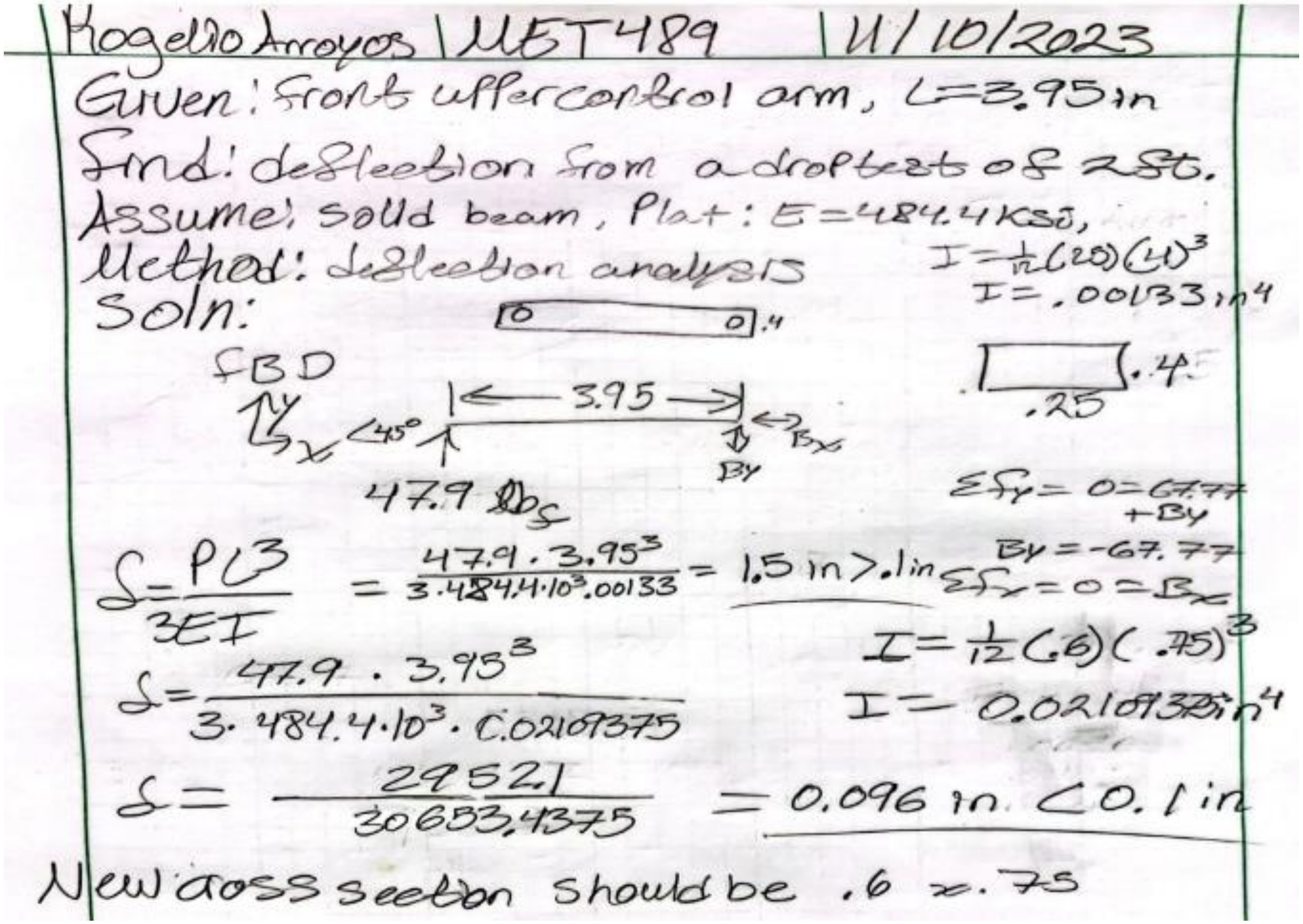


Figure A10.2- Continued.

Appendix A11 – Front upper control arm deflection analysis



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Given: Front upper control arm, $L = 3.95$ in

Find: deflection from a drop test of 2 ft.

Assume: solid beam, Plat: $E = 484.4$ ksi,

Method: deflection analysis

Soln:

$I = \frac{1}{12}(.25)(.4)^3$

$I = .00133\ in^4$

FBD

3.95

$< 45°$

B_x

B_y

47.9 lbs

$\Sigma F_y = 0 = 67.77 + B_y$

$B_y = -67.77$

$\Sigma F_x = 0 = B_x$

$$\delta = \frac{PL^3}{3EI} = \frac{47.9 \cdot 3.95^3}{3 \cdot 484.4 \cdot 10^3 \cdot .00133} = 1.5\ in > .1\ in$$

$I = \frac{1}{12}(.6)(.75)^3$

$I = 0.02109375\ in^4$

$$\delta = \frac{47.9 \cdot 3.95^3}{3 \cdot 484.4 \cdot 10^3 \cdot 0.02109375}$$

$$\delta = \frac{2952.1}{30653.4375} = 0.096\ in < 0.1\ in$$

New cross section should be .6 x .75

Figure A11- Deflection analysis on front upper control arm based on a 2ft drop requirement.

Appendix A12 – Front lower control arm deflection analysis

Rogelio Arroyos | MET 489 | 11/10/23

Given: Lower front control arm $f = 67.77\ lbs$

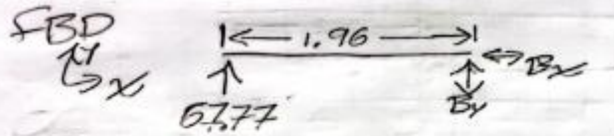
Find: deflection from a drop test impact

Assume: direct load, Plat: $E = 484.4\ KSi$

Method: deflection analysis

Soln:

FBD



$.4"$ × $.25"$

$I = \frac{1}{12}(.25)(.4)^3$

$I = .00133\ in^4$

$\Sigma F_y = 67.77 + B_y \Rightarrow B_y = 67.77\ lbs$

$\Sigma F_x = 0 = B_x$

$$\delta = \frac{PL^3}{3EI} \rightarrow \frac{67.77 \cdot (1.96\ in)^3}{3 \cdot 484.4 \cdot 10^3 \cdot .00133} = \frac{510.3}{1932.8}$$

$$\delta = 0.264 > 0.1\ in$$

New cross section

$.5$ × $.4$

$I = \frac{1}{12}(.4)(.5)^3$

$I = .00417\ in^4$

$$\delta = \frac{67.77 \cdot (1.96)^3}{3 \cdot 484.4 \cdot 10^3 \cdot .00417} = \frac{510.3}{6060}$$

$$\delta = 0.084\ in < 0.1\ in$$

New cross section is to deflect less than 0.1"

Figure A12- Deflection analysis on front lower control arm based on a 2ft drop requirement.

APPENDIX B - Drawings

Appendix B01 – Drawing Tree

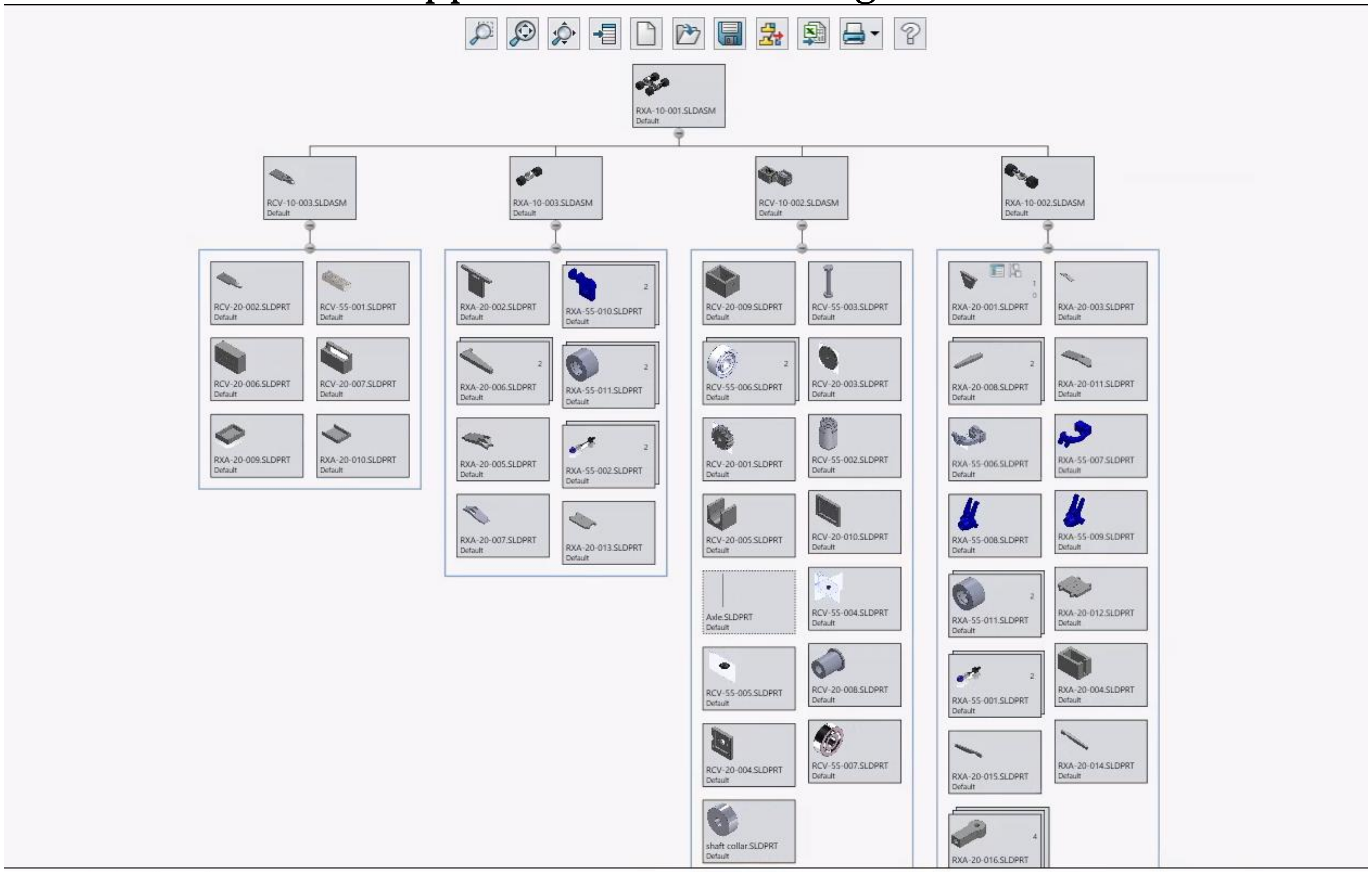


Figure B01- Drawing tree

Type	File Name	Quantity	Active Configuration
	RC Car Assembly Tree.SLDASM	1	Default
	RXA-10-001.SLDASM	1	Default
	RCV-10-003.SLDASM	1	Default
	RCV-20-002.SLDPRT	1	Default
	RCV-55-001.SLDPRT	1	Default
	RCV-20-006.SLDPRT	1	Default
	RCV-20-007.SLDPRT	1	Default
	RXA-20-009.SLDPRT	1	Default
	RXA-20-010.SLDPRT	1	Default
	RXA-10-003.SLDASM	1	Default
	RXA-20-002.SLDPRT	1	Default
	RXA-55-010.SLDPRT	2	Default
	RXA-20-006.SLDPRT	2	Default
	RXA-55-011.SLDPRT	2	Default
	RXA-20-005.SLDPRT	1	Default
	RXA-55-002.SLDPRT	2	Default
	RXA-20-007.SLDPRT	1	Default
	RXA-20-013.SLDPRT	1	Default

Figure B01.1- Drawing tree list.

Type	File Name	Quantity	Active Configuration
	RCV-10-002.SLDASM	1	Default
	RCV-20-009.SLDPRT	1	Default
	RCV-55-003.SLDPRT	1	Default
	RCV-55-006.SLDPRT	2	Default
	RCV-20-003.SLDPRT	1	Default
	RCV-20-001.SLDPRT	1	Default
	RCV-55-002.SLDPRT	1	Default
	RCV-20-005.SLDPRT	1	Default
	RCV-20-010.SLDPRT	1	Default
	RCV-55-004.SLDPRT	1	Default
	RCV-55-005.SLDPRT	1	Default
	RCV-20-004.SLDPRT	1	Default
	RCV-55-007.SLDPRT	1	Default
	RCV-20-011.SLDPRT	1	Default

Figure B01.2- Drawing tree list.

Type	File Name	Quantity	Active Configuration
	RCV-10-003.SLDASM	1	Default
	RXA-10-003.SLDASM	1	Default
	RCV-10-002.SLDASM	1	Default
	RXA-10-002.SLDASM	1	Default
	RXA-20-001.SLDPRT	1	Default
	RXA-20-003.SLDPRT	1	Default
	RXA-20-008.SLDPRT	2	Default
	RXA-20-011.SLDPRT	1	Default
	RXA-55-006.SLDPRT	1	Default
	RXA-55-007.SLDPRT	1	Default
	RXA-55-008.SLDPRT	1	Default
	RXA-55-009.SLDPRT	1	Default
	RXA-55-011.SLDPRT	2	Default
	RXA-20-012.SLDPRT	1	Default
	RXA-55-001.SLDPRT	2	Default
	RXA-20-004.SLDPRT	1	Default

Figure B01.3- Drawing tree list.

Appendix B02 – Drawing Index

Table B02- Drawing Index

Drawing Assignment Num.	Drawing #(s)	Date submitted
Upload: DWG 1	RXA-20-001	10/10/2023
Upload: DWG 2	RXA-20-002	10/17/2023
Upload: DWG 3 & 4	RXA-20-003, RXA-20-004	10/25/2023
Upload: DWG 5 & 6	RXA-20-005, RXA-20-006	10/29/2023
Upload: DWG 7 & 8	RXA-20-007, RXA-20-008	11/07/2023
Upload: DWG 9 & 10	RXA-20-009, RXA-20-010	11/14/2023
DWG 11	RXA-20-011	12/1/2023
DWG 12 & 13	RXA-20-012, RXA-20-013	1/10/2024
DWG 14 & 15	RXA-20-014, RXA-20-015	2/3/2024
DWG 16	RXA-20-016	3/7/2024
Upload: DWG Subassembly 1 & 2	RXA-10-002, RXA-10-003	11/28/2023
Upload: DWG Top Assembly	RXA-10-001	11/28/2023

Appendix B03 – < RCV-10-001> - RC Car Assembly

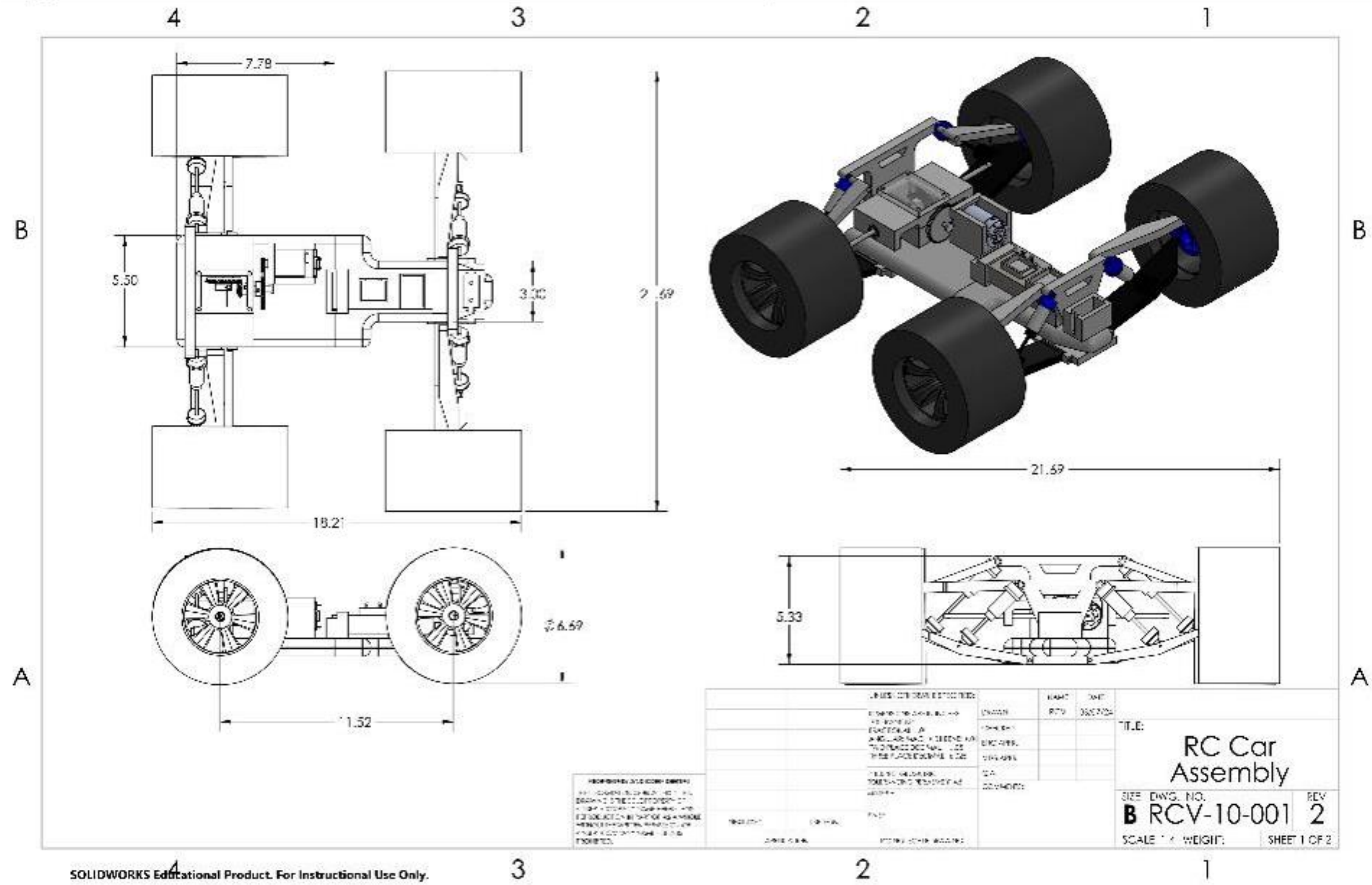


Figure B03- RC Assembly drawing.

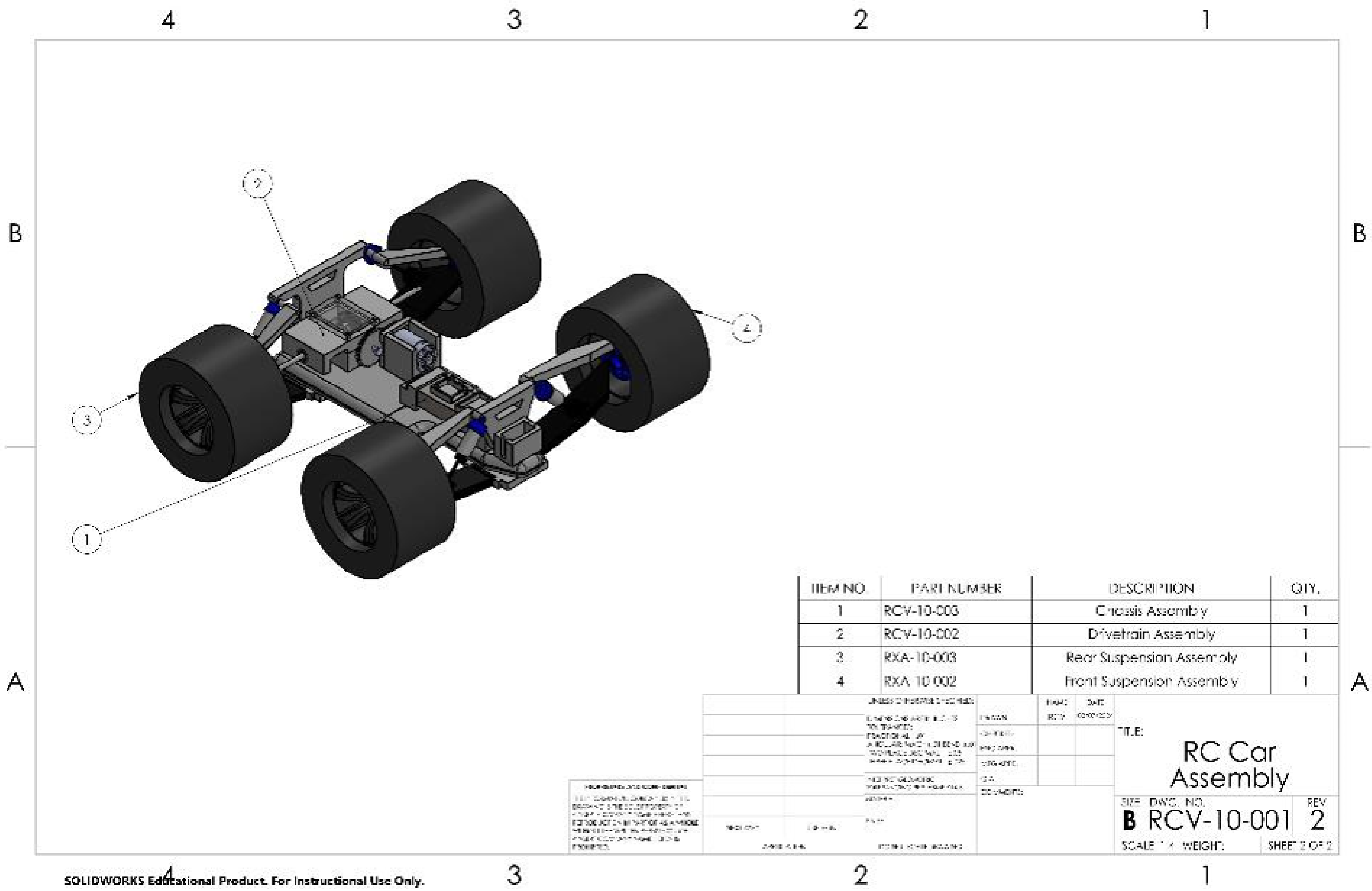


Figure B03.1- RC Assembly drawing continued.

Appendix B04 – < RXA-10-002> - Front Shock Subassembly

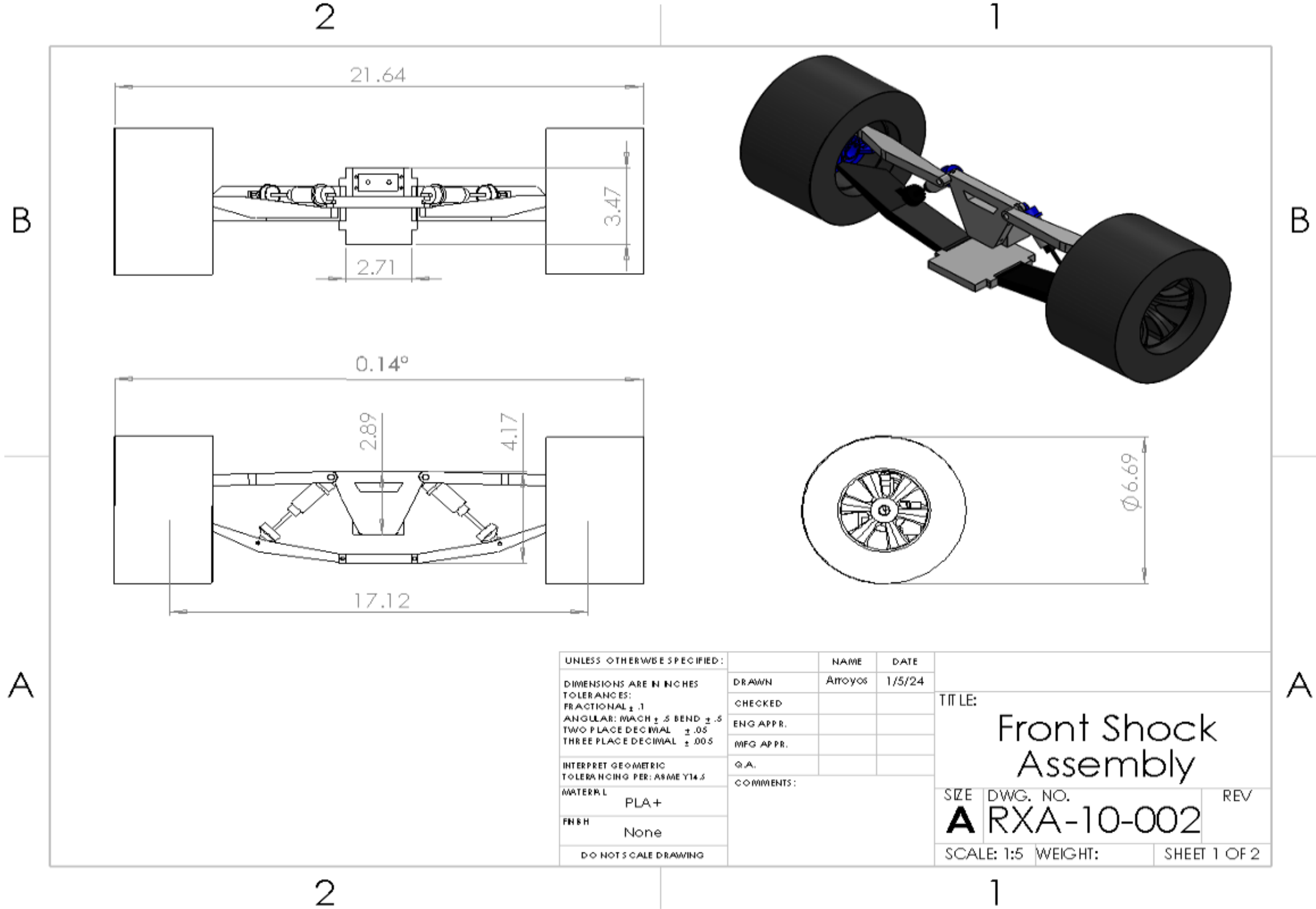


Figure B04- Front Shock Subassembly drawing.

2 1

B B

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	RXA-20-001	Front Shock Tower	1
2	RXA-20-003	Front Lower Left Control Arm	1
3	RXA-20-008	Front Upper Control Arm	2
4	RXA-20-011	Front Lower Right Control Arm	1
5	RXA-55-006	Front Right C- Channel	1
6	RXA-55-007	Front Left C- Channel	2
7	RXA-55-008	Front Left Knuckle	2
8	RXA-55-009	Front Right Knuckle	2
9	RXA-55-011	1/8 RC Monster truck tires	2
10	RXA-20-012	Rear Lower Control Arm Mount	1
11	RXA-55-001	Front Shock	2
12	RXA-20-004	Servo Motor Mount	1

A A

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .1
ANGULAR: MACH ± .5 BEND ± .5
TWO PLACE DECIMAL ± .05
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL PLA+

FINISH None

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Arroyos	1/5/24
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Front Shock Assembly

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

SCALE: 1:5 WEIGHT: SHEET 2 OF 2

2 1

Figure B04.1- Front Shock Subassembly drawing

Appendix B05 – <RXA-10-003> - Rear Shock Subassembly

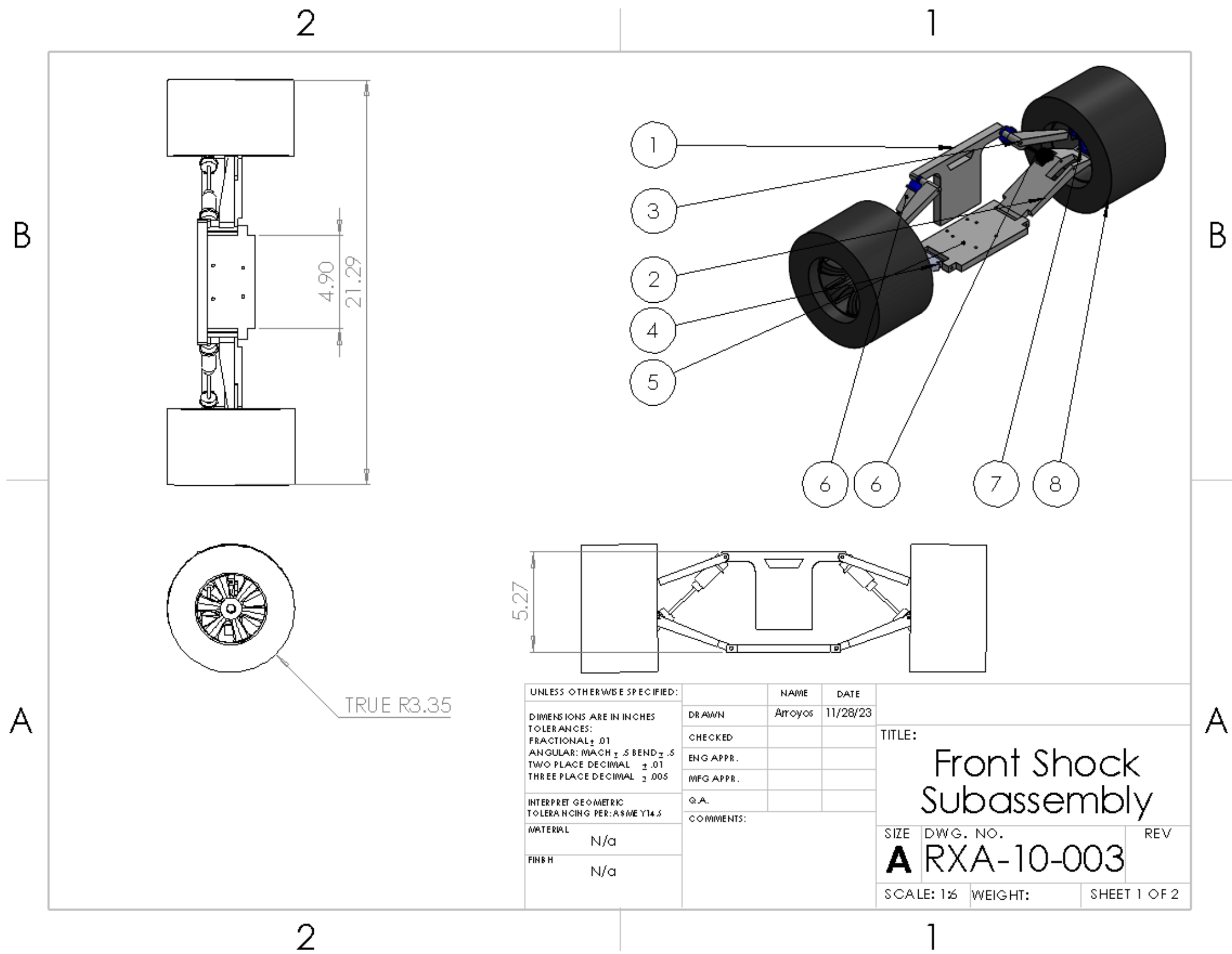


Figure B05- Rear Shock Subassembly drawing.

Appendix B06 – <RXA-20-001> - Front Shock Tower

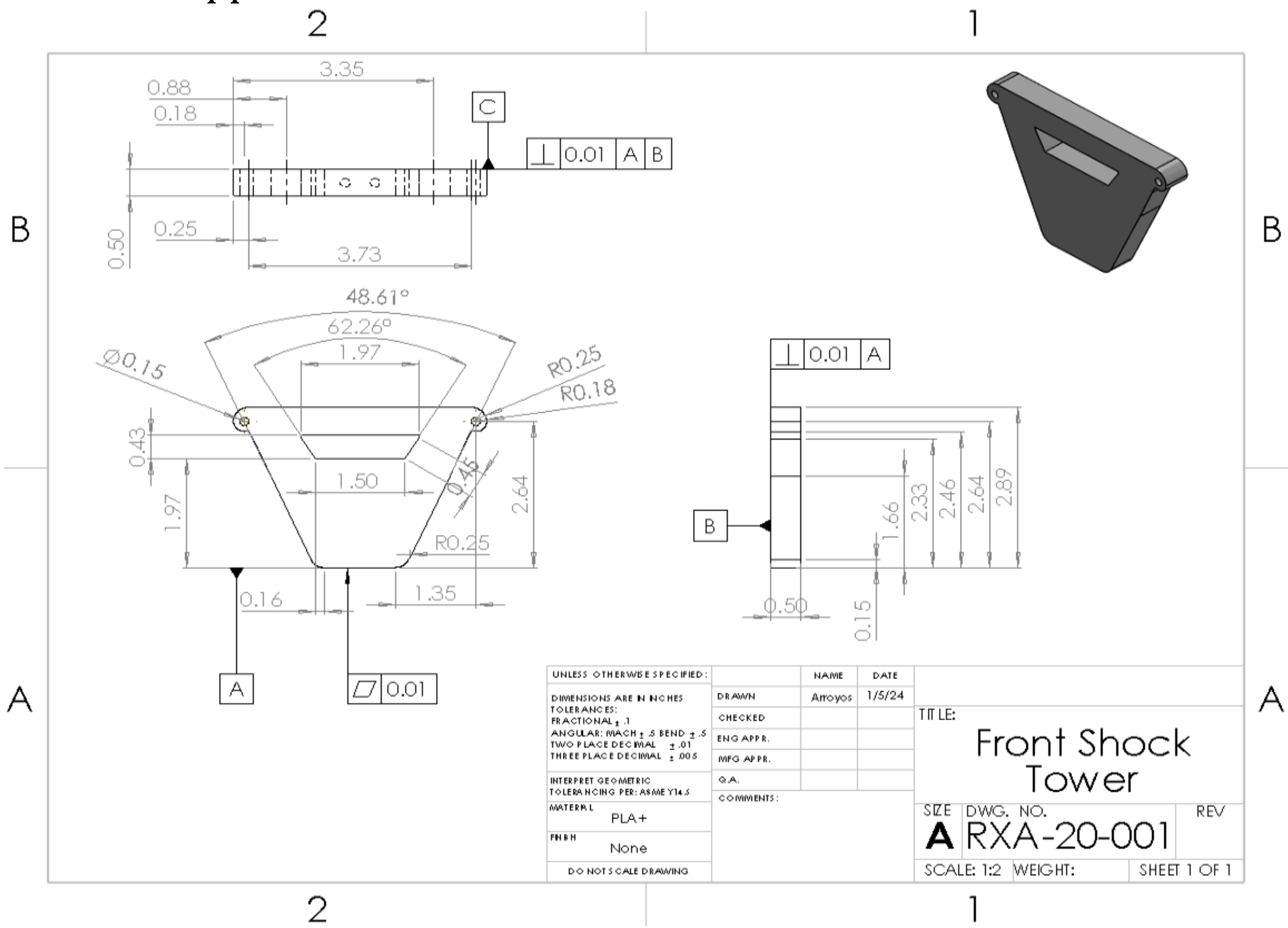


Figure B06- Front shock tower drawing.

Appendix B07 – <RXA-20-002> - Rear Shock Tower

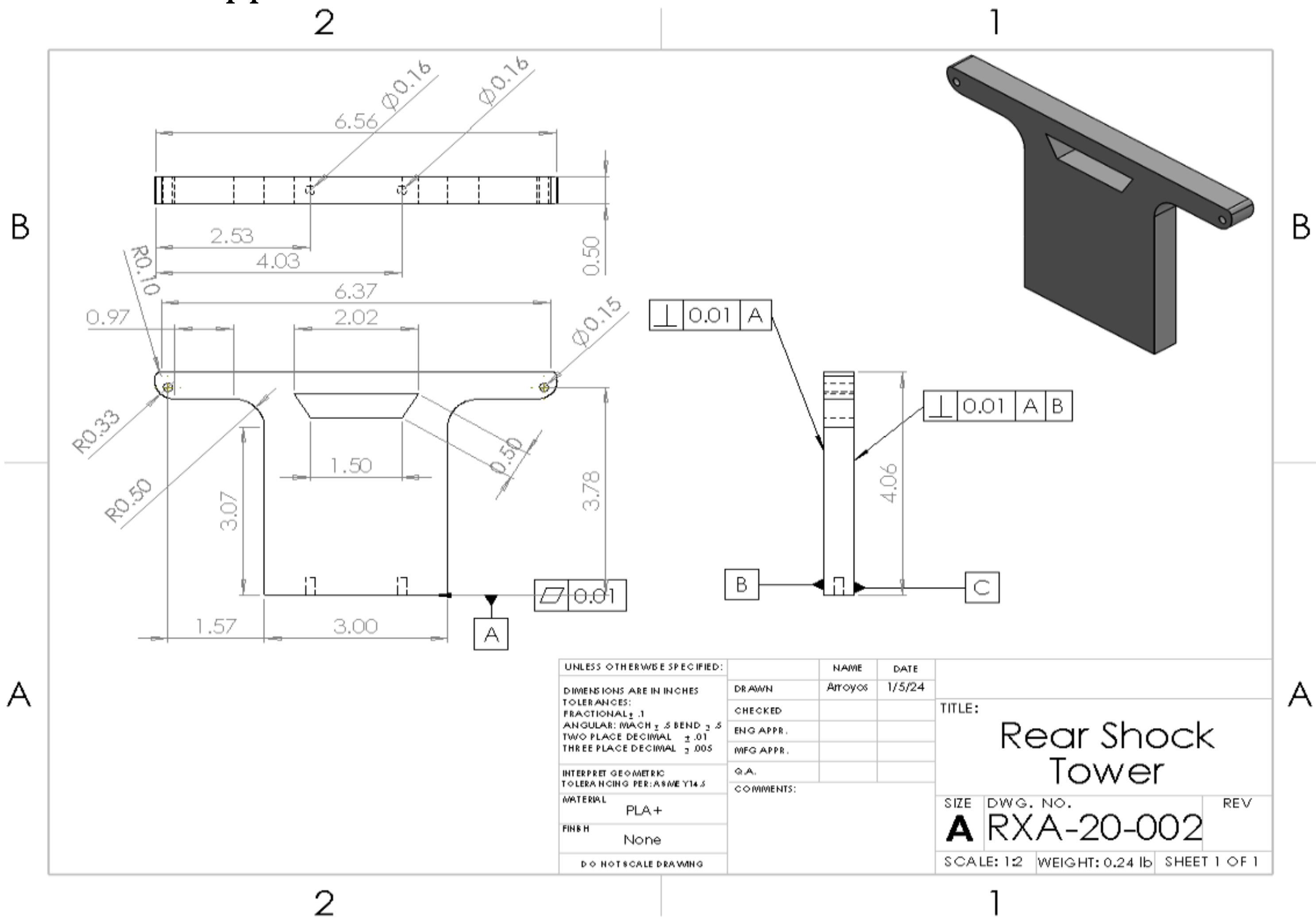


Figure B07- Drawing of the rear shock tower.

Appendix B08 – <RXA-20-003> - Front Lower Left Control Arm

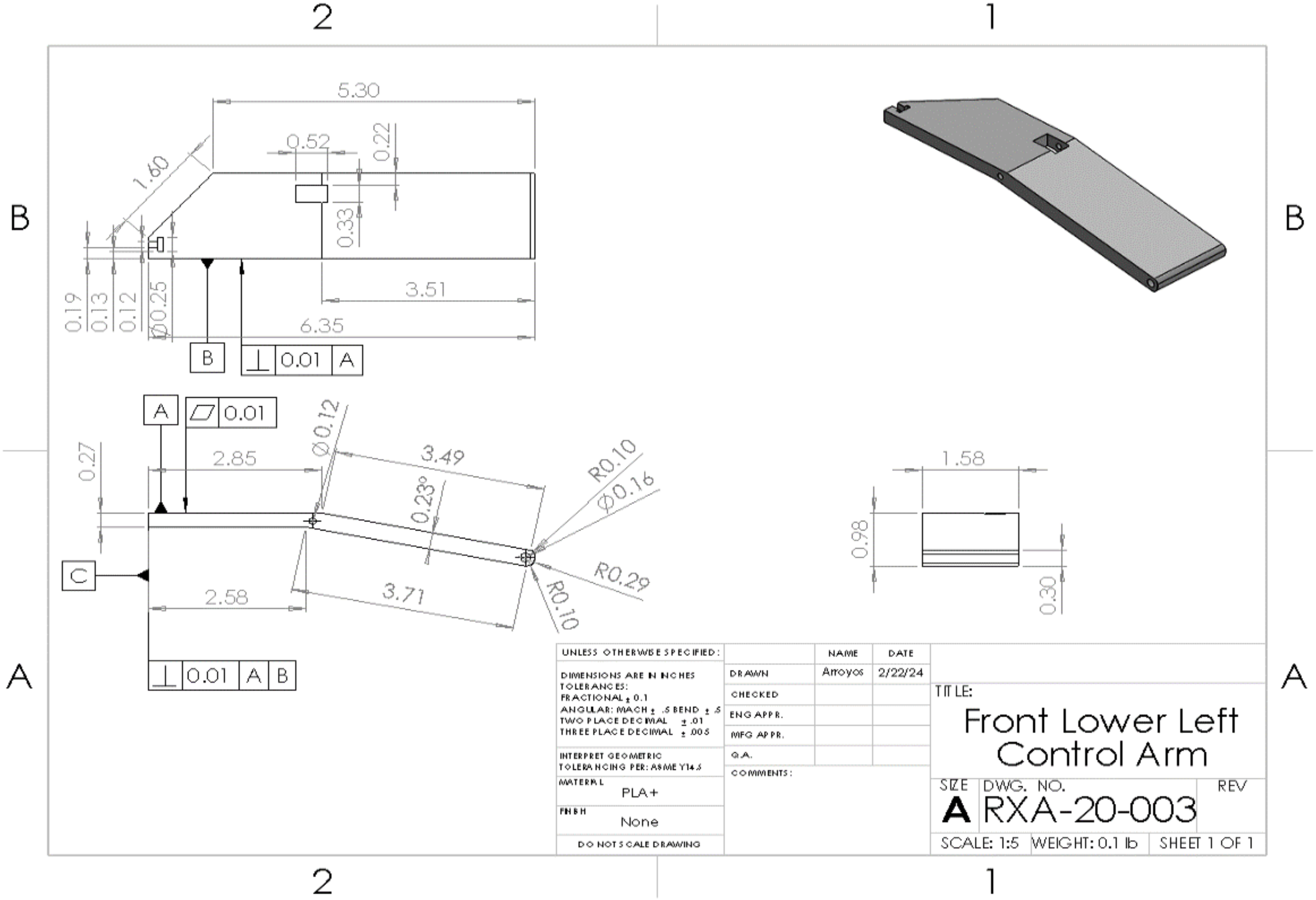


Figure B08- Drawing of the lower control arm.

Appendix B09 – <RXA-20-004> - Servo Motor Mount

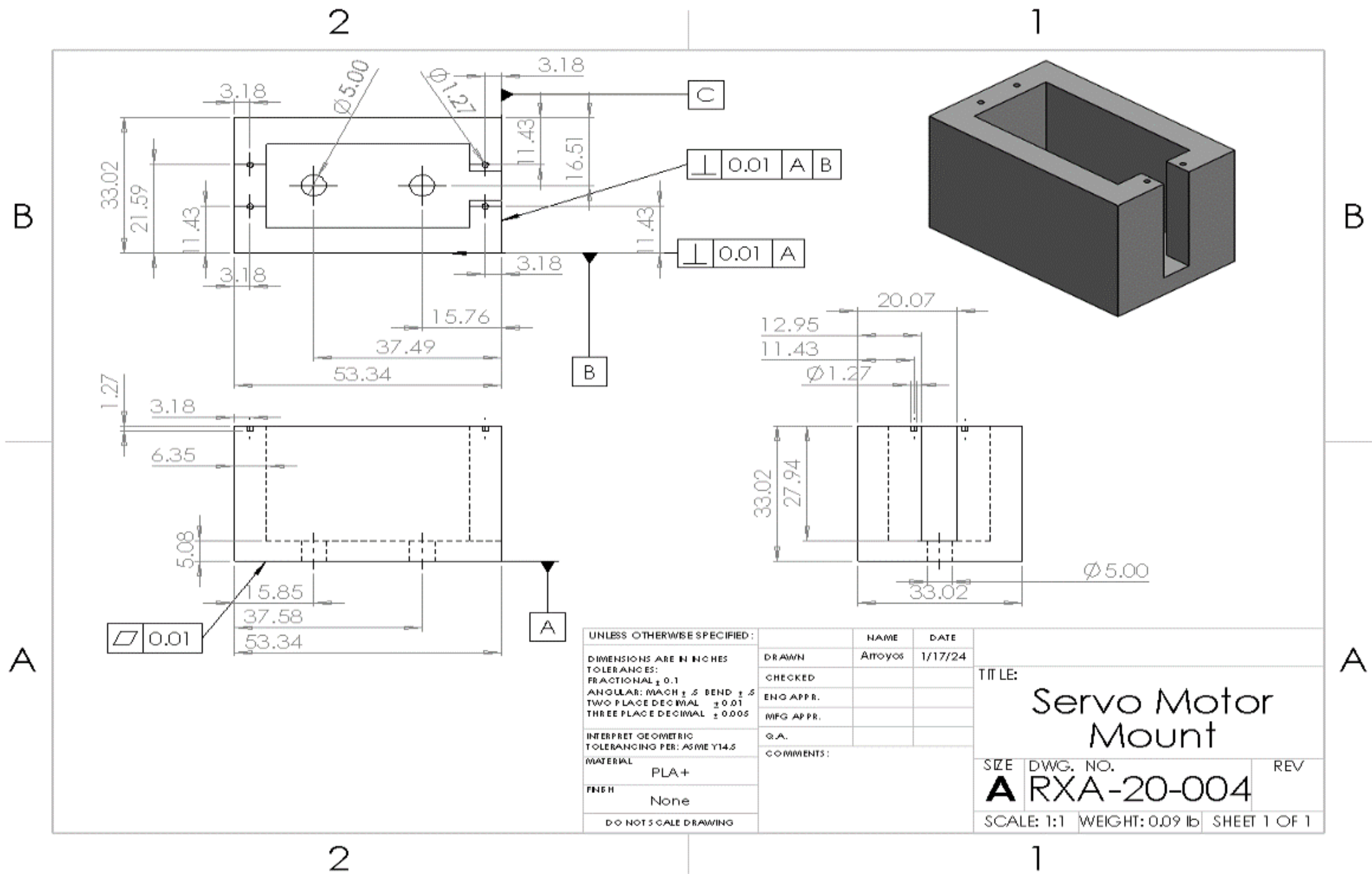


Figure B09- Servo Motor Mount drawing.

Appendix B10 – <RXA-20-005> - Rear Lower Left Control Arm

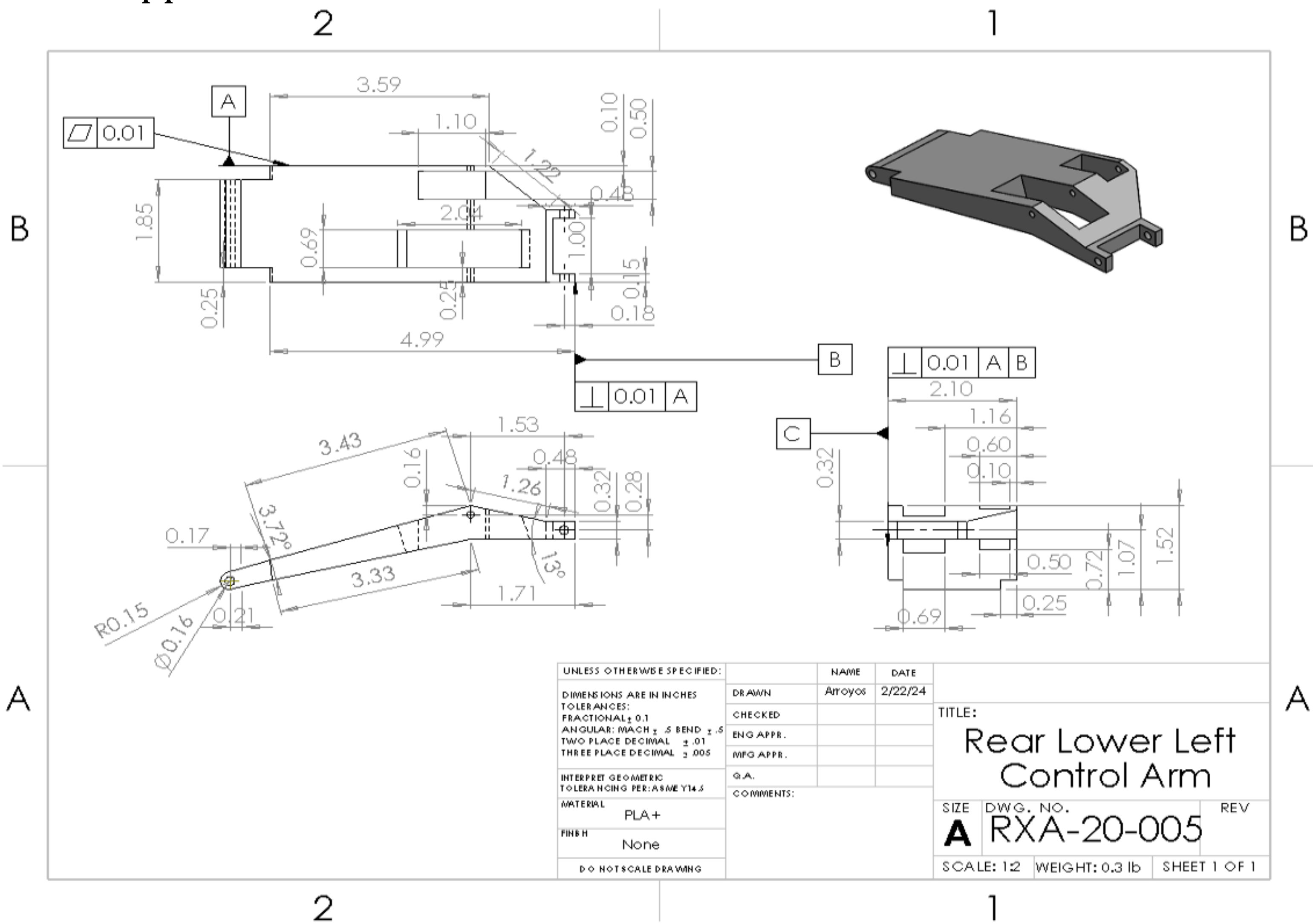


Figure B10- Rear lower left control arm drawing.

Appendix B11 – <RXA-20-006> - Rear Upper Control Arm

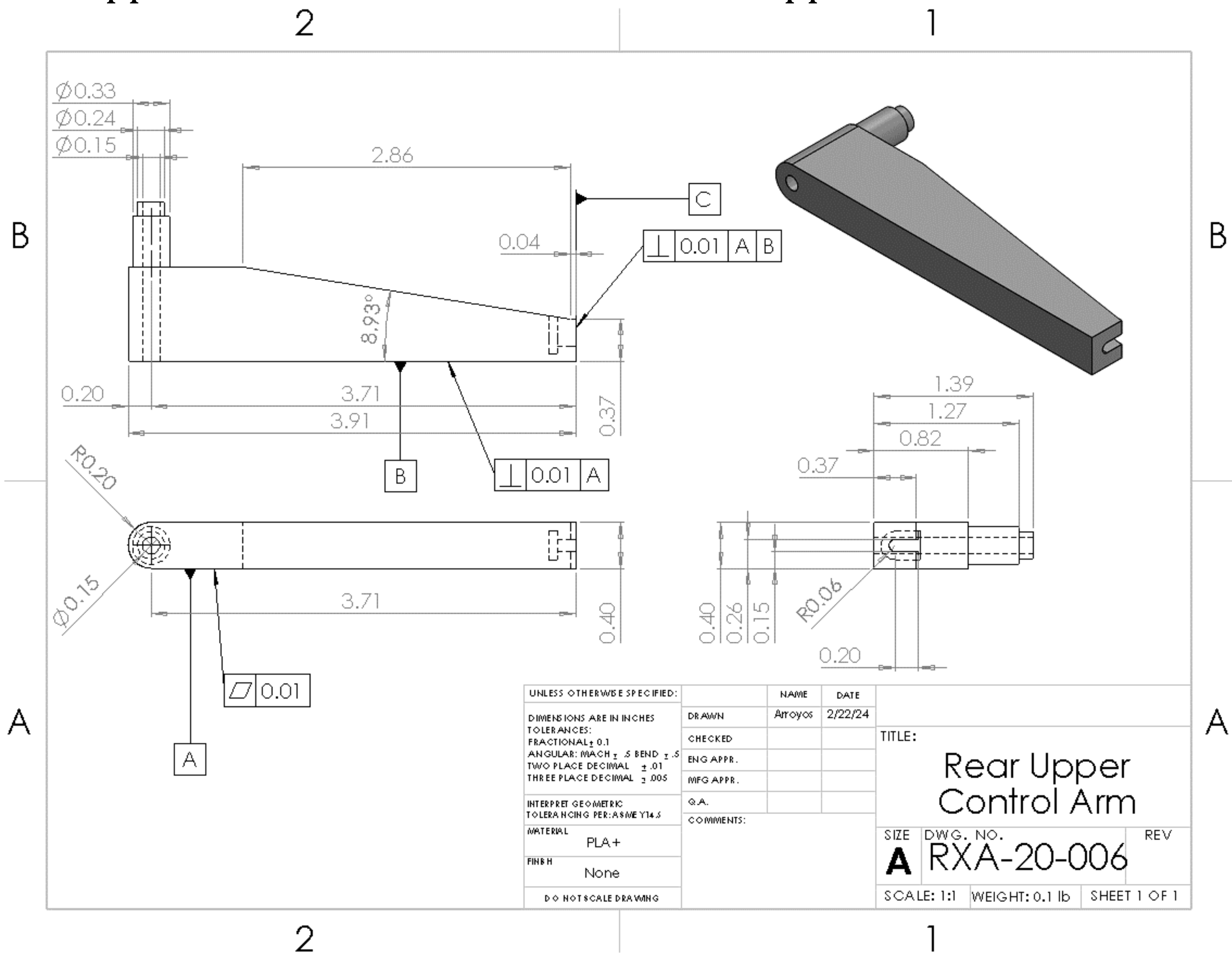


Figure B11- Rear upper control arm drawing.

Appendix B12 – <RXA-20-007> - Rear Lower Right Control Arm

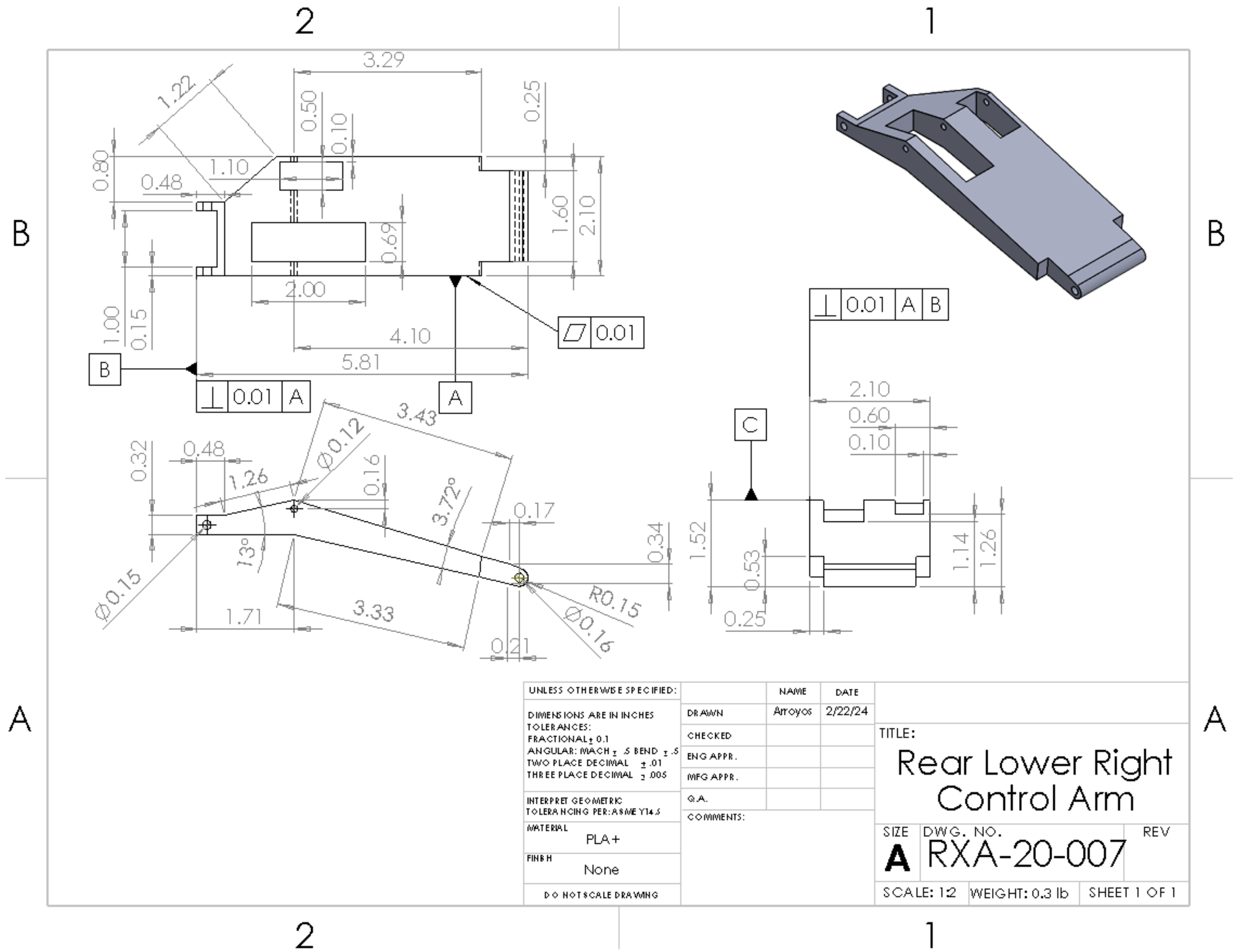


Figure B12- Rear right lower control arm drawing

Appendix B13 – <RXA-20-008> -Front Upper Left Control Arm

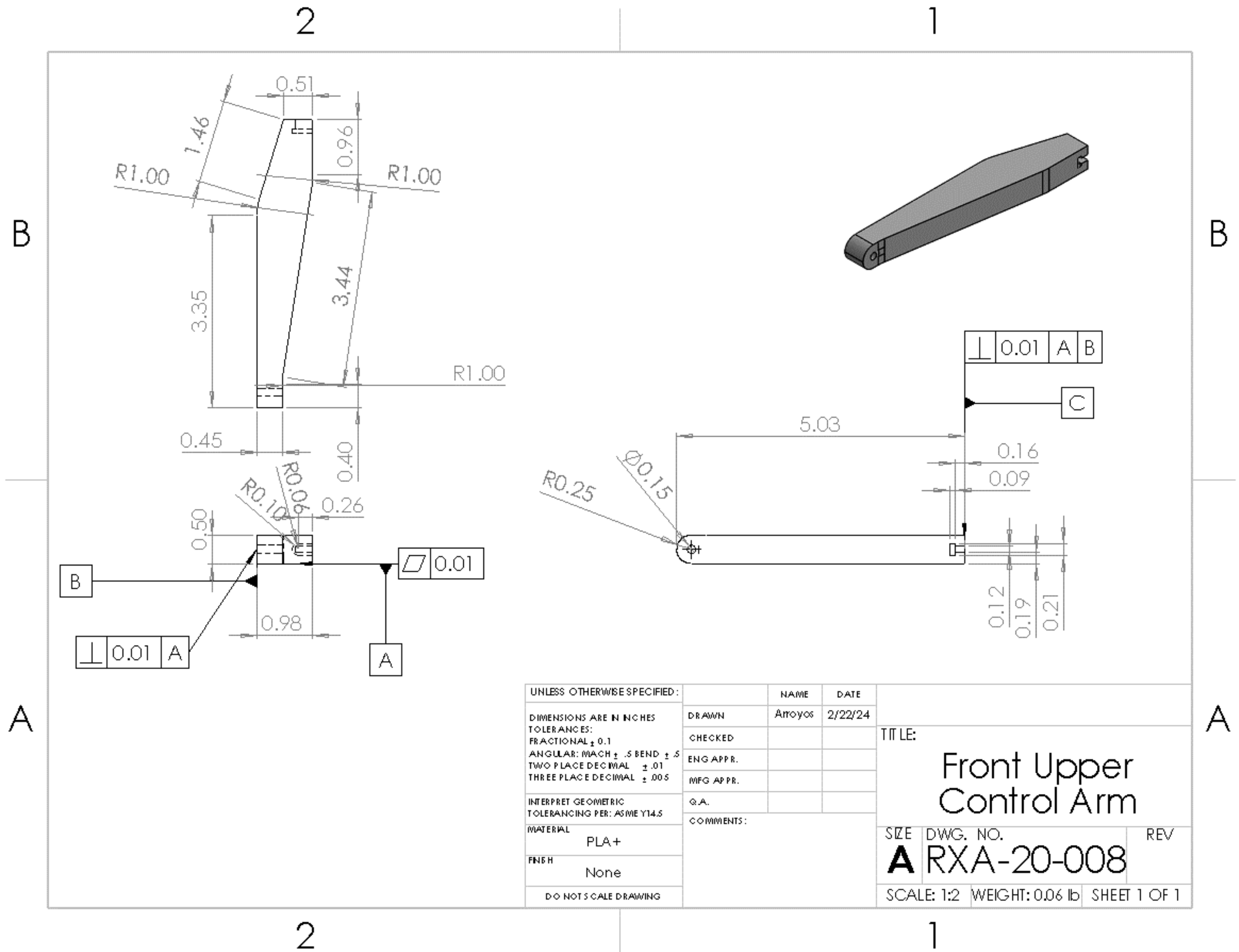


Figure B13- Front left upper control arm drawing.

Appendix B14 – <RXA-20-009> -Receiver Mount

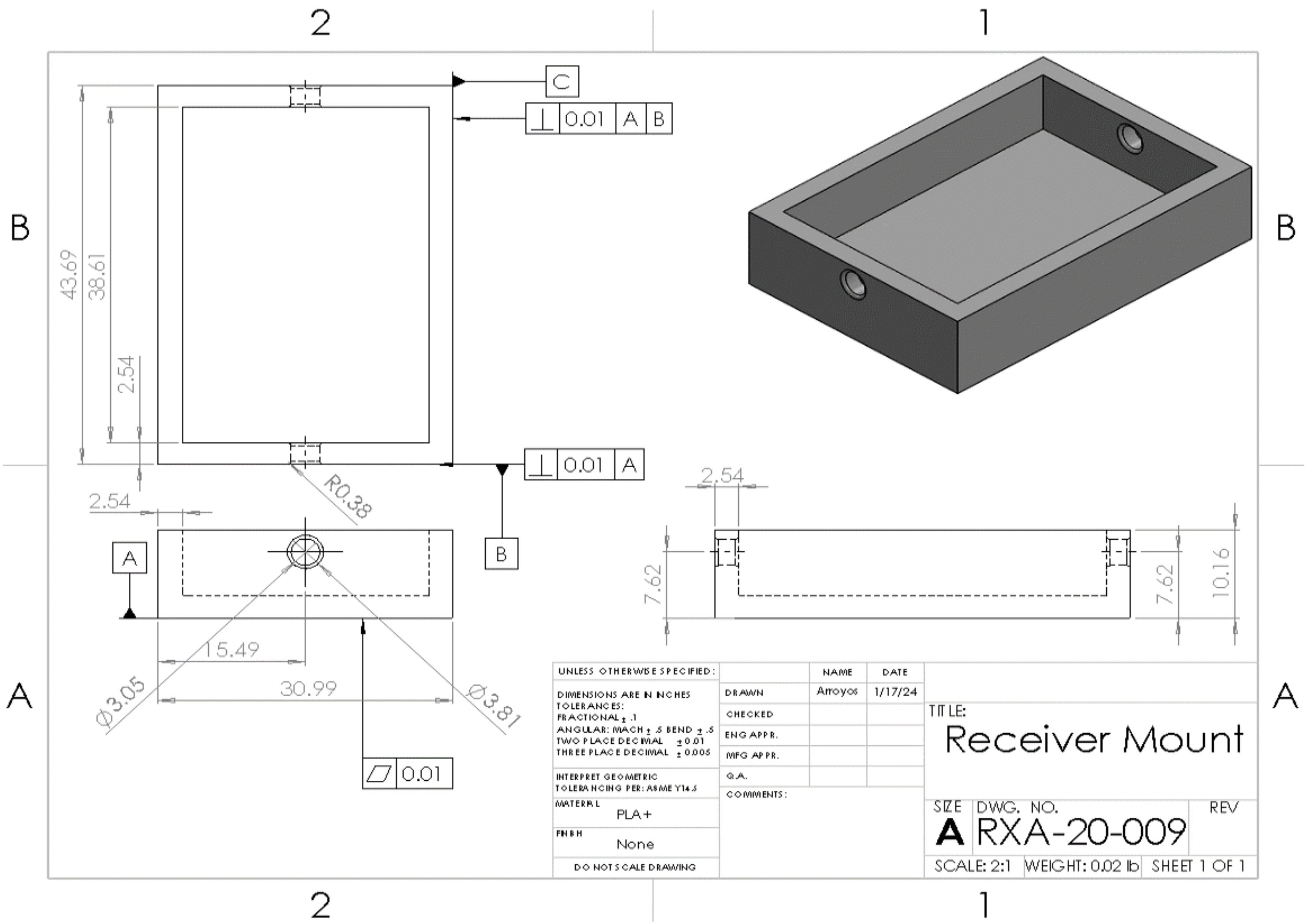


Figure B14- Receiver mount drawing.

Appendix B15 – <RXA-20-010> -ESC Mount

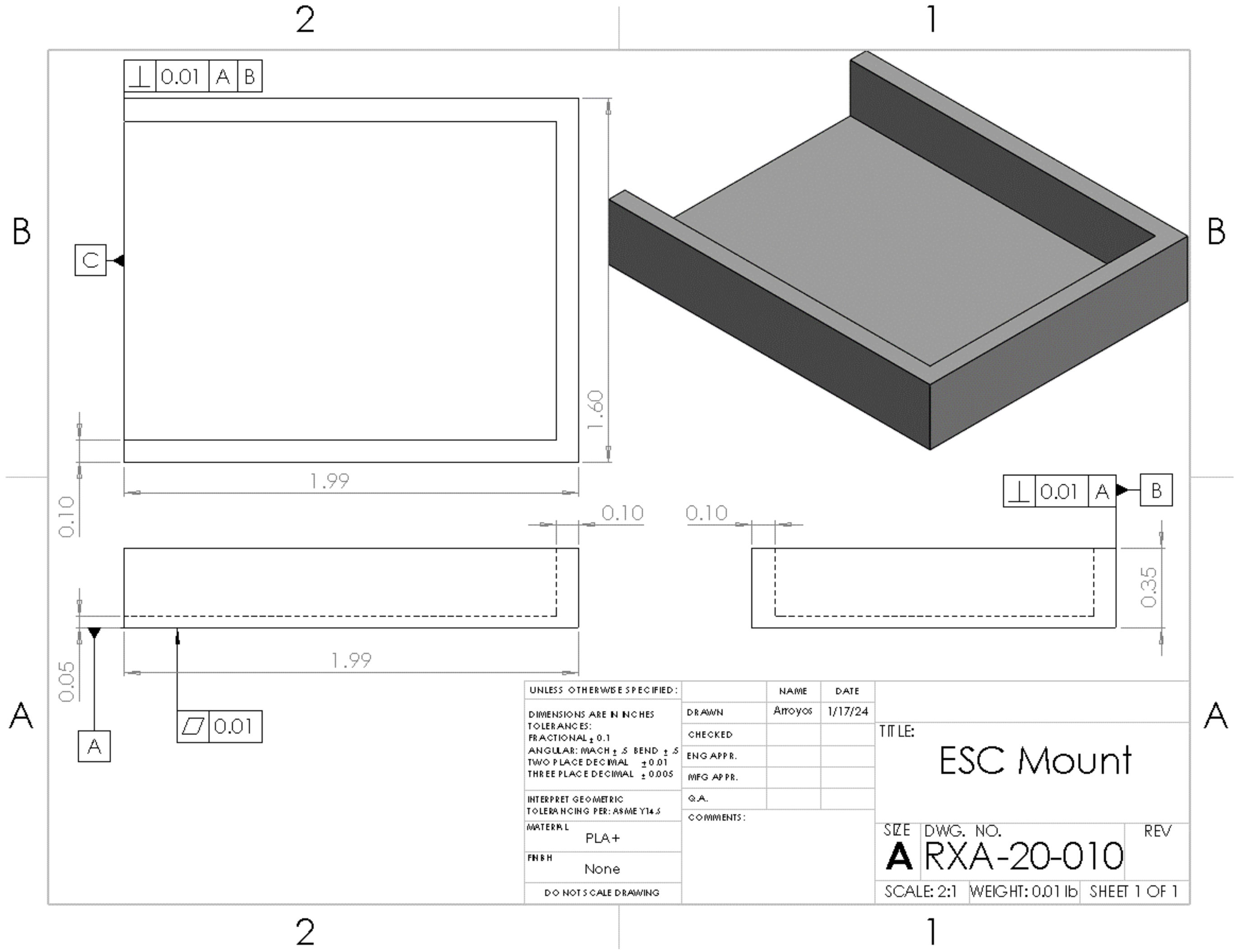


Figure B15- ESC mount drawing.

Appendix B16 – <RXA-20-011> - Front Lower Right Control Arm

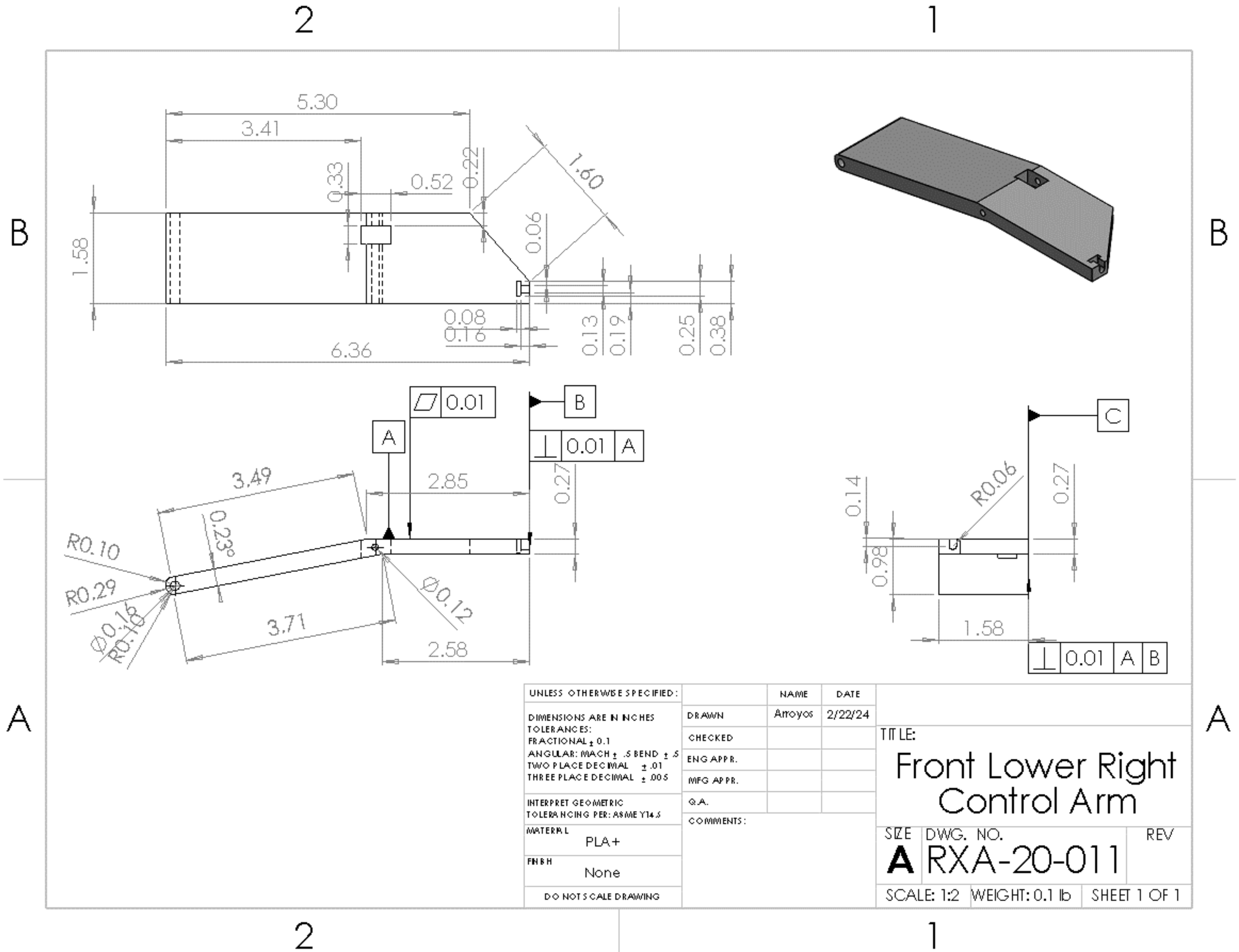


Figure B16- Front Lower Right Control Arm drawing.

Appendix B17 – <RXA-20-012> - Front Lower Control Arm Mount

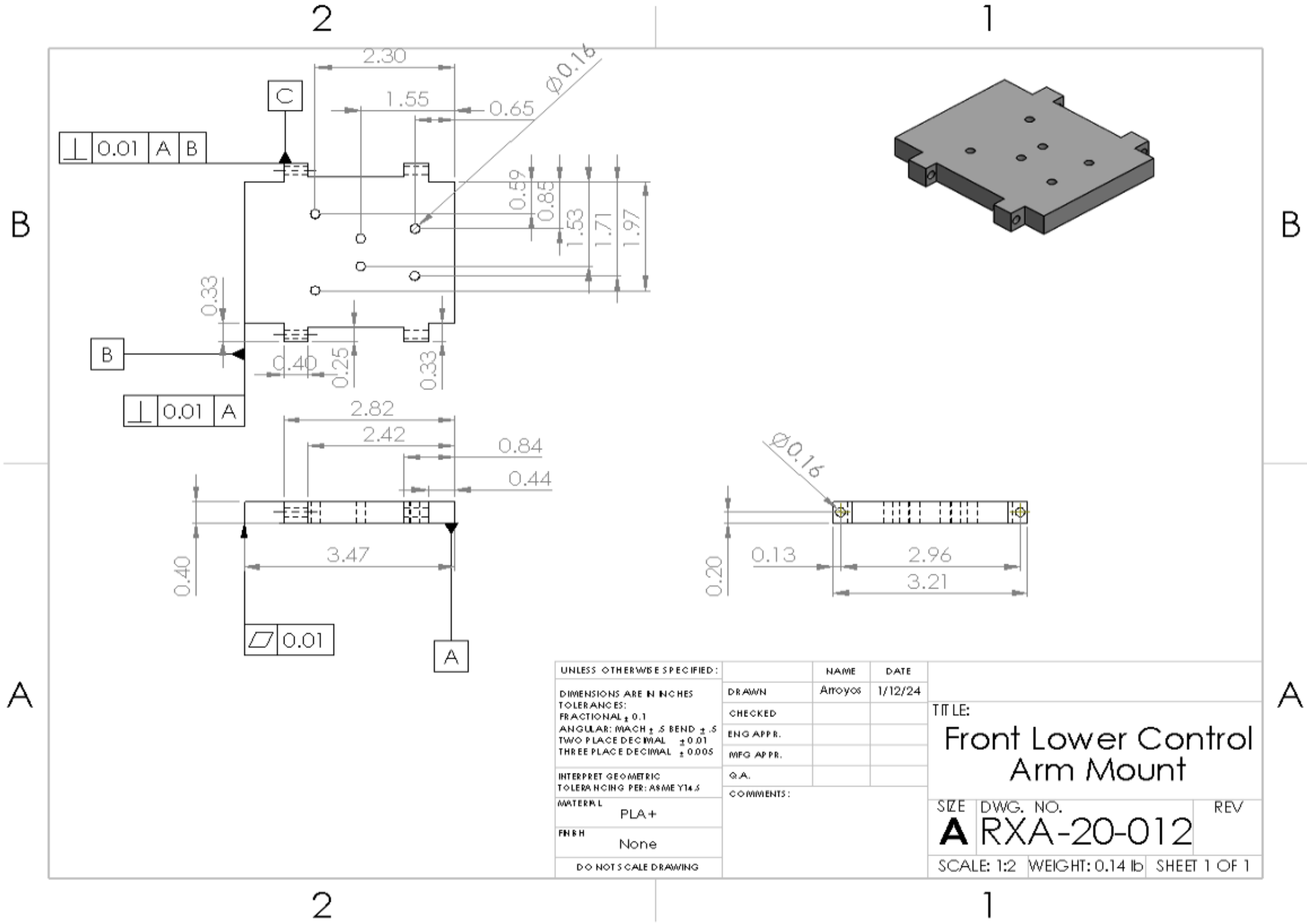


Figure B17- Front Lower Right Control Arm drawing.

Appendix B18 – <RXA-20-013> - Rear Lower Control Arm Mount

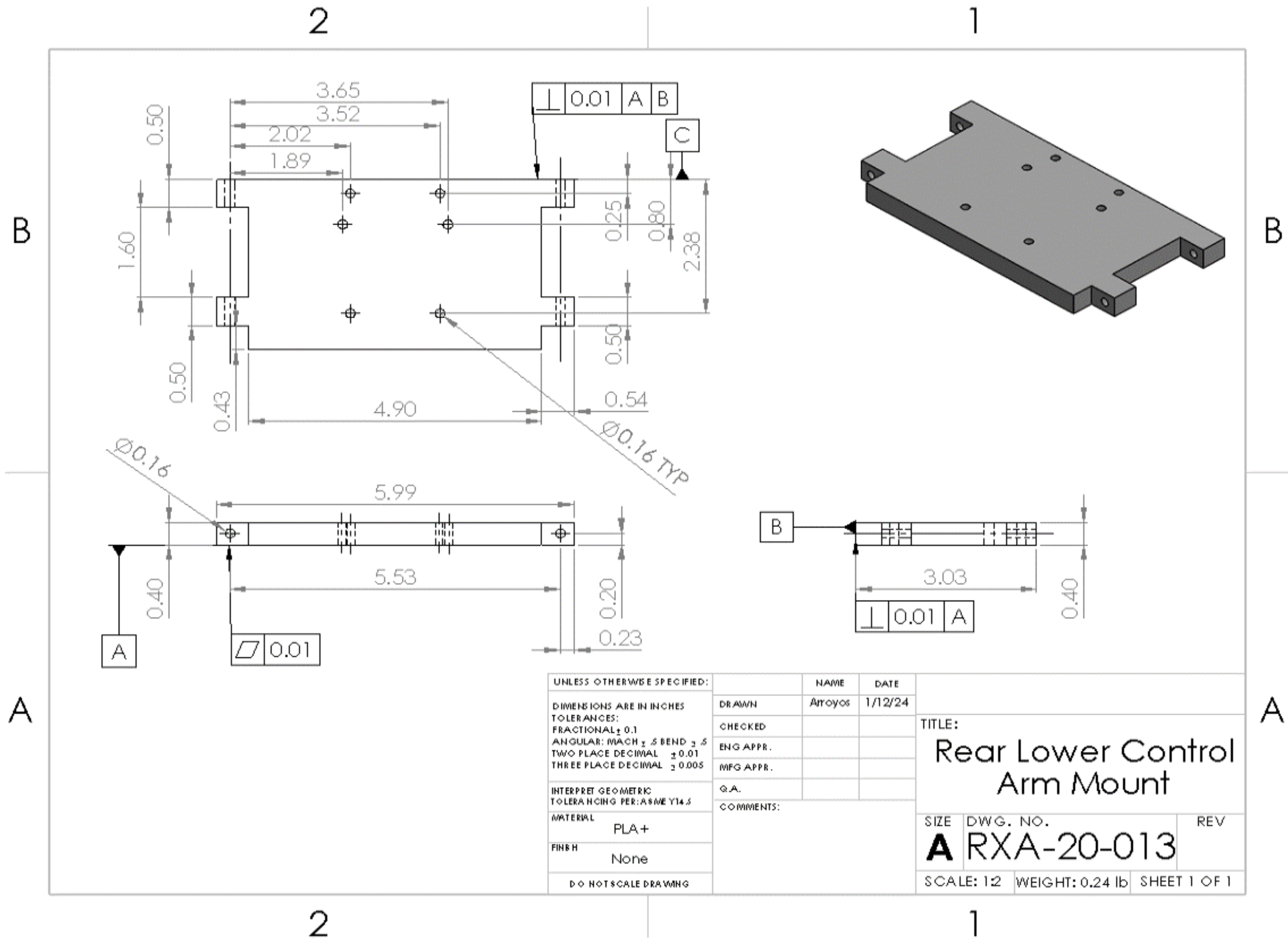


Figure B18- Front Lower Control Arm Mount drawing.

Appendix B19 – <RXA-20-014> - Right Steering Rod

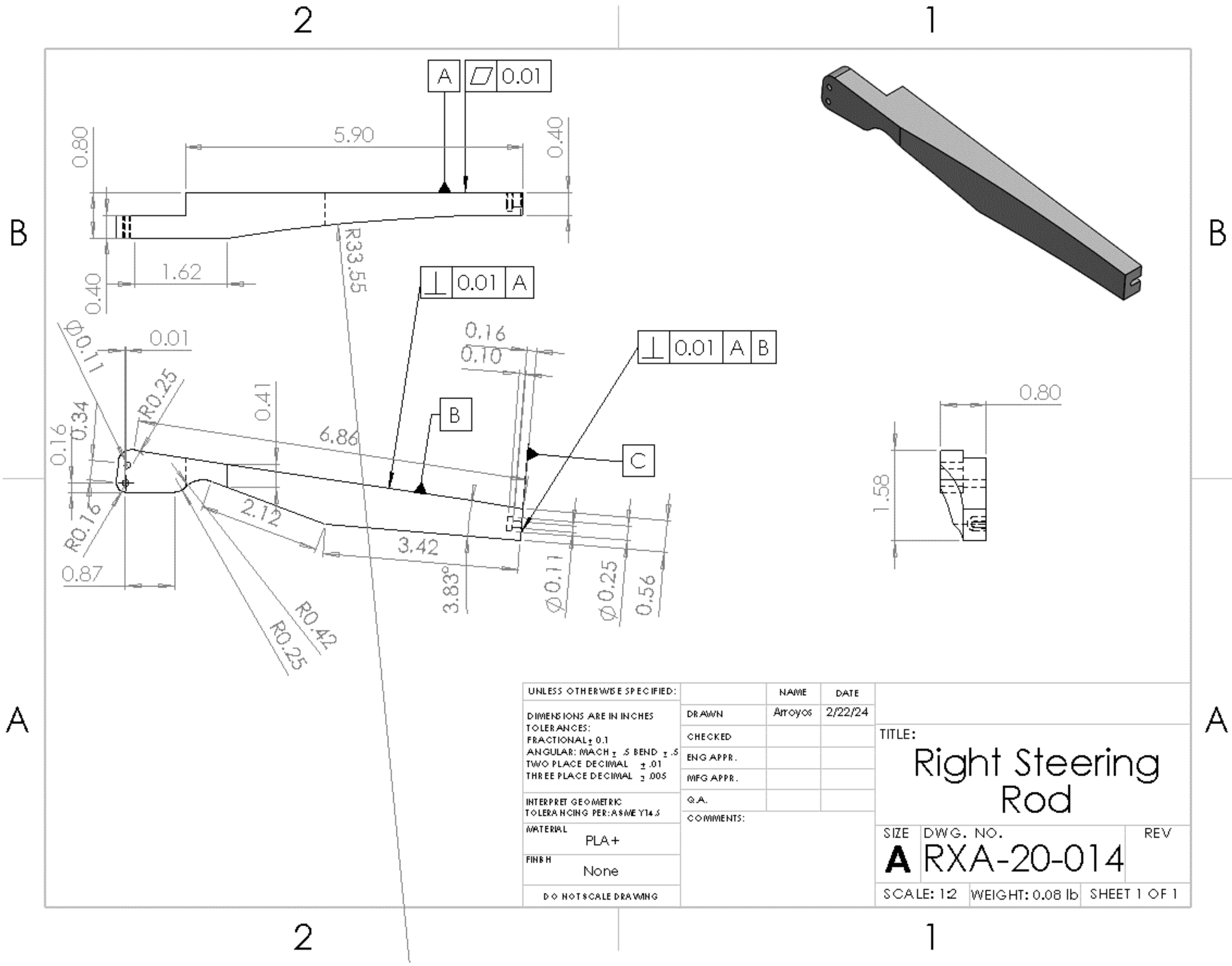


Figure B19- Right Steering Rods drawing.

Appendix B20 – <RXA-20-015> - Left Steering Rod

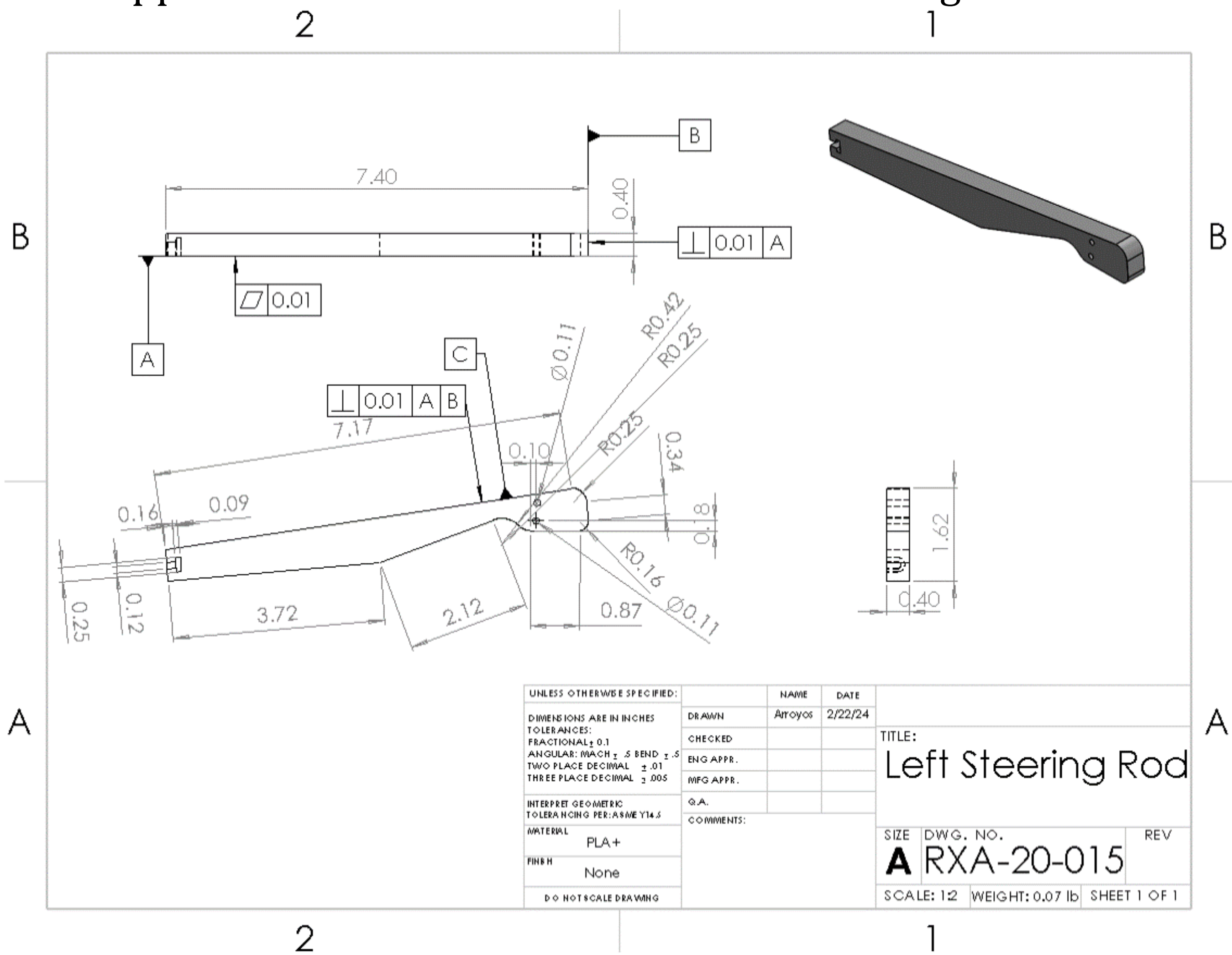


Figure B20- Left Steering Rod drawing.

Appendix B21 – <RXA-20-016> - Ball Joint End

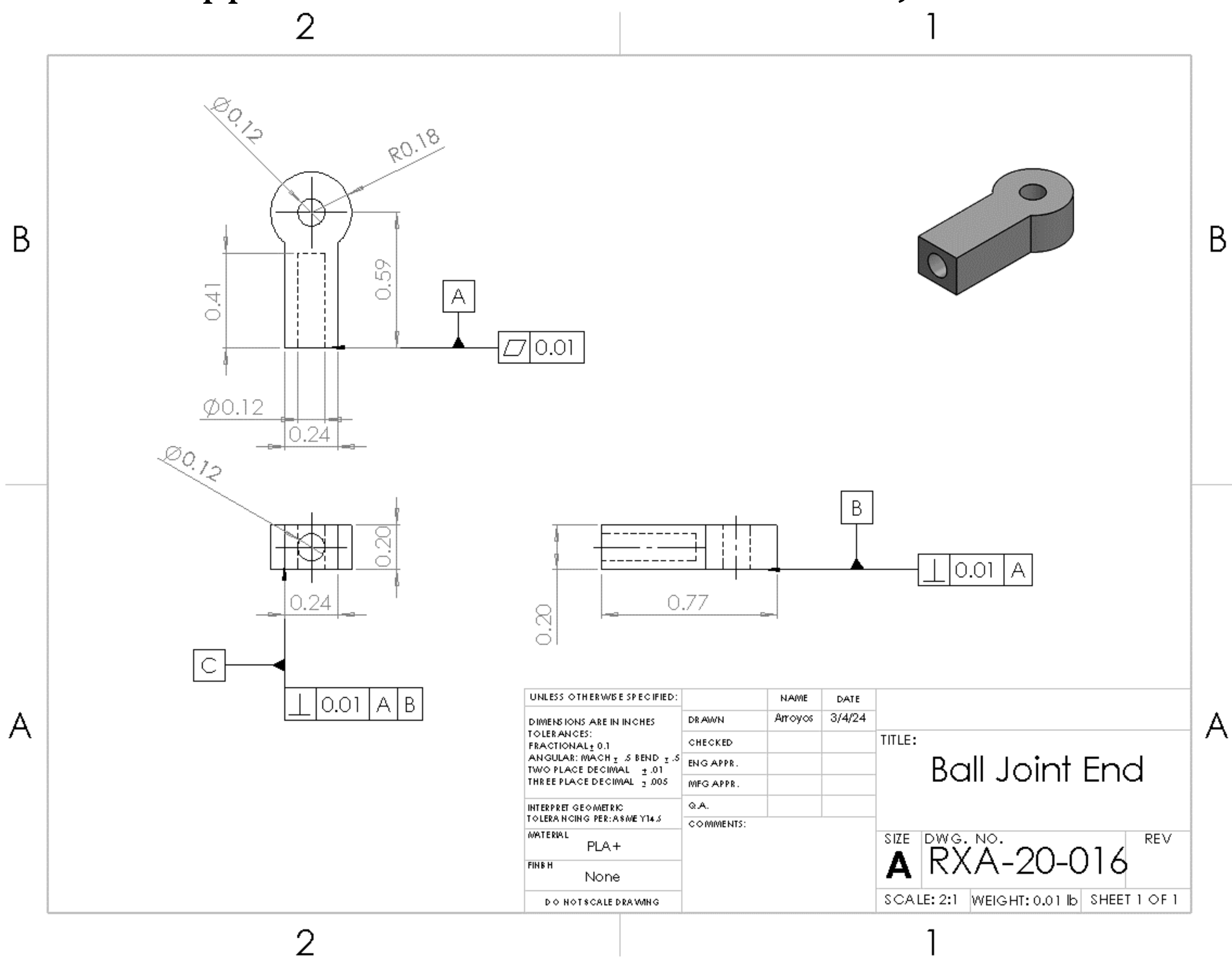


Figure B21- Ball Joint End

Appendix B22– <RXA-55-001> -Front Shock

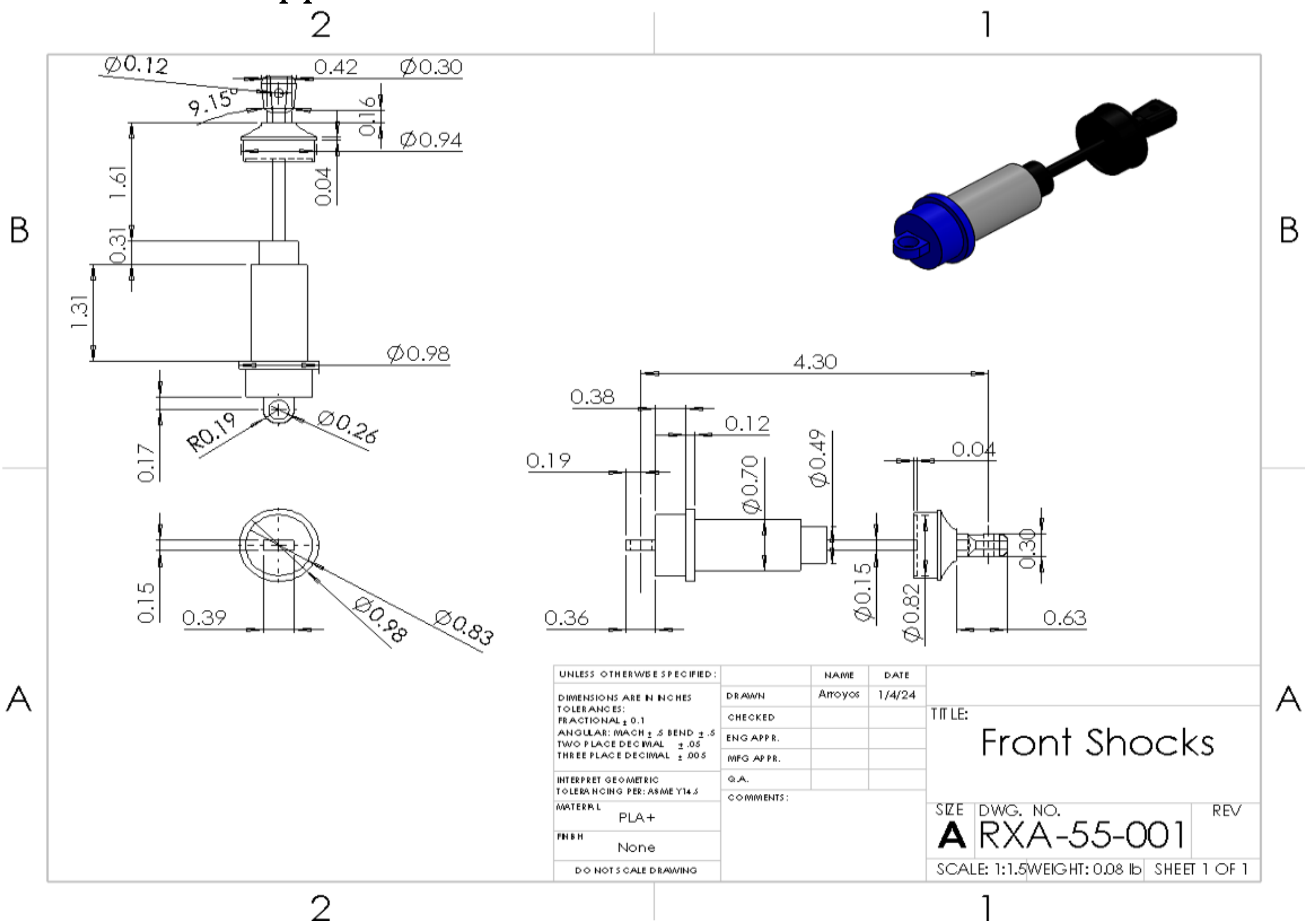


Figure B22- Front shock drawing.

Appendix B23– <RXA-55-002> -Rear Shock

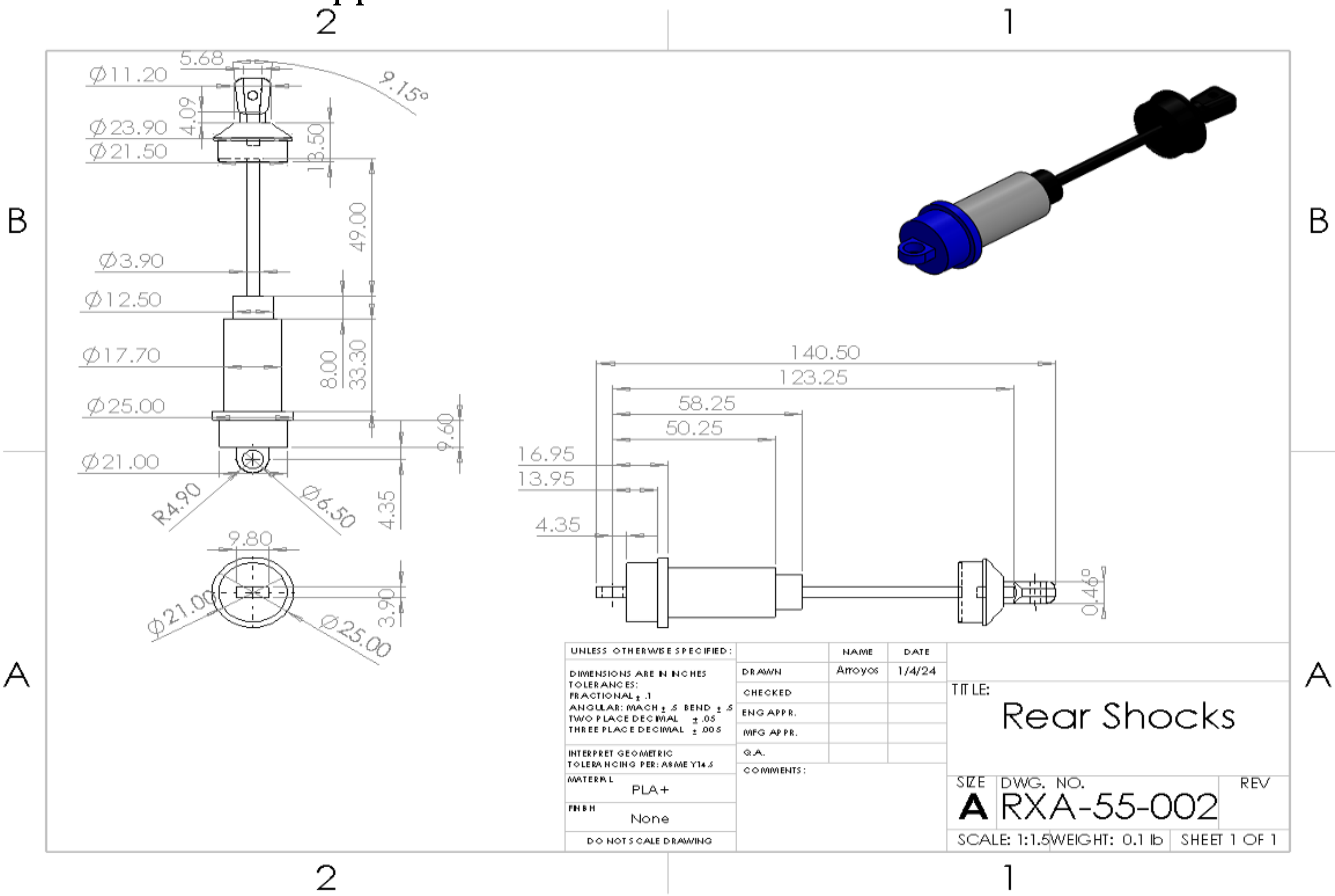


Figure B23- Rear shock drawing.

Appendix B24– <RXA-55-003> - Receiver

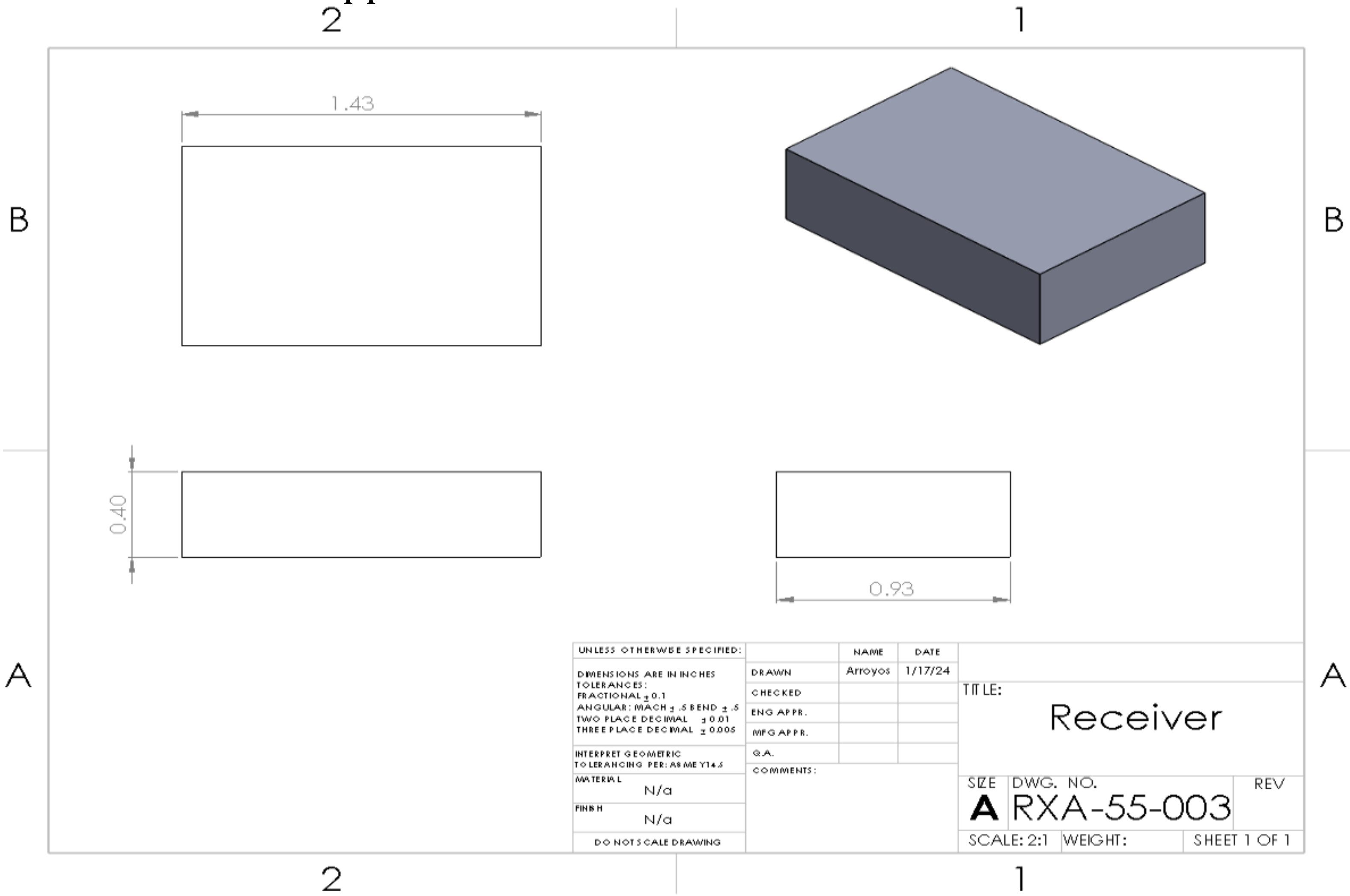


Figure B24- Receiver drawing.

Appendix B25– <RXA-55-004> - UBEC

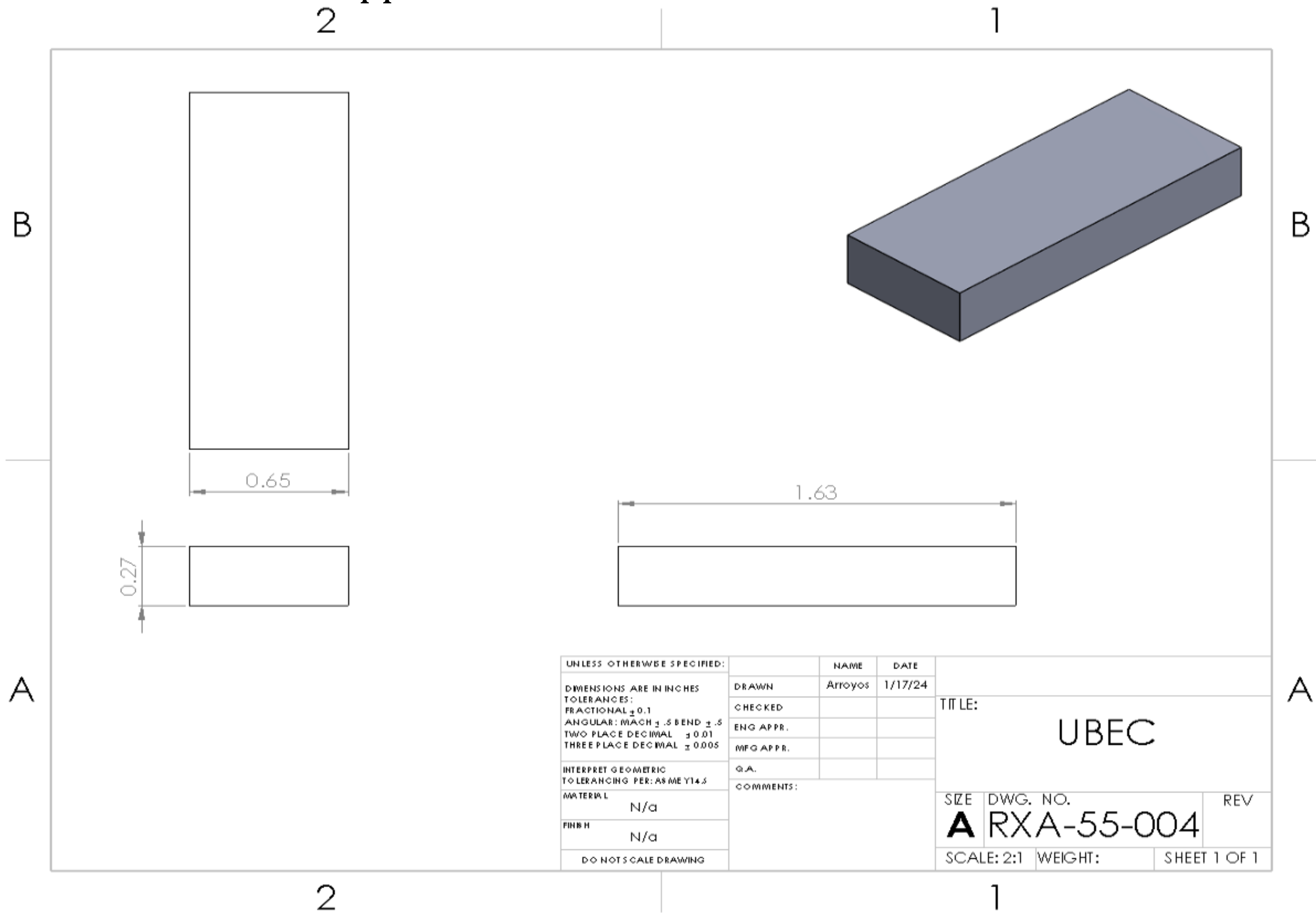


Figure B25- UBEC drawing.

Appendix B26- <RXA-55-005> - Servo Motor

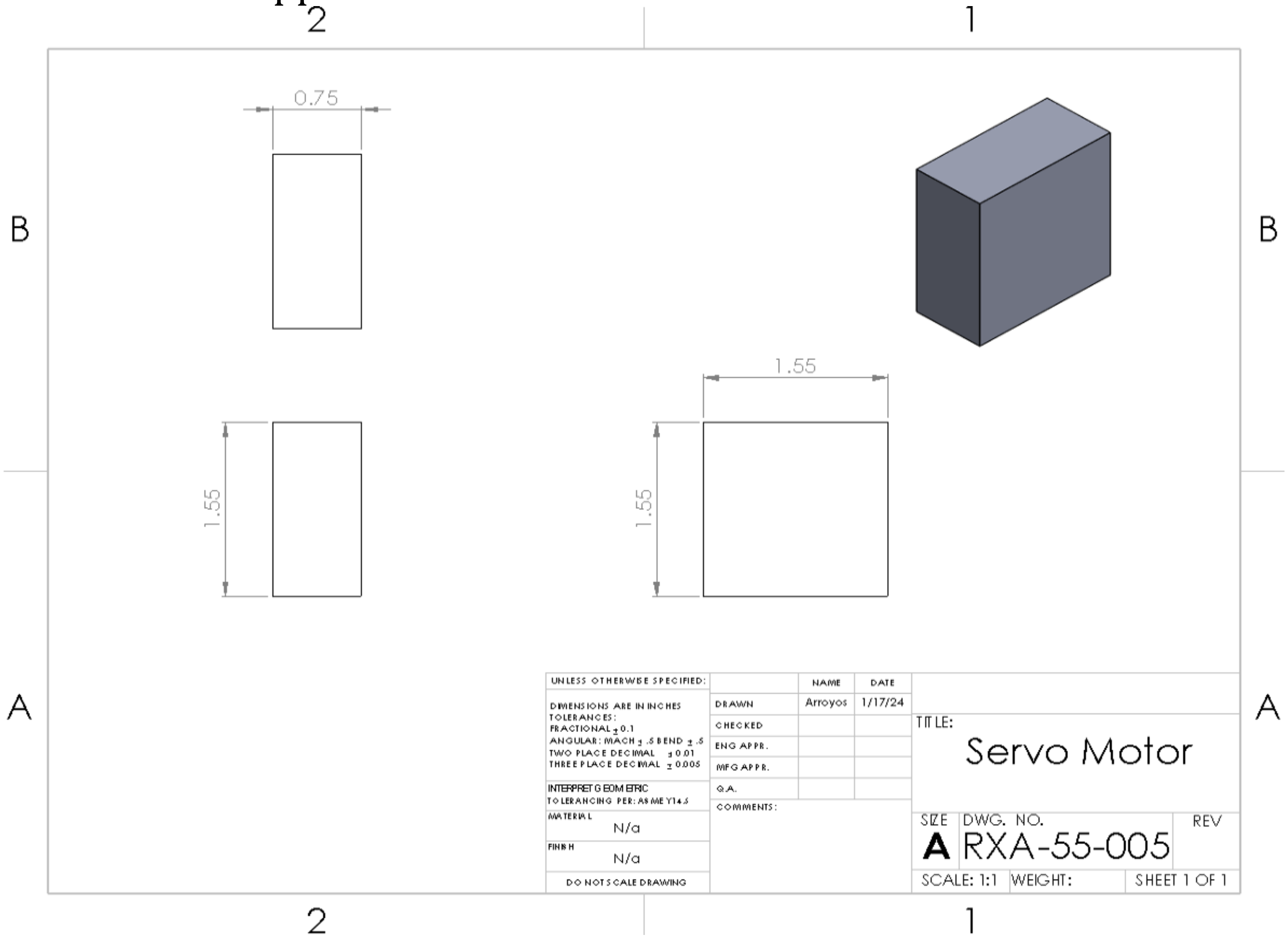


Figure B26- Servo motor drawing.

Appendix B27– <RXA-55-006> - Front Right C- Channel

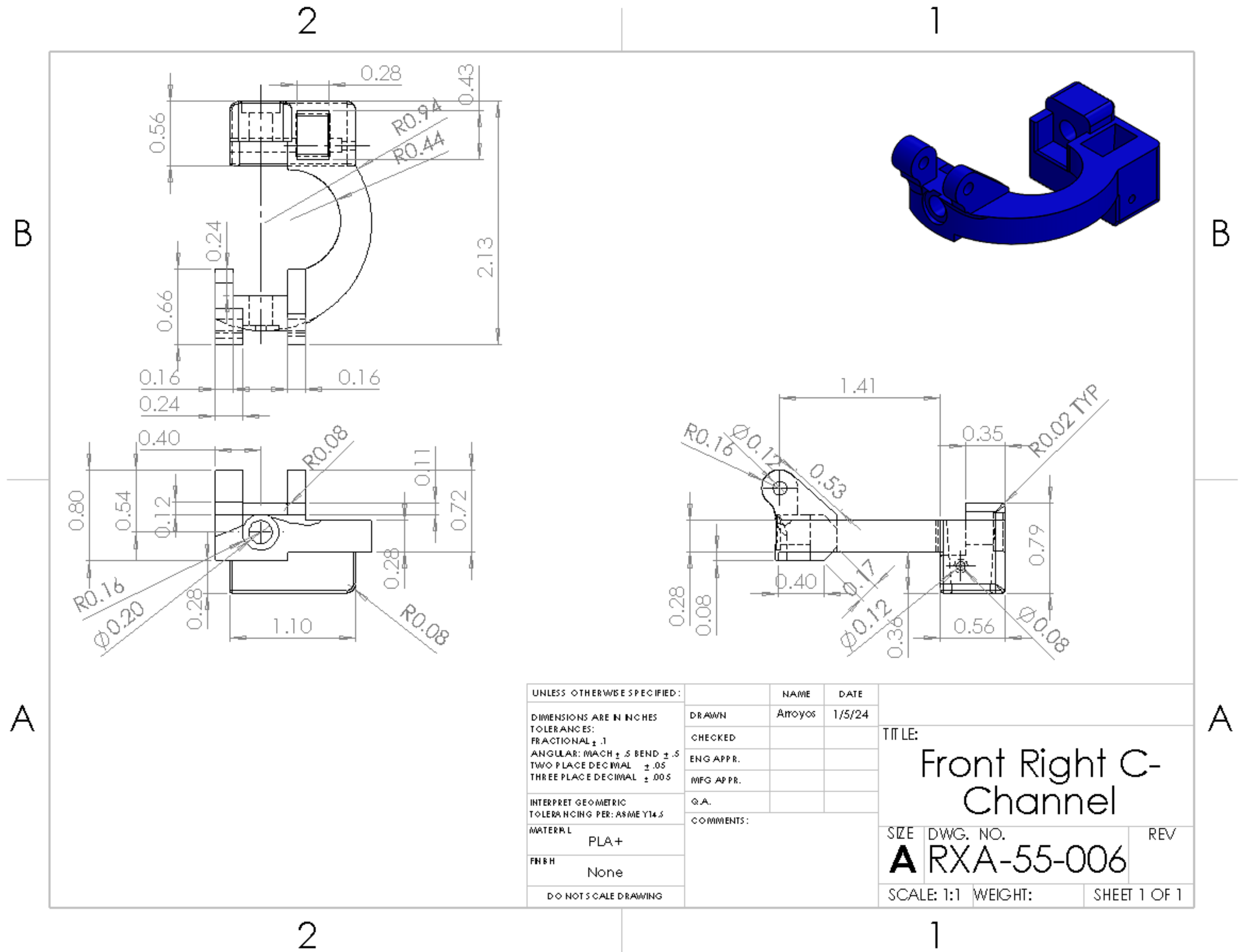


Figure B27- Front right C- Channel

Appendix B28– <RXA-55-007> - Front Left C- Channel

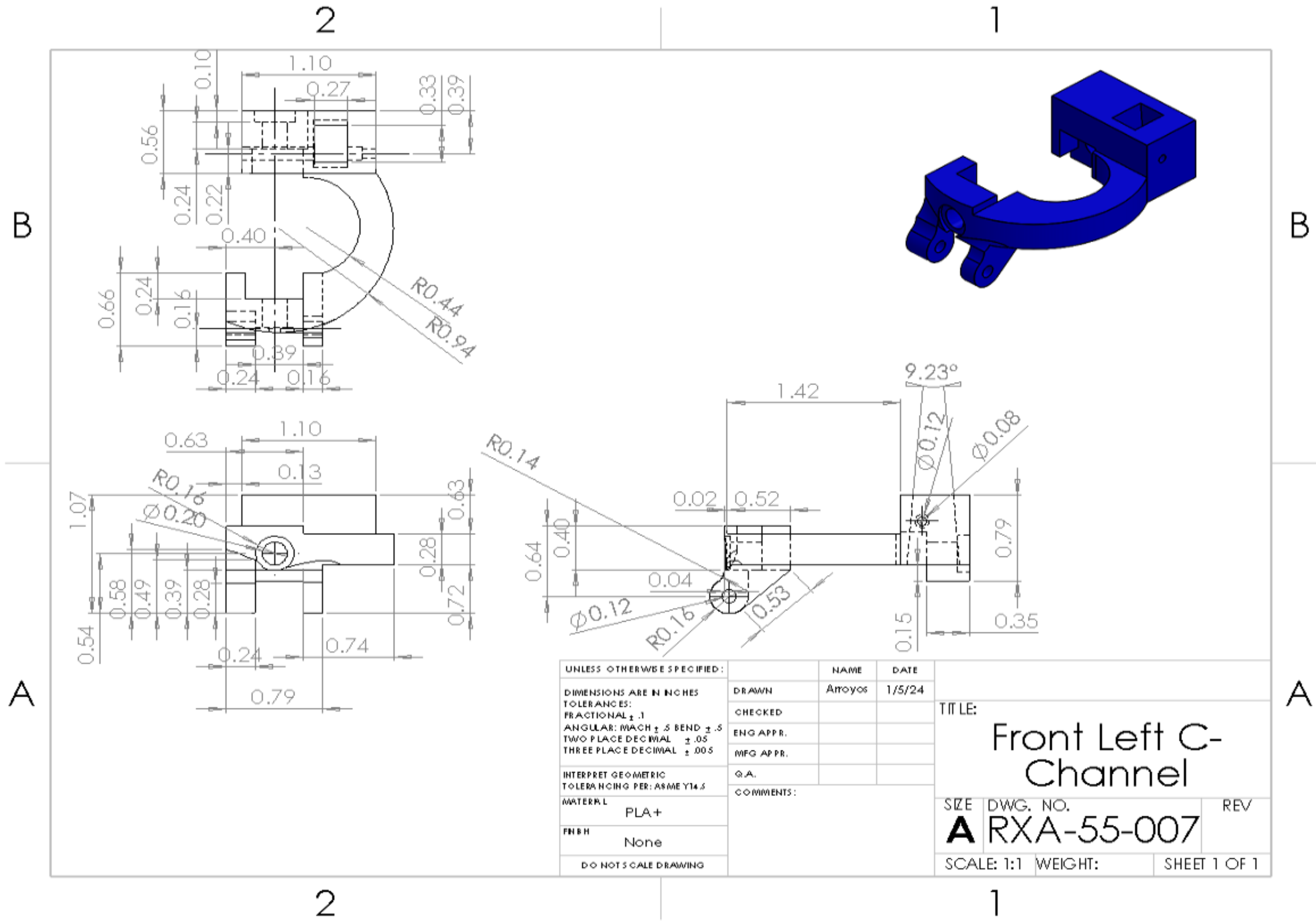


Figure B28- Front left C- channel drawing.

Appendix B29– <RXA-55-008> - Front Left Knuckle

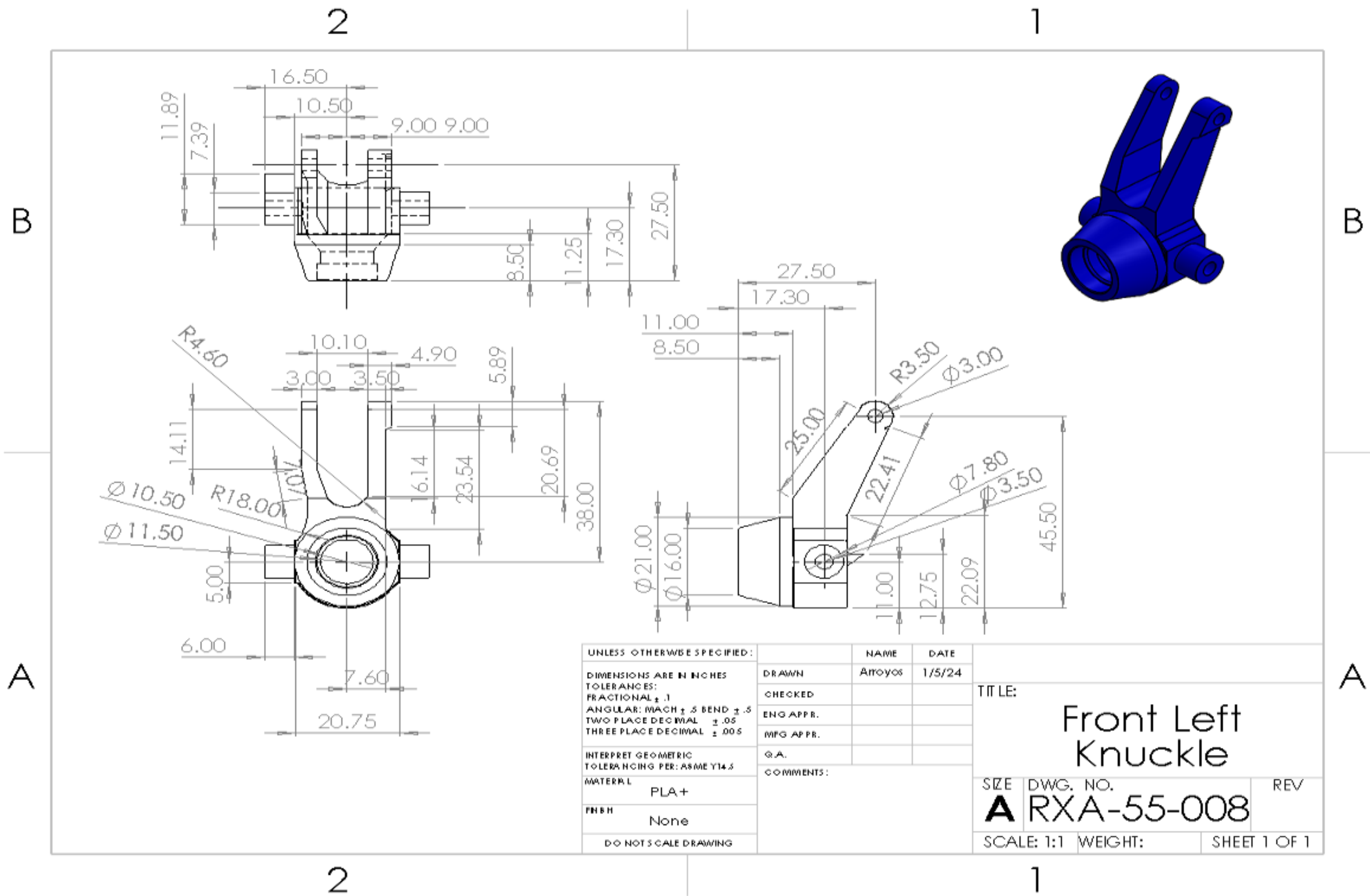


Figure B29- Front left knuckle drawing.

Appendix B30– <RXA-55-009> - Front Right Knuckle

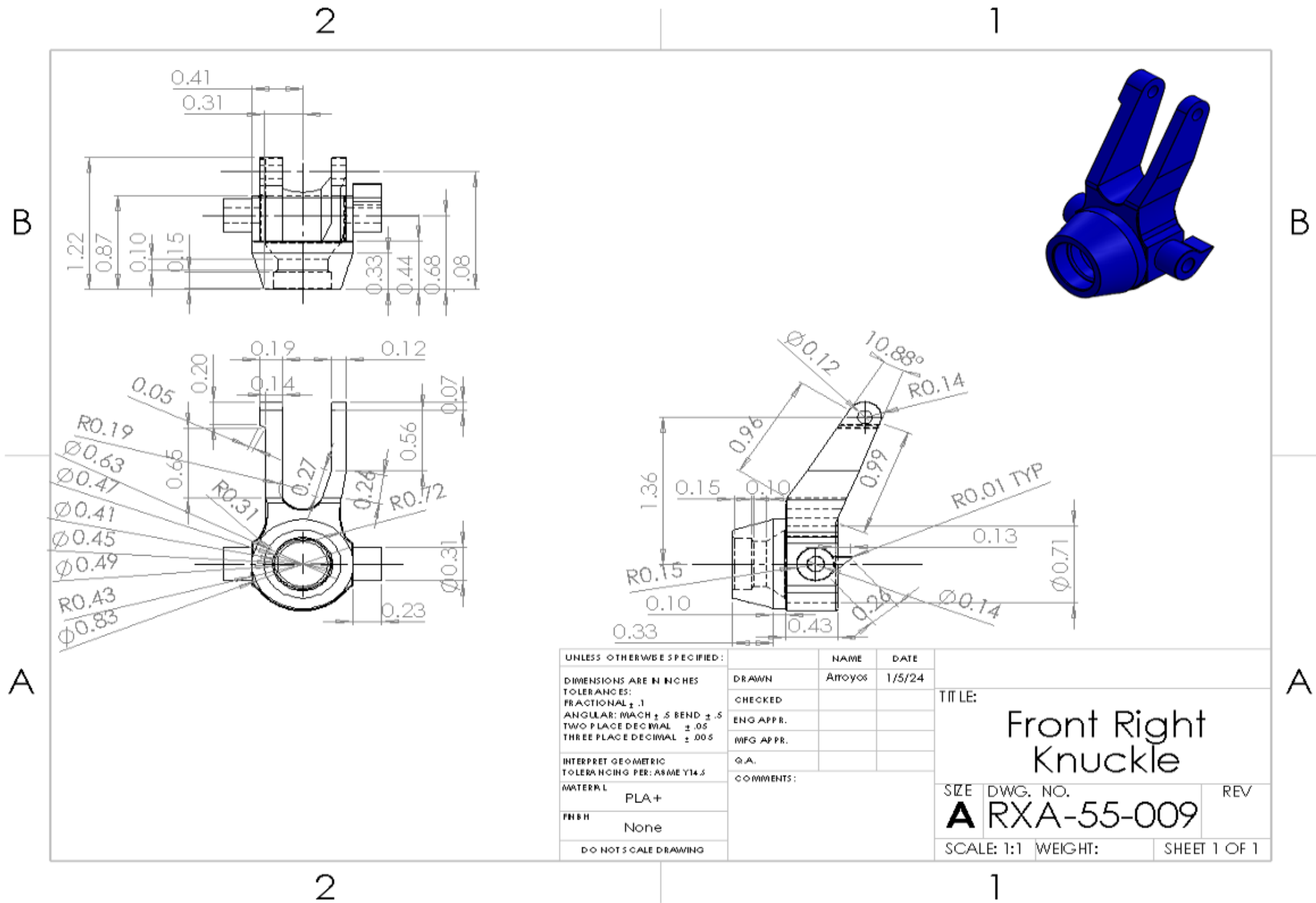


Figure B30- Front Right Knuckle drawing.

Appendix B31– <RXA-55-010> - Rear Knuckle

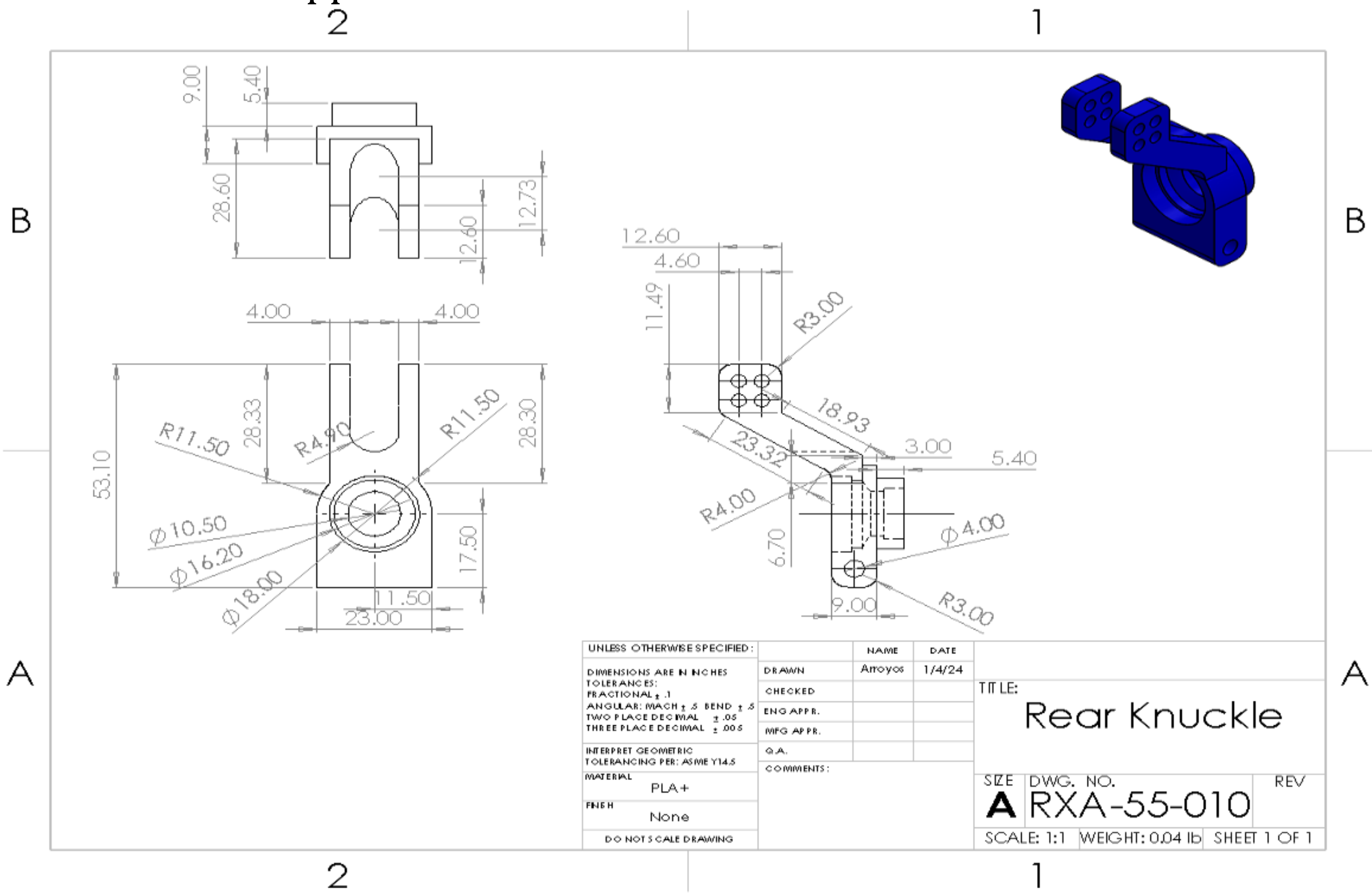


Figure B31- Rear Knuckle drawing.

Appendix B32– <RXA-55-011> - Tire

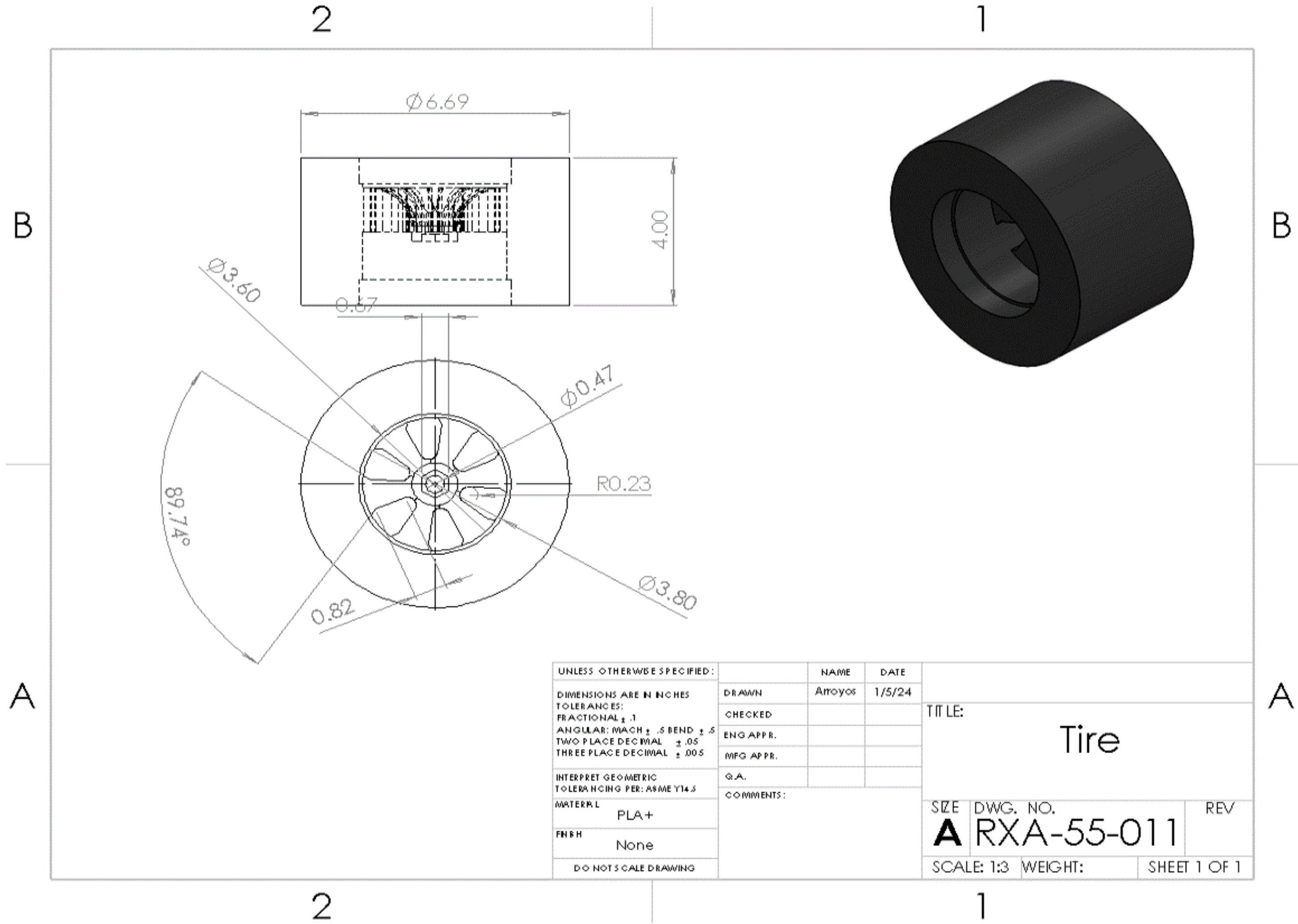


Figure B32- Tire drawing.

Appendix B33– <RXA-55-012> - ESC

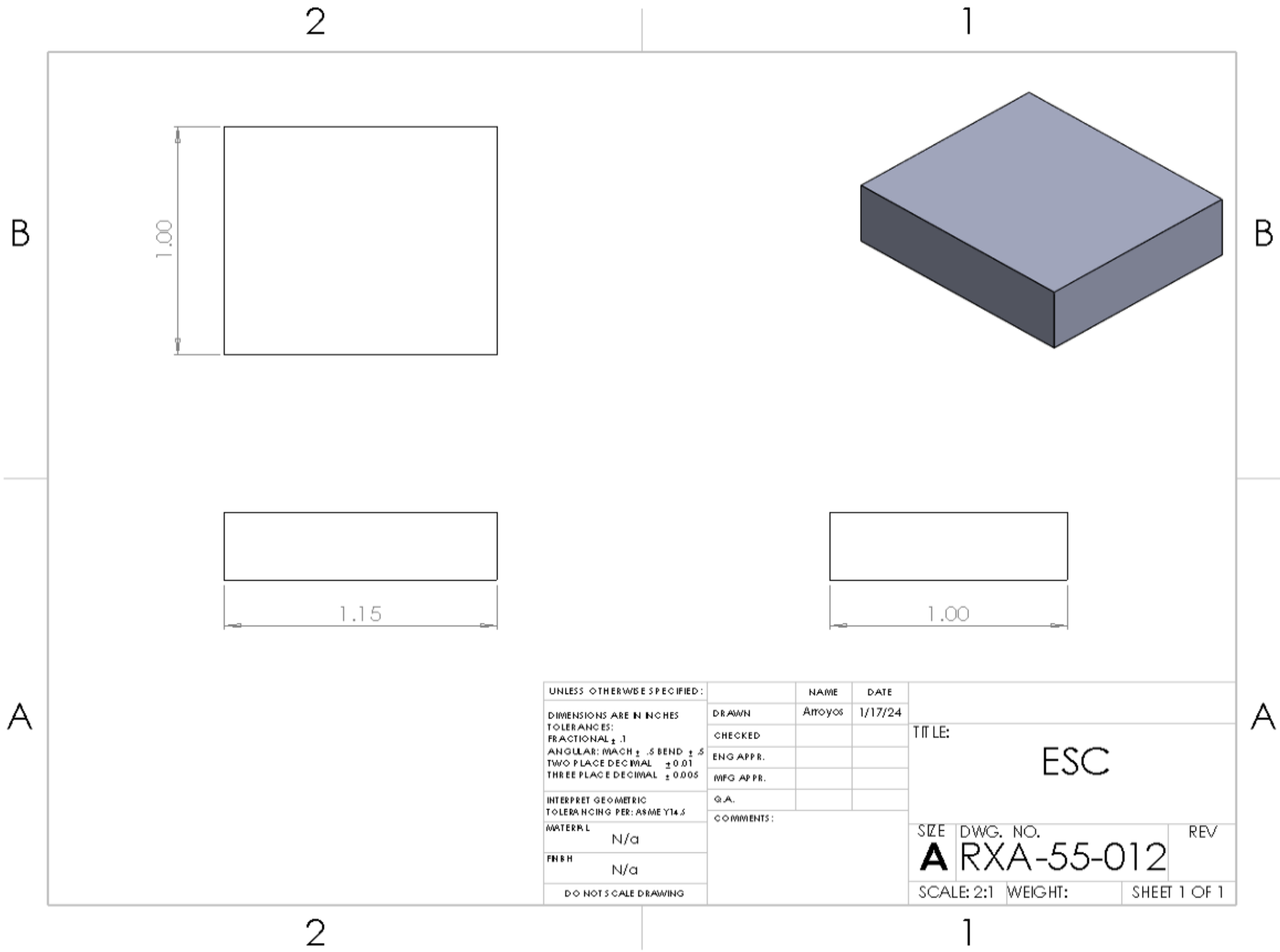


Figure B33- ESC drawing.

Appendix B34– <RCV-10-002> - Drivetrain Sub-Assembly

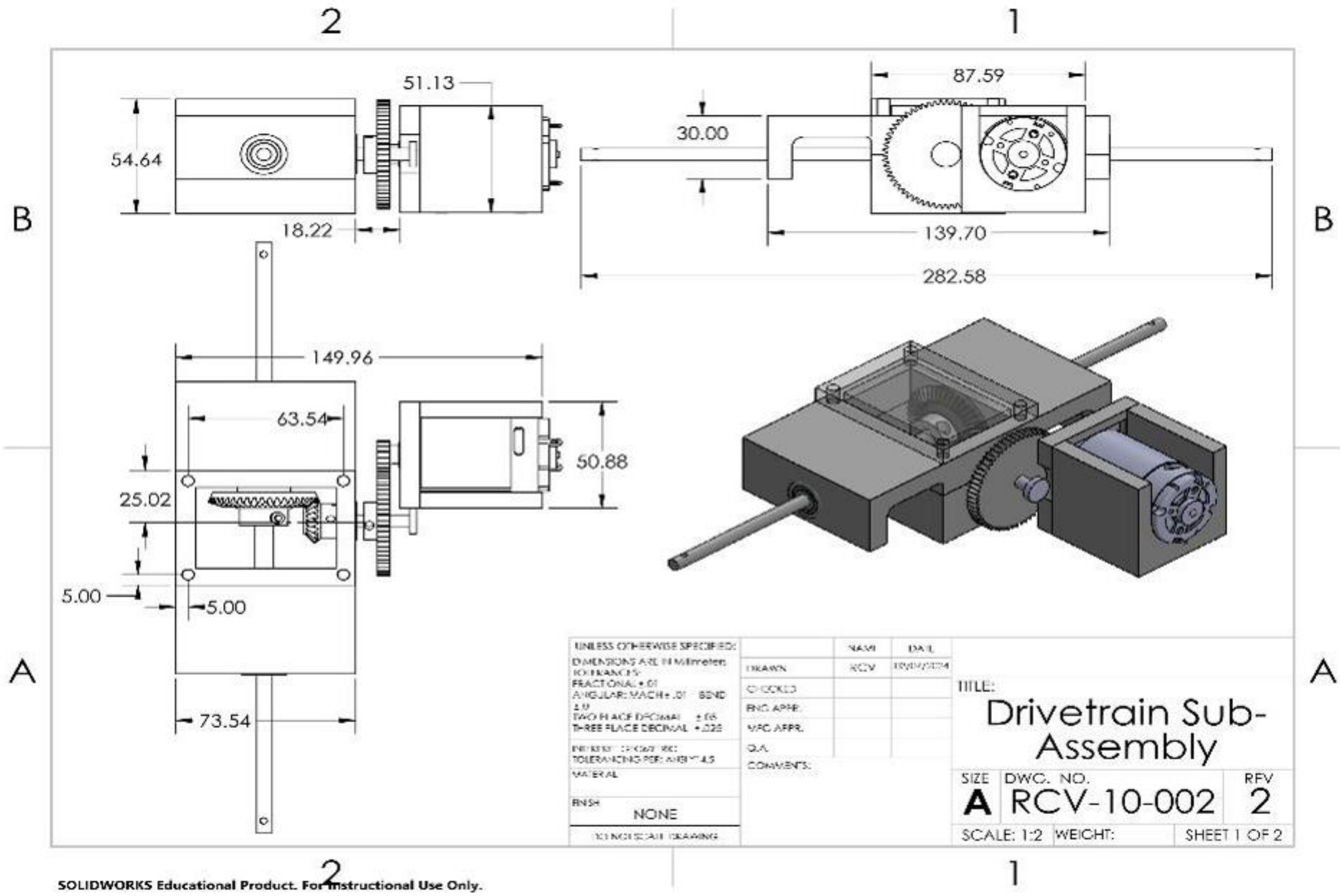
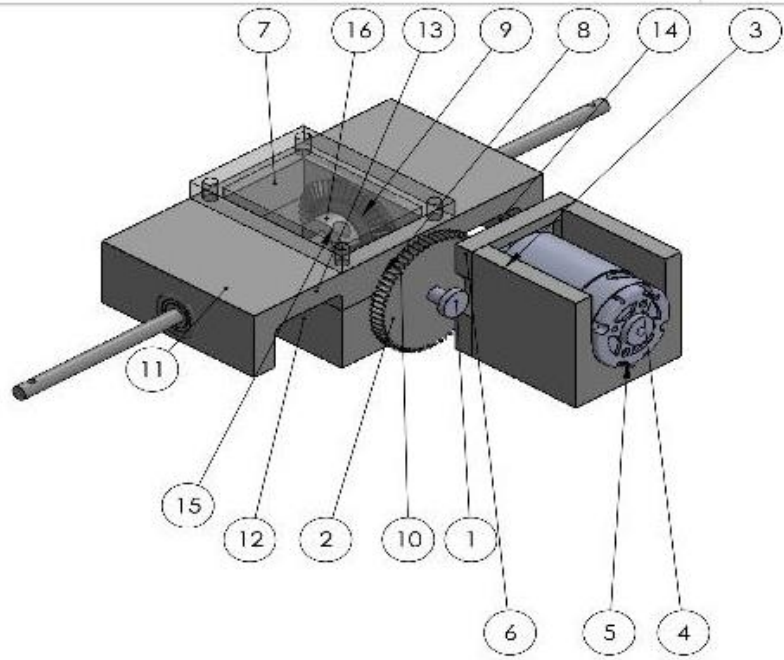


Figure B34- Drivetrain Sub-Assembly drawing.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	RCV-55-003	6mm Gear Axle	1
2	RCV-20-003	63T Spur Gear	1
3	RCV-20-001	15T Pinion Gear	1
4	RCV-55-002	Mabuchi Motor	1
5	RCV-20-005	Motor Mount	1
6	RCV-20-004	Motor Cover	1
7	RCV-20-010	Gearbox Cover	1
8	RCV-55-008	15T Bevel Gear	1
9	RCV-55-009	45T Bevel Gear	1
10	RCV-55-007	6mm Ballbearing	5
11	RCV-20-011	Rear Axle	1
12	RCV-20-015	Gearbox Bottom Half	1
13	RCV-20-016	Gearbox Top Half	1
14	RCV-20-018	Axle Support Clamp	1
15	RCV-20-012	Square Key	1
16	RCV-20-017	8mm Bore Shaft Collar	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN Millimeters
TOLERANCES:
FRACTIONAL ±.01
ANGULAR: MACH ± .01 BEND ±.01
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.025
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5
MATERIAL
FINISH NONE
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RCV	03/07/2024
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE: Drivetrain Sub-Assembly

SIZE A DWG. NO. RCV-10-002 REV 2

SCALE: 1:2 WEIGHT: SHEET 2 OF 2

SOLIDWORKS Educational Product. For Instructional Use Only.

Figure B34.1- Drive Train Sub-Assembly drawing continued.

Appendix B35– <RCV-10-003> - Chassis Sub-Assembly

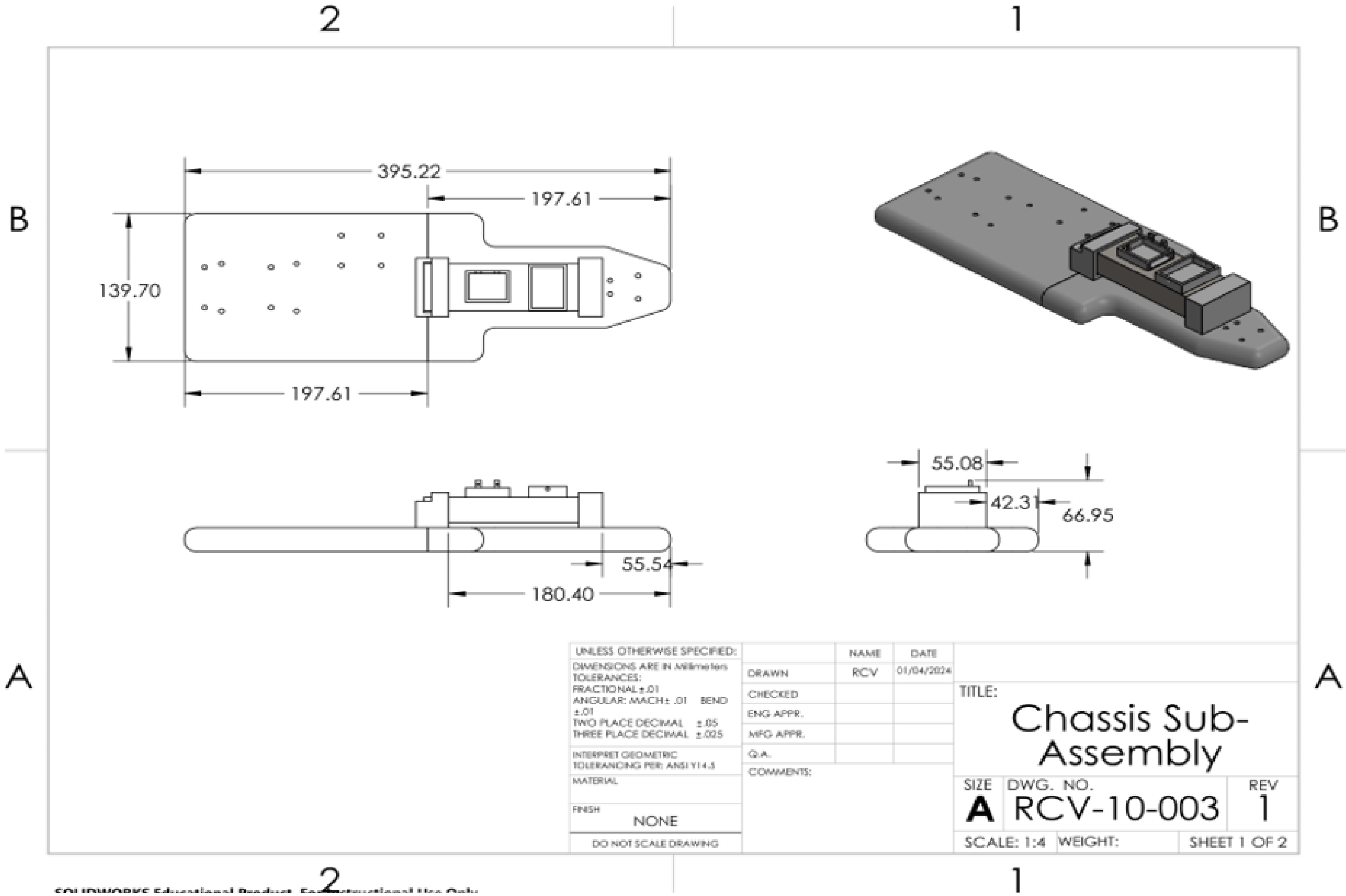
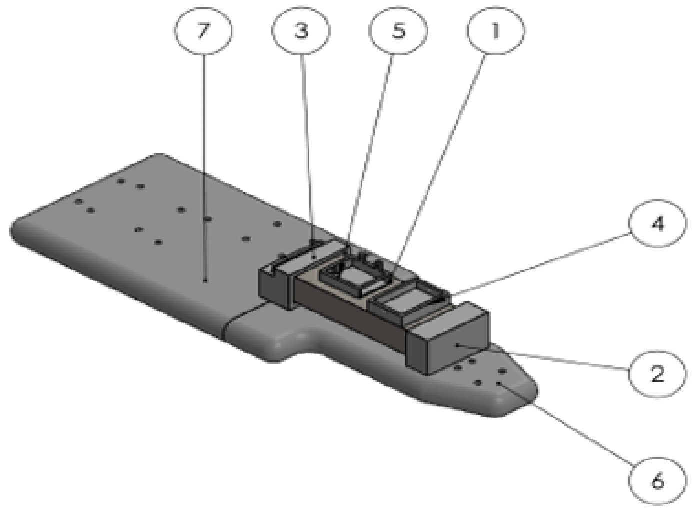


Figure B35- Chassis Sub-Assembly drawing.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	RCV-55-001	Lipo Battery	1
2	RCV-20-006	Right Side Battery Mount	1
3	RCV-20-007	Left Side Battery Mount	1
4	RXA-20-009	Receiver Mount	1
5	RXA-20-010	UBEC Mount	1
6	RCV-20-013	Chassis Front Section	1
7	RCV-20-014		1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN Millimeters
TOLERANCES:
FRACTIONAL ±.01
ANGULAR: MACH ± .01 BEND ±.01
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.025

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5
MATERIAL
FINISH NONE
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RCV	01/04/2024
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Chassis Sub-Assembly

SIZE A | DWG. NO. RCV-10-003 | REV 1

SCALE: 1:4 | WEIGHT: | SHEET 2 OF 2

Figure B35.1- Chassis Sub-Assembly drawing continued.

Appendix B36– <RCV-20-001> - 16T Spur Gear

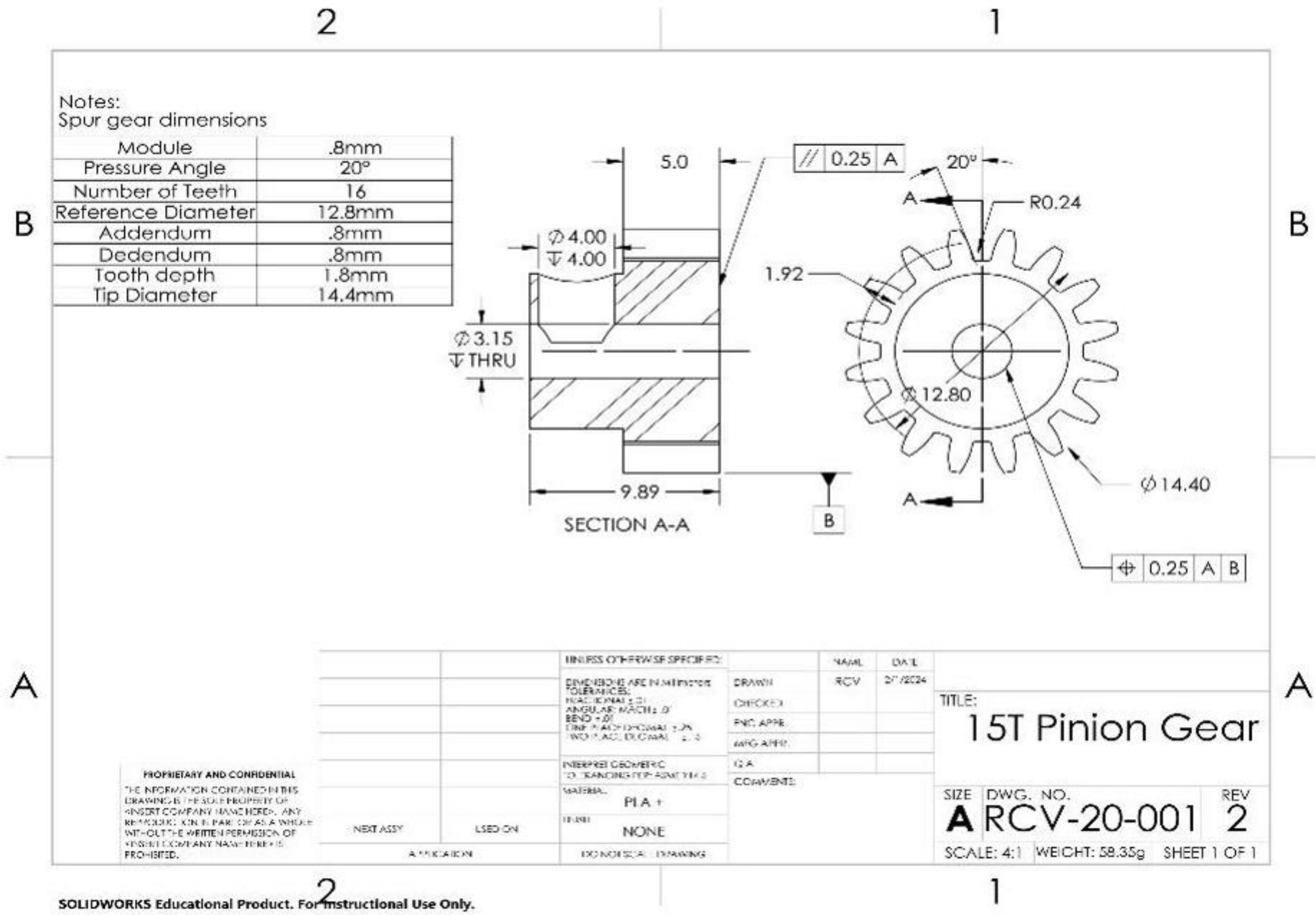


Figure B36- 16T Spur Gear drawing.

Appendix B37– <RCV-20-002> - Chassis

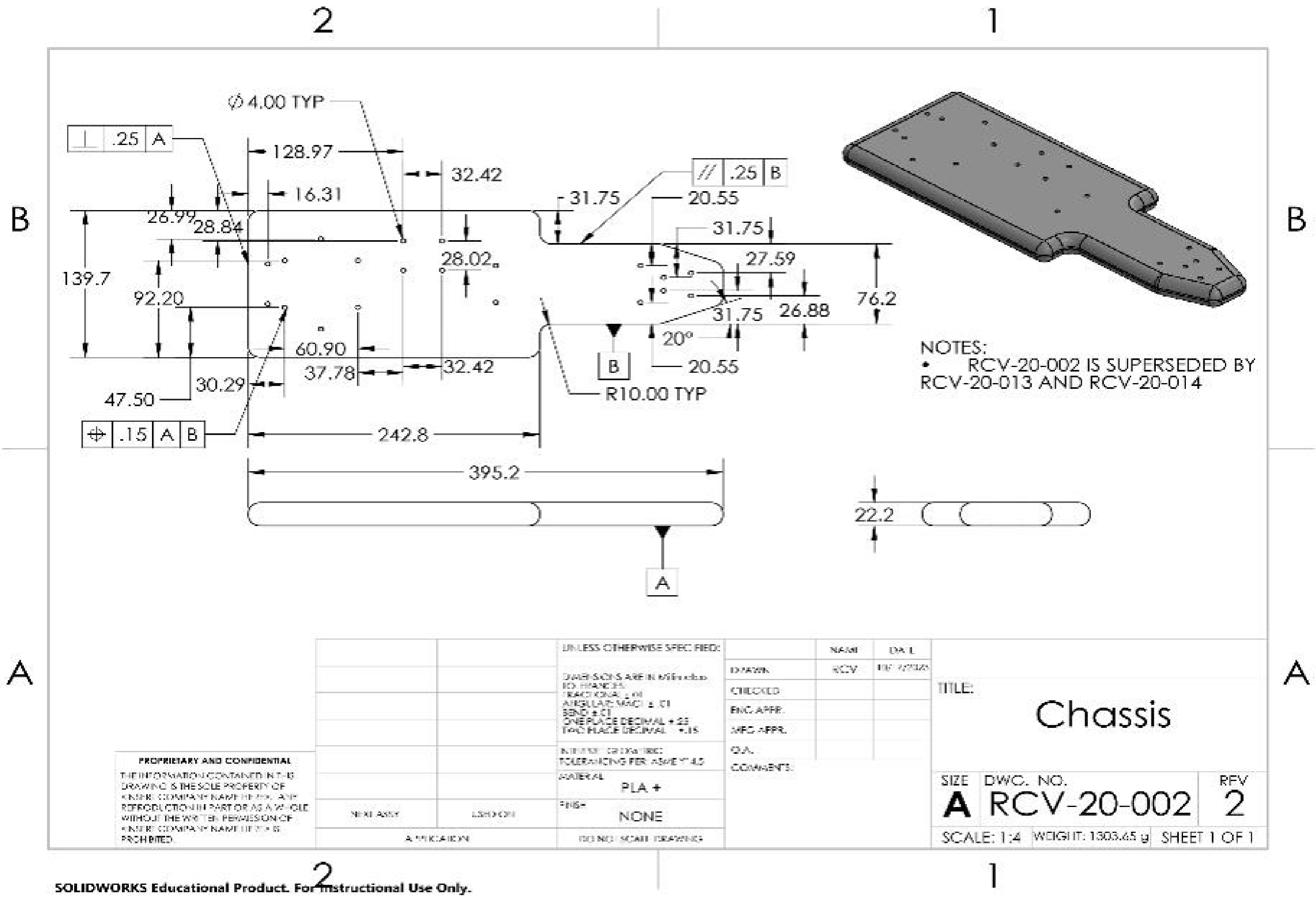


Figure B37- Chassis drawing.

Appendix B38– <RCV-20-003> - 63T Spur Gear

Note:
Pinion Gear dimensions

Module	.8mm
Pressure Angle	20°
Number of Teeth	63
Reference Diameter	50.40mm
Addendum	.8mm
Dedendum	.8mm
Tooth depth	1.8mm
Tip Diameter	52.00mm

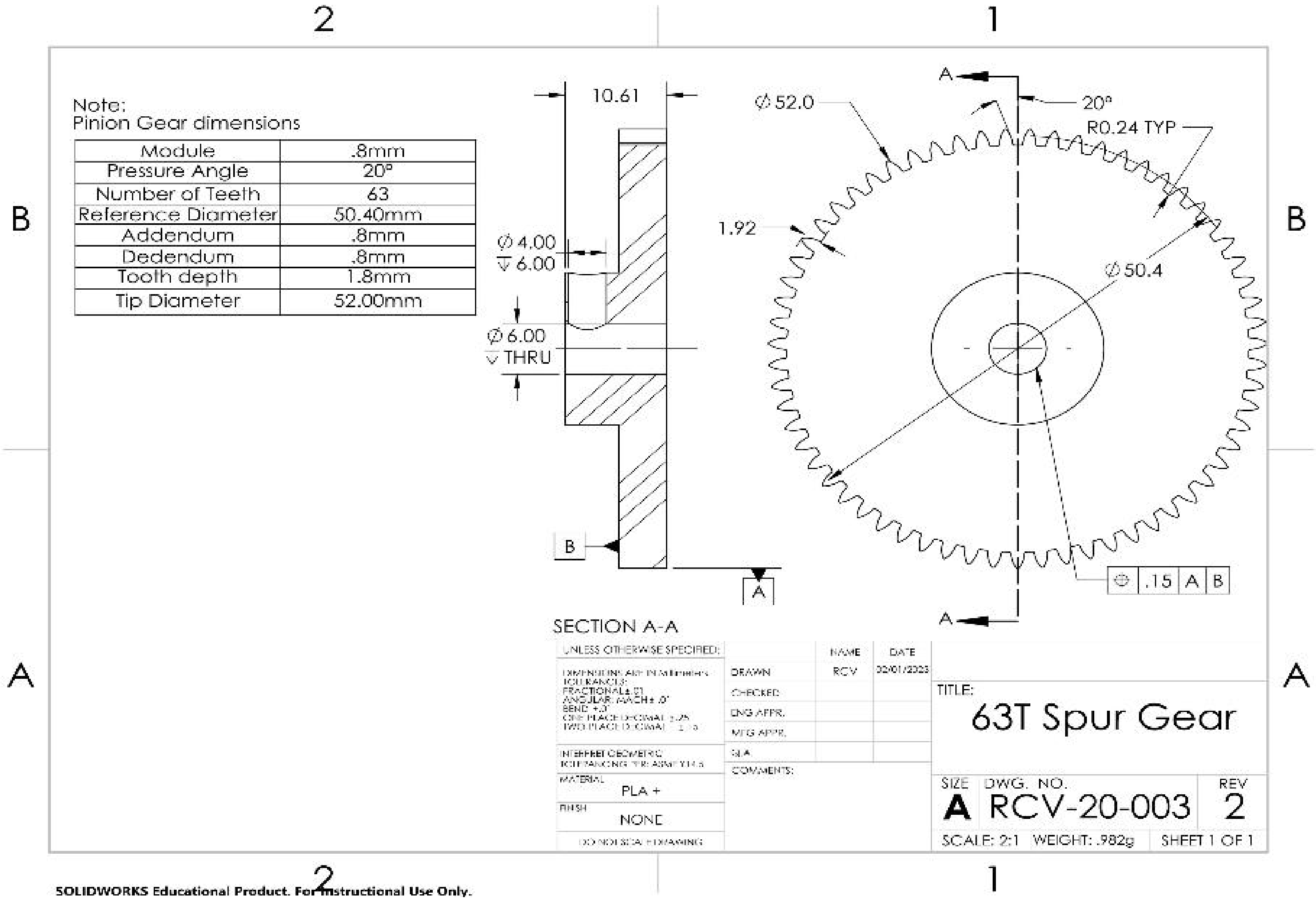


Figure B38- 63T Spur Gear drawing.

Appendix B39– <RCV-20-004> - Motor Cover

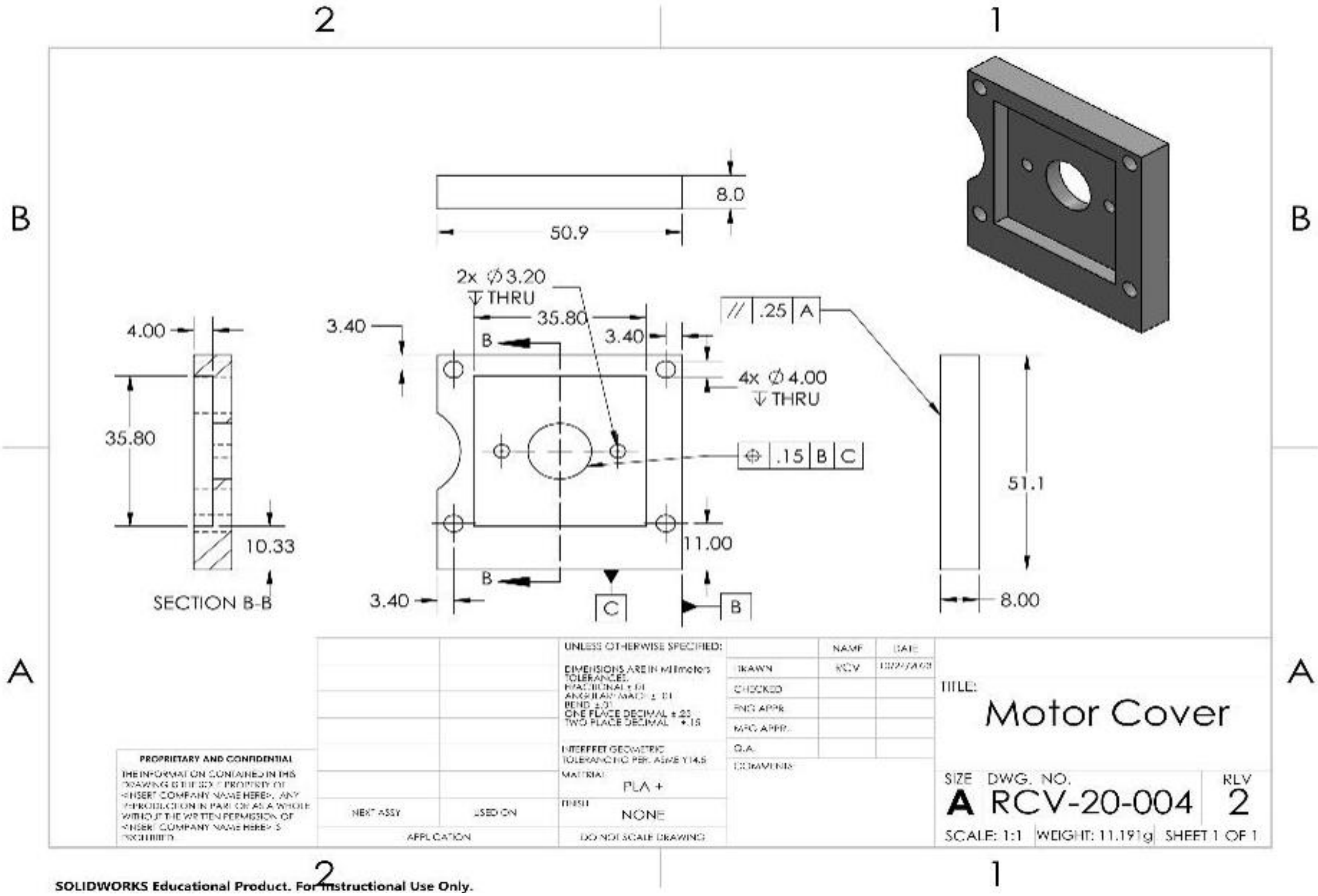


Figure B39- Motor Cover drawing.

Appendix B40– <RCV-20-005> - Motor Mount

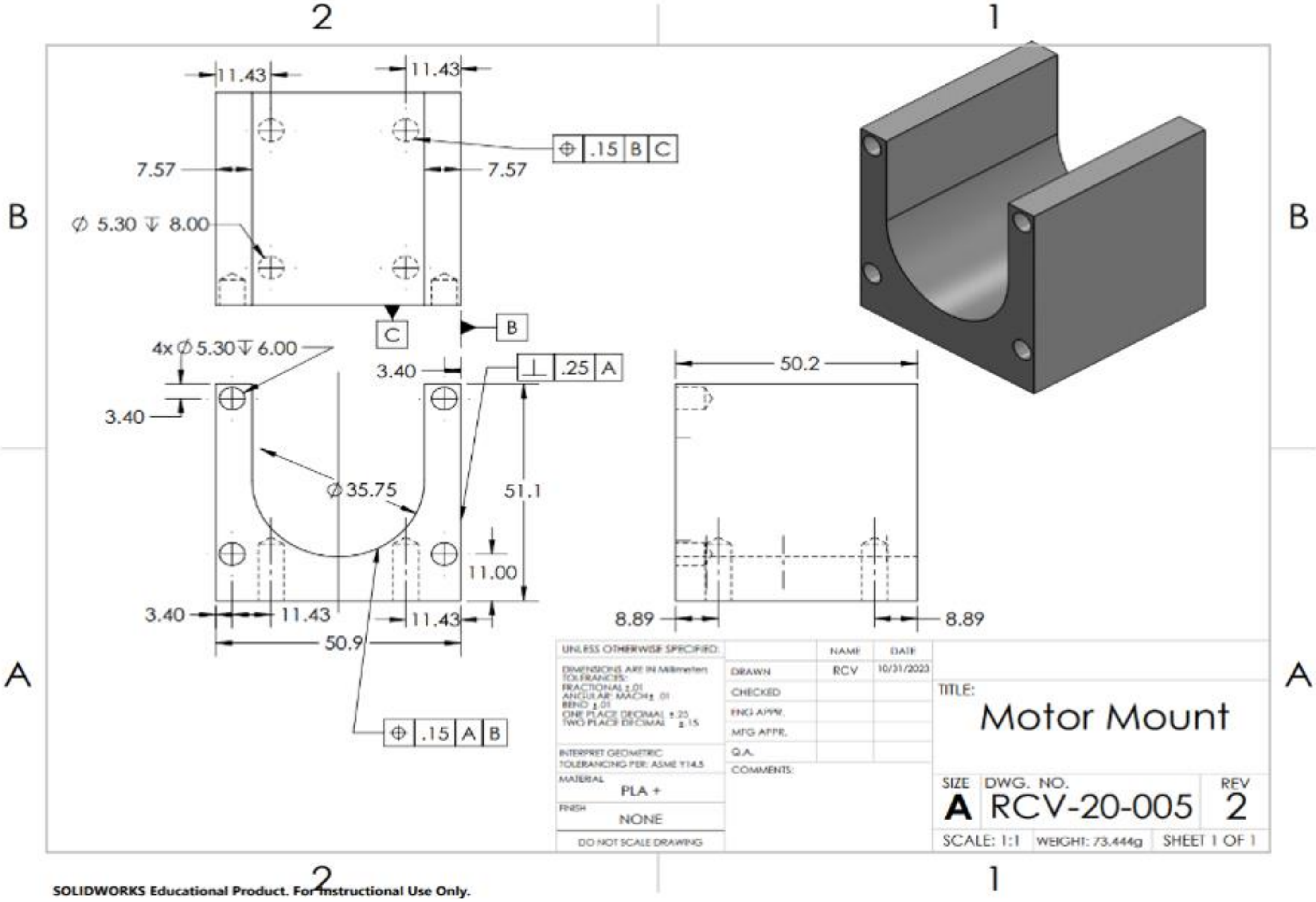


Figure B40- Motor Mount drawing.

Appendix B41– <RCV-20-006> - Right Side Battery Mount

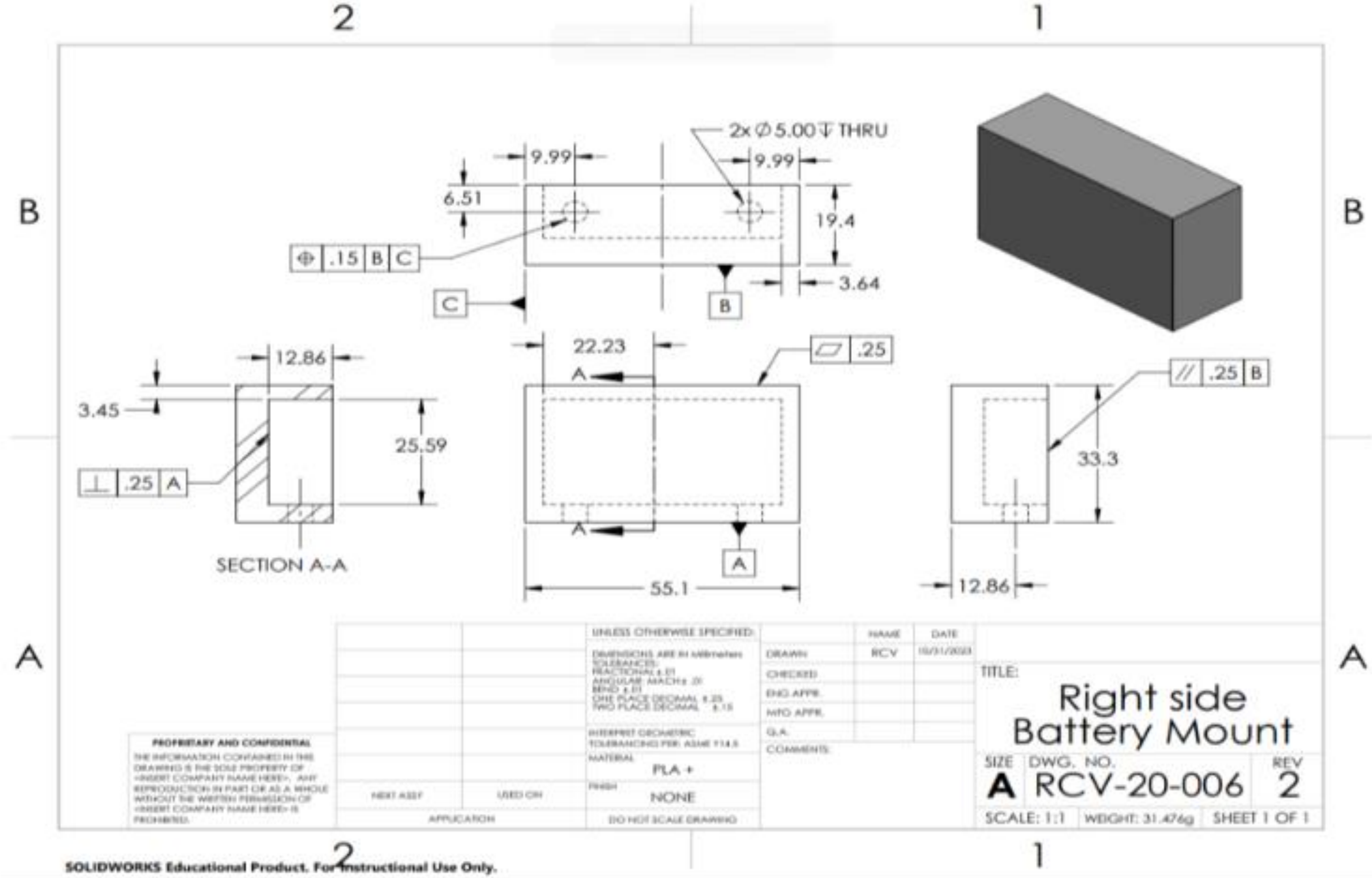


Figure B41- Right Side Battery Mount drawing.

Appendix B42– <RCV-20-007> - Left Side Battery Mount

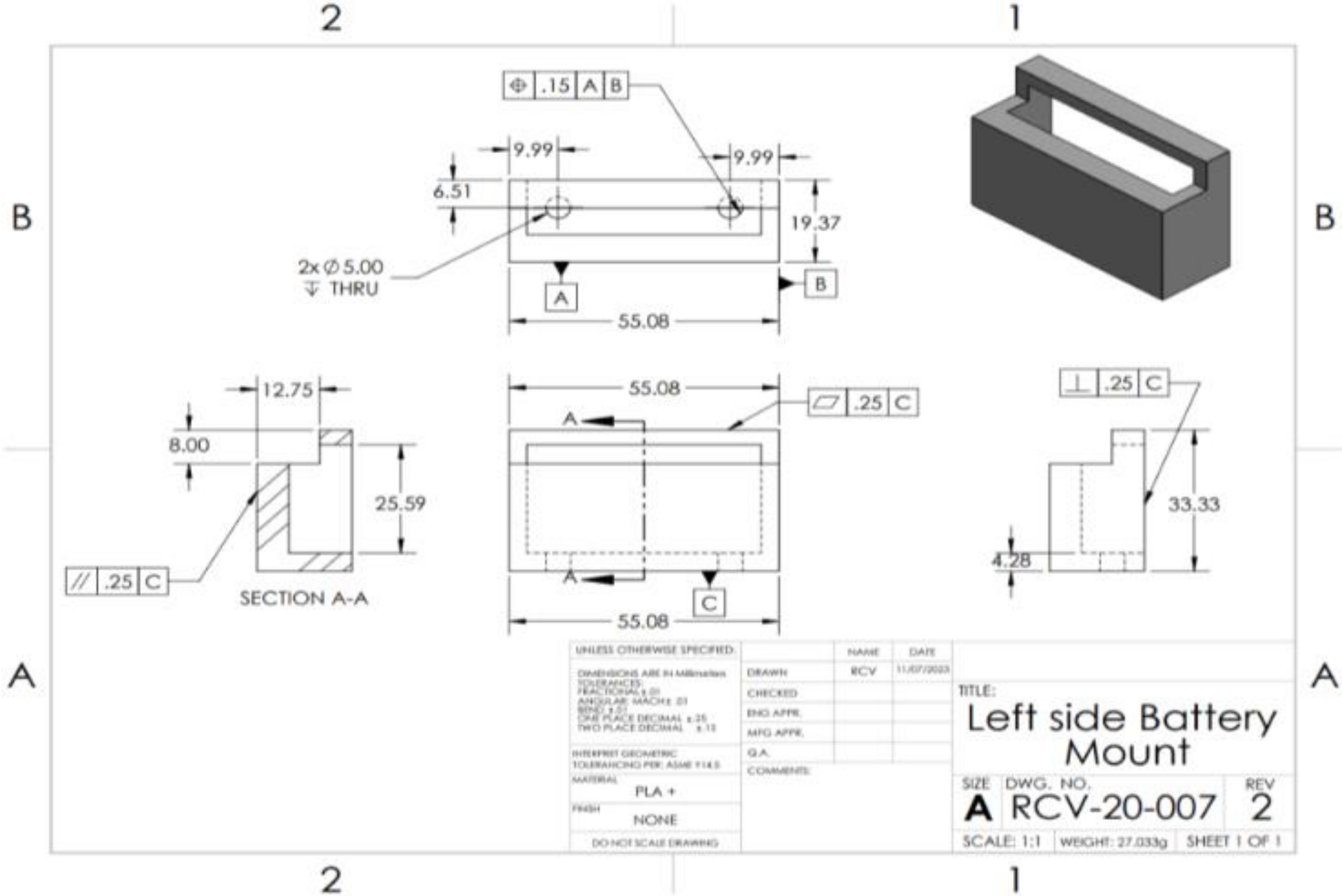


Figure B42- Left Side Battery Mount drawing.

Appendix B43- <RCV-20-008> - Gear Bore Reducer

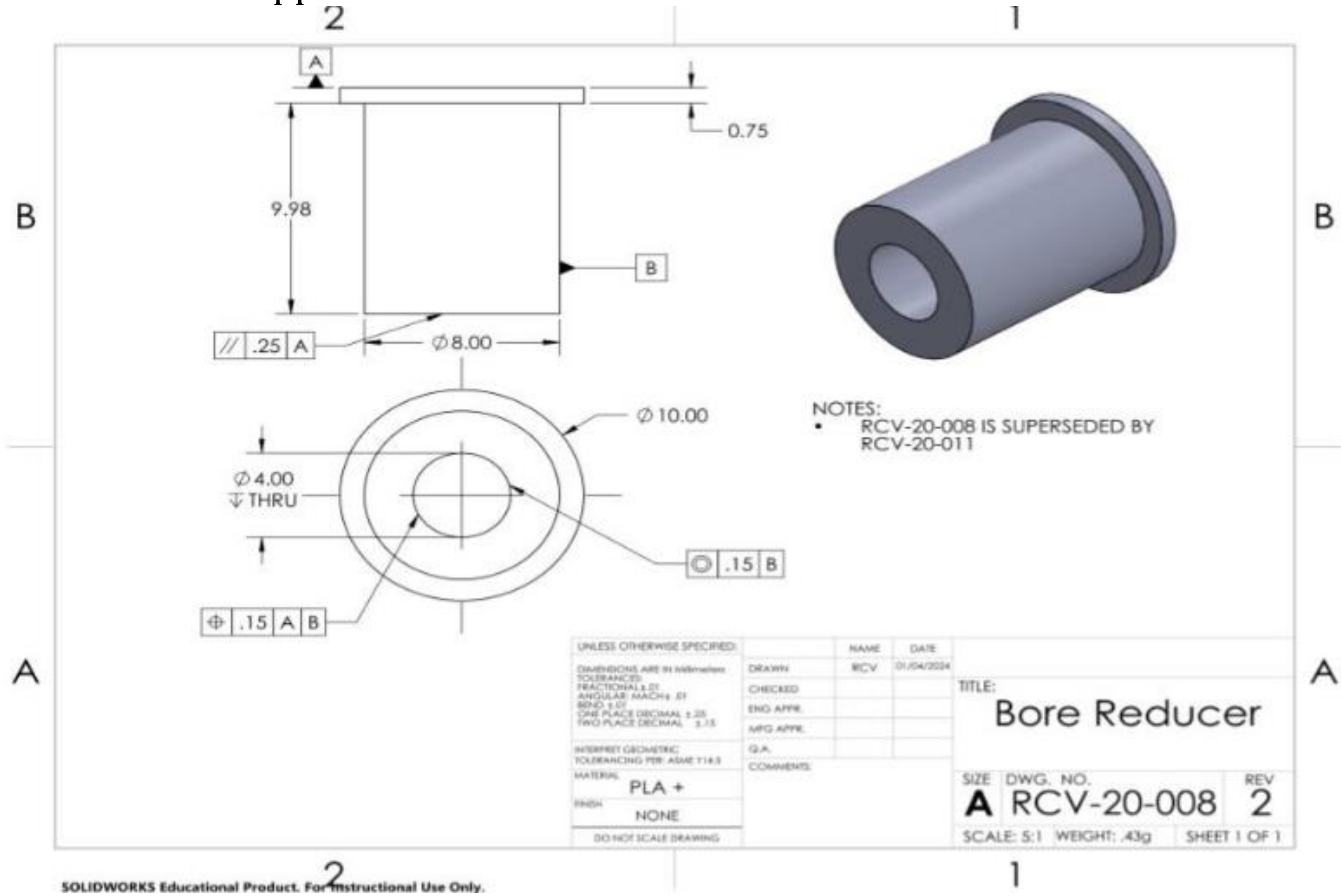


Figure B43- Bore Reducer drawing.

Appendix B44- <RCV-20-009> - Gearbox

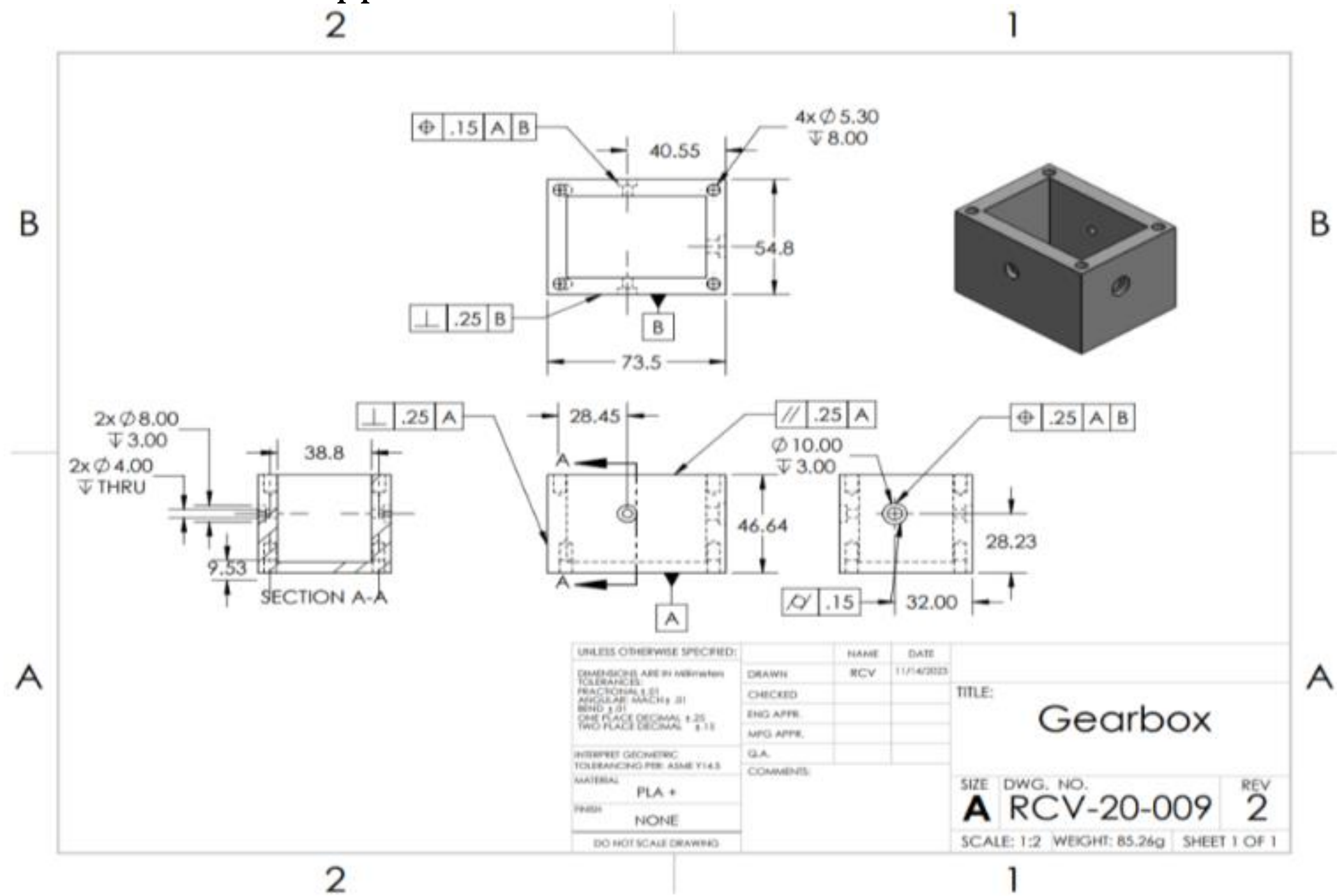


Figure B44- Gearbox drawing.

Appendix B45– <RCV-20-010> - Gearbox Cover

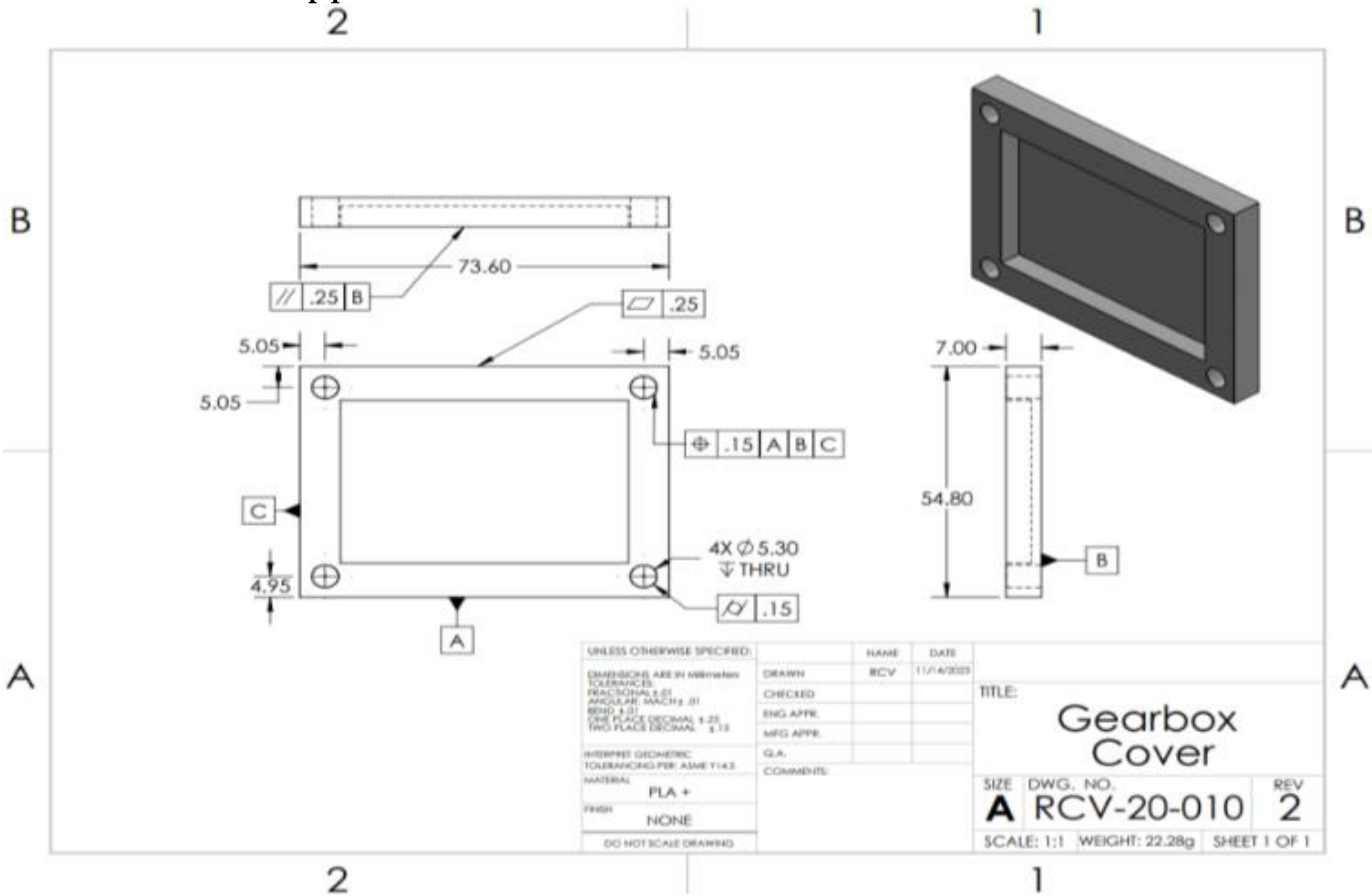


Figure B45- Gearbox Cover drawing.

Appendix B46– <RCV-20-011> - Rear Axle Couple

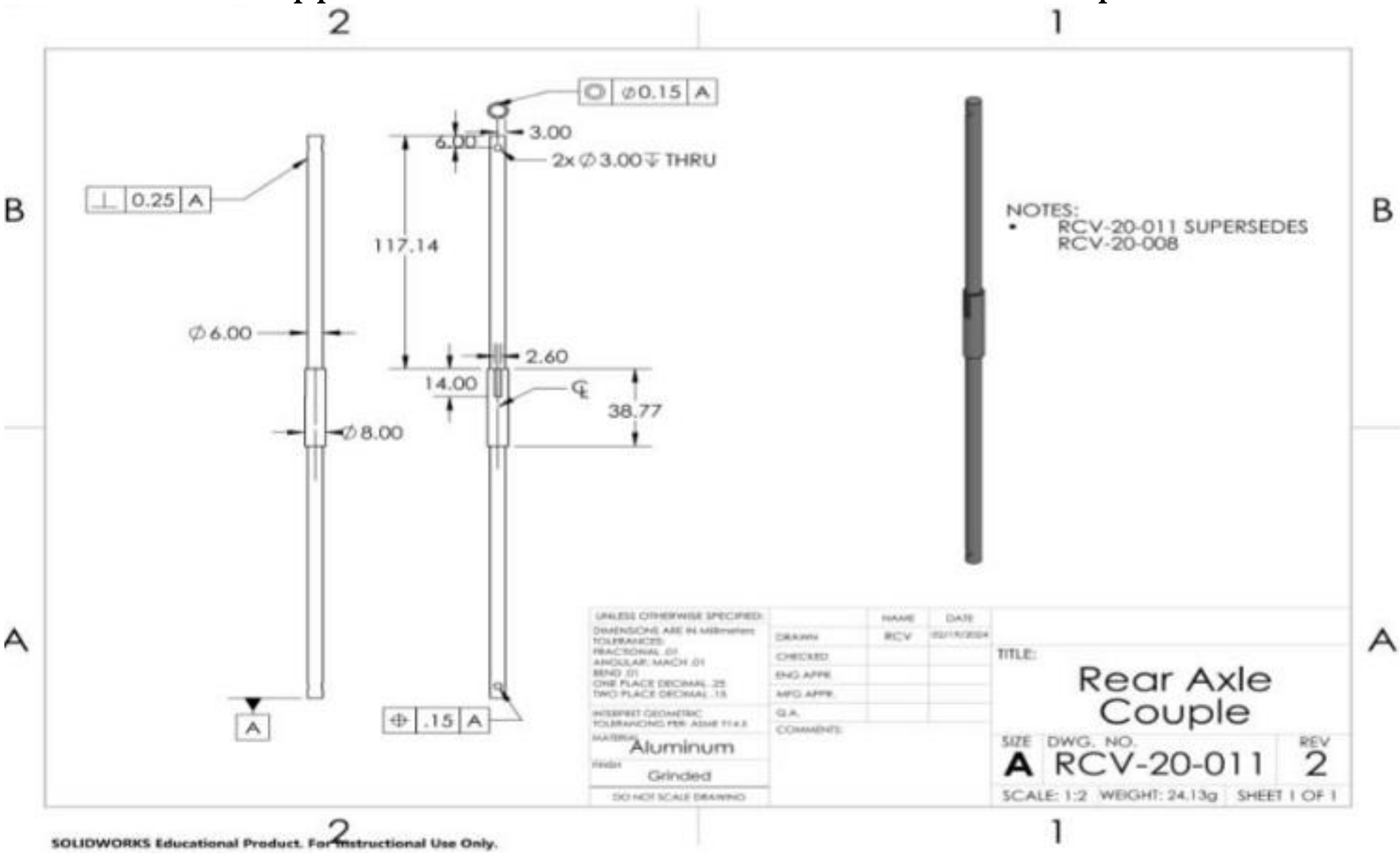


Figure B46- Rear Axle Couple Drawing.

Appendix B47– <RCV-20-012> - Rear Axle Square Key

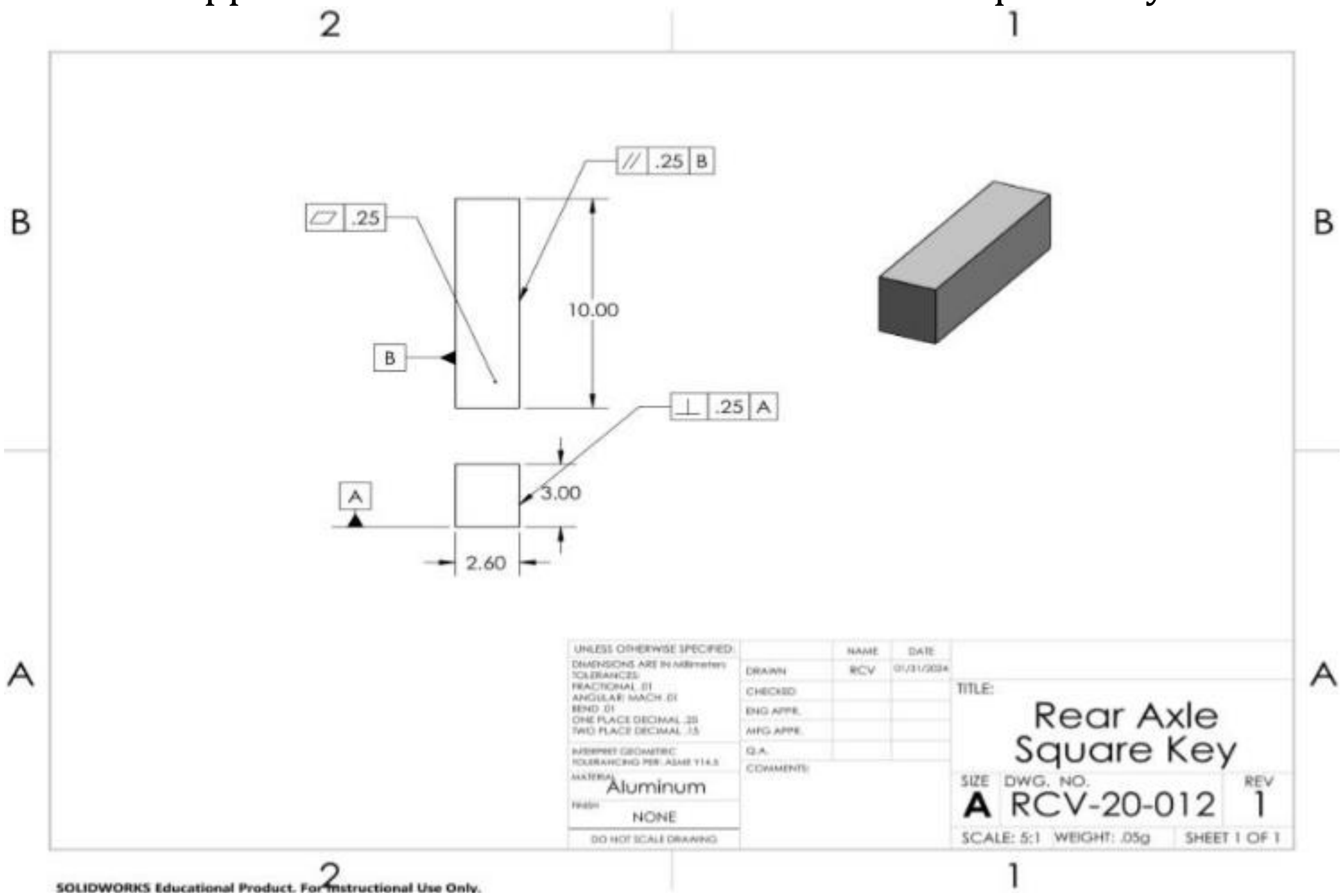


Figure B47- Rear Axle Square Key Drawing.

Appendix B48– <RCV-20-013> - Front Chassis Section

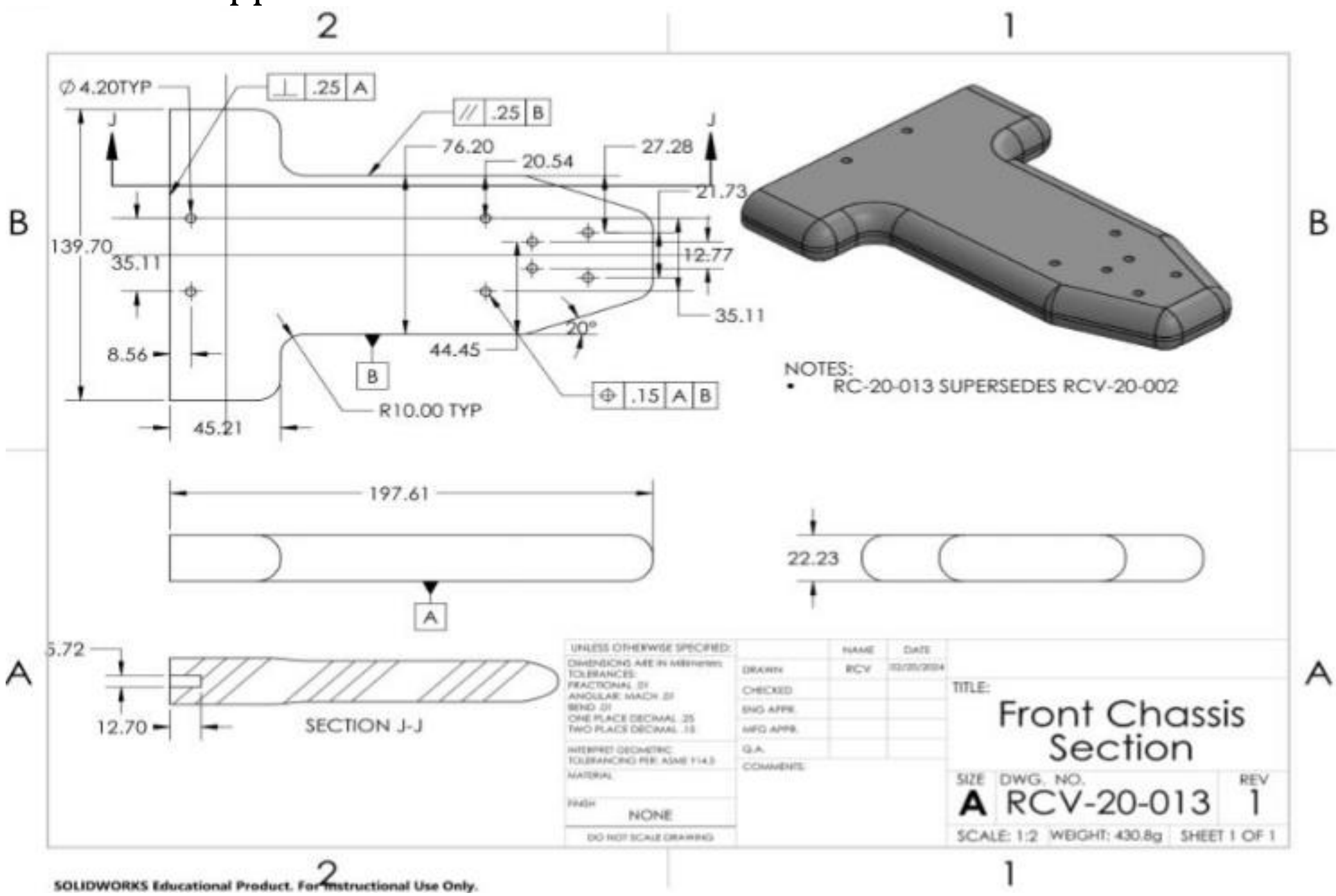


Figure B48- Front Chassis Section Drawing.

Appendix B49– <RCV-20-014> - Rear Chassis Section

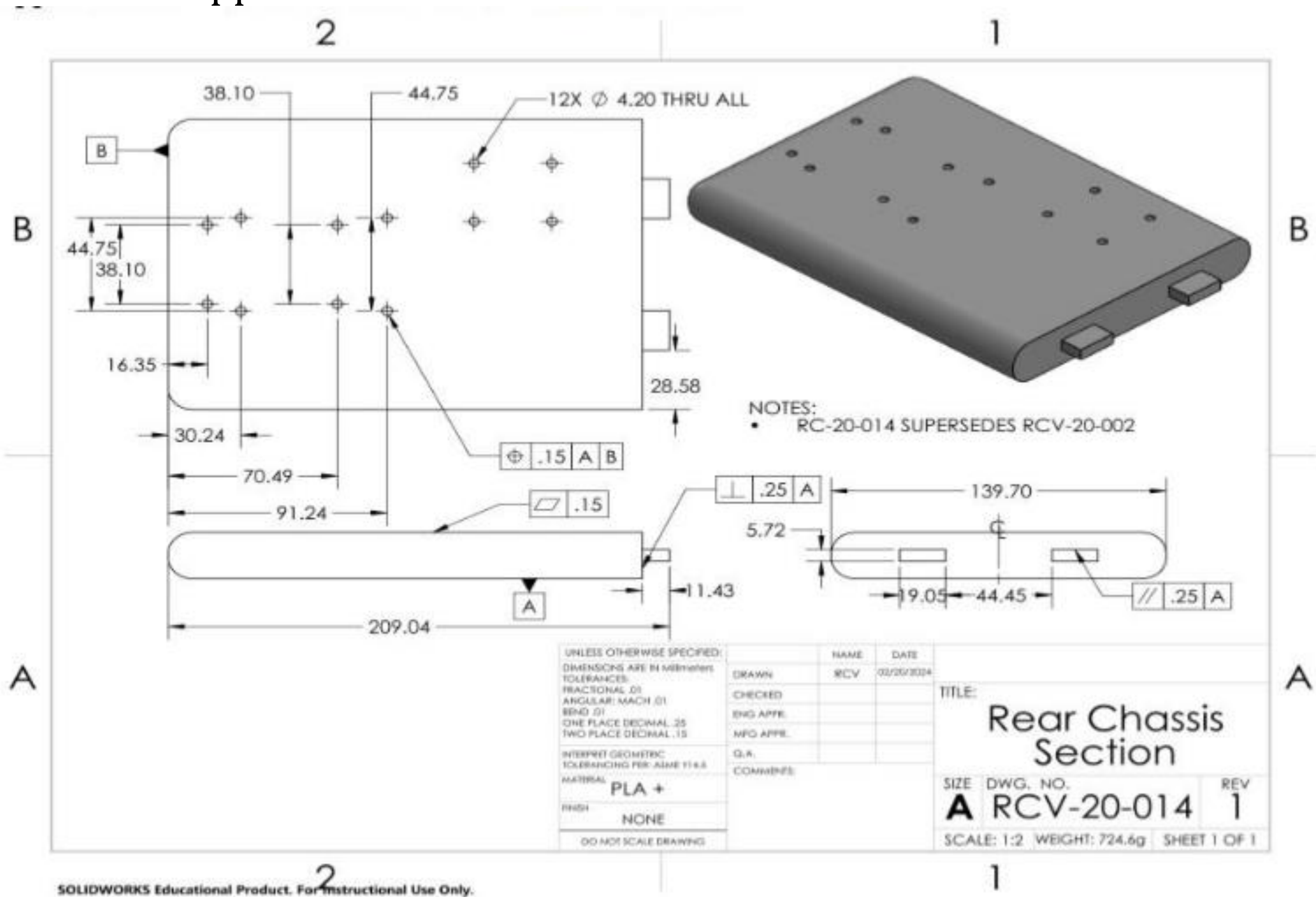


Figure B49- Rear Chassis Section Drawing.

Appendix B50– <RCV-20-015> - Gearbox Bottom Half

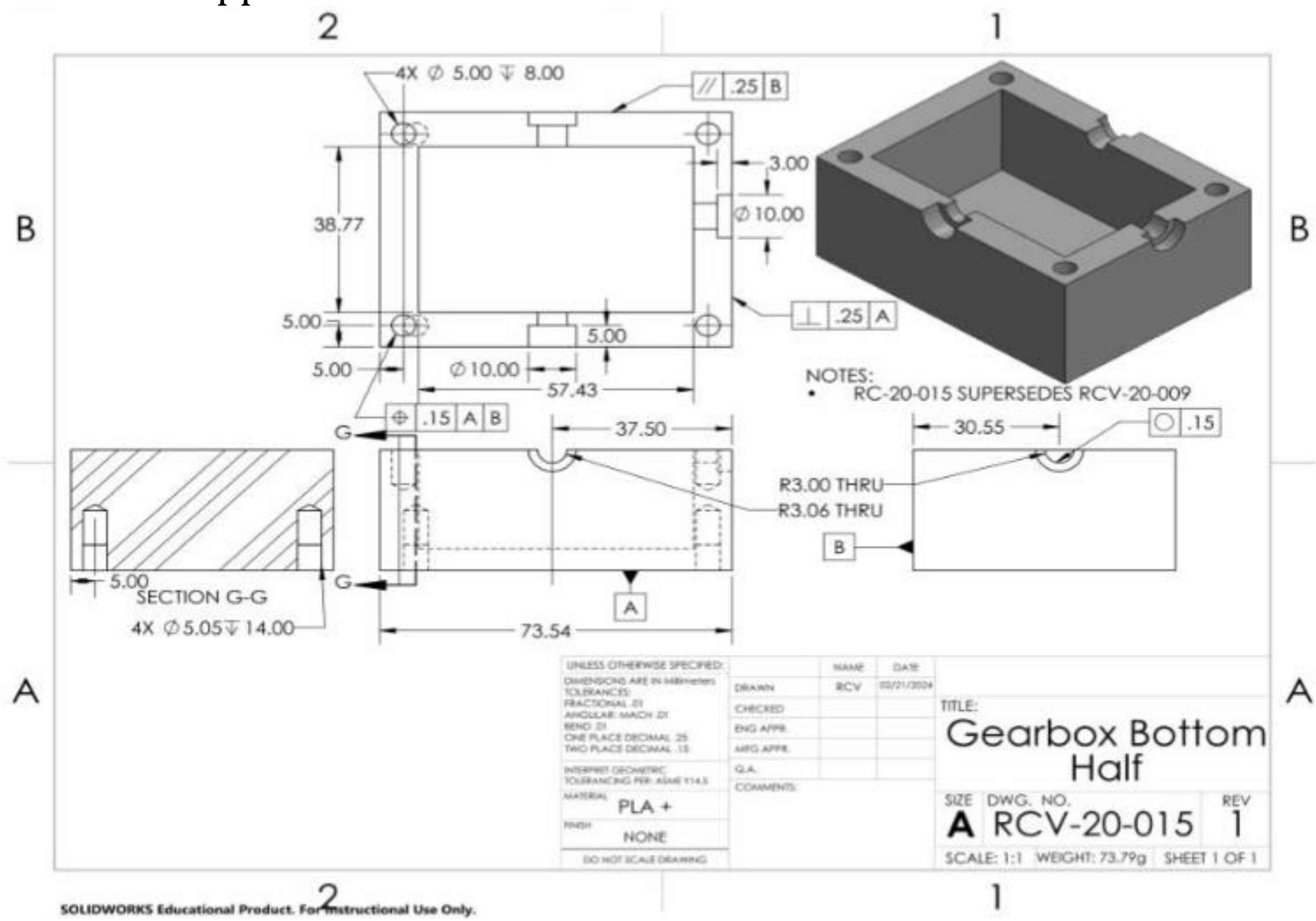


Figure B50- Gearbox Bottom Half Drawing.

Appendix B51 <RCV-20-016> - Gearbox Top Half

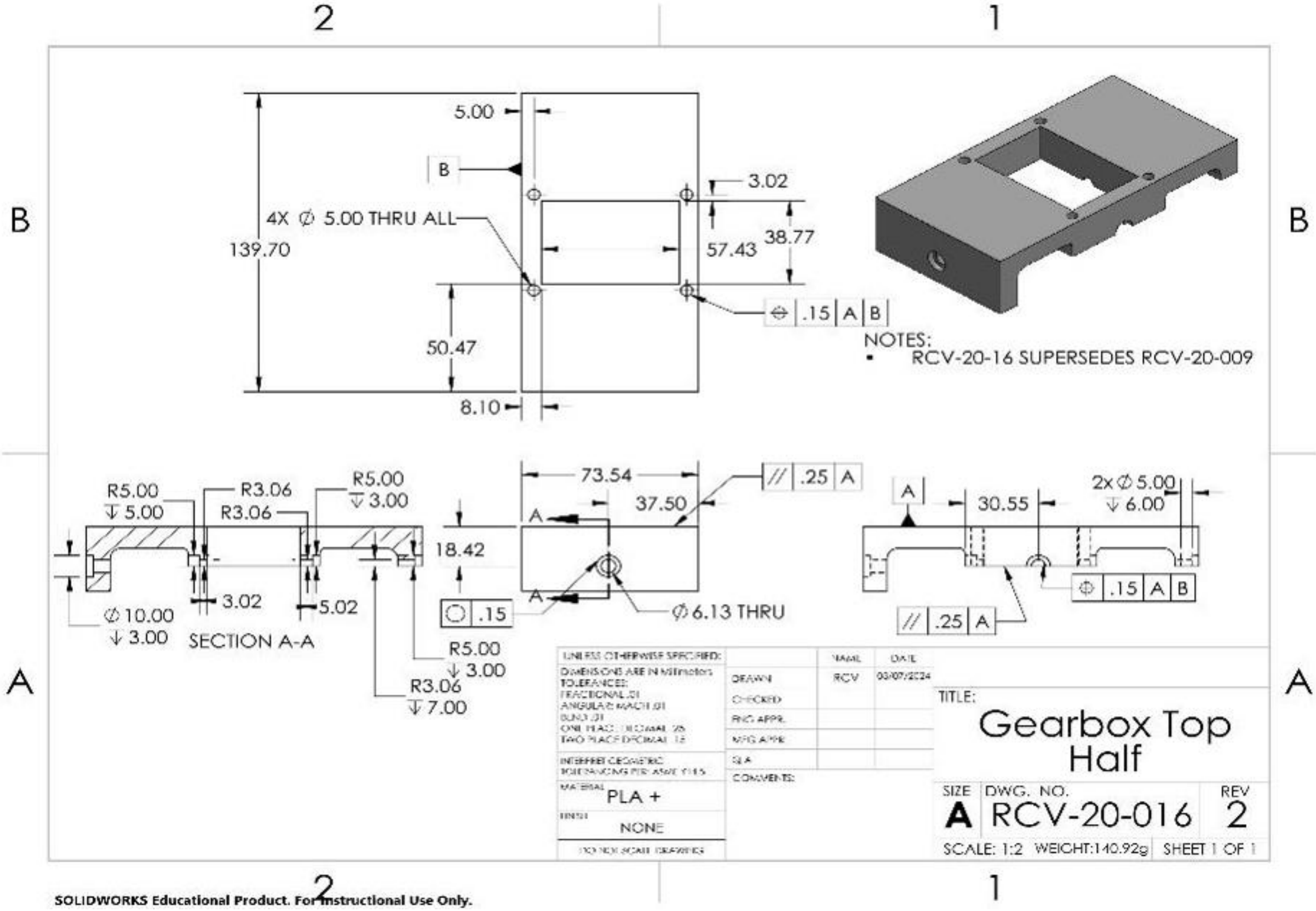


Figure B51- Gearbox Top Half Drawing.

Appendix B52 <RCV-20-017> - 8mm Bore Shaft Collar

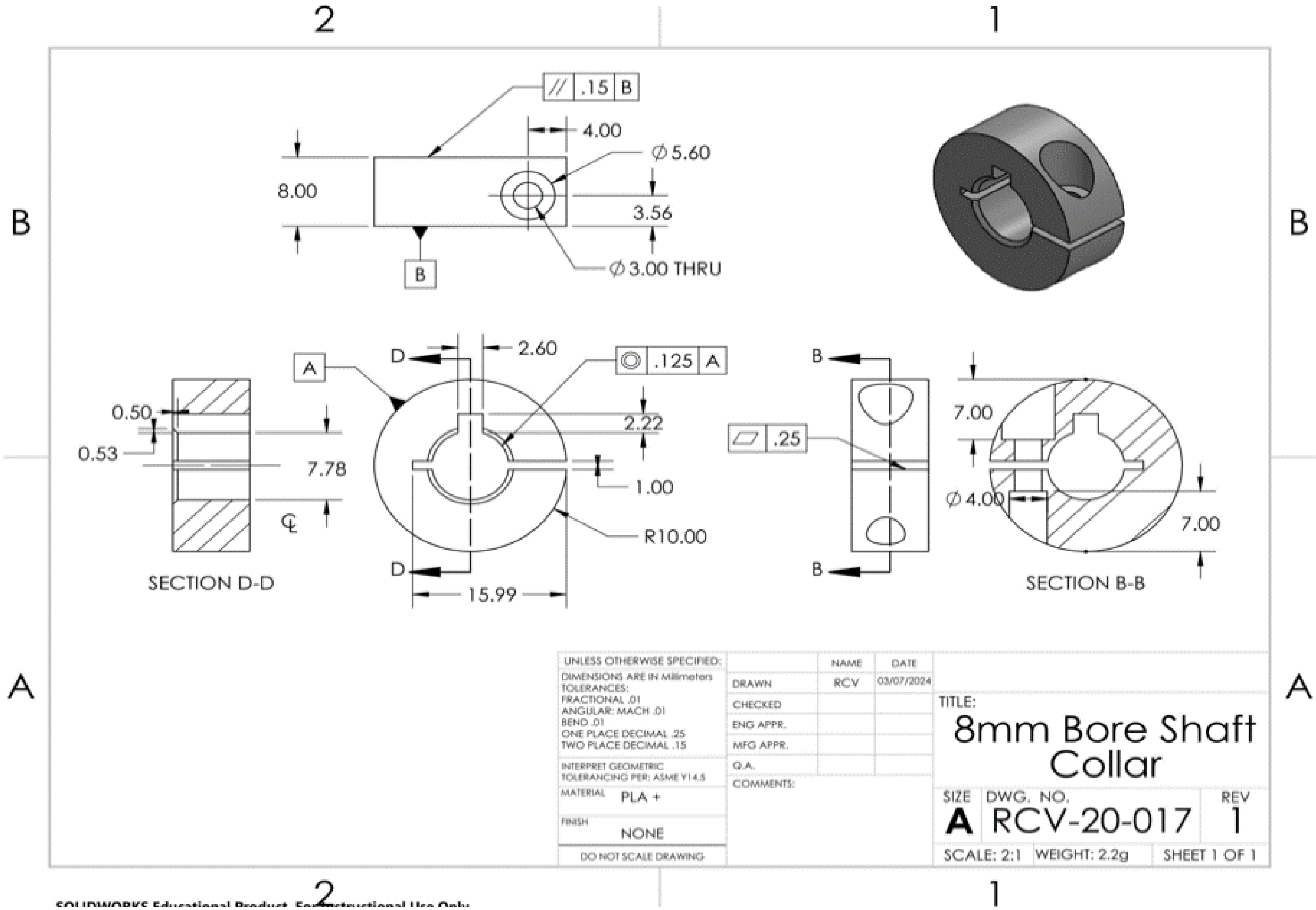


Figure B52- 8mm Bore Shaft Collar Drawing.

Appendix B53 <RCV-20-018> - Axle Support Clamp

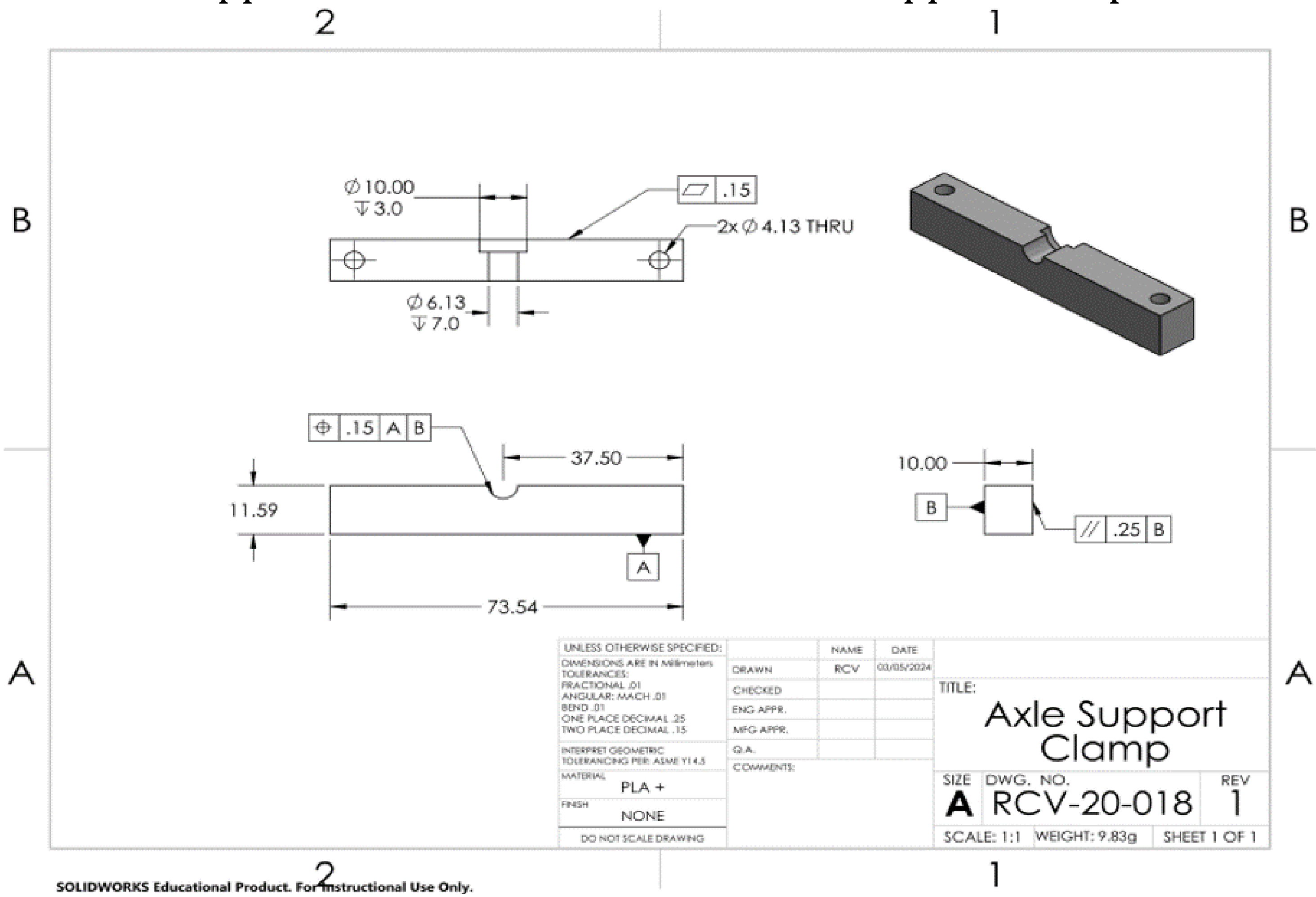


Figure B53- Axle Support Clamp Drawing.

Appendix B54– <RCV-55-001> - 7.4V Lipo Battery

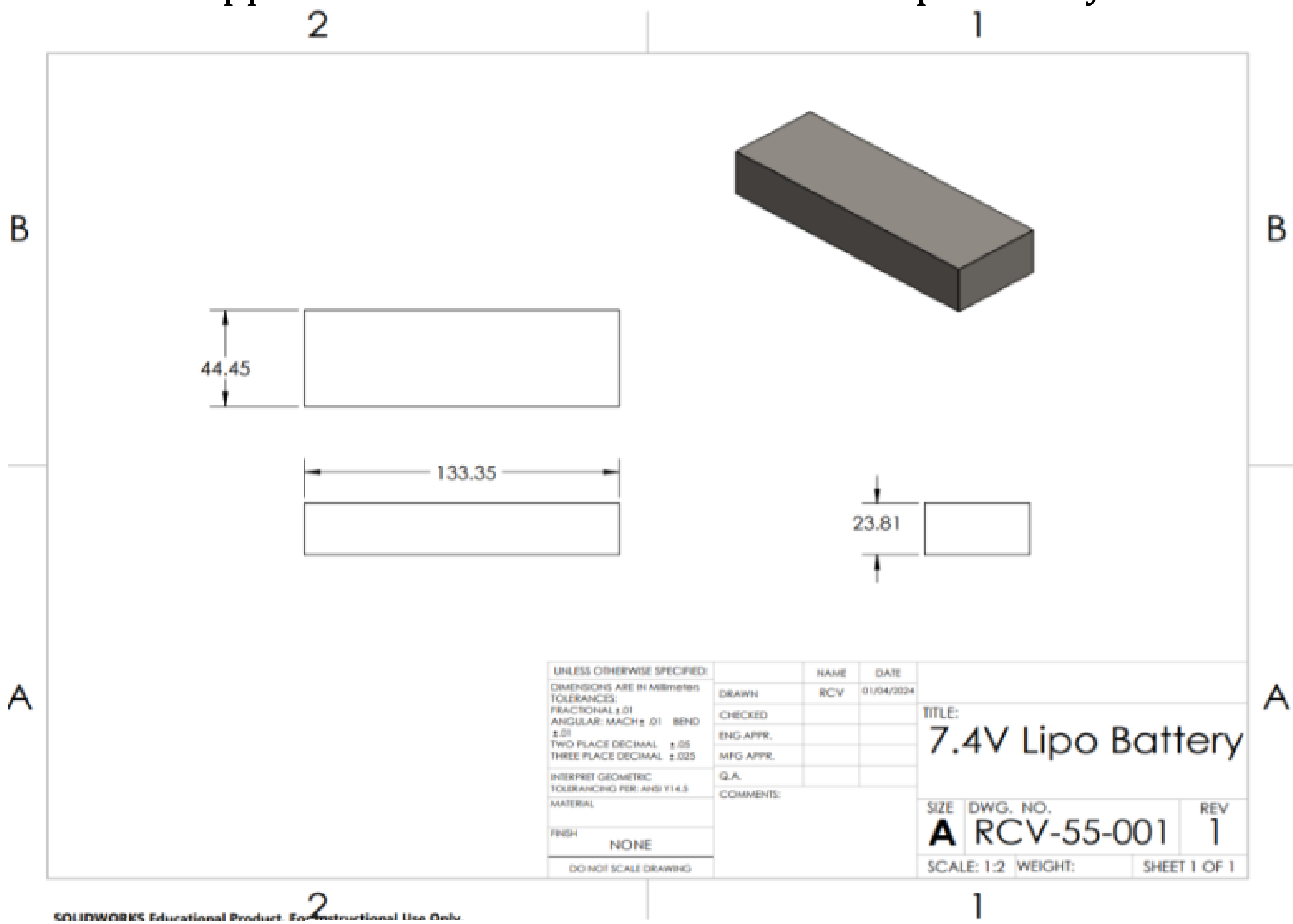


Figure B54- 7.4V Lipo Battery drawing.

Appendix B55– <RCV-55-002> - Mabuchi 540-6527 Brushed Motor

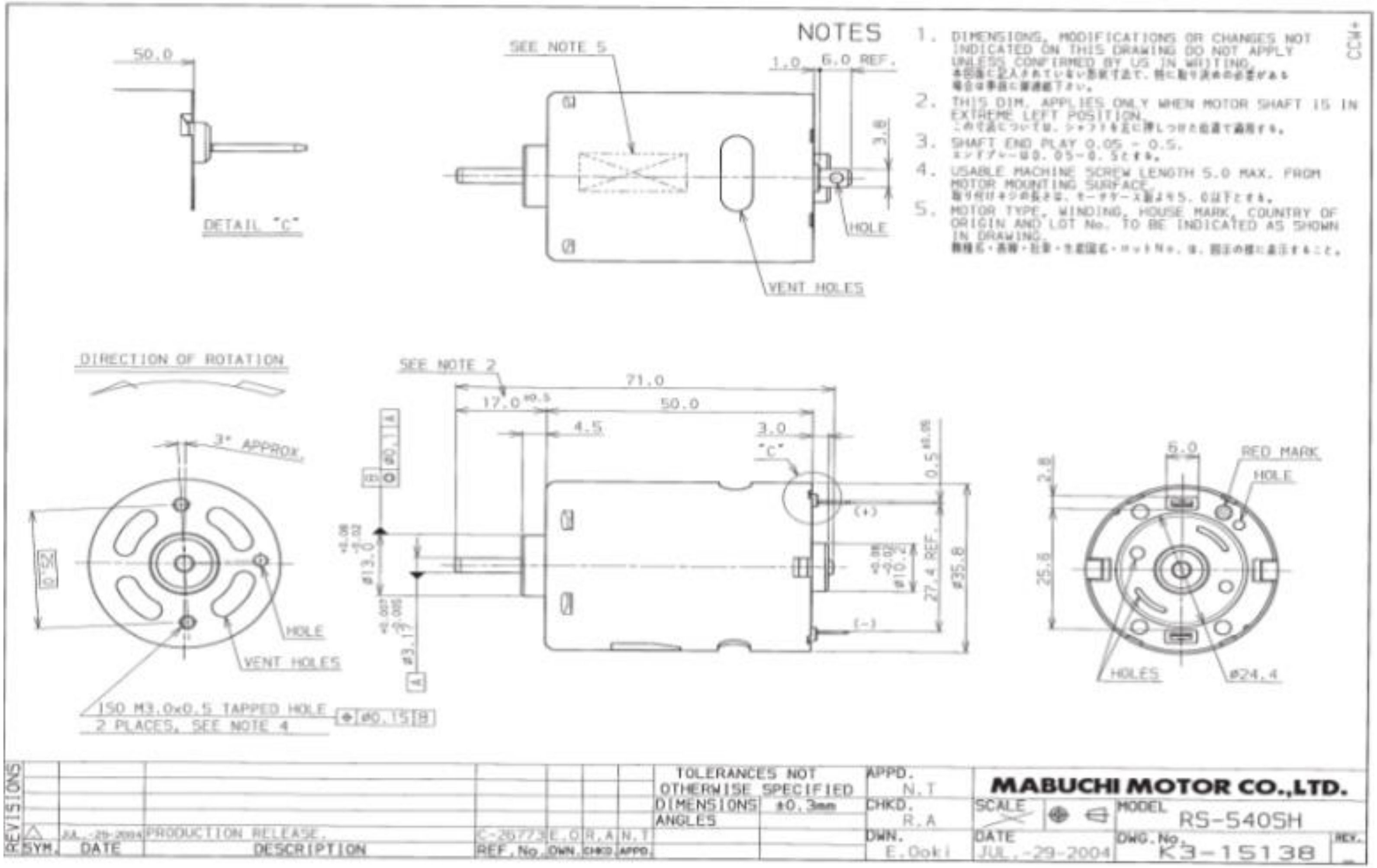


Figure B55- Mabuchi 520-6527 Brushed Motor drawing.

Appendix B56– <RCV-55-003> - 6mm Gear Axle

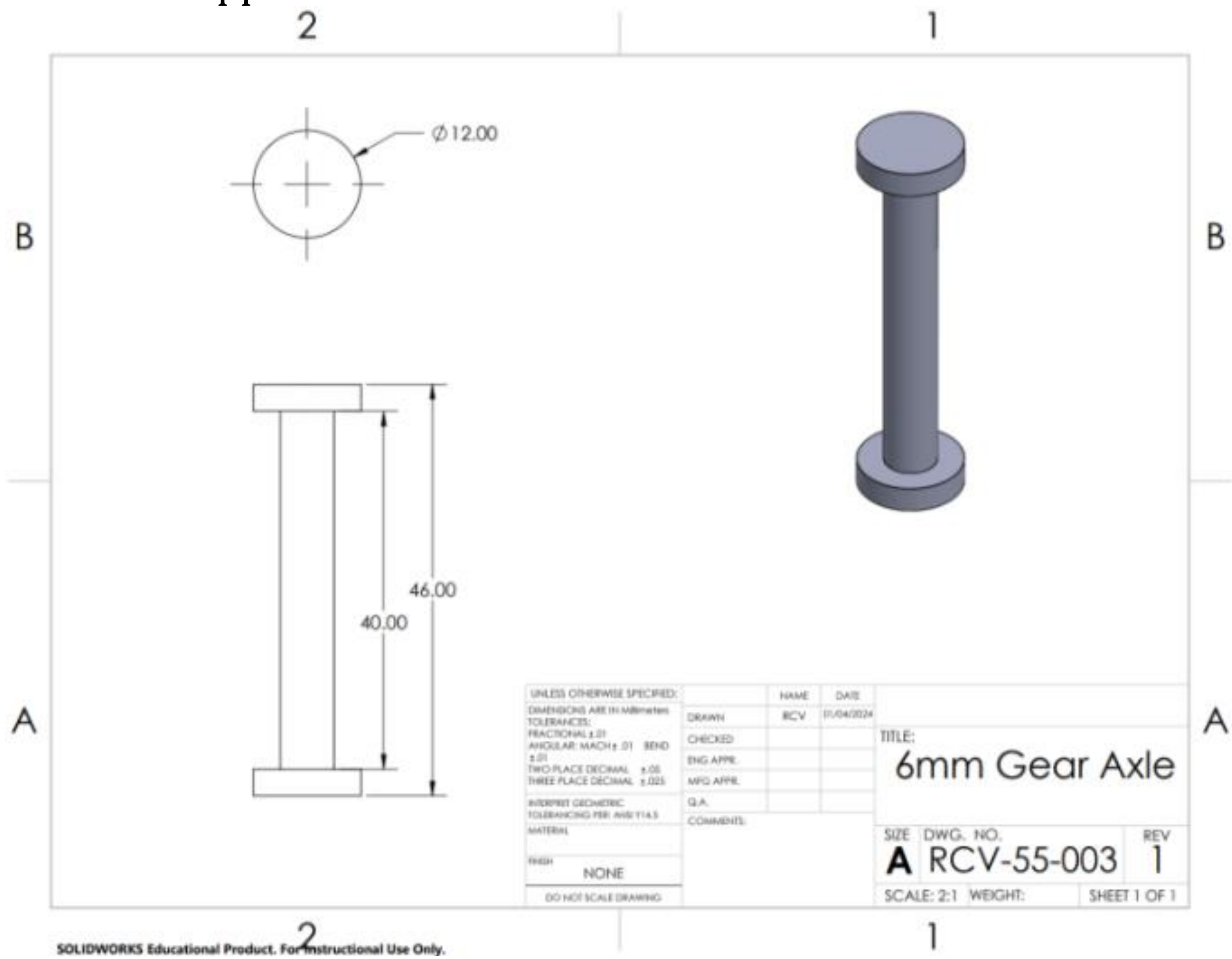


Figure B56- 6mm Gear Axle drawing.

Appendix B57– <RCV-55-004> - 15T Bevel Gear

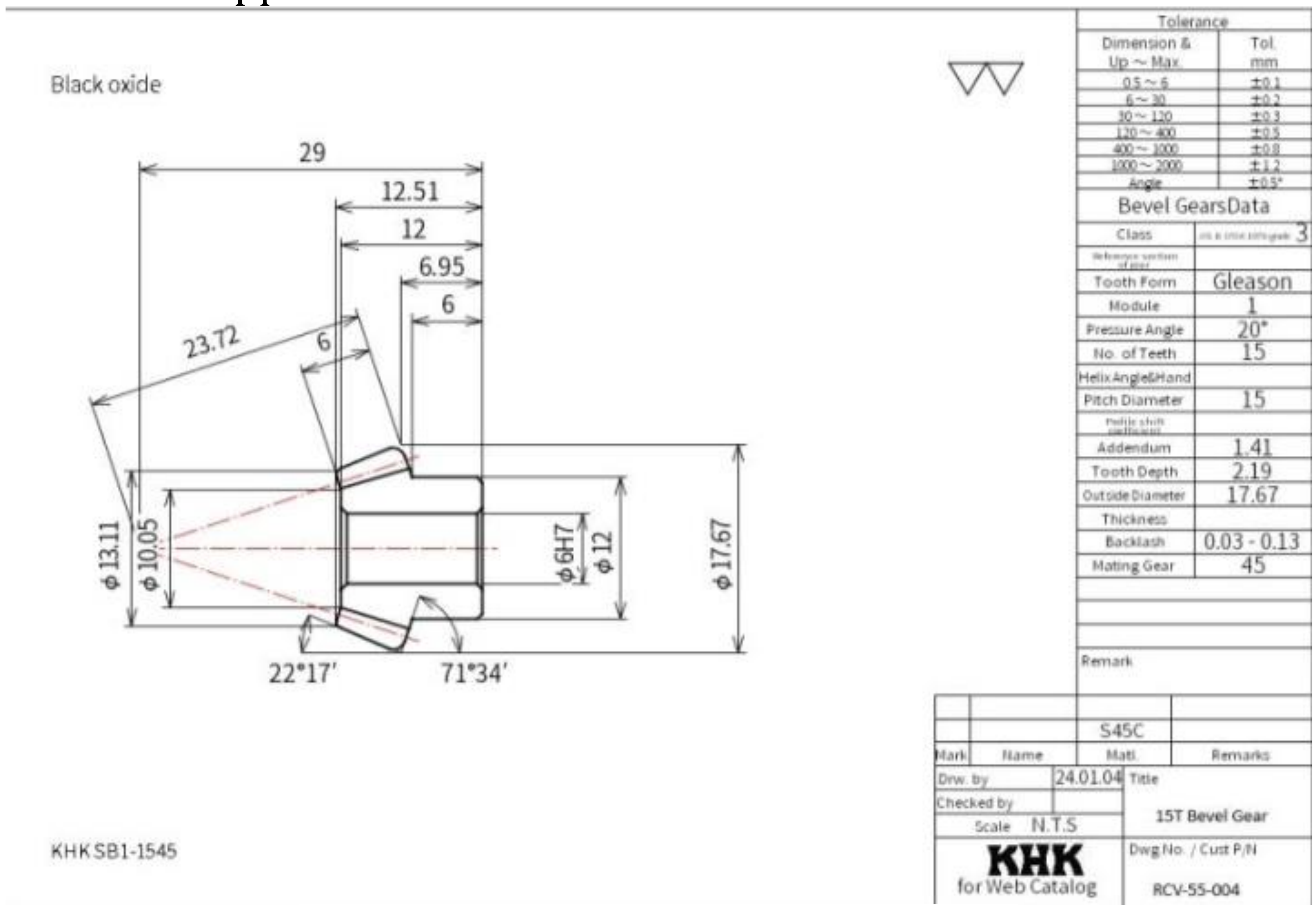


Figure B57- 15T Bevel Gear drawing.

Appendix B58– <RCV-20-005> - 45T Bevel Gears

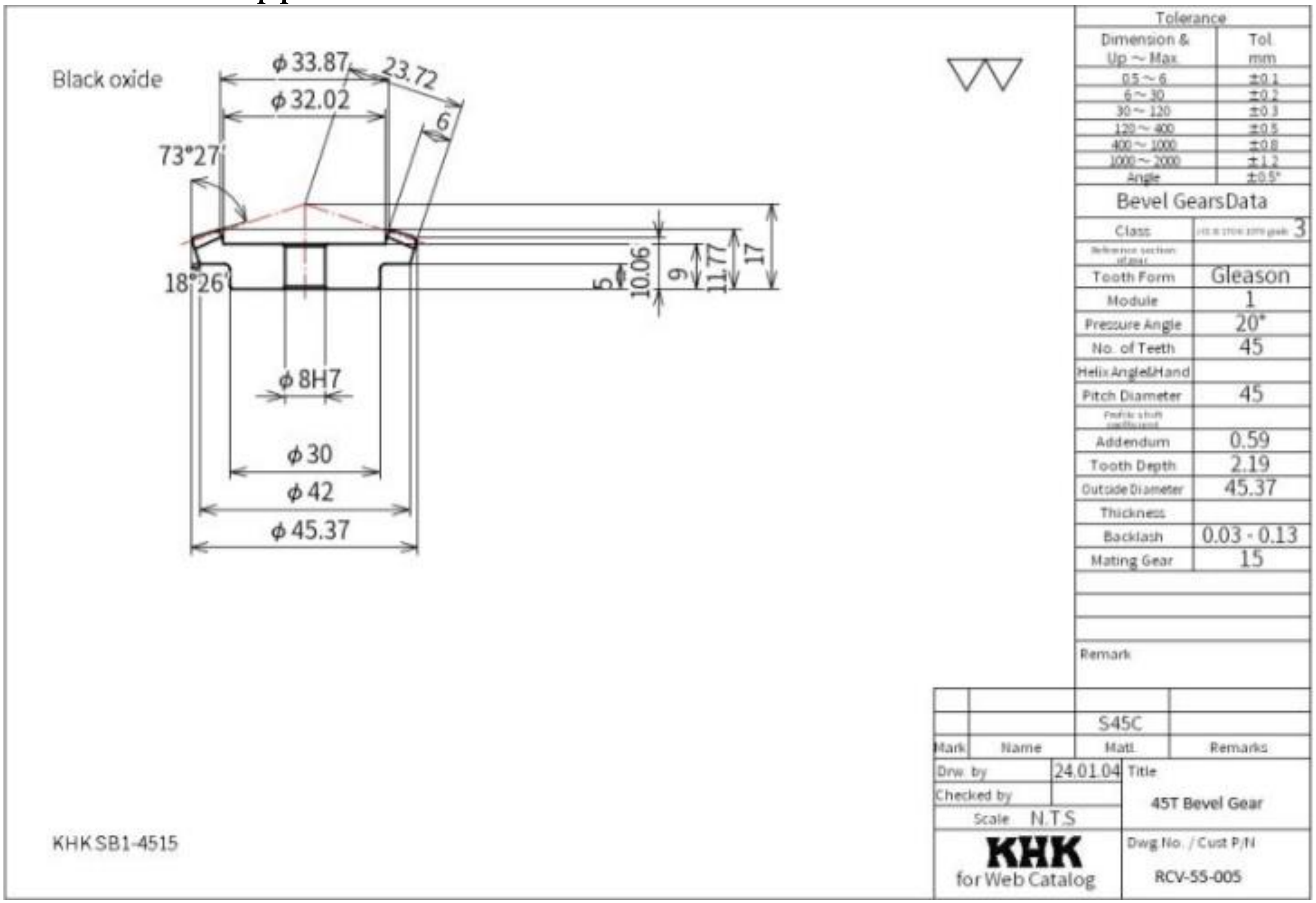


Figure B58- 45T Bevel Gear drawing.

Appendix B59– <RCV-10-003> - 4mm Ball Bearing

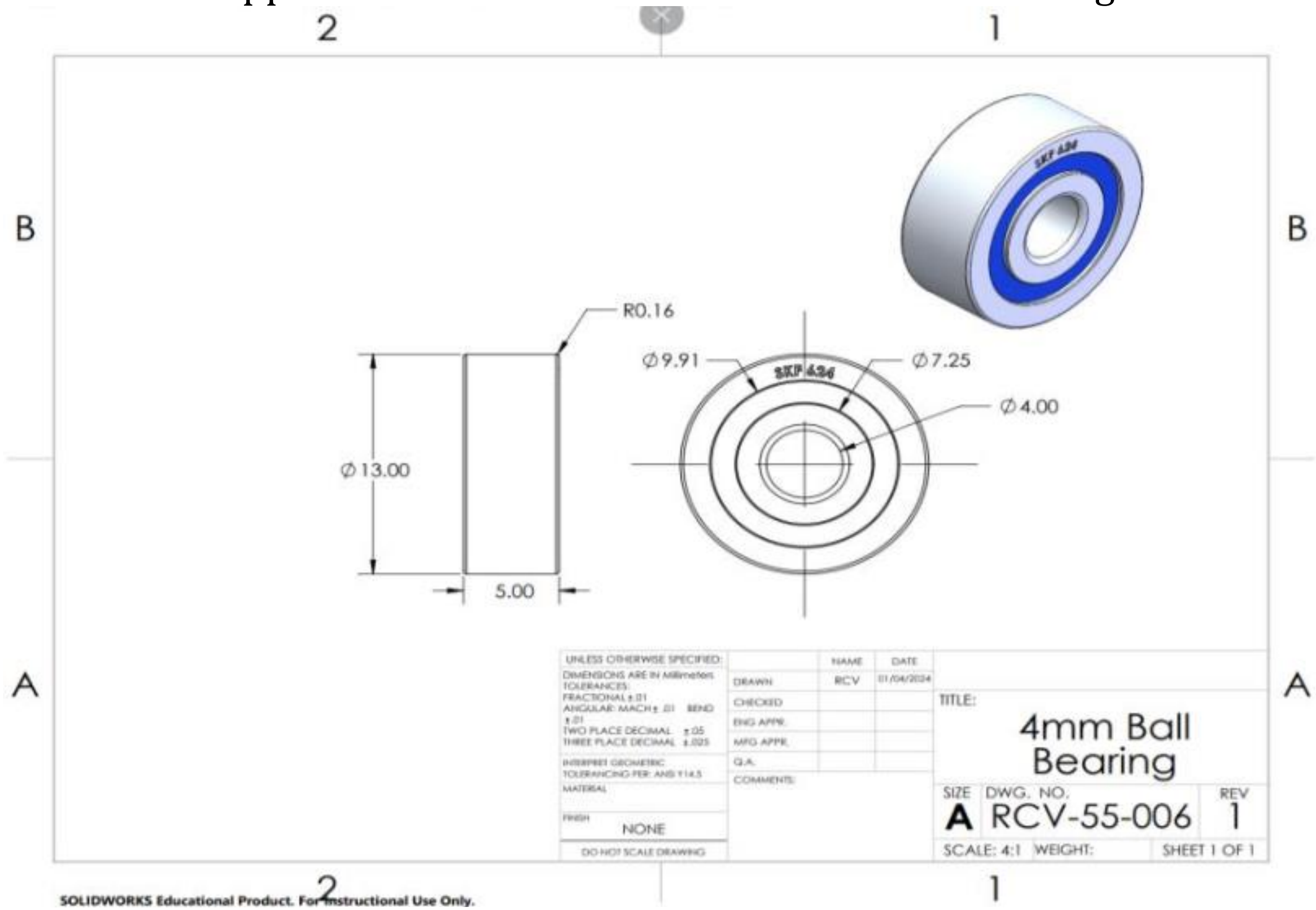


Figure B59- 4mm Ball Bearing drawing.

Appendix B60– <RCV-55-007> - 6mm Ball Bearing

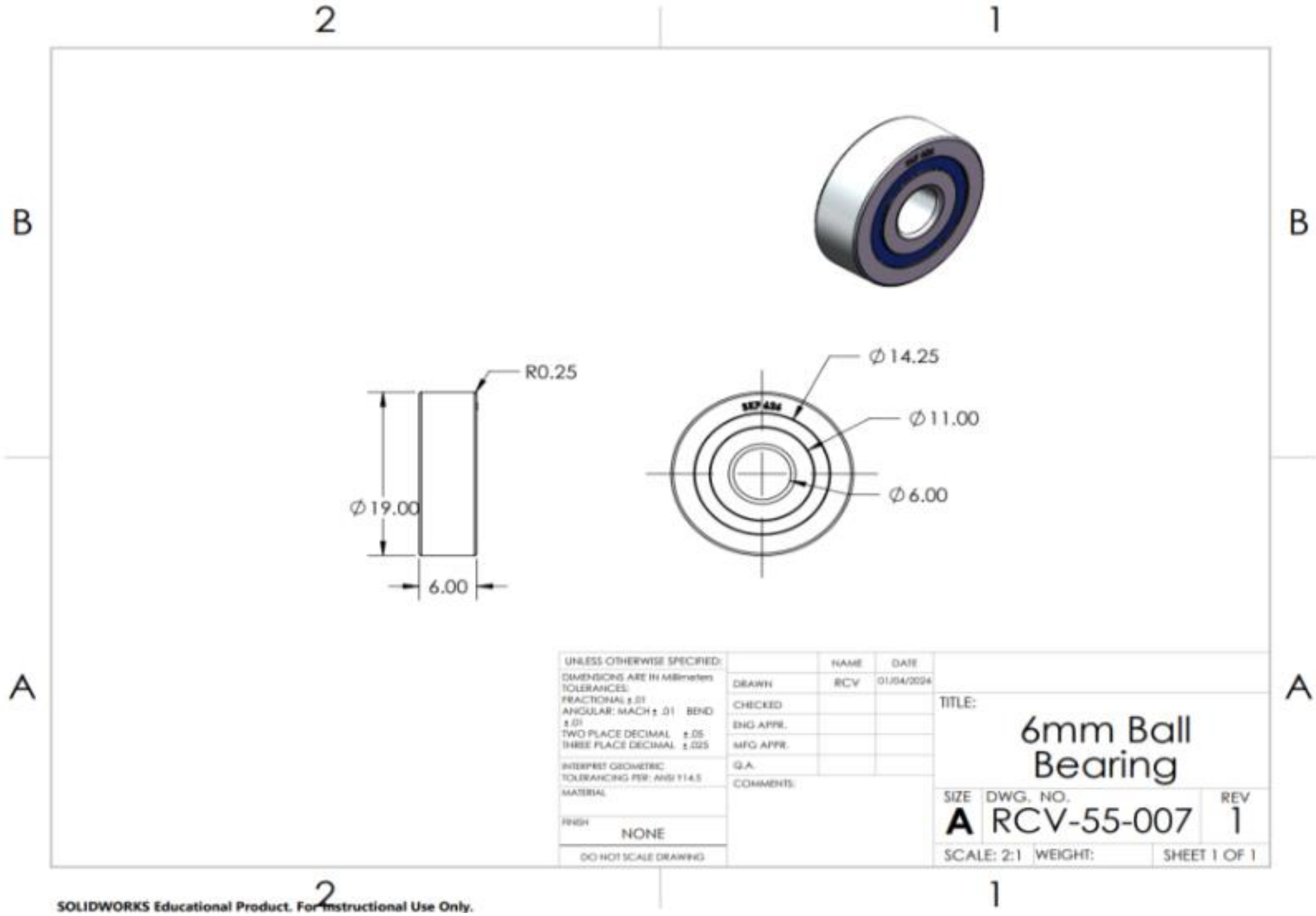


Figure B60- 6mm Ball Bearing drawing.

APPENDIX C – Parts List and Costs

Table C – Parts list.

Part Number	QTY	Part Description	Source	Cost	Disposition
RCV-20-001	1	Pinion Gear	Modeled	$0.02259	3D Printed
RCV-20-002	1	Chassis	Modeled	$29.98	3D Printed
RCV-20-003	1	Spur Gear	Modeled	$1.342	3D Printed
RCV-20-004	1	Motor Cover	Modeled	$0.257	3D Printed
RCV-20-005	1	Motor Mount	Modeled	$1.689	3D Printed
RCV-20-006	1	Right Side Battery Mount	Modeled	$0.723	3D Printed
RCV-20-007	1	Left Side Battery Mount	Modeled	$0.622	3D Printed
RCV-20-008	1	Bore Reducer	Modeled	$.00989	3D Printed
RCV-20-009	1	Gearbox	Modeled	$1.961	3D Printed
RCV-20-010	1	Gearbox Cover	Modeled	$0.513	3D Printed
RCV-20-011	1	Rear Axle	Donated by CWU	$0.0527	Machined
RCV-20-012	1	Rear Axle Square Key	Donated by CWU	$0.00115	Machined
RCV-20-013	1	Front Chassis Section	Modeled	$9.1	3D Printed
RCV-20-014	1	Rear Chassis Section	Modeled	$16.67	3D Printed
RCV-20-015	1	Gearbox Bottom Half	Modeled	$1.70	3D Printed
RCV-20-016	1	Gearbox Top Half	Modeled	$3.24	3D Printed
RCV-20-017	1	8mm Bore Shaft Collar	Modeled	$0.056	3D Printed
RCV-20-018	1	Axle Support Clamp	Modeled	$0.2261	3D Printed
RXA-20-001	1	Front Shock Tower	Modeled	$1.66819	3D Printed
RXA-20-002	1	Rear Shock Tower	Modeled	$2.478	3D Printed
RXA-20-003	1	Front Lower Left Control Arm	Modeled	$1.324	3D Printed
RXA-20-004	1	Servo Mount	Modeled	$1.119	3D Printed
RXA-20-005	1	Rear Lower Left Control Arm	Modeled	$1.324	3D Printed
RXA-20-006	2	Rear Upper Control Arm	Modeled	$0.427	3D Printed
RXA-20-007	1	Rear Lower Right Control Arm	Modeled	$0.427	3D Printed
RXA-20-008	2	Front Upper Control Arm	Modeled	$0.70449	3D Printed
RXA-20-009	1	Receiver Mount	Modeled	$0.172	3D Printed
RXA-20-010	1	ESC Mount	Modeled	$0.09085	3D Printed

RXA-20-011	1	Front Lower Right Control Arm	Modeled	$1.324	3D Printed
RXA-20-012	1	Front Lower Control Arm Mount	Modeled	$1.4996	3D Printed
RXA-20-013	1	Rear Lower Control Arm Mount	Modeled	$2.5047	3D Printed
RXA-20-014	1	Right Steering Rod	Modeled	$0.7	3D Printed
RXA-20-015	1	Left Steering Rod	Modeled	$1.1385	3D Printed
RXA-20-016	2	Ball Joint End	Modeled	$0.1	3D Printed
RCV-50-001	1	6mm Shaft Collar	AMAZON SELLER: AOWEITAL	$7.99	Ordered 12/23/23
RCV-50-002	1	30 Pc Threaded inserts	AMAZON SELLER: Generic	$12.99	Ordered 12/23/23
RCV-50-003	1	5 Pc 4mm Shaft Collar	AMAZON SELLER: uxcell	$10.36	Ordered 1/3/24
RXA-50-001	1	405 Pc M3 & M4 SS Fasteners	AMAZON SELLER: Taiss	$9.99	Ordered 1/3/24
RXA-50-002	1	4 pc Axle end M4 fasteners	AMAZON SELLER: Hobbypark	$8.97	Ordered 1/17/24
RXA-50-003	1	100pc M3 Bolts	AMAZON SELLER: iexcell	$10.45	Ordered 1/22/24
RXA-50-004	1	100 pc M4 Bolts	AMAZON SELLER: iexcell	$10.67	Ordered 1/17/24
RXA-50-005	1	10 pc Ball joint ends	AMAZON SELLER: Vgoodhobby	$12.95	Ordered 1/21/24
RCV-55-001	1	2 Pc 7.4V Lipo Battery 2S 50C 5200mAh	AMAZON SELLER: ZEEE POWER	$32.38	Ordered 10/13/23
RCV-55-002	2	MABUCHI 540-6527 Brushed Motor 90W	HOBBYKING.com	$17.86	Ordered 10/13/23
RCV-55-003	1	12 Pc 6mm Gear Axle	Amazon Seller: YongXuan	$8.99	Ordered 1/3/24
RCV-55-004	1	15T Bevel Gear	KHKGEARS.US	$17.62	Ordered 12/29/2023
RCV-55-005	1	45T Bevel Gear	KHKGEARS.US	$34.60	Ordered 12/29/23
RCV-55-006	1	10 Pc 6mm Ball bearing	AMAZON SELLER: uxcell	$8.49	Ordered 12/23/23
RCV-55-007	1	HobbyKing Sensorless Brushless Car ESC 45A W/ Reverse (2~3S)	HOBBYKING.com	$24.40	Ordered 5/01/24

RCV-55-008	1	Turnigy XK2845-1980KV Brushless Inrunner	HOBBYKING.com	$30.1	Ordered 4/23/24
RXA-55-001	1	2 Pc Front Shocks for 1:8 RC	AMAZON SELLER: ARRAROWN	$28.13	Ordered 10/11/23 4/23/24
RXA-55-002	1	2 Pc Rear Shocks for 1:8 RC			
RXA-55-003	1	HOTRC CT-6A 6 Channel 2.4ghz RC Transmitter and Receiver	AMAZON SELLER: Havcybin Tech	$39.96	Ordered 10/16/23
RXA-55-004	1	2Pc RC UBEC 3 AMPS 6.0-25.5v input / 5v/6v/ Adjustable Output BEC	AMAZON SELLER: JINOARC	$9.71	Ordered 10/16/23
RXA-55-005	1	NestNiche RC servo, 30KG RC Steering Servo with Winch Spool Kit	AMAZON SELLER: Wenjingqi	$17.14	Ordered 10/13/23
RXA-55-006	1	Front Right C- Channel	AMAZON SELLER: RCAWD	$86.39	Ordered 10/13/23
RXA-55-007	1	Front Left C- Channel			
RXA-55-008	1	Front Left Knuckle			
RXA-55-009	1	Front Right Knuckle			
RXA-55-010	1	2 Pc Rear Knuckles			
RXA-55-011	1	4 Pc 1/8 RC Tire	AMAZON SELLER: ACEKEEPS HOBBIES	$72.34	Ordered 10/13/23
RXA-55-012	1	Vgoohobby RC 30A Brushed ESC	AMAZON SELLER: Vgoodhobby	$12.84	Ordered 11/18/23
RXA-55-013	1	T Plug to JST	AMAZON SELLER: FLY RC	$8.63	Ordered 1/21/24
RXA-55-014	1	Battery Charger kit	AMASON SELLER: Haisito Store	$62.55	Ordered 1/21/24
RXA-55-015	1	4 Pc Wheel hub 17mm-12mm adapters	AMAZON SELLER: GTHELE	$14.03	Ordered 1/21/24
RXA-55-016	1	4 Pc Drive shaft axles for 1/8 Arrma vendetta 4x4 3s BLX	AMAZON SELLER: RCMYou	$51.83	Ordered 2/3/24
RXA-55-017	1	GoolRC GA-4H-TX 4CH Receiver and Transmitter	AMAZON SELLER: Xinzhemaoyi	$27.00	Ordered 2/7/24
RXA-55-018	1	Ichiias 60A ESC Brushed	AMAZON SELLER: Blurte432	$20.05	Ordered 2/7/24

RXA-55-019	1	Radiolink Cool 90A ESC	AMAZON SELLER: RadioLink Direct	$30.34	Ordered 3/1/24
RXA-55-020	1	Dkky RCCar Motor Heatsink Dual Fan	AMAZON SELLER: DKKY DKKY Racing	$8.12	Ordered 3/7/24
			Total Cost	$830.59	

Note: Extra items are listed here as backups. The parts and costs listed here have already been considered in the table above. Motor (1), Battery (1), UBEC (1)

Parts that were ordered but were not used in the last version of the RC are in the following table:

Table C1- Unused Parts

Part Number	QTY	Part Description	Source	Cost	Disposition
RCV-20-002	1	Chassis	Modeled	$29.98	3D Printed
RCV-20-009	1	Gearbox	Modeled	$1.961	3D Printed
RXA-55-003	1	HOTRC CT-6A 6 Channel 2.4ghz RC Transmitter and Receiver	AMAZON SELLER: Havcybin Tech	$39.96	Ordered 10/16/23
RXA-55-004	1	2Pc RC UBEC 3 AMPS 6.0-25.5v input / 5v/6v/ Adjustable Output BEC	AMAZON SELLER: JINOARC	$9.71	Ordered 10/16/23
RXA-55-012	1	Vgoohobby RC 30A Brushed ESC	AMAZON SELLER: Vgoodhobby	$12.84	Ordered 11/18/23
RXA-55-018	1	Ichiias 60A ESC Brushed	AMAZON SELLER: Blurte432	$20.05	Ordered 2/7/24
RCV-55-002	2	MABUCHI 540-6527 Brushed Motor 90W	HOBBYKING.com	$17.86	Ordered 10/13/23
RXA-55-019	1	Radiolink Cool 90A ESC	AMAZON SELLER: RadioLink Direct	$30.34	Ordered 3/1/24
			Total Cost	$162.7	

APPENDIX D – Budget

Table D1. Project Budget.

Item	Qty	Description	Cost
3D printed parts	33	Labor (20-XXX parts)	$85.16
Part list and cost	1	All purchased components (50-XXX & 55-XXX parts)	$745.43
		Final prototype cost (Overall cost – unused parts cost)	$667.89
		Purchased Parts	28

Note:
Total cost of project $830.59

· The cost for the 3D printed parts is calculated based off the cost amount per 1kg of spool material multiplied by the mass of the part (in grams) then divided by 1000.

· Spool cost per 1kg: $23

APPENDIX E – Schedule

ID		Task Mode	Task ID	Task Name	Hours	Hours 2	Start	Finish
1				**Senior Project**	**Estima**	**Actual**	**Wed 9/20/2**	**Sat 6/8/24**
100								
101				Subtotal:				
2			**1**	**Proposal**			**Fri 9/22/23**	**Mon 12/4/23**
13				Subtotal:	113	56	Fri 9/22/23	Fri 9/22/23
3			1a	Intro	7	.5	Fri 9/22/23	Thu 10/5/23
4			1b	Analysis	40	11.5	Fri 9/22/23	Mon 11/13/23
5			1c	Methods	25	10	Mon 10/9/23	Sat 10/28/23
6			1d	Testing	10	5	Mon 10/23/2	Tue 10/31/23
7			1e	Budget	4	5	Mon 10/2/23	Mon 11/13/23
8			1f	Schedule	4	8	Mon 9/25/23	Tue 10/10/23
9			1g	Project Management	7	2	Thu 10/19/2	Fri 11/10/23
10			1h	Discussion	5	3	Wed 11/1/23	Wed 11/15/23
11			1i	Conclusion	3	5	Wed 11/15/2	Wed 11/29/23
12			1j	Appendix	8	5	Mon 10/30/2	Mon 12/4/23
14			**2**	**Analyses**			**Thu 9/28/23**	**Fri 12/1/23**
27				Subtotal:	14	13		
15			2a	Drop test analysis	2	2.5	Tue 11/14/2	Tue 11/28/23
16			2b	K Factor analysis	1	1	Thu 9/28/23	Fri 10/13/23
17			2c	Deflection of towers analysis	1	.5	Fri 11/17/23	Tue 11/28/23
18			2d	Rear lower control arms	.5	1	Sun 10/8/23	Mon 10/16/23
19			2e	Bolt stress analysis	1.5	1	Wed 10/18/2	Tue 10/31/23
20			2f	Control arm deflection drop test analysis	1	1.5	Sat 11/11/23	Tue 11/28/23
21			2g	Steering angle & Turning radius analysis	1.5	1	Sun 10/8/23	Thu 11/2/23
22			2h	2ft drop analysis on rear upper control arm	1	1	Tue 10/3/23	Fri 10/27/23
23			2i	2ft drop analysis on rear lower control arm	1	1.5	Fri 10/13/23	Thu 11/2/23
24			2j	Torque on steering pin	1	.5	Tue 11/14/2	Fri 12/1/23
25			2k	Front impact analysis on front upper control arm	1	1.5	Sat 10/28/23	Wed 11/15/23
26			2l	Stress of suspension tower analysis	2	1	Tue 10/3/23	Tue 10/17/23
36			**3**	**Documentation**			**Fri 9/22/23**	**Sun 3/31/24**
65				Subtotal:	78	75.25	Fri 9/22/23	Fri 9/22/23
37			3a	Front upper control arm	4	4.5	Mon 1/1/24	Fri 3/8/24
38			3b	Servo mount	2	3	Sun 1/7/24	Wed 1/24/24
39			3c	Front Right C Channel	5	4	Sun 12/24/2	Fri 1/12/24
40			3d	Front shock tower	2	3	Sun 11/26/2	Fri 1/19/24
41			3e	Rear shock tower	2	3	Sun 11/26/2	Fri 1/19/24
42			3f	Front Shock	2	1	Sun 11/12/2	Fri 1/5/24
43			3g	Front Lower Right Control Arm	4	1	Sun 10/29/2	Sun 1/14/24
44			3h	Front Lower Left Control Arm	4	3.5	Sun 10/29/2	Fri 12/29/23
45			3i	Rear Upper Control Arm	4	3.25	Sun 12/17/2	Mon 1/8/24
46			3j	Rear Lower Right Control Arm	4	3.75	Fri 12/1/23	Fri 12/22/23
47			3k	Rear Lower Left Control Arm	4	5	Sun 12/3/23	Mon 1/8/24
48			3l	ECS Mount	.5	.5	Sun 10/29/2	Tue 12/19/23
49			3m	Rear Shock	2	3	Sun 11/5/23	Sun 12/10/23
50			3n	Receiver Mount	1.5	2	Sat 12/30/23	Mon 3/4/24
51			3o	Receiver	.5	.25	Sun 12/31/2	Fri 1/5/24
52			3p	UBEC	.5	.25	Sun 12/24/2	Mon 1/8/24
53			3q	Servo Motor	.5	.25	Sun 12/31/2	Mon 1/8/24
54			3r	Tire	1	1.5	Sun 12/10/2	Fri 1/5/24
55			3s	Rear Knuckle	3	2.5	Sun 11/5/23	Sun 1/14/24
56			3t	Front Left Knuckle	3	2.5	Sun 11/12/2	Sun 1/7/24

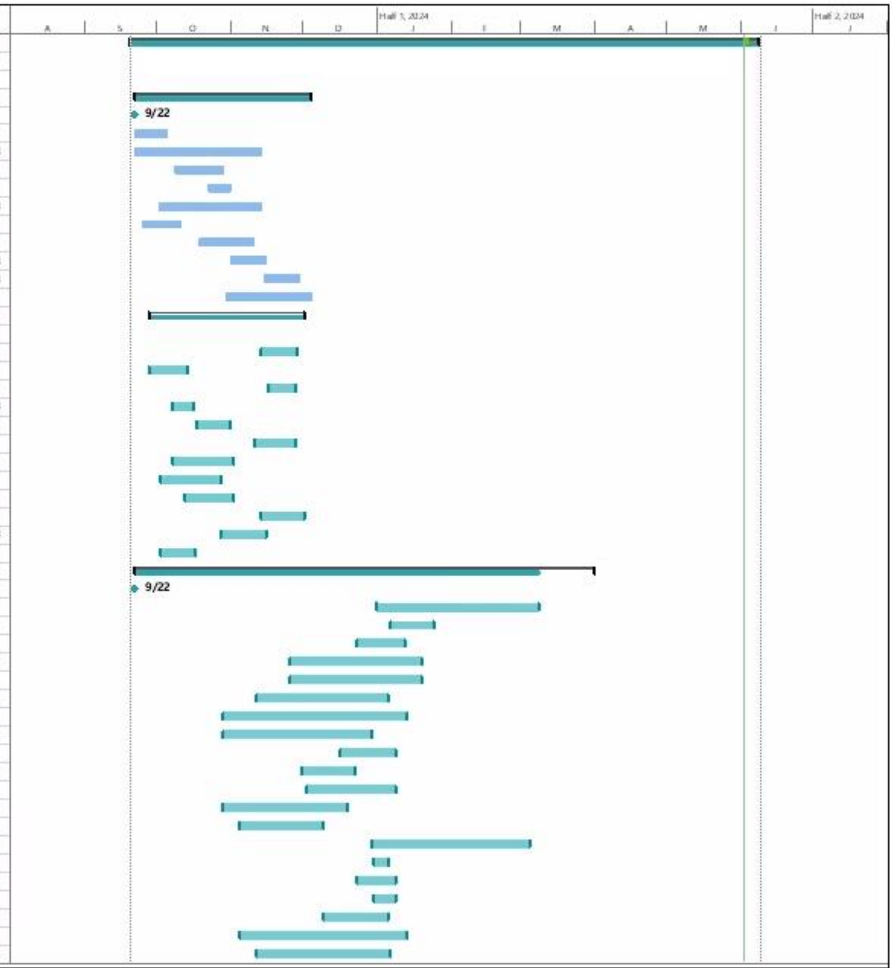


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Figure E01-1. Project Gantt Chart.

ID		Task Mode	Task ID	Task Name	Hours	Hours 2	Start	Finish
57			3u	Front Right Knuckle	2.5	3	Sun 12/3/23	Sun 2/25/24
58			3v	Front right C Channel	3	3.5	Thu 12/21/2	Thu 1/11/24
59			3w	Front Left C Channel	3	2.5	Thu 12/21/2	Thu 1/11/24
60			3x	Rear Lower Control Arm Mount	2	3	Wed 1/10/24	Fri 1/19/24
61			3y	Front Lower Control Arm Mount	2	2.5	Wed 1/10/24	Fri 1/19/24
62			3z	Front shock sub assembly	2	1.5	Sun 12/3/23	Sun 2/18/24
63			3z1	Rear shock sub assembly	2	1.5	Sun 12/10/2	Sun 2/4/24
64			3z2	RC Car Assembly	1	1	Sun 1/14/24	Sun 2/18/24
68			3z3	Left Steering Rod	5	4.25	Fri 2/2/24	Mon 2/5/24
67			3z4	Right Steering Rod	5	4.25	Fri 2/2/24	Mon 2/5/24
66			3z5	Ball Joint End	1	.5	Wed 2/14/24	Fri 3/8/24
69			**4**	**PART MANUFACTURING**			**Fri 12/1/23**	**Sun 3/31/24**
71				Subtotal:	70			
70			4a	Front upper control arm	4	7.5	Mon 1/1/24	Mon 1/22/24
86			4b	Rear upper control arm	4	14.5	Thu 1/18/24	Fri 3/8/24
72			4c	Rear shock tower	5	6	Mon 1/1/24	Mon 1/15/24
73			4d	Front shock tower	5	6.5	Fri 1/5/24	Wed 1/17/24
74			4e	Front lower left control arm	5	18.25	Wed 1/10/24	Mon 2/19/24
75			4f	Front lower right control arm	7	18.25	Wed 1/10/24	Mon 2/19/24
76			4g	Rear lower left control arm	8	11.5	Wed 1/31/24	Mon 3/11/24
77			4h	Rear lower right control arm	7	14.75	Thu 2/1/24	Tue 3/12/24
78			4i	ESC Mount	2	0.75	Wed 3/13/24	Tue 3/26/24
79			4j	Receiver Mount	2	1	Wed 3/13/24	Tue 3/26/24
80			4k	Servo Mount	2	2.25	Wed 3/13/24	Tue 3/26/24
81			4l	Rear lower control arm mount	6	13.0	Tue 3/12/24	Sun 3/24/24
82			4m	Front lower control arm mount	6	4	Tue 3/12/24	Sun 3/31/24
83			4n	Left Steering Rod	3	6	Mon 3/25/24	Sun 3/31/24
85			4o	Right Steering Rod	3	4	Mon 3/25/24	Sun 3/31/24
84			4p	Ball Joint end	1	.5	Wed 2/21/24	Wed 3/27/24
87			**5**	**DEVICE MANUFACTURING**			**Wed 12/27/2**	**Fri 5/31/24**
91				Subtotal:	5	3.5		
88			5a	RC assembly	1	1.25	Mon 2/12/24	Tue 4/30/24
89			5b	Rear suspension subassembly	2	1.25	Fri 2/9/24	Tue 4/30/24
90			5c	Front suspension subassembly	2	1	Wed 1/31/24	Tue 4/30/24
92			**6**	**DEVICE EVALUATION**			**Thu 2/1/24**	**Fri 6/7/24**
93				Subtotal:	5.5	4.5	Wed 2/28/24	Thu 5/9/24
96			6a	Drop test	1.5	3	Tue 4/2/24	Wed 4/10/24
97			6b	Steering angle test	1	.5	Fri 5/3/24	Fri 5/10/24
98			6c	Turning radius test	1	1	Mon 4/22/24	Sat 6/1/24
99			6d	Gather equipment for drop test	1	.5	Sat 3/30/24	Tue 4/2/24
94			6e	Gather equipment for Turning radius test	.5	.5	Fri 4/19/24	Wed 4/24/24
95			6f	Gather equipment for steering angle test	.5	.25	Sat 4/20/24	Mon 5/6/24
28			**7**	**DELIVERABLES**			**Wed 9/20/2**	**Sat 6/8/24**
29				Subtotal:	36	23.5		
30			7a	Web Page/Design	15	8	Wed 3/13/24	Mon 5/27/24
31			7b	Thumb drive	1.5	.5	Fri 5/31/24	Mon 6/3/24
32			7c	Test Report	8	5	Mon 3/25/24	Mon 6/3/24
33			7d	SOURCE poster	2.5	3	Sat 4/27/24	Fri 5/3/24
34			7e	Presentation outline	4	6	Wed 5/22/24	Fri 5/24/24
35			7f	Presentation	5	1	Mon 3/11/24	Mon 5/27/24

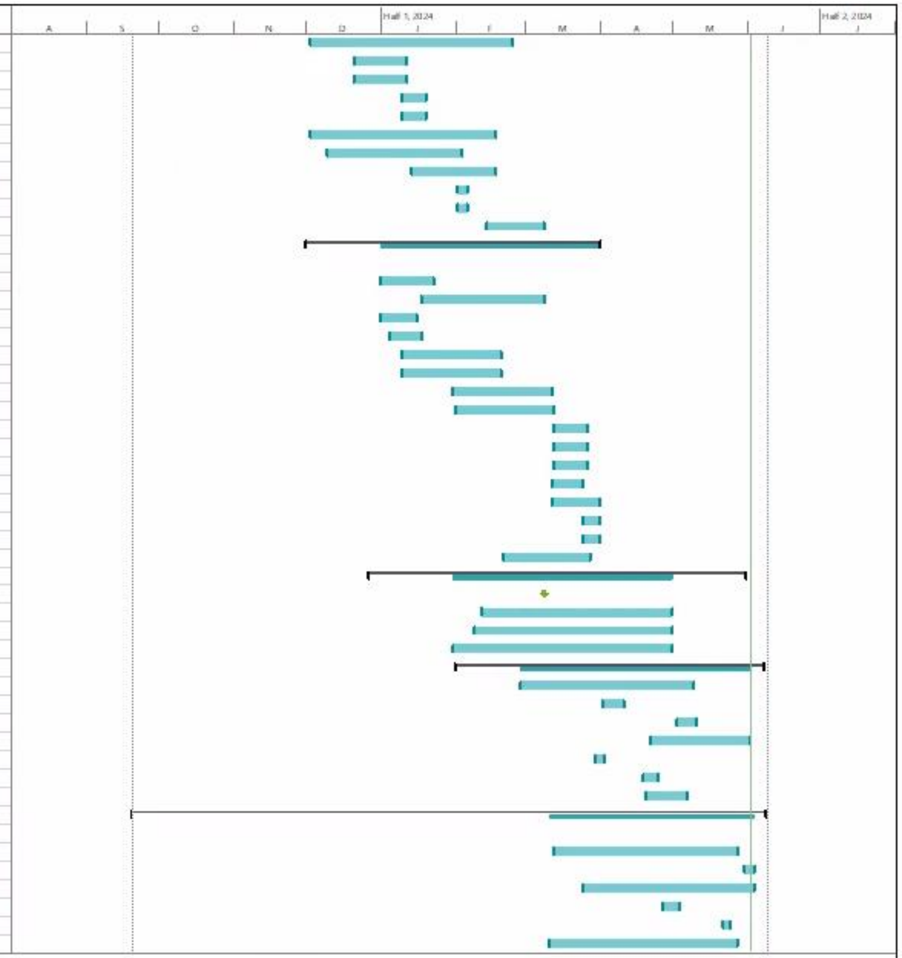

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Figure E01-2. Continuation of the Gantt chart.

APPENDIX F – Expertise and Resources

Criterion	Weight 1 to 3	Best Possible 3	Gear Drivetrain Design	Score x Wt	Belt Drivetrain Design	Score x Wt	Off Road Design	Score x Wt	
Criterion1	1	3	3	3	2	2	1	1	
Criterion2	3	9	2	6	3	9	1	3	
Criterion3	2	6	2	4	1	2	1	2	
Criterion4	2	6	2	4	2	4	1	2	
Criterion5	3	9	2	6	1	3	1	3	
Criterion6	2	6	3	6	3	6	1	2	
Total	13	39		29		26		13	
NORMALIZE THE DATA (muliply by fraction, N)		2.56		74.4		66.7		33.3	Percent

Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits	Good? Then done.	58.1	Average
	Poor Bias:	Standard Deviation is one or less digits	Poor? Change something!!!	22	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	More mass is more cost
Weight	Light weight scores better on the success equation
Prediction precision	Are the engineers calculations sufficient and correct?
Confidence -failure loc	Confidence level in the indicated failure location
Prismatic vs non prismatic	Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:

The gear drivetrain design scored the highest out of the three because it showed the best possibilities of being produced with minimal cost and manufacturability. The off road design scored the least because of its size it would cost more to produce. As for belt drivetrain desing it was similar to the alt gear drivetrain , but it has additional components that would affect cost of manufacturing and create a complication of space availability in the drivetrain.

Figure F01. Matrix decision of RC BAJA sketch designs

Criterion	Weight	Best Possible							
	1 to 3	3	3-D Printing	Score x Wt	CNC Machine	Score x Wt	Laser Cutting	Score x Wt	
Cost	3	9	3	9	1	3	2	6	
Weight	3	9	3	9	1	3	2	6	
Predicition Precision	2	6	3	6	2	4	2	4	
Confidence Failure Loc	1	3	1	1	2	2	2	2	
Prismatic vs non Prismatic	2	6	3	6	3	6	3	6	
Manufacturability	3	9	3	9	1	3	1	3	
Total	14	42		40		21		27	
NORMALIZE THE DATA (muliply by fraction, N)		2.38		95.2		50.0		64.3	Percent
Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits				Good? Then done.		69.8	Average
	Poor Bias:	Standard Deviation is one or less digits				Poor? Change something!!!		23	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	More mass is more cost
Weight	Light weight scores better on the success equation
Prediction precision	Are the engineers calculations sufficient and correct?
Confidence -failure loc	Confidence level in the indicated failure location
Prismatic vs non prismatic	Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:

Cost: 3D printing is the least cost consuming form of manufacturing, while CNC machining is the highest and laser machining is in between.

Weight: 3D printing is the lightest form of manufacturing because it is made of plastic, while the other forms of manufacturing are meant for metals which are heavier.

Prediction Precision: The calculcations are done the same way but with different values of material properties. They all have suitable properties, but 3d printing is much more available.

Confidence Failure Loc: CNC machining and laser cutting are much better decisions for an application where stronger properties are required to withstand the loads, but a 3d printing method would have much more predictable failure locations due to imperfections..

Prismatic vs non Prismatic: The shape would be the same for all, simple squares.

Manufacturability: Manufacturing with 3D printing is simpler than using bigger machines to cut away material, while in contrast the printer adds material.

Figure F02. Matrix decision of manufacturing methods

Criterion	Weight	Best Possible						
	1 to 3	3	Casting	Score x Wt	Welding	Score x Wt	Stamping	Score x Wt
Cost	3	9	1	3	2	6	3	9
Weight	3	9	1	3	2	6	3	9
Prediction Precision	2	6	1	2	2	4	3	6
Confidence Failure Loc	3	9	1	3	1	3	2	6
Prismatic vs non Prismatic	2	6	3	6	2	4	1	2
Manufacturability	3	9	1	3	2	6	2	6
Total	16	48		20		29		38
NORMALIZE THE DATA (multiply by fraction, N)		2.08		41.7		60.4		79.2 Percent

Decide if Bias is Good or Bad — Good Bias: Standard Deviation is two or more digits — Good? Then done. — 60.4 Average

Poor Bias: Standard Deviation is one or less digits — Poor? Change something! — 19 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 More mass is more cost

Weight Light weight scores better on the success equation

Prediction precision Are the engineers calculations sufficient and correct?

Confidence -failure loc Confidence level in the indicated failure location

Prismatic vs non prismatic Is the shape prismatic (retangle, square, etc) or is it inregularly shaped to meet the engineering needs

Manufacturability Is it simple to produce? Are there multiple process for a single component?

Comments:

Cost: Stamping is the least costly form of manufacturing in comparison to welding and casting just due to the processes needed to form a final product.

Weight: Stamping is usually done with thinner materials to form a shape, while welding and casting are additive forms of manufacturing through the use fusion.

Prediction Precision: Casting is inconsistent and welding would be hard to determine if a weld deforms the part, but when stamping it is measured and pressed with a jig.

Confidence Failure Loc: Casting would be hard to get a uniform part with correct dimensions and welding make the material more brittle. While stamping is more consistant.

Prismatic vs non Prismatic: For solid shapes the use of casting and welding are more desireable, but stamping is done with flat sheets, which is not as desireable for this project application.

Manufacturability: Welding and Casting are more available to students than stamping, but stamping is much more feasible because it doesn't require as much skill and setup.

Figure F03. Matrix decision of more manufacturing methods

Criterion	Weight 1 to 3	Best Possible 3	PLA	Score x Wt	PLA +	Score x Wt	Aluminum 6061	Score x Wt	
Cost	1	3	2	2	2	2	1	1	
Prediction Precision	2	6	2	4	3	6	2	4	
Yield Strength	3	9	1	3	2	6	3	9	
Density	3	9	1	3	3	9	1	3	
Manufacturability	1	3	2	2	2	2	3	3	
Total	10	30		14		25		20	
NORMALIZE THE DATA (muliply by fraction, N)		3.33		46.7		83.3		66.7	Percent

Decide if Bias is Good or Bad
Good Bias: Standard Deviation is two or more digits — Good? Then done. — 65.6 Average
Poor Bias: Standard Deviation is one or less digits — Poor? Change something!!! — 18 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	More mass is more cost
Prediction precision	Are the engineers calculations sufficient and correct?
Density	Desnity value of the material
Yield Strength	Materials maximum stress before deformation
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:

Cost : this was not very important as the cost was not something analysis was performed on
Prediction Precision: Analysis was performed to determine possible failure modes
Yield Strength: Very important since it determines the materials maximum stress before dformation
Density: Important since it will determine what the material weight

Figure F04. Matrix decision of material selection

APPENDIX G – Testing Report

Appendix G1- 2ft Drop Test

Introduction

The RC was required to withstand a drop from 2ft, and the 3D printed component were expected to not deflect more than 0.1" from the forces experienced. Appendices A1, A6, A7, and A10 to A12 are analyses related to the 2 ft drop with reasonable assumptions. The deflections were predicted to be less than 0.1" and the calculated values determined the cross sections chosen would allow for a deflection of 0.00224." Changes were made since the analyses were calculated so recorded values will not be the same as the predicted values. The data was collected using an instrument to measure length and a reference to take a measurement from. See task 6a in Appendix E for schedule of 2ft drop test.

Method/Approach

The resources needed to recreate the test are a flat accessible area with a wall at least 2 ft high, a tape measurer, blue tape, the RC, a slow-motion capable camera, paper, and a writing utensil. The test can be done individually but is easiest with the help of another person. The cost of this test is expected to be cheap and easily repeatable. The expense was blue tape and a personal cellphone with slow-motion capability was used instead of purchasing one. The RC was recorded in slow-motion next to a tape measurer to find the most the RC will deflect. This should provide test results of the force and deflection from the 2ft drop. The deflection measurement's accuracy will only be as accurate as the slow-motion camera rate can capture. The data is then recorded, tabulated, and graphed to compare force and deflection.

Test Procedure

Image of Testing Setup:

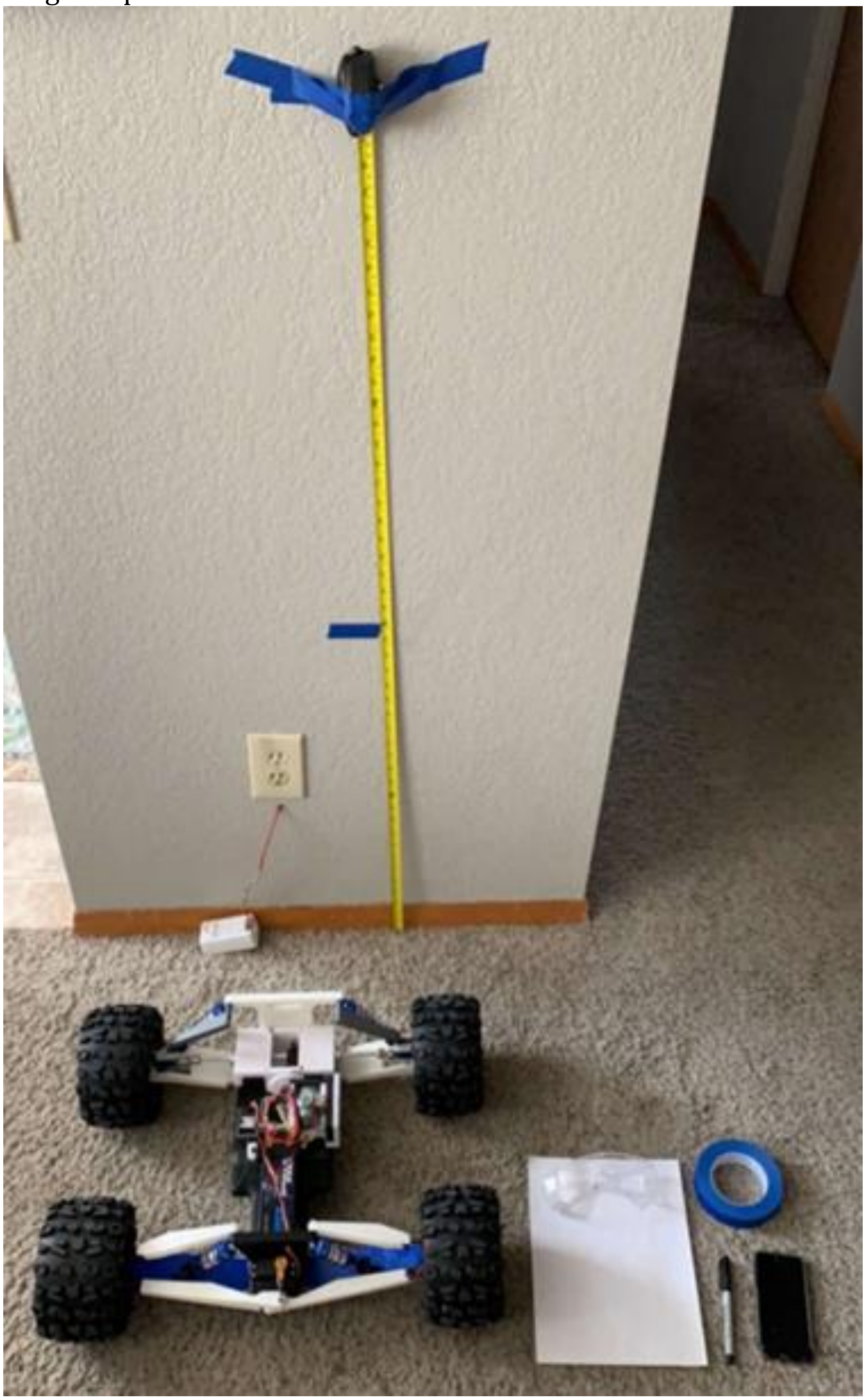


Figure G1- Image of testing set up where all the required materials are shown from the RC device to the measuring tool and writing utensils.

Summary:

This procedure instructs how to perform the test in an orderly matter that requires dropping the RC from 2ft and recording measurements of deflection in the 3D printed components. Blue tape placed at measured distances made the trial able to be repeatable quickly. Then, with a device with the capability of slow-motion, the testing procedures will be recorded and with a tape measure, the deflection measured. Then the force can be calculated based on the weight and the amount of deflection that the device experienced.

Time:
The test was conducted on 4/02/24 from 10:00AM to 1:00PM Fluke lab inside of Hogue Hall. There was 20 minutes of acquiring equipment and setting up before testing. After testing, 10 minutes were dedicated to gathering data and cleaning up.

Place:
Fluke lab Inside Hogue Hall, Central Washington University campus in Ellensburg, WA.

Required Equipment:

- Blue tape
- Tape measurer
- Slow-motion camera (Smart phone)
- RC device
- Writing utensil
- Paper
- Safety glasses
- Hanging Scale

Risk:
The RC was at risk of breaking components because it could be too heavy for the components to withstand the impact repeatably and so a new set of 3D printed components can replace any broken parts easily. Weather is also a risk if it rains because the RC is not waterproof, if it rains the RC can be tested indoors, but Hogue Hall is not open on Saturdays. Tape not sticking to unclean surfaces. The final risk is that the shocks do not contain oil.

Test Procedure:

1. Bring the purchased equipment to the testing site: Rc, blue tape, camera with slow-motion, tape measure, paper and writing utensil, hanging scale from room 127 in Hogue Hall. See figure G1.
2. Arrive outside of Hogue Hall near the loading dock outside the machine shop.
3. Place equipment on the floor near the building wall
4. Set up the camera 4ft away from the wall sitting horizontal on the ground.
5. Place 2 inches of blue tape at the front of the chassis and draw a cross at the center. (This will be used to compare deflections at different states from the normal state)
6. Have someone ready to hold the measuring tape against the wall measuring over 4ft
7. Measure 2ft on the wall and mark it with the blue tape (starting position)

8. Start recording.
9. Hold measuring tape in front of RC
10. Bring the Rc over to the 2ft mark on the wall with the blue tape.
11. Drop the Rc with the front facing the camera.
12. Stop recording.
13. Look at the footage for the most deflection.
14. Record deflection measurement on the table.
15. Repeat steps 8-14 five times.
16. Repeat steps 8-15 once but with the Rc rotated 90deg about its Z-axis. (Total of 12 runs)
17. Measure the force due to its own weight using scale(mg)
18. Record Calculated Values on Table
19. Make a graph with the Force vs Deflection
20. Calculate stress due to the force from the drop
21. Clean up the testing area.
22. Remove tape from walls.
23. Compare the deflection prediction to the gathered data.

Discussion

The testing demonstrated more deflection after each trial in the front view of the RC than in the side view. The challenges faced during testing were dropping the RC to land on all four wheels at the same time. Also, 3d components like the ball joint ends would fatigue after a few trials and so they were replaced with aluminum ball joint ends. At initial predicted value would have best fit if it were demonstrated on the Instron, but it was changed to better fit this test.

Deliverables

The deliverables in this test are to measure the displacement of the RC from a 2ft drop and compare it with the calculated value of 1.4in or 3.6cm. The recorded values averaged 3.795 cm, more than the 1.4 cm calculated. The RC had bottomed out on average in the front section because the front section would get slammed down by the undistributed weight of the RC not letting it land on all four wheels evenly. Nonetheless, the RC showed promising results of surviving the impact from a 2ft drop although the discrepancies like material of the floor and other things associated to the energy loss.

Appendix G1.1 – Procedure Checklist

Ensure RC is functional before the test

Ensure all necessary equipment is acquired before arriving to the testing location

- Collect Materials: Marker
- Blue Tape
- Tape Measure
- Slow-Motion Device (Ie. Smartphone, iPhone)
- RC Device
- Writing Utensil

- Safety Glasses
- Paper
- Hanging Scale

Set up testing location
Measure 2ft height on wall
Start recording
Stop recording
Notate results in table
Clean up

Appendix G1.2 – Data Forms

Table G1- 2ft drop test data table

Front equilibrium point:			K=	Predicted Value:
Front	End Point (cm)	Displacement (cm)	Recalculated displacement (cm)	% Error between displacement
1				
2				
3				
4				
5				
6				
AVG				
Side equilibrium point:				
Side	End Point (cm)	Displacement (cm)	Calculated displacement (cm)	% Error between displacement
1				
2				
3				
4				
5				
6				
AVG				

Weight of vehicle:
Drop height:
Adhesive stress:
Avg. Spring constant:

Appendix G1.3 – Raw Data

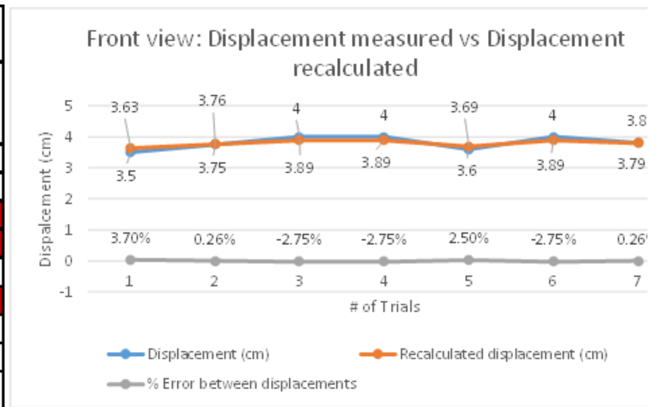
Table G2- 2ft drop test data table

Front equilibrium point: 6.5cm			k=10.4lb/in	Predicted Value: 3.6 cm
Front	End Point (cm)	Displacement (cm)	Recalculated displacement (cm)	% Error between displacements
1	3	3.5	3.63	3.70%
2	2.75	3.75	3.76	0.26%
3	2.5	4	3.89	-2.75%
4	2.5	4	3.89	-2.75%
5	2.9	3.6	3.69	2.50%
6	2.5	4	3.89	-2.75%
AVG		3.8	3.79	0.26%
Side equilibrium point: 6.0 cm				
Side	End Point (cm)	Displacement (cm)	Recalculated displacement (cm)	% Error between displacements
1	3.8	2.7	3.2	18.50%
2	4	2.5	3.07	22.80%
3	3.25	3.25	3.5	7.70%
4	3.75	2.75	3.23	17.45%
5	3.9	2.6	3.14	20.77%
6	4.5	2	2.74	37%
AVG		2.63	3.14	19.39%

Weight of vehicle: 7lbf/ 31.14N
Drop height: 2ft
Adhesive stress: 6.234psi
Avg. Spring constant: 10.4 lbf/in

Appendix G1.4 – Evaluation Sheet

Front equilibrium point: 6.5cm			k=10.4lb/in	Predicted Value: 3.6 cm
Front	End Point (cm)	Displacement (cm)	Recalculated displacement (cm)	% Error between displacements
1	3	3.5	3.63	3.70%
2	2.75	3.75	3.76	0.26%
3	2.5	4	3.89	-2.75%
4	2.5	4	3.89	-2.75%
5	2.9	3.6	3.69	2.50%
6	2.5	4	3.89	-2.75%
AVG		3.8	3.79	0.26%
Side equilibrium point: 6.0 cm				
Side	End Point (cm)	Displacement (cm)	Recalculated displacement (cm)	% Error between displacements
1	3.8	2.7	3.2	18.50%
2	4	2.5	3.07	22.80%
3	3.25	3.25	3.5	7.70%
4	3.75	2.75	3.23	17.45%
5	3.9	2.6	3.14	20.77%
6	4.5	2	2.74	37%
AVG		2.63	3.14	19.39%



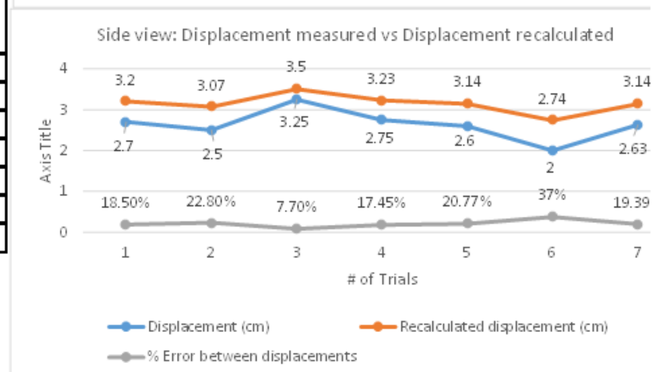


Figure G2- Evaluation sheet.
Weight of vehicle: 7lbf/ 31.14N
Drop height: 2ft
Adhesive stress: 6.234psi
Avg. Spring constant: 10.4 lbf/in

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Given: f = 7 lbf, h = 24 in,

Find: K for 1" displacement, use K to solve for spring force

Assume: find displacement based on spring force and All energy is conserved

Method: NRG of conservation

Soln:

$f = mgh \qquad f = \frac{1}{2}Kx^2$

Assume 1" deflection $\Delta x = 1$ in

$mg = 7$ lb

$h = 24$ in

$7 \cdot 24 = \frac{1}{2}K(1)^2$

$2(168) = K$

$\frac{336 \frac{lb}{in^2}}{32.2} = K \Rightarrow K = 10.4$ lb/in

$mgh = \frac{1}{2}Kx^2$

$168 = \frac{1}{2}10.4\,\Delta x^2$

$\Delta x = 5.68/4$

$\Delta x = 1.42$ in @ all springs

Predicted value: 1.42 in or 3.606 cm

Assuming K = 10.4 lb/in and using measured displacement find f_{spring}

Front view

$f_1 = (10.4)(1.377) = 14.32$ lb

$f_2 =$ " $(1.476) = 15.35$ lb

$f_3 =$ " $(1.575) = 16.38$ lb

$f_4 =$ " $(1.575) = 16.38$ lb

$f_5 =$ " $(1.417) = 14.74$ lb

$f_6 =$ " $(1.575) = 16.38$ lb

Side view

$f_1 = (10.4)(1.063) = 11.06$ lb

$f_2 =$ " $(0.984) = 10.23$ lb

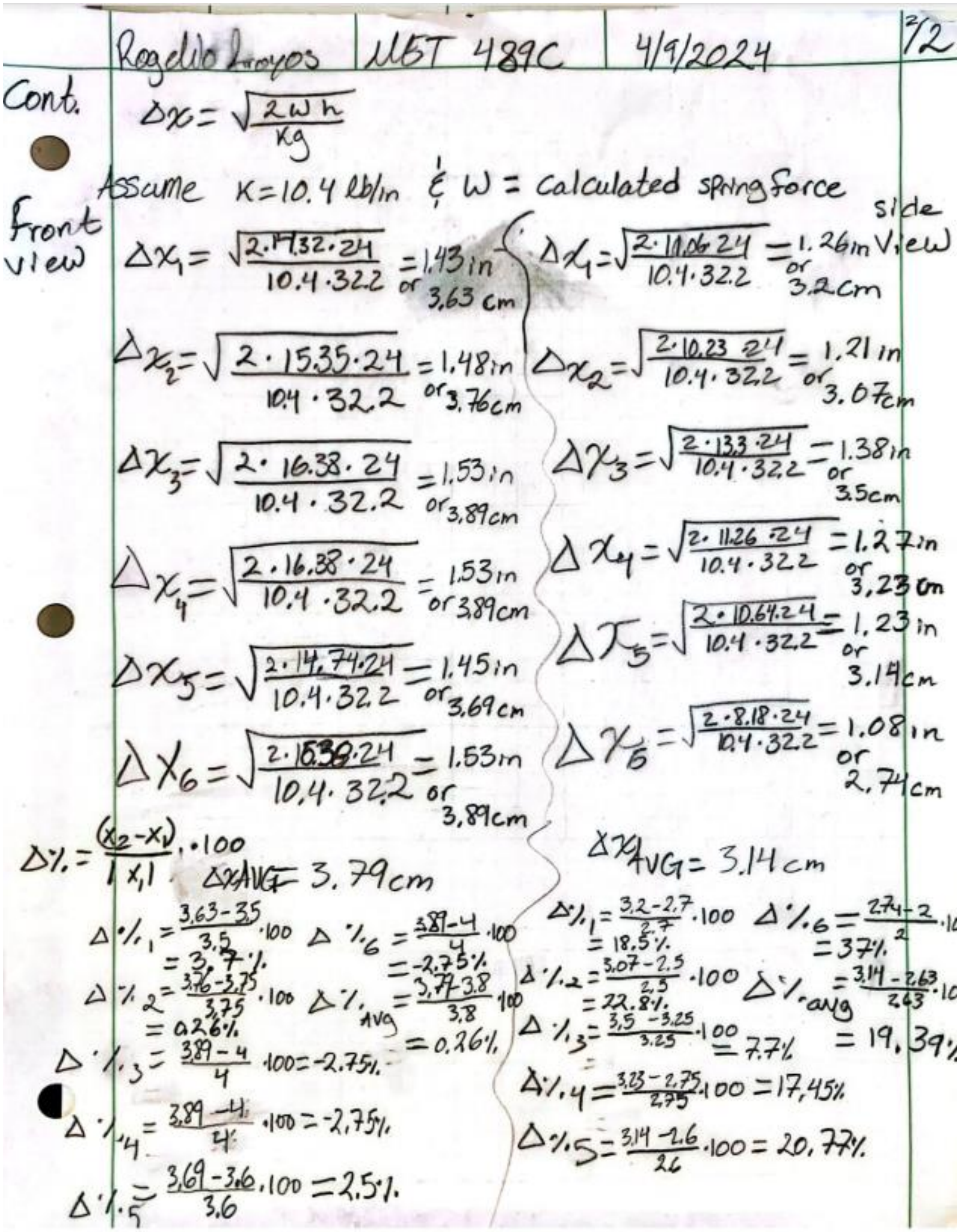
$f_3 =$ " $(1.279) = 13.30$ lb

$f_4 =$ " $(1.083) = 11.26$ lb

$f_5 =$ " $(1.023) = 10.64$ lb

$f_6 =$ " $(0.787) = 8.18$ lb

Figure G3- Evaluation sheet continued.



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Cont.

$$\Delta x = \sqrt{\frac{2Wh}{Kg}}$$

Assume K = 10.4 lb/in & W = calculated spring force

Front view

$$\Delta x_1 = \sqrt{\frac{2 \cdot 14.32 \cdot 24}{10.4 \cdot 32.2}} = 1.43\text{ in or } 3.63\text{ cm}$$

$$\Delta x_2 = \sqrt{\frac{2 \cdot 15.35 \cdot 24}{10.4 \cdot 32.2}} = 1.48\text{ in or } 3.76\text{ cm}$$

$$\Delta x_3 = \sqrt{\frac{2 \cdot 16.38 \cdot 24}{10.4 \cdot 32.2}} = 1.53\text{ in or } 3.89\text{ cm}$$

$$\Delta x_4 = \sqrt{\frac{2 \cdot 16.38 \cdot 24}{10.4 \cdot 32.2}} = 1.53\text{ in or } 3.89\text{ cm}$$

$$\Delta x_5 = \sqrt{\frac{2 \cdot 14.74 \cdot 24}{10.4 \cdot 32.2}} = 1.45\text{ in or } 3.69\text{ cm}$$

$$\Delta x_6 = \sqrt{\frac{2 \cdot 16.38 \cdot 24}{10.4 \cdot 32.2}} = 1.53\text{ in or } 3.89\text{ cm}$$

Side view

$$\Delta x_1 = \sqrt{\frac{2 \cdot 11.06 \cdot 24}{10.4 \cdot 32.2}} = 1.26\text{ in or } 3.2\text{ cm}$$

$$\Delta x_2 = \sqrt{\frac{2 \cdot 10.23 \cdot 24}{10.4 \cdot 32.2}} = 1.21\text{ in or } 3.07\text{ cm}$$

$$\Delta x_3 = \sqrt{\frac{2 \cdot 13.3 \cdot 24}{10.4 \cdot 32.2}} = 1.38\text{ in or } 3.5\text{ cm}$$

$$\Delta x_4 = \sqrt{\frac{2 \cdot 11.26 \cdot 24}{10.4 \cdot 32.2}} = 1.27\text{ in or } 3.23\text{ cm}$$

$$\Delta x_5 = \sqrt{\frac{2 \cdot 10.64 \cdot 24}{10.4 \cdot 32.2}} = 1.23\text{ in or } 3.14\text{ cm}$$

$$\Delta x_6 = \sqrt{\frac{2 \cdot 8.18 \cdot 24}{10.4 \cdot 32.2}} = 1.08\text{ in or } 2.74\text{ cm}$$

$$\Delta\% = \frac{(x_2 - x_1)}{|x_1|} \cdot 100$$

Δx_{AVG} = 3.79 cm

$\Delta\%_1 = \frac{3.63-3.5}{3.5} \cdot 100 = 3.7\%$

$\Delta\%_2 = \frac{3.76-3.75}{3.75} \cdot 100 = 0.26\%$

$\Delta\%_3 = \frac{3.89-4}{4} \cdot 100 = -2.75\%$

$\Delta\%_4 = \frac{3.89-4}{4} \cdot 100 = -2.75\%$

$\Delta\%_5 = \frac{3.69-3.6}{3.6} \cdot 100 = 2.5\%$

$\Delta\%_6 = \frac{3.89-4}{4} \cdot 100 = -2.75\%$

$\Delta\%_{AVG} = \frac{3.79-3.8}{3.8} \cdot 100 = 0.26\%$

Δx_{AVG} = 3.14 cm

$\Delta\%_1 = \frac{3.2-2.7}{2.7} \cdot 100 = 18.5\%$

$\Delta\%_2 = \frac{3.07-2.5}{2.5} \cdot 100 = 22.8\%$

$\Delta\%_3 = \frac{3.5-3.25}{3.25} \cdot 100 = 7.7\%$

$\Delta\%_4 = \frac{3.23-2.75}{2.75} \cdot 100 = 17.45\%$

$\Delta\%_5 = \frac{3.14-2.6}{2.6} \cdot 100 = 20.77\%$

$\Delta\%_6 = \frac{2.74-2}{2} \cdot 100 = 37\%$

$\Delta\%_{avg} = \frac{3.14-2.63}{2.63} \cdot 100 = 19.39\%$

Figure G4- Evaluation sheet continued.

Appendix G1.5 – Schedule (Testing)

92	📌	6	◢ **DEVICE EVALUATION**			**Thu 2/1/24**	**Fri 6/7/24**
93	📌		Subtotal:	5.5	4.5	Wed 2/28/24	Thu 5/9/24
96	📌	6a	Drop test	1.5	3	Tue 4/2/24	Wed 4/10/24
97	📌	6b	Steering angle test	1	.5	Fri 5/3/24	Fri 5/10/24
98	📌	6c	Turning radius test	1	1	Mon 4/22/24	Sat 6/1/24
99	📌	6d	Gather equipment for drop test	1	.5	Sat 3/30/24	Tue 4/2/24
94	📌	6e	Gather equipment for Turning radius test	.5	.5	Fri 4/19/24	Wed 4/24/24
95	📌	6f	Gather equipment for steering angle test	.5	.25	Sat 4/20/24	Mon 5/6/24

Figure G5- Schedule of 2ft drop test.

Appendix G2- Turning Radius Test

Introduction

This test was done to complete the requirement of achieving a 4-foot turning radius according to section 1d. In addition, this relates to the analysis done in Appendix A5. The RC measures 18 inches in track width and 11.5 inches in wheelbase. Using these values, a predicted value of 2ft can be determined using a geometry equation to solve for the turning radius. A test is set up in the Fluke Lab inside Hogue Hall to investigate the prediction. The measurements are taken with a measuring tape and using the inside wheel as the reference for measuring distance from start to end.

Method/Approach

The approach to this test does not require more people or costs to perform. The resources needed to recreate this test is a flat accessible area, measuring tape, blue tape, RC device, RC controller, safety glasses, a straight edge, paper, and a writing utensil. The RC is simply being measured from it starting position and ending position along a straight edge. The measured value is recorded and tabulated to compare with the predicted value based on the RC's track width and wheelbase. The accuracy of the measurements is as accurate as the tape measurer allows to read. To maintain precision, values are rounded to the first decimal point and recorded on the table. The information is then graphed illustrating the values and error %.

Test Procedure

Image of Testing Setup:

Figure G6- Image of test set up equipment laid out from the RC to the blue tape and measuring tape.

Summary:

This procedure explains the process to repeat a turning radius test for the RC Baja. In this test it will be examining the turning radius of the RC and comparing it to its predicted value based on the track width and wheelbase. The track width of the RC is measured with a measuring tape across the front or rear of the RC from center to center of the wheels. Then the same is done for the side but measuring from the center of the rear wheel to the center of the front wheel to measure the wheelbase. The values were measured at 18 inches in trackwidth and 11.5 inches in wheelbase. The predicted value of the RC's turning radius is 2 feet. The following test will determine the accuracy of the predicted result.

Time:

The test was conducted on 4/22/24 from 10:00AM to 11:00PM in the Fluke lab inside of Hogue Hall. There were 10 minutes of acquiring equipment and setting up before testing. After testing, 10 minutes were dedicated to gathering data and cleaning up.

Place:

Fluke lab Inside Hogue Hall, Central Washington University campus in Ellensburg, WA.

Required equipment:

- Safety glasses
- RC device fully charged
- RC controller fully charged
- Measuring tape
- Blue tape
- Straight edge
- Paper
- Writing utensil

Risk:

A risk while performing this test is motor overheating. Due to it being a brushed motor it runs hotter than a brushless motor. This could cause an issue with the drivetrain's 3D printed gears warping and being deemed useless. If that were the case the test could not be conducted because it requires the RC to be drivable. The next risk would be inaccurately placing the RC in the same place, not allowing consistent measurements. Another risk would be the RC not being able to move. The Final risk would be the battery being drained on the RC or the RC controller. This would postpone the test.

Test Procedure:

1) Arrive to the fluke lab with the following materials: safety glasses, Rc device fully charged, Rc controller with fully charged batteries, measuring tape, blue tape, straight edge
2) Using an existing straight edge from the floor of the fluke lab, set a 2-foot marker along the edge. This is the starting line.
3) Using another straight edge set a 2-foot blue tape marker perpendicular to the first marker on the left side. The setup should look like Figure G6.
4) Bring the RC over to the starting line.
5) Turn the ESC on to power the RC using the on/off switch
6) Turn the RC controller on using the on/off switch
7) When the transmitter and receiver are confirmed to be connected make sure the wheels spin in reverse.
8) Set the two rear wheels of the RC on the 2-foot blue tape marker and set the edge of the wheels on the left side parallel to the 2-foot blue tape.
9) Full throttle the power and turn the wheels of the RC to full lock to the left
10) Stop the RC when the rear wheels of the RC complete a half circle and return to the starting edge.
11) Measure and record the distance between the starting and ending position of the inner wheel along the starting line on the paper using a writing utensil.
12) Repeat steps 7-10 4 more times
13) Clean up testing site.
14) Compare calculated value and recorded value.

Discussion

The testing demonstrated more turning radius than predicted. The predicted value of 2 feet was exceeded more than twice and the requirement of less than 4 feet was not met. The average turning radius was calculated to be 4.31 feet. The challenge faced during testing was the RC being placed correctly to perform the test. The RC turning radius results can be improved if the RC had smaller wheels because due to the 7-inch diameter wheels, they create wheel tilt. The wheel tilt creates deviation in the turning radius and so it does not meet the predicted or required values.

Deliverables

The deliverables in this test are to determine the accuracy of the turning radius based on the RC's dimensions. The predicted value of 2 feet was determined by measuring the wheelbase of the RC and dividing that value by the tangent of the turning angle to the left full lock at 25.975 degrees according to the calculations. The predicted value was not reached, it was in fact underestimated because the average turning radius was 4.31 ft. This could be due to the larger wheels creating more wheel tilt and the width of the tires would contribute to the larger turning radius because it would create a larger slip angle, while the RC attempts to stabilize itself as it turns. Nonetheless, the RC's choice of dimensions and tires contributed to the turning radius results observed.

Appendix G2.1 – Procedure Checklist

Ensure RC is functional and charged before the test
Ensure all necessary equipment is acquired before arriving to the testing location
Collect Materials:

- Writing utensil
- Blue Tape
- Measuring tape
- RC Controller
- RC Device
- Safety Glasses
- Paper
- Straight edge

Set up testing location.
Measure 2 feet of blue tape and place it along the straight edge on the ground
Measure 2 feet and place it perpendicular to the first marker on the left-hand side of the tape to create a 90-degree angle.
Turn RC and RC controller on with the on/off switch.
Full throttle and turn the wheel full lock to the left.
Stop RC once it reaches the starting edge after completing a half circle turn.
Notate results in table.
Repeat again for 4 more trials.
Clean up

Appendix G2.2 – Data Forms

Table G3- Data Forms Table

Trials	Turning radius (ft/in)	Error %
1		
2		
3		
4		
5		
AVG		

Calculated turning radius:

Appendix G2.3 – Raw Data

Table G4- Raw Data Table

Trials	Turning radius (ft/in)	Error %
1	4.6 ft 55 in	-56.5%
2	4.1 ft 49.7 in	-51.2%
3	4.2 ft 50.25 in	-52.8%
4	4.25 ft 51 in	-52.9%
5	4.4 ft 52.5 in	-54.5%
AVG	4.31 ft 51.7 in	-53.6%

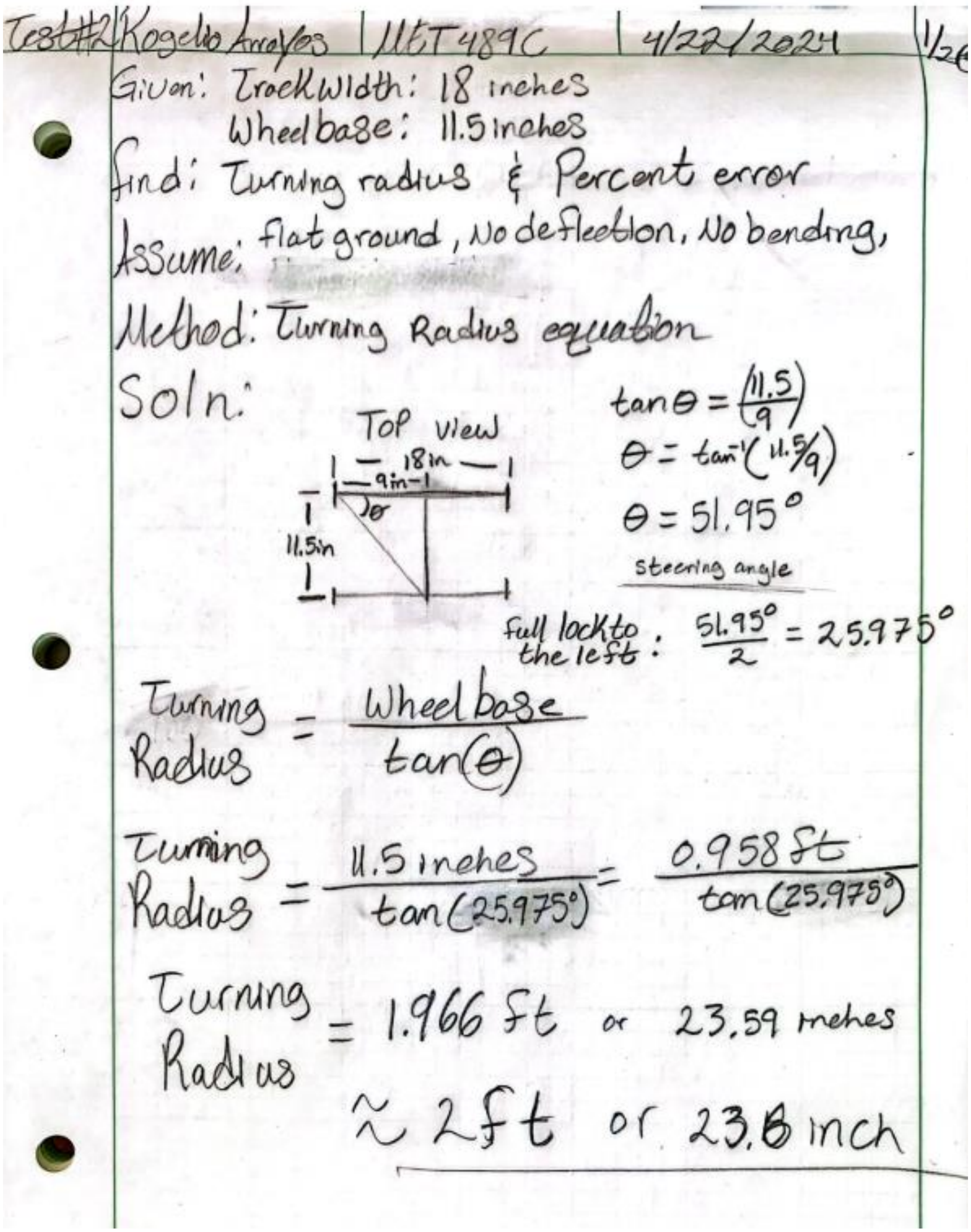
Calculated turning radius: 2 ft

Appendix G2.4 – Evaluation Sheet

Table G5- Evaluation Sheet table

Trials	Turning radius (ft/in)	Error %
1	4.6 ft 55 in	-56.5%
2	4.1 ft 49.7 in	-51.2%
3	4.2 ft 50.25 in	-52.8%
4	4.25 ft 51 in	-52.9%
5	4.4 ft 52.5 in	-54.5%
AVG	4.31 ft 51.7 in	-53.6%

Calculated turning radius: 2 ft



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Given: Track Width: 18 inches
Wheelbase: 11.5 inches

Find: Turning radius & Percent error

Assume: flat ground, No deflection, No bending,

Method: Turning Radius equation

Soln:

$\tan\theta = \left(\frac{11.5}{9}\right)$

$\theta = \tan^{-1}(11.5/9)$

$\theta = 51.95^\circ$

steering angle

full lock to the left: $\frac{51.95^\circ}{2} = 25.975^\circ$

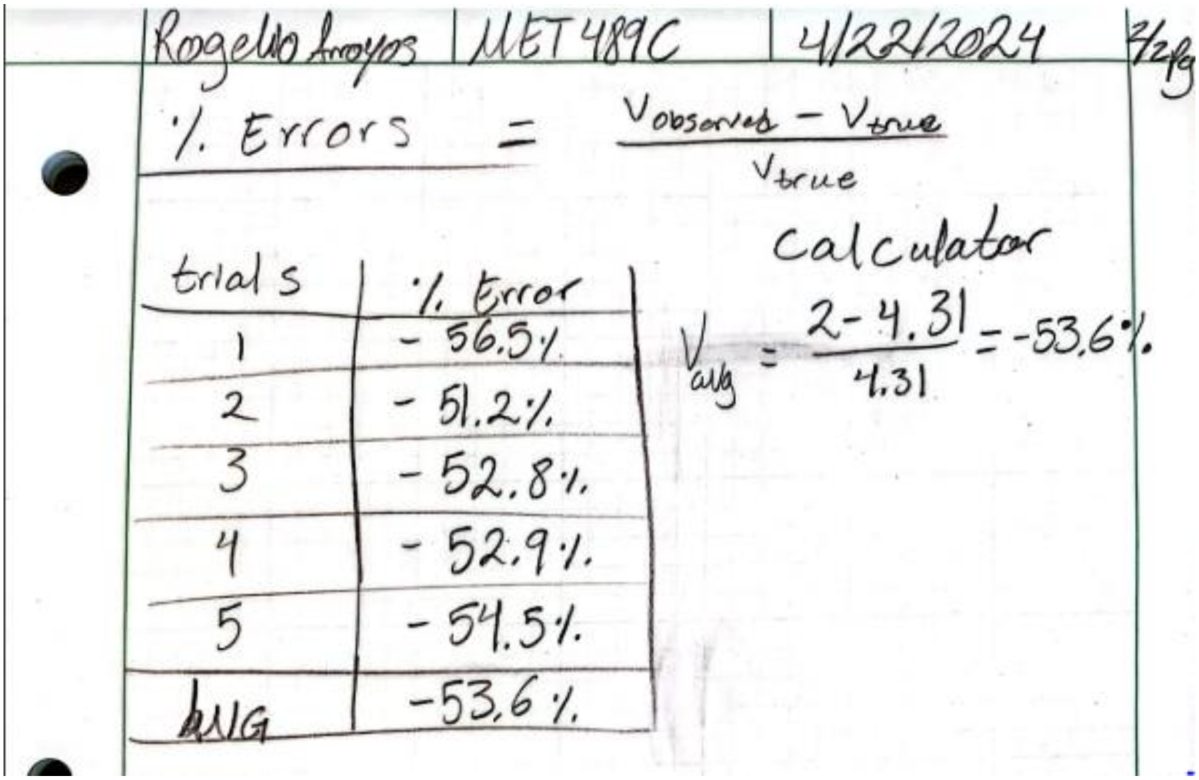
$$\text{Turning Radius} = \frac{\text{Wheelbase}}{\tan(\theta)}$$

$$\text{Turning Radius} = \frac{11.5 \text{ inches}}{\tan(25.975^\circ)} = \frac{0.958 \text{ ft}}{\tan(25.975^\circ)}$$

$$\text{Turning Radius} = 1.966 \text{ ft or } 23.59 \text{ inches}$$

$\approx 2 \text{ ft}$ or 23.6 inch

Figure G7- Turning radius calculations.



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% Errors = $\frac{V_{observed} - V_{true}}{V_{true}}$

trials	% Error
1	-56.5%
2	-51.2%
3	-52.8%
4	-52.9%
5	-54.5%
AVG	-53.6%

Calculator

$V_{avg} = \frac{2-4.31}{4.31} = -53.6\%$

Figure G8- Turning Radius calculations continued.

Appendix G2.5 – Schedule (Testing)

92	📌	**6**	**DEVICE EVALUATION**			**Thu 2/1/24**	**Fri 6/7/24**
93	📌		Subtotal:	5.5	4.5	Wed 2/28/24	Thu 5/9/24
96	📌	6a	Drop test	1.5	3	Tue 4/2/24	Wed 4/10/24
97	📌	6b	Steering angle test	1	.5	Fri 5/3/24	Fri 5/10/24
98	📌	6c	Turning radius test	1	1	Mon 4/22/24	Sat 6/1/24
99	📌	6d	Gather equipment for drop test	1	.5	Sat 3/30/24	Tue 4/2/24
94	📌	6e	Gather equipment for Turning radius test	.5	.5	Fri 4/19/24	Wed 4/24/24
95	📌	6f	Gather equipment for steering angle test	.5	.25	Sat 4/20/24	Mon 5/6/24

Figure G9- Turning radius test schedule.

Appendix G3- Steering angle Test

Introduction

This test is conducted to test the steering angle of the RC wheels. The requirement in this test is if the RC can turn left and right 60 degrees in total as required in section 1d. The RC is predicted to only have a steering angle of 12.7 degrees full lock one way. A total steering angle of 25.4 degrees is what is calculated for the RC based on the wheelbase and the average turning radius. The was calculated using an equation to find maximum steering angle using the RC's track width of 18 inches and wheelbase of 11.5 inches. The test is performed in the Fluke lab in Hogue Hall but can be performed anywhere with enough room for the RC to turn the wheels freely. A protractor is fixed temporarily to the floor under the center of the wheel of the RC and then the test is performed.

Method/Approach

The following equipment is needed for this test: RC device, RC controller, protractor, blue tape, paper, and a writing utensil. This test was performed on an open flat ground using a protractor to measure the steering angle of each wheel. This test can be performed without assistance and can be done quickly if done correctly. The test will have values rounded to the nearest degree higher than measured.

Test Procedure

Image of test equipment:

Figure G10- Test equipment for steering angle test.

This procedure explains the process to repeat a steering angle test for the RC Baja. In this test it will be examining the turning angle and comparing it to the predicted value found using geometry of the RC. The track width of the RC is measured with a measuring tape across the front or rear of the RC from center to center of the wheels. Then the same is done for the side but measuring from the center of the rear wheel to the center of the front wheel to measure the wheelbase. The values were measured at 18 inches in trackwidth and 11.5 inches in wheelbase. The predicted value of the RC's steering angle is 25.4 degrees. The following test will determine the accuracy of the predicted result.

Time:

The test was conducted on 5/6/24 from 10:00AM to 10:30PM in the Fluke lab inside of Hogue Hall. There were 5 minutes of acquiring equipment and setting up before testing. After testing, 3 minutes were dedicated to gathering data and cleaning up.

Place:

Fluke lab Inside Hogue Hall, Central Washington University campus in Ellensburg, WA.

Required equipment:

- Safety glasses
- RC device fully charged
- RC controller fully charged
- Blue tape
- Protractor
- Paper
- Writing utensil

Risk:

There were minimal risks associated with this test. The controller and RC must be charged to perform this test. The RC previously has shown no issues with steering besides the lower control arm ball joint end breaking because it was initially 3d printed, but then was replaced with an aluminum ball joint end and the risk was eliminated during the first test. The RC would have risked overheating if it were pushed beyond its limits, but it would realistically have not happened under the conditions it was tested. Other than that, the RC would have no risks following the procedure assuring everything works before performing the steering angle test.

Procedure:

1) Collect equipment: RC device, RC controller, protractor, blue tape, paper, and a writing utensil
2) Arrive at the testing location Fluke lab in Hogue Hall.
3) Set equipment on the floor
4) Place and tape the protractor on the floor.
5) Set the RC with the center of the front left wheel on the 90-degree marker on the protractor. Keep the RC wheel centered on the protractor.

6) Turn wheel to the left
7) Record measurement of range from equilibrium (90-degree marker)
8) Turn wheel to the right
9) Record measurement of range from equilibrium (90-degree marker)
10) Repeat steps 6-9 for 3 trials in total
11) Repeat steps 5- 11 for the front right wheel.
12) Clean up

Discussion

The testing demonstrated less steering angle than required but exceeded the predicted value of 25.4 degrees. The RC showed a steering angle of at most 35 degrees to the right and a steering angle of 29 degrees to the left. The right wheel was able to pivot more than the left wheel and that can be due to the tie rod needing adjustment or the wheel creating wheel tilt. Bigger wheels in fact create more wheel tilt, which affects the steering angle. The predicted value of 25.4 degrees was exceeded, but the max angle of 60 degrees was not achieved.

Deliverables

The deliverables in this test were to ensure that the required turning angle was achieved and the predicted value was accurate. It was concluded that the required 60 degrees of turning angle was not achieved due to interference in the ball joints of the lower control arms, but it worked out because the RC was able to continue with the obstacle course during the competition. The RC reached at most a turning angle of 35 degrees to the right and 29 degrees at most to the left.

Appendix G3.1 – Procedure Checklist

Ensure RC is functional and charged before the test
Ensure all necessary equipment is acquired before arriving to the testing location
Collect Materials:

- Writing utensil
- Blue Tape
- RC Controller
- RC Device
- Safety Glasses
- Paper
- protractor

Set up testing location.
Set protractor down facing up.
Tape the protractor down to so that it does not move.
Place RC’s left wheel on the pivot point on top of the protractor with the wheel on the 90-degree mark.
Turn RC and RC controller on with the on/off switch.

Turn the wheel to the left and measure the angle from equilibrium (90-degree mark)
Turn the wheel to the right and measure the angle from equilibrium (90-degree mark)
Notate results in table.
Repeat again 2 more times for 3 trials.
Clean up

Appendix G3.2 – Data Forms

Table G6- Steering angle results table

Left Wheel		Right Wheel		Total [Left wheel + Right wheel] (Right turn + Right turn) (Left turn + Left turn)	
Left Turn (in degrees)	Right Turn (in degrees)	Left Turn (in degrees)	Right Turn (in degrees)	Left Turn (in degrees)	Right Turn (in degrees)

Predicted steering angle:

Appendix G3.3 – Raw Data

Table G7- Steering angle results table

Left Wheel		Right Wheel		Total [Left wheel + Right wheel] (Right turn + Right turn) (Left turn + Left turn)	
Left Turn (in degrees)	Right Turn (in degrees)	Left Turn (in degrees)	Right Turn (in degrees)	Left Turn (in degrees)	Right Turn (in degrees)
15	13	14	22	29	35
13	15	15	20	28	35
14	14	13	21	27	35

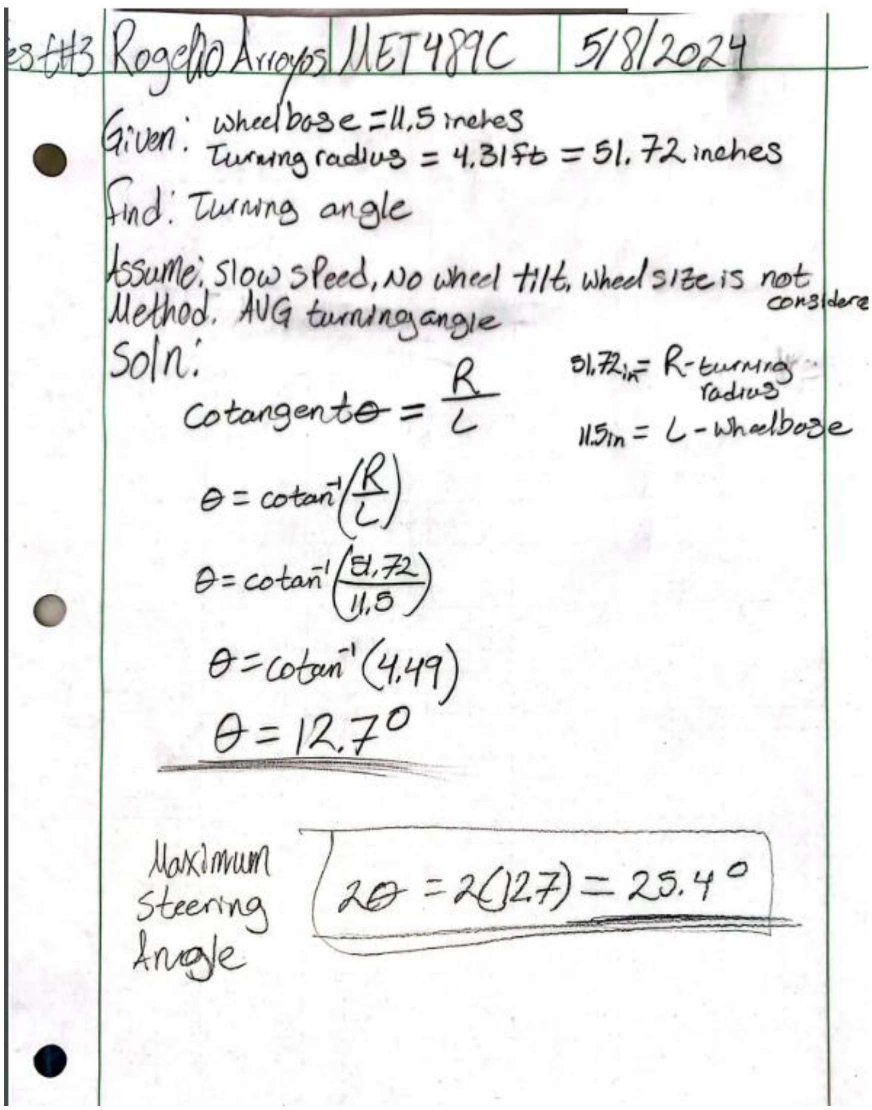
Predicted steering angle: 25.4 degrees

Appendix G3.4 – Evaluation Sheet

Table G8- Steering angle results table

Left Wheel		Right Wheel		Total [Left wheel + Right wheel] (Right turn + Right turn) (Left turn + Left turn)	
Left Turn (in degrees)	Right Turn (in degrees)	Left Turn (in degrees)	Right Turn (in degrees)	Left Turn (in degrees)	Right Turn (in degrees)
15	13	14	22	29	35
13	15	15	20	28	35
14	14	13	21	27	35

Predicted steering angle: 25.4 degrees


...s #3 Rogelio Arroyos MET489C 5/8/2024

Given: wheelbase = 11.5 inches

Turning radius = 4.31 ft = 51.72 inches

Find: Turning angle

Assume: slow speed, No wheel tilt, wheel size is not considere[d]

Method: AVG turning angle

Soln:

$$\text{Cotangent}\,\theta = \frac{R}{L}$$

51.72 in = R - turning radius

11.5 in = L - wheelbase

$$\theta = \cot^{-1}\left(\frac{R}{L}\right)$$

$$\theta = \cot^{-1}\left(\frac{51.72}{11.5}\right)$$

$$\theta = \cot^{-1}(4.49)$$

$$\theta = 12.7^\circ$$

Maximum Steering Angle

$$2\theta = 2(12.7) = 25.4^\circ$$

Figure G9- Steering angle prediction calculations

Appendix G3.5 – Schedule (Testing)

92	**6**	**DEVICE EVALUATION**			**Thu 2/1/24**	**Fri 6/7/24**
93		Subtotal:	5.5	4.5	Wed 2/28/24	Thu 5/9/24
96	6a	Drop test	1.5	3	Tue 4/2/24	Wed 4/10/24
97	6b	Steering angle test	1	.5	Fri 5/3/24	Fri 5/10/24
98	6c	Turning radius test	1	1	Mon 4/22/24	Sat 6/1/24
99	6d	Gather equipment for drop test	1	.5	Sat 3/30/24	Tue 4/2/24
94	6e	Gather equipment for Turning radius test	.5	.5	Fri 4/19/24	Wed 4/24/24
95	6f	Gather equipment for steering angle test	.5	.25	Sat 4/20/24	Mon 5/6/24

Figure G10- schedule of steering angle test.

APPENDIX H – Resume

ROGELIO ARROYOS

OBJECTIVE

Looking to start a career in the broad areas of engineering. I have interests in designing, but also exploring other areas of the field such as machining and manufacturing.

SKILLS & ABILITIES

- PowerPoint, Excel, Word, Proficient in Windows
- VECTORWORKS 2023
- AutoCAD 2022
- SOLIDWORKS 2022
- Native Spanish and English speaker
- Manufacturing (Machining, 3D printing, micro-laser cutting)

Certifications:

- Solid Works ASSOCIATE - Mechanical Design- 2022
- WA State Seal of Biliteracy - June 12, 2021
- SP/2 Certification - 2017

CONTACTS:

E Arroyosr@cwu.edu

EXPERIENCE

COURSE RELATED, CENTRAL WASHINGTON UNIVERSITY, ELLENSBURG, WA

NASA UW SURP INTERNSHIP — SUMMER 2023

•Designing parts in 2D vectorworks, then micrometer laser cutting layers of Kapton, FR4, and adhesive materials to manufacture an autonomous coin sized helicopter and stabilize in the yaw axis.

ETSC 265 — SPRING 2022

•Designing parts in 3D, then setting drawings of the parts to industry ASME standard and learning how to use the SOLIDWORKS program in a professional manner.

MET 355 — FALL 2022

•Designing parts in 3D with more in-depth use of SOLIDWORKS (also HSMworks) tools and simulating machining procedures from raw material. Throughout the course the professor mentored the class by groups on operating large CNC machines to manufacture a hammer from raw materials and customizing some features.

EDUCATION

CENTRAL WASHINGTON UNIVERSITY — SPRING 2024

UNDERGRADUATE

MAJOR: MECHANICAL ENGINEERING TECHNOLOGY BS

HIGH SCHOOL DIPLOMA — JUNE 2021

CHIAWANA HIGH SCHOOL, PASCO, WA

LEADERSHIP/ACTIVITIES/ACHIEVEMENTS

AVELA AT UW — SUMMER 2023

CAMP PROGRAM MEMBER — FALL 2021-PRESENT

WA STATE SEAL OF BILITERACY- SPANISH — JUNE 2021

DEAN'S HONOR ROLL — WINTER 2020/21