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RC Baja Steering and Suspension

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By

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ABSTRACT

The engineering objective of this project are designing, manufacturing, and testing the most efficient and strongest possible RC Baja Steering and Suspension system that the engineer could produce with the provided or acquired equipment, and materials.

This was all done successfully over the school year. During the Fall quarter, the RC car was undergoing designing, and in these design processes, mechanics of materials, statics, and dynamics, were used to come up with the most adequate materials and design. Computer aided designed (CAD) models were then created to get a RC Baja CAD assembly. Winter Quarter of the school year was the manufacturing, and construction process of each and individual part for the RC car. Spring quarter of the RC Car was testing of the entire car to confirm whether the car satisfies the requirements stated in the beginning of the quarter or not.

In the suspension components, the front and rear suspension was to have a 2" articulation. Along with this, the car was listed to have a usable 1" of suspension travel front and rear under its own static weight. It was also noted that that the car needed to make a 180 degree turn in a 3.5' radius, and the car completed this in only a 2' radius, almost a 60% tighter turning radius. After all the research was done, the car met all requirements. Each part of the car met or exceeded the initial requirements made by the engineer.

Keywords: RC Baja, Design, Manufacturing, Testing, Steering, Suspension

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1. INTRODUCTION

a. Description

The Central Washington University senior project “Baja Buggy” is a remote control (RC) car that is built for three different competitions, straight line race, slalom race, and Baja course. The competitions consist of competing against other groups in the Mechanical Engineering & Technology program. Groups were made up of two students and the work was broken up evenly between those two students, steering/suspension, and drivetrain/chassis. The chosen branch of work that was chosen to be focused on in this senior project is suspension/steering. As many remote-control cars fail to imitate full scale vehicles, this project took on the problem/challenge to change the perspective on remote control Baja Buggy’s while still maintaining remote control car characteristic and still being durable enough to withstand the forces, stresses, and elements that were introduced to the car.

b. Motivation

This project was chosen because of the motivation to build a Baja Buggy with mechanical components that closely related to a real-life full-scale trophy truck like Baja vehicle.

c. Function Statement

Steering and Suspension components make it possible for the RC Baja Buggy to steer left to right and absorb rough terrain.

d. Requirements

1. Upper suspension control arm has less than 3/16” deflection under 20lbs or the full weight of the car.

2. Lower suspension control arm has less than 3/16” deflection under 20lbs or the full weight of the car.

3. The car must be able to make a full 180 degree turn in a 3.5 ft radius circle or less.

4. Car must be able to withstand 3+ vertical drops from 2 ft with spring compression greater than 1/8” from solid.

5. The shocks must have a usable suspension travel of 1” under a static load of 20lbs.

6. Front upper control arms must be able to withstand a side load of 10lbs staying under the critical buckling load with 0” of bending.

7. Suspension articulation (one wheel up, one wheel down) with a difference of 2” in the rear axle.

8. Steering tie rods will have less than 1/16” deflection while steering servo is turning to the left and right.

9. Shocks do not sag more than ½” under the entire weight of the car while stationary, allowing for 0.59in (15mm) of droop and 0.59in (15mm) of up travel.

10. Bulkhead fasteners must be able to withstand 10lbs of shear force while remaining in the elastic region of stainless steel (<205MPa).

11. The rear trailing arms must have less than 1/16” deflection under a 20lb load.

Teammates Requirements:

1. The car weighs no more than 15 pounds.
2. The car has a minimum top speed of 20 MPH.
3. The car accelerates to 20 MPH in under 5 seconds.
4. The driveshaft deflects no more than 0.1 inches when a 20-pound weight is hung from either end.
5. The rear axle deflects less than 0.2 inches with no shear failure when 30 pounds of force is applied to the center.
6. The chassis deflects a maximum of 0.2 inches when a 25-pound load is applied to the center.
7. The complete car length is no more than 21 inches.
8. The complete car width is no more than 15 inches.
9. The car has a 50/50 (front back) weight distribution with a maximum difference of 5% in either direction.
10. The chassis roll cage deforms at most 0.1 inches vertically when a load of 40 pounds is applied to the top.
11. Motor mount bolts do not enter plastic deformation zone when a 100-pound tensile force is applied to the mount and the chassis.

12. Front bumper attachments do not enter plastic deformation zone when a 300-pound load is applied in a uniform load across the top.
13. The central gear shaft deflects no more than 0.05” when two 25-lb point loads, spaced ½” apart are applied at the center of the shaft.

e. Engineering Merit

Most remote-control Baja Buggy’s are made from plastic, which is not normally stronger than a well-designed RC car made from metals. Developing the steering and suspension with as much aluminum as possible is utilized in conjunction with common engineering methods such as mechanics of materials, 3D CAD modeling via SolidWorks, and mechanical design, the strongest and most ideal design was developed. Using Mechanics of materials, the deflection and shear forces were calculated for the control arms and other suspension components. Mechanical design aided in developing the correct joints that connect the trailing arms, control arms, and any mechanical suspension and steering components. SolidWorks was the main source of part modeling and assembly visualization prior to manufacturing individual parts of the steering and suspension.

f. Scope of Effort

The scope of effort for the Baja Buggy consists of steering and suspension and how those work with the rest of the chassis, and of course the drivetrain. Because every component needs to work in conjunction with each other. Some specific parts and pieces of the steering and suspension that need to work in conjunction with one another are the control arm mounting location, shock tower, trailing arm location and geometry, and of course the steering servo.

g. Success Criteria

To determine ultimate success, the RC Baja Buggy will complete every competition challenge/race and meet the requirements listed previously, as well as the American Society of Mechanical Engineers (ASME) rule book.

h. Stakeholders

The primary stakeholders of the Central Washington University Baja Buggy will be Chayce Williams, and Caden Harris as personal funds will be used to produce and manufacture parts. Since the Central Washington University Mechanical Engineering & Technology is overseen by the Accreditation Board for Engineering and Technology (ABET), ABET is to also a stakeholder.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

Noted before, many RC cars fail to imitate full scale Baja buggies, due to the size restrictions of RC cars. In this analysis section of the report, the minimum size before failure of each component will be calculated and a safety factor will be applied. Each component will have different sets of calculations, and each set of calculations will likely have a different method for calculating the forces that are acting on the components.

b. Design Description

There have been several different design ideas up until the analysis section, having independent suspension front and rear, or just having front independent suspension and a solid rear axle. And in terms of the suspension, rear wheel steer has been considered, and of course front wheel steer. But for this analysis, front independent and solid rear axle suspension will be used because that is the chosen method of suspension for the RC car, along with front wheel steer with a common method of a steering servo working in accordance with tie rods. The front independent suspension will consist of a lower and upper control arm connected to a spindle at each wheel. The servo that controls the steering will be pushing and pulling the tie rods whichever direction the user wants to go and the tie rods will also connect to the spindle at each wheel. The rear suspension will have a trailing arm, upper long arm, and of course solid rear axle which houses the differential.

c. Benchmark

Mentioned before, many brands fail to produce 1/10th scale RC cars that imitate full scale vehicles. This does not mean that the functionality of the vehicles that are produced are not good. In fact, the functionality of such cars produced by common brands Axial, and Traxxas function extraordinarily. The RC car world is expected to make upwards of $516.18 million by the year 2027 and this is because of the high benchmark that many common RC car brands have created. High end RC cars from these brands can drive for hundreds of miles without failure, so the standard is high. This car produced by the CWU engineers has the standard and goal of reaching maximum performance of successfully meeting all listed requirements and going above and beyond to aim for the benchmark set by major RC car brands while still imitating full scale Baja like trophy trucks.

d. Performance Predictions

This produced RC car will easily be able to drive down sets of stairs while still allowing the user to remain in control. While also operating the vehicle down the stairs, the deflection in the front lower control arms does not exceed 1/16” deflection, along with the rear trailing arms, as those are the components taking most of the forces of driving the vehicle down the stairs. Another failure point is the shock eyelets, and trailing arms joints where the arms make a connection with the frame and rear wheel spindle/hub. The car is exposed to many elements, those being, water, rocks, dirt, mud, and rocks, there will be no failure when the car is exposed to these elements. The steering tie rods will have some deflection when encountering rough terrain and steering, but some deflection/bending will be allowed so there is absorption, the maximum allowable deflection is 1/16”. But again, there will be no failure/fracture or deflection values higher than what is allowed.

e. Description of Analysis

In the analysis, all the forces that act on the car are accounted for. Each component of the steering and suspension that plays a vital role in the functionality of the car has had its strength calculated when it’s exposed to certain climates and terrains. Using mechanics of materials, the stress, strain, deflection, and shear forces are calculated to play a role in what material is used, what method of manufacturing is used, and how big or small a component needs to be to withstand the forces it encounters. Mechanics of materials is the backbone of the RC Baja steering and suspension as it lays out the groundwork for finding out the maximums and minimums of each component.

f. Scope of Testing and Evaluation

Based off the assumptions the requirements needed to be met, and the supplied analysis are an accurate assumption that can prove that the desired design works. And then in the testing stages it is yet again proved to be true. This means that the RC car poses no worry to the engineers that it will succeed in the competition because of the calculations that were made.

g. Analysis

i. Analysis 1 – Trailing Arm Deflection

The called-out requirement for deflection in the trailing arm needed to be less than 1/16”. This is calculated using the material properties of 6061 aluminum in accordance with mechanics of materials. After the calculations had been done, the deflection came out to be only 0.0021 cm. This is with the car being evaluated at under a 20lb load distributed evenly over 4 wheels as a static load. All these calculations are using two different sets of cross sections to ensure accuracy and then allowing the engineer to choose which size to use. Using both cross sectional design parameters (0.675”, 0.5”) and (0.5”, 0.35”) all calculations resulted in a deflection much less than what is required.

This analysis was done with the use of FBD’s, summing the forces in the y-axis, and using beam deflection to calculate deflection. And this intern gave the required/usable sizes of the trailing arm. Please refer to Appendix A01 for copies of calculations.

ii. Analysis 2 – Minimum Steering Angle

As stated in the requirement section, the RC Baja must be able to make a 180^{o} turn in a 3 ½ foot radius or less. This requirement aides in making sure the Baja Buggy will have more than enough turning capabilities and steering angle to complete the slalom race with ease. The design parameter proves that the chosen wheelbase can make the 180 degrees turn in less than 3.5’ feet with 25.46 degrees turning angle with a tolerance of plus or minus 3”.

In analysis 2, the equation for the minimum turning angle is used [$\theta = \tan^{-1}(\frac{Wheelbase}{Radius})$]. Since the maximum wheelbase is used in this calculation, the turning angle will only get smaller, which means better, because the smaller the turning angle to complete the turn, the better. Please refer to appendix A02 for handwritten sketches and calculations.

iii. Analysis 3 – Deflection and Stress of Front Lower Control Arm

As per the requirements, the front lower control arm had to be less than 3/16". Methods of statics, and mechanics of materials have been used to calculate the maximum deflection of the front lower control arm. The maximum deflection was 0.111" under a 20lb force originating from the shock. The design parameter that the deflection calculations determined was the cross-sectional area of the lower control arm to resist deflection to be less than 3/16" while remaining in the elastic region.

The maximum stress that is running through the lower control arm is calculated and the total is equal to 69.28psi. And because the max deflection is found the strain is calculated to then solve for stress that the material can withstand, the total was equal to 277.5psi with the chosen dimensions. Please refer to Appendix AO3 for green sheets.

iv. Analysis 4 – Critical Load of Upper Long Arms

The tie rod must be able to withstand an axial load of 10lbs. Buckling calculations are done to solve for the critical load that the chosen tie rod dimensions can withstand. The slenderness ratio, and transition slenderness ration is calculated to determine if Euler's or Johnsons methods should be chosen to calculate the critical load. The design parameter was that the cross-sectional area determined that the 8mm diameter rod could withstand the 10lb column load being 5" (Plus or minus 0.050") long with no buckling/failure.

Johnson's method of buckling is determined to be the most accurate method to be used as it is a short beam. The maximum critical load that the 8mm diameter shaft that is 5" long is a total of 3048lbs. This is of course if the load is perfectly axially loaded. Please refer to Appendix AO4 for green sheets.

v. Analysis 5 – Critical Buckling Load of Upper Control Arms

In analysis 5, the critical buckling force is calculated to ensure that the chosen design meets the stated requirement 1d.6 that the upper control arm can withstand a 10lb side load while moving and remaining under the critical load of the material. Beam buckling equations are used, and to do that the slenderness ration must be determined to decide whether Euler's or Johnsons method should be used. Johnson's method is used in this case.

The design parameter of cross-sectional area of ¼" x 2 ½" supplies a strength that withstands a 10lb force very easily with no worry of buckling. The cross-sectional area of ¼" x 2 ½" gives a maximum buckling force of 7521lb before buckling occurs. Stress is also found to highlight that there is nowhere near enough stress in the member for it to fail.

vi. Analysis 6 – Maximum Shear Stress of Shoulder Screws

In Analysis 6, the maximum shear stress that the shoulder screws can withstand is calculated. The requirement 1d.10 was that it needed to be able to withstand the 10lb side loads that the upper and lower control arms take on while remaining in the elastic region (<205MPa <29732psi). The shoulder screws are used to fasten the upper and lower control arms to the bulkhead. The shear capacity is calculated from using ($\tau = \frac{0.6(70{,}000psi)(0.012in^2)}{1.5}$). The safety factor being 1.5, the maximum tensile stress 70,000psi, and the cross-sectional area being $0.012in^2$.

The design parameter of the shoulder screws is the diameter/radius of the screw (1/8”). Having the design parameter of a total diameter of 1/8”, a total amount of shear that the screws can withstand is 336lbs and the total amount of stress is 27,379psi. Please refer to Appendix A06 for detailed green sheets of calculations.

vii. Analysis 7 – Shock Spring Rate

In Analysis 7, the shock spring rate at which the car needs if it weighs 20lbs is calculated. The requirement 1d.7 is such that the RC Baja must have 1” of usable suspension travel to be successful. Along with the requirement 1d.9 that states that the sock must not sag more than ½ inch under static load. These requirements are met by calculating the maximum speed that it will undergo when being dropped 2 feet in the drop test, along with the maximum force that it will undergo doing so. Using this force that it undergoes, the spring rate can be calculated by using k=F/D, K = spring rate F = force, and D = usable travel.

The design parameter of having 30mm of usable suspension travel and a total force of 44.25N being exerted on each wheel constitutes a spring rate of 2.95 N/mm or 16.85 lb/in. This is the minimum shock spring rate that can be used to meet the stated requirements previously. In depth green sheet calculations can be found in Appendix A07 – Shock Spring Rate as documentation.

viii. Analysis 8 – Shock Tower Thickness

In Analysis 8, the minimum shock tower thickness is calculated that can withstand the forces acting on the mounting location of the front suspension. The requirement of 1d.4 states that the car must be able to withstand 3+ consecutive drops from 2ft in the air. This means that for the car to handle that kind of scenario the shock tower must be able to handle the forces that are induced on the shock, because whatever forces are acting on the shock, the forces are also acting on the shock tower, as well as the lower control arm (mounting locations of the shock). The total amount of force that acts on the front wheels individually when dropped is calculated and that force is used to calculate the minimum thickness. This is done by using the equation $\tau = F/A$, A = base x height, F = force, τ = shear strength.

The design parameter of deciding a desired cross-sectional area of a height = 1/16" tall gives an output of having a thickness of 0.0112in or 0.000285m. This is a very small cross-sectional area and what it does is highlights just how strong 6061 alum is and that the desired size of the shock tower is free to be chosen. Detailed calculations on green sheets can be found in Appendix A08 for reference. Documentation of the shock tower can be found in Appendix B08 – Shock Tower.

ix. Analysis 9 – Rear Shock Tower Minimum Thickness

The requirement for the rear shock tower was that it needed to withstand 20lb static load and be able to withstand 3+ consecutive drops as stated in requirement 1d.4 and 1d.5. The rear shock tower must be able to withstand the forces that will be acting on the car from these requirements, and for the car to work in conjunction with one another the rear shock tower must have a minimum thickness to not fail.

The minimum thickness of the rear shock tower is found by using cantilever beam deflection formulas and a maximum amount of deflection of 1/16" under a 20lb load. The materials 6061, ABS, and PLA were analyzed in Appendix A09 – Minimum Rear Shock Tower Thickness as documentation, and the analysis showed that with the cross-sectional area of a base that equals ¼", a design parameter of 0.085mm height is given for 6061, a height equal to 0.1212" for ABS, and 0.056" for PLA. The design parameter proves that the desired design is plenty strong enough to withstand the forces without surpassing 1/16" deflection.

x. Analysis 10 – Bearing Stress on Mounting Tabs

Analysis 10 works in correlation with requirement 1d.4, and 1d.7. The rear trailing arms must have mounting locations such that the suspension geometry is at peak performance. If mounting locations are not correct suspension will bind up and the 1” in articulation between wheels will not be achieved in the rear axle. And because the car will also be dropped from 2ft 3+ times the car must also be able to withstand 20+ pound loads.

In Appendix A10, analysis 10 can be found, in that analysis the bearing stress of the tabs are calculated such that with an 1/8” hole and a 20lb force with a safety factor of 5, bearing stress must not exceed the yielding point of the materials that can be chosen from, 6061, PLA, and ABS. With the design parameter of an 1/8” hole for shoulder screws a maximum stress if calculated to be 6400psi acting on the tab. 6400psi exceeds the yield point of ABS so ABS is not chosen, and therefore 6061 and PLA are acceptable materials to be chosen from. Documentation of detailed calculations can be found in Appendix A10 – Bearing Stress of Mounting Tabs.

xi. Analysis 11 – Rear Shock Tower Support (Deflection)

Analysis 11 corresponds with the requirement 1D.4. In order to pick up the car for each of the tests in the testing stages, the rear shock tower support must be a good point of picking up the car with one hand. Also, it is assumed that the rear shock tower will also be used for repeated use while picking up and putting down the car. If this analysis was not done, then the 3D printed rear shock tower support risks being broken.

In the analysis, the rear shock tower was simplified by using beam analysis of the top section of the part. The max deflection of the beam is then calculated while it is under a load of 20lbs with a safety factor of 3. In order to do this though, a design parameter that being the cross-sectional area must be 1” wide, and 0.25” tall to achieve success and make sure the 3D printed part does not break. The cross-sectional design parameter outputs a max deflection of 0.062” under a 60lb load with also only 240PSI of stress which also remains far under the yield point of PLA. Documentation of detailed calculations can be found in Appendix A11 – Rear Shock Tower Support (Deflection) as well as a shop drawing in Appendix B13 – CLW-20-009 – Rear Shock Tower Support.

xii. Analysis 12 – Steering Tie Rod Critical Load

In analysis 12, the steering tie rod critical road is calculated. The tie rod must be able to withstand a total force of 77.16lbs because that is what the chosen servo is rated for. Analysis 12 works alongside requirement 1d.8, this requirement states that the steering tie rods must not have more than 1/16" of deflection while the car is turning.

In the analysis, the critical load must be calculated, and to do so, the slenderness ratio, and transitional slenderness ratio must be calculated. And a design parameter chosen to be the diameter of 1/8" 6061 aluminum. 1/8" diameter is the desired size of the tie rods cross-section. With the needed length and 1/8" diameter rod, Eulers equation is used because the slenderness ratio came out to be larger than the transitional slenderness ratio. So, with a design parameter of an 1/8" diameter, the critical load that the tie rod can handle without bending is 84.1lbs. The design parameter of having an 1/8" diameter suits requirement 1d.8. Documentation of detailed green sheets can be found in Appendix A12 – Steering Tie Rod Critical Load.

h. Device: Parts, Shapes, and Conformation

Various methods of mechanical design, statics, 3D modeling, and manufacturing have been applied to the RC Baja and all the different methods give a different outcome/result as not all methods can be applied to certain applications. With mechanics of materials, stress, strain, shear, deflection, and buckling were used often to calculate failure limits. Using statics, the reaction forces at certain points was very helpful, but to do this the summation of the forces and moments had to be found.

When the stated calculations above were done, a safety factor between 1.5-2 was applied, a higher safety factor associating with a more complex loading and potential for abuse. For example, the front independent suspension lower arms have a higher safety factor (2) associated with them because of the importance of absorbing rough terrain without failure. And due to the front lower arms getting loaded with all different kinds of forces that may not be accounted for in the calculations. Although when considering the rear trailing arm components of the car a lower safety factor (0.5) can be used, not because the trailing arm is considered less important, but because the trailing arm forces can be predicted more accurately. Simultaneously, the material properties of 6061 aluminum being so strong in the chosen cross-sectional area it is very unlikely that the trailing arm would fail from normal use.

Tolerances are applied to all components of the vehicle because of the importance of the final product being readily usable. Some components that take more abuse have a tighter allowable tolerance (-0.050") due to the functionality of the vehicle relying heavily on certain components like the front suspension arms and steering tie rods, along with the shock mounting locations. If tolerances are loose (+0.050") and not accurate there is more movement and "slop" in the car that yet again means, there is far more room for failure and more discrepancies in the prior calculations. Tighter tolerances are used on components that require them to work together with another component so that they work together as intended with high levels of functionality. Tighter tolerance values are anything less than 0.050" and looser tolerance values are to be considered more than 0.050".

The ergonomics of the shape and overall feel mean that all sharp edges and burrs are removed before each part is deemed completed. This is a safety adherence to limit any possibility of the user of the RC car getting cut or poked when physically handling the vehicle.

Overall shape and size of all components are chosen in favor of making sure none of the moving parts like the rear trailing arm, upper long arms, front control arms bind or become hard to move. This is a common issue with much of the car market in the world today. With this RC car it is proven that even at a small scale, suspension kinematics/geometry work smooth and in conjunction with one another.

i. Device Assembly

This RC Baja car has been built for success on the Baja course, which means lots of rough terrain. The philosophy behind doing well on the Baja course means that it does well in the two other competitions (drag race, and slalom). For that to happen, the vehicle must have a wide stance, and long wheelbase to insure complete control by the user. This is followed up by strong, and well manufactured components and of course looking appealing while performing. If the vehicle track width is small, the car is susceptible to roll over, and if the car has as short wheelbase, the car is prone to getting pushed/bounced around by rough terrain.

j. Technical Risk Analysis

With producing the solution to a RC car that imitates a real-life full-scale Baja vehicle while still maintaining functionality there are risks involved in the design. The wider the vehicle gets, the higher likelihood of failure to steering components like the tie rod, as well as suspension components like the upper and lower control arms. The same thing goes for making it longer, however there are still tradeoffs. With the vehicle being bigger it allows for larger and stronger components to be introduced to the vehicle, which can easily make up for the higher stresses that are introduced.

k. Failure Mode Analysis

Finding suspectable failure points in the design was paramount. These failure points are located where the most moving parts are at or high stress locations. These components and locations are ones that are going to be taking forces from the car either being crashed or undergoing extreme rough terrain sending dynamic stress through suspension components and even mounting points. When the vehicle undergoes repeated use, it is expected that suspension joints, and moving components will wear out quicker than if it were not used of course. So, the forces from being crashed and used over rough terrain are considered in the design process to ensure components wear out as slow as possible.

l. Operation Limits and Safety

Of course, nothing is unbreakable, so there must be limits to the RC car. And safety is the most important thing when considering the user could be injured or hurt if they do not handle the RC car in a safe manner. All screws, bolts and fasteners must be checked every 5 hours of operation and only after 1 hour of operation when first being used. This will ensure that all components are properly fastened. On the vehicle, all sharp edges have been taken out and replaced with a fillet or chamfer to ensure that no sharp edges are exposed to the point that they could cut any individual.

3. METHODS & CONSTRUCTION

a. Methods

Most of the RC Baja Steering and Suspension is manufactured and assembled at Central Washington University, where the machine shop, 3D printers, and CAD software are utilized. Most of the sheet metal designed parts are sent out to SendCutSend. By doing so the absolute best accuracy is achieved, SendCutSend utilizes a waterjet to cut each and individual part that was sent in the form of a DXF, the DXF serves as a cutting path for the waterjet. This is done because CWU does not have the proper resources to manufacture sheet metal parts with accuracy and confidence by the engineer. This will later be discussed in Section 3a.i. Once the parts are received from SendCutSend, holes are drilled and tapped if needed, and any small adjustments are then made.

All 3D printing takes place at CWU as there are several printers that can print and are very capable at reaching high accuracy. Models are created via SolidWorks and converted to an STL to then be 3D printed. This process is very quick compared to other forms of prototyping.

All assembly of the RC Baja takes place at CWU, and any changes that need to be made are done at CWU and are not sent out to utilize other resources. At CWU the manufacturing process's goal is to have the motto of "measure twice, cut once", so that no errors are made causing time and resources to go to waste.

i. Process Decisions

There are many different manufacturing methods that could have been chosen from to complete the RC Baja. However, some are better than others for certain tasks at hand. Durability, fit/finish, manufacturability, cost, and confidence in design, and analysis are the main contributors to deciding what method is used and what materials are chosen.

For example, in Appendix F03 – Decision Matrix – Front Suspension Components, a matrix is constructed to weigh the pros and cons of manufacturing the front suspension components via water jet and SendCutSend, 3D printing at CWU, and casted parts in the foundry. The matrix ranks each of these manufacturing methods from the best to worst. Casting each component in the foundry at CWU comes in at last place due to the engineer having low confidence in the accuracy of the pores of aluminum, the molds of each of the components, and the overall fit and finish. Casting tends to lead to poor consistencies with dimensions that are chosen by the engineer prior and the overall fit and finish not being desirable. Casting also tends to be weaker than if something were to be machined or cut.

In Appendix F03, choosing 3D printing to manufacture the front suspension components are ranked second. This is because of the characteristics that 3D printing has, easily manufactured, very low cost due to 3D printers already being provided, and the overall fit and finish. Though, the overall fit and finish isn't rated at the top, this is because prints at times can fail, this can be from changes in temperature of the bed, temperature changes of the extruder, and improper settings such as infill, wall thickness, and even thermal expansion. There are many variables that play a role in a successful print. 3D printing does allow for many parts to be produced and test fitted, and used, so if something were to not fit, a change can easily be made in the CAD model then the updated model could then be re-printed to correct specs. This is the glory of 3D printing. 3D printing is still a main source of ensuring the proper design is chosen even though 3D printing is not chosen for the final product. 3D printing is used to print the front suspension components prior to the final product being created to make sure the proper dimensions are chosen. 3D printing simply does not offer the needed strength that the components need to withstand and that is the major downfall of why it was not chosen.

Utilizing SendCutSend and the waterjet and laser services that is offered is the chosen method of manufacturing for the final product of the front suspension components. This is because by using waterjet or laser cutting the overall strength of the components remains the very high (Appendix A03), the ease of manufacturing is very convenient, and the highest level of precision and accuracy that is met is the best of all the methods that are considered. SendCutSend also promises a one-week turnaround on all parts, this is of course because of the ease to manufacture said parts. Each of the parts can also be anodized and checked for burs and sharp edges prior to being sent back to CWU. Analysis 2g.iii is also based off utilizing SendCutSend and 6061 aluminum, so confidence in the dimensions, and overall design is also higher than the others because of that. The only con of SendCutSend is the added cost of the service, the budget for these services is roughly $400 (Appendix D, Table d.1) for all sheet metal components of the car, not just the front suspension components.

In Appendix F03 – Decision Matrix – Rear Trailing Arm, the manufacturing method of the rear trailing arm is chosen from also ranking the methods just like how the method of manufacturing was chosen for the front suspension. Except this time because of the overall size, SendCutSend is not utilized. SendCutSend was considered, but because of the added thickness of the rear trailing arm being over 0.5" and a rectangular shape the need for complex CNC equipment like the waterjet or laser is not needed. And the added cost of SendCutSend is not worth the service that is provided for this task.

3D printing was also an option for the rear trailing arm, but again much like the front suspension, 3D printing does not offer a strong enough solution to the forces that are introduced. And because the trailing arms are such important pieces to the car to function, no chances of the trailing arm failing can be taken.

From constructing the decision matrix, it is clear that the manufacturing method of machining at the CWU machine shop is the best possible option for manufacturing the rear trailing arm. The engineer has high confidence in achieving desired dimensions, accuracy of tolerances, and the overall fit and finish. Machining will take the longest, but because the material and services being provided by CWU are free and confidence is high, machining is chosen. Only a total quantity of two of the trailing arms are needed as well, so several duplicates are not needed. The machining that takes place consists of using a vertical milling machines, drill presses, calipers, taps, sanding, and even deburring.

Decision matrix in Appendix F04 – Material Choice (Front Lower Control Arms) compares the different materials that can be chosen from to insure no failure. Failure is deflection being higher values than what is required in section 1d.2, fracture, warping, and imperfections. Material selections can also determine manufacturing methods also even though this decision matrix primarily focuses on the kind of material that is chosen for the lower control arm. Steel, aluminum, and PLA are compared, and aluminum is ultimately chosen as the best material to be used for the front lower control arms. Aluminum is much lighter than steel, and it is also much stronger than PLA that has been 3D printed. And because of this, the analysis in Appendix A03 – Deflection in the Lower Control Arm, aluminum is used at the material, so the young modulus is used, along with the yield point being considered. Steel may be stronger than aluminum and less susceptible to failure than aluminum, but steel weighs far too much to be used on an RC car, and it is far too hard to work with when it comes to manufacturing small parts in the machine shop for the engineer to have confidence in the final product. And like mentioned before, 3D printing anything no matter the material chosen, PLA, or even ABS, the needed strength for large components like the front lower control arm cannot be met. On other parts that do not take on as much stress as the rear trailing arm, PLA may be a great option, but in this case it is not. Cost of the aluminum does however cost more than steel, and this is reflected in the material selection matrix, and like mentioned before PLA would be the cheapest option but the least reliable.

In addition to what has already been discussed about 3D printing. The engineer's partner Caden Harris has received a personal 3D printer. Caden is then also able to produce high end and high accuracy parts outside of CWU and by doing so a more efficient process is achieved, as 3D printing can only take place at CWU Monday-Friday and only during certain hours. It should also be noted that, new for Winter quarter 2024 appointments must be made to use the 3D printers at CWU. This results in the engineer having a bit harder access to the printers whereas before the engineer could just walk in and use the printers whenever the engineer wanted to. By Caden Harris having a personal 3D printer, parts can now be produced much easier and faster compared to Fall quarter.

During weeks 5 through 8, the RC Baja car suspension and steering components have been completely completed and are being assembled onto the car. Some minor modifications to the chassis that the engineer Caden Harris made had to be done during this time to ensure that the rear shock tower, front suspension, and steering tie rods had the correct clearance to aid in no binding of the components, and correct fastening to the chassis. The overall design of the rear trailing arm tabs has not changed, however, the mounting location has changed, instead of being mounted to the bottom of the chassis, the rear trailing arms and tabs are now mounted to the top of the chassis (underside). Doing this makes sure that when the cars suspension fully compresses and bottoms out the chassis does not bottom out and hit the ground. If the chassis was hitting the ground excessive damage, and interference with the ground would pose a danger to destructiveness.

b. Construction

i. Description

The entirety of the RC Baja is constructed in sections, each section being set up as a subassembly in SolidWorks prior to manufacturing and construction for ease of understanding. The front suspension is constructed first, along with the rear suspension shortly following. There are approximately 12 parts that are sent to SendCutSend, there is also approximately 10 parts that are bought out through distributors, and all the fasteners are either sourced from

CWU or McMaster Carr. All of which make up all the car. Subassembly parts are put together first, and then followed by smaller easier parts to make. Some parts however were machined and assembled at CWU.

ii. Drawing Tree, Drawing ID's

A drawing tree covers the main assembly, subassemblies (normally more than 1), and all parts that make up the subassemblies. The drawing tree for the RC Baja can be found in Appendix B01. CLW-10-001 is the main assembly, CLW-10-002 is the subassembly of the front suspension, CLW-10-004 is the rear shock tower subassembly, and CLW-10-005 is the subassembly for the steering servo and mount. From there, all subassemblies are broken down into individual parts as the drawing tree goes further down the page. Subassemblies are organized in a fashion such that all the parts are created at the same time and assembled at the same time.

iii. Parts

The entire front suspension assembly (CLW-10-002) is sent to SendCutSend to be waterjet cut. And once they are cut and sent back to CWU, holes are drilled and tapped at the CWU machine shop. The rear suspension shock tower assembly (CLW-10-004) is constructed in a similar way compared to the front suspension assembly, except a added 3D printed support (CLW-20-009) that sits between the two shock tower pieces. The 3D printed piece is built locally at the CWU computer lab 3D printers, the specific 3D printer that is used is the Ender 3 V2. The rear trailing arm piece (CLW-20-001) of the rear suspension is machined locally at the CWU machine shop, drill press operations, milling operations, and deburring take place to construct the rear trailing arm. Heim joints (CLW-55-001) and locking nuts (CLW-50-001) work in conjunction with the machined rear trailing arm.

Going into winter quarter there was very few new parts that needed to be designed or modified except for small spacers needing to be 3D printed for the front shocks to be mounted with no interference. Another small part that needed to be modified and redesigned to ensure proper function was the steering servo mount. The chassis provided just enough room for everything to fit and be mounted to, and because of this, the steering servo had to be modified slightly so that the holes for the mounting screws/bolts fit in a more desirable location.

iv. Manufacturing Issues

Potential risks that are associated with the Baja RC car are that parts sent to SendCutSend not being done in a timely fashion or added delays for shipping. SendCutSend is chosen due to the lack of experience and training on the vertical milling machines and CNC machines to create the sheet metal parts. Another risk is that the entire car is mostly made from aluminum, so for that to happen, the car is going to weigh more than most cars, this will add extra weight and force that is induced on suspension and steering parts. The added risk that comes with this is that with the added stress, shocks, steering knuckles, uprights, and all fasteners have a higher risk of breaking at the event of a crash or abuse.

v. Discussion of Assembly

Since all the ¼” sheet metal designed parts were manufactured first via SendCutSend those parts were the first parts to be finished and assembled. These parts make up the entire front suspension sub-assembly (CLW-10-002), and because of this, the car’s front suspension was assembled by week 4 and shortly following the front suspension, the steering (CLW-10-006) was then assembled now that the steering knuckles (CLW-55-002) could then be mounted to the upper (CLW-20-003) and lower (CLW-20-002) control arms. The hardest part of assembling the steering assembly was getting the correct alignment of the tie rods and tie rod ends so that the front wheels were mirroring each other. To make sure the correct alignment was achieved minor adjustments were made several times till the desired settings were achieved.

Mounting holes did need to be drilled into the chassis to provide mounting location for such parts. By week 5, the entire front end of the car was complete, the shocks had also been mounted as well. Following the front suspension, and steering, the rear shock tower (CLW-10-004) assembly was next to be assembled onto the RC Baja chassis. Once the rear shock tower was mounted, the rear trailing arm tabs (CLW-20-010) were welded to the chassis, following the tabs being welded to the chassis, the rear trailing arms (CLW-20-001) were assembled and fastened to the tabs, which then allowed for the rear shocks to be mounted to the RC Baja. After this point of the project, the majority of all steering and suspension components had been assembled and mounted to the chassis, the servo was mounted, and the car was completely done in terms of the suspension of steering. The list of parts that are made under each of the subassemblies (CLW-10-XXX) can be found in Appendix B01, and along with the that, the drawings for each of the stated parts can also be found in Appendix B below the drawing tree.

Once the car had been assembled, comparing it to the RC Baja benchmark that was set at the beginning of the year, the car had come out weighing more than its benchmark, but also being much stronger and more durable to impacts, and high stresses under abuse while it being driven. Much of the cars that are set at benchmark for this car are made from plastic and end up breaking after short amounts of use the way that it is typically marketed to be used.

4. TESTING

a. Introduction

All, and if not, most of the stated requirements stated in Section 1d need to be tested to figure out if the RC Baja meets or exceeds them. Since the overall function of the RC Baja needs to be tested, testing scenarios that consider the steering, suspension kinematics, and overall offroad performance will be tested, and these testing scenarios directly correlate to Section 1.d Requirements.

It is predicted that even though analysis have been done to predict when failure happens or what design parameters to choose form that best fit the need, that failure may still happen, because the analysis that have been done do not consider each scenario that could happen. Each of the tests that will later be discussed in section 4.b will be formed around each requirement. Some double dipping and testing multiple requirements in one test.

The engineer still has confidence that the car will function very well in each of the tests knowing the materials selected, design for the suspension, fasteners chosen, and chosen mounting locations of each individual part.

b. Method/Approach

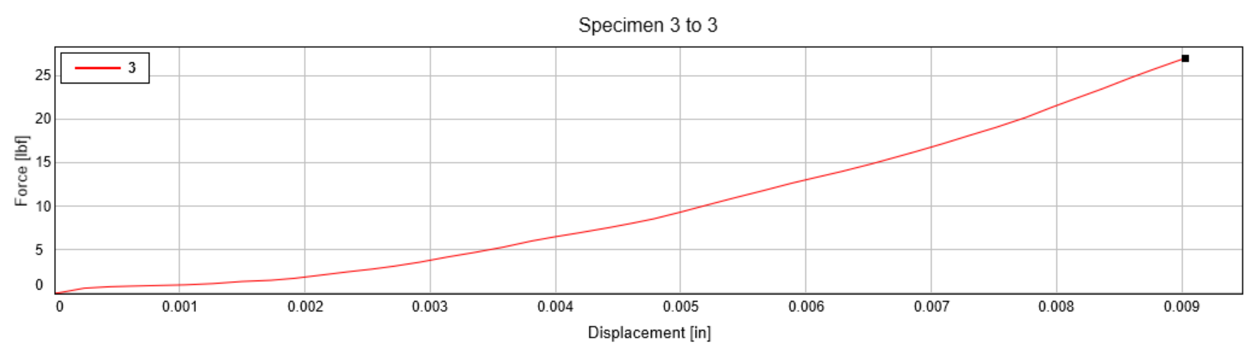
The suspension components will undergo drop testing, suspension articulation, and static loading measurements to see if the car meets requirements 1d.4, 1d.5, 1d.7, and 1d.9. Drop testing will consist of 3+ vertical drops of the car from 2ft off the ground. And measurements with calipers will be taken to the shock shaft to measure usable shock travel under a static loading.

Compressive forces will also be induced onto the upper and lower control arms to measure maximum deflection. This will be done via a compression force being applied to each of the arms and the deflection being measured on the Instron machine. A load of 20lbs will be applied and the upper and lower control arms will not have more than 3/16" of an inch deflection as stated in requirements section 1d.1, 1d.2, and 1d.6. All forces will be axially loaded. Special mounting hardware/jig will be developed to fasten each of the parts to the Intron machine for testing.

An overall offroad test will also be done outdoors with rocks, roots, drops, and even jumps to make sure the RC Baja can take on the challenges of the three competitions (slalom, drag race, and Baja). Photos and video will also be taken to visualize moving parts in slow-motion. This test will happen in the Eastern Washington Beverly OHV park and sand dunes. It is expected that high temperatures (80+ Degrees F) will be induced at this time on the car, the sand will put extra force on every single steering and suspension component and even the drivetrain and chassis. This is an actual offroad park for full size vehicles, but the environment is perfect to push the RC cars abilities to the max. This will ensure that the RC car exceeds the stated requirements and needs that the three competitions call for. What better way to test a Baja RC car than to put it in a Baja like environment.

The rear trailing arms are tested via the Instron machine, the Instron machine will supply a compressive load to test how much deflection (displacement) the rear trailing arm has when the load is applied at the center and when the ends are simply supported. After the test had been done, the Instron "Bluehill" testing app provided a force vs displacement graph to show the engineer just how the rear trailing arm did in the test and how it compares to the requirement that is listed in section 1.d. Initial analysis was done to get a benchmark and an idea of what the initial design parameters needed to be, i.e. cross sectional area, material, design, this can be found in Appendix A01. However, the calculations do not consider the slot in the rear trailing arm that allows for the rear shocks to be mounted to the trailing arm. Therefore, the initial calculation was showing that there would be 0.0008" of deflection under roughly a 5lb load.

However, after beginning the testing process of the rear trailing arm, it was clear that it was hard to get the Instron to show only a 5lb load and give accurate deflection values, so the static load was increased to 20 lbs. The Instron was showing upwards of 0.008" of deflection after a 20lb load was exerted shown in figure 4b.1 below. Even though this value is very low, and is not concerning at all, the deflection rating is still higher than the calculated. Much higher than would be expected even at a 20lb load. But the value is still very small to the point that the yield stress of the aluminum is so high that a deflection value of 0.008" is not bad.

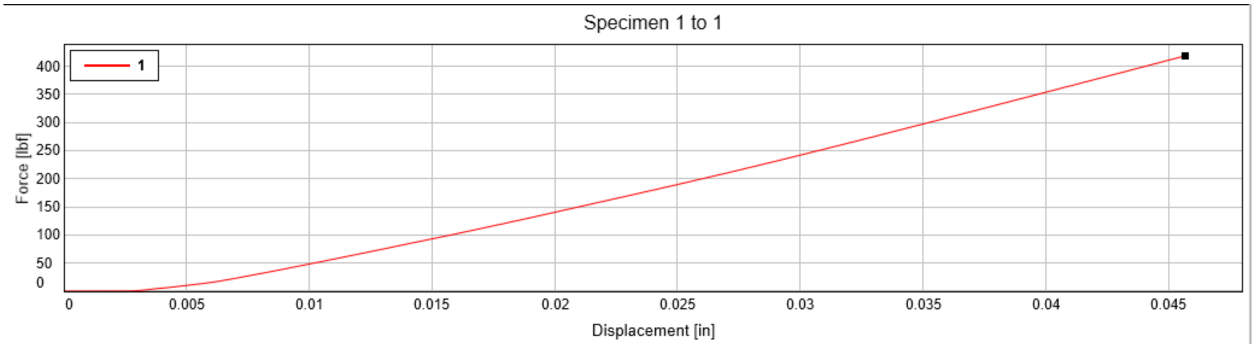


Results

	Maximum Force [lbf]	Displacement at Maximum Force [in]	Maximum Displacement [in]	Force at Break (Standard) [lbf]	Specimen text input	Specimen note
1	418.74	0.05	0.05	418.74	Chassis Trial #1	
2	35.99	0.01	0.01	35.99	Chassis Trial #1	
3	26.97	0.01	0.01	26.97	Chassis Trial #1	

Figure 4b.1: Rear trailing arm displacement vs force graph data (20lbs)

In requirement 1d.11 it was stated that the rear trailing arm had to have less than 1/16" of deflection to be considered suitable for use by the engineer, anything more than 1/16" of deflection and the rear trailing arm would need redesigning. The engineer decided to load the rear trailing arm with a much higher force than 20lbs. A total force of roughly 400lbs was exerted onto the rear trailing arm as a point load, and while it was simply supported at both ends. The total deflection at 400lbs was only 0.045" shown in figure 4b.1 below, which is still lower than 1/16”. By supplying a 400lb load to the rear trailing arm, it gave the engineer an idea just how strong the rear trailing arm was with the slot because the initial calculation did not account for the slot. By doing so, the engineer has complete confidence that the rear trailing arm is suitable and passes all requirement to be used on the RC Baja rear suspension.



Results

	Maximum Force [lbf]	Displacement at Maximum Force [in]	Maximum Displacement [in]	Force at Break (Standard) [lbf]	Specimen text input	Specimen note
1	418.74	0.05	0.05	418.74	Chassis Trial #1	

Figure 4b.2: Rear trailing arm displacement vs force graph data (400lbs)

After all the testing had been done on the rear trailing arm, it can be assumed that because in the initial analysis (calculation) the trailing arm slot was not accounted for, the deflection values are going to be a lot lower than what they were. This can be changed so that the calculated deflection value is more correct by using a smaller inertia value for the cross-sectional area so that the slot is accounted for. Or FEA software can be used to simulate the rear trailing arm deflection accurately.

There were no issues with the trailing arm test other than having to increase the load onto the trailing arm to get adequate data that could be measured on the force Vs. displacement graphs shown above. If the load was kept at 5 lb. the amount of data points that would be useful to the engineer would be slim.

The following test after the rear trailing arm had been tested on the Instron was the steering angle and turning radius test. The method of how the turning angle was tested was such that a protractor is used to measure the angle at which the car was able to turn left to right. The problem with method of testing was that at times it was hard to keep the paper from sliding/ripping when letting the RC car turn left to right. The front tire side walls when turning left to right tend to roll over and cause the car to lean excessively. The issue of the side wall rolling over was combated by acquiring tire inserts that were stiffer than the original foam that came inside the tires originally. This modification allows for the car to turn more effectively. The car also turns further to the right than it does to the left. This issue was combated by changing the orientation of the connecting rods on the steering assembly, fastening the tie rods on the underside of the steering arms made the turning better, but the suspension now when cycling binds up when the car cycles through its travel.

There were no issues with the procedure of the test, so the overall structure and method of getting the data from the steering angle and radius test was not difficult to acquire. The only part that was moderately difficult to get accurate was the turning angle test with the piece of paper that was used, so there was a 1–2-degree tolerance when measuring for the angle that the car could turn at.

c. Test Process

The entire testing process was to happen in a controlled environment where specific data is required to be given and where the overall use of the car is analyzed. Per the requirement section 1.d, there are requirements relating to the turning radius, suspension articulation, usable suspension travel, suspension sag, and drop testing where a flat consistent surface is required. This flat surface will require the engineer to find an area such as the loading dock of Hogue ETSC building, or the Fluke lab of Hogue ETSC building. For drop testing a high-end camera to video record data will be needed to acquire slow-motion video of the spring compression and articulation. A small team of 2 people are required to get this data during the drop test, one person to video, one person to drop the car. All deflection data on each individual part is gathered in the materials room 211 of Hogue ETSC building where all testing equipment for testing stress, deflection, deformation are located. The Instron machine is reserved for compression and tension testing to get deflection data. Safety glasses, testing fixtures a long with Excel data sheets are used to complete the successful testing of deflections of each part.

d. Deliverables

All data that is recorded will be taken note in Microsoft Excel, and this engineering report in Appendix G Testing Report. Data such as photos, video will also be shown on the engineer’s website that follows the RC Baja Steering and Suspension. In order for the engineer to had completed the proper testing and testing reports, proper scheduling of each test had to be done, any jigs that needed to be done before testing were completed/scheduled the first 2-3 weeks of Spring quarter. The proper scheduling of spring quarter which is when the testing takes part in is located in this engineering report in Appendix E -Schedule. All data that is acquired from the testing of the RC Baja is then taken and Force Vs. Deflection graphs are constructed, stress curves are also acquired, Force Vs Deflection of a spring, and the data that makes it possible to construct such graphs are made in Excel and then shown in the testing report, as well as the engineers website. Acquiring this data confirms that the car functions the way that it was designed to, and that the car is deemed a successful complete RC car at the end of Spring quarter. Some data from some of the tests like the rear trailing arm had a graph displayed straight from Bluehill elements app where the compressive forces and deflection values are given from the Instron. This made it easy for the engineer to take screen shot of the data and use the force vs. displacement graph shown above.

5. BUDGET

a. Parts

During Fall quarter, parts CLW-20-002 to CLW-20-007 referenced in Appendix C table C.1 Parts Table, are designed via SolidWorks in house but are then sent to SendCutSend to manufacture, however holes are drilled later. Parts CLW-20-001 to CLW-20-007 are all front-end suspension components of the RC Baja, that consist of the upper and lower control arms, bulkhead pieces, and shock tower. The cost of the parts in Appendix C table C.1 Parts List will be the bulk of the cost when it comes to parts, the projected budget for all SendCutSend parts is $400 according to Appendix D table D.1.

Lower cost parts such as the fasteners still rack up a high cost due to the amount of them that are needed for all the sheet metal parts. The added cost mostly comes from the shoulder screws (CLW-50-002) with a quantity of 15 according to Appendix C Table C.2 Fasteners. The added cost is due to the high prices that McMaster Carr has set for product. The shoulder head screws are vital for the upper and lower control arms to be fastened to the bulkhead and for them to work properly, so the added performance come with a price.

Most bought parts that have not been designed by the engineer are bought from Amazon to avoid added shipping costs because the engineer has Amazon Prime as well as promotions and reliability of the vendor to ship put parts in a timely fashion. Parts CLW-55-001 is the only exception of parts that are not bought from Amazon. CLW-55-001 is a heim join that is bought from McMaster Carr referenced in Appendix C Table C.3 Bought Parts. The heim joint is used for both the ends of the rear trailing arm. CLW-55-002 the Tamiya C-Hub works in conjunction with the front suspension and was very hard to find the correct configuration. Along with CLW-55-003 it was also hard to find. With the aid of Amazon, the parts are still able to be found and ordered in the exact configuration.

During the 1st and 2nd week of Winter quarter (January 3rd – January 15th) all parts are completed or are in the process of being manufactured. All SendCutSend parts are ordered at the same time to get a better price, and parts form Amazon is ordered as they are needed due to shipping and parts being in stock is relatively consistent and reliable.

By the beginning of Spring quarter all parts had been manufactured and already installed onto the car. In fact, the car was completely operational by week 8 of Winter quarter. Over the time of assembly and revisions there were some problems that did come up, however. The rear shocks did not fit into the original trailing arm slots, and if the slots were made wider to accommodate for the larger rear shock eyelet, the wall thickness of the slot would have been way to small/thin. So, 2 new rear trailing arms were manufactured so that the wall thinness of the slot was not an issue for the rear trailing arms. This resulted no added cost to the engineer as all material that was used was from the machine shop stock room, which is donated material for MET senior students to use on projects. The new trailing arms did however add to the amount of time that was spent in the machine shop, but not by much because the rear trailing arm is an easily producible part to manufacture.

During the entire Spring period of the project there was no added cost from parts produced by the engineer. Therefore, no added funding was required, and the project remained well under budget from where it last was at the end of winter quarter, which was when all the manufacturing and construction took place.

For parts that underwent failure, or problems during manufacturing, implantations were set into place so that the same mistake did not happen again. Special notation when calling out a drill and tap was made for the engineer to go slow, and be patient while cutting threads, as well as double checking drills were the correct size for what the tap called for. If the engineer were to go back and redesign the components that required threads to be cut into the material, all holes would have been water jet cut from SendCutSet so that the engineer didn't have to spend so much time drilling holes. At SendCutSend the holes would have been cut out via water jet and the holes would still be way more than accurate enough to be able to tap. This would have saved time and money for the engineer.

b. Outsourcing

Parts CLW-20-002 to CLW-20-007 found in Appendix C Table C.1 Parts Table are outsourced to SendCutSend for laser cutting. These parts like mentioned before are the upper and lower control arms, bulkhead pieces, and shock tower, overall, the entire front suspension. The budget for all SendCutSend parts being outsourced is $400 found from Appendix D Table D.1 Total Budget. SendCutSend will also perform deburring, and anodizing services for all parts. These parts cannot be confidently laser cut or plasma cut with accuracy with Central Washingtons Equipment, this is another reason for outsourcing these parts.

All the way through the end of Winter quarter and Spring quarter, no other outsourcing was required so that the RC car would be completed. All outsourcing took place at the very end of Fall or at the very beginning in the Winter.

c. Labor

Labor costs for the engineer are $35 per hour. The estimated amount of time of working in the machine shop is budgeted to be 125 hours for winter quarter found in Appendix D Table D.1. Much of the parts sent out for manufacturing need holes being drilled and tapped, along with fine tuning and small adjustments to ensure a desired fit. All 125 hrs of work will take place in the machine shop and this consists of work on lathes, mills, and CNCs, as well as assembly.

By the end of the Winter quarter and going into Spring quarter, the engineer did not need all 125 hours to produce and manufacture all RC car components and parts. Most of the front suspension components that otherwise would have taken the engineer a long time to produce were sent to SentCutSend for cheap, and quick water jet cutting. The engineer has roughly used a total of 65 hours in labor to complete the RC car for the entire year. This labor accounts for all assembling, manufacturing, and testing time.

d. Estimated Total Project Cost

The estimated total cost of the RC Baja Steering and Suspension is $5775 (Appendix D Table D.2 Total Budget Cost). Most of the total budgeted costs comes from the $35/hr for 125 total hours during winter quarter (Appendix D Table D.1 Budget). Material, purchased parts, fasteners, and all SendCutSend parts make up for exactly $1,000 of the budget (Appendix D Table D.1 Total Budget). All budget line items already have an included 8%-10% increase in price to account for taxes and shipping costs if needed. The total price including tax and shipping are included in Appendix C and D tables C.1, C.2, C.3, and D.1.

e. Funding Source

The cost of this project is funded by the engineers Chayce Williams and Caden Harris. These are personal funds for the engineers, so the best most cost-effective methods are used.

f. Winter Updates

5a. There have been no major updates and or cost in the manufacturing processes of the RC Baja during winter quarter. There have been some small mistakes consisting of a broken tap while threading holes for the front shock tower, and rear trailing arms. But the tap was able to be removed and or the part was redone with left over raw stock to complete the part. No major changes to the overall design of the RC Baja have been done, the overall design during Fall quarter was well thought out so that all the suspension and steering components worked in conjunction with one another. However, there have been some minor sanding/grinding to edges of parts to achieve proper fitment with no rubbing or interference.
5b. During the winter quarter all parts have been sent to SendCutSend and received and then completed. This process came out to be under budget and the timeline of these parts have arrived well before when they were required to be received. Within the first 2 weeks of the Winter quarter beginning, the needed ¼" aluminum parts have been received.

5c. As of Winter quarter, the total budget allocated towards manual labor is plenty enough to complete all tasks that will result in a functioning car. At the time of when all the sheet metal parts have been completed, only 10% of the budgeted time has been used to complete the parts. And most of the budget has been used by drilling, tapping, milling, and assembling. After week 5 of the winter quarter, majority of parts that are left to complete are only 3D printing small parts which take up little to no time compared to machining.

g. Spring Updates

5a. As of the beginning of the Spring quarter of the project, no extra funding has been required by the engineer to purchase any new parts or manufacture any large components. Therefore, no changes to the budget, and the cost that the engineer has paid for has remained well under budget. The only mistakes that the engineer made was purchasing buyout parts that are not licensed by real world companies, because of that licensing the cost of the components goes up drastically. The engineer could have cut down on cost by buying cheaper coil-over shocks, the amount of performance and settings the shocks are able to provide do not provide enough increase in performance to make the extra added cost worth it. The engineer also would have been better off by purchasing tires/wheels that came with stiffer foam inserts, the foam inserts that the wheels/tires that the engineered purchased were not up to standard for peak performance when testing the turning radius. The actual cost for tax and shipping was very close to the predicted amount in the fall and winter. These costs were tied into the total allocated budget and were less than $100 for all shipping and taxes for the components, the actual costs were roughly $87. Majority of shipping was free because most parts were purchases on Amazon and the engineer has Amazon prime which gives free shipping in most cases.

5b. There is no added labor for manufacturing components of the RC car, in fact there is 11 total hours of testing time used from the allocated time to this project as seen in Appendix E, Section 6. This time is added into the total hours that is used to complete the entirety of the project as of week 8 during the Spring quarter. A total of 125 hours has been allocated to this project, and roughly 65 hours of labor has been used to manufacture, and test. This does not include the amount of time used from Fall quarter to design.

5d. Some of the mistakes done while testing consisted of not being able to acquire data sheets in Excel from the BlueHill Elements app while doing the deflection vs force test with the rear trailing arm. The engineer was only able to extract graphs and no tables. As well as the engineer not having proper login credentials to perform testing without an instructor on the Instron. This all-added time to the testing process that was not accounted for. Accounting for the extra time and setting up time periods with instructors to perform Instron testing has since been taken note of for any future testing on the Instron to mitigate deficiencies. With these mistakes it added to the amount of time that was allocated to the project for testing which means it costed the engineer more money for less efficient work. This has since been corrected and will not happen again going into the future for all testing that has to do with the Instron.

The engineer had to replace small buyout components such as tie rod ends because of failures during top speed testing done by the other engineer Caden Harris. Caden crashed the car a couple times during testing and resulted in 1 broken tire rod and tie rod end. This crash happens by hitting a curb at roughly 20 mph in a congested area. This costed the engineer more money to install a new tie rod and tie rod end as well as time. To mitigate the risk of this happening again, the engineer opted for larger tie rod ends, and larger diameter tie rods. These changes would only result in about a $10 increase in cost.

6. SCHEDULE

a. Design

Fall: During the Fall quarter the design of the Baja buggy began along with the proposal. The motivation behind scheduling was staying ahead on tasks and due dates, and this taught the engineer to become more efficient. Proposal/Report Writing, Analysis, and Documentation sections of the schedule (Appendix E) took place during the Fall Quarter. During the time there were no major scheduling issues that changed the outcome of the Baja buggy. The analysis that took place took less time than anticipated, and the proposal and report writing section took longer than anticipated. Drawings took the same amount of time as the predicted time. The engineer stayed ahead on tasks by working consecutive 10–14-hour days. A detailed schedule can be found in Appendix E, fall tasks are labeled as sections 1, 2 and 3.

b. Construction

Fall: The construction of the Baja buggy began during the Winter quarter. During the time of Fall quarter, it was anticipated to utilize SendCutSend and send out as much sheet metal designed parts to be water jet and laser cut. This aided in allowing for more time during the schedule to be allocated for other tasks that required more time on task to finish. Some parts that are not possible to make in house are bought, so some of these items are bought during the Fall quarter and this as well gives the engineer more time for other tasks. The engineer was responsible for assembling the entire front suspension, from control arms, bulkhead, and spindle/hub. The rear suspension portion of the car is also constructed by the engineer as well as working closely with the drivetrain and chassis engineer. Please refer to Appendix E for detailed schedule tasks, spring tasks are sections 4 and 5.

Winter: Winter quarter is when all the manufacturing took place. All ¼" sheet metal designed parts were waterjet cut via SendCutSend and were received by week 2 of the beginning of the winter quarter. This allowed for the engineer to then drill and tap any necessary holes that were needed post waterjet cutting. Following that, during week 4 and 5 the engineer was then able to start assembling the front suspension subassembly. As of week 5-6, the engineer was ahead of schedule and most of the tasks shown in Appendix E Schedule were complete with time to spare. There were at times some parts needed to be redone to ensure accuracy and precision, like the rear trailing arms, but these problems did not result in a time conflict of the engineering falling behind on scheduled part manufacturing. Manufacturing the rear trailing arms, and front suspension components took longer than expected when previously planned out in the Gantt chart located in Appendix E, however, because the engineer realized this at the start of the winter quarter, the engineer worked several hours late into the day to complete parts. At the time of winter quarter, all tasks have been completed on time of ahead of schedule.

c. Testing

Fall: A test is created around the stated requirements of the car to see if the car does or doesn’t meet the requirements. This takes place before the RC Baja competition to ensure the car can function at the highest ability it can and the way that it was designed. Refer to the requirements section 1d for the list of requirements. A detailed list of the schedule can be found in Appendix E Gantt chart sections 6 and 7 that lays out the testing and deliverables portion of this project.

Some scheduling issues that quickly became apparent were that the RC Baja competition took place before all testing could be done. This was not the initial plan expected by the engineer. So only 2 out of the 3 component and system testing could be done by the time it was time to compete in the RC Baja. The exact date of the RC Baja was unknown at the beginning of the project, it was estimated that it would be during the month of May, but the competition ended up taking place mid-April. Even though this was not expected by the engineer the car still performed very well overall because even though detailed testing was not done to acquire data, lots of test driving of the car was done. So, the engineer Chayce Williams and Caden Harris had lots of practice to see how the car would react and perform prior to competing in the competition.

In the initial schedule created at the beginning of the project and construction phases, there was no deflection test for the rear trailing arm in the Gantt chart. By the end of the construction phase, the engineer figured that it would be a good idea to test the rear trailing arm for its deflection since there was some discrepancies in the analysis for accuracy and the importance of that component. So, the deflection test for the rear trailing arm was added at the beginning of the testing phases of the project and that was the first test to be conducted, and this took place on the Instron. Other than the miss communication of when the RC Baja competition would be, and the types of tests done in the testing phases of the project, there was very little that has gone wrong or incorrectly.

7. PROJECT MANAGEMENT

The main risk to the RC Baja Steering and Suspension is of course that the car could not function correctly if not designed well, but if that is the case the engineer doing the designing does not graduate on time. However, this risk is unlikely as the engineer has undergone the proper training and expertise to properly design the RC Car to the proper specifications. Many other smaller risks also play a role, much of the sheet metal parts of the suspension are sent to SendCutSend for sheet metal cutting, this is great, but for some off reason it is possible that SendCutSend could not manufacture the parts on time or on schedule. This risk is being mitigated by all sheet metal parts being designed first and being send out as soon as possible, and that being before winter quarter even begins. Another risk is that some parts could break or fail while manufacturing or testing the vehicle, however this is a rare circumstance. The engineer's absolute best judgment is used to make sure no parts are exposed to unnecessary environments that the car was not designed for, or in other words, the car will not be exposed to unnecessary abuse. With all the engineers training and expertise all risks are lessened to as close to zero as possible without remaining to conservative.

a. Human Resources

The largest human resource for the RC Baja Steering and Suspension is the engineer, Chayce Williams, Chayce's resume can be found in Appendix H. Although, human resources from Caden Harris is another source of help that is going into the RC Baja. Caden Harris is Chayce Williams's partner in completing the RC Baja, Caden is responsible for drive train and chassis. Human resources from SendCutSend is also used, even though all the manufacturing is done by CNC machines, proper planning is done by SendCutSend employees. There is however a small risk that SendCutSend does not complete parts on time or becomes behind schedule with a longer turn around, this is unlikely though.

b. Physical Resources

Utilizing custom laser cutting services from SendCutSend is a major source of the manufacturing process for the entire front control arms, bulkhead, and shock tower. SendCutSend estimates at the most a one-week turnaround. In house manufacturing is responsible for the rear trailing arm, and the assembly, are done by Chayce Williams in vertical milling machines, lathes, and then specific holes are drilled on drill presses to then be tapped. Risk from not machining the rear trailing arm consists of not staying within tolerances, and error in sizing. This error is mitigated as there is lots of material to be used, and lots of time to manufacture due to a lot of the components being sent out to other resources to be made.

c. Soft Resources

Soft resources such as SolidWorks, Microsoft Word, Excel, Project, 3D printing software such as Creality, and MakerBot are all used in the span of the project. There is very low risk associated with SolidWorks as Chayce has a strong knowledge of 3D Modeling within SolidWorks. And if mistakes are made in the 3D models, changes can be made very easily. This also goes along for Word, and Excel, there is very low risk associated with them. Excel is used to track part numbers, again, very low risk as changes can be made easily. The entirety of the RC Baja is tracked/scheduled on Microsoft Project, time periods at which tasks are supposed to be started and finished are all stated so that the project stays on track to finish on time. Majority of the 3D printing that is done is only for prototyping certain parts to check fitment, alignment, and overall geometry. Very little 3D printing parts are being implemented into the car so there is room for mistakes and time to be had to fix those mistakes with little to no risk of failure.

d. Financial Resources

All financial responsibility it put on both Chayce Williams and Caden Harris. No outside funding or sponsors that has been acquired for this project. Chayce is responsible for all steering and suspension components of the car and is also responsible for funding them. If the budget listed in Appendix D D.1 is not enough, then the cost of the project will have to go over budget. The goal is still to remain under budget but there is a small risk that the car could go over budget but is unlikely because all costs have been accounted for and an extra padding has been added.

8. DISCUSSION

a. Design

The overall design of the RC car took place during Fall Quarter 2023, during the design phase, there were many ideas that were brainstormed. These brainstormed ideas consisted of mainly independent or a solid axle front and rear suspension design along with all the components that would be different between the different ideas. Steering changes on the RC car is different if a solid axle or independent suspension is chosen for the front. This also changes how the shocks are mounted and how efficient they work. Typically, an independent front suspension design performs better under higher speeds and is much smoother over rapid and repeated bumps, and because of this, independent front suspension is chosen for the front of the car early in the design phase. However, if a solid front axle was chosen the front suspension assembly for the car would have more suspension articulation during low speeds, making the car a better "crawler". A crawler car is one that goes very slow over big rocks, roots, and modulations in the terrain, and therefore must be relatively slow to not role over, this is where the crawler name comes from. But in this competition of the RC Baja, a Baja like RC car must be created, and in Baja races higher speeds are introduced over a little but easier terrain.

At the time of Fall quarter, some small additions, and revisions to the requirements section (section 1.d) were made, the original requirements made for the car remained the same, but additions to them were added to give more detail and a higher level of benchmark that the car must be at. Some of these additions were suspension sag under a static load, side hits to the car being introduced to the upper and lower control arms, as well as the steering tie rods. Other than small additions to the requirements of the RC car, there was no major changes to the overall design of the car during Fall quarter, the engineer prior to designing the car has a relatively high level of experience when it comes to offroad vehicles and how different suspension designs work, so it made choosing an overall design for the RC Baja easy.

Some risks however are still present in the choices made for manufacturing which then snowball down into the design phases. Much of the car is made from 0.25" aluminum, which leads the engineer into choosing waterjet cutting to ensure high accuracy. CWU does not have a waterjet, so outside resources must be acquired. These parts are sent to SendCutSend, so much of the manufacturing of these components is not in the engineer's hands. Time restraint risks, and budget risks are the main risk factors that are playing a role in outsourcing all sheet metal parts to be water jet cut. These risks were overcome by all sheet metal parts being designed and sourced out before any of the other parts were made, doing so gave the engineer more than enough extra time to send the parts out to be made before any other parts, and designing parts with the least amount of unnecessary geometry to cut down on cost, as SendCutSend raises the prices for advanced cutting geometry for features.

Much of the success that is achieved in the design portion of the RC car comes from the analysis completed, 3D modeling, correct fasteners being chosen and so on, however there has been some failure, failure of 3D printing individual parts for test fit has been incorrect at times, this was from improper measurements being taken, and improper printer settings being used causing prints to fail. At the time of designing and test fitting miscellaneous parts to assure proper design, there has been little failure other than the 3D printing, due to much of the car having yet to be manufactured and produced or even tested.

b. Construction

Construction phase began during the winter quarter of the 2023-2024 academic school year. During this phase, parts are machined, waterjet, 3D printed, bought, and all fasteners and mounting hardware is acquired. During the manufacturing of the rear trailing arms (CLW-20-001), an issue was encountered when drilling and tapping the ends of the arm with 1/4" – 28 threads 3/4" deep. While drilling the pilot hole, the smaller drill bit broke off inside the trailing arm, which resulted in the trailing arm being deemed a failed part. This came down too much material being clogged up in the flutes of the bit. This resulted in a 3rd trailing arm having to be made and an extra 3 hours in the machine shop to complete manufacturing.

Another issue that was encountered during the construction and manufacturing phase of the RC Baja was that a tap was broke while tapping a hole, which then resulted in the tap being stuck/lodged in the hole and making the engineer unable to take the tap out. This happened on the front shock tower (CLW-20-007). Since majority of the threads that are being used in the RC Baja Project are M3, that means that the taps run a higher chance of breaking since they are so small and could break easily. Because of this happening a new shock tower was water jet cut and then completed for assembly, knowing what the engineer knows now about drilling and tapping it is that it is very important to take the extra time to remain cautious and to not rush the tapping process.

During the first 3-4 weeks of winter quarter, 33% of all the RC Baja steering and suspension components/parts were manufactured and finished, these parts consisted of the entire front suspension assembly. Most of the front suspension assembly parts were waterjet cut and then drilled/tapped for completion. Most of the harder parts to manufacturing were manufactured at the very start ahead of time to allow for extra time for manufacturing in the future just in case extra time was needed. Thankfully, no large amounts of extra time were needed to complete the machining, and water jet cutting processes. It was a huge success of planning on the engineer's behalf to have all sheet metal parts waterjet cut from a 3rd party, by doing so it allowed for much more time to stay on task on other parts. This is why making sure 33% of the manufactured parts were done in the first 3-4 weeks of the quarter was so easy.

Once all sheet metal parts were manufactured and assembled, all the 3D printed parts could then be manufactured and created for assembly. After this was done, majority of the steering and suspension components of the car was ready for complete assembly. The steering tie rods and connecting rods for the steering assembly and servo were saved to do last and if there were any changes to the servo mounting location and distance it wouldn't result in a complete useless part. As the RC Baja car began to fully develop, it was a smart move to save the connecting rod manufacturing line items last to be made. Because the steering servo and steering arms locations did indeed have to change to account for more space/room for the motor, battery, and ESC to fit properly on the chassis. Clear communication and design strategies had to be used here between Chayce Williams and Caden Harris.

c. Testing

During the beginning stages of testing the rear trailing arm was the first components to be tested. Much of the testing process can be found in section 4 of this engineering report as well as the procedure located in Appendix G Testing Report. Some of the issues that occurred to the testing of the rear trailing arm were that it was incredibly hard to get a time slot to be able to use the Instron machine in room 127 of Hogue Hall. Mechanical engineering students are adequately trained to use the Instron machine if the buddy system is being used. However, to get logged into the Instron there is a login and password to the Bluehill elements app that the engineers do not have access to. So, the engineer had to wait for staff to login in to the Instron to complete this test, and it took upwards of 2 days to get staff to login to the Bluehill Elements app on the computer, as well as working with other engineers that were planning on using the Instron machine at the same time.

During the testing of the rear trailing arm, there was also a problem with getting continually logged out and or locked out of the Instron testing app. After 2-3 quick tests on the Instron, the Instron app (Bluehill Elements) would be required to be restarted for it to then work properly. If this was not done, the Instron remained locked, and the engineer would not be able to set zero point on the part and be able to start the deflection test. And of course, like mentioned before, when the Instron testing app needed to be restarted a staff member would need to re-enter login and password information, this caused the testing process to be delayed more than expected. The login in and password information step was added to the procedure found in Appendix G “Testing Report”, so that whoever may be reproducing the rear trailing arm deflection test will know to get a professor, staff member, or admin to login to the Instron testing app ahead of time so there are no major delays.

The testing risk associated with the rear deflection test and any other test that has to do with the Instron machine and deflection testing could result in a material, part, or components failure. A failure can consist of a deformation from the material property of the component being exceeded, like the yield point. When the yield point of a certain material of a component is exceeded, the material undergoes permanent deformation and the previous material properties would then not be present in the component, the components would be much weaker. To minimize this, the engineer chose to manufacture extra components during the winter quarter so that there was no risk of a component breaking and there not being a backup. So, if the engineer chose to de destructive testing to find the max failure point of a part the engineer could do so without any risk. Or if a component broke when it wasn’t supposed to. The idea of having an extra rear trailing arm in the procedure in Appendix G is not discussed, however, it is in the nature of the rear trailing arm to be strong so that it wouldn’t fail under a 20lb load like the testing procedure requires.

When figuring out if a test was successful or not, pre-experiment analysis is done before any manufacturing or testing is done. When these analyses are done for each part, it lays out a design parameter that the components must abide by (Cross-sectional area, overall design, material, manufacturing method). With this design parameter, it was likely that a deflection, stress, value associated with that analysis, and those exact calculated values can be tested view the Instron. A test is considered successful if the tested values match closely with the calculated values, or if the tested values far exceed the initial requirements. These values are of course tested several times and the average of the test values are used to compare the calculated values. If values do not far exceed the initial requirements, or calculated values of the initial analysis, a new analysis is done to determine where the initial calculation went wrong in determining the expected tested value. If this was not enough for the engineer to have confidence that the component would perform FEA analysis via Inventor Nastran software to test more complex components otherwise very difficult to hand calculate with accurate data.

If testing data did not meet the requirements stated in section 1.d, the component that did not fit the requirement more analysis would be done to figure out why the component did not perform the way it was intended to. And if further analysis was done and a solution was found for a given component a new component would then be manufactured or the preexisting component would be modified and further tested until it met the requirements. Testing to figure out if the new and updated component consisted of Instron compression/tension testing, drop testing, articulation testing, steering measurement testing, or overall vehicle function testing until the vehicle met the engineers' standards and requirements.

Some problems that quickly became apparent when beginning testing on the Instron machine was that the engineer did not have the login and password. Students of CWU are not given the login to the testing software, so any time the engineer wanted to perform an Instron test the engineer would have to get in contact with the facilitators/professors that had the login and password. Because of this, the engineer was under time constraints when the test could be completed. Another issue that was related to this problem of the login and password was that the Instron testing app "Bluehill Elements" would at times freeze or crash, and the app would then need to be restarted. And as it can probably be assumed at this point, the app would require to be re-logged in, and a facilitator/professor would have to login the engineer. This problem extended the testing period where the Instron machine was used to perform a compression or tensile test which was not anticipated in the beginning. There has not been a fix/solution to the freezing on the testing app at this time and the engineers have not been given the login and password to the Instron testing app. These steps and information regarding freezing of the Instron app and login/password information has since been added to the testing procedure in Appendix G1 Testing Procedure.

In Appendix A01 – “Rear Trailing Arm Bending Deflection” the rear deflection is calculated initially with a solid cross-sectional area. However, the actual rear trailing arm when through revisions and a larger slot was added to it. With the slot in the rear trailing arm now, there will be far more deflection. And the results show just that in Appendix G1 – “Deliverables” where the total deflection for two tests are shown, one test at a total of 20lbs, and another deflection at 400 lb. The maximum amount of deflection achieved was 0.045” in this deliverable section. The raw data sheet is in the form of a graph and multiple deflection points can be found in the graph, so the graphs are inputted into the deliverable section. The data for the graphs were difficult to get usable data from when only supplying a 5lb load to the rear trailing arm, this is also another reason why the load was increased from 5lb to 20lb. Because at 20lb, the deflection vs. force graph is much more readable and there is much more usable data that can be acquired.

In the turning radius test performed, it was evident that the surface that the engineer performed the test on was not perfectly ideal. Even though the car had the required turn angle to perform the required turning radius with the given turning angle, the surface was slippery and posed a problem for grip for the front wheels of the car. This is a problem because the car should have been able to meet the stated requirement 1d.3 if it weren’t for the slick testing surface. However, no surface that the car would be driving on would be perfect for the given test, however, some surfaces would still be better than the wood surface that the test was done on. Concrete was the next best option to perform the test on because it gave the front wheels of the car to more grip so that it could steer more efficiently.

9. CONCLUSION

a. Design

The function of the RC Baja steering and suspension was to allow for the RC Car to be able to steer left to right and absorb rough terrain while driving. In section 2.g there are a total of 12 analysis that assist is making the correct design parameter decisions that will support the overall function of the RC Car and meet the stated requirements in section 1.d. Analysis covers the structural integrity of each of the vital suspension and steering components that take on higher risk of larger forces and repeated use.

Some of these analyses that cover the stated higher risk of forces and repeated use are Analysis A01 – Rear Trailing Arm Bending Deflection where the allowable maximum deflection allowed for the rear trailing arm must be below 1/16" and because 6061 is the chosen material for the rear trailing arm the max deflection calculated is only 0.0021", which proves an extremely worthy design with no failure.

Analysis A03 – Deflection in Front Lower Control Arms analysis the max deflection allowable much like the previously discussed trailing arm, and because a design parameter of a quarter inch thick 6061 material is chosen, the actual maximum deflection of the control arm under a 20lb load is well within the required limit. In analysis A05 – Critical Buckling Load of Upper Control Arm also results in a successful design parameter with a quarter inch 6061 thickness, though buckling load is calculated for the upper control arm, the outcome is still a successful design like the lower control arm.

For all the discussed components/parts to successfully work the way they were intended to, the components/parts much be fastened correctly to insure no pre-determined failure, and correct kinematics. And because of this, Analysis A06 – Maximum Allowable Bolt/Screw Shear is calculated for all the 1/8" hardware that utilizes stainless steel 5-40 shoulder screws. The chosen shoulder screws can handle a total of tensile strength of 70 ksi, and a yield point of 30-40ksi. The analysis covers the shear capacity of each shoulder screws, which comes out to be approximately 336lbs, the likelihood of an RC car undergoing a load of 336lbs is highly rare, and if a car is undergoing that much force there are much bigger problems that are introduced than just shear capacity of fasteners.

Analysis A08 and A09 cover the minimum shoch tower thickness for the rear and front shock tower. Since majority of the forces being introduced to the shock towers are directly from the shocks, most of the forces can be assumed to be in the Y-direction since that is the orientation that the shocks are mounted. And because of this, beam deflection formulas can be used to calculate the maximum bending deflection when the car is being used. The result of choosing quarter inch shock towers is a strong and reliable design as the minimum thickness needed is less than 1/16".

And finally, of course the components/parts must be mounted to the car and be structurally sound, the bearing stress of mounting tabs need to exceed the required minimums forces/stresses that are introduced to the car when it is jumped, dropped, and crashed. The total amount of bearing stress that is introduced to the cars mounting tabs while under a large 100lb load is 6400psi, and because of this, 6061 is a good choice for the tabs because the yield point of 6061 is 35,000 psi, and if the engineer wants to 3D print the tabs to save on the total cost of the RC car, 3D printing the tabs with PLA will also be suitable, as PLA has a yield point of roughly 10,152 psi.

Most of the analysis that are done require substantial engineering merit, and most of the merit that is needed is from mechanics of materials, statics, and dynamics, to cover all structural applications of each of the components. And while doing the analysis, the manufacturing methods also need to be discussed a chosen during the same time as the analysis. Roughly 75% of the car’s components have been designed in a way that sheet metal design is used so that all complicated geometry parts can be cut using a waterjet, even though the cost of doing so rises compared to machining, higher accuracy is achieved, and a faster more efficient turnaround time is acquired. Some machining will have to take place but a more detailed description of what will be done will be discussion in section 9b.

The entirety of the RC Baja has been well thought out and constructed based off prior experience in mechanics of materials calculations, statics, and dynamics like mentioned, but a large portion of where the engineer’s confidence comes from the chosen design for the RC Baja comes from the engineer’s experience in the real life offroad industry and knowledge of the best suspension designs. And combining the engineer’s technical engineering knowledge/merit with real world offroad car and RC car experience, a top-of-the-line RC Baja Car design is conceived and ready for construction/manufacturing.

b. Construction

During the construction phases of the RC Baja that took up the entire winter quarter, all components were built and assembled. There were very few issues that occurred during the manufacturing that resulted in there being very few changes to the design being required. The only changes that needed to be done were small adjustments to the rear trailing arms, steering tie rods, and rear upper long arms. The changes to the rear trailing arms were so that the rear shocks could fit in the slot of the trailing arm and work more efficiently. The steering tie rods needed the lengths of the all thread to be adjusted several times, this was not an issue with the design, but more so the engineer’s ability to get the front wheels aligned properly. The rear upper long arm length had to be made longer to correspond with the engineer’s partner Caden Harris’s design better. Caden had designed the rear axle to be rotated further back than what it was, and the upper long arms are what control the angle of the rear axle is, so with longer upper long arms, the axle was rotated more clockwise. This gives the rear driveshaft a better more efficient angle to transmit power from the motor to the differential inside the rear axle housing. Making these changes allows for the car to work far more efficiently than what it was prior to being updated. The entire front suspension sub-assembly worked exactly the way that it was designed to, along with the rear suspension design. The steering also worked flawlessly, in the analysis section of the report, it was calculated that the car was required to be able to have a turning angle of roughly 25 degrees to make a 180 degree turn in a 3.5’ radius, and the steering assembly achieves that easily. In the entire manufacturing process there had to be extensive deburring, sanding, and filing so that all sharp edges posed no issues to sharp edges, and no risk to cutting anyone that could pick up the car. With all of this being done, it has maximized the likelihood of the car working efficient, and resilient to the elements and forces that are introduced onto the car as the car has been designed and manufactured to be successful.

c. Testing

Testing was among the final stages of the RC Baja Steering and Suspension that took most of the allocated time during Spring quarter. Spring quarter marks the end of the year, and the end of the project. During this time, 3 total tests were done, along with full complete test reports being done for each individual one of these tests. The 3 tests that were done was the rear deflection in the rear trailing arm (Appendix G1), turning radius/angle test (Appendix G2), and overall suspension articulation (Appendix G3).

These three tests encompass the overall function of the car, deflection testing to exemplify the overall strength of the rear suspension components, as well as showing that because each and every part of the car is held to the same standard as the rear trailing arm, it is trustworthy that all the other components that went through the same design, and manufacturing methods can be trusted as well for their structural integrity. The rear trailing arm meets the requirement the engineer initially laid out at the beginning of the year in the Fall (Requirement 1d.11). The rear trailing arm was able to withstand 400 total pounds and could go heavier if needed. This test was done on the Instron machine, for all the testing procedures done for this test, they can be seen and referred to in Appendix G1.

Test #2 tests the overall steering capabilities and efficiencies of the car. There was analysis done to calculate the needed turning angle to meet a 180-degree turn in less than a 3.5’ turning radius and that needed angle was a minimum of 25 degrees. The car met this requirement in the turning angle test, and the car was able to turn further to the right compared to when turning to the left. This was from binding in the steering tie-rods which would cause the tie rods to come in contact with other components, space was very limited. The reason for this after farther investigation was that the ground clearance on the car was simply too tall, this was resulting in an excessive angle in the tie-rods and binding. The turning angle was then testing to see if the car would meet the turning radius requirement and did not meet the requirement turning to the left, but it did meet the requirement turning to the right. This is still a failed test. The engineer made changes to the tire inserts, ground clearance, and the fastening method for the tie-rods to the turning arms which then helped the car make better turns after the test had been completed. The engineer now has confidence that the RC car would meet the requirement turning to the left and to the right.

For the final test (#3), the overall suspension articulation was tested. This was measured by 3D printing blocks and putting them under each opposing tire/wheel of the car on a flat surface. If one of the wheels/tires lifted off the ground on its own the car would “fail.” The car was however able to exceed the requirement of 2” created in the Fall. The car was able to articulate a total of roughly 4.5” before any of the tires/wheels lifted off the ground, this is great success! However, sometimes more suspension travel doesn’t always mean better performance. Having more suspension travel with this car means that the car can rollover easier at higher speeds. A sway bar, limit straps, or even shorter travel shocks would mean the car would be able to operatable at higher speeds easier, and still be able to articulate the required 2”.

At the end of testing, it is evident that small changes needed to be made to maximize the RC cars design. However, a lot of these were not major, the car still meets a lot of the requirements stated at the beginning of the quarter, but the car could still be better, it can always be improved upon. But, after concluding the testing and competition of this RC car, the engineer deems it a huge success.

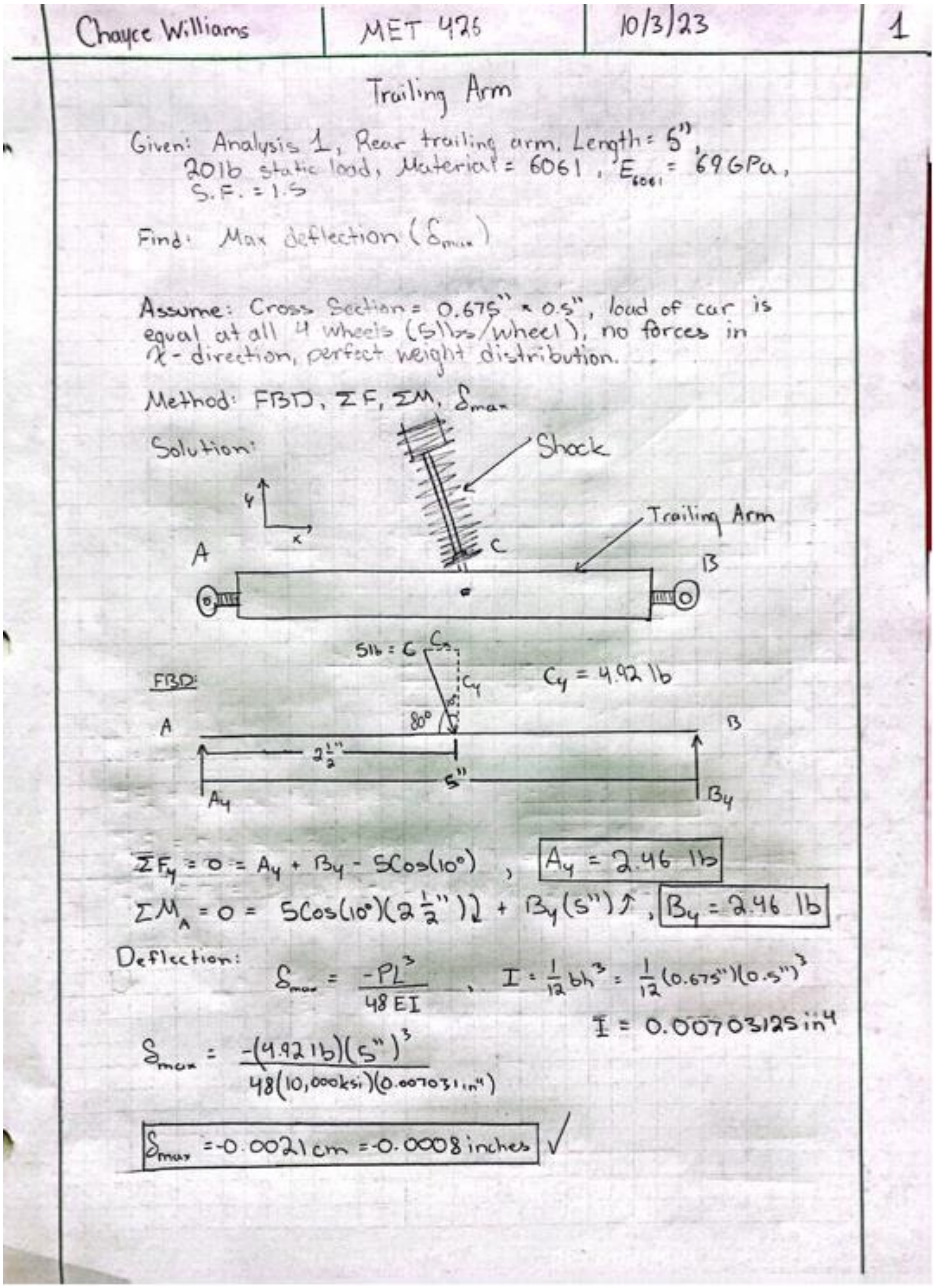
10. ACKNOWLEDGEMENTS

A special thank you goes to Caden Harris for being reliable as a partner and always putting in the maximum effort as well as Caden's family for providing steel tubing for the cage that surrounds the RC Car to protect components. Another special thanks goes to Chayce Williams's parents/family for providing the funding to purchase all parts and services needed to complete the RC Baja. They have also been supportive to Chayce Williams's effort and dedication to complete The RC Baja Steering and Suspension, as well as graduating at the completion of the RC Baja.

References

APPENDIX A - Analysis

Appendix A01 – Rear Trailing Arm Bending Deflection



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Trailing Arm

Given: Analysis 1, Rear trailing arm, Length = 5", 20lb static load, Material = 6061, E_{6061} = 69 GPa, S.F. = 1.5

Find: Max deflection (δ_{max})

Assume: Cross Section = 0.675" × 0.5", load of car is equal at all 4 wheels (5lbs/wheel), no forces in x-direction, perfect weight distribution.

Method: FBD, ΣF, ΣM, δ_{max}

Solution:

$\Sigma F_y = 0 = A_y + B_y - 5\cos(10°)$, $A_y = 2.46$ lb

$\Sigma M_A = 0 = 5\cos(10°)(2\frac{1}{2}")] + B_y(5")\curvearrowleft$, $B_y = 2.46$ lb

Deflection:

$\delta_{max} = \frac{-PL^3}{48EI}$, $I = \frac{1}{12}bh^3 = \frac{1}{12}(0.675")(0.5")^3$

$I = 0.00703125 \text{ in}^4$

$\delta_{max} = \frac{-(4.92\text{ lb})(5")^3}{48(10{,}000\text{ ksi})(0.007031\text{ in}^4)}$

$\delta_{max} = -0.0021$ cm $= -0.0008$ inches ✓

Appendix A01 – Continued

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Given: Same as previous trailing arm calculation, except,
Cross Section = 0.5" • 0.35"

Find: Max Deflection (δ_{max})

Assume: Same as previous except cross-section

Method: FBD, ΣF, ΣM, δ_{max}

Solution:

$$\Sigma F_y = 0 = A_y + B_y - 5\cos(10^\circ) \quad , \quad \boxed{A_y = 2.46\ lb}$$

$$\Sigma M_A = 0 = 5\cos(10^\circ)(2\tfrac{1}{2}")] + B_y(5") \quad , \quad \boxed{B_y = 2.46\ lb}$$

Deflection:

$$\delta_{max} = \frac{-PL^3}{48EI} \quad , \quad I = \frac{1}{12}bh^3 = \frac{1}{12}(0.5)(0.35)^3$$

$$I = 0.0017864583\ in^4$$

$$\delta_{max} = \frac{-(4.92\ lb)(5")^3}{48(10{,}000\ ksi)(0.0017864)\ in^4}$$

$$\boxed{\delta_{max} = -0.00182\ cm = -0.000717\ in}$$

Appendix A02 – Steering Angle

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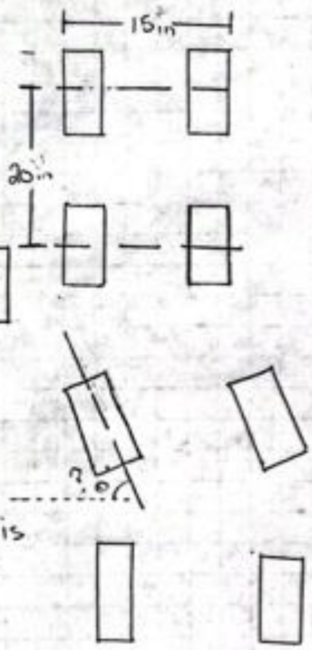
Analysis 2
Steering Angle

Given: Max Track Width = 15" Max Wheel Base = 20"
Tolerance = ±1° ± 3"
Find: Minimum turn angle to complete 180° turn within $3\frac{1}{2}$ foot radius circle.

Method: Turning Radius Eq. Mechanical Design

Assume: Flat Ground, each wheel has same turn angle, rear differential locked 24/7.

Solution: θ = turn ∠
R = Radius
WB = Wheelbase



$$R = \frac{(WB)}{\tan\theta}, \quad \theta = \tan^{-1}\left(\frac{WB}{R}\right)$$

$$\theta = \tan^{-1}\left(\frac{20in}{42"}\right), \quad \boxed{\theta = 25.46^\circ}$$

$$3\tfrac{1}{2}ft \times \frac{12in}{1ft} = 42"$$

If the maximum wheelbase of 20" is used the minimum turning angle to make a 180° u-turn is 25.46°.

Analysis AO3 – Deflection in Front Lower Control Arm

Chayce Williams | MET 489a | 10/14/2023 | 1

Analysis 3

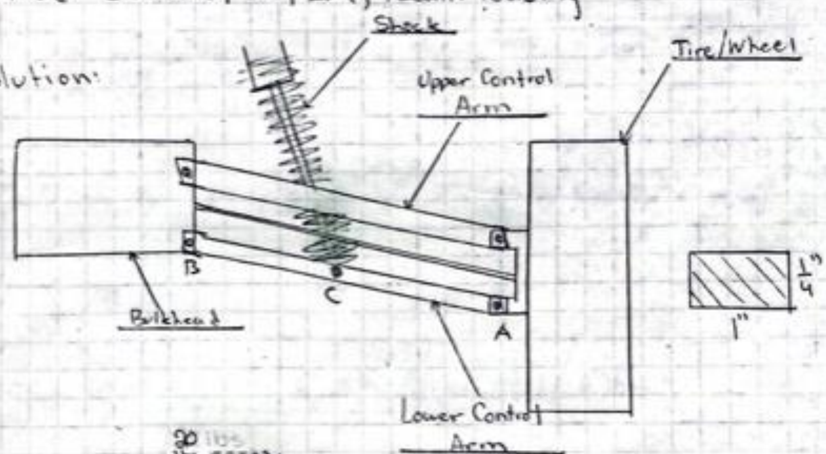
Given: Front lower control arm, $\frac{1}{4}''$ (± 0.050) thick, 4" (± 0.050) long, 6061,

Find: Deflection from shear and moment.

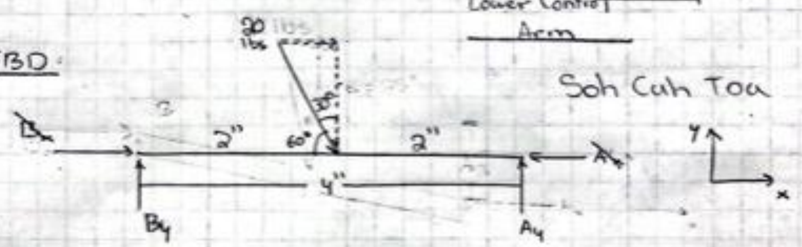
Assume: No material imperfections, tight tolerances, SendCutSend manufactured part.

Method: Statics, ΣF, ΣM, Beam loading

Solution:



FBD:



Soh Cah Toa

$\Sigma F_x = 0 = B_x - A_x + 20\sin(30°)$

$\Sigma F_y = 0 = B_y + A_y - 20\cos(30°)$, $\boxed{B_y = 8.66\text{ lbs} \uparrow}$

$\Sigma M_B = 0 = -20\cos(30°)(2'') + A_y(4'')$, $\boxed{A_y = 8.66\text{ lbs} \uparrow}$

Deflection

$$y_{max} = \frac{-PL^3}{48EI} = \frac{-(20\cos 30°)(4'')}{48(10\text{ksi})(\frac{1}{12}(1'')(.25'')^3)}$$

$\boxed{\text{Max Deflection} = 0.111''}$

Appendix A03 – Continued

Chayce Williams | MET 484a | 10/14/23 | 2

Max stress:

$$\sigma_{max} = \frac{F_{max}}{A} = \frac{20\cos 30^\circ \text{lbs}}{\frac{1}{4}'' \times 1''}, \quad \underline{\sigma_{max} = 69.28 \text{ lb/in}^2}$$

* Assume safety factor of 2. *

$$\varepsilon = \frac{y_{max}}{L_o} = \frac{0.111''}{4''}, \quad \underline{\varepsilon = 0.02775} = 2.78\%$$

$$\sigma = E \cdot \varepsilon = (10\text{ksi})(0.02775), \quad \underline{\sigma = 277.5 \text{ psi}}$$

$$\sigma_{max} < \sigma,$$

$$\boxed{69.28 \text{ psi} < 277.5 \text{ psi}}$$

With safety factor of 2, deflection and stress is still within requirenments.

$$\frac{277.5 \text{ psi}}{2} = 138.5 \text{ psi}$$

Want to stay in the elastic region of stress strain curves of 6061.

Analysis AO4 – Critical Buckling Load of Upper Long Arms

Chayce Williams | MET 489A | 10/14/23 | 1

Analysis 4

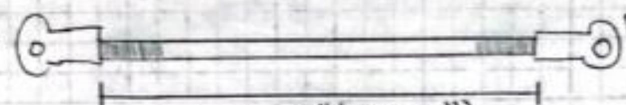
Given: 8mm diameter upper long arms, 5" long (127mm).

Find: P critical of long arm

Method: Beam buckling

Assume: Homogeneous material, low carbon steel rods.

Solution:



Slenderness Ratio:

$R_g = \sqrt{\frac{I}{A}}$

r = smallest radius of gyration

Transition Slenderness Ratio

$= \sqrt{\frac{2\pi^2 E}{S_y}}$

$= \sqrt{\frac{2\pi^2 (29\times10^6 \text{ psi})}{47{,}900 \text{ psi}}} = 109.32$

$I = \frac{\pi D^4}{64} = \frac{(\pi)(0.3149")^4}{64} = 4.82\times10^{-4} \text{ in}^4$

$= \sqrt{\frac{4.82\times10^{-4} \text{ in}^4}{\pi (0.157)^2}} = 0.0788$

Slenderness Ratio $= \frac{L(k)}{R_g} = \frac{(5")(1)}{0.0788}$, Slenderness Ratio $= 63.45$

$63.45 < 109.32$ (Johnsons Formula)

Appendix A04 – Continued

Chayce Williams | MET 489A | 10/14/23 | 2

Johnsons Formula for Short Columns:

$$P_{cr} = A \cdot S_y \left[1 - \frac{S_y S_r^{\,2}}{4\pi^2 E} \right]$$

S_y = yield strength

S_r = Slenderness Ratio

$$P_{cr} = (\pi(0.157")^2(47{,}900\,psi)\left[1 - \frac{(47{,}900\,psi)(63.45)^2}{4\pi^2 (29\times10^6\,psi)} \right]$$

$$P_{cr} = (3709)(0.83156)$$

$$\boxed{P_{cr} = 3084.46\ lbs}$$

Assuming perfectly axial.

Analysis AO5 – Critical Buckling Load of Upper Control Arm

Chayce Williams | MET 489A | 10/21/23 | 1

Analysis #5

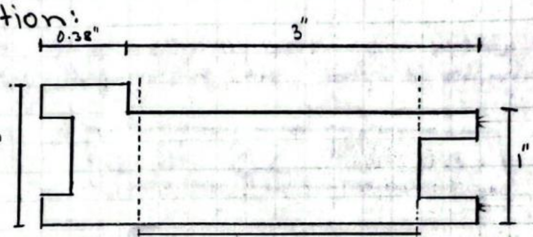
Given: Upper Control Arm, Material = 6061, Length = $3\frac{5}{8}''$, Width = $1''$

Find: Critical buckling load (Side load to car)

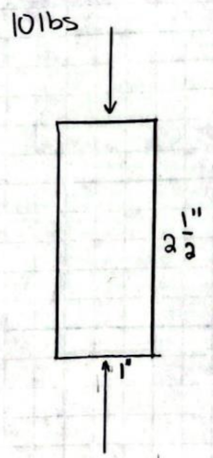
Assume: Rectangle cross section, no material imperfections.

Method: Beam buckling equations, Slenderness ratio.

Solution:



This is the section the load will be analyzed.



Requirement is upper control arm $< \frac{1}{8}''$ δ.

Pinned - Pinned, $k = 1$

$$R_g = \sqrt{\frac{I}{A}}, \quad I = \frac{1}{12}(b)(h)^3$$

$$I = \frac{1}{12}\left(\tfrac{1}{4}''\right)\left(2\tfrac{1}{2}''\right)^3, \quad I = 0.325$$

$$R_g = \sqrt{\frac{0.325}{\left(\frac{1}{4} \times 2\frac{1}{2}\right)}}, \quad R_g = 0.7211$$

$$\text{Slenderness Ratio} = \frac{L(k)}{R_g} = \frac{\left(2\frac{1}{2}''\right)(1)}{0.7211}$$

$3.5 < 128$

$S_r < C_c$

$S_r = 3.5$

$$\text{Transition } S_r: = \sqrt{\frac{2\pi^2 E}{S_y}} = \sqrt{\frac{2\pi^2 (10{,}000\text{ksi})}{12{,}038\text{ psi}}} = 128 = C_c$$

Chayce Williams | MET 489A | 10/21/23 | 2

Slenderness ratio determined Johnsons formula

$$P_{cr} = A \times S_y \left[1 - \frac{S_y S_r^2}{4\pi^2 E}\right]$$

$$P_{cr} = \left(\tfrac{1}{4}'' \times 2\tfrac{1}{2}''\right)(35{,}000\ \text{PSI})\left[1 - \frac{12{,}038\ \text{PSI} \times 3.5^2}{4\pi^2\ (10{,}000\ \text{ksi})}\right]$$

$$P_{cr} = 7{,}521\ \text{lb-f} = 233.76\ \text{lb-m}$$

The upper control arm can withstand 7,521 lbs, this means the arm is plenty strong.

10 lbs << 7521 lbs

$$\text{Stress} = \frac{F}{A} = \frac{10\ \text{lbs}}{\left(\tfrac{1}{4}'' \times 2\tfrac{1}{2}''\right)}, \quad \sigma = 16\ \text{psi}$$

$$\text{Stress} = \frac{7521\ \text{lbs}}{\left(\tfrac{1}{4}'' \times 2\tfrac{1}{2}''\right)}, \quad \sigma = 12{,}033\ \text{psi}$$

Analysis AO6 – Maximum Allowable Bolt/Screw Shear

Chayce Williams | MET 489A | 10/21/23 | 1

Analysis 6

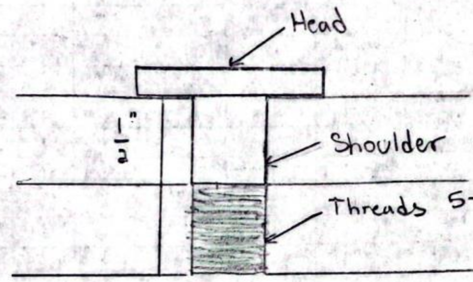
Given: Same-Size thread 18-8 Stainless steel shoulder screws, Thread Size = 5-40, Tensile strength is = 70,000 psi. Drive size = 5/64

Find: Shear Stress

Assume: Double shear, 100 lbs of loading

Method: Maximum shear stress, allowable shear stress,

Safety Factor = 1.5



$$\text{Shear Capacity} = \frac{0.6(70{,}000\,psi)(0.012\,in^2)}{1.5}$$

A

τ Capacity = 336 lbs ✓

$$\text{Shear Stress} = \frac{\tau_{max}}{A} = \frac{336\,lbs}{(\pi .0625)^2}$$

σ_{τ} = 27,379 psi ✓

* McMaster Carr P#: 91273A116 *

Appendix A07 – Shock Spring Rate

Chayce Williams	MET 489a	10/29/23	1

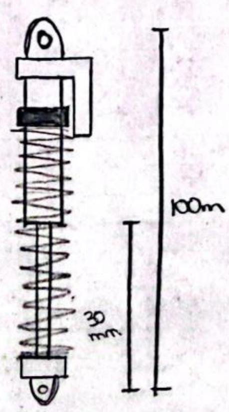
Analysis 7

Given: 20lb Car, Drop Height = 2ft, Shock Length
$E_{ye} - E_{ye}$ = 100mm, Usable travel = 1.18" = 30mm

Find: Spring Rate

Assume: All Springs the same, and the same load going through each shock.

Method: FBD, Statics, Spring rate, kinematics



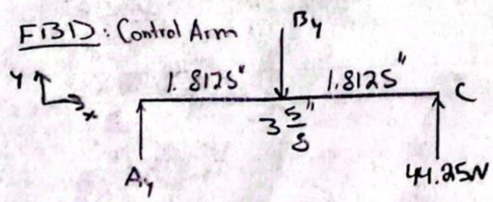
① Drop Height Force:

$v = \sqrt{2gh} = \sqrt{2(9.81\frac{m}{s^2})(0.61m)}$, $\underline{v = 3.45\frac{m}{s}}$

$F = \frac{m \times v^2}{h} = \frac{(9.072kg)(3.45\frac{m}{s})^2}{0.61m}$, $\underline{F = 177.01N}$

② Distribute Across 4 Wheels, $\underline{F = 44.25N = 9.89lb\text{-}f}$

③ FBD: Control Arm



$\Sigma M_A = 0 = B_y(0.046m) + 44.25(0.0921m)$

$\underline{B_y = 88.6N = 19.91b\text{-}f}$

$k = \frac{F}{D} = \frac{88.6N}{30mm}$, $k = 2.95\frac{N}{mm}$

Answer

$$k = 2.95\frac{N}{mm} = 16.85\frac{lb}{in}$$

Spring Rate

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Appendix A08 – Shock Tower Thickness

Chayce Williams | MET 489a | 10/29/23 | 1

Analysis 8

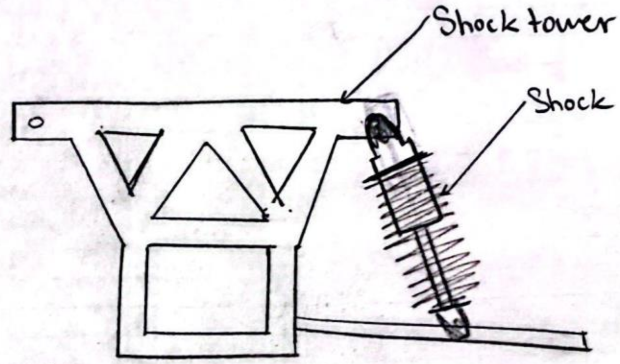
Given: 6061 Alum, Shocktower, 1/8" holes, $\frac{1}{16}$" tall (0.0015m)

Assume: 5" Wide Side - Side, evenly distribution of forces, Dropped 2ft, 50N, Single Shear.

Find: Thickness of Shocktower

Method: FBD, Statics, Mechanics of mat.

Solution:



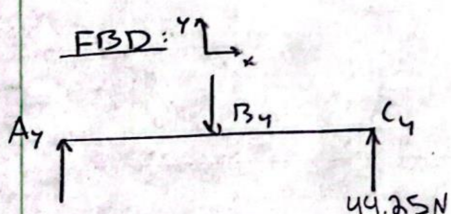
① Solve for force when dropped 2 feet.

$v = \sqrt{mgh} = \sqrt{(2)(9.81\frac{m}{s^2})(0.61m)}$, $v = 3.45\frac{m}{s}$

$F = \frac{m \times v^2}{H} = \frac{(9.072kg)(3.45\frac{m}{s})^2}{0.61m}$, $F = 177.01N$

Each Wheel = 44.25N

FBD:



$\Sigma M_A = 0 = B_y(0.046m) + 44.25N(0.0921m)$

$B_y = 88.6N = 19.9\ lb\text{-}f$

Shock Tower: Because 88.6N is exerted at bottom of shock, 88.6N is exerted at top of shock, (Shock-Tower). (Shear)

$\tau = \frac{F}{A} = 207MPa = \frac{88.6N}{(0.0015m \times H)}$, Thickness $= 0.000285m = 0.0112in$

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Appendix A09 – Rear Shock Tower Minimum Thickness

Chayce Williams | MET 489a | 11/4/23 | 1

Analysis # 9

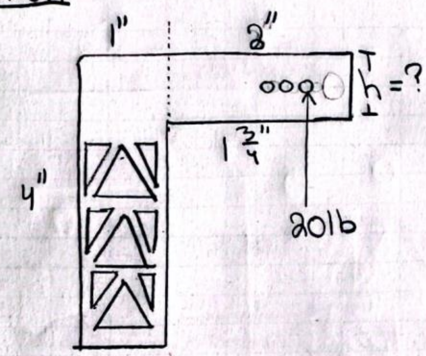
Given: Rear Shock tower, 6061 Alum, Shock mounting locations (3x), 4" tall, 2" long, $y_{max} = \frac{1}{16}$"

Find: Rear Shock tower minimum thickness

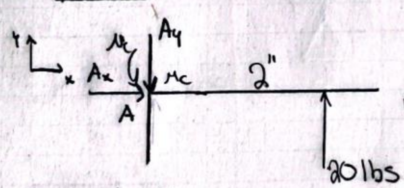
Assume: $\frac{1}{4}$" thick, Cantilever Beam, load applied at very end of beam, 20lb load

Method: Cantilever beam deflection, FBD

Solution:



FBD:



$\Sigma F_x = 0 = A_x, A_x = 0$

$\Sigma F_y = 0 = -A_y + 20lbs$

$A_y = 20\,lbs$

$\Sigma M_A = 0 = 20lb(1\frac{3}{4}") + M_c$

$M_c = 35lbs$ acting on Point A.

Force between A-B:

$$y_{max} = \frac{-Px^2}{6EI}(3L - x)$$

$$\frac{1}{16}" = \frac{-(20)(1\frac{3}{4}")^2}{6(10{,}000ksi)(\frac{1}{12}(\frac{1}{4}")(h))}\left(3(2") - 1\frac{3}{4}"\right)$$

$h = 0.003332"$

$h = 0.085mm$

Trying $\frac{1}{8}$" thick

$h = 0.006664"$

*Still ok to use both $\frac{1}{4}$" and $\frac{1}{8}$" thick 6061 Alum.

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Appendix A09 – Continued

Chayce Williams	MET 489A	11/4/23	2

Analysis #9 Cont.

Given: What if ABS or PLA?

Assume: 3D Printed

ABS: $E = 1.9 - 2.5\ GPa = 275ksi - 362ksi$

$$0.0625'' = \frac{(-20)(1\frac{3}{4})}{6(275ksi)(\frac{1}{12}(\frac{1}{4})(h))}(3(2) - 1\frac{3}{4})$$

$h = 0.1212''$

What if $\frac{1}{8}''$ thick?

$h = 0.242''$

PLA: $E = 4.107\ GPA = 595ksi$

$$0.0625'' = \frac{(-20)(1\frac{3}{4})}{6(595ksi)(\frac{1}{12}(\frac{1}{4})(h))}(3(2) - 1\frac{3}{4})$$

$h = 0.056in$

What if $\frac{1}{8}''$ thick?

$h = 0.112''$

If 6061 is used, thicknesses of $\frac{1}{4}''$ and $\frac{1}{8}''$ easily meet the $\frac{1}{16}''$ deflection requirements, as well as if was 3D printed with PLA, ABS, and $\frac{1}{4}''$ $\frac{1}{8}''$ thicknesses. When considering the desired height of the cross sectional area.

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Appendix A10 – Bearing Stress of Mounting Tabs

Analysis #10

Given: - Tabs for rear axle and chassis
- Material (6061, PLA, ABS)
- Dimensions/Image of tab

Find: - Bearing Stress on tab

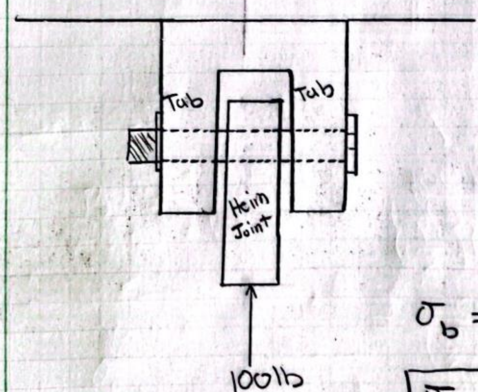
Assume: - Uniform load on hole,
- $\frac{1}{8}''$ hole/Pin

Method: Bearing stress

Solution:

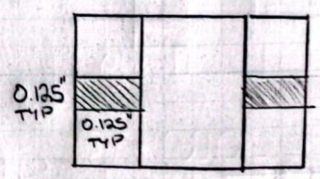
Top View

Axle



Cross-Sectional View

Front



$$\sigma_b = \frac{P}{A} = \frac{P}{bh} = \frac{100\text{lb}}{(\frac{1}{8}'')(\frac{1}{8}'')}$$

$$\boxed{\sigma_b = 6400 \text{ psi}}$$

6400 psi on each individual tab ↗

σ_y 6061	= 35,000 psi	✓
σ_y PLA	= 10,152 psi	✓
σ_y ABS	= 6433 psi	✗

Must use 6061 Alum if using aluminum (leftover) or 3D printing PLA mounting locations.

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Appendix A11 – Rear Shock Tower Support (Deflection)

Chayce Williams | MET 489a | 11/11/23 | 1

Analysis #11

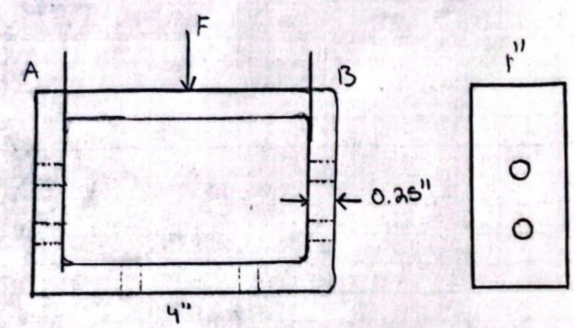
Given: Rear shock tower support, 0.25" thick, 1" wide, 4" long, 3D Printed PLA.

Find: Max Deflection of top surface to simulate someone picking up the car with their hands.

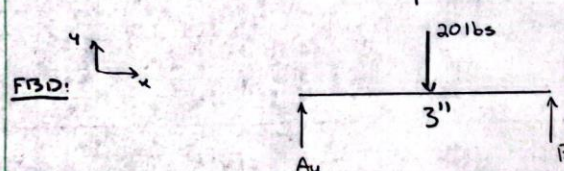
Assume: Perfect Point Load, SF 3

Method: Beam deflection formulas, FBD

Solution:



FBD:



$I = \frac{1}{12}(1")(0.25")^3$

$I = 0.00130 \text{ in}^4$

$\Sigma F_y = 0 = A_y + B_y - 20\text{lbs}$, $A_y = 10\text{lbs}$

$\Sigma M_A = 0 = 20(1.5")] + B_y(3")$ ↺ , $B_y = 10\text{lbs}$

$y_{max} = \frac{-PL^3}{48EI} = \frac{-(20\text{lbs})(3")^3}{48(415{,}794\text{ psi})(0.0013\text{ in}^4)}$

$y_{max} = 0.021"$ @ 20lbs

$y_{max} = 0.062"$ @ 60lbs SF 3

Stress: $\sigma = \frac{F}{A} = \frac{60\text{lbs}}{(1" \times 0.25")}$, $\sigma = 240 \text{ PSI}$

Yield Point of PLA: 3770 PSI

240 PSI < 3770 PSI ✓

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Appendix A12 – Steering Tie Rod Critical Load

Chayce Williams | MET 489a | 11/11/23 | 1

Analysis #12

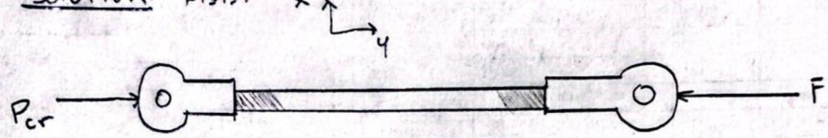
Given: Steering tie rod, $\frac{1}{8}$" 6061 rod, $3\frac{3}{4}$" long, cold worked, T6, Hardened, 35 kg Servo.

Find: $P_{critical}$, buckling load

Assume: Axial loading

Method: S_r, r, P_{cr}, Euler? Johnson?

Solution: FBD:



$$I = \frac{\pi D^4}{64} = \frac{(\pi)(0.125)^4}{64} = 1.198\times10^{-5}\ in^4$$

$$R_g = \sqrt{\frac{I}{A}} = \sqrt{\frac{1.198\times10^{-5}\ in^4}{(\pi)(\frac{0.125}{2})^2}},\quad R_g = 0.03124$$

Slenderness Ratio:

$$\frac{(3.75")(1)}{0.03124} = 120.04 = S_r$$

Transition Slenderness Ratio

$$\sqrt{\frac{(2)(\pi)^2(10,000\,ksi)}{35,000\ PSI}} = 75.1 = \text{Transitional}$$

$$S_r > 120.04 > 75.1 \quad (\text{Eulers})$$
$$S_r > C_c$$

$$P_{cr} = \frac{\pi^2(E)(I)}{(kL)^2} = \frac{(\pi)^2(10,000\,ksi)(1.198\times10^{-5}\,in^4)}{[(1)(3.75)]^2}$$

$$\boxed{P_{cr} = 84.1\ lbs = 38.15\ kg}$$

38.15 35 kg Servo < 38.15 kg

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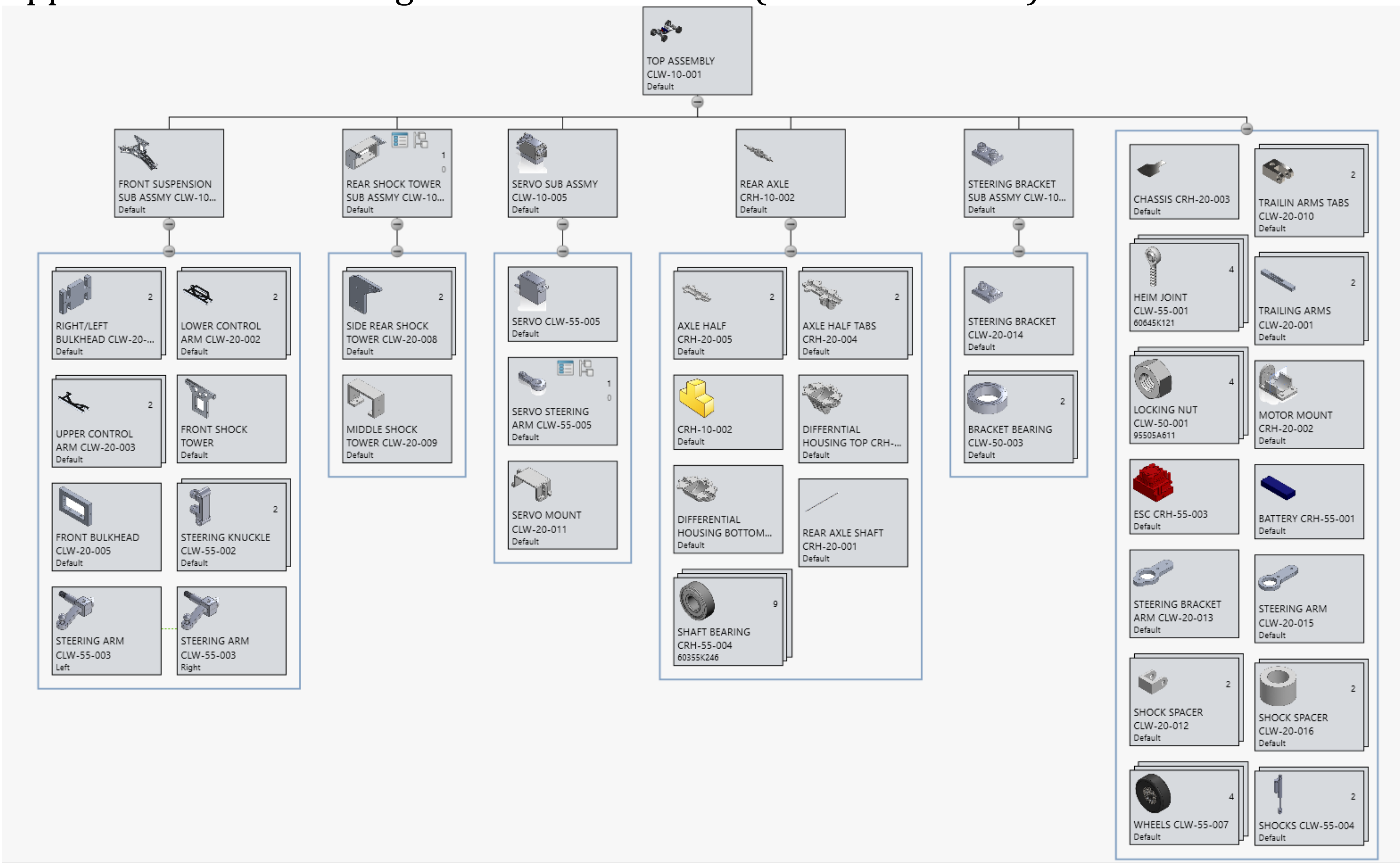
APPENDIX B – Drawings

Appendix BO1 – Drawing Tree – CLW-10-001 (TOP ASSEMBLY)

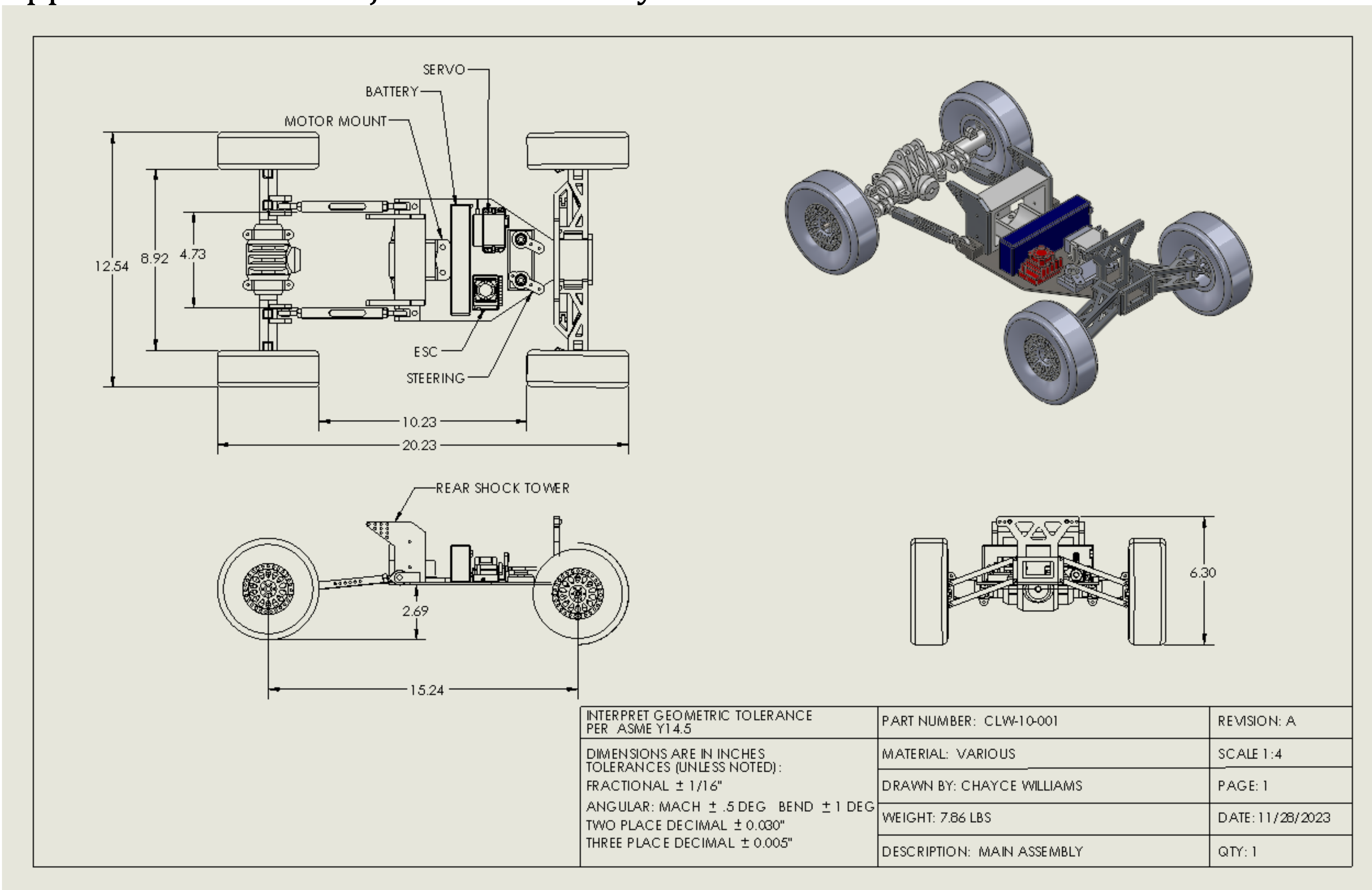


Appendix BO2 – Drawing Index

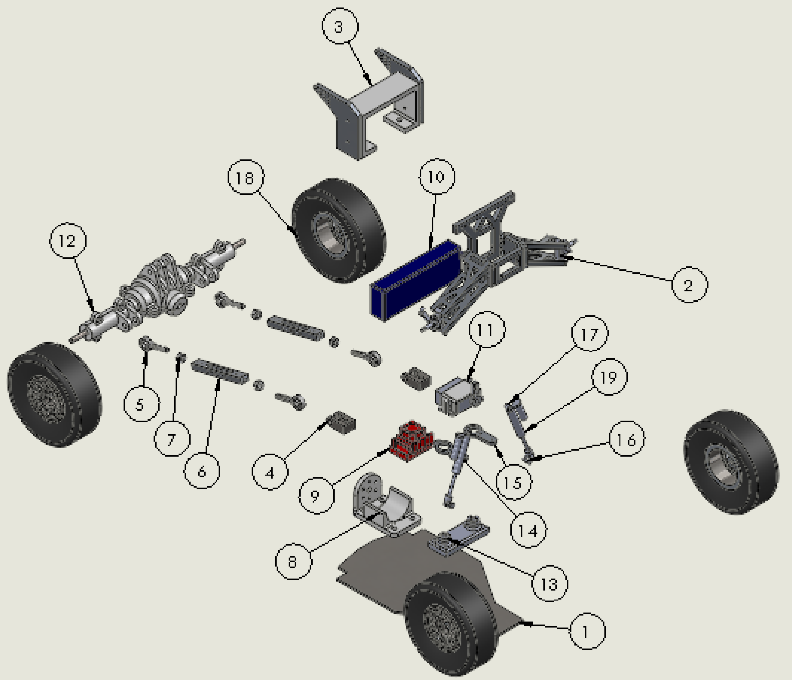
Table B02. Drawing Index

Drawing Assignment Num.	Drawing #(s)	Date Submitted
Upload DWG 1	CLW-20-001	October 11th 2023
Upload DWG 2	CLW-20-002	October 18th 2023
Upload DWG 3 and 4	CLW-20-003 and CLW-20-007	October 25th 2023
Upload DWG 5 and 6	CLW-20-004 and CLW-20-005	November 1st 2023
Upload DWG 7 and 8	CLW-20-008 and CLW-20-009	November 8th 2023
Upload DWG 9 and 10	CLW-20-010 and CLW-20-011	November 14th 2023
Upload DWG 11 and 12	CLW-10-001 and CLW-10-002	November 28th 2023
Upload DWG 13, 14, 15, 16 and 17	CLW-20-012, CLW-20-013, CLW-20-014, CLW-20-015, and CLW-10-004	January 5th 2024

Appendix BO3 – RC Baja Main Assembly – CLW-10-001



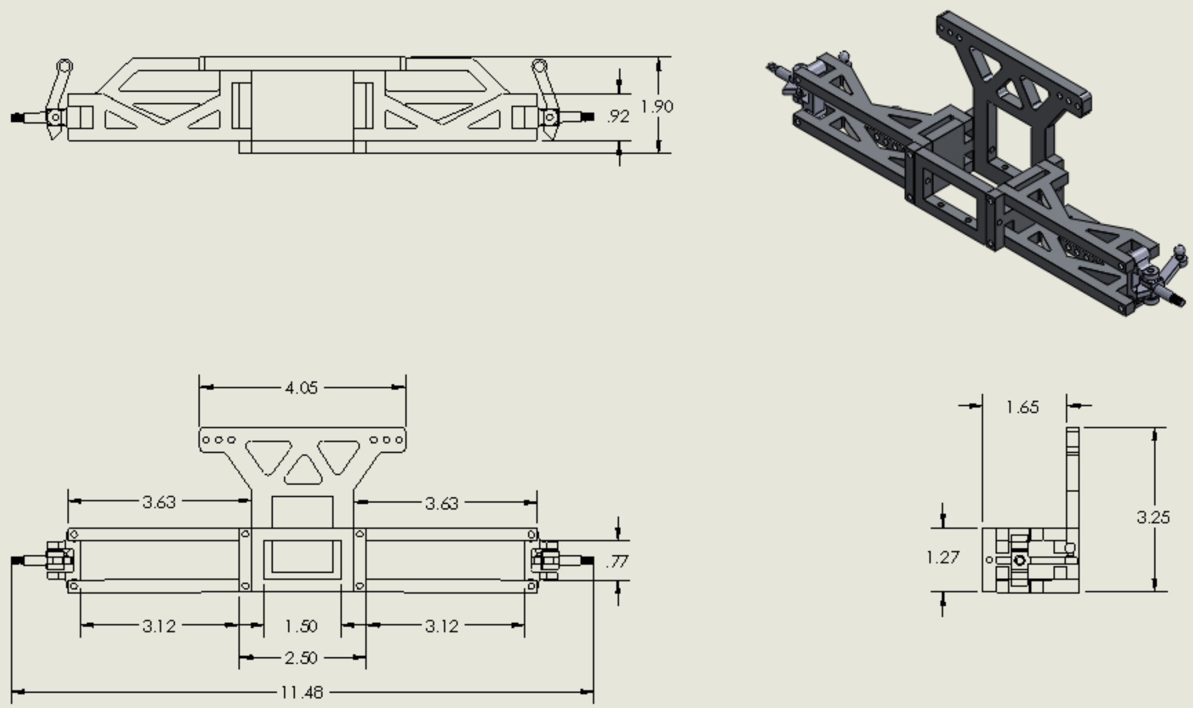
Appendix B03 – Continued



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	CRH-20-003	CHASSIS PLATE/FRAME	1
2	CLW-10-002	FRONT SUSPENSION	1
3	CLW-10-004	REAR SHOCK TOWER	1
4	CLW-20-010	TRAILING ARM MOUNT	2
5	CLW-55-001	BALL JOINT ROD END	4
6	CLW-20-001	TRAILING ARM	2
7	CLW-50-001	TRAILING ARM LOCKING NUT	4
8	CRH-20-002	MOTOR MOUNT	1
9	CRH-55-003	ESC	1
10	CRH-55-001	BATTERY	1
11	CLW-10-005	SERVO	1
12	CRH-10-002	REAR AXLE	1
13	CLW-10-006	STEERING BRACKET	1
14	CLW-20-013	STEERING BRACKET ARM	1
15	CLW-20-015	STEERING BRACKET ARM	1
16	CLW-20-012	SHOCK SPACER	2
17	CLW-20-016	SHOCK SPACER	2
18	CLW-55-007	WHEEL/TIRE	4
19	CLW-55-004	FRONT KING SHOCK	2

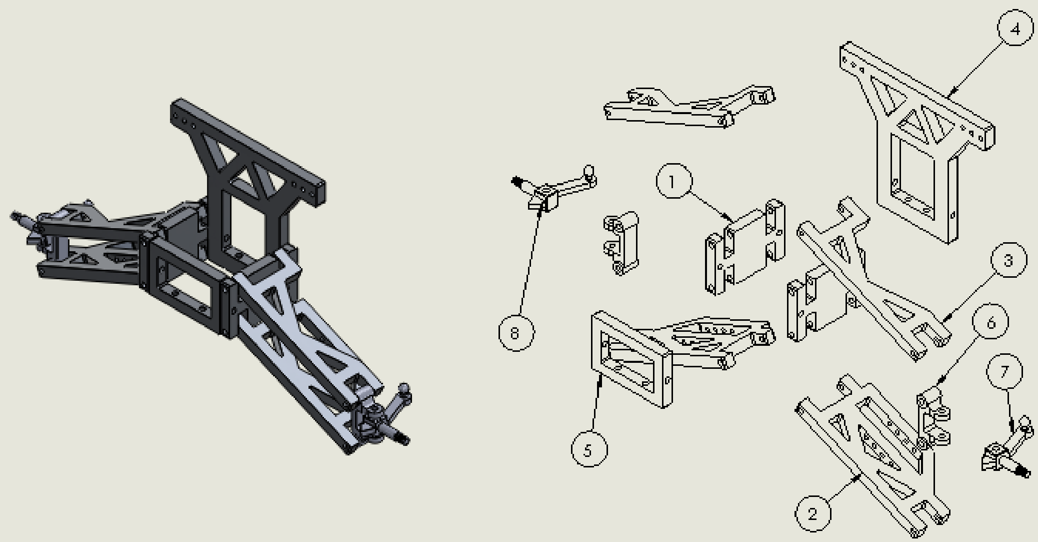
INTERPRET GEOMETRIC TOLERANCE PER ASME Y14.5	PART NUMBER: CLW-10-001	REVISION: A
DIMENSIONS ARE IN INCHES TOLERANCES (UNLESS NOTED): FRACTIONAL ± 1/16" ANGULAR: MACH ± .5 DEG BEND ± 1 DEG TWO PLACE DECIMAL ± 0.030" THREE PLACE DECIMAL ± 0.005"	MATERIAL: VARIOUS	SCALE 1:4
	DRAWN BY: CHAYCE WILLIAMS	PAGE: 2
	WEIGHT: 7.86 LBS	DATE: 11/28/2023
	DESCRIPTION: MAIN ASSEMBLY	QTY: 1

Appendix BO4 – Front Suspension Sub-Assembly – CLW-10-002



INTERPRET GEOMETRIC TOLERANCE PER ASME Y14.5	PART NUMBER: CLW-10-002	REVISION: A
DIMENSIONS ARE IN INCHES TOLERANCES (UNLESS NOTED): FRACTIONAL ± 1/16" ANGULAR: MACH ± .5 DEG BEND ± 1 DEG TWO PLACE DECIMAL ± 0.030" THREE PLACE DECIMAL ± 0.005"	MATERIAL: 6061	SCALE 1:2
	DRAWN BY: CHAYCE WILLIAMS	PAGE: 1
	WEIGHT: 0.543 LBS	DATE: 11/28/2023
	DESCRIPTION: FRONT SUSPENSION	QTY: 1

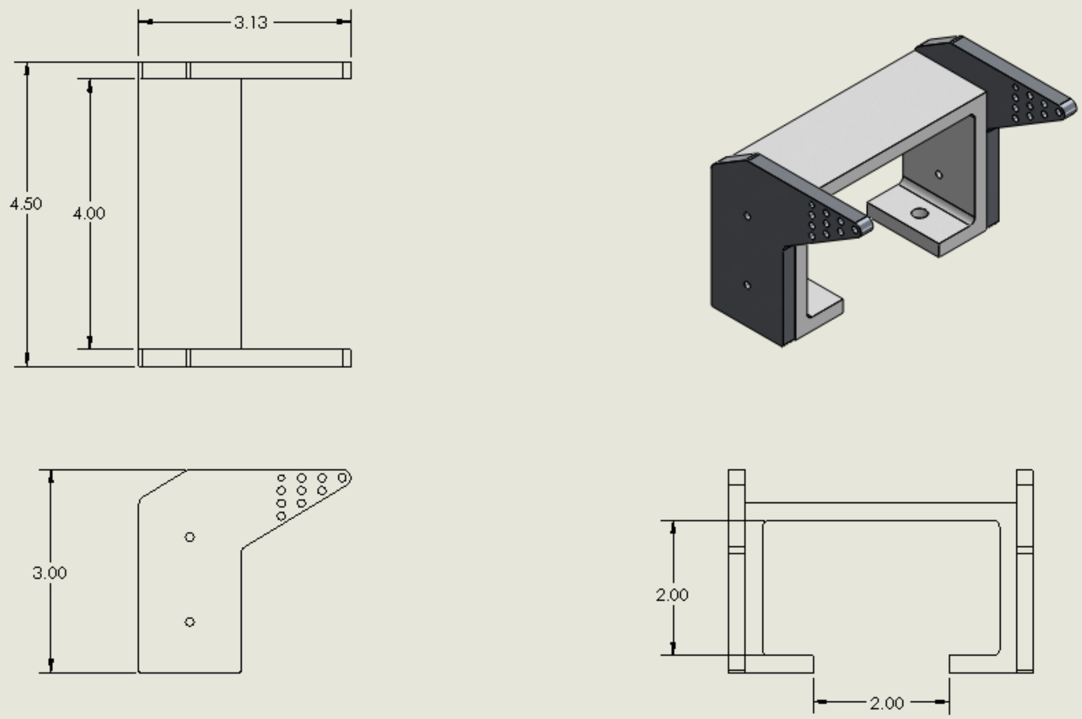
Appendix B04 - Continued



ITEM NO.	PART NUMBER	QTY.
1	CLW-20-004	2
2	CLW-20-002	2
3	CLW-20-003	2
4	CLW-20-007	1
5	CLW-20-005	1
6	CLW-55-002	2
7	CLW-55-003	1
8	CLW-55-003	1

INTERPRET GEOMETRIC TOLERANCE PER ASME Y14.5	PART NUMBER: CLW-10-002	REVISION: A
DIMENSIONS ARE IN INCHES TOLERANCES (UNLESS NOTED): FRACTIONAL ± 1/16" ANGULAR: MACH ± .5 DEG BEND ± 1 DEG TWO PLACE DECIMAL ± 0.030" THREE PLACE DECIMAL ± 0.005"	MATERIAL: 6061	SCALE 1:2
	DRAWN BY: CHAYCE WILLIAMS	PAGE: 2
	WEIGHT: 0.543 LBS	DATE: 11/28/2023
	DESCRIPTION: FRONT SUSPENSION	QTY: 1

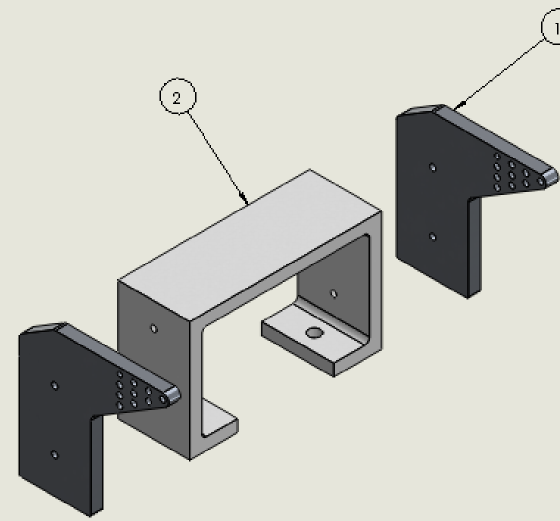
Appendix BO5 – Rear Shock Tower Sub Assembly – CLW-10-004



NOTES:
1. SUB-ASSEMBLY OF REAR SHOCK TOWER
2. MOTOR MOUNT HAS TO FIT IN CUTOUT
3. MIDDLE SHOCK TOWER SUPPORT IS RIGID
4. NO PAINT (COLOR DOES NOT MATTER)
5. DEBURR AND REMOVE ALL SHARP ADGES

INTERPRET GEOMETRIC TOLERANCE PER ASME Y14.5	PART NUMBER: CLW-10-004	REVISION:
DIMENSIONS ARE IN INCHES TOLERANCES (UNLESS NOTED):	MATERIAL: PLA AND 6061	SCALE 1:2
FRACTIONAL ± 1/16"	DRAWN BY: CHAYCE WILLIAMS	PAGE: 1
ANGULAR: MACH ± .5 DEG BEND ± 1 DEG TWO PLACE DECIMAL ± 0.030"	WEIGHT: 0.4 LBS	DATE: 1/5/2024
THREE PLACE DECIMAL ± 0.005"	DESCRIPTION: REAR SHOCK TOWER	QTY: 1

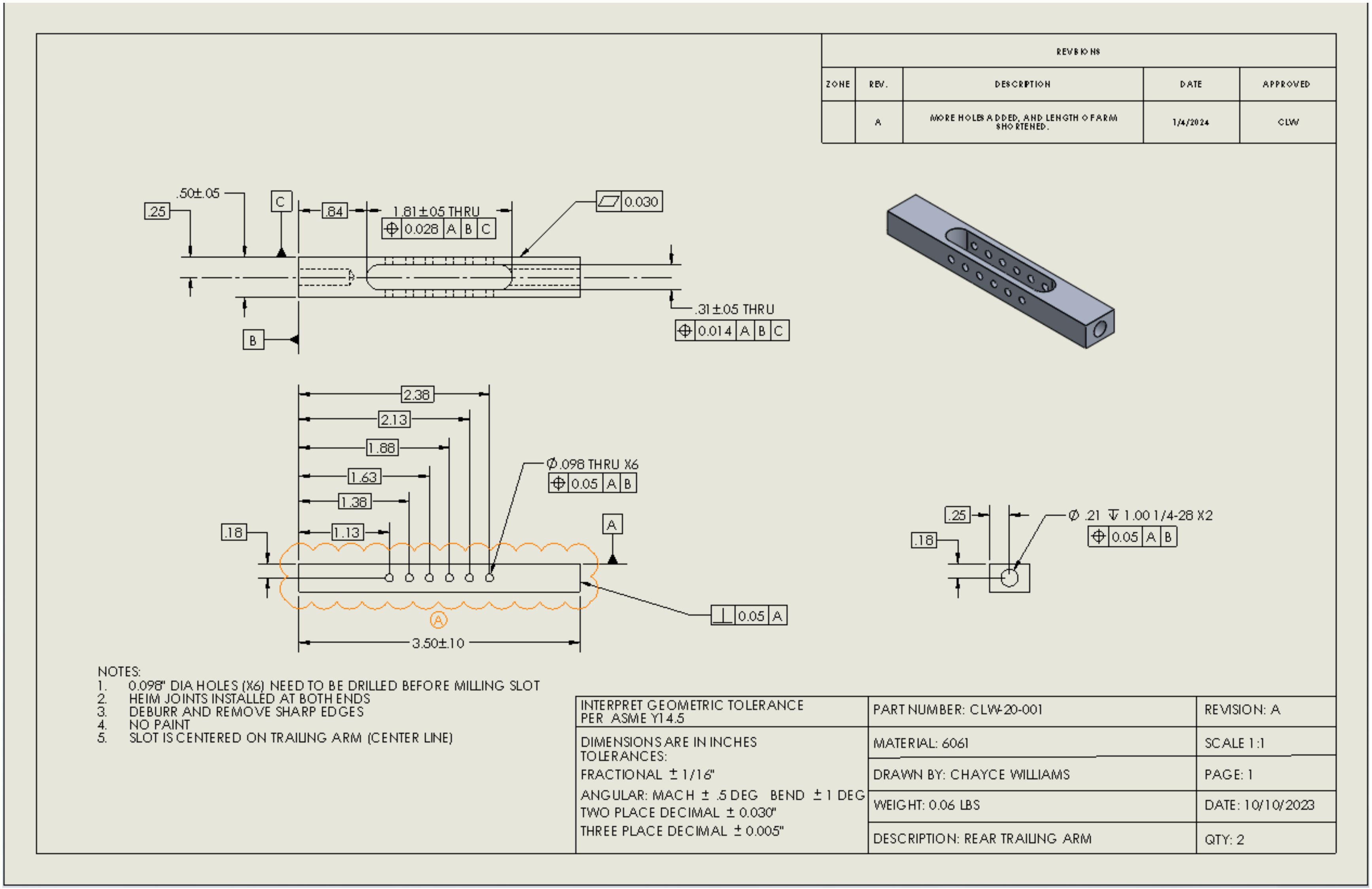
Appendix B05 – Continued



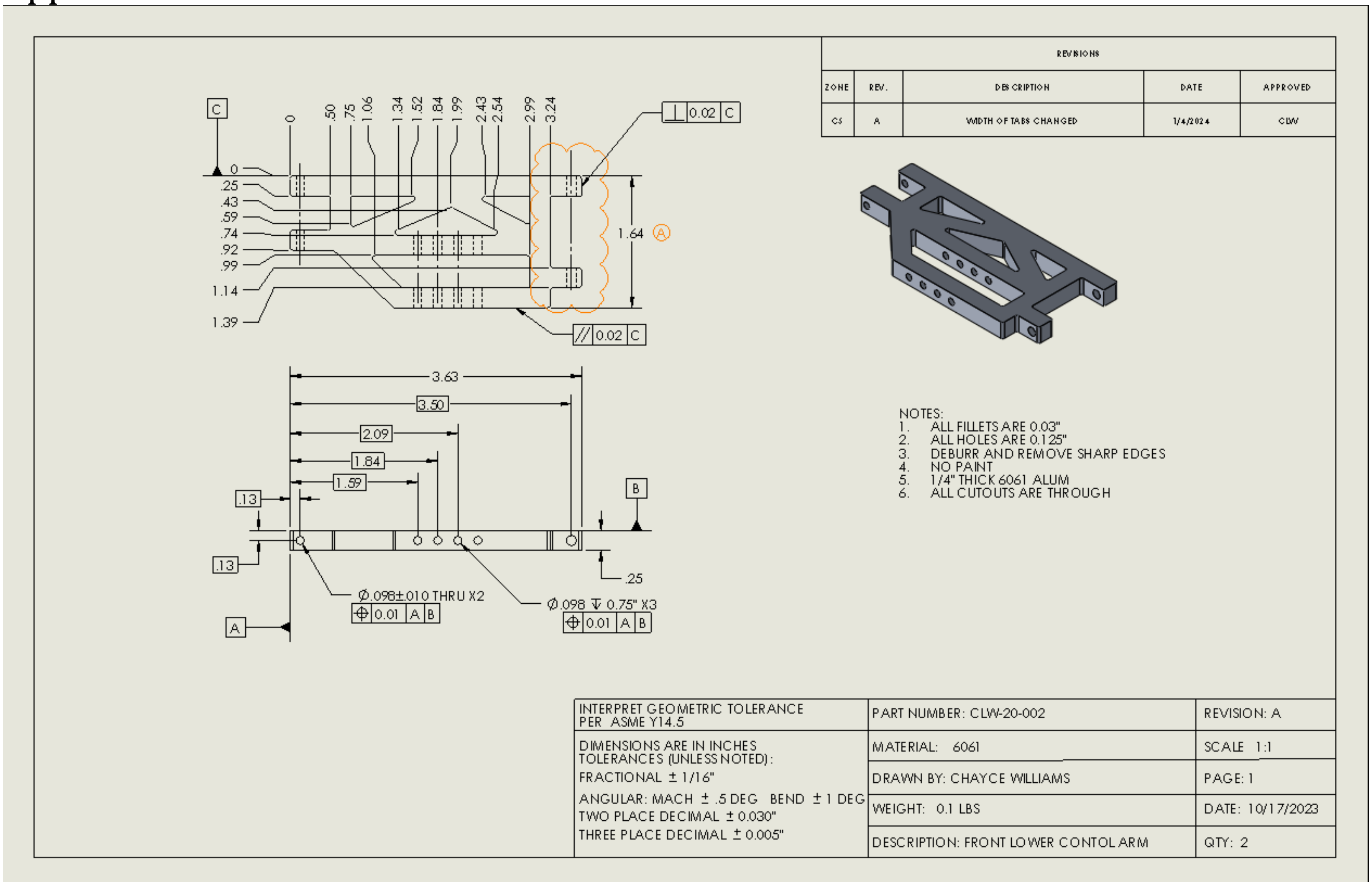
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	CLW-20-008	REAR SHOCK TOWER	2
2	CLW-20-009	REAR SHOCK TOWER SUPPORT	1

INTERPRET GEOMETRIC TOLERANCE PER ASME Y14.5	PART NUMBER: CLW-10-004	REVISION:
DIMENSIONS ARE IN INCHES TOLERANCES (UNLESS NOTED): FRACTIONAL ± 1/16" ANGULAR: MACH ± .5 DEG BEND ± 1 DEG TWO PLACE DECIMAL ± 0.030" THREE PLACE DECIMAL ± 0.005"	MATERIAL: PLA AND 6061	SCALE 1:2
	DRAWN BY: CHAYCE WILLIAMS	PAGE: 2
	WEIGHT: 0.4 LBS	DATE: 1/5/2024
	DESCRIPTION: REAR SHOCK TOWER	QTY: 1

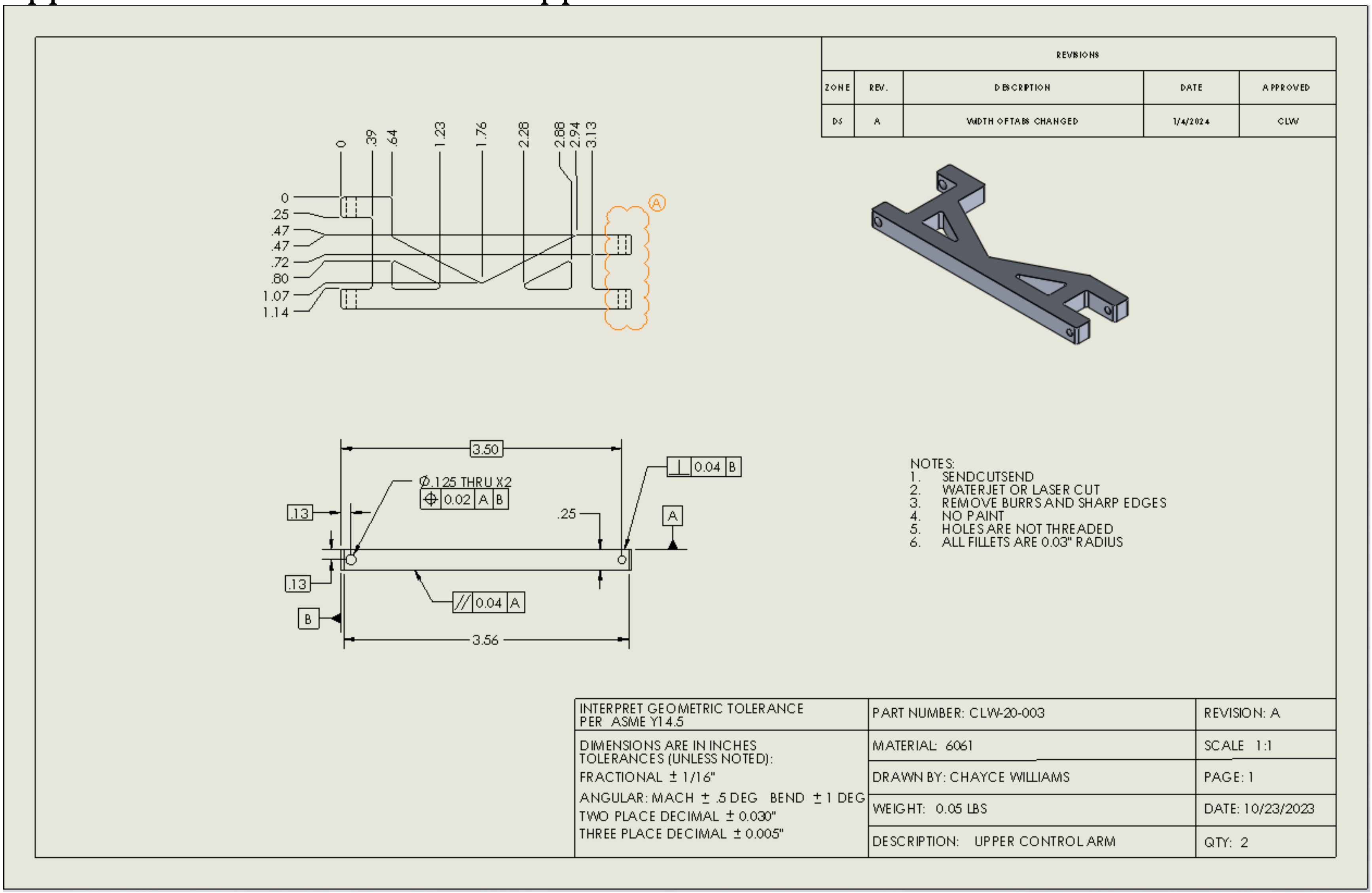
Appendix BO6 – CLW-20-001 – Trailing Arm Drawing



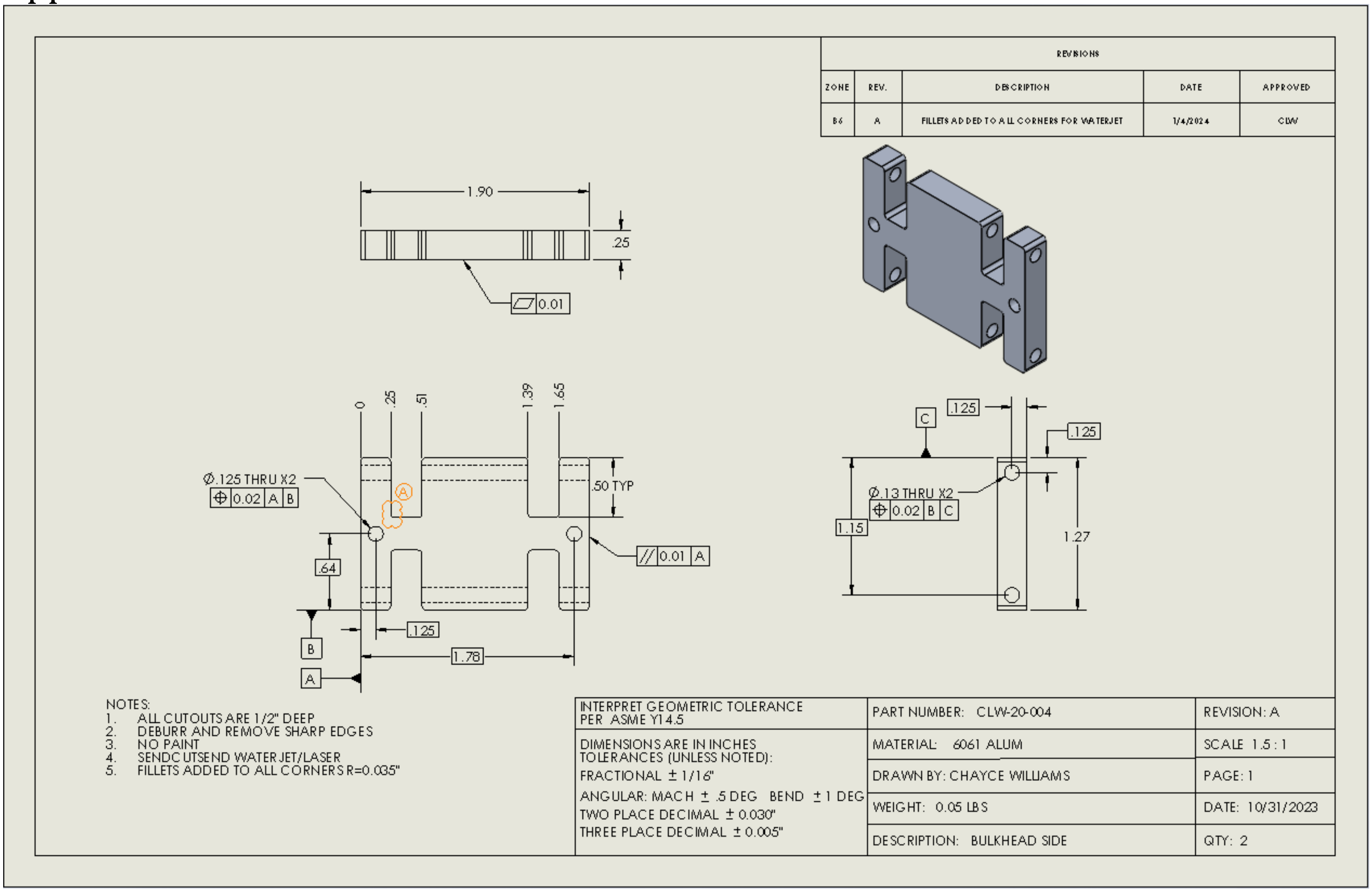
Appendix B07 – CLW-20-002 – Front Lower Control Arm



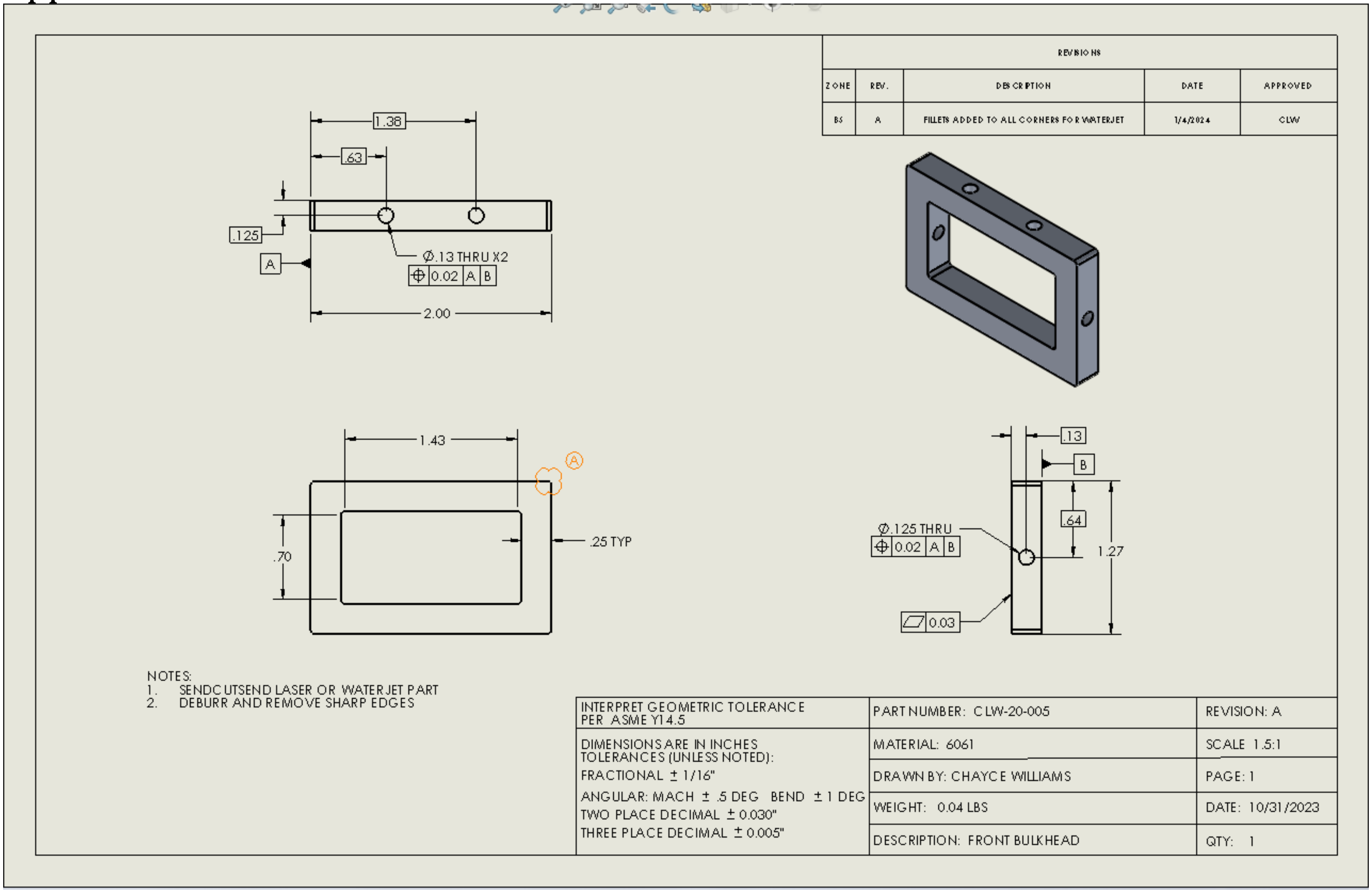
Appendix BO8 – CLW-20-003 – Upper Control Arm



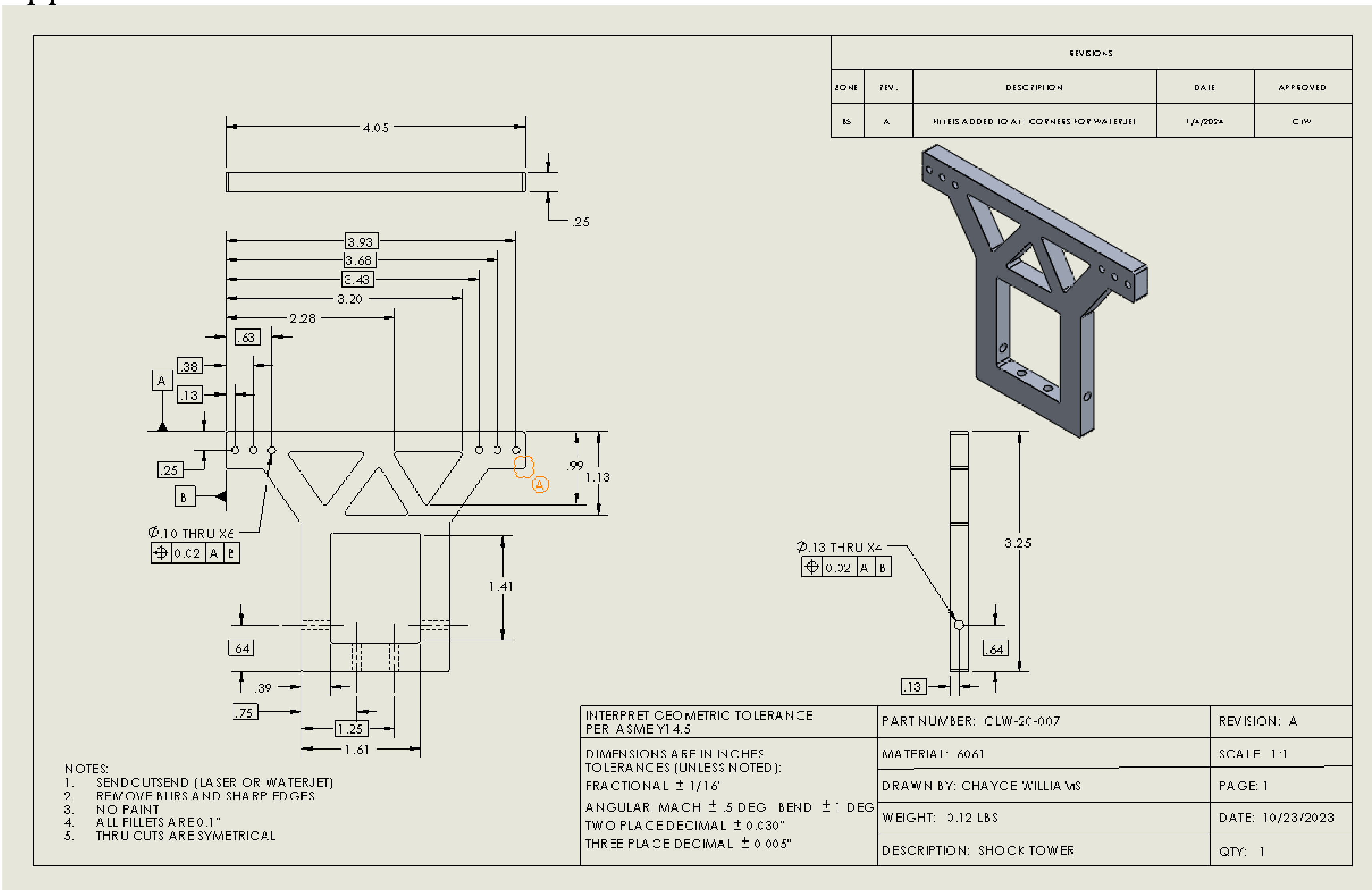
Appendix BO9 – CLW-20-004 – Side of Bulkhead



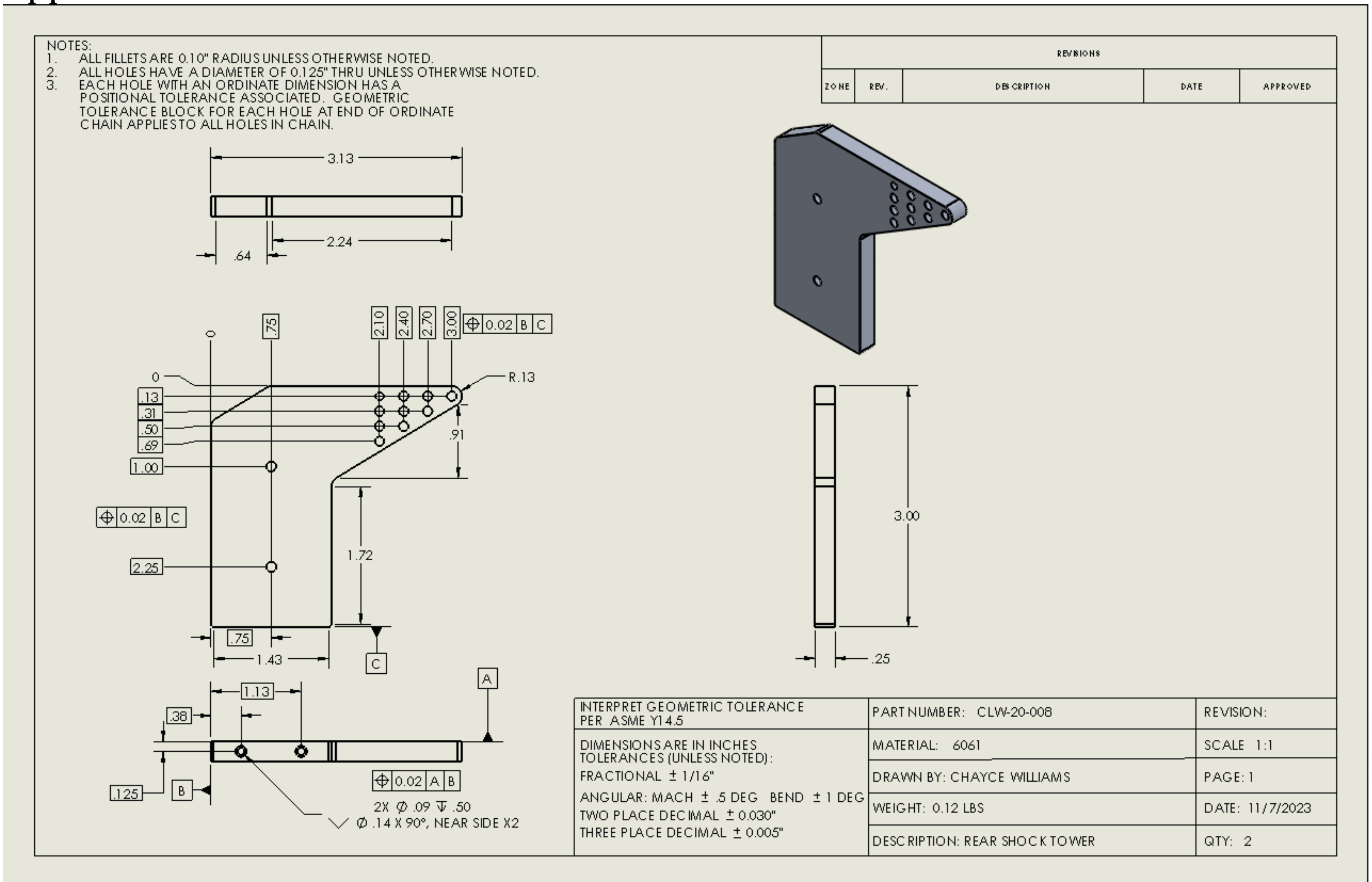
Appendix B10 – CLW-20-005 – Front of Bulkhead



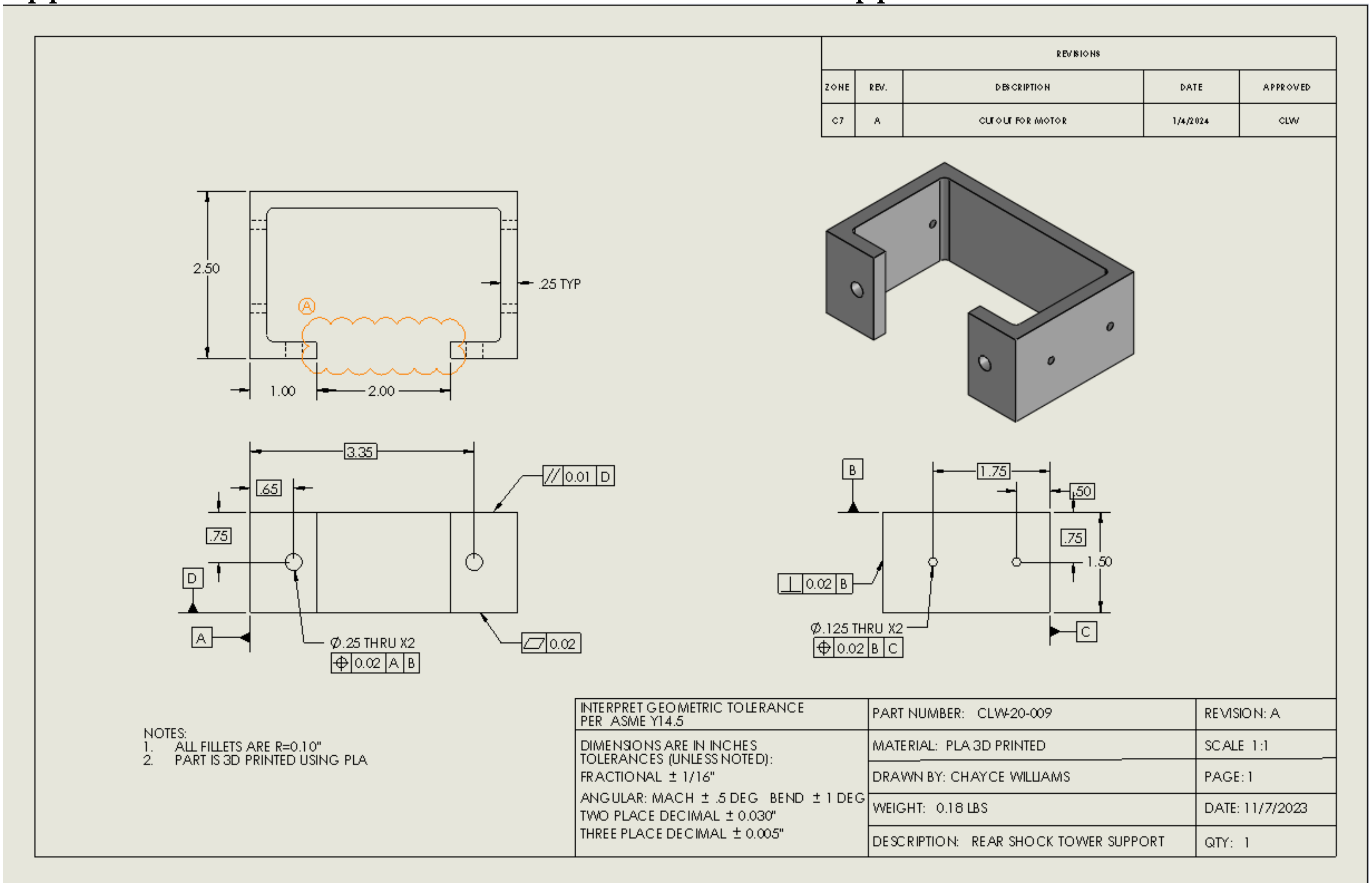
Appendix B11 – CLW-20-007 – Shock Tower



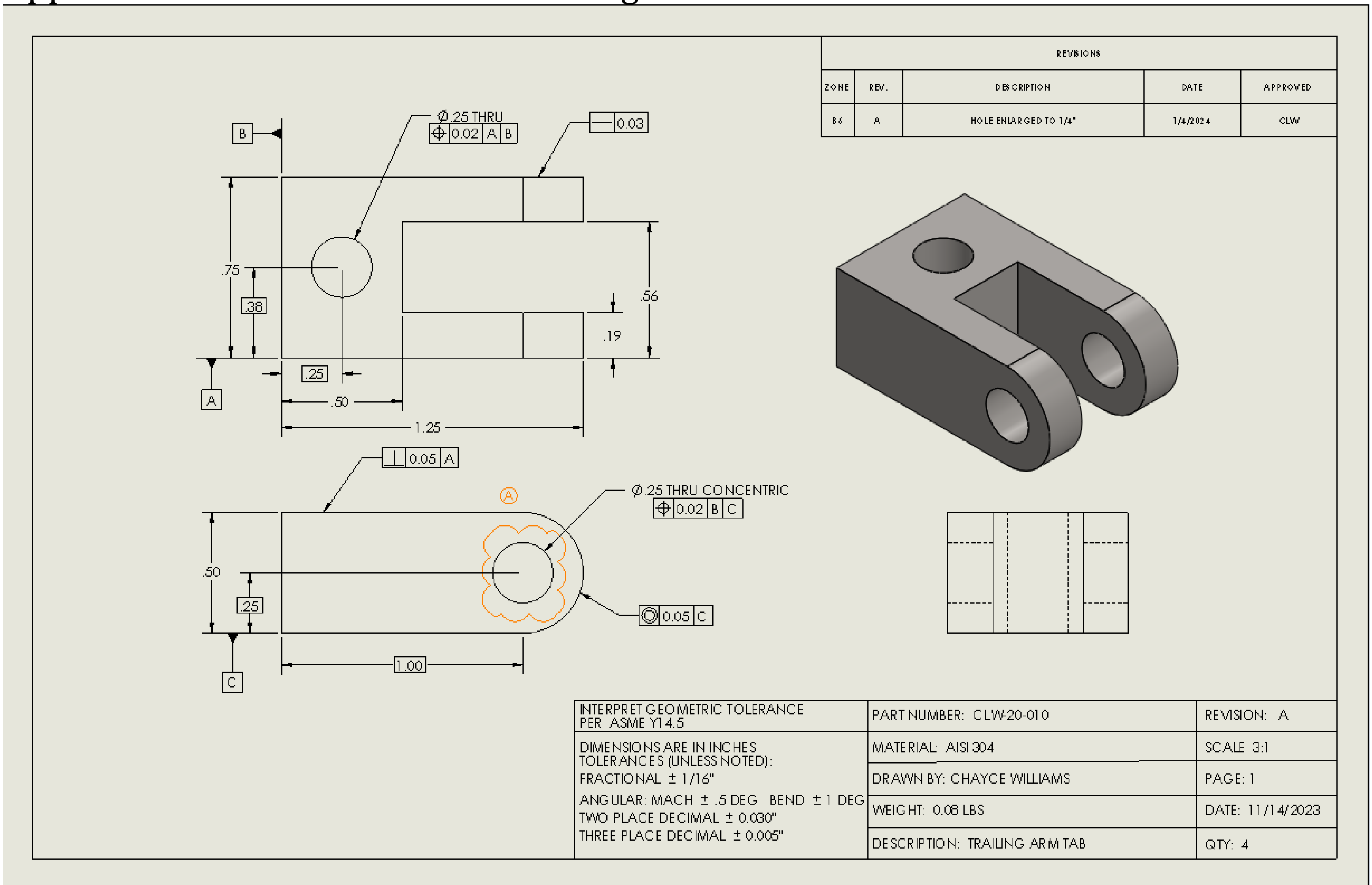
Appendix B12 – CLW-20-008 – Rear Shock Tower



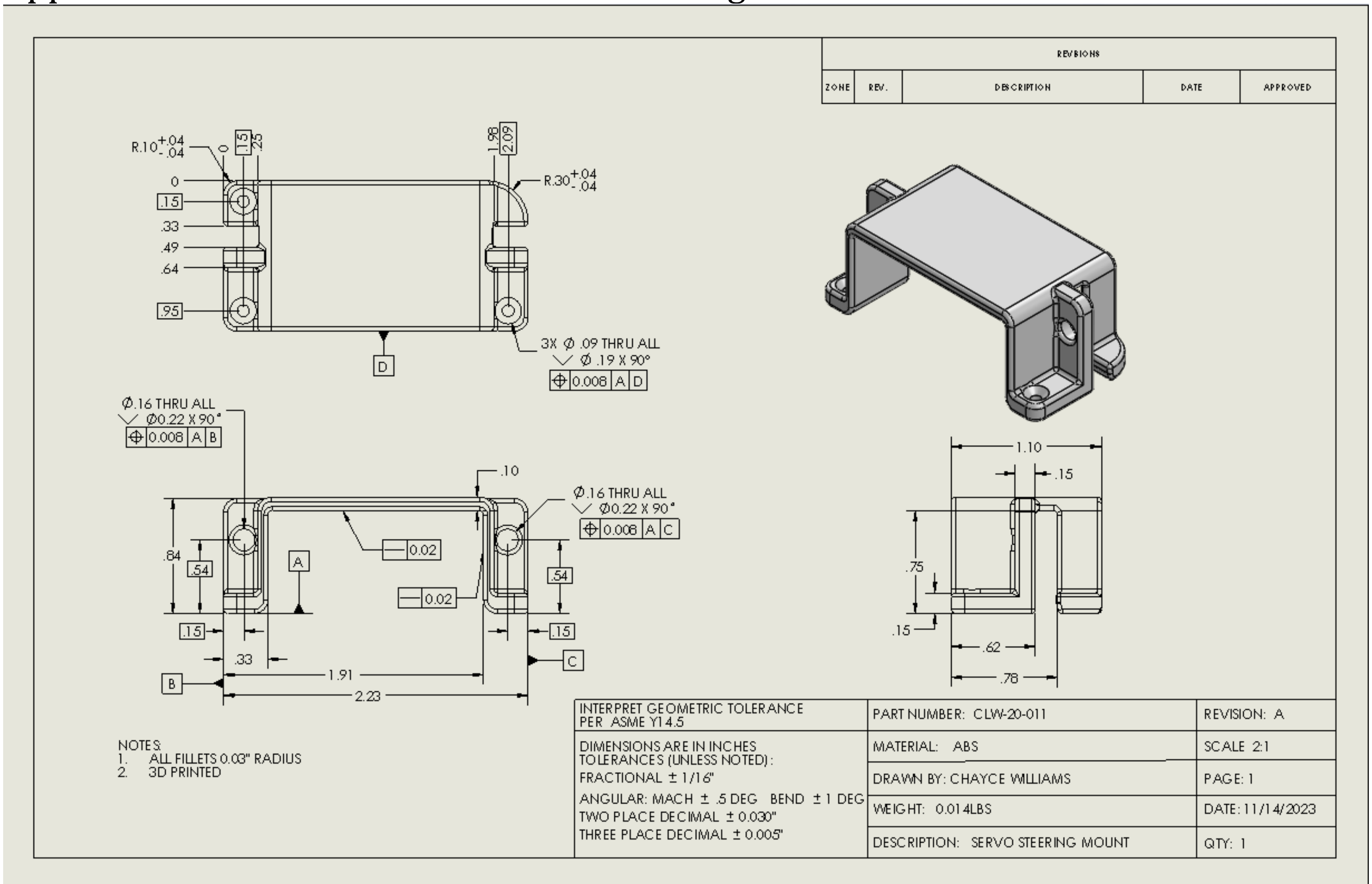
Appendix B13 – CLW-20-009 – Rear Shock Tower Support



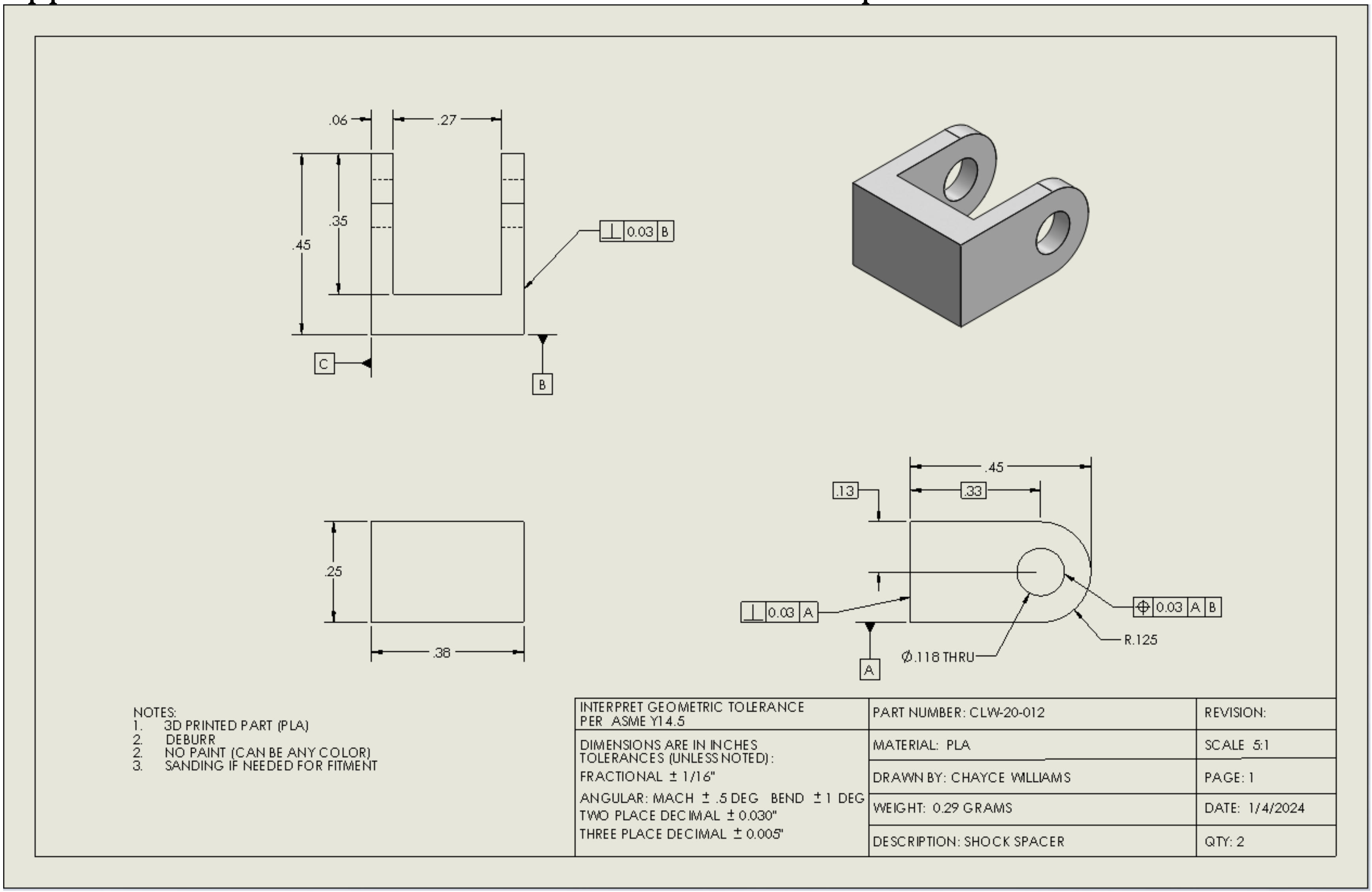
Appendix B14 – CLW-20-010 – Trailing Arm Tabs



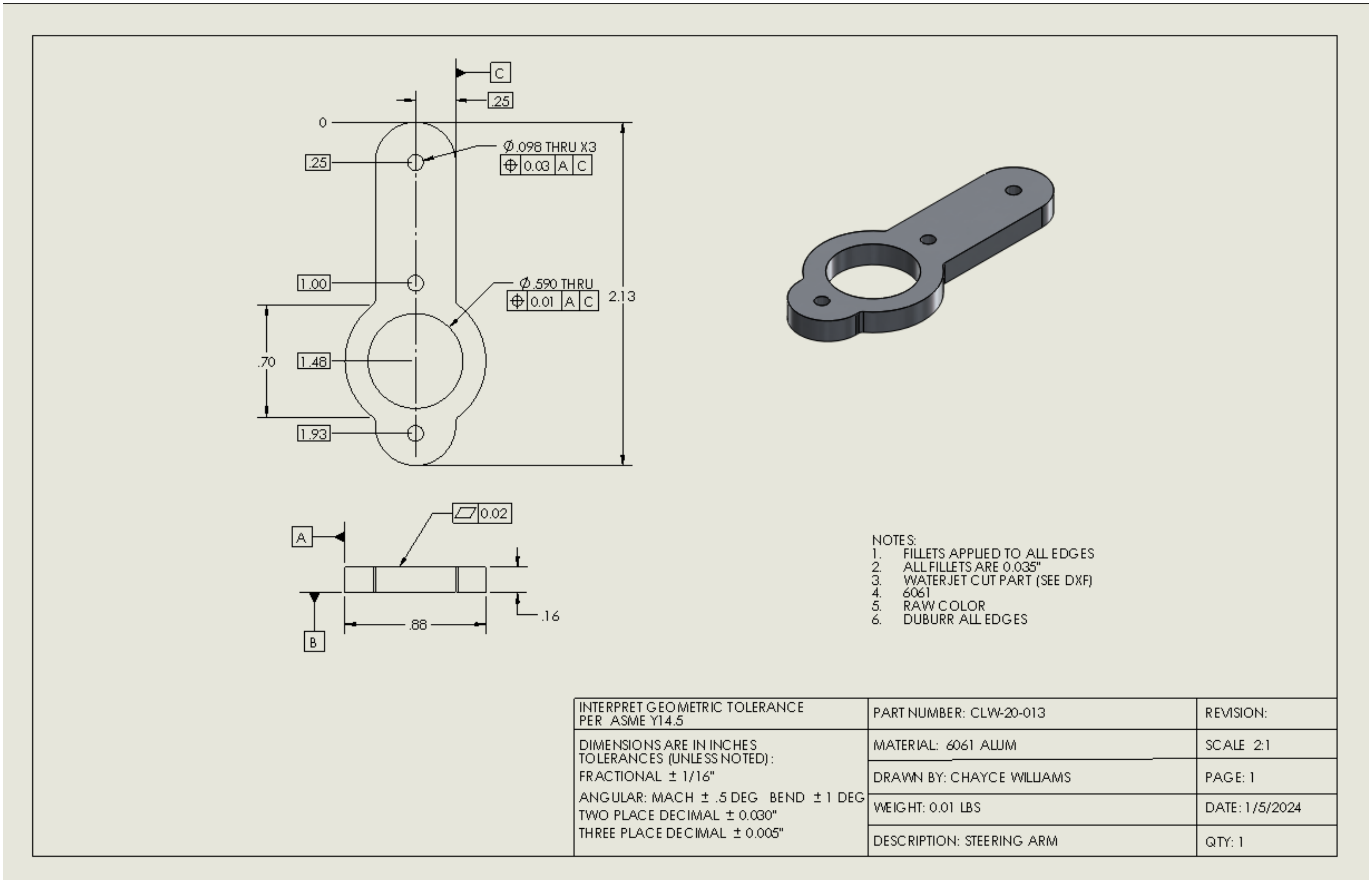
Appendix B15 – CLW-20-011 – Servo Steering Mount



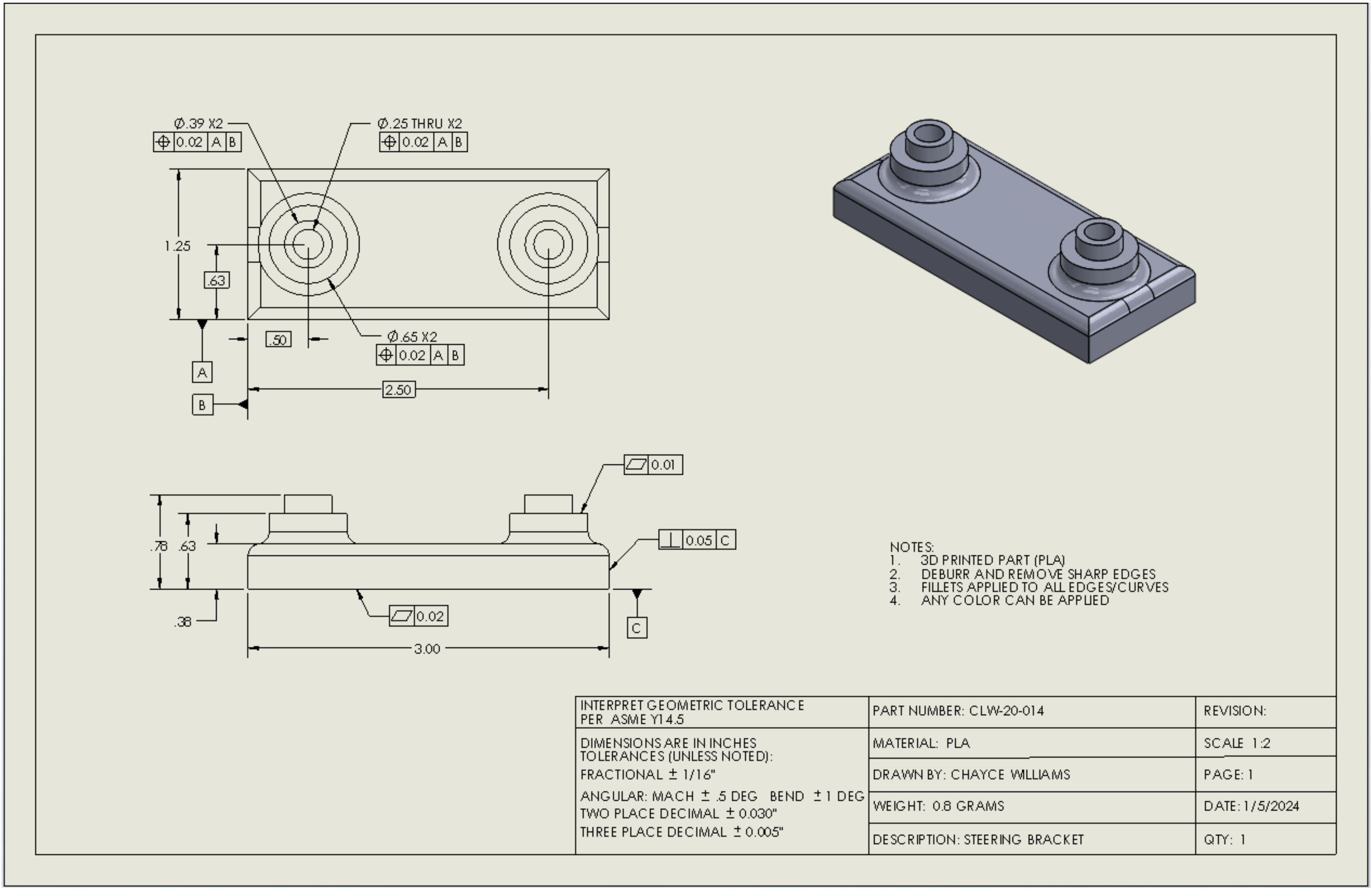
Appendix B16 – CLW-20-012 – Double Shear Shock Spacer



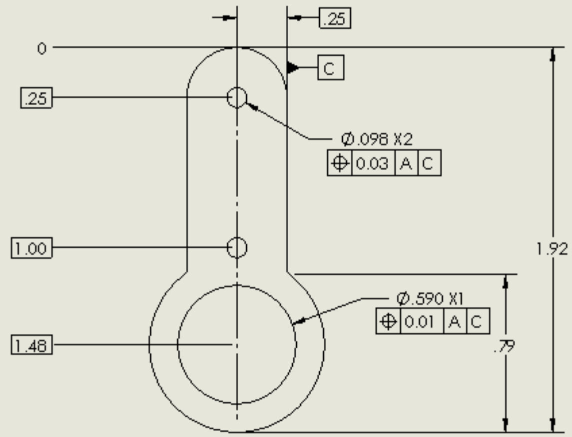
Appendix B17 – CLW -20-013 – Steering Arm

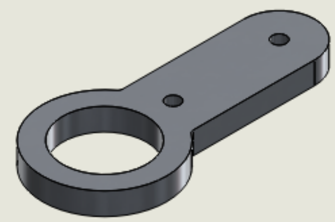


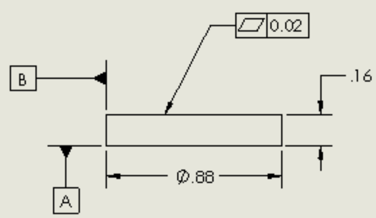
Appendix B18 – CLW-20-014 – Steering Bracket



Appendix B19 – CLW-20-015 – Steering Arm







NOTES:
1. WATER JET CUT PART (SEE DXF)
2. DEBURR AND REMOVE SHARP EDGES
3. ALL CORNERS HAVE FILLETS
4. ALL FILLETS ARE 0.035"
5. NO PAINT (COLOR DOES NOT MATTER)

INTERPRET GEOMETRIC TOLERANCE PER ASME Y14.5	PART NUMBER: CLW-20-015	REVISION:
DIMENSIONS ARE IN INCHES TOLERANCES (UNLESS NOTED): FRACTIONAL ± 1/16" ANGULAR: MACH ± .5 DEG BEND ± 1 DEG TWO PLACE DECIMAL ± 0.030" THREE PLACE DECIMAL ± 0.005"	MATERIAL: 6061 ALUM	SCALE 1:2
	DRAWN BY: CHAYCE WILLIAMS	PAGE: 1
	WEIGHT: 0.01 LBS	DATE: 1/5/2024
	DESCRIPTION: STEERING ARM	QTY: 1

APPENDIX C – Parts List and Costs

Table C.1 Parts List

Part Number	QTY	Part Description	Source	Cost	Disposition
CLW-20-001	2	REAR TRAILING ARM	SENDCUTSEND	$30.00	1/8/2024 DELIVERED
CLW-20-002	2	LOWER CONTROL ARM	SENDCUTSEND	$30.00	1/8/2024 DELIVERED
CLW-20-003	2	UPPER CONTROL ARM	SENDCUTSEND	$30.00	1/8/2024 DELIVERED
CLW-20-004	2	SIDE OF BULKHEAD	SENDCUTSEND	$30.00	1/8/2024 DELIVERED
CLW-20-005	1	FRONT OF BULKHEAD	SENDCUTSEND	$20.00	1/8/2024 DELIVERED
CLW-20-007	1	FRONT SHOCK TOWER	SENDCUTSEND	$25.00	1/ 8/2024 DELIVERED
CLW-20-008	2	REAR SHOCK TOWER	SENDCUTSEND	$50.00	1/8/2024 DELIVERED
CLW-20-009	1	REAR SHOCK TOWER SUPPORT	3D PRINTERS CWU	$0	1/4/2024 DELIVERED
CLW-20-010	2	REAR TRAILING ARM TABS	SENDCUTSEND	$30.00	1/8/2024 DELIVERED
CLW-20-011	1	STEERING SERVO MOUNT	3D PRINTERS CWU	$0	1/4/2024 BUILD DATE
CLW-20-012	2	DOUBLE SHEAR SHOCK SPACER	3D PRINTERS CWU	$0	11/6/2023 DELIVERED
CLW-20-013	1	STEERING ARM	SENDCUTSEND	$15.00	1/8/2023 DELIVERED
CLW-20-14	1	STEERING BRACKET	3D PRINTERS CWU	$0	1/5/2024 DELIVERED
CLW-20-015	1	STEERING ARM	SENDCUTSEND	$15.00	1/8/2023 DELIVERED

Table C.2 Fasteners List

CLW-50-001	4	LOCKING NUT	MCMASTER CARR P/N 95505A611	$30.00	12/8/2023 DELIVERED
CLW-50-002	15	SHOULDER SCREW	MCMASTER CARR P/N 91273A116	$92.00	12/8/2023 DELIVERED

Table C.3 Bought Parts List

CLW-55-001	4	HEIM JOINT	MCMASTER CARR P/N 60645K121	$30.00	1/8/2024 DELIVERED
CLW-55-002	2	TAMIYA C-HUB	AMAZON	$30.00	10/23/2023 DELIVERED
CLW-55-003	2	TAMIYA SPINDLE	AMAZON	$20.00	10/23/2023 DELIVERED
CLW-55-004	2	RC4WD 100MM KING SHOCKS	AMAZON	$40.00	10/23/2023 DELIVERED
CLW-55-007	4	WHEELS/TIRES	AMAZON	$40.00	12/12/2023 DELIVERED
CLW-55-008	2	REAR SHOCKS	RC4WD	$48.00	12/12/2023 DELIVERED
CLW-55-009	1	SERVO	AMAZON	$30.00	12/15/2023 DELIVERED

TOTAL AMOUNT OF PARTS	21

APPENDIX D – Budget

Table D.1 Total Budget

ITEM	QTY	DESCRIPTION	COST
MANUFACTURING LABOR	125 HRS ($35/HR)	IN HOUSE MACHINE SHOP TIME WORKING.	$4375
MATERIAL	3	PLA, ABS, ALUMINUM	$100
PURCHASED PARTS	5	SHOCKS (FRONT AND REAR), STEERING SERVO, C-HUBS, KNUCKLES,	$300
FASTENERS	100	NUTS, BOLTS, SCREWS, WASHERS.	$200
SEND CUT SEND	10	ALL SHEET METAL PARTS	$400

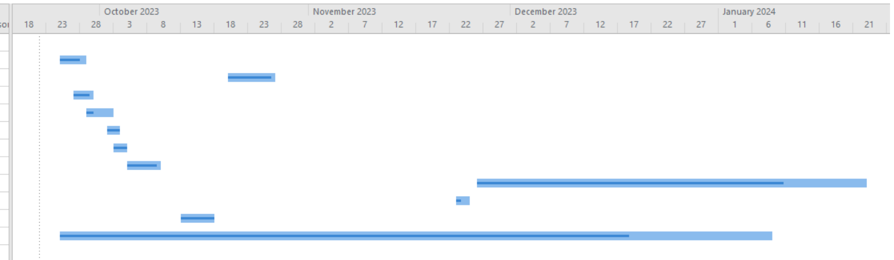
Table D.2 Total Project Budget

TOTAL PROJECT EXPENDITURES	$5375

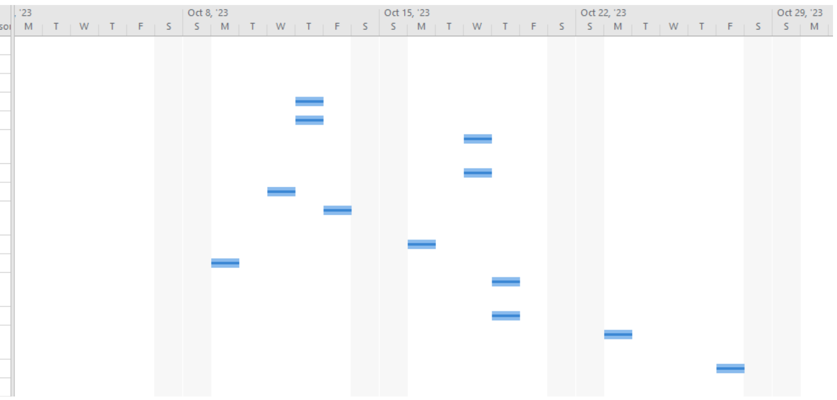
APPENDIX E – Schedule

Gantt Chart: Fall – Sections 1,2,3

	ⓘ	Task Mode	Task Number	Task Name	Est Hours	Start	Finish	Duration	Actual Hours	% Complete	Predecessors
1				Proposal/Report Writing						0%	
2			1a	Intro	6 hrs	Mon 9/25/23	Thu 9/28/23	4 days	7hrs	75%	
3			1b	Analysis	4 hrs	Fri 10/20/23	Thu 10/26/2:	5 days	5 hrs	90%	
4			1c	Methods	10 hrs	Wed 9/27/23	Fri 9/29/23	3 days?	7 hrs	75%	
5			1d	Testing	5 hrs	Fri 9/29/23	Mon 10/2/23	2 days	3 hrs	50%	
6			1e	Budget	4 hrs	Mon 10/2/23	Tue 10/3/23	2 days?	1 hrs	100%	
7			1f	Schedule	3 hrs	Tue 10/3/23	Wed 10/4/2:	2 days	1 hrs	100%	
8			1g	Project Management	9 hrs	Thu 10/5/23	Mon 10/9/23	3 days?	3 hrs	75%	
9			1h	Discussion	12 hrs	Sun 11/26/23	Mon 1/22/24	41 days	4 hrs	80%	
10			1i	Conclusion	5 hrs	Thu 11/23/23	Fri 11/24/23	2 days	3 hrs	45%	
11			1j	Drawings	10 hrs	Fri 10/13/23	Tue 10/17/2:	3 days	15 hrs	100%	
12			1k	Appendix	10 hrs	Mon 9/25/23	Mon 1/8/24	76 days	3 hrs	80%	
13				Subtotal:					36 hrs	0%	

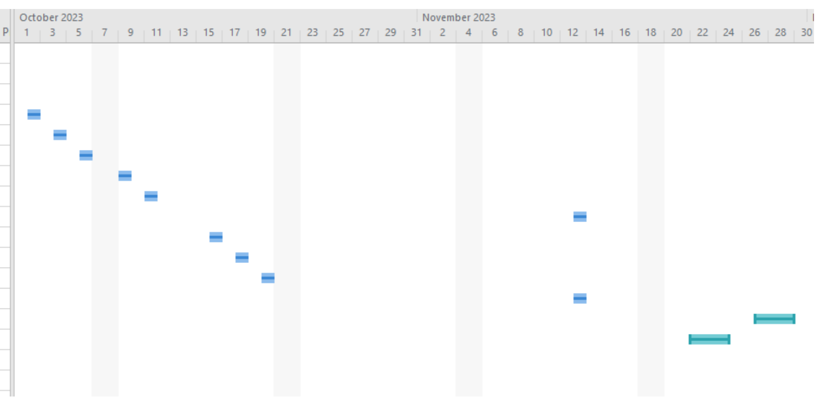


	ⓘ	Task Mode	Task Number	Task Name	Est Hours	Start	Finish	Duration	Actual Hours	% Complete	Predecessors
13				Subtotal:					36 hrs	0%	
14										0%	
15				Analysis						0%	
16			2a	Lower Control Arm	3 hrs	Thu 10/12/23	Thu 10/12/2:	1 day	2 hrs	100%	
17			2b	Upper Control Arm	3 hrs	Thu 10/12/23	Thu 10/12/2:	1 day	2 hrs	100%	
18			2c	Rear Shock Tower Deflection	3 hrs	Wed 10/18/23	Wed 10/18/23	1 day	2 hrs	100%	
19			2d	Front Shock Tower	3 hrs	Wed 10/18/23	Wed 10/18/2	1 day	2 hrs	100%	
20			2e	Rear Trailing Arms	3 hrs	Wed 10/11/23	Wed 10/11/2	1 day	2 hrs	100%	
21			2f	Steering Tie Rod Critical Load	3 hrs	Fri 10/13/23	Fri 10/13/23	1 day	2 hrs	100%	
22			2g	Upper Long Arms (REAR)	3 hrs	Mon 10/16/23	Mon 10/16/2	1 day	2 hrs	100%	
23			2h	Steering Angle	3 hrs	Mon 10/9/23	Mon 10/9/23	1 day?	1hrs	100%	
24			2i	Maximum Bolt Shear Stress	3 hrs	Thu 10/19/23	Thu 10/19/23	1 day?	2 hrs	100%	
25			2j	Shock Spring Rate	3 hrs	Thu 10/19/23	Thu 10/19/2:	1 day?	1 hrs	100%	
26			2k	Rear Shock Tower Thickness	3 hrs	Mon 10/23/23	Mon 10/23/23	1 day?	3 hrs	100%	
27			2l	Chassis Mounts	3 hrs	Fri 10/27/23	Fri 10/27/23	1 day?	2 hrs	100%	
28				Subtotal:					23 hrs	0%	



GANTT CHART

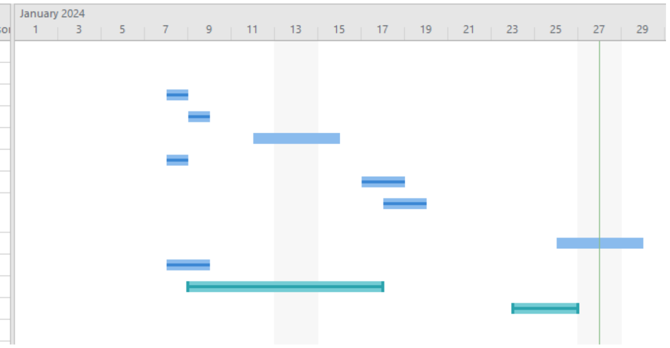
	Task Mode	Task Number	Task Name	Est Hours	Start	Finish	Duration	Actual Hours	% Complete	P
28			Subtotal:					23 hrs	0%	
29									0%	
30			Documentation						0%	
31		3a	CLW-20-001	1	Mon 10/2/23	Mon 10/2/23	1 day?	1	100%	
32		3b	CLW-20-002	1	Wed 10/4/23	Wed 10/4/2:	1 day?	2	100%	
33		3c	CLW-20-003	1	Fri 10/6/23	Fri 10/6/23	1 day?	2	100%	
34		3d	CLW-20-004	1	Mon 10/9/23	Mon 10/9/23	1 day?	2	100%	
35		3e	CLW-20-005	1	Wed 10/11/23	Wed 10/11/2	1 day?	2	100%	
36		3f	CLW-20-010	1	Mon 11/13/23	Mon 11/13/2	1 day	2	100%	
37		3g	CLW-20-007	1	Mon 10/16/23	Mon 10/16/2	1 day?	2	100%	
38		3h	CLW-20-008	1	Wed 10/18/23	Wed 10/18/2	1 day?	2	100%	
39		3i	CLW-20-009	1	Fri 10/20/23	Fri 10/20/23	1 day?	2	100%	
40		3j	CLW-20-011	1	Mon 11/13/23	Mon 11/13/2	1 day?	2	100%	
41		3k	CLW-10-002	2	Mon 11/27/23	Wed 11/29/2	3 days	2	100%	
42		3l	CLW-10-001	1	Wed 11/22/23	Fri 11/24/23	3 days	1	100%	
43									0%	
44			Subtotal:					22 hrs	0%	



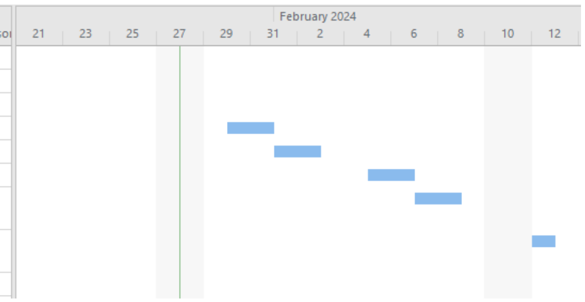
ANTT CHART

Gantt Chart: Winter – Sections 4,5

		Task Mode	Task Number	Task Name	Est Hours	Start	Finish	Duration	Actual Hours	% Complete	Predecessors
46										0%	
47				Part Manufacturing						0%	
48	✓		4a	Find Material	2 hrs	Mon 1/8/24	Mon 1/8/24	1 day?	1 hrs	100%	
49	✓		4b	Send Files SendCutSend	1 hrs	Tue 1/9/24	Tue 1/9/24	1 day?	1 hrs	100%	
50			4c	Make Rear Axle	5 hrs	Fri 1/12/24	Mon 1/15/24	2 days		0%	
51	✓		4d	Buy Front/Rear Spindles	1 hrs	Mon 1/8/24	Mon 1/8/24	1 day?	1 hrs	100%	
52	✓		4e	Make Bulkhead	5 hrs	Wed 1/17/24	Thu 1/18/24	2 days	2 hrs	100%	
53	✓		4f	Make Shocktower (SendCutSend)	2 hrs	Thu 1/18/24	Fri 1/19/24	2 days	2 hrs	100%	
54			4g	Update Website	1 hrs	Fri 1/26/24	Mon 1/29/24	2 days		0%	
55	✓		4h	Manufacture Plan	1 hrs	Mon 1/8/24	Tue 1/9/24	2 days	1 hrs	100%	
56	✓		4i	Make Trailing Arms	5 hrs	Tue 1/9/24	Wed 1/17/2	7 days	8 hrs	100%	
57	✓		4j	Rear Shock Tower	4 hrs	Wed 1/24/24	Fri 1/26/24	3 days	4 hrs	100%	
58				Subtotal:						0%	



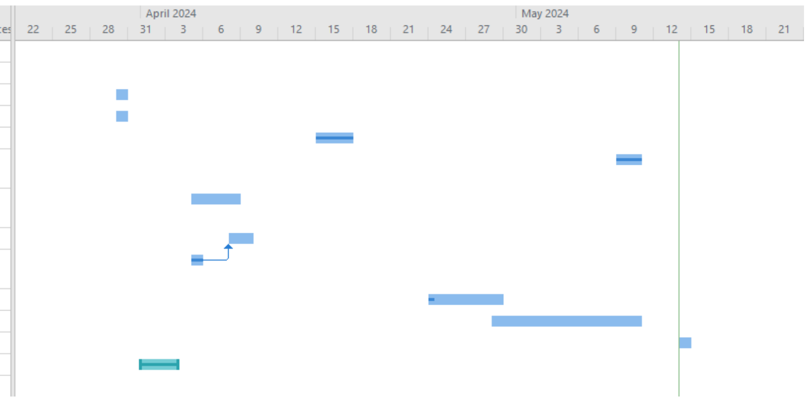
		Task Mode	Task Number	Task Name	Est Hours	Start	Finish	Duration	Actual Hours	% Complete	Predecessors
58				Subtotal:						0%	
59											
60				Device Manufacturing						0%	
61			5a	Assemble Bulkhead	1 hrs	Tue 1/30/24	Wed 1/31/2	2 days		0%	
62			5b	Assemble Shock Tower	1 hrs	Thu 2/1/24	Fri 2/2/24	2 days		0%	
63			5c	Assemble Rear Axel	1 hrs	Mon 2/5/24	Tue 2/6/24	2 days		0%	
64			5d	Assemble Steering Components	1 hrs	Wed 2/7/24	Thu 2/8/24	2 days		0%	
65			5e	Take Pictures of Assembled Parts	1 hrs	Mon 2/12/24	Mon 2/12/24	1 day?		0%	
66				Subtotal:						0%	



APPENDIX E - CONTINUED

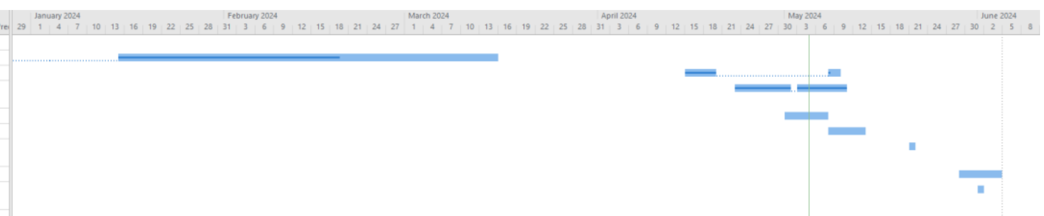
Gantt Chart: Spring – Sections 6,7

	Task Number	Task Name	Est Hours	Start	Finish	Duration	Actual Hours	% Complete	Predeces
70									
71		Device Evaluation						0%	
72	6a	Drop Test	1 hrs	Sat 3/30/24	Sat 3/30/24	1 day?		0%	
73	6b	Ground Clearance Test	1 hrs	Sat 3/30/24	Sat 3/30/24	1 day?		0%	
74		Turning Radius Test	1 hrs	Mon 4/15/24	Wed 4/17/24	3 days?	3 hrs	100%	
75	6c	Articulation Suspension Test	3 hrs	Thu 5/9/24	Fri 5/10/24	2 days?	3 hrs	100%	
76	6d	Overall Function of Car Offroad	5 hrs	Fri 4/5/24	Mon 4/8/24	2 days		0%	
77	6e	Make Test Sheets	5 hrs	Mon 4/8/24	Tue 4/9/24	2 days		0%	78
78	6f	Rear Trailing Arm Deflection Test	2 hrs	Fri 4/5/24	Fri 4/5/24	1 day	1 hrs	100%	
79	6g	Test Plan	8 hrs	Wed 4/24/24	Mon 4/29/24	4 days	1 hrs	10%	
80	6h	Perform Evaluation	10 hrs	Mon 4/29/24	Fri 5/10/24	10 days		0%	
81	6i	Take Testing Pics	2 hrs	Tue 5/14/24	Tue 5/14/24	1 day?		0%	
82	6j	Test Procedure	3 hrs	Mon 4/1/24	Wed 4/3/24	3 days	3 hrs	100%	
83		Subtotal:					11 hrs	0%	



TT CHART

	Task Mode	Task Number	Task Name	Est Hours	Start	Finish	Duration	Actual Hours	% Complete	Pre
85			Deliverables						0%	
86		7a	Web Page/Design	20 hrs	Sun 10/29/23	Fri 3/15/24	88 days	16 hrs	78%	
87		7b	SOURCE	20 hrs	Mon 4/15/24	Thu 5/9/24	7 days	2 hrs	75%	
88		7c	Make Presentation Poster	20 hrs	Tue 4/23/24	Fri 5/10/24	13 days	6 hrs	100%	
89		7d	Test Reports	10 hrs	Wed 5/1/24	Tue 5/7/24	5 days		0%	
90		7e	Update Website	10 hrs	Wed 5/8/24	Mon 5/13/24	4 days		0%	
91		7f	Make USB Drive (All files)	1 hrs	Tue 5/21/24	Tue 5/21/24	1 day?		0%	
92		7g	Final Presentation	8 hrs	Wed 5/29/24	Tue 6/4/24	6 days		0%	
93		7h	Final Report Submission Finished	1 hrs	Sat 6/1/24	Sat 6/1/24	1 day?		0%	
94			Subtotal:					24 hrs	0%	



APPENDIX F – Expertise and Resources

Appendix F01 – Decision Matrix – Analysis #1 Rear Trailing Arm

Criterion	Weight 1 to 3	Best Possible 3	Design #1	Score x Wt	Design #2	Score x Wt	Design #3	Score x Wt	
Prediction Precision	1	3	2	2	3	3		0	
Manufacturability	2	6	1	2	3	6		0	
Deflection	3	9	3	9	3	9		0	
Amount of Material Needed	1	3	1	1	3	3		0	
Confidence	2	6	3	6	2	4		0	
Total	9	27		20		25		0	
NORMALIZE THE DATA (muliply by fraction, N)		3.70		74.1		92.6		0.0	Percent

Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits	Good? Then done.	55.6 Average
	Poor Bias:	Standard Deviation is one or less digits	Poor? Change something!!!	49 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

Amount of Material Needed	How much total material between the designs?
Prediction precision	Are the engineers calculations sufficient and correct?
Confidence -failure loc	Confidence level in the indicated failure location
Deflection	How much does the component deflect/bend
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:

Comment about why you scored each design as you did.

The chosen design is design 2. As per the decision matrix outcomes from the criterion. Less material will be needed, and the amount of deflection is far under what is required. There is no need to overbuild the trailing arm farther than this design. This design will be plenty strong enough and fit the needs of mounting the shock. There is no design 3 due to

Appendix F02 – Decision Matrix – Front suspension Components Manufacturing

Criterion	Weight 1 to 3	Best Possible 3	Design #1	Score x Wt	Design #2	Score x Wt	Design #3	Score x Wt	
Durability	3	9	3	9	1	3	2	6	
Fit/Finish	2	6	3	6	2	4	1	2	
Manufacturbility	3	9	3	9	3	9	1	3	
Cost	1	3	1	1	3	3	3	3	
Confidence in Design	2	6	3	6	1	2	1	2	
Total	11	33		31		21		16	
NORMALIZE THE DATA (muliply by fraction, N)		3.03		93.9		63.6		48.5	Percent
Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits				Good? Then done.		68.7	Average
	Poor Bias:	Standard Deviation is one or less digits				Poor? Change something!!!		23	Std Dev.
		You can change the criteria, weighting, or the projects themselves…							

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

Criterion	
Durability	Beign susceptible to abuse and overall intended use.
Fit/Finish	Complete looking, cool factor, tolerances.
Manufacturability	How easy is it to manufacture?
Cost	How expensive?

Comments:

Comment about why you scored each design as you did.

Design #1: SendCutSend 6061 Alum Front Susupension Components

Fully developed suspension components that are sent to SendCutSend to be manufactured. Components are likely to be cut using a waterjet.

Design #1 Chosen

Design #2: 3D Printed Front Suspension Components

Suspension components are modeled in SolidWorks and converted to STLs to then be 3D printed using the Creality and MakerBot printers. However, this is the weakest way of manufacturing.

Design #2 Not Chosen

Design #3: Casted Front Suspension Parts

Design #3 Not Chosen

Suspension components are casted in the foundry and then later machined. Confidence is low for this method and this method would take the most to complete. So therefore not chosen.

Appendix F03 – Decision Matrix – Rear Trailing Arm Manufacturing

Criterion	Weight 1 to 3	Best Possible 3	Design #1	Score x Wt	Design #2	Score x Wt	Design #3	Score x Wt	
Durability	3	9	3	9	1	3	3	9	
Fit/Finish	2	6	3	6	3	6	2	4	
Manufacturbility	3	9	2	6	3	9	3	9	
Cost	1	2	1	1	3	3	3	3	
Confidence in Design	2	6	3	6	1	2	3	6	
Total	11	32		28		23		31	
NORMALIZE THE DATA (muliply by fraction, N)		3.13		87.5		71.9		96.9	Percent
Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits			Good? Then done.			85.4	Average
	Poor Bias:	Standard Deviation is one or less digits			Poor? Change something!!!			13	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	
Durability	Beign susceptible to abuse and overall intended use.
Fit/Finish	Complete looking, cool factor, tolerances.
Manufacturbility	How easy is it to manufacture?
Cost	How expensive?
Confidence in Design	Confidence in calculations prior to manufacturing.

Comments:

Comment about why you scored each design as you did.

Design #1: SendCutSend 6061 Alum Rear Trailing Arm

SendCutSend would be a great option, but with how thick the material is the added cost would be to high.

Design #1 Not Chosen

Design #2: 3D Printed Rear Trailing Arm

The 3D printed rear trailing arm would be the easiest to manufacture but the strength that it gives is not high enough.

Design #2 Not Chosen

Design #3: Machined Rear Trailing Arm

Design #3 Chosen

Machined reat trailing arm is the most logical to do. Very small amounts of machining will have to be done and the only task that willr equire time is using a drill press to drill through holes.

Appendix F04 – Decision Matrix – Material Choice (Front Lower Control Arms)

Criterion	Weight 1 to 3	Best Possible 3	Design #1	Score x Wt	Design #2	Score x Wt	Design #3	Score x Wt	
Durability	3	9	3	9	1	3	3	9	
Fit/Finish	2	6	3	6	2	4	1	2	
Manufacturbility	3	9	3	9	3	9	1	3	
Cost	1	2	1	1	3	3	3	3	
Confidence in Design	2	6	3	6	1	2	1	2	
Total	11	32		31		21		19	
NORMALIZE THE DATA (muliply by fraction, N)		3.13		96.9		65.6		59.4	Percent

Decide if Bias is Good or Bad

Good Bias: Standard Deviation is two or more digits — Good? Then done. — 74.0 Average

Poor Bias: Standard Deviation is one or less digits — Poor? Change something!!! — 20 Std Dev.

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

Sensitivity

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

Durability: Beign susceptible to abuse and overall intended use.

Fit/Finish: Complete looking, cool factor, tolerances.

Manufacturability: How easy is it to manufacture?

Cost: How expensive?

Confidence in Design: Confidence in calculations prior to manufacturing.

Comments:

Comment about why you scored each design as you did.

Design #1: 6061 Alum Front Control Arms

Design #1 Chosen

Utilizing aluminum for the front control arms is the perfect mix between it being strong enough and not weighing to much. Aluminum is also far easier to manufacture than steel. A higher confidence is assocaited with material and therefore chosen.

Design #3: Steel Front Control Arms

Design #3 Not Chosen

Steel front lower control arms would be the strongest material to use. But, the weight would be to much. Steel is also hard to work with in the machine shop, steel can be very difficult to work with compared to the other materials listed.

Design #2: 3D Printed PLA Front Control Arms

Design #2 Not Chosen

The 3D pritned front control arms would be the cheapest, and easiest to make in terms of the material and the way that it is 3D printed. However, the PLA does not offer the strength that is needed for the application.

APPENDIX G – Testing Report

Appendix G1

Introduction

The rear trailing arms are tested via the Instron machine, the Instron machine will supply a compressive load to test how much deflection (displacement) the rear trailing arm has when the load is applied at the center and when the ends are simply supported. After the test had been done, the Instron "Bluehill" testing app provided a force vs displacement graph to show the engineer just how the rear trailing arm did in the test and how it compares to the requirement that is listed in section 1.d. Initial analysis was done to get a benchmark and an idea of what the initial design parameters needed to be, i.e. cross sectional area, material, design, this can be found in Appendix A01. However, the calculations do not consider the slot in the rear trailing arm that allows for the rear shocks to be mounted to the trailing arm. Therefore, the initial calculation was showing that there would be 0.0008" of deflection under roughly a 5lb load.

Method/Approach

After beginning the testing process of the rear trailing arm, it was clear that it was hard to get the Instron to show only a 5lb load and give accurate deflection values, so the static load was increased to 20 lbs. The Instron was showing upwards of 0.008" of deflection after a 20lb load was exerted shown in figure 4b.1. Even though this value is very low, and is not concerning at all, the deflection rating is still higher than the calculated. Much higher than would be expected even at a 20lb load. But the value is still very small to the point that the yield stress of the aluminum is so high that a deflection value of 0.008" is not bad.

In requirement 1d.11 it was stated that the rear trailing arm had to have less than 1/16" of deflection to be considered suitable for use by the engineer, anything more than 1/16" of deflection and the rear trailing arm would need redesigning. The engineer decided to load the rear trailing arm with a much higher force than 20lbs. A total force of roughly 400lbs was exerted onto the rear trailing arm as a point load, and while it was simply supported at both ends. The total deflection at 400lbs was only 0.045" shown in figure 4b.1 below, which is still lower than 1/16". By supplying a 400lb load to the rear trailing arm, it gave the engineer an idea just how strong the rear trailing arm was with the slot because the initial calculation did not account for the slot. By doing so, the engineer has complete confidence that the rear trailing arm is suitable and passes all requirement to be used on the RC Baja rear suspension.

After all the testing had been done on the rear trailing arm, it can be assumed that because in the initial analysis (calculation) the trailing arm slot was not accounted for, the deflection values are going to be a lot lower than what they were. This can be changed so that the calculated deflection value is more correct by using a smaller inertia value for the cross-sectional area so that the slot is accounted for. Or FEA software can be used to simulate the rear trailing arm deflection accurately.

Test Procedure

The scope of this procedure it to test requirement 1d.11, the rear trailing arms must have 1/16” deflection or less under a static 20lb load. To do this, the Instron 34SC-5 is used to complete a compression test at the middle point of the rear trailing arm as it lays flat to simulate where the rear shock will be mounted. The Instron will compress the rear trailing arm to 20lbs until the test has been completed the results have been found (the amount of deflection/displacement). The rear trailing arms are tested at approximately 12:00pm during the day, the setup time takes approximately 15-20 minutes from start until finish, including cleanup. The test happens at CWU Hogue hall room 127 (Materials lab). And the resources that are needed to complete the test are the Instron machine, spare rear trailing arm, safety glasses, point load Instron fixture, simply supported at both ends fixture base, desktop computer hooked up to Instron, and USB to collect and save raw data. There is very little risk to the engineer’s safety or other safety around the test, the testing environment still needs to be stood clear of. There is no risk if the rear trailing arm breaks, an extra rear trailing arm has been manufactured just to be used to test. All safety precautions that ensure the engineers safety include no baggy clothes, safety glasses, no long sleeve shirts/coats, pants, and close toed shoes. All of which are to make extra double sure that no hazards are present.

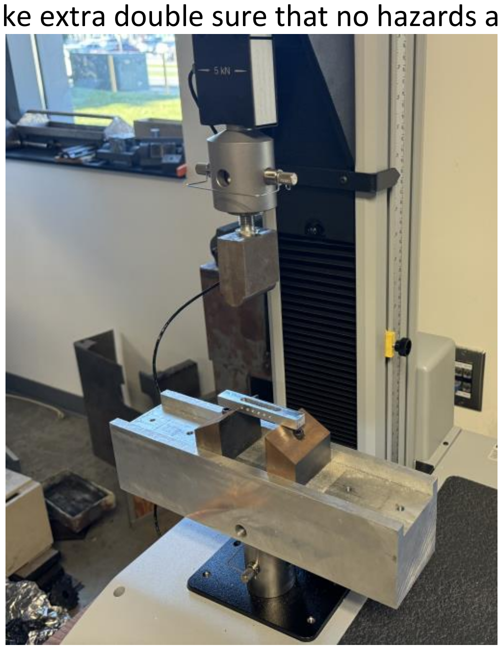


Figure 1: Complete Instron setup with test sample.

Steps:

1. Go to room 127 located in Hogue located at Central Washington University.
2. Once inside room 127 go to back right of the room where the Instron 34SC-5 is located. There will be a desktop computer setup to the right of the Instron.
3. After locating the Instron, turn on the Instron by flipping the switch on the back right of the Instron.

Figure 2: On/Off Switch

4. After turning on the Instron, turn on the desktop computer and login with student email and login.

5. Find the “Bluehill Elements” app and double click to open.

Figure 3: Bluehill Elements App Logo

6. The “Bluehill Elements” app will try and automatically connect with the Instron, click “Cancel”.

7. Login into “Bluehill Elements” with the user ID provided by Professor Capovilla and Professor Pringle. See them for login information to the app. Once logged in, the Instron will automatically pair with the computer.
8. Once logged into the desktop station, acquire the lower stationary supports (simply supported ends) that are shown in figure 4 and mount the supports the closet inwards that they can go and take a 4mm allen wrench to fasten each screw that the support uses to fasten into the base. (These screws do not need to be tightened very hard, just get them snug)

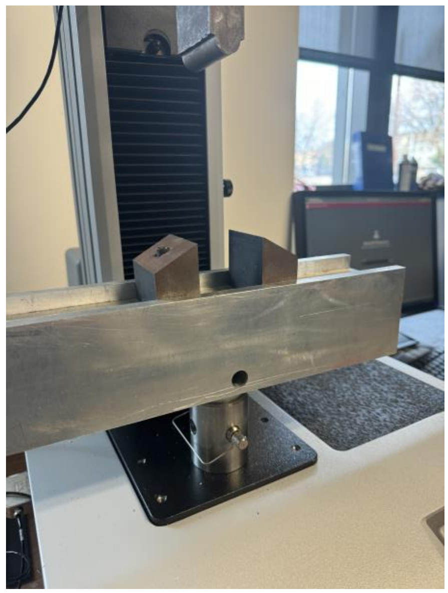


Figure 4: Lower Base Test Fixture

9. Fasten the testing fixture base to the Instron by putting the snap pin through the fixture and Instron. (Shown in Figure 4)

10. Acquire the top testing fixture, this will simulate a concentrated point load onto the test piece. This is put onto the Instron by taking a snap pin and putting it through the testing fixture and Instron. (See Figure 5)

Figure 5: Top Point Load Test Fixture.

11. Now that the testing environment has been setup, go back to the desktop. A screen showing “TEST”, “METHOD”, and “ADMIN” will be present, click “TEST” to begin testing and get to settings/scenario choices. (Compression or Tension).

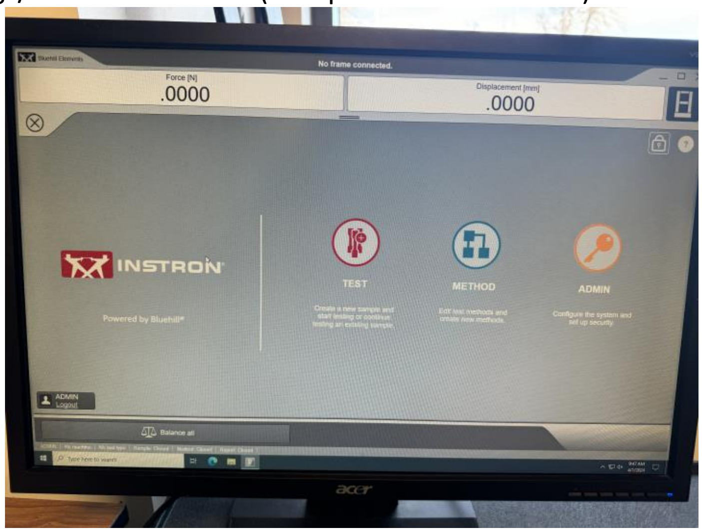


Figure 6: Instron Home Screen.

12. Select “Quick Test”

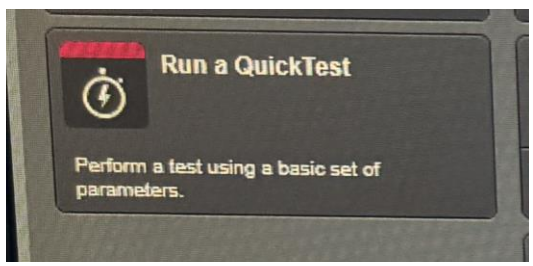


Figure 7: Instron Test Scenarios, Run Quick Test.

13. Load the test sample (rear trailing arm) into the Instron, lay it in flat orientation so that it is evenly supported by the testing fixture base at both ends (simply supported ends).
14. Select the test prediction to be “compression.”

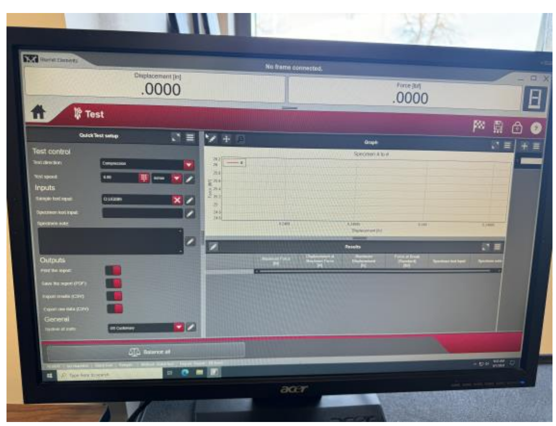


Figure 8: Live testing screen/graph.

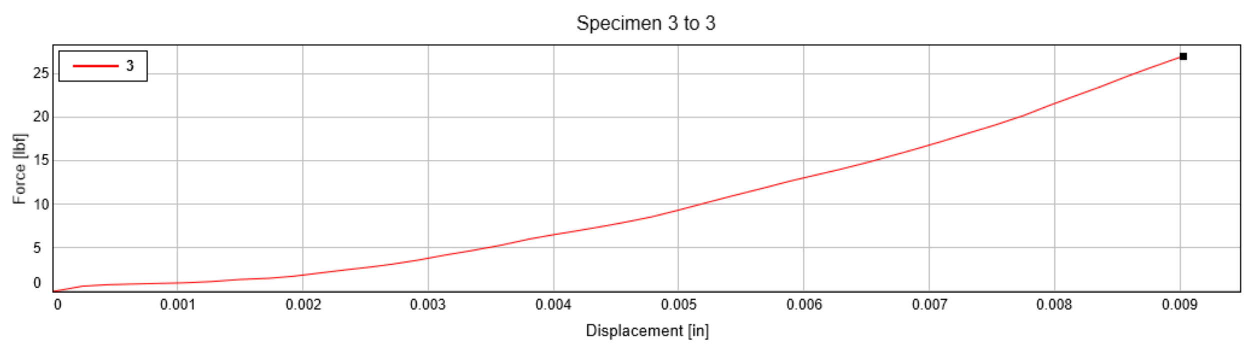
15. Finally, lower the fixture that simulated the point load so that it is just barely touching the top surface of the trailing arm, and then click “Balance all” on the desktop so that force and displacement are equal to 0. Then set sample test speed to 0.5 in/min.
16. The test is now ready to begin, first, make sure approved eye pro is being worn correctly, and all belongings, loose clothing, or other people’s limbs are not in the testing environment before beginning.
17. Make sure E-stop is not active by twisting the red button on the Instron display cluster. Then press the down arrow to lower the testing fixture until the maximum amount of force reaches 20lbs.

Figure 9: Instron display cluster.

18. Once the readout on the desktop reaches 20lbs stop lowering the Instron point load and click “Finish test”.
19. Save the data by plugging in USB drive to desktop computer and then “save as” raw data on the testing screen onto the USB drive. After the force and displacement data has been saved, release the force by raising the point load on the Instron display cluster using the “up” arrow until a safe position has been achieved. (Until the testing piece is loose and no longer being pressed/compressed)
20. E-Stop the Instron and close out the testing software and then click “eject” USB to acquire the data without corruption.
21. The test has been completed (Put data into excel and create desired force vs displacement graphs and charts).

Deliverables:

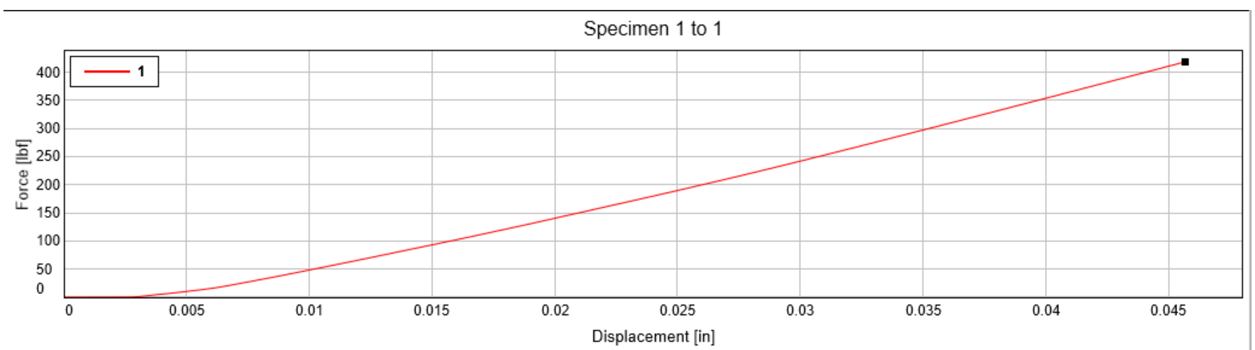
In this section "Deliverables" the force VS. displacement graphs is shown. The initial analysis was done at a 5lb load for the rear trailing arm, but because the graphs do not show adequate data at 5lb the force is upped to roughly 20lb so that in figure 10 a nice smooth displacement and force function can be seen and interpreted. To ensure that the rear trailing arm is suitable for the RC Baja, a 400lb test is done as shown in figure 11 and the total amount of deflection is well below the stated requirement of 1/16" in Section 1d.



Results

	Maximum Force [lbf]	Displacement at Maximum Force [in]	Maximum Displacement [in]	Force at Break (Standard) [lbf]	Specimen text input	Specimen note
1	418.74	0.05	0.05	418.74	Chassis Trial #1	
2	35.99	0.01	0.01	35.99	Chassis Trial #1	
3	26.97	0.01	0.01	26.97	Chassis Trial #1	

Figure 10: Trailing arm deflection data (20lb)



Results

	Maximum Force [lbf]	Displacement at Maximum Force [in]	Maximum Displacement [in]	Force at Break (Standard) [lbf]	Specimen text input	Specimen note
1	418.74	0.05	0.05	418.74	Chassis Trial #1	

Figure 11: Trailing arm deflection data (400 lb.)

Appendix G1.1 – Procedure Checklist

Instron Machine
Safety Glasses
Simply Supported Supports/Reactions
Point Load Fixture
BlueHill Elements Testing App
Rear Trailing Arm
Desktop Computer

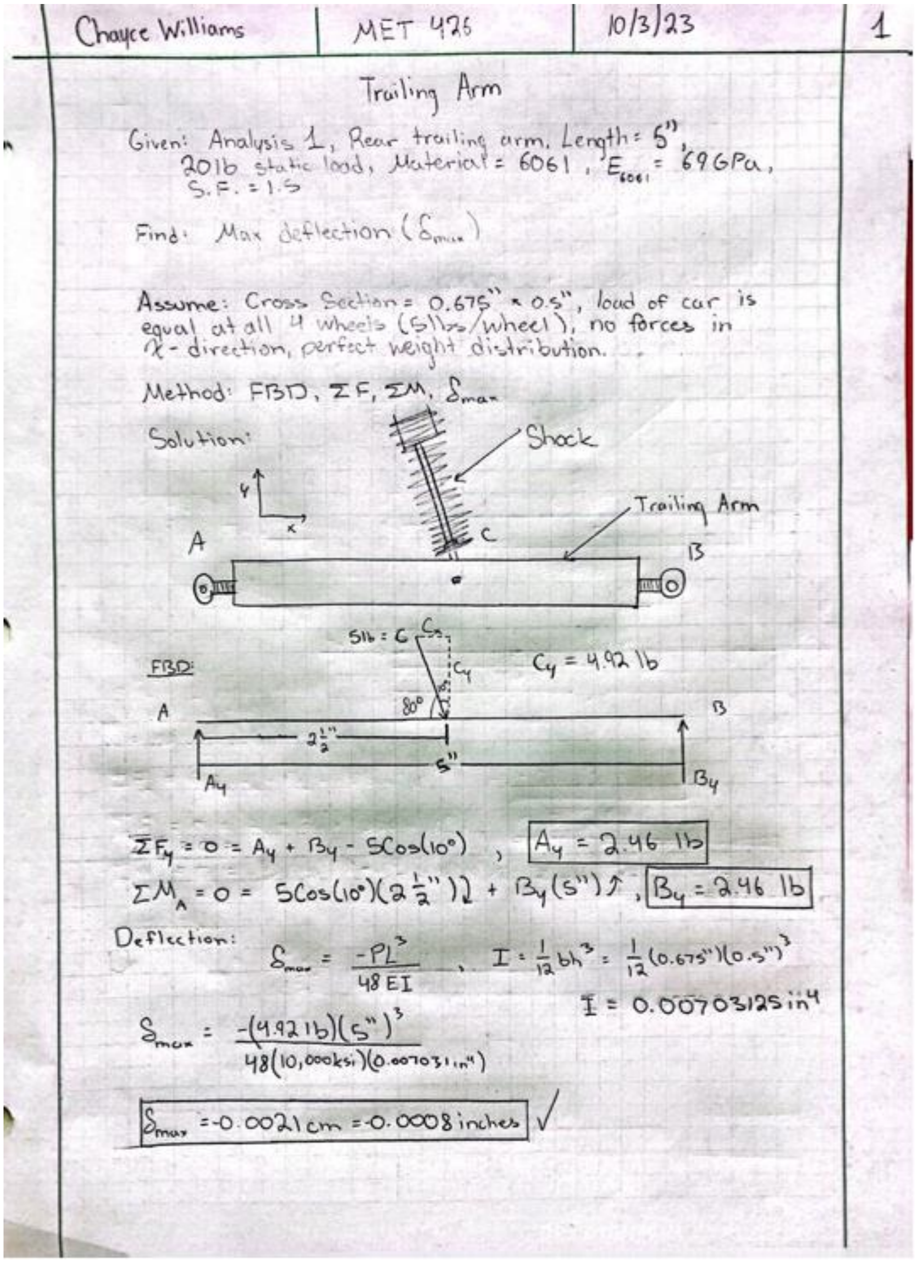
Appendix G1.2 – Data Forms

Not available, all data collection forms were drawn from the BlueHill elements app on the Instron testing lab station computer. These data sheets can be seen in Appendix G1 "Deliverables" figures 10 and 11.

Appendix G1.3 – Raw Data

See Appendix G1 section "Deliverables" Figures 10 and 11 (trailing arm deflection data at 20lb and 400lb).

Appendix G1.4 – Evaluation Sheet



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Trailing Arm

Given: Analysis 1, Rear trailing arm, Length = 5",
20lb static load, Material = 6061, E_{6061} = 69GPa,
S.F. = 1.5

Find: Max deflection (δ_{max})

Assume: Cross Section = 0.675" × 0.5", load of car is equal at all 4 wheels (5lbs/wheel), no forces in x-direction, perfect weight distribution.

Method: FBD, ΣF, ΣM, δ_{max}

Solution:

$\Sigma F_y = 0 = A_y + B_y - 5\cos(10°)$, $A_y = 2.46$ lb

$\Sigma M_A = 0 = 5\cos(10°)(2\frac{1}{2}")) + B_y(5")$, $B_y = 2.46$ lb

Deflection: $\delta_{max} = \frac{-PL^3}{48EI}$, $I = \frac{1}{12}bh^3 = \frac{1}{12}(0.675")(0.5")^3$

$I = 0.00703125\,in^4$

$\delta_{max} = \frac{-(4.92\,lb)(5")^3}{48(10{,}000ksi)(0.007031\,in^4)}$

$\delta_{max} = -0.0021\,cm = -0.0008\,inches$ ✓

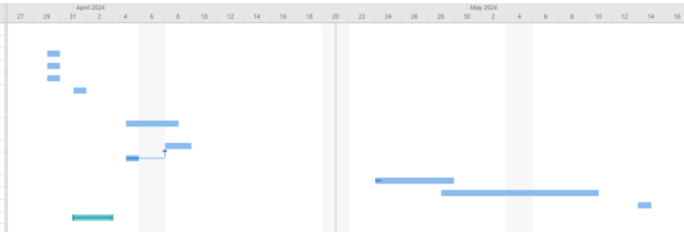
Figure G1.4.1

This analysis that was done utilizes beam deflection formulas. However, this analysis was done at 5lb to simulate a 20lb static load dispersed evenly on all 4 wheels of the RC car. The testing data that was gotten simulated a 20lb load on the trailing arm. The initial analysis did not account for the large slot in the trailing arm, hence the deflection being so small. With the slot, it is expected that the deflection will be more. The testing results confirm that the design is still adequate for the application.

Appendix G1.5 – Schedule

Rear Trailing Arm Test Began 4/5/2024 and ended on 4/5/2024.

	Task Number	Task Name	Est Hours	Start	Finish	Duration	Actual Hours	% Complete
70								
71		Device Evaluation						0%
72	6a	Drop Test	1 hrs	Sat 3/30/24	Sat 3/30/24	1 day?		0%
73	6b	Ground Clearance Test	1 hrs	Sat 3/30/24	Sat 3/30/24	1 day?		0%
74		Turning Radius Test	1 hrs	Sat 3/30/24	Sat 3/30/24	1 day?		0%
75	6c	Obtain Resources for Overall Function of Car Offroad Test	3 hrs	Mon 4/1/24	Mon 4/1/24	1 day?		0%
76	6d	Overall Function of Car Offroad	5 hrs	Fri 4/5/24	Mon 4/8/24	2 days		0%
77	6e	Make Test Sheets	5 hrs	Mon 4/8/24	Tue 4/9/24	2 days		0%
78	6f	Rear Trailing Arm Deflection Test	2 hrs	Fri 4/5/24	Fri 4/5/24	1 day	1 hrs	100%
79	6g	Test Plan	8 hrs	Wed 4/24/24	Mon 4/29/24	4 days	1 hrs	10%
80	6h	Perform Evaluation	10 hrs	Mon 4/29/24	Fri 5/10/24	10 days		0%
81	6i	Take Testing Pics	2 hrs	Tue 5/14/24	Tue 5/14/24	1 day?		0%
82	6j	Test Procedure	3 hrs	Mon 4/1/24	Wed 4/3/24	3 days	3 hrs	100%
83		Subtotal:					4 hrs	0%



Appendix G2

Introduction

Turning radius is among one of the biggest deciding factors whether an RC car can be controllable, especially for its intended use. In this turning radius and angle test the angle that the car can turn to the left and to the right is measured. And then the radius that it takes for the car to be able to make a full 180-degree turn (U-Turn). In the fall analysis was done to find the required turning angle to make a 180-degree turn in less than a 3.5' radius (7' Diameter). And this value came out to be roughly 24-25 degree which can be seen in Appendix A02. The car's turning angle is measured in this test and from that turning angle, the cars' ability to complete requirement 1d.3 at that tested turning angle.

Method/Approach

In theory, if the RC car has a turning angle of 25-degrees, the car should be able to complete a 180-degree (U-Turn) in 3.5' (7' Diameter) with ease. However, this is not always the case. This is the approach to this test, just because the car could meet the required turning angle, it still may not be able to complete the turning radius test successfully, this can be because of the tires on the car, a locked rear differential, tire side wall rollover, and the front tires sliding and causing the car to be pushed further towards the outside of the direction it is trying to steer.

The turning angle is measured by taking a green sheet engineering formatted paper with grids and drawing a line down the middle and putting it on a flat surface. From this flat surface, the RC Car is set on top of the paper with the front wheels parallel with the line, the car then turns left to right, and a line is drawn parallel with the tire after it has been turned. A protractor can then be used to measure the angle that the tire was able to turn at. This can be done for both the left and the right tire when turning to the left and to the right.

After the turning angle has been measured, the radius test could then be tested. Blue painters' tape is placed onto a flat, wood surface, and then another piece of blue painters' tape is placed exactly 7 feet offset from the original blue painters' tape that was placed onto the ground. It was very important that these pieces of tape were as close to parallel to possible for the sake of the test. The car was then placed onto the inside of the painters' tape paralleled to it. The car then turned to the left and began moving forward, and this was also done turning to the right. Once the car made a full 180-degree turn the distance away from the other piece of tape is measured, whether it went over the 7-foot distance or not, it did not matter.

When doing this method and approach to testing if this car would meet the requirement listed by the engineer at the beginning of the year, the overall steering capabilities of the car were able to be tested. And doing it this way the engineer could test more than just the steering components; the engineer could test the overall car and its system because there are many other variables that could cause the car to succeed or fail in the test and they can be dealt with accordingly.

Test Procedure

(Turning Angle)

1. Acquire green sheet engineering formatted piece of paper.
2. Use a straight edge to draw a straight line down the center of the paper that is roughly 6”-7”. (See Appendix G2.3 Figure G2.3.1)
3. Go to any flat surface where the entire RC car can sit flat and fit on top of.
4. Take piece of paper and tape all 4 sides to the flat surface.
5. Place the working RC car on top of the piece of paper where the inside of the front left tire is parallel and centered next to the line.
6. Make sure battery is charged on the RC car, plug it in to the car, turn on the car and remote.
7. Turn the front wheels to the right using the remote and then once the car turns all the way to the right take a straight edge and draw a parallel line to the wheel/tire of the RC car.
8. Remove the RC car from the green sheet engineering paper and extend the angled lined so that it is now touching the vertical line down the center of the paper.
9. Measure the angle that is apparent on the paper with a protractor.
10. Repeat steps 5-9 except in step 5 turn to the left instead of to the right.
11. Once steps 5-10 have been completed place the inside of the front right tire/wheel is centered and parallel with the same line at the center of the green sheet engineering paper.
12. Repeat steps 7-9 for the right tire turning to the left and turning to the right.
13. After all data has been collected write the angles into the test data sheet found in Appendix G2.4 begin cleaning up the testing area and get prepared for the turning radius test.

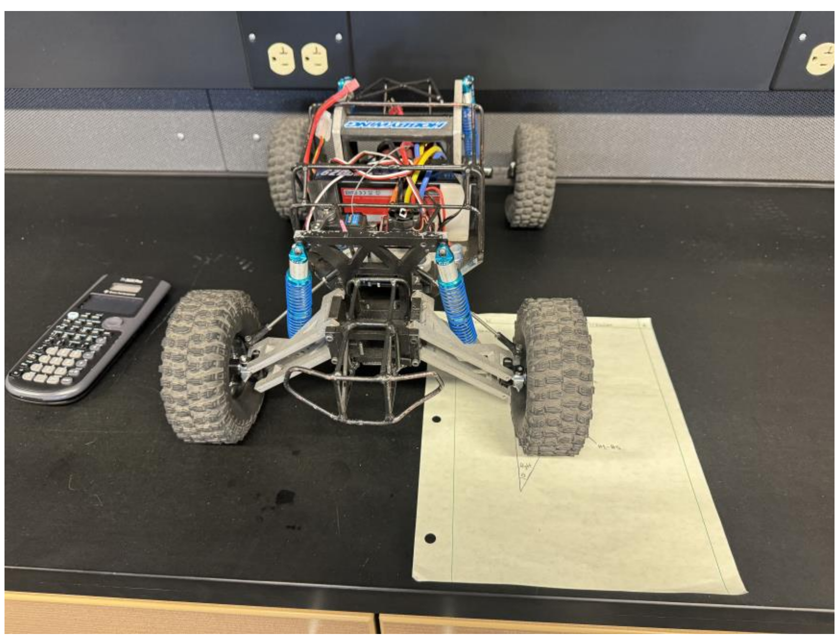


Figure G2-1: Overall Turning Angle Test Setup

(Turning Radius Test)

1. Go to wooded floor area called “Benders Knuckle” where the wind turbine is located inside of Hogue Hall at Central Washington University. A flat wooded surface will be located there and that is where the test is conducted.
2. Take a piece of tape and stick it to the ground anywhere in the center of the wood floor.
3. Take a tape measure and measure from the piece of tape that was stuck to the ground 7’ out and stick the next piece of tape to the wood floor (make sure both pieces of tape are parallel with one another).
4. Place charged, ready to drive/run RC car front right wheel on the inside of the right piece of tape. Make sure the car is parallel and centered on the piece of tape as well as being parallel with the other piece of tape.
5. Turn the RC car all the way to the left and begin driving forward slowly until it makes a full 180-degree (U-turn) and is parallel with the piece of tape that was laid down opposite of the starting position.
6. When the RC car completes the 180-degree turn stop the RC car.
7. Take a tape measure and measure how far away the right wheel of the RC car is away from the piece of tape that is 7’ away from the originating starting position. This will show the engineer the total turning radius that it took to make a 180-degree turn.
8. Repeat steps 4-7 except move the car so that its starting position is on the opposite piece of tape, and it can then turn to the right.
9. Once all data is collected write down all data in the data sheet seen in G2.3 figure G2.3.2.

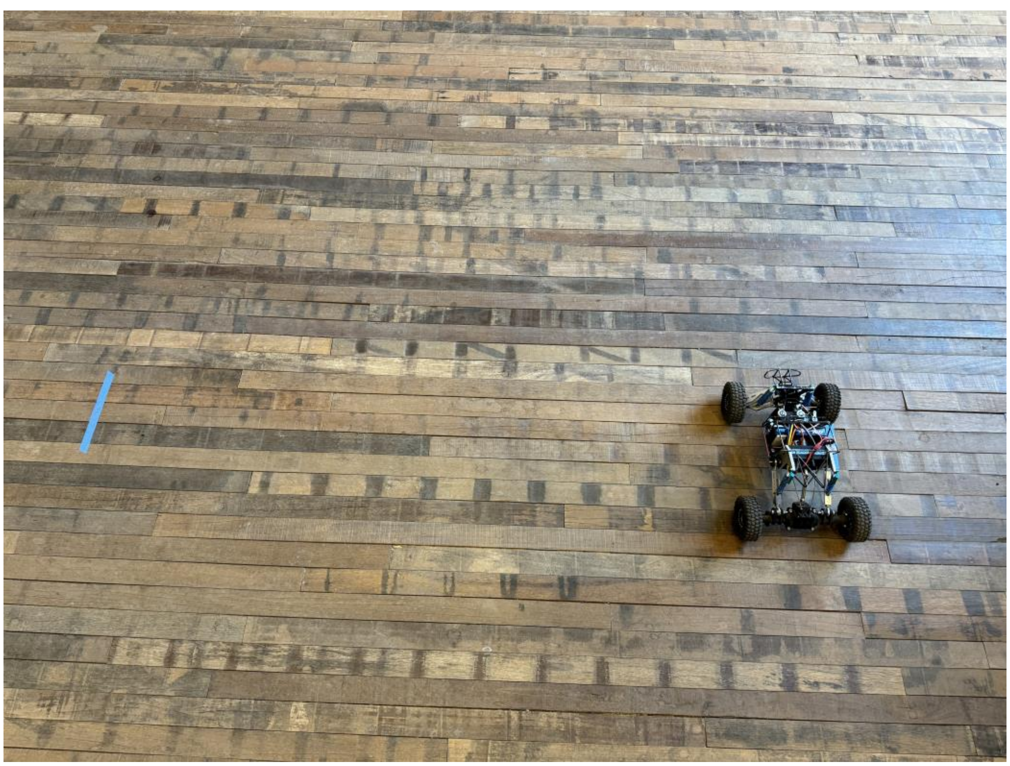


Figure G2-2: Full Test Setup of Turning Radius

Deliverables

In Appendix G2 the second test of the testing stages was done. And in this test the vehicles steering/turning abilities is tested like previously mentioned. The car needed to make a 180-degree (U-turn) in less than a 3.5' radius, or a 7' diameter. And to do this a steering angle analysis was done to ensure the RC car would meet the requirement stated as requirement 1d.3 in section 1 of the report. This analysis provided that with the given initial wheelbase and trackwidth the car would need to have roughly a 25-degree angle.

While testing the turning angle of the car, the car had a turning angle with the left tire of 32 degrees turning to the right, and 26 degrees turning to the right. The right tire turning to the left had a turn angle of 25 degree turning angle, and a 35-degree turning angle turning to the right. With these results gathered from the first half of this test turning in either direction satisfied the required turning angle that is needed to make a 180-degree (U-turn) turn in less than a 3.5' radius or 7' diameter (refer to figure G2.3.2, and G2.3.1)

In the last half of the test the turning radius was tested to see even with the turning angle that the car has if the car can still make the required turn without needing a larger turning radius. And in this test the car did not fully meet the requirement of making a 180-degree turn in less than a 3.5' radius or 7' diameter. The vehicle was able to satisfy the requirements turning to the right by only taking 5'-6' 3" to make the turn. Turning to the left the car needed between 6'7" – 7' 3.5" to make the turn. So, this means that the car can make the 180-degree turn to the left within the required spec, but not consistently during every trial. And to be considered successful it needs to be able to do so consistently. The reason for not meeting this exact requirement consistently is likely because of the solid rear axle with no differential pushing the front end while it's trying to turn, the soft sidewalls for the front tires causing tire rollover, and to sharp of a tie rod angle resulting is deficiency of the turning angle.

So, even though the vehicle can meet the required turning angle to make a 180-degree turn within a 7' diameter the car cannot do so because of the slick ground, soft sidewalls on the tires, the locked rear solid axle, and excessively tall ground clearance leading to sharp tie rod angles. Stiffer tire inserts, a lower ground clearance (lower center of gravity), and a grippier surface would all lead to a sharper turning radius and possibly a more successful result.

Appendix G2.1 – Procedure Checklist

Functional Ready to Run RC Baja Car W/ Remote
Charged Battery for RC Car
Tape Measure
Protractor
Painters Tape
Engineering Green Sheet Formatted Paper
Straight Edge (Ruler)

Appendix G2.2 – Data Forms

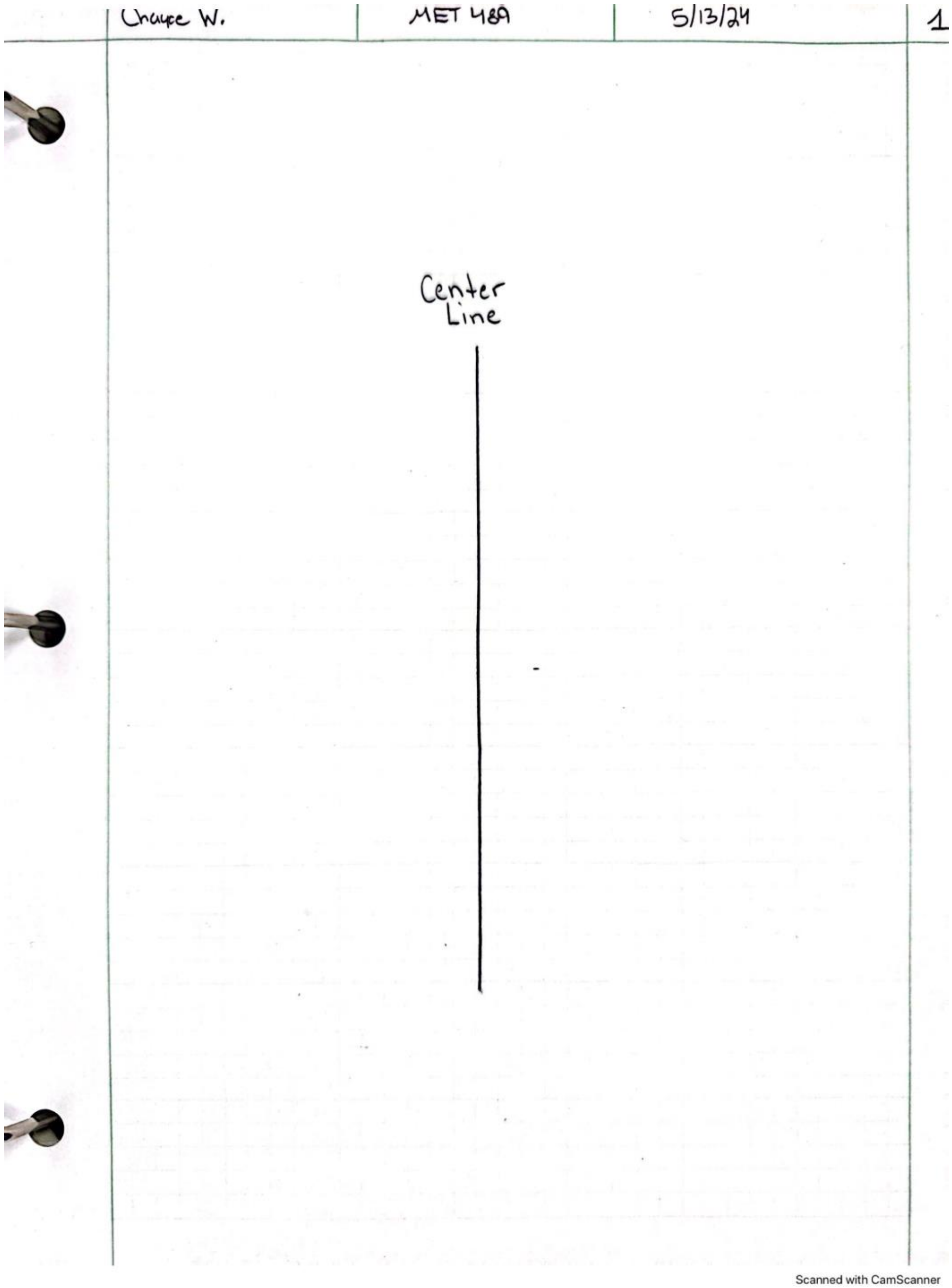


Figure G2.2-1: Turning Angle Data Form

Appendix G2.3 – Raw Data

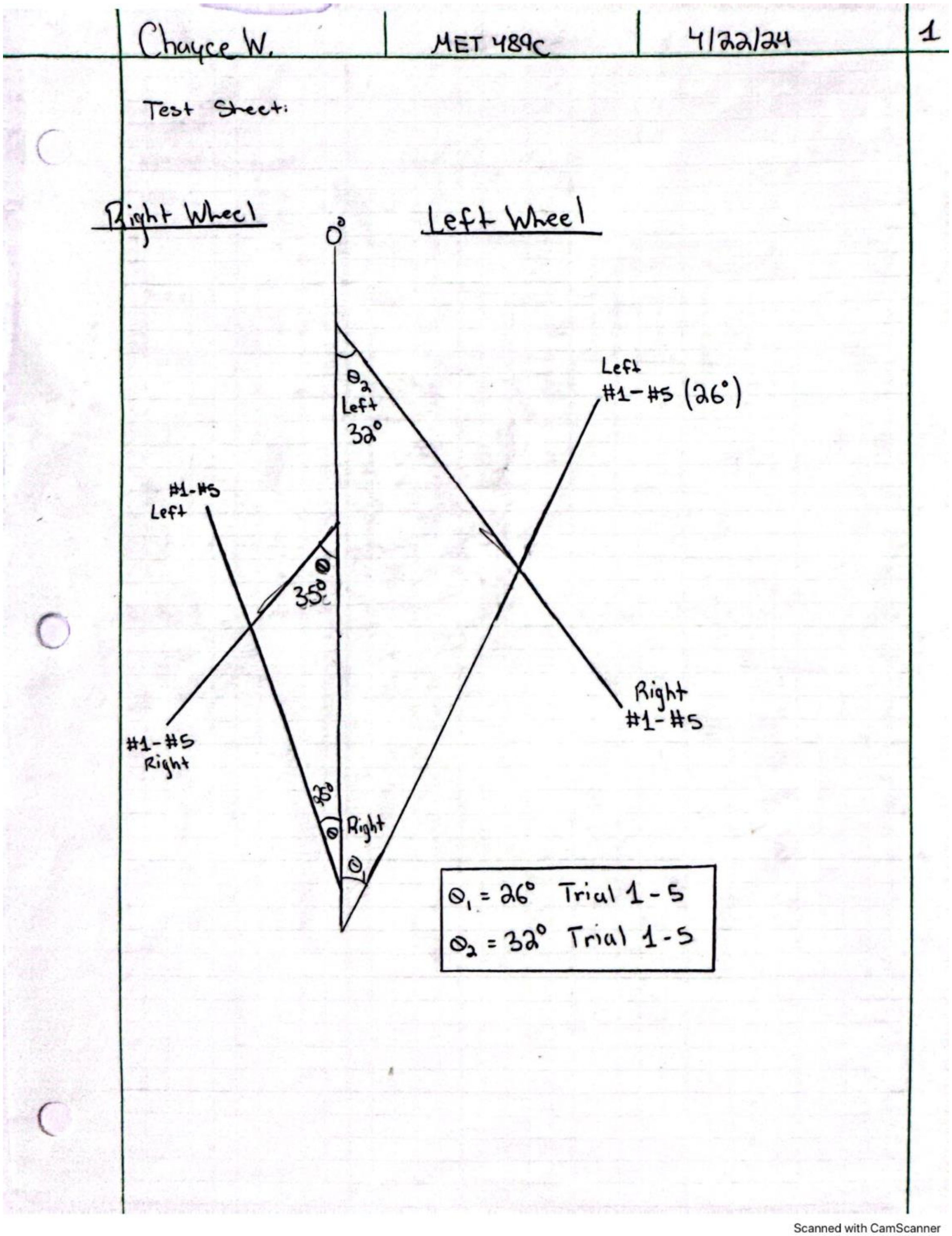


Figure G2.3.1: Turning Angle Paper and Data

Chayce Williams

MET 489C Test Data #2

TDR #2

Trial Number	Turning Angle [Degrees] Left Tire		Turning Radius (Diameter/Radius) [in]
	Left	Right	
Trial #1	32°	26°	7' 3 1/2"
Trial #2	32°	26°	6' 8"
Trial #3	32°	26°	6' 7"
Trial #4	32°	26°	7' 3"

Right turning radius

6' 2"

6' 3 1/2

6' 1"

5' 9"

Turning Angle Right Tire

Left	Right
25°	35°
25°	35°
25°	35°
25°	35°
	35°

Figure G2.3.2: Turning Angles and Turning Radius Raw Data

Appendix G2.4 – Evaluation Sheet

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Analysis 2
Steering Angle

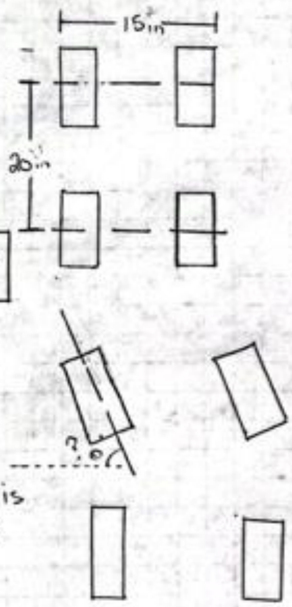
Given: Max Track Width = 15" Max Wheel Base = 20"
Tolerance = ±1° ± 3"

Find: Minimum turn angle to complete 180° turn within $3\frac{1}{2}$ foot radius circle.

Method: Turning Radius Eq. Mechanical Design

Assume: Flat Ground, each wheel has same turn angle, rear differential locked 24/7.

Solution: θ = turn ∠
R = Radius
WB = Wheelbase



$$R = \frac{(WB)}{\tan\theta}, \quad \theta = \tan^{-1}\left(\frac{WB}{R}\right)$$

$$\theta = \tan^{-1}\left(\frac{20in}{42"}\right), \quad \boxed{\theta = 25.46°}$$

$$3\frac{1}{2}ft \times \frac{12in}{1ft} = 42"$$

If the maximum wheelbase of 20" is used the minimum turning angle to make a 180° U-turn is 25.46°.

Figure G2.4.1: Steering Angle Green Sheet Calculation

Appendix G2.5 – Schedule (Testing)

	Task Number	Task Name	Est Hours	Start	Finish	Duration	Actual Hours	% Complete	Predeces
70									
71		Device Evaluation						0%	
72	6a	Drop Test	1 hrs	Sat 3/30/24	Sat 3/30/24	1 day?		0%	
73	6b	Ground Clearance Test	1 hrs	Sat 3/30/24	Sat 3/30/24	1 day?		0%	
74		Turning Radius Test	1 hrs	Mon 4/15/24	Wed 4/17/24	3 days?	3 hrs	100%	
75	6c	Articulation Suspension Test	3 hrs	Thu 5/9/24	Fri 5/10/24	2 days?	3 hrs	100%	
76	6d	Overall Function of Car Offroad	5 hrs	Fri 4/5/24	Mon 4/8/24	2 days		0%	
77	6e	Make Test Sheets	5 hrs	Mon 4/8/24	Tue 4/9/24	2 days		0%	78
78	6f	Rear Trailing Arm Deflection Test	2 hrs	Fri 4/5/24	Fri 4/5/24	1 day	1 hrs	100%	
79	6g	Test Plan	8 hrs	Wed 4/24/24	Mon 4/29/24	4 days	1 hrs	10%	
80	6h	Perform Evaluation	10 hrs	Mon 4/29/24	Fri 5/10/24	10 days		0%	
81	6i	Take Testing Pics	2 hrs	Tue 5/14/24	Tue 5/14/24	1 day?		0%	
82	6j	Test Procedure	3 hrs	Mon 4/1/24	Wed 4/3/24	3 days	3 hrs	100%	
83		Subtotal:					11 hrs	0%	

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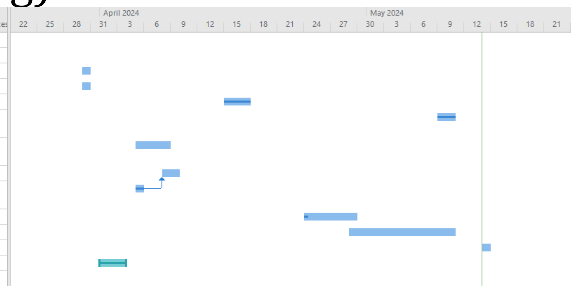


Appendix G3

Introduction

For the last and final test of the spring quarter, the overall suspension function was tested via an articulation test. An articulation test tests the overall function of the RC cars front and rear suspension by having one of the wheels higher than the other in both the front and the rear. In requirement 1d.7 it was stated in Fall quarter that the RC car had to be able to withstand 2” total of articulation without any of the wheels leaving the ground and losing traction. If the wheels ended up being lifted off the ground the overall control of the RC car for the user would then be lost and unpredictable.

Method/Approach

The approach to testing requirement 1d.7 was such that if the wheels in the articulation test lift off the ground or even become unweighted the car would not pass test and not meet the requirements. The correct vehicle geometry and suspension design aides in giving the vehicle enough suspension travel to articulate. The solid rear axle gives the vehicle more articulation over an independent suspension system. The front of the car has an independent suspension system that has less articulation than the rear end of the car, but because of the wide track width and long upper and lower control arms the limited suspension travel is increased to a larger amount that is more align with the rear of the car.

Even if the car has enough articulating to not lift a tire off the ground, if too much articulation occurs, overall vehicle stability can still be lost when operating the vehicle at higher speeds. So, finding the happy medium for both the front-end suspension system and rear end was vital. This is why the front-end suspension utilizes independent suspension, and the rear utilizes a solid rear axle with trailing arms and upper long arms.

Using 3D printed blocks that are 2” x 2” and 1”, 2” and 3” tall the articulation is tested. With different trials that are done, the maximum amount of articulation can be tested to see exactly when one of the wheels lifts off the ground. If the vehicle can articulate and all wheels are still on the ground after the 3” tall block, blocks are then able to be stacked on top of each other to further the height difference.

Test Procedure

1. 3D print blocks out of PLA, 20% Infill, and any color.
    - (2”x2”x1” QTY 2) (2”x2”x2” QTY 2) (2”x2”x3” QTY 2)
2. Measure blocks to ensure they are correct sizing with calipers. If blocks are not within ±0.0625” of the posted size, re-print the blocks and account for thermal expansion.
3. Go to any flat surface available that provides an area big enough for the entire car to sit, along with the blocks.
4. Lay out all blocks on table and set car down onto flat surface.
5. Begin test by taking the 1” tall block and placing it under the front left tire.
6. Followed by step 5, place the other 1” block not being used already and place it under the rear right tire.
7. Analyze the car and see if any of the tires that are not on the blocks are no longer touching the ground. (If tires are not touching ground, test is a failure)
8. Measure the height difference of the opposing front tires and opposing rear tires. Record data into raw data sheet.
9. After ensuring that the tires that are not on the blocks are still in contact with the ground remove the 1” blocks from under the car and replace them with the 2” tall blocks.
10. Repeat steps 5-8 for the 2” and 3” tall block.
11. If the RC car’s tires that are not on the blocks are still in solid contact with the flat surface, leave the 3” blocks under the tires, but now add the 1” block onto of the 3” block to make a combined 4” tall block.
12. If the tires that are not on top of the blocks are still in contact with the flat surface, remove the 1” block from on top of the 3” tall block and replace it with the 2” tall block.
13. After 5” it is unlikely that the car is still in solid contact with the flat testing surface.
14. When the tire lifts off the ground, measure the distance off the ground the tires are.
15. Test is now over, write down all data onto raw data sheet/table so it is not forgotten.
16. Remove the RC car from on top of the blocks are place it outside of the testing environment.
17. Put away and clean up the blocks and move them from outside the testing environment.
18. The End

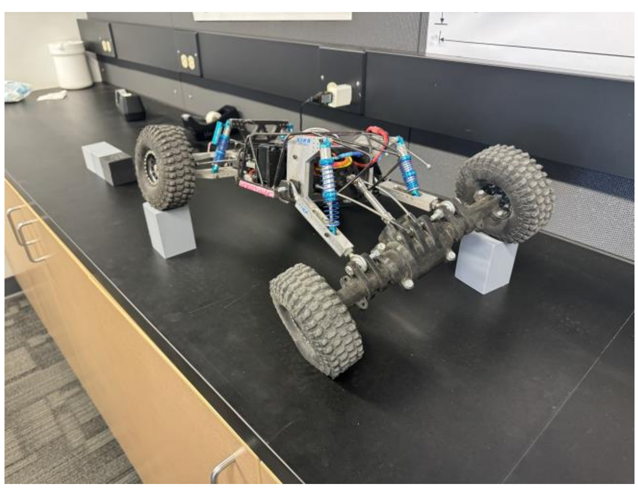


Figure G3-1: Overall Articulation Testing Setup

Deliverables

In the test, the RC car was able to articulate the required 2" very easily. The RC car's tires that were not on top of the 3D printed blocks eventually lifted off the ground after 4" total. It was calculated that just with the articulation that the rear trailing arm can provide with the desired ride height, and stroke length of the coil over shock that the vehicle would have 1" of total up travel, and 1" of down travel, this means that in theory from this calculation the vehicle would be able to articulate 2" total before using all the usable suspension travel. However, with the added length provided with the heim joints at both ends of the trailing arm, and the wide rear axle, the amount of articulation will grow to be larger. And because the tires that are being used on this RC car have soft side walls, and the inserts inside the tire allow for an extra 0.5" of suppleness the car will end up having even more articulation. The engineer knew that with the spec'd shock stroke length the minimum requirements would be met and then exceeded because of the heim joints, wide rear axle, and soft tires. The calculation where the engineer figured that the shock mounting location on the rear trailing arm would be okay, and what the ride height would be is determined in Appendix G3.4 figure G3.4.1.

To be successful in terms of the requirement and success criteria the RC car calculated meets the requirement, as well as the tested value. However, when is too much suspension travel and articulation? After driving the RC car around the time of this test it was quickly apparent that because of how much suspension travel the RC car has the car can be hard to control at higher speeds at times. Because of the body role, and high center or gravity the car quickly can get out of control if the user is not attentive to what it is happening. Thankfully, the cars ride height can be adjusted and the shock stroke length can be adjusted because of that with how much up or down travel that it is. That will modify the articulation outcomes, but having a vehicle that can still articulate at lower speeds and is still able to quickly be adjusted for higher speed settings is the best of both worlds.

Appendix G3.1 – Procedure Checklist

Ready to Run Assembled RC Car
2x (2"x2"x1") 3D Printed PLA Blocks
2x (2"x2"x2") 3D Printed PLA Blocks
2x(2"x2"x3") 3D Printed PLA Blocks
Ruler
Calipers
Raw Data Sheet

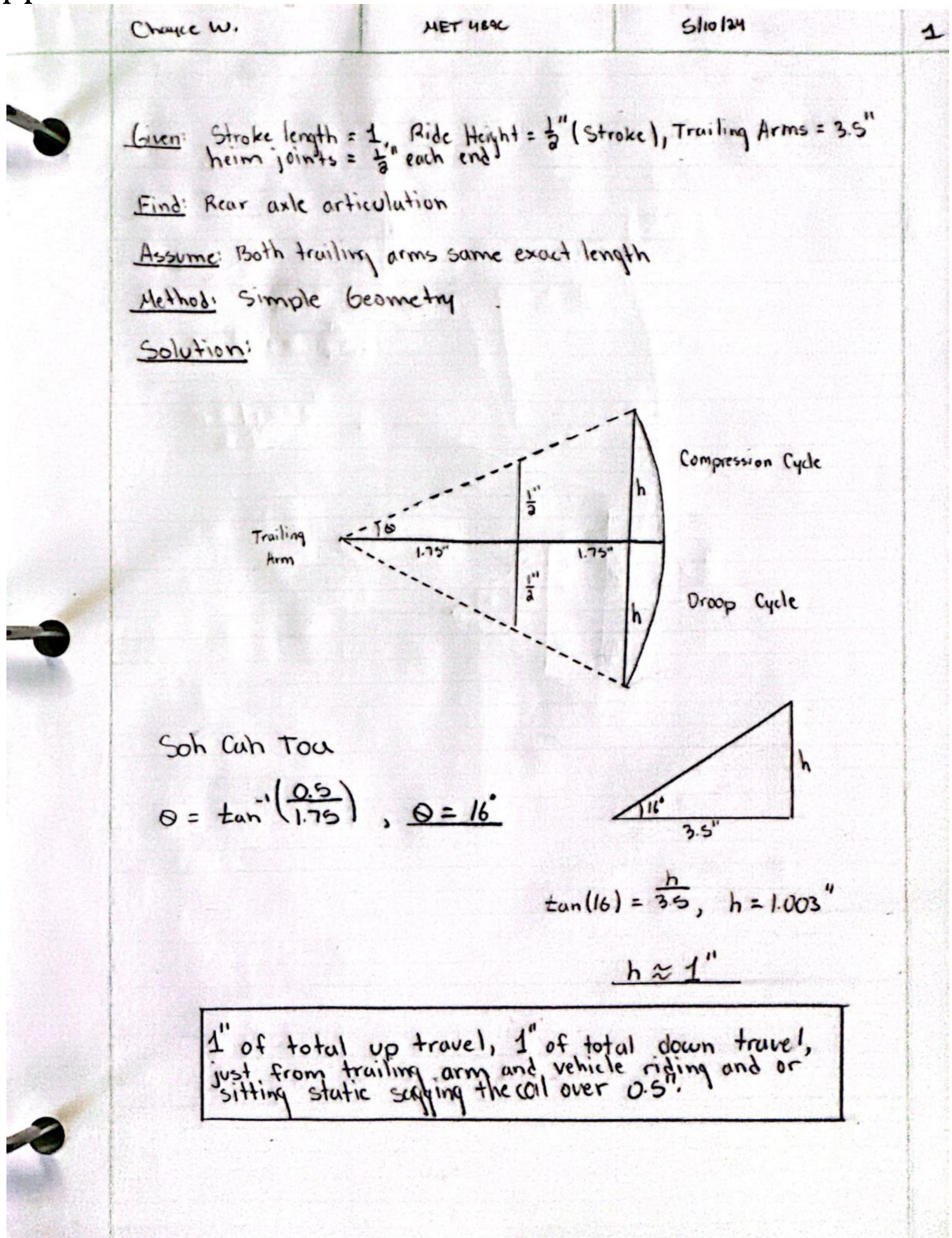
Appendix G3.2 – Data Forms

Trial # (And Specific Block)	How Much Articulated Successfully (Without Lifting a Tire)
Trial 1 (2”x2”x1”)	
Trial 2 (2”x2”x2”)	
Trial 3 (2”x2”x3”)	
Trial 4 (2”x2”x4”)	
Trial 5 (2”x2”x5”)	

Appendix G3.3 – Raw Data

Trial # (And Specific Block)	How Much Articulated Successfully (Without Lifting a Tire)
Trial 1 (2”x2”x1”)	1” (No Tire Lift)
Trial 2 (2”x2”x2”)	2” (No Tire Lift)
Trial 3 (2”x2”x3”)	3” (No Tire Lift)
Trial 4 (2”x2”x4”)	4” (No Tire Lift)
Trial 5 (2”x2”x5”)	4.18” (Tire Lifted Off Ground 0.82”)

Appendix G3.4 – Evaluation Sheet



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Given: Stroke length = 1", Ride Height = $\frac{1}{2}$"(Stroke), Trailing Arms = 3.5"
heim joints = $\frac{1}{2}$" each end

Find: Rear axle articulation

Assume: Both trailing arms same exact length

Method: Simple Geometry

Solution:

Soh Cah Toa

$\theta = \tan^{-1}\left(\frac{0.5}{1.75}\right)$, $\theta = 16^\circ$

$\tan(16) = \frac{h}{3.5}$, $h = 1.003"$

$h \approx 1"$

1" of total up travel, 1" of total down travel, just from trailing arm and vehicle riding and or sitting static sagging the coil over 0.5".

Scanned with CamScanner

Figure G3.4.1: Suspension Articulation from Trailing Arm and Shock Location

Appendix G3.5 – Schedule (Testing)

	Task Number	Task Name	Est Hours	Start	Finish	Duration	Actual Hours	% Complete	Predeces
70									
71		Device Evaluation						0%	
72	6a	Drop Test	1 hrs	Sat 3/30/24	Sat 3/30/24	1 day?		0%	
73	6b	Ground Clearance Test	1 hrs	Sat 3/30/24	Sat 3/30/24	1 day?		0%	
74		Turning Radius Test	1 hrs	Mon 4/15/24	Wed 4/17/24	3 days?	3 hrs	100%	
75	6c	Articulation Suspension Test	3 hrs	Thu 5/9/24	Fri 5/10/24	2 days?	3 hrs	100%	
76	6d	Overall Function of Car Offroad	5 hrs	Fri 4/5/24	Mon 4/8/24	2 days		0%	
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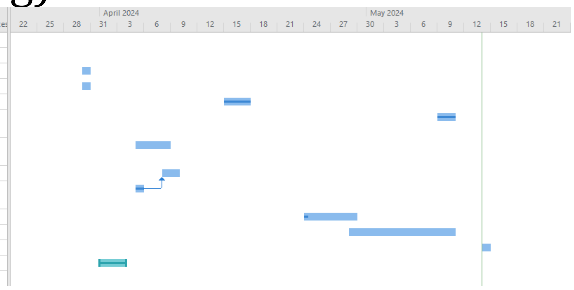
80	6h	Perform Evaluation	10 hrs	Mon 4/29/24	Fri 5/10/24	10 days		0%	
81	6i	Take Testing Pics	2 hrs	Tue 5/14/24	Tue 5/14/24	1 day?		0%	
82	6j	Test Procedure	3 hrs	Mon 4/1/24	Wed 4/3/24	3 days	3 hrs	100%	
83		Subtotal:					11 hrs	0%	



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APPENDIX H – Resume

Chayce Williams

| Email: WilliamsChay@cwu.edu | Phone: xxx-xxx-xxxx | Location: |

Objective: Goal oriented person seeking a **Mechanical Design Engineer** position with prior background in product development and design with success on consumer and commercial levels for large and small reputable companies.

Skills

- SolidWorks
- AutoCAD
- Geometric Dimensioning and Tolerancing
- CAD/CAM
- 3D Printing
- Microsoft Office
- Prototype Testing
- Verbal and Written Communication
- Load Calculations
- Testing Report and Analysis

Experience

06/2023 – 09/2023 **Design Engineer**
Stageplan Inc. (Internship)

- Lead a project proving to Blue Origin that a redesigned drip pan had less than 1/8" deflection under 1000lb point load with new design requirements. Blue Origin engineers liked and chose to manufacture the new drip pans.
- Took a concept design/model platform from Blue Origin for the AFT Module under construction and redesigned their concept to fit their needs. Varying height platform, railings, folding platform surface, roll on vertical support.
- Worked in group effort to design Nick's Magnificent tiny town. Designed jail bar doors, bar windows, lobby columns, mezzanine columns, lobby tables, railings, double column doorway with arch, balcony and more.
- Designed pivoting hidden double door and wall for new Washington Square Mall YETI store.
- 500+ hours of SolidWorks modeling experience during internship period.

06/2020 – 09/2022 (Summers) **Prototype/Field Tester**
Specialized Bicycle Components

- Conduct field tests on bicycle tires in development stages to determine functionality which would then be provided to the engineers.
- Supported, implemented, and helped shape testing approaches with a goal/question in mind.
- Studied rubber compounds, layups, tread patterns, side wall protection, durability, damping, and how these reacted to different environments and scenarios.
- Several of these tires went on to win bike races on the national and world stage, along with the best-selling tires Specialized Bicycle Components has had in past 5 years.

Education and Training:
Expected in 06/2024 **Bachelor of Science**: Mechanical Engineering & Technology

Central Washington University – Ellensburg, WA

- 2020 – Present: Deans List
- Trustees Tuition Award Recipient

Certifications:

- Certified SolidWorks Associate in Mechanical Design.

Extracurriculars:

- Member of the American Society of Mechanical Engineers (ASME) Club at CWU.