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RC Baja Competition - Suspension and Steering

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RC Baja Competition

-Suspension and Steering-

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ABSTRACT

The objective of this project is to design and construct a vehicle that will compete in the RC Baja Competition. As this project will be split between two students, this paper will be focusing on suspension and steering while the partner will focus on chassis and drivetrain. The vehicle will be tested in three different categories: the sprint, the slalom, and the Baja. These categories will test its speed, turning capabilities, and its overall capability in rough terrain.

As this paper focuses on the suspension and steering. Several analyses and decision matrix were used to find the best dimension along with material needed for the structural components. The Baja will test the vehicle's capability in handling stress along with finding the necessary suspension and turning radius.

To ensure success in the sprint portion, the vehicle deviates less than 5 inches when driving for 50 feet. To give a competitive edge in the slalom the vehicle has a turn radius of 10 inches. Finally, the wishbones have been tested in deflection and buckling capabilities. The wishbones will not buckle under a 75 lb. axial load, nor deflect more than 0.2 inches (5mm) under a 25 lb. perpendicular load. Furthermore, the vehicle can be dropped at 3 feet with the springs only compressing 1 inch. All of this ensures the vehicle will have the capability to survive the rough terrain in the Baja competition.

Keywords: Sprint, Slalom, Baja, Suspension, Steering, Vehicle, Analyses, Decision Matrix

Contents

1. INTRODUCTION

a. Description

The RC Baja Competition is a ASME competition that many colleges partake in. The competition consists of three challenges the sprint, slalom, and a Baja course. With the sprint, vehicles are to be tested in their speed, having them race down a specified distant in the best time possible. While the slalom tests the turn capabilities of the vehicle in that a set of cones will be set up so that the vehicle will have to weave in and out in the most efficient manner. While the Baja is the main event where the competitors will have to go head-to-head and will have to converse a rough terrain putting the vehicle's durability and design to the test.

Giving the engineers the task to not only make the best handling and fastest vehicle but a vehicle that can survive a multitude of tests and the rough terrain. Resulting in tests having to be made on the components ability to handle forces from different directions. While also having to apply the learnings of statics, mechanics of material, and physics to practice. Taking additional research and some brainstorming design ideas to produce the winning vehicle.

b. Motivation

The RC Baja Competition will help apply the learners of the last couple of years into practice. Giving experience on what it is to calculate, design, and test a product. This and the interest in automotives as a career choice are what drives the desire to compete in the Baja.

c. Function Statement

The suspension needs to be able to absorb and reduce the amount of force that the vehicle experiences in its terrain and testing. While the steering must control the direction of the vehicle.

d. Requirements

The requirements below are to prepare the suspension and steering for the RC Baja competition. For these requirements will be the basis for which the components will be designed to.

1. Suspension must be able to absorb at least 300% of the vehicle's weight before bottoming out.

2. From the bottom of the chassis to the ground there must be at least a 3-inch (75mm) clearance.
3. Turn 180 degrees within a turn radius of 10 inches (250 mm), while going at any throttle percentage.
4. The steering rods must not deflect more than 0.2 inches (5mm) upon a 20 lb. load.
5. Vehicle must not deviate more than 5 inches in a straight line for 50 feet (15m) while in 75% throttle.
6. Tires must be within 5 degrees of alignment from each other.
7. All 4 tires need to keep in contact with the ground from 0 to 75 precent immediate throttle.
8. Vehicle must have a flex of 2 inch (50mm) before more than one tire leaves the ground.
9. Suspension of vehicle must be able to experience a 3ft drop without compressing the suspension more than 1 inch.
10. The suspension will allow for a 0.5 inch down travel or 0.5-inch droop.
11. The wishbones are not to buckle under a 75lb axial load.
12. Steering rod is not to buckle under a 25lb axial load.

d. Engineering Merit

To design the components properly for the varying requirements, several calculations must be made for the design process. To find the right material and the amount of stress that the component will need to with stand. Statics and Mechanics of Material will be applied for the design process for the suspension and the steering. Physics will show how much force will be produced by the fall test to be able to calculate the amount of resistance needed in suspension. While Mechanic of Material and Statics will help find the best material and geometry for the axels and steering. Some simpler calculations will help find the proper tolerance and ensure that parts fit together. The calculations done throughout this project will help ensure that the proper design will be made to carry out through all tests and challenges.

f. Scope of Effort

The suspension and steering will be the scope of the project in producing and designing acceptable components for RC Baja Competition.

g. Success Criteria

For the vehicle to succeed it must have a completive edge in all three challenges: sprint, slalom, and the Baja course. Along with completing all the requirements that have been stated above.

h. Stakeholders

- Skyler Gordon and Sammy Wang- As the sponsors for the project
- Judges of the Competition
- MET Professors - The teachings and guidance for the project.
- Machining Faculty - Supervision of the making of the components.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

With designing a component that can absorb the forces that car may experience and be able to control the direction of the vehicle. Several design ideas were brainstormed such as a multilink, double wishbone, and MacPherson strut suspension. Using a design matrix shown in Appendix F 1.1, it was decided that a double wishbone would best suit the application for this competition.

b. Design Description

The design of the project is to create a steering and suspension systems, strategically tailored to enhance both performance and maneuverability. At the front is a design with a double wishbone configuration, a design known for its performance in off roading and adaptability. This choice ensures optimal control over the wheel movement and toe angles, crucial when performing in the terrains of the RC Baja Competition. Complementing this, the rear suspension will be designed to the MacPherson suspension system. The MacPherson suspension, features a single suspension arm and trial arm, promoting stability and cutting weight.

This combination of suspension designs is a balance between responsive handling and robust performance. The design aims to optimize traction, minimize body roll, and provide the driver with a responsive and controlled driving experience. Giving the team the competitive edge needed to be a top competitor in the RC Baja Competition.

c. Benchmark

The “Holyton 1:10 Large High-Speed Remote-Control Car” will be the benchmark for the design because of already having it in possession. With this it will be easier to have a closer look on how a commercial grade RC car would be made. While this will be used often, a collective of champion RC cars were expected to see what they did and what made them the best cars.

d. Performance Predictions

With the calculations and the research that is put into this design it is one of the top competitors in the RC Baja competition. The suspension has enough resistance to with stand 300% of the vehicle’s body weight and a 3-foot drop before reaching maximum compression. The vehicle was able to make a full U-turn within a 10-inch radius. While the control arms did not deflect more than 0.2 inches under a 20-pound axial load. The suspension was able to allow the car to go from 0 to 75 percent throttle without causing the car to go into a wheelie and have a 2-inch flex with its independent suspension. Also allowing the car to drive in a straight line for 50 feet at 75 percent throttle. While the steering was able to be fully locked and only have about a 5-degree difference within the aliment.

e. Description of Analysis

In designing all components, an analysis with engineering merit will need to be applied. Using a full body diagram and Statics a force can be calculated to be able find the amount of resistance that is needed within the springs for the suspension. While Mechanics of Material will allow to calculate for the proper diameter of the springs along with the correct material. Mechanics of Material will also help find the proper cross-sectional area needed for the wishbones, control arms, and any other smaller components that will be needed for stress testing. While also calculating the amount of deflection that the control arm and the wishbone will experience for axial load testing. Some components will need an analysis for column buckling such as the control arms, wishbone, and shock tower ensuring that they do not exceed their critical load. Smaller components like the link for the control arms to the chassis will need calculations for the amount of shear that will be acted upon them, finding the material and diameter needed to ensure stability in all testing. This will ensure that all components will have enough structure to not fail while in testing and competing in the RC Baja Competition.

f. Scope of Testing and Evaluation

All requirements stated in 1d will be tested and evaluated to see if the desired requirements were meet. While also going through the competition to see its speed, control, and durability capabilities.

g. Analysis

Analysis 01 – Steering Rod Deflection

In the requirements stated in 1-D.4 the steering rods must not deflect more than 0.2 inches under a 20 lb. axial load. Within the Appendix 01, it shows the analysis done on the steering rod assuming a length of 7.0 inches. First a full body diagram was made to find the needed forces. With choosing aluminum as a material and having most tie rods as a solid cylinder in a tube type of a design, both shapes were needed to be calculated. Once the axial load deflection equation was plugged in, a cross-sectional area of 0.00007 in^2 was found. Allowing for the calculation of the diameter of the solid cylinder and tube can be found. With the outside diameter being assumed to be 3/16 of an inch. The minimal diameter of the cylinder came to be 0.01 inches and a minimal 0.18726 inches for an inner diameter for the tube.

Analysis 02 – Suspension Resistance (Drop Test)

Analysis 2, stated in Appendix A02, involved finding the correct k-factor needed for requirement 9 in section 1d. The spring with a 1-inch travel for a vertical impact force from a 3 ft drop. First an impact force was needed, so that Hooke's Law can be applied, and the k-factor can be found. A safety factor of 2 was applied, this being the go-to safety factor for suspensions in the automotive industry. A k-factor of at least 147 kg/s^2 was found.

Analysis 03 – Front Lower Wishbone Buckling

The deflection of the wishbone that is caused by the force of the suspension was needed to ensure no failure in the drop test shown in Appendix A03. First the force that was caused by the 1d-9 requirement was brought in from analysis 2 stated in Appendix A02, a force of 3.67 N. A safety factor of 2.0 was applied to the calculations due to this being the same safety factor applied to the suspension. With a length assumed to be 4 inches and a deflection of 0. The moment of inertia that is needed is 5.763 in^4 spread across multiple members.

Analysis 04 – Front Lower Wishbone Deflection

The wishbone will also need to pass requirement 11 in section 1d. So, a $P_{allowed}$ was giving to the analysis of 75 lbs. stated in Appendix A04 with a safety factor of 2.0. The member was given a base of 0.125 inches as this is similar to other parts on amazon and thus allowing for a height to be found. The wishbone will disburse the force across two different members dividing the load by 2. With the membered being double pinned a moment of inertia of 0.000012 in^4 was found. Allowing a height of at least 0.105 inches.

Analysis 05 – Turn Radius

The vehicle must have a turn radius of 10 inches as stated in requirement 3 of section 1d. In Appendix A05 an assumed length of 10 inches was giving to the device. With the wheelbase know along with the turn radius. An angle of which that tires that will need turn will be 45 degrees for the vehicle to be able to have a turn radius of 10 inches.

Analysis 06 – Steer Rod Buckling

The steering rod will need to pass requirement 12 in section 1d. So, a $P_{allowed}$ was giving to the analysis of 25 lbs. stated in Appendix A06 with a safety factor of 1.5. The member was given a base of 0.125 inches as this is similar to other parts on amazon and thus allowing for a height to be found. With the membered being double pinned a moment of inertia of 0.00000304 in^4 was found. Allowing a height of at least 0.066 inches.

Analysis 07 – Rear Control Arm Buckling

The rear control arm will need to pass the buckling requirement 11 in section 1d. So, a $P_{allowed}$ was giving to the analysis of 75 lbs. stated in Appendix A07 with a safety factor of 2.0. The member was given a base of 0.125 inches as this is similar to other parts on amazon and thus allowing for a height to be found. The control arm will disburse the force across two different members dividing the load by 2 including a length of 4.5 inches. With the membered being double pinned a moment of inertia of 0.0000154 in^4 was found. Allowing a height of at least 0.114 inches.

Analysis 08 – Rear Control Arm Deflection

The deflection of the rear control arm that is caused by the force of the suspension was needed to ensure no failure in the drop test shown in Appendix A08. Similar to analysis two stated in appendix A02 expected the rear control arm will be 4.5 inches in length instead of 4 inches. First the force that was caused by the 1d-9 requirement was brought in from analysis 2 stated in Appendix A02, a force of 3.67 N. A safety factor of 2.0 was applied to the calculations due to this being the same safety factor applied to the suspension. With a length assumed to be 4.5 inches and a deflection of 0.0625 inches. The moment of inertia that is needed is 0.000003351 in^4 spread across multiple members.

Analysis 09 – Suspension Resistance (Applied Weight)

In section 1d requirement 1 states, that the suspension must not bottom out or have a travel more than 1.5 inches when 300% of vehicles weight is applied to the suspension. Shown in Appendix A09, a safety factor of 2.0 was given to the analysis as this is a standard in the automotive industry for suspensions. The vehicles weight was assumed to be 2 kgs, once the safety factor and 300% applied the force came out to be 117.7 N was applied. Using Hooke's Law, a needed k-factor of at least 3.1 KN/m was found.

Analysis 10 – Front Shock Tower Thickness

In requirement 1D-9, the suspension must be able to support a 3-foot drop without causing more than 1 inch travel. This analysis shown in Appendix A10, is to find the needed shock tower thickness. First the impact force was found with an assumed mass of 2 kg. A force avg of 14.715 N across 4 tires dividing the load by 4. Then giving an impact force of 3.679 N or 1.654 lbs. Using a full body diagram and equations of equilibrium a force acting on the spring came to be 5.876 lbs. Assuming the length of the wishbone to be 4 inches with the suspensions being 1.3 inches away from the chassis. A 2.0 safety factor was applied giving a force of 11.75 lbf. The stress equation was applied allowing for the cross-sectional area for the shock tower to be found. With the base of .25 inches assumed a thickness of at least 0.0098 inches was found.

Analysis 11 – Material Needed for Steering Rods

In requirement 1D-12, the steering rod must not buckle under a 25 lb axial load. This material will need to be able to support the axial load with the dimensions of 3/8 x 1/4 inch. This gave the component a moment of inertia of 0.000488 in4. Applying a safety factor or 1.5 and a Pallowable of 25 lbs, a Pcr of 37.5 lbs was given. With an assumed length of 4 inches and that the column was double pinned. A design parameter of 124,000 psi was found for the Elastic Modulus. When looking at the possible candidates for materials ABS, 6061 T6 Aluminum, and Low Carbon Steel were suitable materials for this application as they all met the design parameter of 124,000 psi in their Elastic Modulus as shown in Appendix A11. After a decision matrix was made and an evaluation was giving. The ABS came to be the most suitable material for this application due to its low cost and easy production.

Analysis 12 – Rear Shock Tower Thickness

In requirement 1D-9, the suspension must be able to support a 3-foot drop without causing more than 1 inch travel. First the impact force was brought from analysis 10, giving a force of 14.715 kN across 4 tires dividing the load by 4. Then giving an impact force of 3.679 N or 1.654 lbs. Using a full body diagram and equations of equilibrium a force acting on the spring came to be 7.277 lbs. Assuming the length of the wishbone to be 4.25 inches with the suspensions being 1 inch away from the chassis, giving a more vertical reaction compared to the front shock. A 2.0 safety factor was applied giving a force of 14.55 lbf. The stress equation was applied, with the base of .25 inches assumed a thickness of at least 0.01216 inches was found, shown in Appendix A12.

h. Device: Parts, Shapes, and Conformation

When designing the vehicle for the RC Baja Competition, the parts and shapes will be inspired from other RC car models along with some of the top competitors in off road racing. Then applying engineering merit in the form of analyses, as this will be what helps find the necessary materials and dimensions needed for the components to function as intended. Safety factors will be applied to all analyses as this will range from 1.0-2.0, looking at what the automotive industry uses when deciding on a safety factor. The safety factor will accommodate for any unforeseen force and the fatigue stress that the components will be experiencing during the testing phase and within the competition.

The tolerance will be decided from case to case, as smaller components may need tighter tolerances while larger components, such as the wishbones, will require a more relaxed tolerance. Tolerances will range from 0.05 inches to 0.005 inches as this will be specified within each drawing. While the tolerance is important in functionality of the components, the tolerance will be to ensure a good fit and that the car can be easily be assembled with in the construction phase.

Using the requirements stated in section 1-D, the kinematics of the design will mimic the kinds of stress that the components would be experiencing during the competition. Analyses such as deflection and column buckling will be crucial for the wishbones and steering rod. As it’s predicting and addressing the primary stresses, axial load and bending, ensuring that each element is engineered to withstand the demanding conditions encountered in the RC Baja Competition environment.

i. Device Assembly

The suspension and steering assembly will be able to compete in the RC Baja Competition while passing all requirements stated in 1-D. The front double wishbone independent suspension will provide the durability needed to survive the competition. While the coil covers will be able to provide the proper clearance needed and the suspension resistance that will follow some of the requirements stated in 1-D. It is assumed that the rear suspension will not experience as much force, so a single wishbone or a MacPherson suspension will be used reducing the weight of the car. A small toe in for the rear tires is going to be implemented predicting that this will cause the car to drive in a straighter line. Passing some of the requirements and giving a competitive edge in the sprint portion of the competition.

j. Technical Risk Analysis

The suspension and steering design of the vehicle is to be optimized and ensure optimal terrain absorption and maneuverability. Recognizing that the car's performance and ease of maneuvering are pivotal to have a competitive edge, the design prioritizes these aspects. In the demanding competition environment where the vehicle must perform in rough terrain and repeated testing, it is crucial the vehicle has the ability to endure intense abuse.

Failure to meet these durability standards not only hampers the car's competitive edge but also results in increased costs and time risks. Manufacturing and purchases to replace broken parts will become a financial and logistical burden. Therefore, the suspension and steering must be designed to not only maximize its performance in the competition, but also prioritize durability as this will minimize the cost risk associated with the project.

k. Failure Mode Analysis

For the suspension and steering, some of the more structural parts such as the wishbones and shock towers are more suspect to break. To account for the stress that these parts will be experiencing during the competition. A buckling, deflection, impact, and stress analyses were applied to these components including requirements stated in 1-D. As these analyses will help predict what would be the best material, size, and geometry of the components. When possible, the components will be 3D printed, but after a deflection and buckling analysis, it shows that PLA would not be advised for the wishbones and aluminum would be a more optimal choice. While the shock towers prove to be suitable for not PLA but ABS.

l. Operation Limits and Safety

To ensure the structural integrity and longevity of the car, operational limits have been established for buckling, deflection, and impact testing. The car will have a max drop test of three time before competing in the competition. Including that when testing the components in their buckling and deflection requirements. The test is to only go to the load of when the component "fails" or reaches the required load. The failure will be indicated in the buckling when the component begins to buckle, while the deflection will fail at the point of when it reaches its max deflection specified in 1-D. These limits are to avoid pushing the tested parts beyond what was calculated in the analyses. These testing protocols will prioritize the car's durability, not compromising the vehicles long-term functionality.

3. METHODS & CONSTRUCTION

a. Methods

The manufacturing methods that will be taken into consideration for the vehicle will consist of 3D printing, CNC, machining, plasma cutting, casting, and outsourcing. Send Cut Send provides waterjet cutting for more complex parts but costing more compared to the other options. While 3D printing will provided easy construction and cheap production for parts that will experience less stress. For parts with simple geometry CWU Machine and Casting lab will provide the necessary equipment and tools for machining.

i. Control Arm –Process Decision

All controls arms will use the same material and machining processes. The possible methods were casting, 3D printing, CNC, or outsourcing for waterjet cutting. When making the decision of what methods to use weight, strength, manufacturability, cost, and accuracy was taken into consideration. Seen in Appendix F 1.2, using waterjet to machine the control arms will be the most appropriate method, due to its accuracy and the manufacturability.

ii. Shock Tower – Process

The rear and front shock towers will use the same machining processes and material. With the shock tower not taking as much force as the control arm the strength portion of the matrix decision will have less weight. In the decision matrix weight, strength, manufacturability, cost, and accuracy will be considered. As seen in Appendix F 1.3, 3D printing will be the most suitable method for producing the components. Allowing for low cost and easy production of complex components.

In the manufacturing this part, a test piece was first made with 15% infill with a cubic pattern. Issues accorded when the part could not properly adhere to the bed. This was resolved by changing the initial layer temperature of the bed from 60 C to 65 C. Making the filament take longer to cool, allowing it to further seep into the grooves of the bed. As the height and width of the part needed to be alternated as the original design did not give the suspension the intended angle. The angle was important as this was the angle used in many analyses, shown in Appendix A. This setting was then used for the final print once the test piece was used for ensuring proper fitting. The infill was then brought up to 80% printing the final design of the shock tower.

iii. Steering Rod– Material Decision

The steering rod has a buckling requirement of 25lbs stated in 2d - 12. With the dimension of the component already known. The analysis in section 2G-11, shows that ABS, 6061 T6 Aluminum, and Low Carbon Steel would all be suitable materials for the steering rod under the stated loading. A decision matrix was used to see which material would be best for this application. Cost, weight, strength, accessibility, and manufacturability were all considered. Shown in Appendix F 1.4 ABS's fits best for all these categories, becoming the most suitable material.

iv. Secondary Deck– Process

The original design of the front assembly consisted of a front sub frame that connected the shock tower and wishbones. This design did not allow for the structure and material needed to keep it 3D printed. So, a secondary deck uses 6 mounting points directly to the chassis. Connecting the bottom bracket, steering system, upper wishbone, and shock tower. The 6 mounting points allowed for the all the stress and tension to be put on to the bolts instead of the 3d print material. While also putting the steering manipulators on ¼ inch bolts, giving them less play when operating. With a 3/8 inches bolts to the front of the assembly where most of the impact force would be located. Some additional designing was needed for this component as the mounting point for the wishbone failed. So, this portion will be increased in thickness and the material will be swapped out for ABS instead of PLA.

b. Construction

i. Description

The construction of the vehicle will begin with all the structural components 3D printed in PLA. With all the parts purchased and printed everything will be fitted looking for unforeseen mating issues. Any dimensions and designing alternations needed will be addressed accordingly. Then some of components will be 3D printed in ABS or PLA +. While other components that are experiencing more stress like the control arms. Will be outsourced though Send-Cut-Send made of T6 6061 Aluminum. The steering and suspension will be assembled in three different groups: front suspension, rear suspension, and steering. The subframe and shock towers will be the first to be assembled as this will be where the rest of the front suspension components will join. Then the control arms will be installed. Allowing for the suspension and wheel hubs to be installed. The rear suspension will follow the same order as the front suspension. The assembled suspension will then be mounted directly to the chassis, along with the servo and steering. Connecting the steering rods to the wheel hub.

ii. Drawing Tree, Drawing ID's

The Drawing Tree shows the necessary parts and sub-assemblies to make the steering and suspension. The front suspension will have a sub-assembly for the front sub frame. The order of which the tree is created will be the same order that the parts will be created/purchased. Shown in Appendix B1, the drawing tree shows the three major sub-assemblies for the steering and suspension while some additional subassemblies show the necessary assemblies for the driveline and chassis.

iii. Parts

Fall:
A parts list is stated in Appendix C, giving a list of all purchased components and raw materials. The list also contains all the parts that will be manufactured or printed. The front and rear control arms will be made from 6061 T6 Aluminum. The rear upper control arm will be made within CWU. While the more complex geometry like the rear lower and front control arms will be ordered through Send-Cut-Send.

Parts that will be experiencing less stress will be 3D printed. Components such as the shock towers and steering rods will be printed in ABS while components such as the front subframe will be printed in PLA. All components will be using a cubic 60-80% infill. Including a 6-layer wall along with a .15mm layer depth. The components will all be printed on an Ender 3 S1.

The servo, wheel hubs, and suspension will be purchased. Some components will be modified. Such as, a spring with a strength of 12.5 lbs./in, will be purchased and replace the springs that come with the purchased suspensions kit. This may lead to additional modifications and may take machining. In Appendix C a parts and cost list are shown, providing information on bought parts/material.

Winter:
The wishbones had some design alterations, so the rear upper control ended with taking on a more complex shape. So, it and the other wishbones were outsourced through Send-Cut-Send, manufacturing in 6061 Aluminum at 0.125-inch. These parts were laser cut, once receiving the parts. They were then deburred, drilled with the appropriate hole sizes/location, and then tumbled. Once cleaned up the aluminum was then oxidized and then brushed with a wire brush giving it a black rustic finish, as seen on the website.

Originally the steering rod was to be 3D printed, while based off Analysis 11. ABS would be a suitable material for the column buckling requirement stated in 1D-12. Although a purchased aluminum adjustable steering rod was more practical. As this did add an additional cost of $20.99 but did reduce time of manufacturing and designing. While giving the steering system the adjustments needed for when resigning.

Some redesigning of the steering system did occur in the end of winter break/beginning of winter quarter. This did add additional parts but simplified the steering system. Parts such as the Servo Housing Skid Plate (SRG-20-013) and Front Secondary Deck (SRG-20-007) were added. While the Front Suspension Bracket (SRG-20-001), Front Shock Tower (SRG-20-004), Servo Housing (SRG-20-005), Front Lower Wishbone Mount (SRG-20-008), and Steering Manipulator (SRG-20-011) had some design alterations. They were all still 3D printed in PLA or ABS. The Front Suspension Bracket, Servo Housing, and Front Screw Spacer (SRG-20-012) were all printed in PLA while the remaining components were printed in ABS. All final prints were printed in 6-layer walls with 40% infill with a cubic pattern.

iv. Manufacturing Issues

Fall:
Some design issues may occur, this will be due to some overlooks and resource availability. Currently issues with the strength of the suspension have accorded. Some redesigning and additional components will be needed. Components that will be 3D printed will run the risk of time. As the machines can be unreliable and a multitude of prints may be needed for one component. Sometime will have to be set aside for trouble shooting and making modifications to the software settings. Send-Cut-Send also raises some concerns for cost of production and for no room for mistakes, as the company will not redo a part for free. Some risks run with shipping as some parts or materials may be delivered late or arrive damaged. While the machine room will have lack of availability as this will only be available during the specified times.

Winter:
The first part to be manufactured was the shock tower (SRG-20-009), a test piece was first made with 15% infill and a cubic pattern. Issues accorded when the part could not properly adhere to the bed. This was resolved by changing the initial layer temperature of the bed from 60 C to 65 C. Making the filament take longer to cool, allowing it to further seep into the grooves of the bed. As the height and width of the part needed to be alternated as the original design did not give the suspension the intended angle. The angle was important as this was the angle used in many analyses, shown in Appendix A. This setting was then used for the final print once the test piece was used to ensure proper fitting. The infill was then brought up to 40%, printing the final design of the shock tower.

The front secondary deck (SRG-20-007) is an important piece to the front suspension/steering system. As this part gave a mounting point for the shock tower, upper wishbone, steering manipulator, battery placement, and adding structural elements. As with the rest, a test piece was printed at 15% infill and a cubic pattern. The original design brought the upper wishbone to far forward causing inference with the suspension. More issues accord as the structural mounting points in the back was too far forward giving now room for the servo. While the structural mounting points in the front had misalignment of holes along with an incorrect hole's size due to shrinkage. The component was then redesign. Once again printing a test piece, this time the fitting of the piece was correct. Then starting on the final print, which was a 6-layer wall and an 40% infill with a cubic pattern. These settings were chosen due to the structural integrity that the part needed.

When doing the final prints of components that were in ABS, issues with bed adhesion became increasingly problematic. Some time was spent redesign components and giving them increased fillets. As when the ABS would cool the sharp edges would shrink and left from bed eventually bumping the printed and knocking it off. The settings of the print needed some adjusting as the bed was brought to 100 C. A temperature tower was also printed as the needed temperature of the nozzle was unclear. Temperature towers are a g-code file that can be downloaded by the 3D printing community were several angles of degrees, bridges, holes, and fine points are printed at 5 degrees integrals. Giving the user a proper look of what temperatures will best suite the applications that the project may need. After examining the tower, 250 C nozzle temperature seemed to be the best fit for the printer. The prints continued to lift so the components were printed with a raft along with putting glue directly to the bed. This set the project back by 4 days, as time risk was one of the originally concerns with 3D printing.

v. Discussion of Assembly

The Full Assembly of the suspension and steering is broken up into two sub-assemblies: Front Suspension and Rear Suspension. Shown in Appendix B01, the assemblies join to complete the suspension and steering. The front suspension is directly bolted to the chassis, as the Front Secondary Deck (SRG-20-007) allows for a point where all varying components can join. This is also where the bolts can be inserted and connect to the chassis with the Servo Housing (SRG-20-005), Front Bolt Spacers (SRG-20-012), and Front Suspension Bracket (SRG-20-001).

The bolts are what gives the structural integrity that the servo housing needs to endure the fatigue and torsion that this component will be experiencing. Putting all the stress on the bolts and chassis. The bolt then brings the Servo Skid Plate (SRG-20-013) tight to the bottom of the chassis protecting the bottom of the servo.

Assembling the Rear suspension is simply as the Rear Upper Wishbone (SRG-20-010), Rear Lower Wishbone (SRG-20-006), and Rear Shock Tower (SRG-20-009) are directly mounted to the rear differential. Saving space and giving simplicity of the rear assembly.

4. TESTING

a. Introduction

All requirements, designs, and analyses were in preparation for out competing all members in the RC Baja Competition. There will be three parts of the competition testing its speed, mobility, and capability. This is what inspired the requirements that were stated in section 1d. For preparation of the Baja the vehicle will be tested prior to the competition in the beginning of Spring quarter.

Many of the buckling and defection requirements were to ensure that the vehicle had the durability to survive the duration of the testing of vehicle and competing in the Baja race. While requirement 3 of 1d states that the vehicle must have a turn radius of 10 inches preparing it for the slalom portion of the competition. As the vehicle will need to be able to weave in and out of a series of cones providing a small turn radius beneficial to the race.

Section 1d also has requirements 5, 6, and 7 preparing the vehicle for the sprint portion of the race. 5 and 7 is to make sure the vehicle will have the ability to drive straight. 5 having a straight-line deviation test and 7 having the requirement for alignment within the tires. As this was a problem from last year with most vehicles. Requirement 6 is to prepare the vehicle with a good start, by requiring that when a sudden increase in throttle is applied the vehicle does not wheelie.

b. Method/Approach

1. The suspension must be able support 300% of the vehicle's weight without bottoming out. To test this the vehicle be weighed prior and then additional weight will be added on to the top of the vehicle until it is bottom out. The weight added to the vehicle along with the vehicles weight will be measured to see if the test was passed or failed.

2. There must be clearance of 3- inches from the bottom of the chasses to the ground. A ruler should suffice for this requirement.

3. The vehicle must have a turn radius of 10 inches, some tape and measuring utensils will be needed for this. A starting point will be place on the ground marked by tape. The vehicle will be placed on the starting line and then will turn 180 degrees. Using measuring utensils to find how much of a radius was needed to reach a full U-turn.

4. The steering rod must not deflect more than 0.2 inch upon a 3-point 20lb static load. This will be test by using a press in the Mechanics of Material lab. This machine will be able to measure the displacement and the load of which is being put onto the object.

5. The vehicle must be able to drive in a straight line for 50 feet while in 75% throttle. Stripes of tape will be place in a C-shape, the top and bottom sides of the shape will be the start and finish marking the 50-foot distance. While the long side of the shape of the side piece will be used to find the deviation for which the vehicle veered off from.

6. The tires must be within 5 degrees of alignment, a top view picture will be taken of the front portion of the vehicle. Using computer assisted editing tools, the tires orientation of direction will be measured and will be used to verify the difference in alignment.

7. Vehicle must not pop a wheelie from a 0 to 75 percent immediate throttle. A slow-motion video will be taken of the vehicle to see if there is any lift in the front tires.

8. The Vehicle must have a flex of 2 inch (50mm) before more than one tire leaves the ground. A 2-inch block will be needed for this test. The block would place under on the tires and then visual absorbed if any other ties are leaving the surface.

9. The suspension must be able only compress 1 in under a 3 ft drop test. A yard stick will need to be placed vertically with a slow-motion video of the vehicle taken from the side. Then the video the vehicle being drop at increments of 6 inches.

10. The suspension must have a droop of 0.5 inches. This can be tested by measuring the height of the vehicle and then lifting the vehicle until the wheels leaves the surface. Then measuring the new height, subtracting this from the original height should give the vehicles droop.

11. The control arms must not begin to buckle under a 75 lb. axial load. This will be measured in the machine press as stated before. This will measure if any displacement occurs, showing that the component has begun to buckle.

12. The steering rod must not begin to buckle under a 25 lb. axial load. This will also be measured in the machine press. Measuring if any displacement occurs, showing that the component has begun to buckle.

Issues With Procedures in Testing –

Drop Test:

The drop test procedure originally, shown in Appendix G 1.1 and 4b-6, states that the vehicle is to be dropped at increments of 6 inches until the springs compress 1 inch. But when testing the vehicle, it performed half of what was expected. Compressing the spring 1 inch at 18 inches. This gave little information on the suspension, so more data points needed to be collected. Additional testing was added at increments of 3 inches starting at 6 inches. This allowed for not only three data points to be collected but five. Giving a better look at the capabilities of the vehicle's suspension.

c. Test Process

For testing in the driving capabilities, a need for a flat even surface will be required. The sidewalk directly South of Hogue could be suitable area as this is open, non-slip, and a flat area. An iPhone will be used for photographing and slow-motion capture, this will help find the alignment of the tires and the drop test. The drop test will also need a yard stick, as the yard stick and phone will by used with each other to see the compression that the car will experience when dropped.

Multiple parts will need to be tested in its resistance in column buckling and beam deflection. For the wishbones a specialized test jig will be needed to ensure proper mounting when testing these parts in Instron, provided within CWU's Metallurgy lab. Which will be the device used to find the change in distance and the amount of load that these components will experience.

Some plated weights will be added to the vehicle to show that it meets the requirements for vehicle to be able support 300% of the vehicle's weight without the suspension bottoming out. A 3D printed 2-inch block will also be constructed to see if the suspension can produce a flex that is specified within the requirements.

d. Deliverables

The various testing will be recorded and documented onto a excel sheet. Photos, charts from the Instron, and testing reports will be implemented into Appendix G. Some of the slow-motion capture will be uploaded onto the website shown in the testing section. Captures of the vehicle's performance will also be uploaded into Appendix G, showing that the vehicle passed the specified requirements shown in 1D.

Drop Test –

The drop test was to measure and record the drop height from which the device could be dropped before compressing the springs 1 inch. As per requirements 1D-9, when the device is dropped from 3 feet the springs cannot compress any more than 1 inch. In Analysis 02, shown in Appendix A02, the spring constant needed was 12.4 lbs./in. With only a spring constant of 15.9 lb./in available on McMaster, this what was used. Using Conservation of Energy and Hooke's Law. A predicted value max height of 3 inches was found. Being significantly different than the calculated analysis. Due to the wrong method of analysis being used in Analysis 02, impact force and Hooke's law were used to find the spring constant, giving an invalid value.

Shown in Appendix G1, is a detailed instruction on how the drop test was conducted. Using a 3D printed spring compression tool shown in Appendix B19 and a slow-motion capturing device. The compression of the springs could then be measured on the impact from the drop. The results showed that dropping from 18 inches the springs compressed 1 inch. This is 500% more than the predicted value, and 50% less than the requirement stated in 1D-9. The vehicle's weight was to be assumed to be 10 lbs. as this was inaccurate giving a false reading for the predicted value. Some additional measurements will be needed to give a more realistic predicted value. Some additional potential energy could have also been within the oil of the oil-filled springs which could be the source of the error. Some additional results were that the car does bottom out at 21 inches, with a shock tower failure when the car was dropped at 3 feet four consecutive times.

The original plan was to test the vehicle at increments of 6 inches. But with the expected height being half. More data points needed to be calculated so additional testing was added at increments of 3 inches. This allowed for not only three data points but five. Giving a better-looking graph and a more set data collection. As stated, before the shock tower did fail when dropping at 3 feet. This is assumed to be due to fatigue as this was an original part from months before testing. The failure was at the screw points, due to this being a stress concentration. So, some extra material and thickness were added to the material surrounding the screw holes.

Turn Radius Test –

The turn radius was to measure and record the turning capabilities of the device, as this would play a factor in the slalom portion of the competition. As per requirements 1D-3, the vehicle must be able to turn 180° in a 10-inch radius. In Analysis 05, shown in Appendix A05, the wheels needed to turn 45°. This valve was found by taking the assumed wheelbase of 10 inches, and then dividing it by the required turn radius. Then taking the tan inverse of that, as shown here $\theta = \tan^{-1}(WB)/R$. The vehicle ended up having an increased wheelbase that was previously assumed to be 10 inches but is currently 14 inches. This was not an issue as the vehicle was able to achieve a 60° angle in the wheels.

Shown in Appendix G2, is a detailed instruction on how the turn radius test was conducted. Using simple tools such as a measuring tape and masking tape. The results showed that the vehicle could turn to the right at a turning radius of 11 inches while having a 22-inch turn radius to the left. This is nearly meeting requirements 1D-3 when turning to the right but doubles it to the left. Some theories for the issue are due to the tie rods binding in some unknown places. Or when zeroing the 90-degree servo it's causing limitations to the side it had to zero from. An additional servo will be purchased with 180-degree turning capabilities while doing some further inspections for any binding.

5. BUDGET

a. Parts

Parts will be primally bought from Amazon or the local RC shop. Smaller components like nuts and screws will be purchased at the Knudson Lumber yard along with ACE hardware store. Stock material will be purchased at Rach and Home with some possible donations from CWU. Sticking with mostly 1060 and 6061 Aluminum for easy machining and lower cost to keep the RC car under budget. Some more complicated material or designs to manufacture will be purchased and ordered through Send-Cut-Send. A parts list can be found in Appendix C with specified purchase location, identification, description, and costs.

Parts of Appendix B19-22 were needed to be 3D printed. No additional cost was needed though as the leftover PLA was used from the construction process. This did however take an additional 14 hours to print, but did not add any cost to the project. However, additional cost was needed after conducting the turn radius test. As the vehicle had double the turn radius from one side to the other. It's expected to be from zeroing the 90-degree servo causing limitation to the side it had to zero from. So, an additional servo will be purchased with 180-degree turn capabilities cost an additional $20.00.

b. Outsourcing

The shock tower will be a complex part that will made in carbon fiber. With carbon fiber being so expensive per sheet. Send-Cut-Send will be used to keep costs lower without having to buying a whole sheet. The outsourcing should not cost any more than $100.

c. Labor

Machinist get paid about $30.00 an hour for novice employees. With 100 hours expected in machining and constructing the RC car an estimated cost of $3000.00 is made. Some addition time will be needed for calculations and research for the project but will not be included within the labor cost.

Testing took approximately 18 hours, for conducting, processing, and reporting tests. An additional 25 hours were needed in redesigning and printing new parts. With the same pay of $30.00. This will add an additional $768.00, in costs. This will not be included in the current budget as no pay was given for testing.

e. Estimated Total Project Cost

Currently a total cost for the RC car will be roughly $4,000.00, while the Appendix D only estimates to be $3,245.74. Due to some addition costs having not been implemented into the total budget. With the pay rate being $30.00 for an estimated 100 hours of work in machining and constructing the RC car an estimated labor cost of $3000.00 is made. The current cost for parts and materials is $134.94, while the source for all parts was Amazon giving free shipping to students. With sales tax being 8% in Washington a total of $10.80 was spent based of the $134.94 parts cost. With the current estimated cost for outsourcing being $100 bring the total budget to $3,245.74.

e. Funding Source

The project will be funded by Skyler Gordon and Sam Wang. Sam will be funding the chassis and drive train. While Skyler will be funding the suspension and steering of the vehicle. Components such as the controller, motor, radio, and other major components in the build that don't necessarily fall under one of these two categories will be funded by both. Some raw materials will be donated to the project by Central Washington University.

f. Winter Updates

5a: The original budget did not include some of the additional parts that have been implemented into the steering and suspension. Along with this each part took additional test prints that weren't original expected. With each print, total cost of manufacturing increases. While this is true, the budget included a full roll of ABS and PLA which can been seen in Appendix C. While an extra roll was needed for PLA no additional purchase was needed for the ABS. Increasing the current cost of parts by $23.99, reflecting this in Appendix C and D. Increasing the total cost of parts from $182.94 to $206.92.

5b: Currently no additional cost has been added to outsourcing. Send Cut Send will still be the primary resource for outsourcing any parts. The front secondary deck, SRG-20-007 shown in Appendix B11, is a possible candidate for an additional part that will be added to the list of parts that are currently being outsourced to Send Cut Send. Some additional testing and some design alteration may take place to avoid this, as this would lower cost.

5c: Originally 100 hours of labor were expected for the analysis, design, construction, and testing of the steering and suspension. Currently 19 hours have been spent in analysis, 20 hours in drawing, 25 hours in manufacturing, and 8 hours assembling. Giving a total of 72 hours spent on this project. Being under the current 100 hours expected, once all manufacturing is completed along with testing it still expected that 100 hours will be needed in labor, but currently not adding any additional cost to the project. As labor costs are separated out and correlated to the time shown in the schedule.

g. Spring Updates

5a: With the drop test the rear shock tower broke from fatigue. This did not add any additional cost as the part was 3D printed. So leftover filament from the construction phase was used to reconstruct the part. This did however take time and set the schedule back a few days. However, additional cost was needed after conducting the turn radius test. As the vehicle had double the turn radius from one side to the other. It's expected to be from zeroing the 90-degree servo causing limitation to the side it had to zero from. So, an additional servo will be purchased with 180-degree turn capabilities cost an additional $20.00.

5b: These new design alterations and the purchasing of a new servo only added $20.00. The leftover filament was used from the construction phase. This did add additional time of about 25 hours of 3D printing new housing for the servo and shock tower. If this was to be included it would cost an additional $750.00 in labor.

5c: Through all main tests, the failure of parts was of concern. After failing in the rear shock tower. To avoid any part failure, failure requirements were put into place to ensure that the components would exceed any stresses that would be unnecessary. This ensured that no additional components broke during testing.

6. SCHEDULE

a. Design

Fall:

Within Appendix E, a schedule covering everything that needed to be completed for the Proposal Writing, Analysis, and Documentation. This kept the design process on track and completed within the time frame given. As the Fall quarter continued, things got easier to estimate compared to some of the time estimates from the beginning of the quarter. Some issues accumulated with writing the of the Analysis h-l portion of the Proposal. With some poor time, management, the project fell behind. Time was spent the next week to do small portions of the report until it was completed, getting the project back on track. Analysis were being underestimated at the start of the quarter, with some adjustments it become easier to be able to estimate how long one should take based on the research that was made prior to the analysis and what kind of analysis was to be made.

b. Construction

Fall:

The parts have been designed, with engineering merit and the beginning of manufacturing, constructing, and assembly begins in the Winter quarter. A list of the designs is in Appendix E with their estimated time and schedule. While the estimated time may be off due to the same learning curve as with the Fall quarter. Some extra time will be needed for troubleshooting, material locate, and tooling issues. The times estimated should be within the ballpark and by the end of the quarter with the schedule keeping on track for a full assembly of the RC car should be ready for competition and testing.

Winter:

The front suspension assembly will be the first to be manufactured and assembled. The manufacturing process began November 07, 2023, shown in Appendix E. The manufacturing of the parts continued completing the front assembly January 26, 2024. Issues with bed adhesion, shrinkage, and various other printing failures. This did affect the expect time needed for the parts to be manufactured, underestimating many parts. As the manufacturing continued, estimated time came to be closer to actual. Every part began with a printing setting of a cubic infill pattern, 15% infill, and 2 layered walls. This printing setting was continued to be used as more protypes were to be manufactured as this reduced time for incorrect parts and filament material. After testing and fitting, the final part is printed to the specified printing settings stated in the drawing blocks, shown in Appendix B.

Beginning with the first part, task 4b/shock tower, poor adhesion to the bed caused multiple failed prints. After playing with settings, the initial printing temperature was brought from 60 C to 65 C. This allowed for a higher successful print rate, a setting that was used for the remaining parts. The part then needed to be adjusted as the original design was too short and narrow. Causing the suspension to have the incorrect angle, as this angle was used in many of the calculations that can be seen in Appendix A. From the printing the first protype to the final product, the part toke 5 hours to manufactured, when only two were expected.

c. Testing

Fall:

The testing will begin at the start of the Spring quarter, with the list of tests in Appendix E. The tests will be seeing if all the requirements mentioned in section 1-D was met. Then putting it into the RC Baja Competition at the end of the Spring quarter. This will measure the amount of work put into the project and reflect on how well the engineering problem was tackled. Sometime will be needed if any parts break or fail during the testing, which will set the project back until that part is replaced. With this sometime should be set aside in case of a situation like this accrues. With some adjustments and sticking to the schedule stated in Appendix E the project will be completed on time at the end of the Spring quarter.

Spring:

The drop test fell behind schedule, this was due to the original method of measuring the spring's compression being faulty. This was corrected by creating a 3D-printed measuring device (SRG-40-001) that would directly attach to the front of the suspension. Giving an accuracy of a 1/16th of an inch. After redoing the test, the procedure had some corrections finally giving reliable results. This set the testing schedule back by a week, as the first attempt of the measuring device had some geometry issues and did not line up parallel with the suspension. Once everything was printed, corrected, and rewritten in Appendix G1 the demonstration of the test was still able to be presented on time. Shown in Appendix E, Task 6b.

7. PROJECT MANAGEMENT

This project will need to be able to have a competitive edge in the RC Baja competition. With the focusing being the suspension and steering, the risk is the functionality of the vehicle. It will need to be optimized to maneuver, handle rough terrain, and endure repeated stresses. The main limitation of this project is time and money. Analyses will be used to find what components will need the stronger materials and what component will need cheaper materials such as PLA, to cut costs. Decision matrix and project management will be used to determine the component's material and machining processes minimizing risk of financial depletion. A schedule will be used to keep track of when designs, production, and testing should be completed. This will minimize risk of time. With these tools and the proper resources, the project will project will be a success.

a. Human Resources

The principal engineer will take the lead in conducting analyses, designing, machining, and testing for the suspension and steering. In Appendix H a resumes represents the Cad drafting skills, machining experiences, and schooling background needed to complete this project.

Professors will be provided guidance and insight of how to work through problems within the project. Helping with analyses, designs, and material recommendations will be their specialty. The shop supervisor will be a helpful resource for guidance in machining components along with having a stock of raw materials. Availability of these resources will be the main limitation and will have to be managed accordingly.

b. Physical Resources

Computer labs, CNC, machine equipment, metallurgy testing equipment, and a 3d printers will all be available for use during the designing and construction process of the vehicle. A window of availability will restrict usage of all these resources and will have some time risks involved. A schedule will be needed to keep track of when and how long each component of the vehicle should take. This will reduce the risk of running out of time by the end of Winter quarter.

c. Soft Resources

SolidWorks will be the most used software throughout the development and design process of the RC car. SolidWorks is a great designing software but is quite touchy with how one designs a part. This will require some extra time management as this will be needed for troubleshooting in accomplishing desired shapes and dimensions. Some extra time will also be needed to redesign and dimension parts for when assemblies do not work in real life compared to the Solid Works assembly. A schedule has been constructed to minimize the time risk with using this software.

UlitMaker Cura will be the slicer program to make the SolidWorks drawing into 3D printed parts. To test parts fitting and how the parts interact in the real world. Cura has some settings that will need to be experimented and tested with to see what will work best with the project. This will take some time and will have to managed accordingly. Time prior to the end of Fall quarter will be taken to experiment and work out any problems. Minimizing risk of time for when constructing the RC car during the Spring.

d. Financial Resources

The primary sponsors for this project will be Skyler Gordon and Sam Wang. As Skyler will be sponsoring the suspension and steering of the vehicle. While Sam will sponsor the drive and chassis. Components that do not fall under one of these categories, such as the antenna and controller, will be sponsored by both. Some raw materials such as aluminum will be possibly donated by Central Washington University. With a small number of financial sponsors some risk of budget is in play. If money runs low Joni Massey will be a backup financial support.

8. DISCUSSION

a. Design

The design process was broken into four major groups. The suspension and steering would be approached in this order by designing the front suspension, rear suspension, steering, and then finally 3D printing all structural components. Testing for fitting and any unforeseen mating issues as this would cut risks of time and cost next quarter when constructing the project.

First the front control arms were designed, following with the front sub frame and shock tower. Once the wheel hubs and suspension were purchased, the front components were 3D printed. The thickness of the control arms showed to be too small as the screws for the suspensions and wheel hubs were 1/8 inches in diameter while the control arm thickness was a ¼ inch. This created a risk of failure as there was not enough material around the screw holes. The thickness of the material was then brought up to 3/8 inch as this left much more material around the screw hole and this thickness was used for all the other structurally designed components. More issues occurred when constructing the front suspension. As the top control would rub against the suspension and cause interference. The upper control also was not long enough nor at the correct location for mating to the purchased wheel hub. The control was then redesigned to allow for more clearance and to properly connect to the wheel hub.

The shock tower was also redesigned as it was not tall nor wide enough. When the suspension was connected to the shock tower and lower control arm the suspension had less than an inch of travel while also not being at the angle as intended. This would risk some requirements to not be met, as a number of the analyses would base its calculations for a 60-degree suspension angle. As an example, requirement 1D-8 would require at least a 2-inch travel. With the original design lacking, a full redesign was made to the shock tower making it taller, wider, and adding better mounting points. Resulting in the front suspension now having a 2.5-inch travel.

Having to redesign and re-3D print a number of components some risk with time occurred as the design process takes time and some analyses had to be redone. Using 3D printing also brings time risks as they can take some time to print, while also having the possibility to fail and having to reprint. This did cut the risk of time for next quarter when constructing as the parts have already been tested for fitting. Also cutting the risk of cost as this would ensure that the component will work, so when outsourcing no additional revision parts will be needed.

With the front suspension completed and proper dimensions and geometry found. Designing the rear suspension was smoother. As some designs were reused and small adjustments were made to them. Some adjustments had to be made to the shock tower as the rear design required a more vertically angled suspension. Once all the components were 3D printed both the rear and front suspension were added to the chassis. These assemblies along with the necessary components for the drive, control, and servo caused for an unexpected weight gain. Having to redo some analyses as the suspension had less than an inch in the back. So, a new suspension was bought as this one was 110mm while the original was 100mm, giving some additional travel. While also purchasing stronger springs as this would significantly increase the how travel the vehicle had. This redesign did cause some risk of cost as this was not expected when evaluating for the budget. Having to buy new suspension and after stock springs that will then be needed to be fitted and cut to the correct dimensions for the suspension.

The steering was the final assembly to be made. The original design had some concerns about failure as the manipulator was long and skinning. As the manipulator to the steering will be made of ABS and 3D printed. The redesign is simpler and requires fewer small parts as the elongated piece would be more acceptable to bending. The simpler design can also be tested and if necessary, constructed with aluminum after further testing.

The unpredictable nature of the design process proved unforeseen mating issues, resolving these issues as they aroused at each stage. Despite the challenges, the repeated testing of components during the design phase mitigated risks associated with time and cost in the subsequent construction phase. The experiences gained from overcoming these obstacles contributed to a more robust and refined final design, ensuring the project's success and functionality.

b. Construction

The first part to be manufactured was the shock tower (SRG-20-009), a test piece was first made with 15% infill and a cubic pattern. Issues accorded when the part could not properly adhere to the bed. This was resolved by changing the initial layer temperature of the bed from 60 C to 65 C. Making the filament take longer to cool, allowing it to further seep into the grooves of the bed. As the height and width of the part needed to be alternated as the original design did not give the suspension the intended angle. The angle was important as this was the angle used in many analyses, shown in Appendix A. This setting was then used for the final print once the test piece was used to ensure proper fitting. The infill was then brought up to 40%, printing the final design of the shock tower.

The front secondary deck (SRG-20-007) is an important piece to the front suspension/steering system. As this part gave a mounting point for the shock tower, upper wishbone, steering manipulator, battery placement, and adding structural elements. As with the rest, a test piece was printed at 15% infill and a cubic pattern. The original design brought the upper wishbone to far forward causing inference with the suspension. More issues accord as the structural mounting points in the back was too far forward giving now room for the servo. While the structural mounting points in the front had misalignment of holes along with an incorrect hole's size due to shrinkage. The component was then redesign. Once again printing a test piece, this time the fitting of the piece was correct. Then starting on the final print, which was a 6-layer wall and an 40% infill with a cubic pattern. These settings were chosen due to the structural integrity that the part needed.

Following with the front suspension bracket (SRG-20-001), this gave the prober spacing for the upper and lower wishbone. Along with giving the mounting point needed for the shock tower. The test print had the same settings as before. With the first test print, the piece broke after inserting one of the bolts that would connect the secondary deck, front bracket, lower mounting bracket, and the chassis. The failure of the part was due to the shrinkage that was caused by the heat of the filament. The hole was then increased, then again printing a test piece. With the success of the test fitting, the final part was then made with a 40% infill and a cubic pattern.

As for the wishbones, things went smoothly as 3D printed parts were made for testing the fitting of the components. Some design alterations were needed as some upper wishbones over extended causing the wheels to toe in. After the components had a successful fitting, the drawings where then sent to Send-Cut-Send to be laser cut with 6061 Aluminum. The part was then deburred, tumbled, and the appreciated holes were drilled once receiving the parts.

After some testing, some of the components that were experiencing a higher force failed. Components such as the front secondary deck (SRG-20-007), front lower wishbone mount (SRG-20-008), and front/rear shock tower (SRG-20-004)/(SRG-20-009) all failed while the vehicle was in operation. The solution for this was to bring all these components from PLA to ABS, with a 6-layer wall and a 40% cubic infill. ABS has higher resistance to impact forces then PLA making it a great candidate for a stronger material. The thickness of the lower wishbone mount and secondary deck were both brought from 0.25 inches to 0.375 inches. An additional groove for a metal wire was also included to the design giving addition strength to components. Making sure that the ABS does not break at the printed layers as this is where the components failed initial.

The original steering system proved to be over complicated, as the multiple moving components took too much room and left no space for the battery. A simpler design was implemented where the servo is brought to the center of the chassis with only one moving component, when the original design had three. Directly attaching the steering rods to the servo by a 3D printed extension (SRG-20-011). This gave the addition room needed to have a placement for the battery.

c. Testing

Drop Test –

Adjustments to the testing procedures were needed, as initially the procedure involved dropping the vehicle in increments of 6 inches. Until reaching the requirement stated in 1D-9 of the springs compressing only 1 inch. With success concluding of a 3-foot drop with a 1-inch compression in the springs. However, due to discrepancies between predicted and actual results, additional testing increments of 3 inches were needed. This adjustment provided more data points, enhancing the collected data and giving better graphical clarity.

Some testing risks to the drop test were damage to the vehicle resulting in risk of time and cost. Additional purchases of parts could cause the team to go over budget and the time to receive/manufacture the part could inflict with the competition day. To overcome these risks a failure requirement was brought into the procedure. As the requirement of the vehicle was 3 feet, the vehicle was not directly brought to this height. As shown in Appendix G1, the vehicle was to be dropped from increments of 6 inches. Then given a fail requirement of 1 inch compression in the springs. So once the springs compress 1 inch the vehicle would no longer be dropped. Not adding any unnecessary impact forces to the vehicle.

Data collection was a success as a multitude of data points were collected to give a good reading of the suspension's capabilities in its dropping limitations. For failures, the vehicle only reached 18 inches before the springs compressed 1 inch. This is 50% less than the requirement stated in 1D-9. Some additional springs could be purchased with increased spring rating or just buy higher quality suspension. An alternative could be to attempt to cut weight as this would lighten the impact force of the vehicle, putting less force on the springs. Additionally, the rear shock tower did fail. This is assumed to be due to fatigue as this was an original part from months before testing. The failure was at the screw points, due to this being a stress concentration. So, some additional material and thickness were added to the material surrounding the screw holes. Further strengthening the shock tower to deal with the stress from the suspension.

These adjustments and modifications to testing procedures were essential in overcoming risks and improving the reliability and accuracy of the testing process, ultimately contributing to informed decisions for future iterations and enhancements of the device's suspension.

Turn Radius Test –

The turn radius was to measure and record the turning capabilities of the device, as this would play a factor in the slalom portion of the competition. Per requirements 1D-3, the vehicle must be able to turn 180° in a 10-inch radius. In Analysis 05, shown in Appendix A05, the wheels needed to turn 45°. This valve was found by taking the assumed wheelbase of 10 inches, and then dividing it by the required turn radius. Then take the tan inverse of that. The vehicle ended up having an increased wheelbase that was previously assumed to be 10 inches but is currently 14 inches. This was not an issue as the vehicle was able to achieve a 60° angle in the wheels.

This test had little risk involved. Minimum stresses, tools, and space were needed for conducting the turn radius test. The only possible risk was putting too much strain on the steering manipulator's gears. If the turn radius was increased too high, it could cause some of the gears to break from the wheels binding from other components. To mitigate this the turning degree from the servo was turned down, allowing only the wheels to turn right before any binding occurred.

Shown in Appendix G2, is a detailed instruction on how the turn radius test was conducted. Using simple tools such as a measuring tape and masking tape. The results showed that the vehicle could turn to the right at a turning radius of 11 inches while having a 22-inch turn radius to the left. This is nearly meeting requirements 1D-3 when turning to the right but doubles it to the left. Some theories for the issue are due to the tie rods binding in some unknown places. Or when zeroing the 90-degree servo it's causing limitations to the side it had to zero from. An additional servo will be purchased with 180-degree turning capabilities while doing some further inspections for any binding.

9. CONCLUSION

a. Design

This project had the objective to design and construct a fully functional remote-controlled car capable of competing in the sprint, slalom, and the Baja course made by the ASME. The project focused on the steering and suspension components of the RC Baja car requiring to provide effective directional control and terrain absorption on the competition course.

Critical analyses, encompassing drop test, impact evaluation, maneuvering assessments, buckling, and deflections. Using mechanic of materials for the control arms, shock towers, steering, and suspension played a pivotal role in ensuring the success of the RC Baja. These analyses were based on the requirements stated in 1-D, as these requirements are to be thought the necessary characteristics needed for the steering and suspension to have success in the competition.

These analyses provide insight on what materials would be appropriate for the components of the car. The car will primarily consist of aluminum and ABS, as the necessary resource to get it done will be available. CWU will provides the manufacturing needed, along with a personal 3D printer and Send-Cut-Send will provided water jet cutting for any complex parts. Concluding the state of the complete design readiness for the construction phase of Winter 2024.

b. Construction

c. Testing

10. ACKNOWLEDGEMENTS

References

APPENDIX A - Analysis

Appendix A01 – Steering Rod Deflection

Skyler Gordon Steer Rod | 20231010 | 1/1

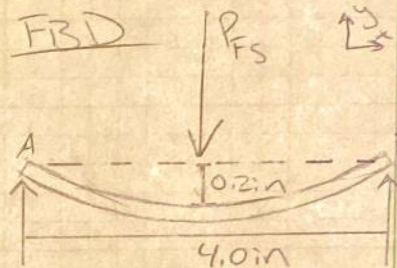
Given: $\delta = 0.2in$ SF = 1.5 P = 20 lbf

Find: $\varnothing$ of Control Arm as a solid Cylinder

Assum: 1060 Aluminum - $E = 10\times10^6$ psi ← (Website: The Engineering Tool Box)
L = 4in or 100 mm

Method: FBD
Deformation of a Beam
$y_B = y_{max} = \frac{-PL^3}{48EI}$ (Appendix 14 Table A14-1)
$I \Rightarrow \varnothing$

Solution:



$P_{FS} = FS \times P = 1.5\times30$ lbf

$P_{FS} = 45$ lbf

$\delta = \frac{-PL^3}{48EI}$

$I = \frac{-PL^3}{48E\delta} = \frac{(30lb)(4.0in)^3}{48(10\times10^6 lb/in^2)(0.2in)} = 0.00002in^4$

$I \Rightarrow \varnothing$

Appendix I $I = \pi\phi^4/64$

$\phi = \sqrt[4]{\frac{I(64)}{\pi}} = \sqrt[4]{\frac{(0.00002in^4)(64)}{\pi}} = 0.14in$

For a deflection of 0.2in under a 30lb load. The diameter of a solid 4in cylinder will need to be at least 0.14 inches.

Appendix A02 – Suspension Drop Test

Skyler Gordon MET 489 | Vertical Drop

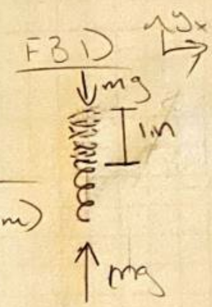
Given: $\Delta y = 3ft$ (Vertical Drop)

Find: k factor on the springs to full resiste the force made by the drop test

Assum: $m = 1.5 kg$
$x = 25 mm$ or 1 inches
only y direction force
Loads evenly across all 4 tires

Method: FBD
Impact Force
Force on one spring
Hooke's Law: $F_s = kx$

Solution:



Impact Force

$$F_{avg} = \frac{0.5(mv^2)}{\Delta y}$$

$$v = \sqrt{2gh} = \sqrt{2(9.8\,m/s^2)(0.9144m)}$$

$$v = 4.24\,m/s$$

$$F_{avg} = \frac{0.5 \cdot (1.5kg)(4.24)^2\,m^2/s^2}{0.9144m}$$

$$= 14.715\,kg\,m/s^2 \text{ or } 14.715\,N$$

$$F_s = 14.715N/4 = 3.679N \text{ per spring}$$

Hooke's Law

$$F_s = kx \Rightarrow 3.679N = k(.025m)$$

$$\boxed{k = 147.15\ N/m}$$

A material with correct k will be needed to have k factor of 147.15 kg/s² for each spring

Appendix A03 - Wishbone Deflection

Skyler Gordon | Wishbone Deflection | 20231015 | 1/1

Given: $F = 3.679\,N$, $L = 4\,in$, $F_S = 2.0$ (Force produce from Vertical Drops test. Refer to Appendix A02)

Find: The I needed to have zero deflection from the force of the suspension

Assume: 1060 Aluminum $E = 10\times10^6$ psi (The Engineer Tool Box)

θ of suspension = 60°

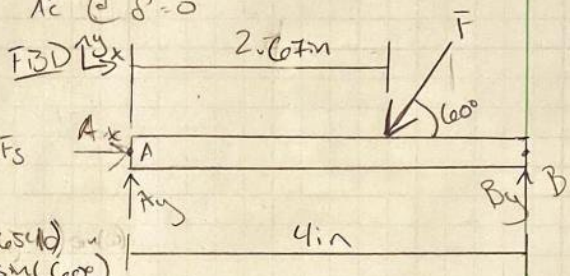
F @ 2/3 of L

Method: FBD

Equilibrium Equation

solve for Ic @ $\delta = 0$

Solution:



$F = 3.679\,N = 0.827\,lbf \times F_S = 1.654\,lbs$

$+\circlearrowleft M_A = 0 = (4in)B_y - (2.67in)(1.654lb) \times \sin(60°)$

$B_y = 0.956\,lb$

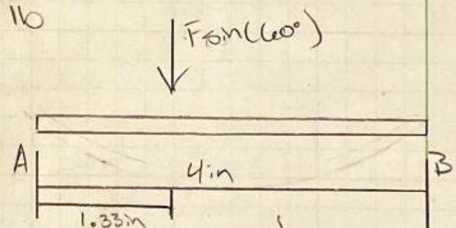
$\Sigma F_y = 0.956\,lb - (1.654lb)\sin(60) + A_y$

$A_y = 0.476\,lb$

$\Sigma A_x = 0 = (1.654\,lb)\cos(60) - A_x$

$A_x = 0.826\,lb$

Deflection



$F\sin(60°) = 1.432\,lb$

$$\delta = \frac{-Px}{48EI}(3L^2 - 4x^2)$$

$$0 = \frac{1.432\,lb(1.33in)}{48(10\times10^6\,lb/in^2)\,I}\left(3(4in)^2 - 4(1.33in)^2\right)$$

$I = 5.763\,in^4$

Appendix A04 – Wishbone Buckling

Skyler Gordon | Wish Bone Buckle | 20231015 | 1/1

Given: P_{cr} = 75 lb SF = 2.0 b = 0.125 in

Find: Base of geometrical shape with a Base of 0.125 inches

Assume:
- Load is distrubuted across two members ← members are Indentical
- Material 1060 Aluminum
  - E = 10 x 10^6 psi (The engineer tool Box)
- L = 4 in
- Double Pinned

Method:
- Pcr with SF ⇒ Dived by two
- Find moment interia needed
- Solve for h with I & b found

Solution:

$P_{cr} = 75 lb (2.0) = 150 lb$

Divided across two members

$150 lb/2 = 75.0 lb$

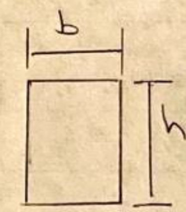
$P_{cr} = \frac{\pi^2 E I}{L}$

$75 lb = \frac{\pi^2 (10 \times 10^6 lb/in^2) I}{(4 in)^2}$

$I = 0.0000122 in^4$

$I = \frac{b h^3}{12}$

$0.0000122 in^4 = \frac{(0.125 in)(h^3)}{12}$



h > 0.105 in

Appendix A05 – Turn Radius

Skyler Gordon | Turn Radius | 20231021 | 71

Given: Radius = 10 inches or 250 mm

Find: The angle of the Tire needed to achieve a turn radius of 10 inches

Assume: Wheel Base = 10 inches

Method: $R = (WB)/\tan\theta$

Solution:

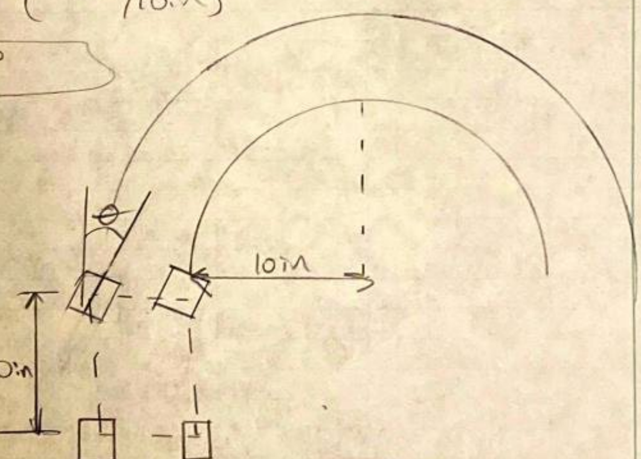
$$R = (wb)/\tan\theta$$

$$\tan\theta = wb/R$$

$$\theta = \tan^{-1}((wb)/R)$$

$$= \tan^{-1}(10\,in/10\,in)$$

$$\theta = 45^{\circ}$$



Appendix A06 – Steer Rod Buckling

Skyler Gordon | Steering Rod Buck | 20231021 | 1/1

Given: $L = 4\,in$ $SF = 1.5$ $P_{allowed} = 50\,lb$

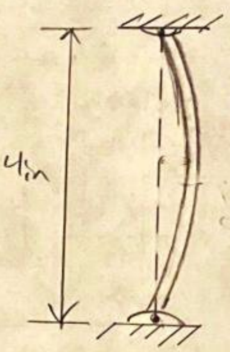
Find: The moment of Interia needed so the Steering Rod won't Buckle under a 25 lb load

Assume: Double Pinned Beam $B = 0.125\,in$
Material: 1060 Aluminum
- $E = 10 \times 10^6\,Psi$ (The engineer tool Box)

Method: $P_{allowed} = P_{cr}(FS)$
Find moment Interia needed

Solution:

$$P_{cr} = P_{allow}(FS)$$
$$= 50\,lb\,(1.5)$$
$$= 75\,lb$$

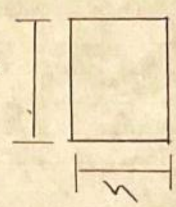


$$P_{cr} = \frac{\pi^2 E I}{L}$$

$$75\,lb = \frac{\pi^2 (10 \times 10^6\,lb/in^2)(I)}{(4\,in)}$$

$$I = 0.00000304\,in^4$$

$$I = \frac{bh^3}{12}$$



$$0.00000304\,in^4 = \frac{(0.125\,in)(h)^3}{12}$$

$$h = 0.066$$

A hieght of at least 0.066 in h will be needed

Appendix A07 – Rear Control Arm Buckle

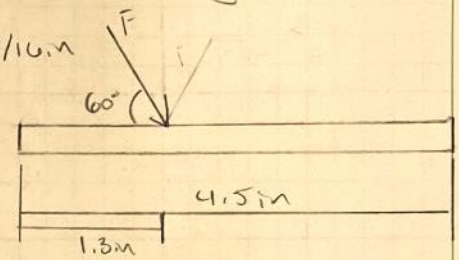
Skyler Gordon | Rear Contr. Arm Defl. | 20231029 | 1/1

Given: $F = 3.679\,N$ (Force Produce By vertical Drop test. Refer App. A02)
$L = 4.5\,in$
$FS = 2.0\,in$

Find: Dimension needed so the control does not Defect in vertical drop test

Assume: 6061 Aluminum, Suspension is @ 60°
$E = 10 \times 10^6\,psi$ (The engineering tool Box)

Method: Find P
Solve for I @ $\delta = 1/16\,in$



Solution:

Deflection

$3.679\,N = 1.654\,lbs$

$P = F\sin(60) = (1.654\,lbs)(\sin(60°))$
$= 1.432\,lb$

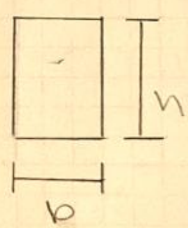
$$\delta = \frac{-Px}{48EI}(3L^2 - 4x^2)$$

$$0.0625\,in = \frac{-(1.432\,lb)(1.3\,in)}{48(10\times10^6\,lb/in^2)I}\left(3(4.5)^2 - 4(1.3)^2\right)in^2$$

$I = 0.0000003351\,in^4$

$$I = \frac{bh^3}{12}$$

$$0.0000003351\,in^4 = \frac{(0.125)(h^3)}{12}$$



$h > 0.0161\,in$

Appendix A08 – Rear Control Arm Deflection

Skyler Gordon Rear Contr. Arm Buckle 20231029 1/1

Given: $P_{cr} = 75\,lb$ SF = 2.0 b = .125 in

Find: The dimensions needed for the trusses within the rear wishbone

Assum:
- Load is distrubed across two members
- Material - 6061 Aluminum
  - E = 10x10⁶ psi (The engineering toolbox)
- L = 4.5 in
- Double Pinned

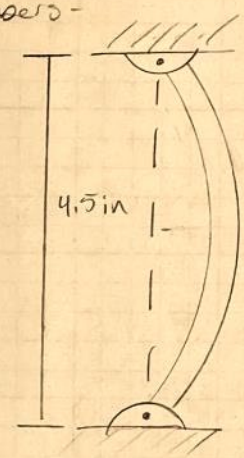
Method:
- Pcr with SF ⇒ Divided by two
- Find moment of interia
- Solve for h with I & b found

Solution:

$P_{cr} = 75\,lbf\,(2.0) = 150\,lb$

- Diveded across two members -

$150\,lb/2 = 75\,lb$



$P_{cr} = \frac{\pi^2 E I}{L^2}$

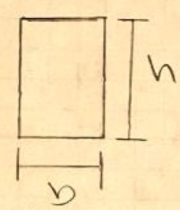
$75\,lb = \frac{\pi^2 (10\times10^6\,lb/in^2)\,I}{(4.5\,in)^2}$

$I = 0.0000154\,in^4$

$I = \frac{bh^3}{12}$

$0.0000154\,in^4 = \frac{(0.125\,in)(h^3)}{12}$

$h > 0.114\,in$



Appendix A09 – Suspension Weight Resistance

Skyler Crowder | Suspension Res. | 11052023 | 1/1

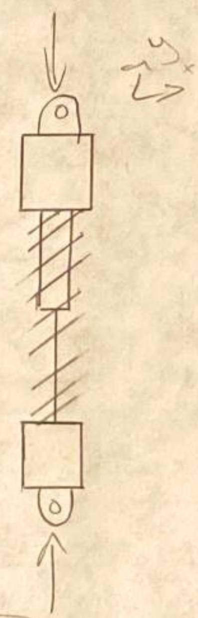
Given: SF = 2.0 WM = 300 % $x = 1.5\text{in}$

Find: Suspension Resistance needed for 300% vechile wieght

Assume: $m = 2\text{kg}$

Method: Apply SF
Hooke's Law

FBD



Solution:

$2\text{kg} \times 300\% = 6\text{kg}$

$6\text{kg} \times SF = 12\text{ kg}$

Hooke's Law

$F = 12\text{kg} \times 9.81\text{m/s} = 117.7\text{N}$

$F = kx$

$1\text{in} = 0.0254\text{m}$

$117.7\text{N} = k(0.0381\text{m})$

$k = 3089\ \text{N/m}$ or $3.1\ \text{kN/m}$

Appendix A10 – Front Shock Tower Thickness

Skyler Gordon | Shock Tower | 2023 11 05 | 1/2

Given: $\Delta y = 3ft$ (Vertical Drop)
$b = .25 in$ Suspension @ 60°

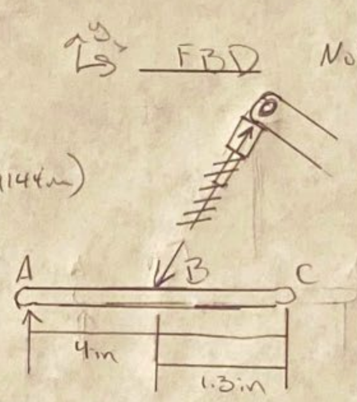
Find: Thickness needed for shock tower To survive the Drop test

Assume: $m = 1.5 kg$
PLA
$\therefore \sigma =$
$SF = 2.0$

Method: Impact force
Solve for AC
AC ⇒ Thickness

Solution:

Impact force



$F_{avg} = \frac{0.5mv^2}{\Delta y}$

$v = \sqrt{2gh} = \sqrt{2(9.81 m/s^2)(0.9144 m)}$
$v = 4.24 m/s$

$F_{avg} = \frac{0.5(1.5kg)(4.24 m/s)^2}{0.9144 m}$
$= 14.715 \, kg\,m/s^2$ or $14.715 N$

$A_y = 14.715 N / 4 = 3.679 N \Rightarrow 1.654 lbs$

$+\circlearrowleft \Sigma M_C = 0 = 1.3in(B_y) - 4in(1.654 lb)$
$B_y = 5.089 lb$

$R_B = 5.089/\sin(60°)$

$R_B = 5.876 lb \times SF$
$R_B = 11.75 lb$

$\tau = F/A$

$4786 PSI = 11.75 lb / A_c$

$A_c = 0.00246 \, in^2$

$b \times h = A_c = (.25 in) \times h = 0.00246$

$h > 0.0098 in$

Appendix A11 - Steering Rod Material

Snyder Gordon | Material Needed | 11 08 2023 | 1/1

Steering Rod

Given: $P_{cr} = 25 \text{ lbs}$
$L = 4 \text{ in}$ Double Pinned

Find: E needed for a 25 lb buckling Column

Assum: b = .375 inches h = .25 inches SF = 1.5

Method: Colume Buckling

Solution:

$$P_{cr} = P_a \, SF$$

$$P_{cr} = (25 \text{ lb})(1.5) = 37.5 \text{ lb}$$

$$P_{cr} = \frac{\pi^2 E I}{L^2}$$

$$\frac{P_{cr} L^2}{\pi^2 I} = E$$

$$I = b h^3 / 12$$

$$= (.375 \text{ in})(.25 \text{ in})^3 / 12 = 0.000488 \text{ in}^4$$

$$\frac{(37.5 \text{ lb})(4 \text{ in})^2}{\pi^2 (0.000488 \text{ in}^4)} = 124503 \text{ psi}$$

FBD (y, x)

Elastic Modulus

ABS	Aluminum 6061 T6	Low-Carbon Steel
326 ksi > 124 ksi	10,000 ksi > 124 ksi	2.9×10^4 ksi > 124 ksi
✓	✓	✓

Appendix A12 – Rear Shock Tower Thickness

Skyler Gordon Rear Shock Tower 20231119 1/1

Thickness

Given: $\Delta y = 3$ft (Vertical Drop)

b = .25 in Suspension @ 60°

Impact Force = 14.715 kg m/s² or 14.715 N (From Analysis A10)

Find: Thickness needed for Rear Shock Tower To survive Drop test

Assume: SF = 2.0 m = 1.5 kg

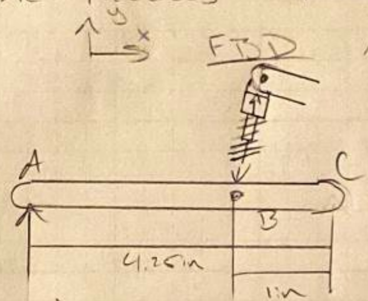
τ = 4786 PSI — From Mechanics of Material

Method: FBD

Equilibrium ⇒ Ac ⇒ thickness

Solution:

FBD Not to Scale



A_y = 14.715N/4 = 3.679N

1.654lbs

$+\Sigma M_c = 0 = 1\,in(B_y) - 4.25\,in(1.654lbs)$

B_y = 7.0295 lb

R_B = 7.0295 lb / sin(75°)

R_B = 7.277 lb × SF

R_B = 14.55 lb

$\tau = F/Ac$

4786 PSI = 14.55 lb / Ac

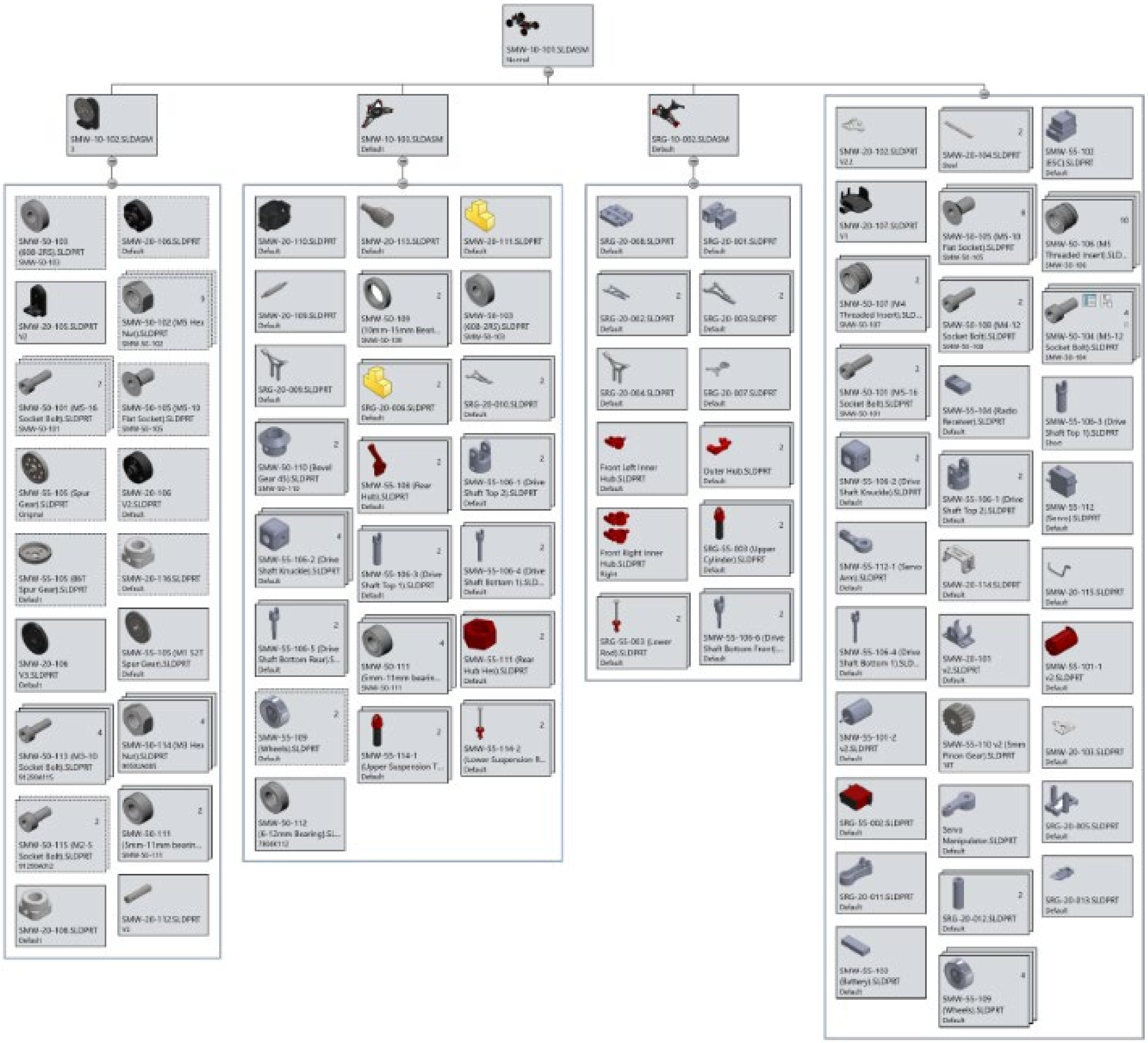
Ac ~ 0.00304 in

b×h = Ac = 0.00304 in = (.25 in) × h = 0.0122 in

∴ h > 0.0122 in

APPENDIX B - Drawings

Appendix B01 – Drawing Tree



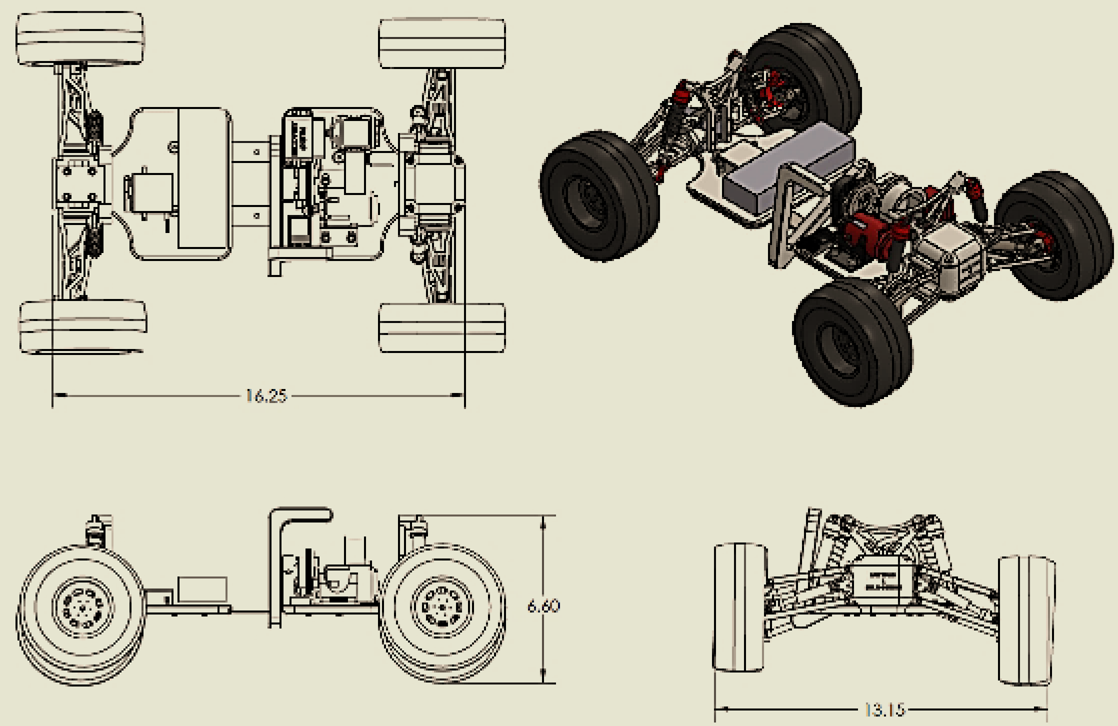
Appendix B02 – Drawing Index

Table B02- Drawing Index

Drawing Assignment Num.	Drawing #(s)	Date Submitted
Upload: DWG 1	SRG-20-001	10/11/2023
Upload: DWG 2	SRG-20-002	10/18/2023
Upload: DWG 3 & 4	SRG-20-003 & SRG-20-004	10/25/2023
Upload: DWG 5 & 6	SRG-20-005 & SRG-20-006	11/01/2023
Upload: DWG 7 & 8	SRG-20-007 & SRG-20-008	11/08/2023
Upload: DWG 9 & 10	SRG-20-001 & SRG-20-009	11/15/2023

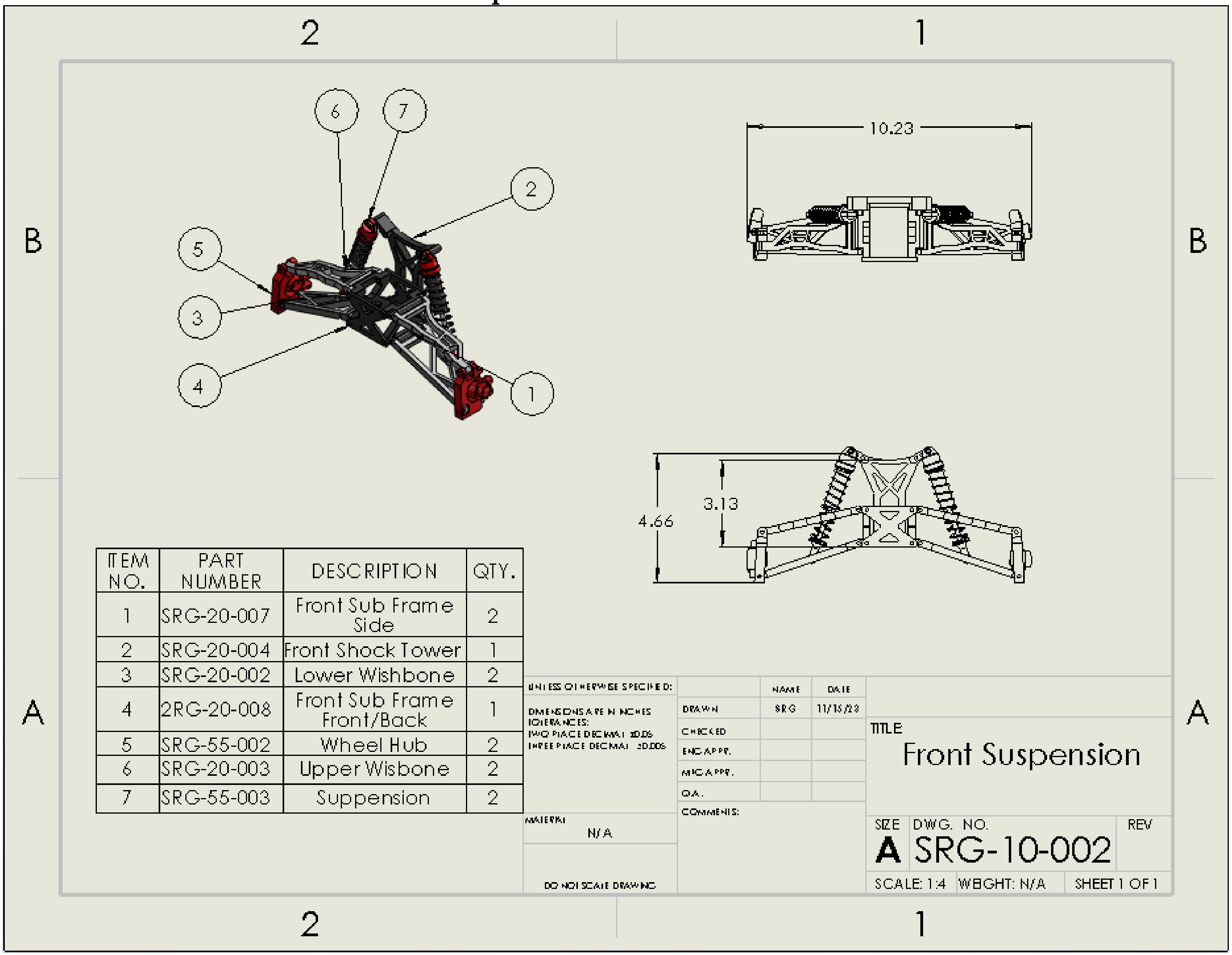
Appendix B03 – SRG-10-001 – RC Baja Full Assembly

ITEM NO.	PART NUMBER	QTY.
1	SMW-20-102	1
2	SMW-20-103	1
3	SMW-20-104	2
4	SMW-20-101	1
5	SMW-55-110 (Pinon Gear)	1
6	SMW-55-102 (ESC)	1
7	SMW-55-103 (Battery)	1
8	SMW-20-107	1
9	92125A208	8
10	94180A361	14
11	94180A351	2
12	91290A148	2
13	91290A228	4
14	91290A232	2
15	SMW-55-104 (Radio Receiver)	1
16	SMW-55-106-6 (Drive Shaft Bottom Front)	2
17	SMW-20-108	1
18	SMW-55-109 (Wheels)	2
19	SMW-55-112 (Servo)	2
20	SMW-55-112-1 (Servo Arm)	2
21	SMW-20-114	1
22	SMW-55-101-1	1
23	SMW-55-101-2	1
24	SMW-10-102	1
25	SMW-10-103	1
26	Front Suspension 2.0	1
27	SMW-20-115	1



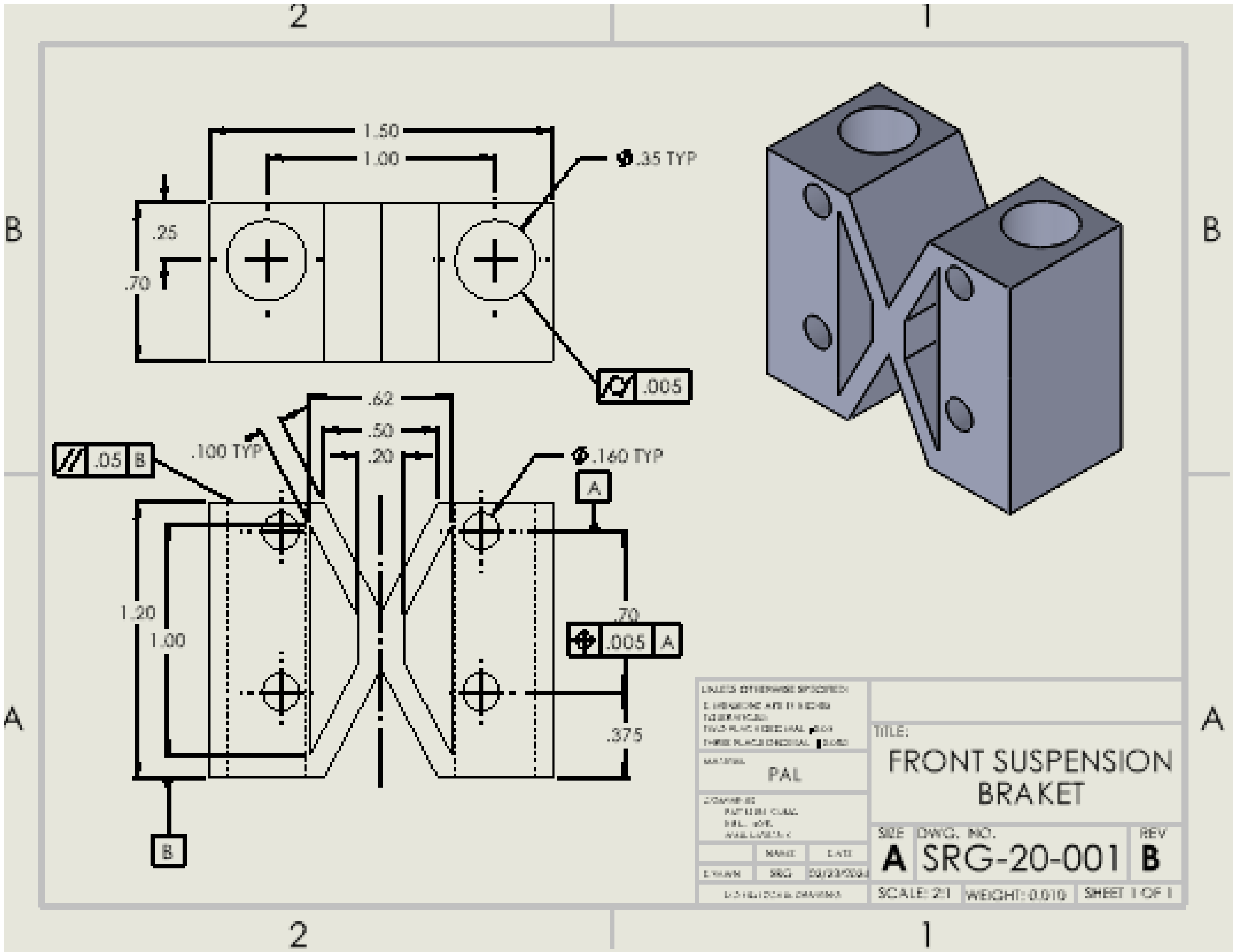
UNLESS OTHERWISE SPECIFIED:
MATERIAL: VARIOUS
FINISH: AS SHOWN
DO NOT SCALE DRAWING
DRAWN: SMW
TITLE: FULL VEHICLE ASSEMBLY
SIZE: B
DWG. NO. SRG-10-101
REV: 1
SCALE: 1:4 WEIGHT: 5 LB SHEET 1 OF 1

Appendix B04 – SRG-10-002 – Front Supension

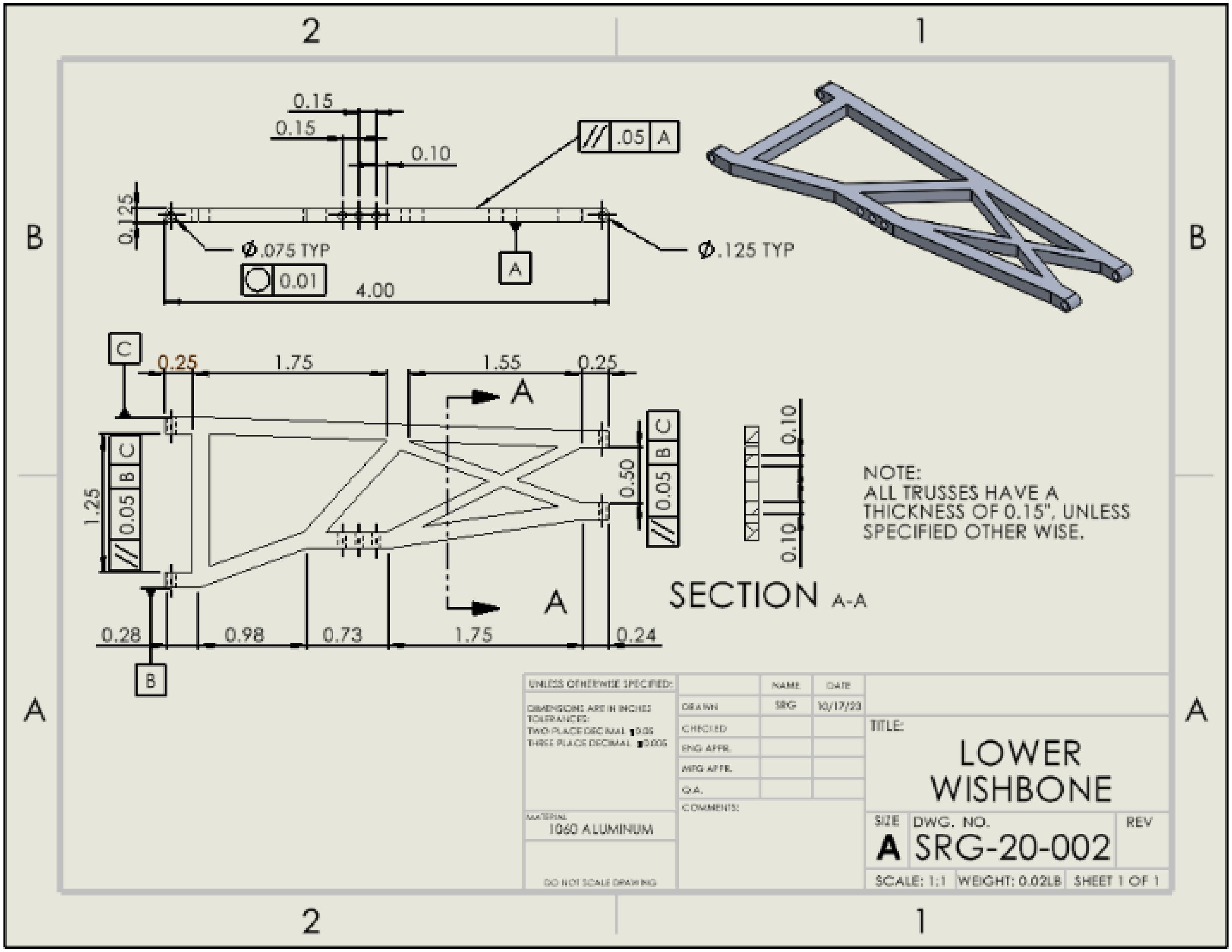


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SRG-20-007	Front Sub Frame Side	2
2	SRG-20-004	Front Shock Tower	1
3	SRG-20-002	Lower Wishbone	2
4	2RG-20-008	Front Sub Frame Front/Back	1
5	SRG-55-002	Wheel Hub	2
6	SRG-20-003	Upper Wisbone	2
7	SRG-55-003	Suppension	2

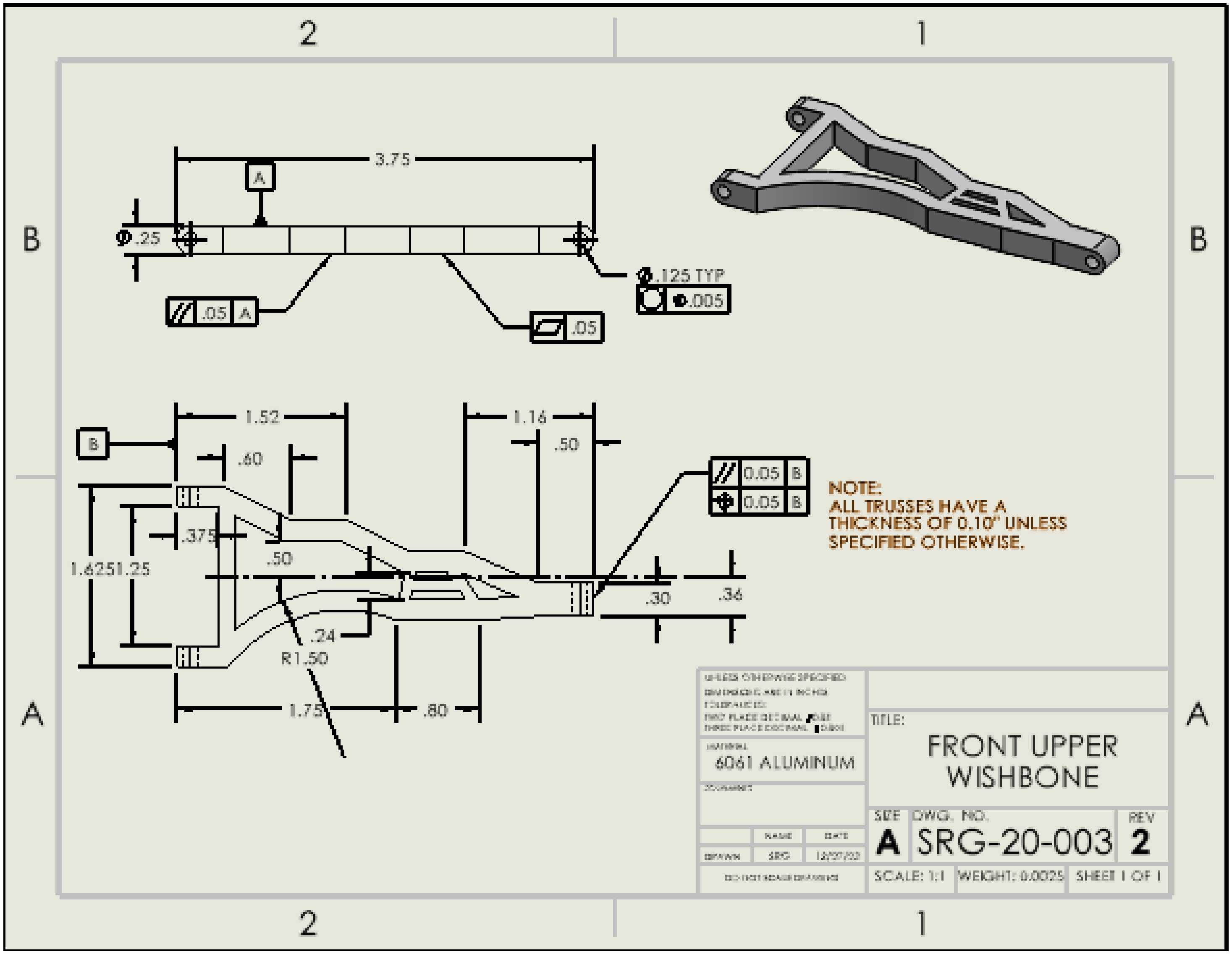
Appendix B05 – SRG-20-001 – Front Suspension Bracket



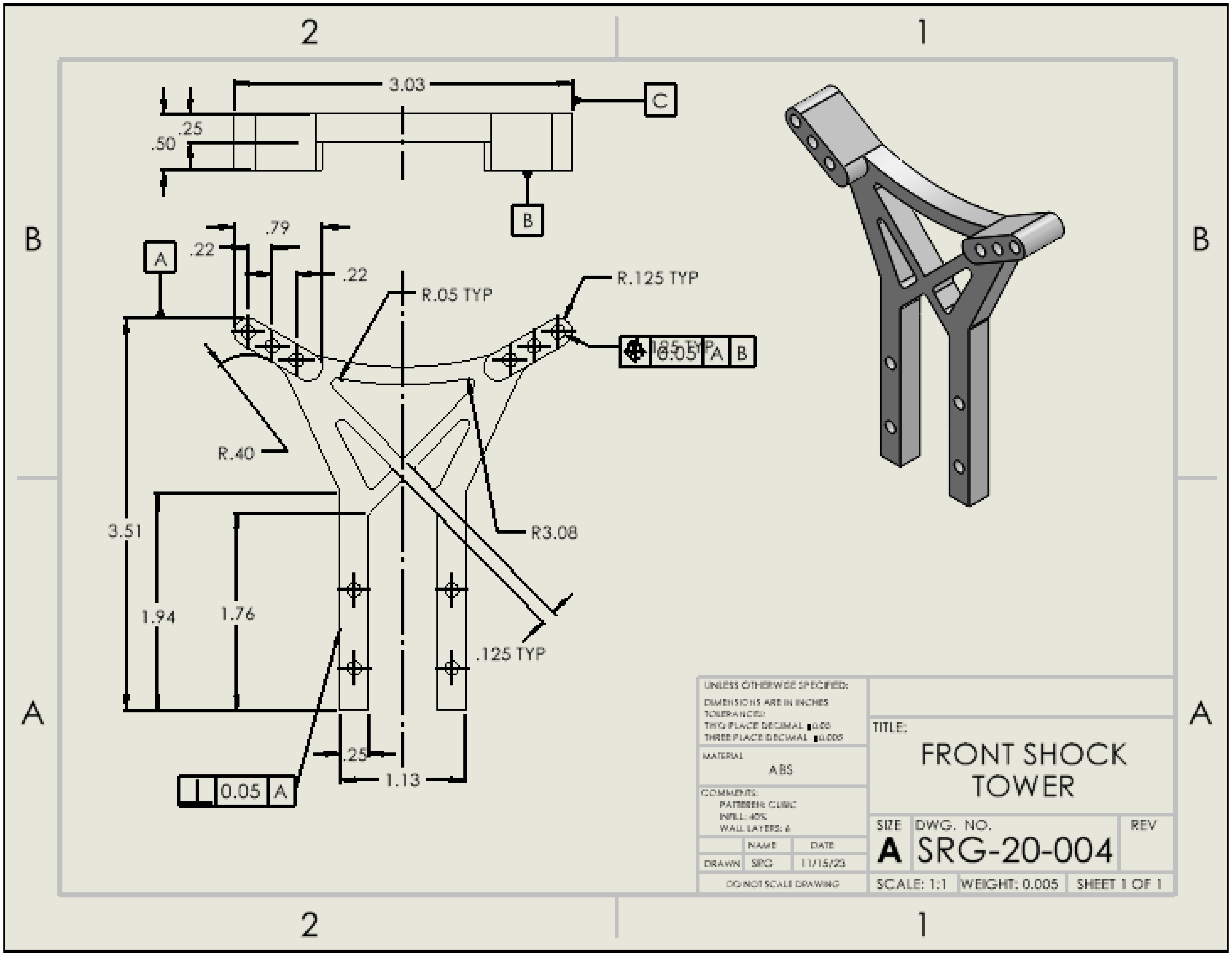
Appendix B06 – SRG-20-002 – Front Lower Wishbone



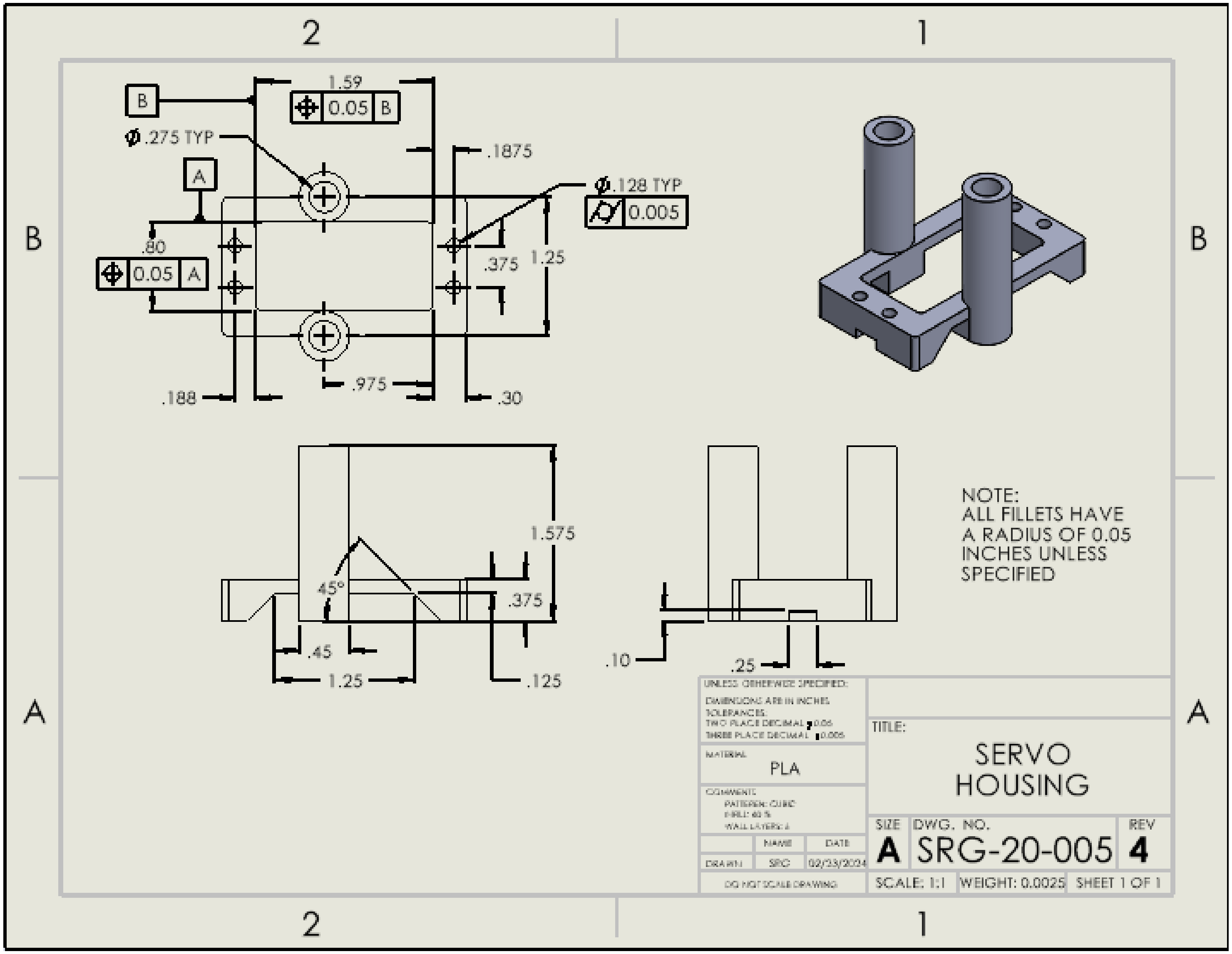
Appendix B07 – SRG-20-003 – Front Upper Wishbone



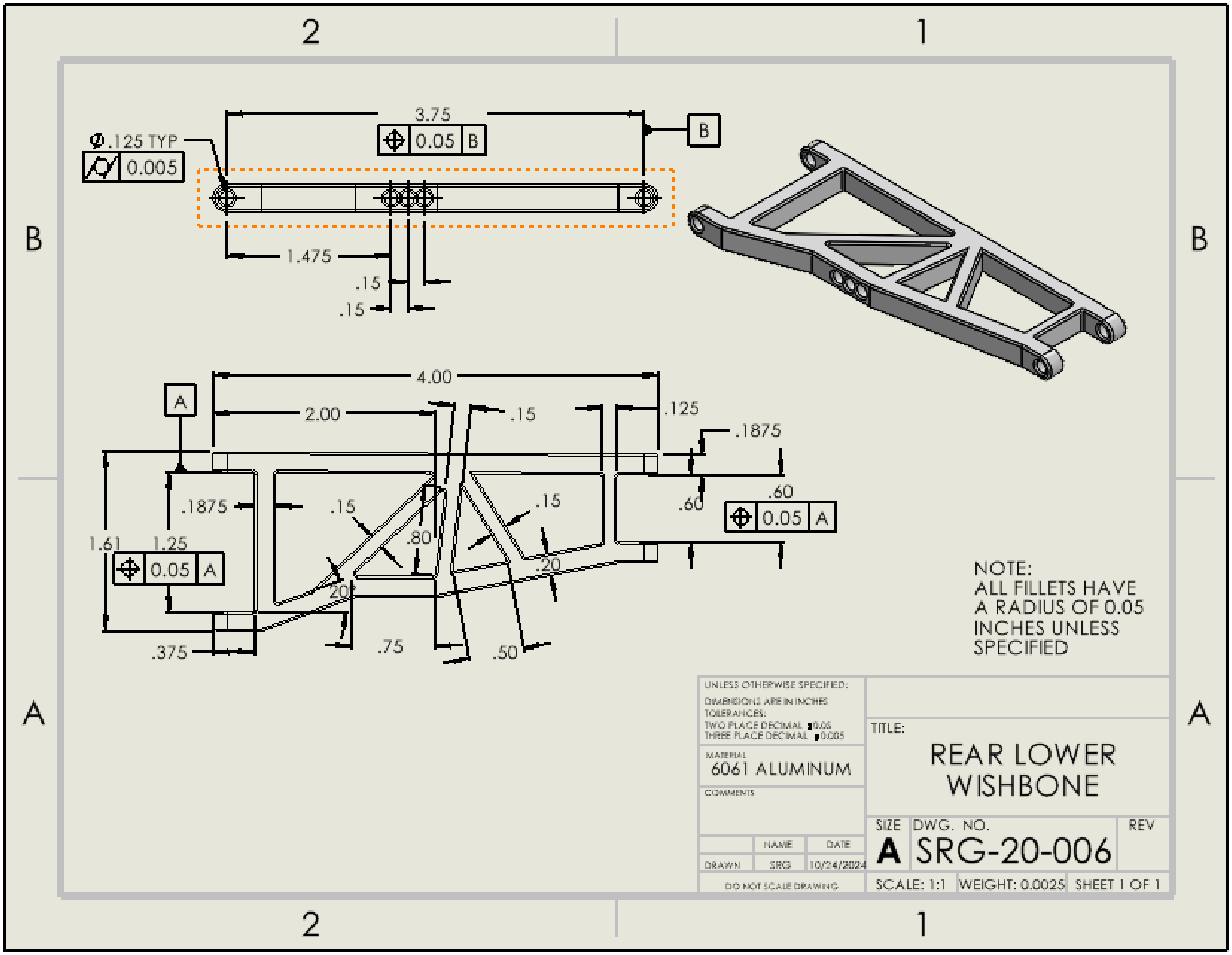
Appendix B08 – SRG-20-004 – Front Shock Tower



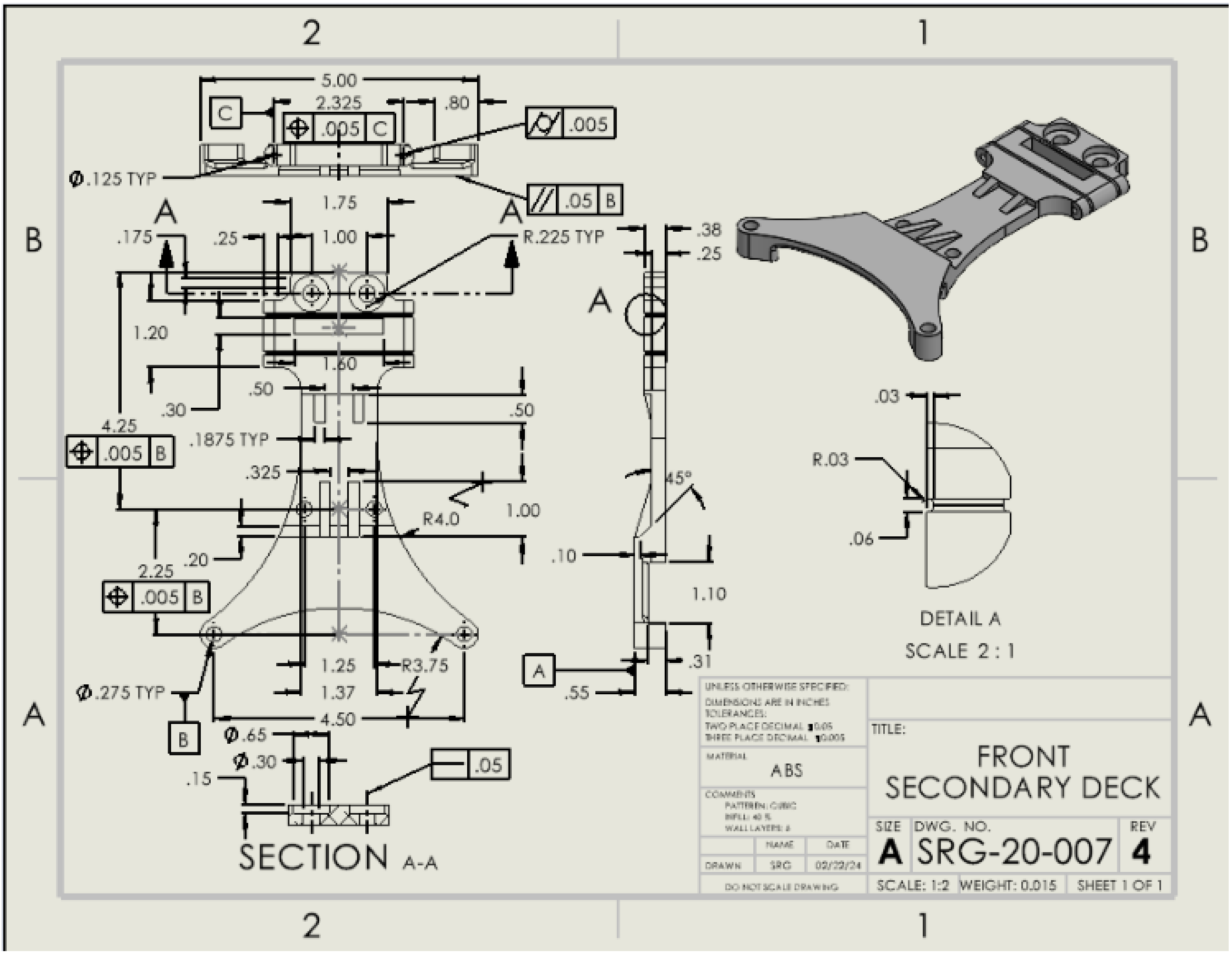
Appendix B09 – SRG-20-005 – Servo Housing



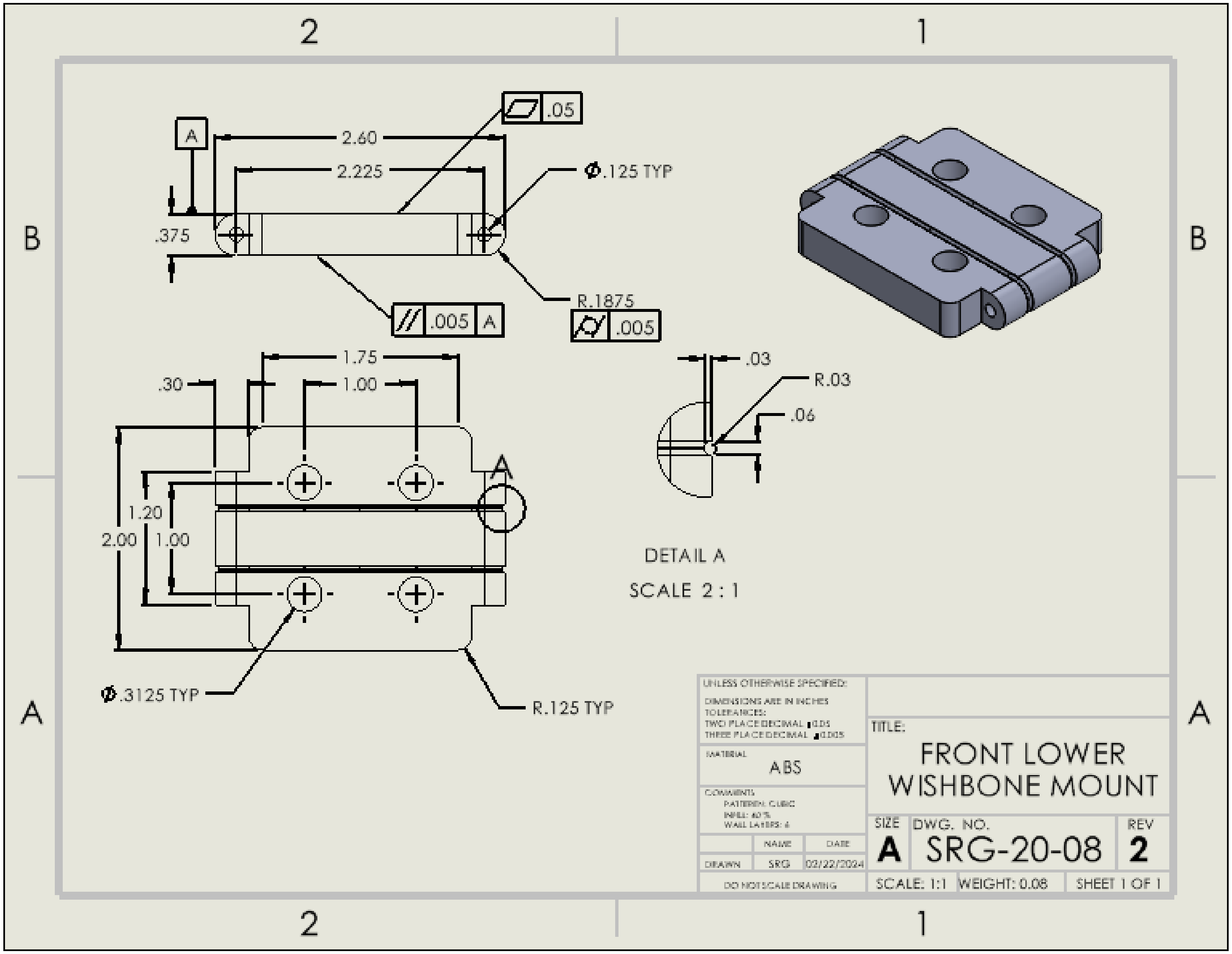
Appendix B10 – SRG-20-006 – Rear Lower Wishbone



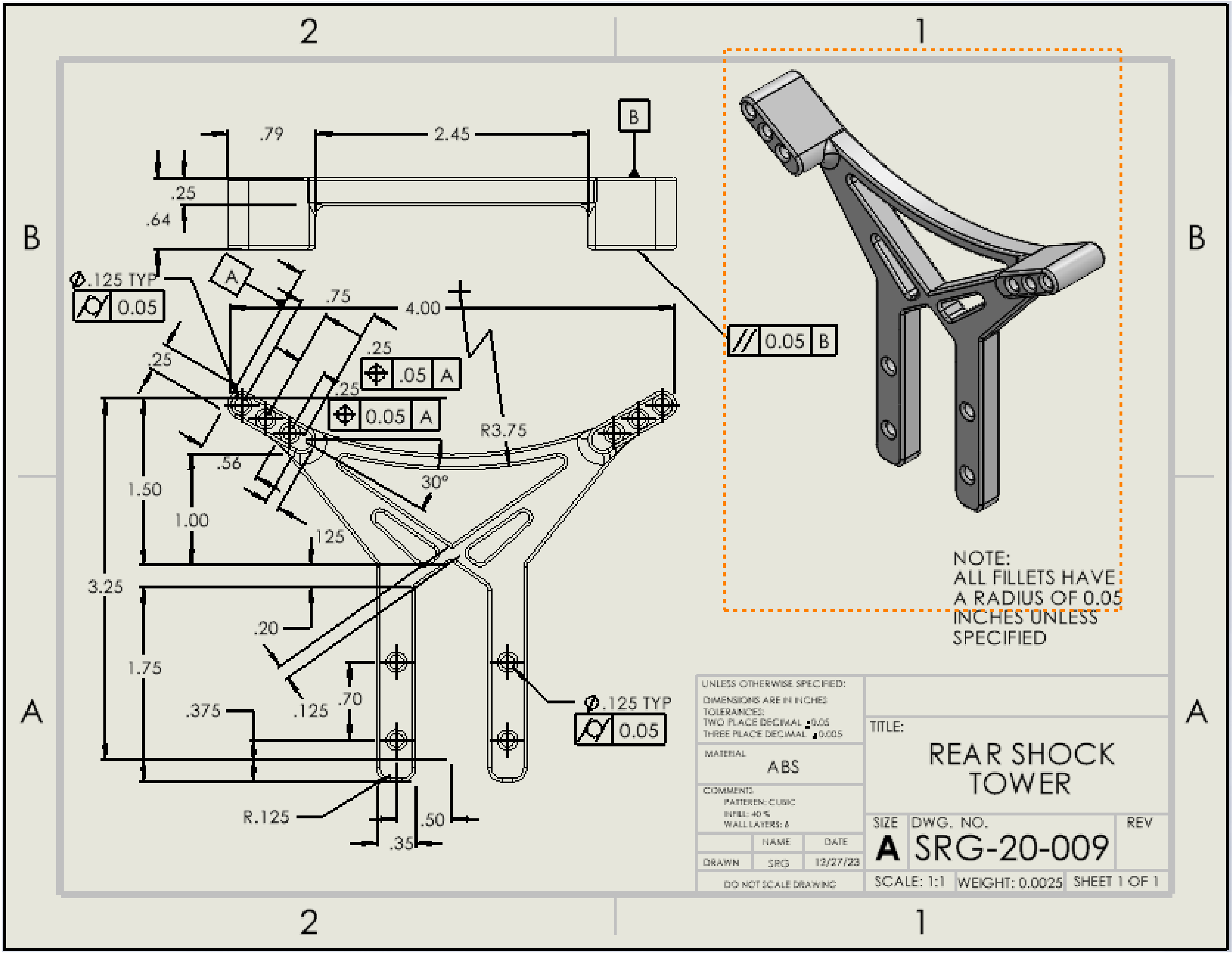
Appendix B11 – SRG-20-007 – Front Secondary Deck



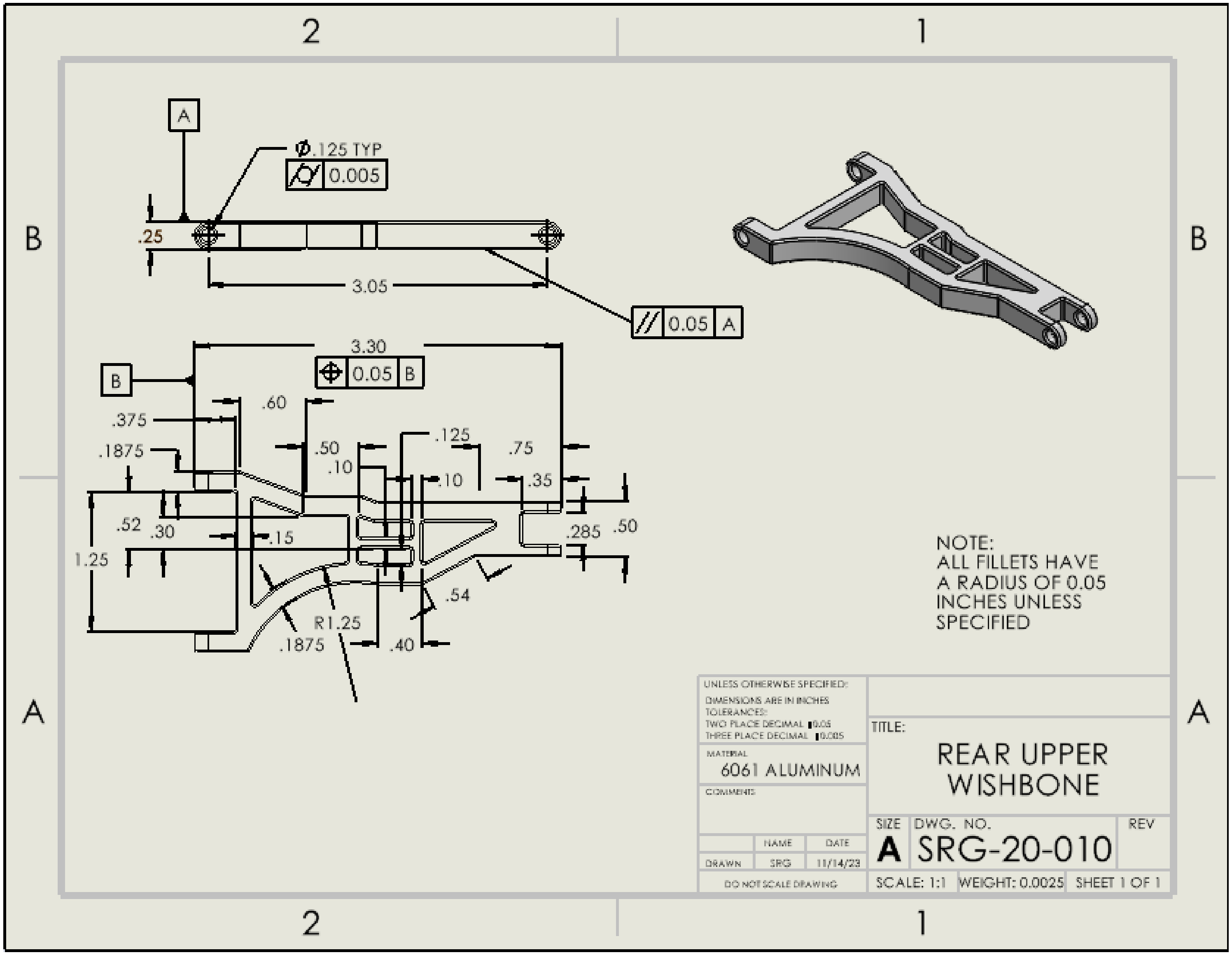
Appendix B12 – SRG-20-008 – Front Lower Wishbone Mount



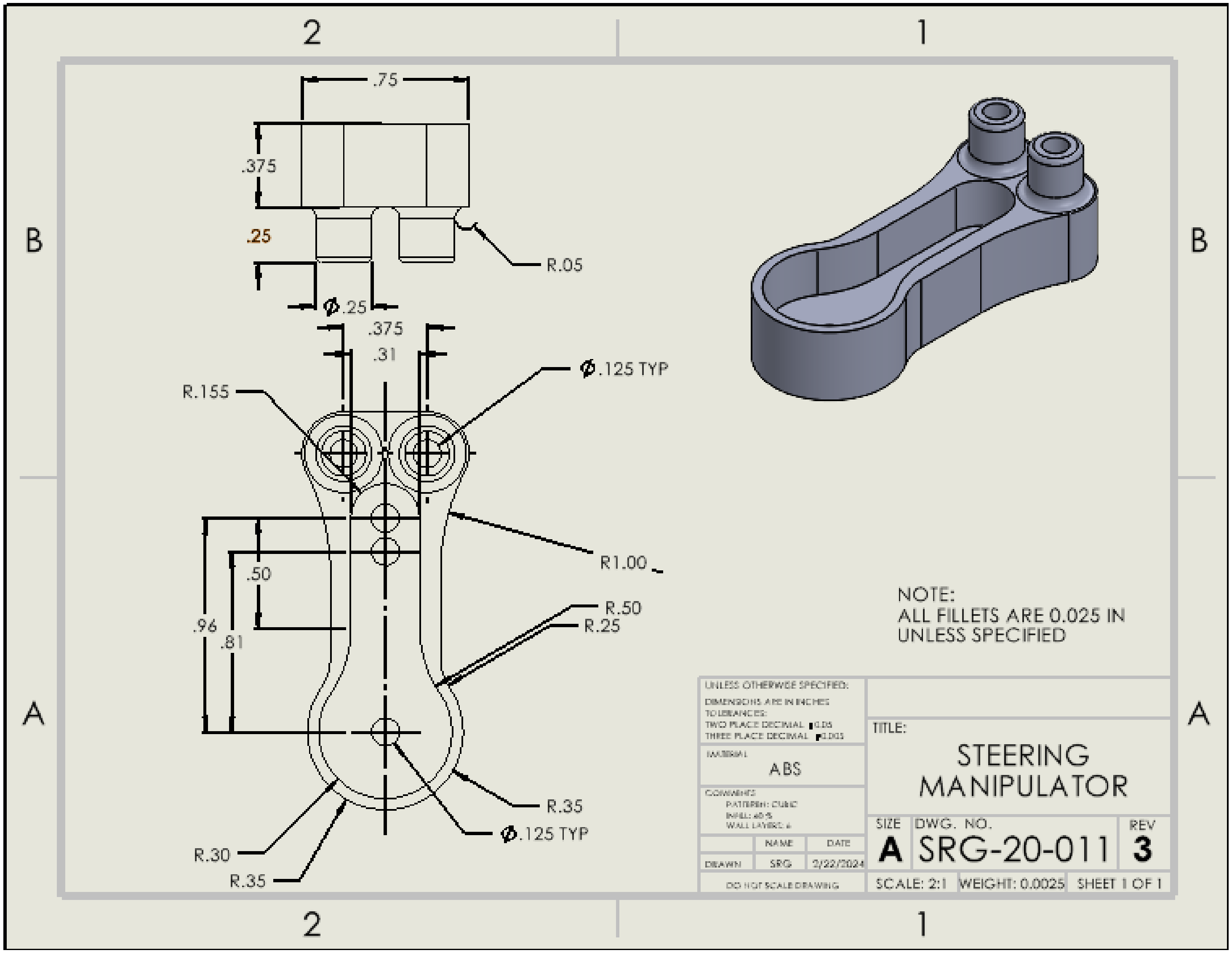
Appendix B14 – SRG-20-009 – Rear Shock Tower



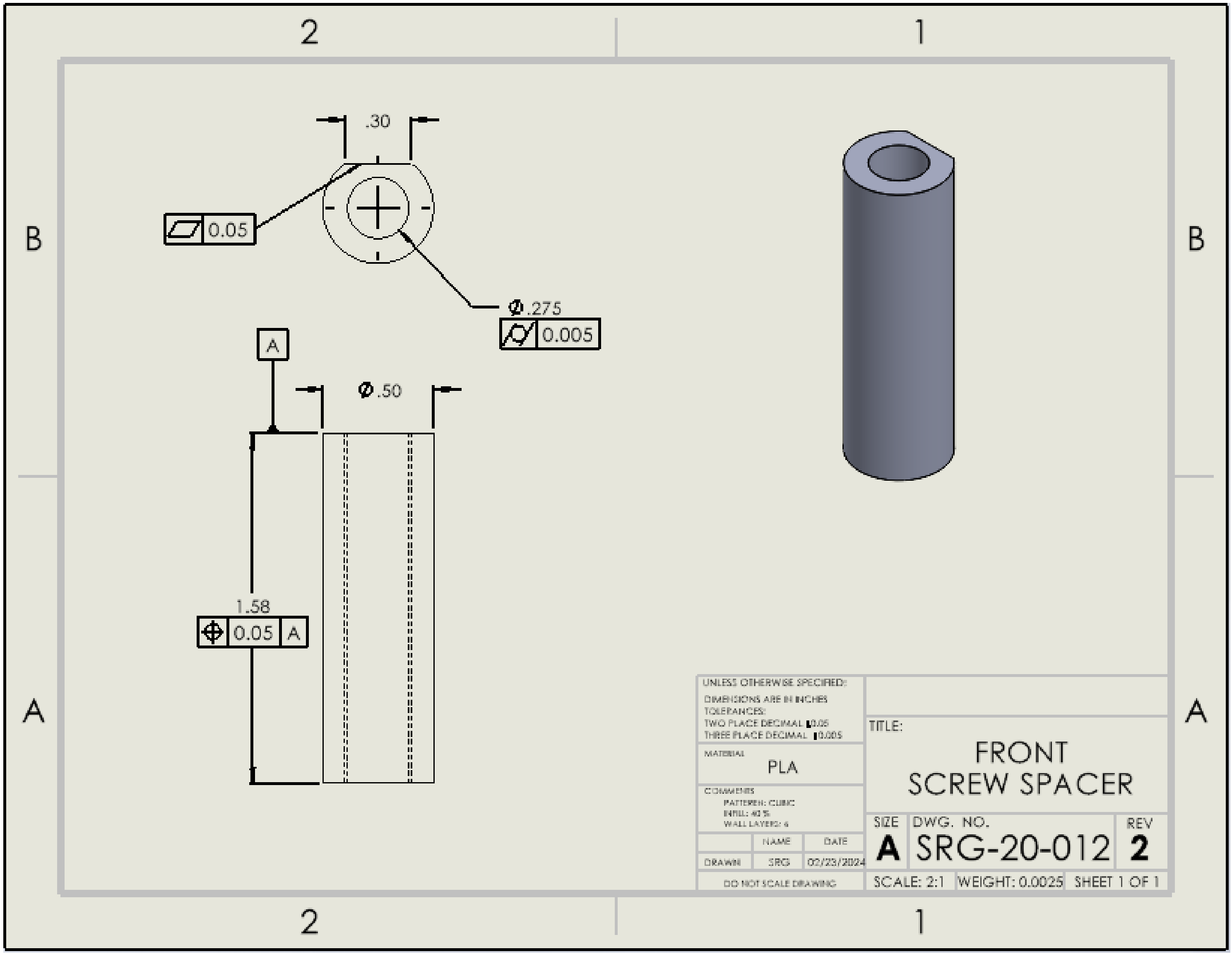
Appendix B15 – SRG-20-010 – Rear Upper Wishbone



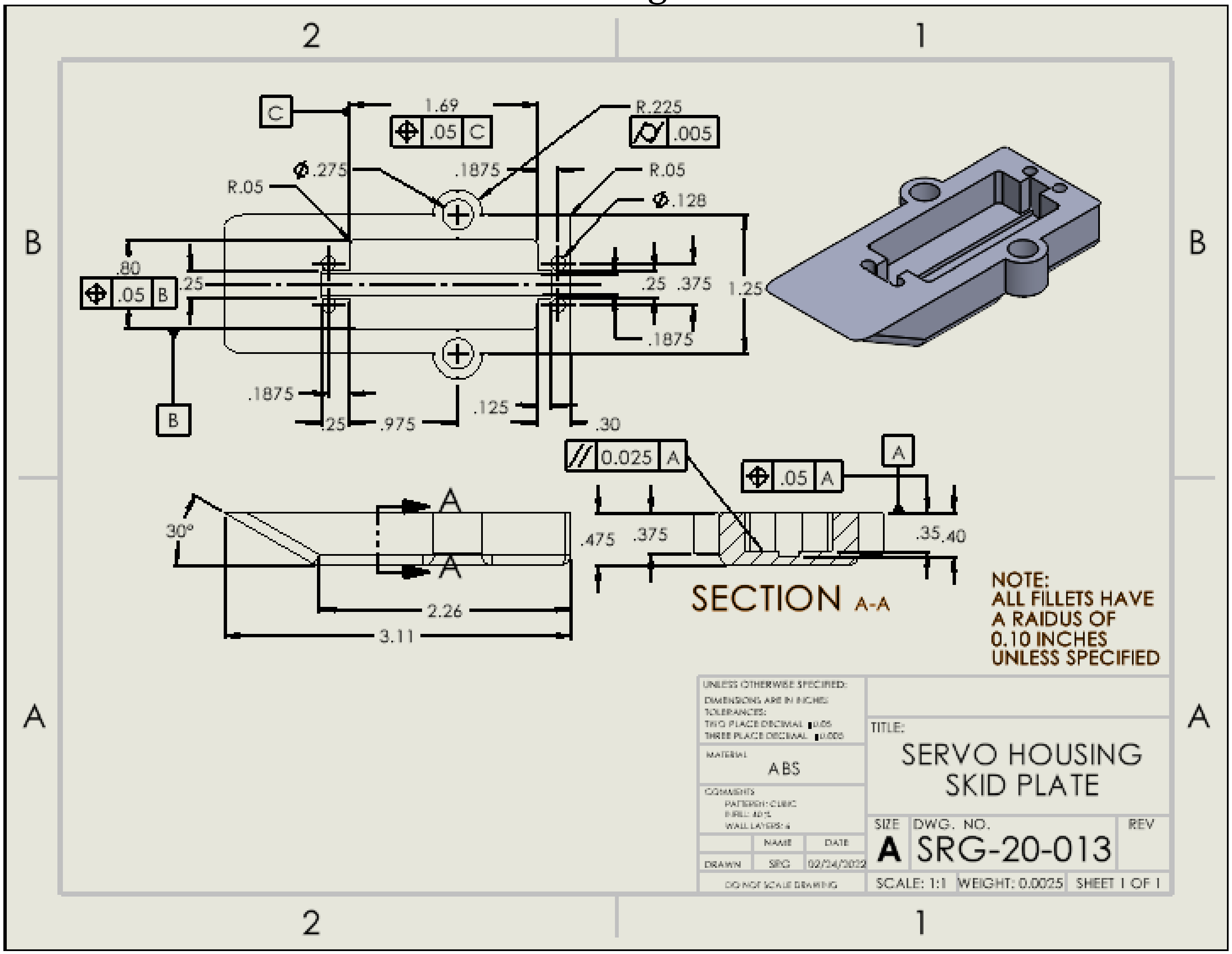
Appendix B16 – SRG-20-011 – Steering Manipulator



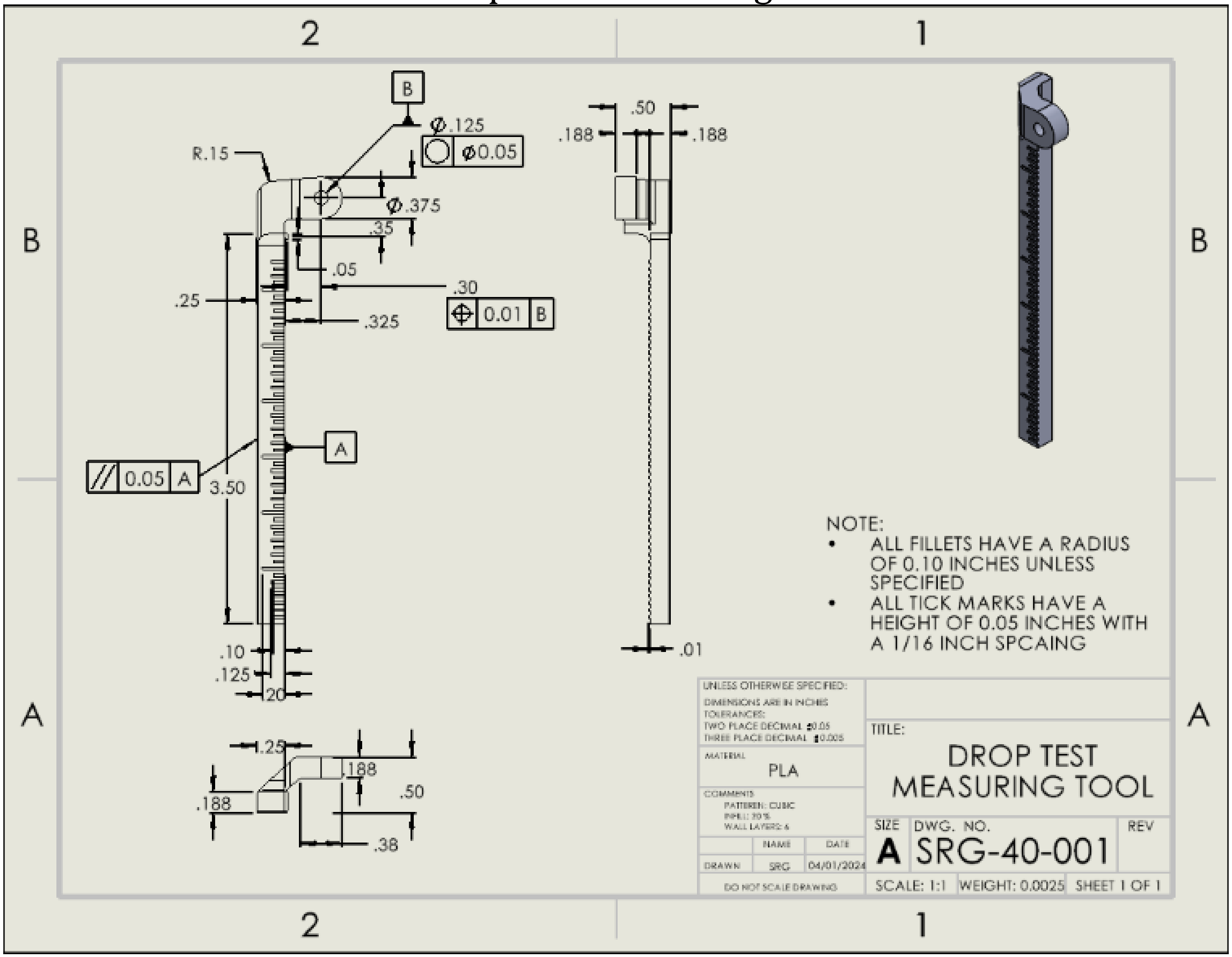
Appendix B17 – SRG-20-012 – Front Screw Spacer



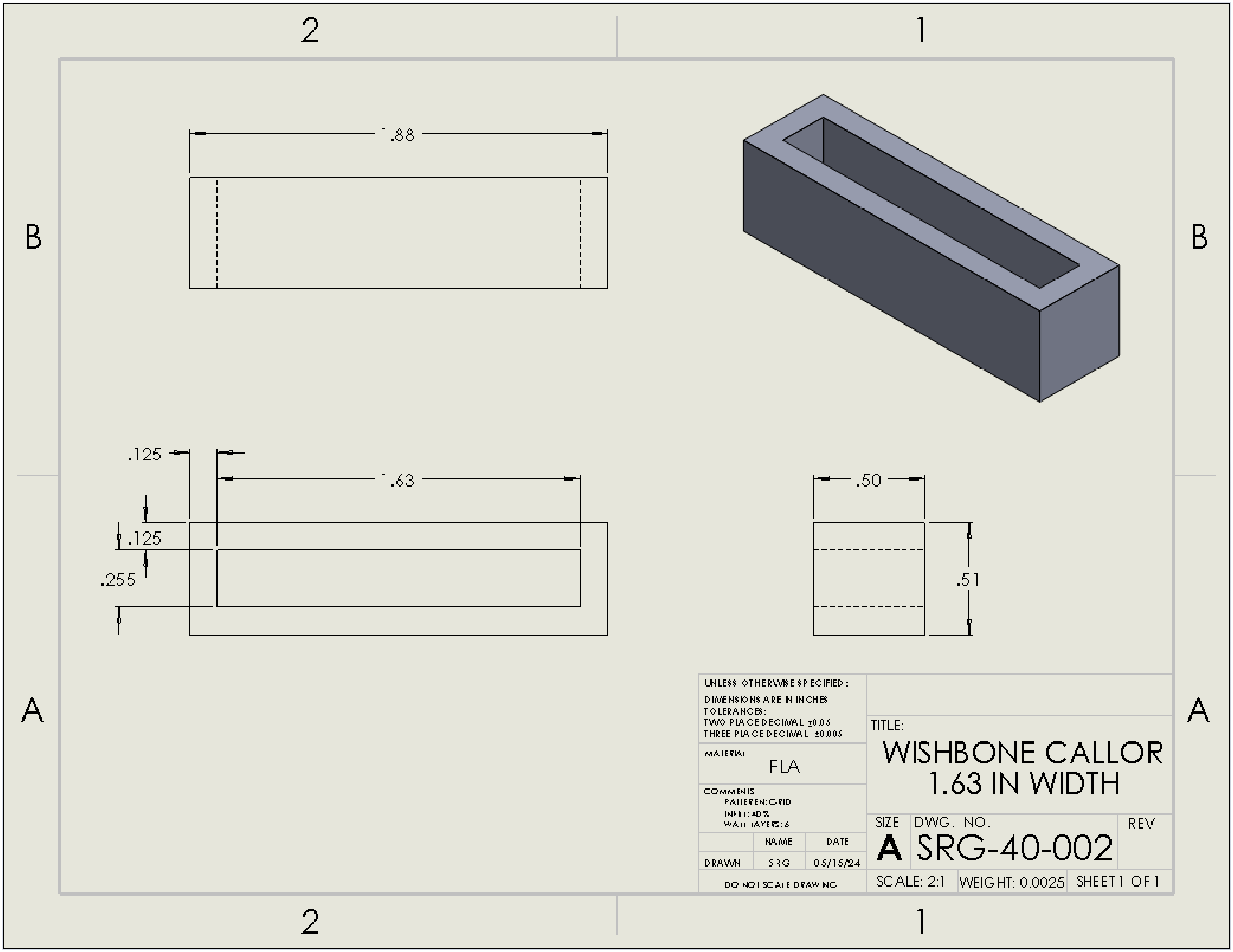
Appendix B18 – SRG-20-013 – Servo Housing Skid Plate



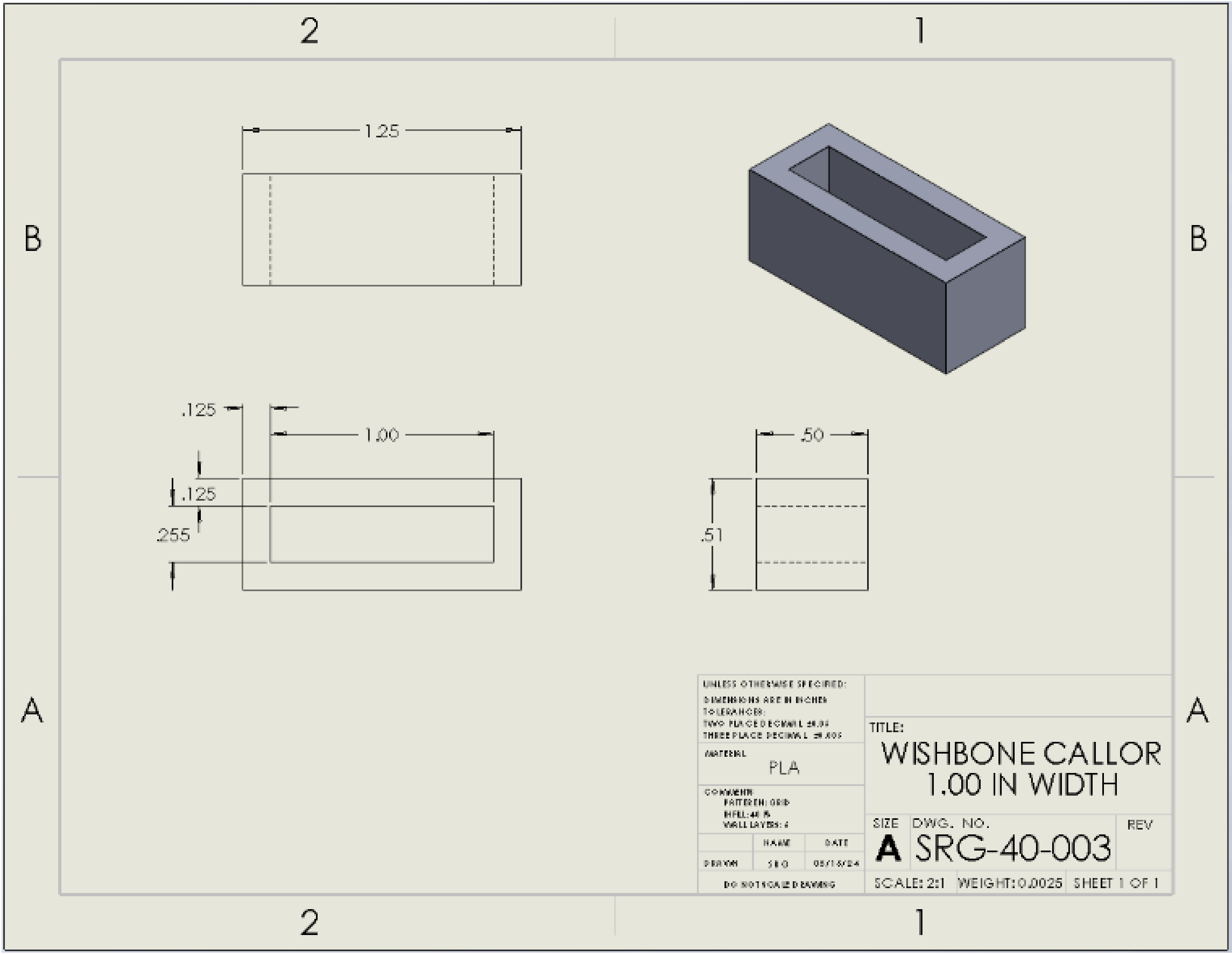
Appendix B19 – SRG-40-001 – Drop Test Measuring Tool



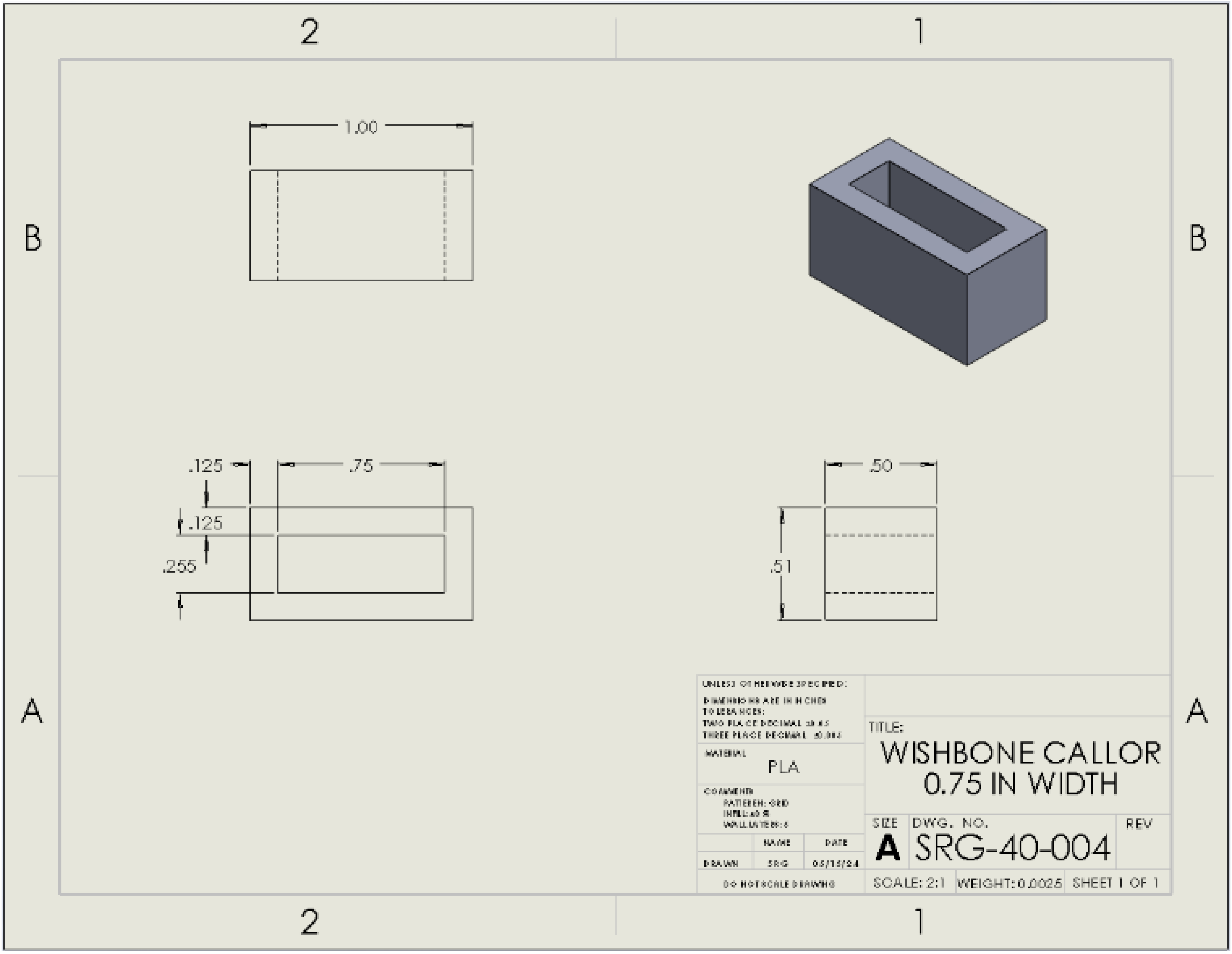
Appendix B20 – SRG-40-002 – Wishbone Collar 1.63 in Width



Appendix B21 – SRG-40-003 – Wishbone Collar 1.00 in Width



Appendix B22 – SRG-40-004 – Wishbone Collar 0.75 in Width



APPENDIX C – Parts List and Costs

Table C1. Parts List

Part Number	Qty	Part Description	Source	Cost	Disposition
SRG-20-001	1	Front Suspension Bracket	Amazon	N/A	1/16/2024
SRG-20-002	1	Front Lower Wishbone	Amazon	N/A	2/23/2024
SRG-20-003	1	Front Upper Wishbone	Amazon	N/A	2/23/2024
SRG-20-004	1	Front Shock Tower	Amazon	N/A	1/4/2024
SRG-20-005	1	Servo Housing	Amazon	N/A	12/21/2023
SRG-20-006	1	Rear Lower Wishbone	Amazon	N/A	3/15/2024
SRG-20-007	1	Front Secondary Deck	Amazon	N/A	1/10/2024
SRG-20-008	1	Front Lower Wishbone Mount	Amazon	N/A	2/23/2024
SRG-20-009	1	Rear Shock Tower	Amazon	N/A	12/21/2023
SRG-20-010	1	Rear Upper Wishbone	Amazon	N/A	2/23/2024
SRG-20-011	1	Steering Manipulator	Amazon	N/A	12/10/2024
SRG-20-012	1	Front Screw Spacer	Amazon	N/A	1/2/2024
SRG-20-013	1	Servo Housing Skid Plate	Amazon	N/A	12/21/2023
SRG-45-001	1	HATCHBOX ABS Filament	Amazon	$ 23.99	Order 11/20/2023
SRG-45-002	2	Creality PLA Filament	Amazon	$ 23.99	Order 11/07/2023
SRG-50-001	1	M Size Varity Pack Screw	Amazon	$ 16.99	Order 02/14/2024
SRG-50-002	4	1/4 in x 3 in Steel Bolt	ACE Hardware	$ 0.65	Purchased 02/20/2024
SRG-50-003	2	5/16 in x 2.5 in Steel Bolt	ACE Hardware	$ 0.75	Purchased 02/20/2024
SRG-50-004	2	5/16 in x 1.5 in Steel Bolt	ACE Hardware	$ 0.50	Purchased 02/20/2024

SRG-50-005	4	1/4 in Nut	ACE Hardware	$ 0.35	Purchased 02/20/2024
SRG-50-006	4	5/16 in Nut	ACE Hardware	$ 0.45	Purchased 02/20/2024
SRG-50-007	1	M Size Varity Pack Thread Inserts	Amazon	$ 15.69	Order 02/16/2024
SRG-50-008	1	6-32 Thread Rod	ACE Hardware	$ 3.99	Purchased 02/17/2024
SRG-50-009	8	6-32 Nut	ACE Hardware	$ 0.15	Purchased 02/17/2024
SRG-50-010	1	M3 x 30mm - 50mm Stainless Steel	Amazon	$ 23.99	Order 03/01/2024
SRG-50-011	1	18 Gauge Aluminum Wire 165 ft	Amazon	$ 6.99	Order 03/01/2025
SRG-55-001	1	OGRC Aluminum Front & Rear Wheel Hubs	Amazon	$ 38.99	Order 10/20/2023
SRG-55-002	1	25KG RC Servo Motor	Amazon	$ 16.99	Order 10/24/2023
SRG-55-003	1	INJORA RC Shock Absorbers	Amazon	$ 22.98	Order 10/24/2023
SRG-55-004	1	INJORA 1.9 Tires Karen	Amazon	$ 26.99	Order 09/25/2023
SRG-55-005	1	RXZIXYL Stainless Steel Linkage Chassis Link Rod	Amazon	$ 20.85	Order 12/12/2023
			Total Cost:	$ 275.92	

APPENDIX D – Budget

Table D1. Project Budget

Item	Qty	Description	Cost
Labor	100 hrs.	Time Spent on Machining Costume Parts and Assembling; $ 30.00/hr.	$ 3,000.00
Part	TBD	All cost parts, Reference Appendix C	$ 275.92
Taxes	N/A	Washington Sales Tax, 8%	$ 26.39
Machining Outsourcing	4	Send-Cut-Send	$ 54.00
		Total Budget:	$ 3,356.31

APPENDIX E – Schedule

		TASK ID:	Description	Est. Work	Actual Work	Start	Finish	% Work Complete
1								
2		1	**PROPOSAL/REPORT WRITING**	**288 hrs**	**159 hrs**	**Mon 9/25/23**	**Fri 5/3/24**	**85%**
3	✓	1a	Abstract	1 hr	1.5 hrs	Mon 3/25/24	Fri 3/29/24	100%
4	✓	1b	Intro	3 hrs	4 hrs	Mon 9/25/23	Sun 11/19/23	100%
5		1c	Analysis	50 hrs	45 hrs	Mon 9/25/23	Sun 11/19/23	91%
6		1d	Methods	25 hrs	16 hrs	Mon 10/2/23	Mon 2/12/24	25%
7		1e	Testing	20 hrs	8 hrs	Mon 10/23/23	Wed 4/24/24	10%
8		1f	Budget	50 hrs	7 hrs	Mon 10/9/23	Wed 2/7/24	20%
9		1g	Schedule	30 hrs	18 hrs	Mon 10/2/23	Mon 1/29/24	20%
10		1h	Project Management	15 hrs	3 hrs	Mon 10/30/23	Fri 11/10/23	15%
11		1i	Discussion	30 hrs	18 hrs	Sat 11/4/23	Fri 5/3/24	30%
12		1j	Conslusion	30 hrs	10 hrs	Mon 11/13/23	Fri 12/1/23	0%
13		1k	Drawings	30 hrs	21 hrs	Mon 10/2/23	Fri 12/8/23	71%
14		1l	Appendix	20 hrs	11 hrs	Mon 11/20/23	Sat 4/6/24	65%
15	✓	2	**ANAYSIS**	**19 hrs**	**18 hrs**	**Sun 10/1/23**	**Sun 11/19/23**	**100%**
16	✓	2a	Steering Rod Delfection	1 hr	3 hrs	Sun 10/1/23	Tue 10/3/23	100%
17	✓	2b	Sespension Resistance	1 hr	2 hrs	Mon 10/9/23	Wed 10/11/23	100%
18	✓	2c	Wishbone Buckling	1 hr	1 hr	Fri 10/13/23	Sun 10/15/23	100%
19	✓	2d	Wishbone Delfection	1 hr	1 hr	Sat 10/14/23	Sun 10/15/23	100%
20	✓	2e	Turn Radius	1.5 hrs	2 hrs	Sat 10/21/23	Sun 10/22/23	100%
21	✓	2f	Steer Rod Buckling	0.5 hrs	1 hr	Sat 10/21/23	Sun 10/22/23	100%
22	✓	2g	Rear Control Arm Buckling	1.5 hrs	1.5 hrs	Sat 10/28/23	Sun 10/29/23	100%
23	✓	2h	Rear Contral Arm Deflection	1.5 hrs	1.5 hrs	Sat 10/28/23	Sun 10/29/23	100%
24	✓	2i	Suspesion Tower Thickness	1 hr	1 hr	Sat 11/4/23	Sun 11/5/23	100%
25	✓	2j	Suspesion Resistance For Vechile Wieght	1 hr	1 hr	Sat 11/4/23	Sun 11/5/23	100%
26	✓	2k	Material Needed For Steering Rod	1 hr	1 hr	Sat 11/11/23	Mon 11/13/23	100%
27	✓	2l	Rear Suppension Thickness	1 hr	1.5 hrs	Sat 11/11/23	Sun 11/19/23	100%
28	✓	3	**DOCUMENTATION**	**20 hrs**	**21.5 hrs**	**Mon 10/9/23**	**Fri 12/8/23**	**100%**
29	✓	3a	SRG-20-001	1 hr	2 hrs	Mon 10/9/23	Wed 10/11/23	100%
30	✓	3b	SRG-20-002	2 hrs	2 hrs	Mon 10/16/23	Wed 10/18/23	100%
31	✓	3c	SRG-20-003	3 hrs	3.25 hrs	Mon 10/23/23	Wed 10/25/23	100%
32	✓	3d	SRG-20-004	1 hr	2 hrs	Mon 10/23/23	Wed 10/25/23	100%
33	✓	3e	SRG-20-005	2 hrs	2 hrs	Mon 10/30/23	Wed 11/1/23	100%
34	✓	3f	SRG-20-006	2 hrs	0.75 hrs	Mon 10/30/23	Wed 11/1/23	100%
35	✓	3g	SRG-20-007	1 hr	0.5 hrs	Mon 11/6/23	Wed 11/8/23	100%
36	✓	3h	SRG-20-008	1 hr	0.5 hrs	Mon 11/6/23	Wed 11/8/23	100%
37	✓	3i	SRG-20-009	1 hr	0.5 hrs	Mon 11/13/23	Wed 11/15/23	100%
38	✓	3j	SRG-20-010	1 hr	1.5 hrs	Wed 11/15/23	Mon 11/20/23	100%
39	✓	3k	SRG-20-011	2 hrs	2 hrs	Thu 11/23/23	Tue 11/28/23	100%
40	✓	3l	SRG-20-012	1 hr	1 hr	Thu 11/23/23	Tue 11/28/23	100%
41	✓	3m	SRG-20-013	1 hr	0.5 hrs	Thu 11/30/23	Mon 12/4/23	100%
42	✓	3n	SRG-10-002	1 hr	1.5 hrs	Mon 12/4/23	Fri 12/8/23	100%
43	✓	4	**PART MANUFACTURING**	**25 hrs**	**26 hrs**	**Tue 11/7/23**	**Fri 3/15/24**	**100%**
44	✓	4a	SRG-20-001	3 hrs	5 hrs	Wed 1/3/24	Tue 1/16/24	100%
45	✓	4b	SRG-20-002	0.5 hrs	1 hr	Mon 2/19/24	Fri 2/23/24	100%
46	✓	4c	SRG-20-003	0.5 hrs	1 hr	Mon 2/19/24	Fri 2/23/24	100%
47	✓	4d	SRG-20-004	2 hrs	5 hrs	Tue 11/7/23	Thu 1/4/24	100%
48	✓	4e	SRG-20-005	3 hrs	3.5 hrs	Thu 12/14/23	Thu 12/21/23	100%
49	✓	4f	SRG-20-006	3 hrs	6 hrs	Wed 11/15/23	Fri 3/15/24	100%
50	✓	4g	SRG-20-007	4 hrs	5 hrs	Wed 1/3/24	Wed 1/10/24	100%
51	✓	4h	SRG-20-008	0.5 hrs	1 hr	Mon 2/19/24	Fri 2/23/24	100%
52	✓	4i	SRG-20-009	2 hrs	2 hrs	Mon 12/11/23	Thu 12/21/23	100%
53	✓	4j	SRG-20-010	0.5 hrs	1 hr	Mon 2/19/24	Fri 2/23/24	100%
54	✓	4k	SRG-20-011	2.5 hrs	2 hrs	Sat 11/25/23	Sun 12/10/23	100%
55	✓	4l	SRG-20-012	1 hr	1.5 hrs	Thu 12/21/23	Tue 1/2/24	100%
56	✓	4m	SRG-20-013	4 hrs	5 hrs	Mon 12/11/23	Thu 12/21/23	100%
57	✓	5	**DEVICE MANUFACTURING**	**8 hrs**	**9 hrs**	**Mon 11/20/23**	**Fri 3/1/24**	**100%**
58	✓	5a	Front Suspension Assembly	3 hrs	5 hrs	Mon 1/1/24	Fri 3/1/24	100%
59	✓	5b	Rear Suspensoin Assembly	3 hrs	2 hrs	Mon 11/20/23	Fri 3/1/24	100%
60	✓	5c	Steering Assembly	2 hrs	2 hrs	Mon 12/18/23	Fri 1/19/24	100%
61		6	**DEVICE EVALUATION**	**14 hrs**	**10 hrs**	**Sun 3/24/24**	**Mon 5/13/24**	**0%**
62		6a	Test Report	12 hrs	8 hrs	Sun 3/24/24	Wed 4/24/24	0%
63	✓	6b	Drop Test	1 hr	2 hrs	Mon 4/8/24	Wed 4/10/24	100%
64	✓	6c	Turn Radius Test	1 hr	2 hrs	Mon 4/22/24	Wed 4/24/24	100%
65	✓	6d	Wishbone Buckling	1 hr	2 hrs	Mon 4/29/24	Fri 5/3/24	100%
66		6e	Wishbone Deflection	0 hrs	0 hrs	Mon 5/13/24		0%
67		7	**DELIVERABLES**	**19 hrs**	**16 hrs**	**Wed 9/27/23**	**Fri 5/3/24**	**80%**
68		7a	Web Page/Design	6 hrs	9 hrs	Wed 9/27/23	Wed 4/24/24	80%
69	✓	7b	Fall Presentation	2 hrs	2 hrs	Mon 11/27/23	Wed 11/29/23	100%
70	✓	7c	Winter Presentation	2 hrs	2 hrs	Mon 3/4/24	Wed 3/6/24	100%
71	✓	7d	TDR 01	1 hr	1 hr	Mon 4/15/24	Fri 4/19/24	100%
72	✓	7e	TDR 02	1 hr	1 hr	Mon 4/22/24	Fri 4/26/24	100%
73		7f	SOURCE	5 hrs	3 hrs	Mon 4/29/24	Fri 5/3/24	0%

Figure E1. Gannt Chart

APPENDIX F – Expertise and Resources

Appendix F1.1 – Suspension/ Steering Design Matrix

Criterion	Weight 1 to 3	Best Possible 3	Design #1	Score x Wt	Design #2	Score x Wt	Design #3	Score x Wt	
Criterion1	2	6	2	4	2	4	1	2	
Criterion2	1	3	2	2	2	2	2	2	
Criterion3	3	9	3	9	2	6	3	9	
Criterion4	2	6	3	6	2	4	1	2	
Criterion5	3	9	2	6	3	9	1	3	
Total	11	33		27		25		18	
NORMALIZE THE DATA (muliply by fraction, N)		3.03		81.8		75.8		54.5	Percent
Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits			Good? Then done.			70.7	Average
	Poor Bias:	Standard Deviation is one or less digits			Poor? Change something!			14	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	Higher the cost the more it may take away from other components
Weight	Light weight scores better on the success equation
Funcation	Does the design work best on rough terrian
Durability	What compents are more likley to break
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:	
Design #1	Double Wishbone
Design #2	Macperhson
Design #3	Multilink

Appendix F1.2 – Control Arm Manufacturing Method Design Matrix

Criterion	Weight 1 to 3	Best Possible 3	Design #1	Score x Wt	Design #2	Score x Wt	Design #3	Score x Wt	Design #4	Score x Wt	
Criterion1	2	6	2	4	3	6	2	4	1	2	
Criterion2	1	3	2	2	3	3	2	2	2	2	
Criterion3	3	9	2	6	1	3	3	9	3	9	
Criterion4	2	6	2	4	3	6	2	4	3	6	
Criterion5	3	9	2	6	3	9	1	3	3	9	
Total	11	33		22		27		22		28	
NORMALIZE THE DATA (multiply by fraction, N)		3.03		66.7		81.8		66.7		84.8	Percent

Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits	Good? Then done.	71.7	Average
	Poor Bias:	Standard Deviation is one or less digits	Poor? Change something!	10	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	Higher the cost the more it may take away from other components
Weight	Light weight scores better on the success equation
Strength	Higher the Tensile strength less likely for the part to break
Accuracy	Does the final result closely represents the design
Manufacturability	How easy could the comment be produced?

Comments:	
Method #1	Casting
Method #2	3D printing
Method #3	CNC
Method #4	Water Jet

Appendix F1.3 – Shock Tower Manufacturing Method Design Matrix

Criterion	Weight 1 to 3	Best Possible 3	Design #1	Score x Wt	Design #2	Score x Wt	Design #3	Score x Wt	Design #4	Score x Wt	
Criterion1	2	6	2	4	3	6	2	4	1	2	
Criterion2	1	3	2	2	3	3	2	2	2	2	
Criterion3	1	3	2	2	2	2	3	3	3	3	
Criterion4	2	6	1	2	3	6	2	4	3	6	
Criterion5	3	9	2	6	3	9	1	3	3	9	
Total	9	27		16		26		16		22	
NORMALIZE THE DATA (multiply by fraction, N)		3.70		59.3		96.3		59.3		81.5	Percent

Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits	Good? Then done.	71.6	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	Higher the cost the more it may take away from other components
Weight	Light weight scores better on the success equation
Strength	Higher the Tensile strength less likely for the part to break
Accuracy	Does the final result closely represents the design
Manufacturability	How easy could the comment be produced?

Comments:	
Method #1	Casting
Method #2	3D printing
Method #3	CNC
Method #4	Water Jet

Appendix F1.4 – Steering Rod Material Design Matrix

Criterion	Weight 1 to 3	Best Possible 3	Material #1	Score x Wt	Material #2	Score x Wt	Material #3	Score x Wt	
Criterion1	2	6	3	6	2	4	1	2	
Criterion2	2	6	3	6	2	4	1	2	
Criterion3	1	3	1	1	2	2	3	3	
Criterion4	3	9	3	9	2	6	2	6	
Criterion5	3	9	3	9	2	6	2	6	
Total	11	33		31		22		19	
NORMALIZE THE DATA (multiply by fraction, N)		3.03		93.9		66.7		57.6	Percent

Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits	Good? Then done.	72.7	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	Higher the cost the more it may take away from other components
Weight	Light weight scores better on the success equation
Strength	Higher the Elastic Modulus strength less likely for the part to break
Accessibility	How easy could the material be accessible
Manufacturability	How easy could the component be produced?

Comments:	
Material #1	ABS
Material #2	6061 T6 Aluminum
Material#3	Low Carbon Steel

APPENDIX G – Testing Report

Appendix G1 Drop Test

Introduction

This will be testing if the vehicle meets requirement 1D-9. Stating the vehicle must be able to be dropped from 3 feet and only compressing the springs 1 inch. In this test the vehicle will be dropped at increments of 6 inches until reaching the parameter of interest, being the height of which springs compressing 1 inch. These measurements will be recorded by using the 3D-printed measuring tool shown in Appendix B19 (SRG-40-001) and a slow-motion camera. With the increased weight of the RC car, some assumptions made in Spring were faulty, as shown in Appendix A02. So, when redoing the calculations, shown in Appendix G1.4, it is expected that the car should be able to resist 1 inch of compressing at 18 inches. The test will be conducted on April 8th and should take about an hour as shown in Appendix E and Appendix G1.5.

Method/Approach

A slow-motion capturing camera will be used to see the compression of the vehicle's springs. This combined with the 3D-printed measuring tool, SRG-40-001. Will allow for a 1/16th of an inch accuracy of the displacement of the spring's compression. A well-light area, flat ground, and wall will be needed to conduct this test. Using the equipment stated below the RC car will be dropped at increments of 6 inches until reaching a spring compression of 1 inch. This limitation is applied to ensure that the vehicle won't be dropped at an unnecessary height, mitigating any damage to the car. This will also see if the vehicle meets requirement 1D-3. When the testing setup is complete, the first drop can begin. The first drop will begin at 6 inches with the camera recording. After the drop is made, the footage will be reviewed to see how far the springs compress, and then documenting the results on the data form. Repeating the steps at an additional 6 inches each time until the springs compress of 1 inch, concluding the test. This will all then be inputted and stored within an Excel sheet, to give a line graph of the amount of compression in the springs over the height dropped.

Required Equipment:

- Camera/Phone with Slow-Motion Capabilities
    - Camera/Phone Stand to Hold Up Device
- Sharpie
- Level Ground
- 3D Printed Suspension Measuring Tool (Appendix B19)
- Excel
- RC Car
- Masking Tape
- Data Form

Test Procedure

This procedure is to test if the vehicle meets requirement 9 in section 1D. Stating that the vehicle's suspension must compress no more than 1 inch from a 3-foot drop. Various tools and equipment will be used to get the most accurate reading. As the following will give a step-by-step guide of the actions taken to complete this test.

Figure G1.1 – Testing Setup

Required Equipment:

- Camera/Phone with Slow-Motion Capabilities
    - Camera/Phone Stand to Hold Up Device
- Sharpie

- Level Ground
- 3D Printed Suspension Measuring Tool (Appendix B19)
- Excel
- RC Car
- Masking Tape
- Data Form

Time: The test took place April 8th from 8am to 10am within Hougue Hall. The test will take 10 minutes to constructed and 10 minutes to take back down. The test will take an hour to collect the necessary data and footage.

Place: This test will be conducted in the Interdisciplinary Lab of Hogue Hall, as this will give an open well-lit area. Another well-lit area with flat surfaces maybe also adequate for this testing.

Risks: Adding the additional measuring equipment technically will add weight to the vehicle causing the springs to further compress. As the equipment only weighs 8 grams, making this weight negligible. Additionally, if the vehicle is dropped slightly unbalanced this will add an uneven amount of impact force to the four springs, giving an invalid reading. As the vehicle would have to be dropped perfectly to avoid this. There will be a slit error in the measurement.

Procedure:

1. Gather the necessary equipment.
    a. Camera/Phone
    b. Stand for Device
    c. Sharpie
    d. 3D Printed Suspension Measuring Tool (Appendix B19)
    e. RC Car
    f. Tape
    g. Data Form
2. Tape masking tape starting at 3 feet, with the top of the tape to the measurement needed. As shown in figure G1.2.
3. Tape additional markings at increments of 6 inches, as shown in Figure G1.1, with the same technique as in step 2.
4. Position camera to capture a clear reading when the car is to land.
5. Acquire the RC car.
6. Unscrew the bolts holding the front suspension to the shock tower on either side.
7. Screw the measuring tool to the front side of the suspension and shock tower as shown in Figure G1.3 and Figure G1.4.

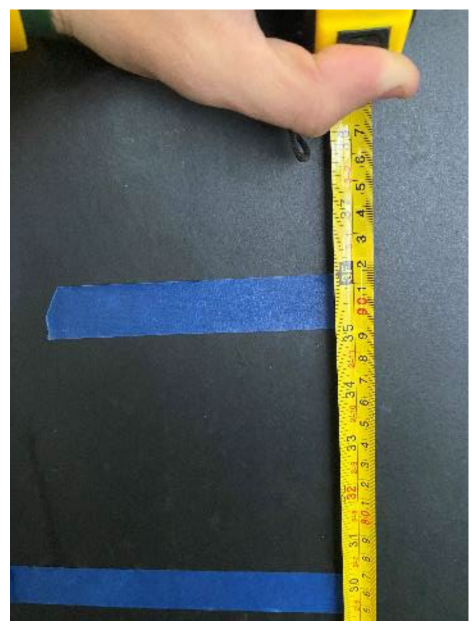


Figure G1.2 – Sowing how place masking tape.

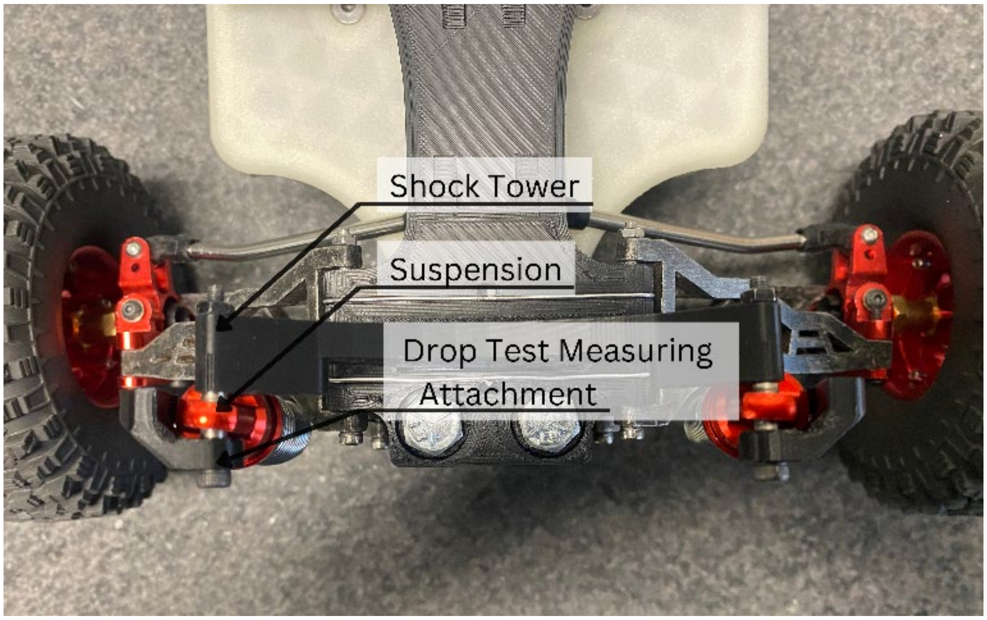


Figure G1.3 – Representation of location of the measuring tool to suspension.

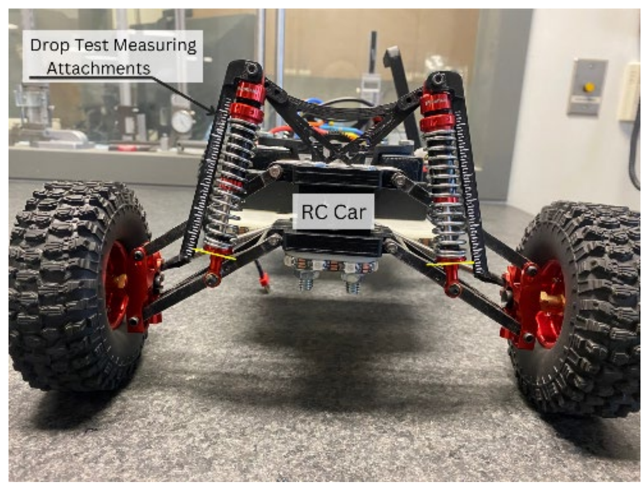


Figure G1.4 – Representation of location of the measuring tool to suspension.

8. Take note of tick mark that lines with the bottom of the spring housing shown in Figure G1.4.
9. Turn on camera.
10. Set too Slow-Motion.
11. Start the slow-motion recording.
12. Bring the vehicle to first tape marking.
13. Position the vehicle to top of the tape marking (at 6 inches) with the front of the vehicle facing the direction of the camera.
14. Drop vehicle, make sure it is as level as possible when dropping to mitigate error.
15. Stop the slow-motion recording.
16. Review footage to acquire a measurement from the 3D printed tools, as each tick mark is 1/16th of an inch.
17. Record data of both front suspensions, to the data form shown in Appendix G1.2.
18. Repeat steps 9 through 17, for each 6-inch increment.
19. Plug recorded values into Excel and created a line graph.

Discussion: The testing procedure was originally written so that the car would be dropped from 3 feet for 5 trails to see how much the springs compressed each time. After further consideration, it was thought that this would give little insight of the vehicle’s suspension. Especially with the vehicle bottoming out at 2 feet. So, the steps of dropping at increments of 6 inches was implemented. Showing the rate of where the springs compress with the height dropped. While also shown where the vehicle failed the requirement of the springs compressing 1 inch.

Deliverables

With the 3D printed suspension measuring tool. The raw data did not need any further process. Resulting the vehicle having a compression of 1 inch at an 18 inch dropped height as shown in Appendix G2.3 and G2.4. Data collection was a success as a multitude of data points were collected to give a good reading of the suspension's capabilities in its dropping limitations. For failures, the vehicle only reached 18 inches before the springs compressed 1 inch. This is 50% less than the requirement stated in 1D-9. Some additional springs could be purchased with increased spring rating or just buy higher quality suspension. An alternative could be to attempt to cut weight as this would lighten the impact force of the vehicle, putting less force on the springs.

Appendix G1.1 – Procedure Checklist

✓ - Collect:
- RC car
- Camera
- Measuring Tape
- Masking Tape
- Printed Data Form

✓ - Construct Testing
✓ - Follow testing procedure stated in Appendix G1
✓ - Deconstruct Testing
✓ - Store Data on Excel
✓ - Process Data

Appendix G1.2 – Data Forms

Drop Test					
Height Dropped (Inches)					
Suspension Compressed (Inches)					

Table G1.1 – Data Form

Appendix G1.3 – Raw Data

Drop Test					
Height Dropped (Inches)	6	12	15	18	21
Suspension Compressed (Inches)	0.33	0.50	0.67	1.00	1.25

Table G1.2 – Raw Data

Appendix G1.4 – Evaluation Sheet

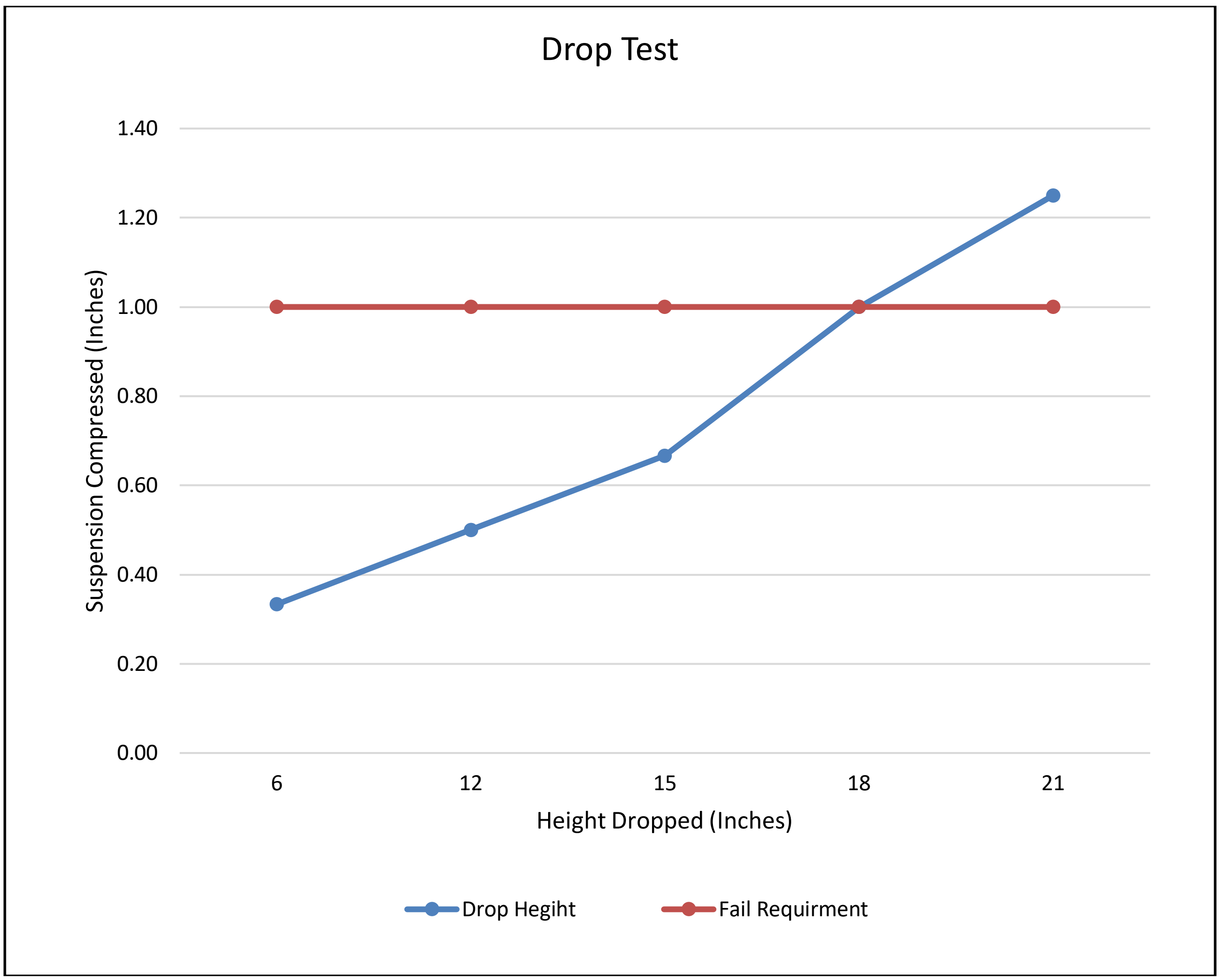
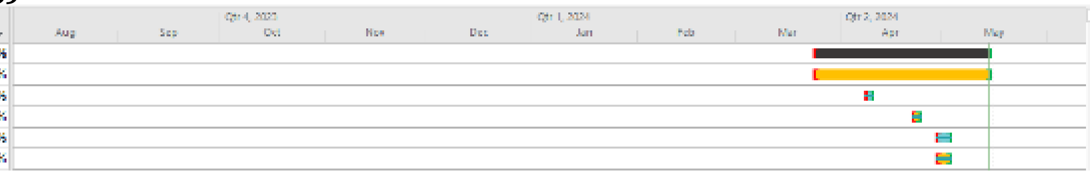


Figure G1.5 – Graphed Results

Appendix G1.5 – Schedule (Testing)

		TASKID	Description	Est. Work	Actual Work	Start	Finish	% Work Complete
61		6	**DEVICE EVALUATION**	**16 hrs**	**18 hrs**	**Sun 3/24/24**	**Wed 5/15/24**	**0%**
62		6a	Test Report	12 hrs	14 hrs	Sun 3/24/24	Wed 5/15/24	0%
63	✓	6b	Drop Test	1 hr	2 hrs	Mon 4/8/24	Wed 4/10/24	100%
64	✓	6c	Turn Radius Test	1 hr	2 hrs	Mon 4/22/24	Wed 4/24/24	100%
65	✓	6d	Wishbone Buckling	1 hr	2 hrs	Mon 4/29/24	Fri 5/3/24	100%
66	✓	6e	Wishbone Deflection	2 hrs	2 hrs	Mon 4/29/24	Fri 5/3/24	100%



Appendix G2.1 Turn Radius

Introduction

This will be testing if the vehicle meets requirement 1D-3. Stating the vehicle must be able to have a turning radius of 10 inches. In this test, the vehicle will need to start with the length of the vehicle lined up to some straight edge or line. Then turn until it meets parallel to the starting line. This will give a turning diameter but the parameter of interest is radius so this value will be cut in half. This diameter will then be measured by finding the distance from the starting line to the outside of the wheel, using a measuring tape. With the increased length of 4 inches to the RC car, some assumptions made in Spring, shown in Appendix A05, were faulty. However, the vehicle can turn an additional 20 degrees than expected. So, the vehicle still has a predicted turn radius of a 10-inch radius. The test will be conducted on April 22nd and should take about an hour as shown in Appendix E and Appendix G2.5.

Method/Approach

Simple tools such as a measuring tape and marking utensils, such as masking tape, will be needed for this test. The masking tape will be used, to make a T-shape. Where the car will be placed, for a starting reference. Lining up the length of the car with one side of the tape and lining the rear with the tape perpendicular to it. The car will then turn its wheels to max, slowing throttling it. Until the car reaches parallel with the starting tape. Then using the measuring tape, the distance from where the car started and reached parallel. The measured distance will be recorded within the printed data form shown in Appendix G2.2. This measurement will be within ¼ of an inch, as any more precision is unnecessary. When operating the steering it can exceed a certain threshold, leading to gears breakage due to steering components binding. To address this, the servo's turning degree is limited, ensuring that the wheels turn just before encountering any binding, thus mitigating any risk of failure. The measurements will then be transferred and stored in Excel. Where the data will convert into a bara-graph.

Required Equipment:

- Measuring Tape
- Masking Tape
- Level Ground
- Excel
- Pencil
- RC car
- Data Form

Test Procedure

The turn radius test is to measure and record the turning capabilities of the device, as this would play a factor in the slalom portion of the competition. This test will also determine if meets requirement 1D-3. The vehicle must be able to turn 180° in a 10-inch radius.

Required Equipment:

- Measuring Tape
- Masking Tape
- Level Ground
- Excel
- RC Car
- Printed Data Form
- Pencil

Time: The test took place April 22nd from 3pm to 5pm directly outside of Hougue Hall. The test will take 10 minutes to constructed and 10 minutes to take back down. The test will take no longer than 30 minutes to collect the necessary data.

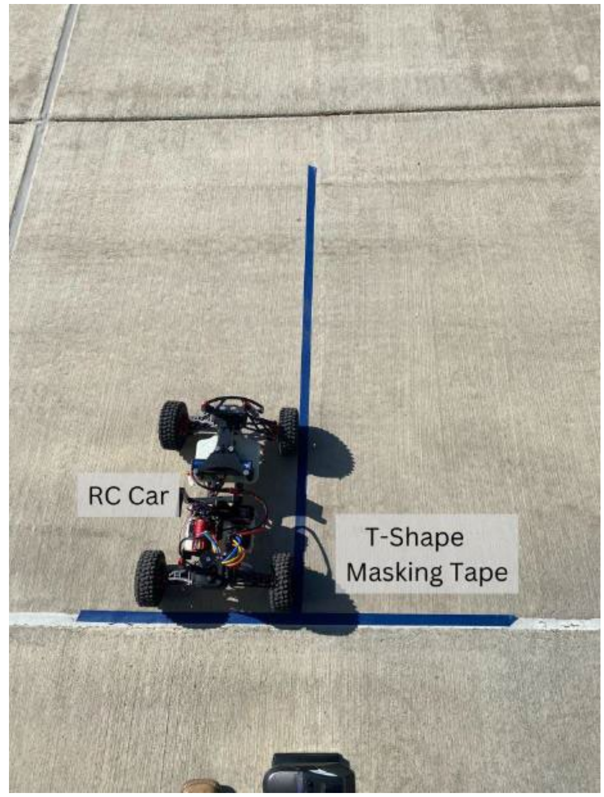


Figure G2.1 – Test Set Up

Place: This test will be conducted in the directly outside the Interdisciplinary Lab of Hogue Hall, as this will give an open with good traction area, as the inside the lab has a smooth surface causing slippage. Another well-traction area with flat a surface may also adequate for this testing.

Risks: This test presents minimal risk factors. The primary concern is potentially overloading the gears in the servo. If the steering exceeds a certain threshold, it could lead to gear breakage due to steering components binding. To address this, the servo's turning degree will be reduced, ensuring that the wheels turn just before encountering any binding, thus mitigating the risk.

Procedure:

1. Gather the necessary equipment.
   - Measuring Tape
   - Masking Tape
   - RC Car
   - Printed Data Form
   - Pencil
2. Use approximately 2 feet of masking tape masking tape to make the horizontally make shown in Figure G2.2

3. Like step 2, use approximately 2 feet of masking tape to make the vertical mark shown in Figure G2.2
    a. Looking for perpendicularity of the tapes, to make a T-shape.
4. Acquire the RC car.
5. Position the right side of the car to the left side of the vertical tape. As shown in Figure G2.1.
6. Turn the wheel to the right at to max.
7. Then throttle the RC car at any throttle until reaching parallel with the vertical tape. As shown in Figure G2.3.
8. Once reaching final destination, measure the distance of the RC car from the vertical tape to the outside of wheel. As shown in Figure G2.3.
9. This will give the turn diameter of the vehicle. Which will be recorded for trail 1 of the right turn.
10. Repeat steps 5-9. Until trails 1-5 are completed for the right turn.
11. Once complete, place the left side of the vehicle to the right side of the tape.
12. Then repeat steps 5-9 for all 5 trails to turning to the left.
13. Once collecting all data divided all turn diameters by two. To give a turn radius.

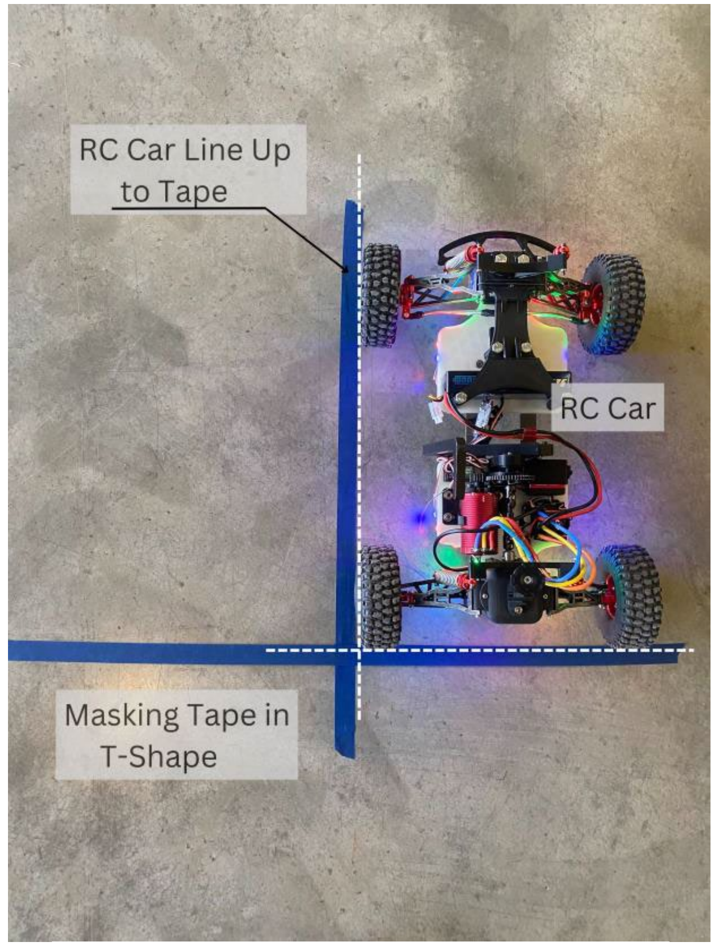


Figure G2.2 – Aline RC Car Along Masking Tape

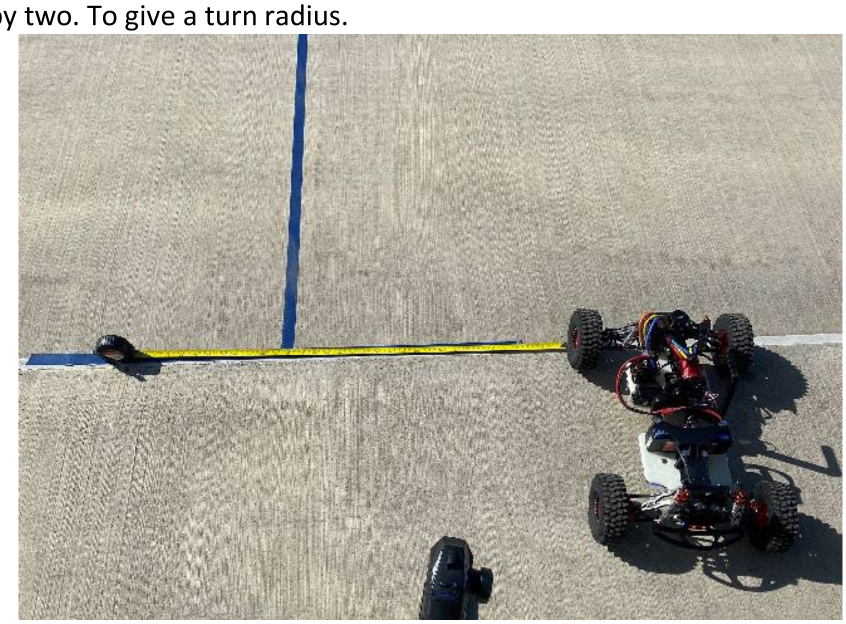


Figure G2.3 – Measuring Turning Diameter

Discussion: The testing was simple, so not much was changed to the procedure. However, the test was originally going to be tested inside as seen in Figure G2.2. But when conducting the test some slipping was noticed on the smooth surface. It was determined that this could potentially pose issues with the accuracy of the testing. To address this the testing was simply brought outside to a surface with more traction. When continuing the testing there was no longer notable slippage.

Deliverables

As shown in Appendix G2.3, the turning diameter resulted in an average of 49.05 inches to the left with 22.20 inches to the right. Each trial was then cut in half to find the turn radius, as this was what was of interest. The results showed that the car has a turning radius of 24.53 inches to the left and 11.10 inches to the right on average. Nearly meeting the 10-inch turn radius to the right but failing to the left. This difference in turn radius is thought to be due to when zeroing the 90° servo it's causing limitations to the side it had to zero from. So, an additional servo is being purchased with a turning degree of 180°. To hopefully result in a steering system that can meet requirement 1D-3 in both directions.

Appendix G2.1 – Procedure Checklist

✓ - Collect:
- RC car
- Measuring Tape
- Masking Tape
- Printed Data Form

✓ - Construct Testing
✓ - Follow testing procedure stated in Appendix G2
✓ - Deconstruct Testing
✓ - Store Data on Excel
✓ - Process Data

Appendix G2.2 – Data Forms

Turn Diameter (Inches)						
Trail	1	2	3	4	5	Average
Left						
Right						

Table G1.1 – Data Form

Appendix G2.3 – Raw Data

Turn Diameter (Inches)						
Trail	1	2	3	4	5	Average
Left	49.50	50.00	46.50	49.75	49.50	49.05
Right	21.50	21.75	23.00	22.50	22.25	22.20

Table G1.2 – Raw Data

Appendix G2.4 – Evaluation Sheet

Turn Radius (Inches)						
Trail	1	2	3	4	5	Average
Left	24.75	25.00	23.25	24.88	24.75	24.53
Right	10.75	10.88	11.50	11.25	11.13	11.10

Table G1.3 – Calculated Turn Radius

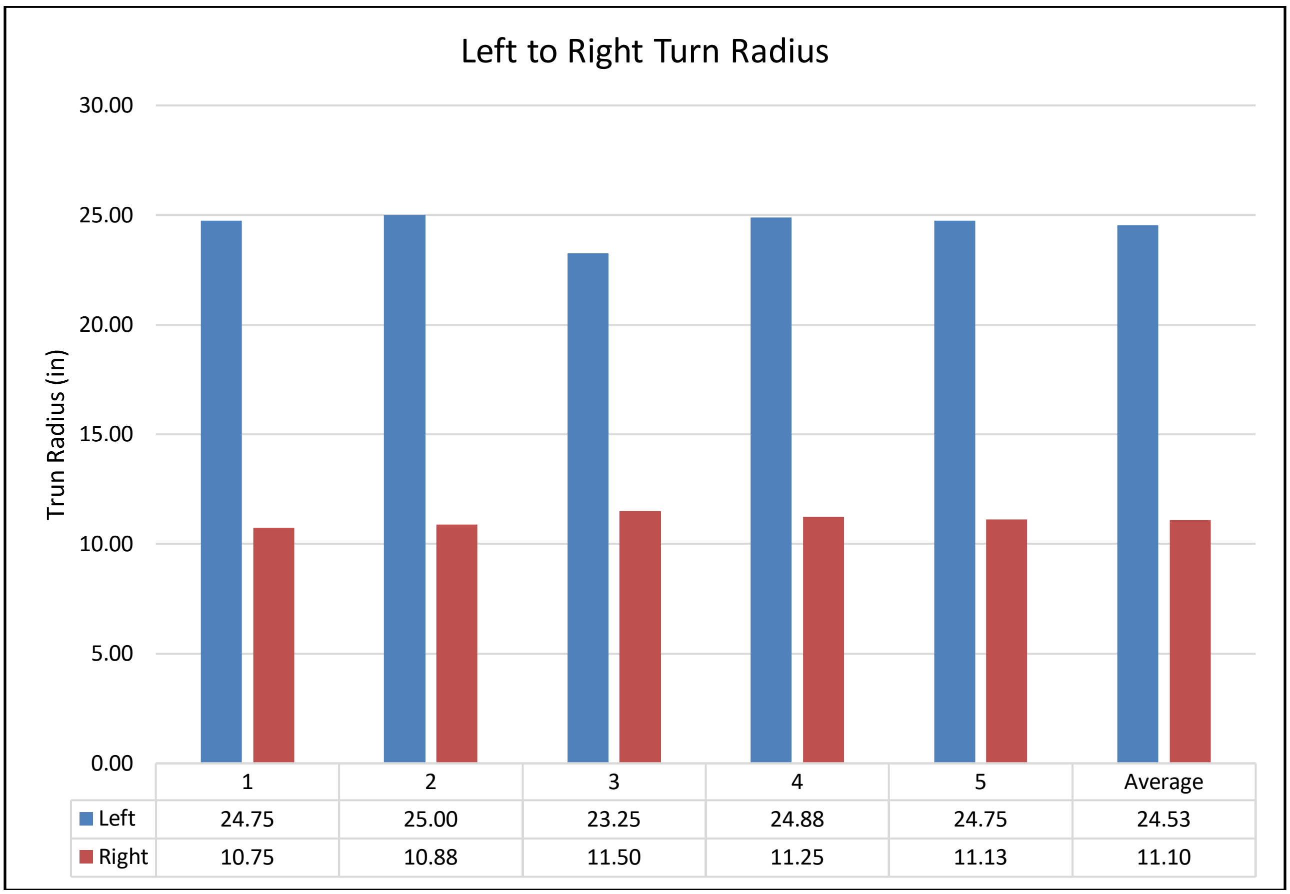
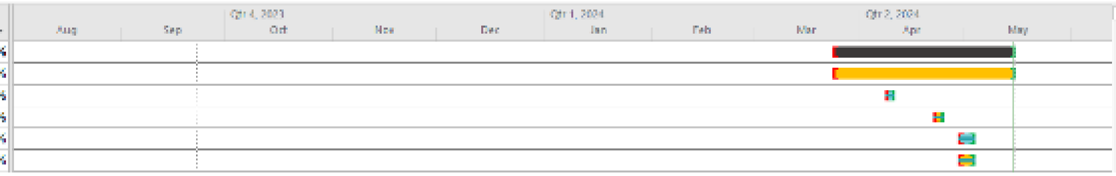


Figure G2.4 – Graphed Results

Appendix G2.5 – Schedule (Testing)

		TASK ID	Description	Est. Work	Actual Work	Start	Finish	% Work Complete
61		6	DEVICE EVALUATION	16 hrs	18 hrs	Sun 3/24/24	Wed 5/15/24	0%
62		6a	Test Report	12 hrs	14 hrs	Sun 3/24/24	Wed 5/15/24	0%
63	✓	6b	Drop Test	1 hr	2 hrs	Mon 4/8/24	Wed 4/10/24	100%
64	✓	6c	Turn Radius Test	1 hr	2 hrs	Mon 4/22/24	Wed 4/24/24	100%
65	✓	6d	Wishbone Buckling	1 hr	2 hrs	Mon 4/29/24	Fri 5/3/24	100%
66	✓	6e	Wishbone Deflection	2 hrs	2 hrs	Mon 4/29/24	Fri 5/3/24	100%



Appendix G3 Wishbone Buckling

Introduction

The wishbone buckling test will be to determine if requirement 1D-11, where the wishbones are not to buckle under a 75 lb. axial load. With load being applied, the parameter of interest will be to see the displacement in distance. Anything above 0.10 inches of displacement will be considered a failure, as the wishbones have surpassed the critical load. Based on the buckling analysis conducted in Appendix A04, the wishbone shouldn't buckle until reaching a 75lb load. An Instron will be used to give a measurement of load in lbs. and a displacement in inches. This will then be extracted into an Excel sheet. The test will be conducted on May 01st and should take about an hour as shown in Appendix E and Appendix G3.5.

Method/Approach

A professor will be needed to login into the Instron program. Along with the connected computer, 3D printed collars, and Instron will also be needed. The collars will be used to ensure that the wishbones don't roll as the ends are rounded. Once the collars have been placed onto either end of the wishbones, testing can begin. The Instron will be lowered until a slight load is applied indicating that the Instron has contacted the wishbones. The load and displacement will then be zeroed. After zeroing, the operator will start the Instron until it meets 0.10 inches, or the load surpasses 75 lbs. Indicating that the part has failed or passed the requirement. The measured load and distance will then be shown within Intron's program. The data will be extracted from the program into an Excel sheet, where it will be stored. The data will be created into line graphs of load over displacement. This measurement will be within 0.0001 of accuracy in displacement and its load.

Required Equipment:

- 3D print Sleeves
- USB Drive
- Wishbones
- Instron
- RC Car

Test Procedure

The wishbone buckling test is to measure and record the amount of force the wishbones can take from an axial load. Impacts from spin-outs and crashes could cause these components to break in competition. Using the Instron, will give a measurement of displacement to force applied to a 0.0001-inch accuracy. Per requirement 1D-11, the wishbones are not to buckle under a 75-pound axial load.

Required Equipment:

- 3D print Sleeves
- USB Drive
- Wishbones
- Instron
- RC Car

Time: The test took place May 1st from 8am to 10am inside the Metallurgy Lab. The test will take 10 minutes to setup. The test will take approximately 45 minutes to collect the necessary data on all 4 wishbones.

Place: This test will be conducted in the Metallurgy Lab within Hogue. This is where the Instron is located and where the testing will be conducted.

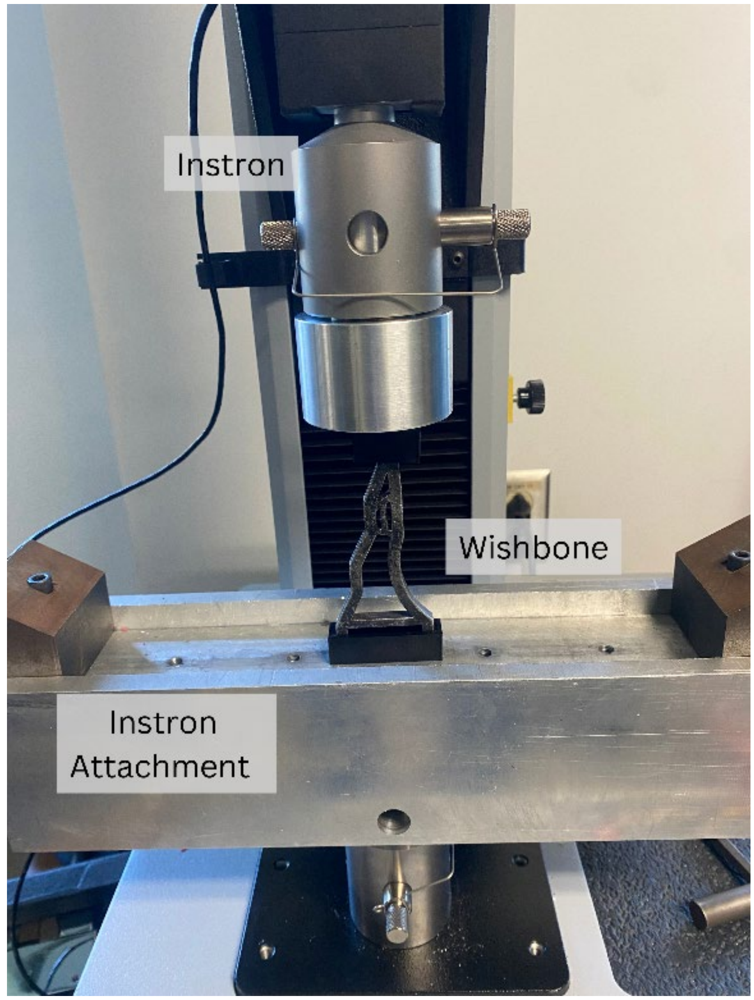


Figure G3.1 – Testing Set Up

Risks: This test does pose a risk with time and cost. The axial loading of the machine could spike quickly damaging the wishbones. This would require for additional outsourcing. Putting the testing schedule back by a week. While also cutting more into budgeting. To mitigate any possible damage the Instron will be stopped at either 0.1 inches of displacement or 75 lb. load.

False reading maybe also be a risk. The Instron measures the displacement of distant for where the machine is zeroed at. So, the machine must be in full contact with the component before proceeding to zero it. Or the displacement to load could become faulty data.

Procedure:

1. Gather the necessary equipment.
    - 3D Printed Sleeves

- USB Drive
- Wishbones
- Instron
- RC Car

2. Place the 3D printed sleeves to the top and bottom of the wishbones, see Figure G3.2. Look to Appendix B 20, 21, and 22 for callors
    a. The sleeves are to keep the wishbones up right, keeping them from rolling from the rounded ends.

Figure G3.2 – Collars on Wishbones

3. Turn on Instron and the connected computer.
4. Open Instron, and sign in.
5. Select compressive axial loading.
6. Once the program and Instron is ready to run, attach the appropriate attachments, seen in Figure G3.1.
7. Make sure the collars are slightly above the wishbones, see Figure G3.3.
    b. This will minimize the risk for unnecessary displacement.
8. Place the wishbones with the collars into Instron, see Figure G3.1.
9. Lower the Instron until a slight load (1-5lbs) has begun to be applied.

a. Showing that the Instron has made contact to the wishbone.
10. On the computer, zero the load and displacement.
11. On the Instron push unlock and then Play.
12. The Instron will begin to lower.
13. Once displacement reaches 0.1 or 75 lbs stop machine.
14. Bring the Instron up.
15. Retrieve the wishbone.
16. Collect and name the wishbone that was tested.
17. Repeat steps 7-14 for all 4 wishbones.
18. Once all wishbones are completed, use personal USB to export all data from the Instron.

Figure G3.3 – Depth of Collar on Wishbone

Discussion: Some issues occurred with how tight the collars were to the wishbones. Where it was hard to tell if the Instron was applying a load to the wishbones or still pushing the collars. So, Figure G3.3 and Step 7 were added to the procedure. It is expected that the data collected for the lower and upper wishbones were faulty. Due to what is expected that the displacement represented is from the movement of the wishbone's collars and not the buckling of the wishbones. Due to this, some retesting was done making sure to follow step 7 of the procedure.

Deliverables

The results of the wishbones are shown below, with their load and displacement before stopping the Instron, shown in Appendix G3.3. As stated above some error within the displacement is expected. Shown in the evaluation sheet Appendix G3.4. The load had a huge spike in load, this is thought to be where the Instron contacted the wishbone. The displacement of when it started to where the spike was made was subtracted to find the true displacement in the wishbone. However, this did make it difficult to know when to stop the Instron in case the wishbones began to buckle. So, the lower rear wishbone was stopped prematurely, as the displacement became greater than 0.10 inches, the failure requirement, but never showed a spike in a load.

Appendix G3.1 – Procedure Checklist

✓ - Collect:

Wishbones
3D Printed Collars
USB

✓ - Grab a professor to login into Instron program.
✓ - Attach the correct Instron attachments.
✓ - Follow testing procedure stated in Appendix G3
✓ - Export data from Instron and save onto personal USB.
✓ - Process Data

Appendix G3.2 – Data Forms

No data forms are necessary, as the Instron records and collects testing results.

Appendix G3.3 – Raw Data

Raw Data							
Lower Front Wishbone		Lower Rear Wishbone		Upper Rear Wishbone		Upper Front Wishbone	
Displacement	Force	Displacement	Force	Displacement	Force	Displacement	Force
(in)	(lbf)	(in)	(lbf)	(in)	(lbf)	(in)	(lbf)
0.0004	2.909	0.0001	0.3785	0.0216	64.4212	0.0002	1.0784
0.0057	23.9034	0.0072	16.6615	0.0216	64.6813	0.0014	4.9445
0.0099	23.6388	0.0139	17.6454	0.0217	65.8598	0.0027	4.5776
0.0145	24.9826	0.0184	18.0218	0.022	71.7056	0.0039	5.9542
0.0179	24.8803	0.0255	30.1989	0.0224	80.0997	0.0048	10.3349
0.0224	26.5106	0.0297	40.6723	0.0228	88.3703	0.0056	19.7756
0.0262	26.0068	0.0405	46.4775	0.0233	91.4659	0.0065	31.3493
0.03	37.9426	0.0442	46.6845	0.0237	85.3537	0.0073	43.4347
0.0333	51.3615	0.0559	50.7793	0.0241	87.6676	0.0085	61.0453
0.037	61.0759	0.0675	53.9312	0.0245	90.0626	0.0097	79.4008
0.0404	57.108	0.078	56.5183	0.025	90.1213	0.0107	94.3402
0.0442	58.3143	0.0834	58.636	0.0254	90.7442	0.0114	107.7835
0.0474	58.8848	0.0884	60.4248	0.0258	92.7767	0.0122	121.461
0.0512	59.9644	0.0967	62.7451	-	-	0.0131	136.6847
0.0545	82.0301	0.0992	63.1234	-	-	0.0138	149.858
0.057	128.1431	0.1009	63.2813	-	-	-	-
0.0584	156.4993	-	-	-	-	-	-

Table G3.1 – Raw Data from Instron

Appendix G3.4 – Evaluation Sheet

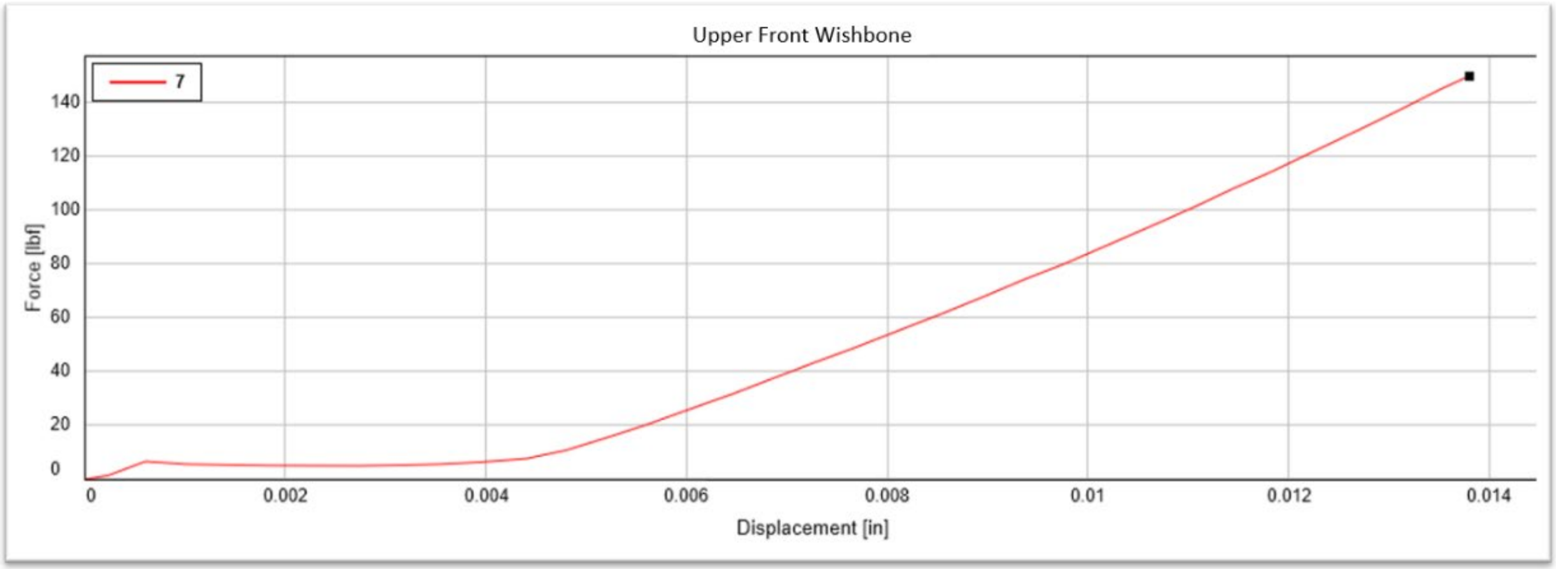


Figure G3 – Lower Front Wishbones Results

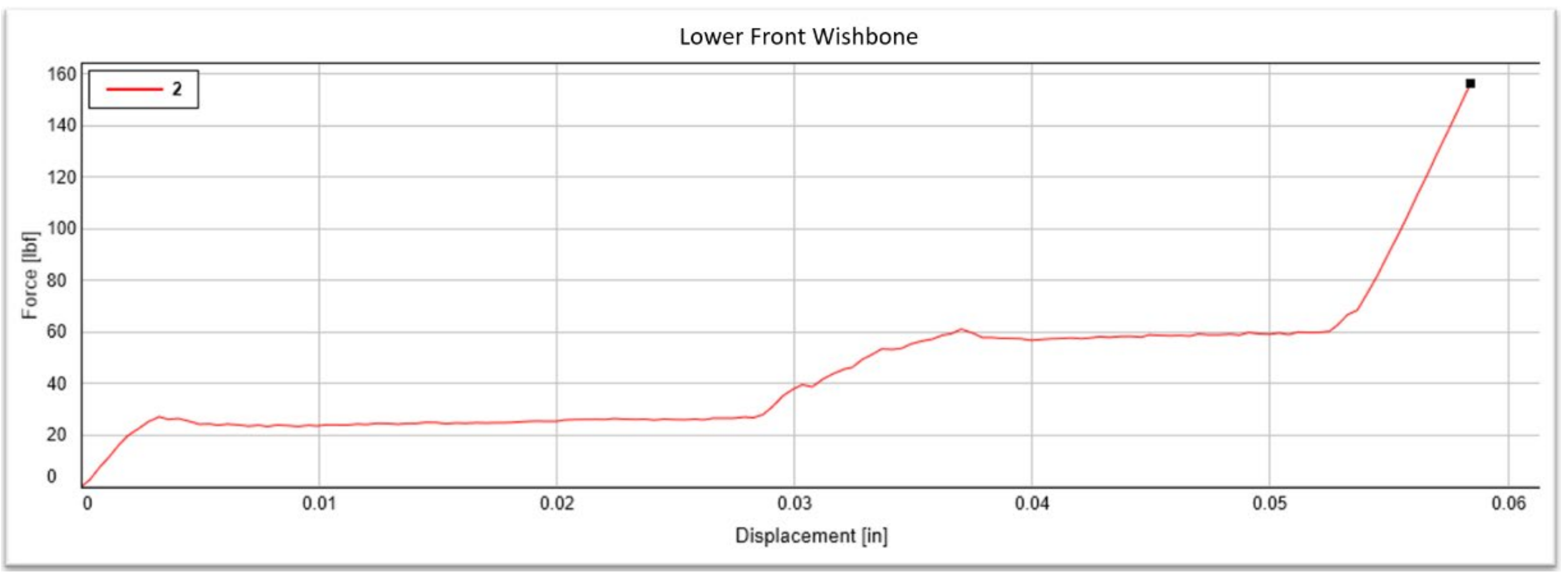


Figure G3 – Lower Front Wishbones Result

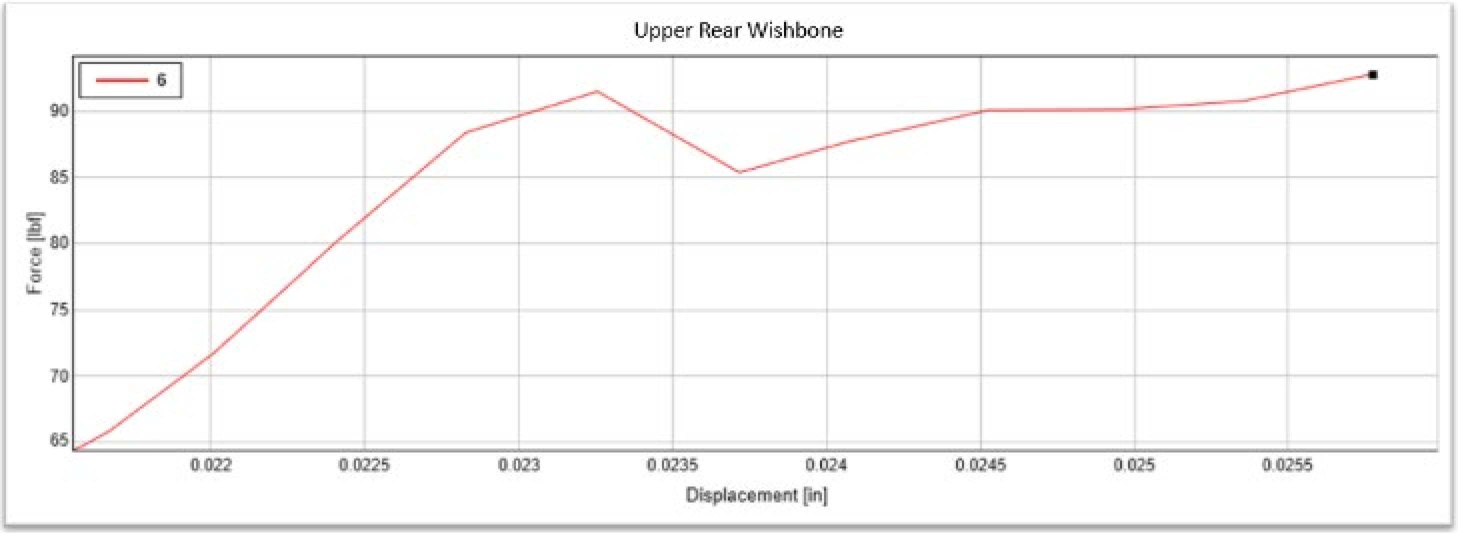


Figure G3 – Upper Rear Wishbones Results

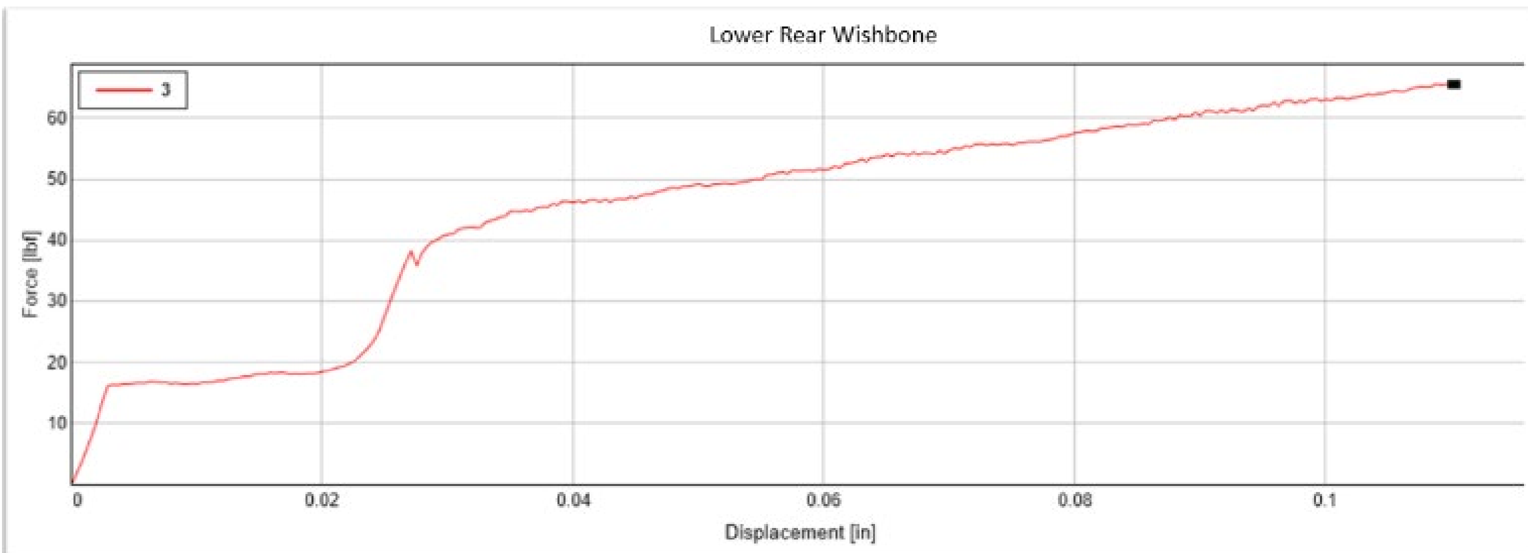
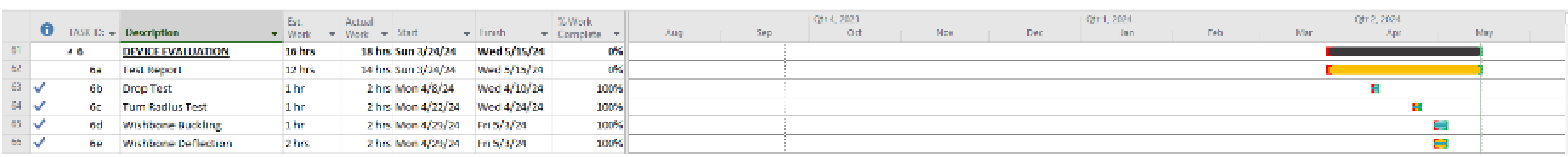


Figure G3 – Lower Rear Wishbones Results

Recalculated Displacement							
Lower Front Wishbone		Lower Rear Wishbone		Upper Rear Wishbone		Upper Front Wishbone	
Displacement (in)	Force (lbf)	Displacement (in)	Force (lbf)	Displacement (in)	Force (lbf)	Displacement (in)	Force (lbf)
0	24.8803	0	30.1989	0.0216	64.4212	0	31.3493
0.0045	26.5106	0.0042	40.6723	0.0216	64.6813	0.0008	43.4347
0.0083	26.0068	0.015	46.4775	0.0217	65.8598	0.002	61.0453
0.0121	37.9426	0.0187	46.6845	0.022	71.7056	0.0032	79.4008
0.0154	51.3615	0.0304	50.7793	0.0224	80.0997	0.0042	94.3402
0.0191	61.0759	0.042	53.9312	0.0228	88.3703	0.0049	107.7835
0.0225	57.108	0.0525	56.5183	0.0233	91.4659	0.0057	121.461
0.0263	58.3143	0.0579	58.636	0.0237	85.3537	0.0066	136.6847
0.0295	58.8848	0.0629	60.4248	0.0241	87.6676	0.0073	149.858
0.0333	59.9644	0.0712	62.7451	0.0245	90.0626	-	-
0.0366	82.0301	0.0737	63.1234	0.025	90.1213	-	-
0.0391	128.1431	0.0754	63.2813	0.0254	90.7442	-	-
0.0405	156.4993	-	-	0.0258	92.7767	-	-

Table G3.2 – Recalculated Displacement

Appendix G3.5 – Schedule (Testing)



TASK ID	Description	Est. Work	Actual Work	Start	Finish	% Work Complete
6	DEVICE EVALUATION	16 hrs	18 hrs	Sun 3/24/24	Wed 5/15/24	0%
6a	Test Report	12 hrs	14 hrs	Sun 3/24/24	Wed 5/15/24	0%
6b	Drop Test	1 hr	2 hrs	Mon 4/8/24	Wed 4/10/24	100%
6c	Turn Radius Test	1 hr	2 hrs	Mon 4/22/24	Wed 4/24/24	100%
6d	Wishbone Buckling	1 hr	2 hrs	Mon 4/29/24	Fri 5/3/24	100%
6e	Wishbone Deflection	2 hrs	2 hrs	Mon 4/29/24	Fri 5/3/24	100%

APPENDIX H – Resume

SKYLER GORDON

MECHANICAL ENGINEERING TECHNOLOGY AT CENTRAL WASHINGTON UNIVERSITY

gordonsk@cwu.edu

skylergordon44.wixsite.com/seniorproject

(509) 393 - 3031

SKILLS

- **SolidWorks** used my senior project and other various projects using **GD&T, CAD-CAM,** and **INTRSON**
- **AutoCAD** involving the production of maps used in bidding and surveying at CWU.
- **3D Printing** used my senior project for prototypes, testing, and manufacturing parts.
- **Microsoft Project** used for constructing a schedule for my senior project while estimating time for tasks.
- Well experienced in **Excel** through developing functions, pivot charts, and graphs.
- Used **Lean Manufacturing** for STEM Gautier production.

EXTRACURRICULAR

- ASME
- Rocketry Club
- Intramural
    - Flag Football
    - Dodge Ball
        - 2023 Champ
- Wrestling Coach

EDUCATION

Central Washington University
Ellensburg, WA – Expected in 06/2024
GPA: 3.443

Bachelor of Science - Mechanical Engineering Technology
Minor - Mathematics

EXPERIENCE

Central Washington University - AutoCAD Technician

Ellensburg, WA • 06/2022 – Current

- Consulted with project managers, design consultants, and sub-contractors to produce and alter utility **AutoCAD** maps on a 40-million-dollar renovation and 79-million-dollar construction project.
- Assisted multiple Project Managers with utility installment, renovation, biddings, and repairs.
- Operated **GNSS** equipment to locate utilities within a 4-inch accuracy.
- Interpreted technical drawings and schematics for 380 acres of CWU property.
- Created technical writing documents for **SOP** purposes.

Gus's Construction Business – General Contractor

Chelan, WA • 06/2015- 09/2023

- Planned and laid out work from blueprints, drawings, and models.
- Collaborated with crew to work as a team for safety and job completion.
- Maintained a variety of hand tools, portable power tools, and standard measuring instruments on daily job assignments.

Assistant/Volunteer Wrestling Coach

Chelan, WA • 06/2019- 09/2023

- Developed **leadership**, **emotional intelligence, time management**, and **conflict resolution** skills.
- Produced practice plans for performance improvement and **team building.**

PROJECTS

RC Baja Competition – Senior Project

(For more details go to https://skylergordon44.wixsite.com/seniorproject)

- Used Mechanics of Material, Statics, and Mechanical Design in analyses for 13 fully engineered customized components.
- Using **SolidWorks**, parts were modeled and then made into drawings applying **GD&T** to all components.
- All components were 3D printed into prototypes using **Ulti Maker Cura**, **Creality**, and **Mesh Mixer**.
- Processes such as laser cutting, milling, drilling, tumbling, and oxidizing were used to create the aluminum components of the projects.
- Predicted Max Speed – 35 mph.
- Predicted Turn Radius – 10 in (Wheels turn at 60°)

NASA Rocket – Rocketry Club

- Reports such as CDR and PDR were written giving information on design, calculations, safety, and material as specified by NASA.
- Used **SolidWorks** to model and make **GD&T** drawings.
- Predicted Apogee – 5079 ft
- Maximum Velocity – 664 ft/s