RC Baja - Suspension and Steering

By

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ABSTRACT

The engineers at Central Washington University were each asked to produce a device to compete in the ASME RC Baja competition. The principle-engineer set out to create a system that allowed an RC car to be controllable over a variety of terrain utilizing suspension and steering principles. The steering and suspension designed by the engineer was implemented in part with a drive train and chassis that was designed by a partner engineer.

The Engineer chose to utilize an independent front suspension with a solid rear axle for his design. This design was chosen because the independent front end allowed for the front to stay very stable and the trailing arms in the rear allowed for the car to have a lot of suspension travel and suspension flex. This proposal covers the design, manufacturing, and testing of the device throughout the fall, winter, and spring quarter.

The device was completed at the end of the winter quarter and testing began at the beginning of the spring quarter. The testing results showed that the device met some key requirements, the suspension deflection was 3" after a 3' drop and the steering angle met the 50-degree requirement. The device performed well and met the engineer's requirements stated in section 1.d of the proposal.

Keywords: RC Baja, Independent suspension, Solid Rear Axle

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1. INTRODUCTION

a. Description

The objective of this project was to create a remote-controlled car that was capable of performing well in a variety of circumstances. Three competitions that were tested at the end were straight line racing, slalom racing, and a Baja course race. The car suffered a lot of abuse during each of these three competitions and was designed accordingly. The suspension was to be designed with a balance between being good at absorbing impacts as well as being stiff enough for proper turning stability. The chassis was designed to be stiff enough that it didn't have noticeable body roll, however the weight was also to be considered. Designing each component on this car was like a balancing act to ensure that the car performed well in all three races. Engineering was used to obtain the optimal performance out of each part, this included making careful material selection, analyzing spring rates, and calculating reaction forces under theoretical loadings.

b. Motivation

This project was motivated by a need for an RC car that can perform well in a small-scale Baja course as well as a slalom and straight line race. This need was established by a desire to compete in the engineering competition at Central Washington University.

c. Function Statement

The steering and suspension worked together to make the RC car controllable.

d. Requirements

The requirements for the RC Baja are designed to ensure that the car performs well and maintains drivability during all three competitions. The requirements are as follows:

1. Shock eyelet pins were required to not yield under 40 lbs. of shear force in double shear.
2. Car needed to have a 50-degree minimum turn angle.
3. Lower control arm had to deflect less than 0.0625" under 20lb load.
4. Trailing arms and rear axle had to actuate at least one inch up or down.
5. Shock tower had to weigh less than 4oz.
6. Needed a minimum of 3" of ground clearance at static ride height.
7. Needed to not compress shocks more than 3" after a 2' drop.
8. Arm of shock tower had not deflect more than 0.0625" under 8 pound total static load (2 pound load at each tire).
9. Tie rods and control arms needed to not deflect more than 0.0625" during a front-end impact at 5 mph.
10. Trailing arms had to deflect less than 0.0625" under a 8.5 pound point load at the center of the long axis.
11. Tie-Rods had to resist buckling from a 20lb axial load.
12. The shear stress on the control arm/bulkhead bolt had to not exceed 42,500psi.

13. Bearing stress on control arm mounting hole had to be less than 4351psi.
14. Shear on caster block pin had to be less than 42,500psi.
15. Trailing arms had to be able to resist buckling under 100lb axial load.
16. Upper long arm had to be able to resist buckling under 40lb axial load.
17. Steering rack connecting bar had to resist buckling under 25kgf load
18. Deflection of rear shock tower arm had to be less than 0.0625" under 24lbf load

Static ride height: How tall the chassis of the car sits of the ground when the car is fully assemble and not moving.

Partners requirements:

1. The RC car needed to have a top speed of at least 20 mph.
2. The RC car needed to reach top speed in 45 seconds.
3. The RC car had to have a length of 20" long.
4. The RC car had to have a width of 10" wide.
5. The total weight of both the chassis and drivetrain had to not exceed 8.5 lbs.
6. The car had to be operated by a radio-controlled remote with a minimum range of 16 meters.
7. The vehicle had to be able to endure a 2-foot drop without the chassis distorting beyond a .5 inch.
8. The RC car had be able to sustain a speed of 20mph for a duration of no less than 2 minutes.
9. The RC car had to have a battery that will last for a minimum of 25 mins.
10. All components of the RC car had to not exceed the cost of $800.

e. Engineering Merit

For steering and suspension there were many calculations done in order to ensure that the end results were desirable. For example, statics was used to determine the pre-loading of the shocks. Mechanics of materials was used to determine the deflection in the trailing arms when under load. Mechanics of materials was also used to ensure that tie rods and control arms survived a front end collision at 5 mph.

f. Scope of Effort

The suspension and steering were the scope of this project. Another engineer designed the drivetrain and chassis. Together, the two projects were assembled as an RC Baja car. Suspension and steering included selection of servo motor, designing control arms and tie rods, integrating wheel hubs with spindles, creating trailing arms, as well as selecting and adjusting spring rates.

g. Success Criteria

The resulting RC car was finished on time and was able to successfully complete the three part competition as well as met the previously mentioned requirements in part 1-d as well as satisfied the ASME RC Baja rule book.

h. Stakeholders

- Noah Stevens and Beni Filemon
    - These two students designed, manufactured, and tested the RC Baja car for an engineering class.
- Dr. Choi and Professor Pringle
    - These two professors facilitated the engineering class that the students were participating in.
- Family of the students
    - The families of the students provided a portion of the funding.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

The design for suspensions and steering had to work together to make the RC car controllable. In order to meet this function, there were multiple iterations of possible design decisions, some of which never made it to a green sheet or even a sketch. Some of the design options discussed were independent suspension front and rear vs solid rear axle, four-wheel drive vs two-wheel drive, and front wheel drive vs rear wheel drive. Each design had its own pros and cons, therefore a decision matrix (Appendix F figure F1) was implemented to assist in choosing a design.

b. Design Description

The final design consisted of independent front suspension and solid rear axle with trailing arms. This design was chosen because independent front suspension usually does the best job of absorbing different types of terrain. This was especially important for the front wheels because the steering would suffer if the front end wasn't moving smoothly over terrain. The rear suspension was designed as a solid rear axle with trailing arms. Solid rear axle was decided to be sufficient for the rear end because steering is less effected by the rear wheels. Also designing the rear end as a solid rear axle made the designs simpler without significant sacrifices in performance. The designs were simpler because the rear axle doesn't have to pivot on each side of the differential.

b. Benchmark

The Arrma Senton is designed for similar use as the RC Baja was. The Senton is a high-end consumer RC car that can be purchased on amazon. The engineers at Arrma decided to use independent front and rear suspension with four-wheel drive. These design choices make the car absorb terrain well and maintain controllability. The design is also very complicated, because the rear axle (figure 2.1) must pivot about the differential. Also, the front wheels (figure 2.2) require a drive axle in addition to their control arms and tie rods. This combination in the front end of the Arrma makes for a very tight fit for all the parts. Overall, the Arrma is a well-engineered RC car and makes a great benchmark.

Figure 2.1 Arrma Senton rear end

Figure 2.2 Arrma Senton front end

c. Performance Predictions

The RC Baja performed well, and the suspension allowed the vehicle to maintain controllability over terrain. The suspension travels more than 2.25" allowing the vehicle to absorb very large variations in terrain. The 50 degree turn angle of the car allows it to navigate very technical terrain. The control arms have an upward angle of 10 degrees allowing the car to sit high enough off the ground so that it can straddle small obstacles. The deflection limits on the tie rods, shock tower, and control arms ensure that the RC was durable and didn't break under extreme circumstances.

d. Description of Analysis

The analysis of the steering and suspension was completed using many of the different skills engineers learn. Dynamics was used to make impact calculations, statics was used to calculate static loadings, and mechanics of materials was used to calculate stresses in the materials. Once the stresses in the components were calculated, the proper material decisions were made using material properties.

e. Scope of Testing and Evaluation

The scope of testing ranged from drop tests and utilizing slow motion cameras to monitor deflection, to running the car into a wall to see the deflection in the control arms. Weights were used to analyze the compression of the suspension. Driving tests were also used to ensure that the steering angle requirement of 50 degrees was met. Each deflection requirement was measured under static load and an impact load of some sort, whether it was a drop or driving impact. Column analysis from mechanics of materials was used to determine the buckling force for the tie rods, upper long arms, and trailing arms; The column analyses each determined the required cross sectional size for a given length. After the column analyses were done a tensile testing device was used to verify the precision of the results. Statics was used to determine the static loading on the shocks, this calculation was used along with kinematics to determine what spring rates should be used for the shocks. Mechanics of materials was used to determine the deflection in the control arms and trailing arms, these results were used to determine the dimensions of the cross section for each part. Shear stress analysis from mechanics of materials was used to determine the pin size for the control arms, trailing arms, and shock eyelet bolts. Each analysis determined a design parameter whether it was size, weight, or a material property.

g. Analysis

i. Analysis 1 – Shock tower arm deflection

The front shock tower arm was required to deflect less than 0.0625" when under a total static load of 8 pounds (2 pounds at each shock) to meet requirement listed in 1d.8.

The analysis showed that the original design of a .25” square cross section of 6061 aluminum was sufficient for a 2-pound load on the single arm.

Requirement: less than 0.0625” of deflection under a 2-pound load at the shock.
Analysis: finding deflection from a 2-pound load 2 inches from shock tower body.
Design Parameter: Size of cross section in order to resist deflection.
Documentation: In the green sheet for analysis 1 in appendix A.01 the design is determined to be sufficient (.25” square cross section of 6061 aluminum).

ii. Analysis 2- Rear trailing arm deflection

The rear trailing arms were required to deflect less than 0.0625” when a load of 8.5 pounds was applied to the center to meet the requirement listed in 1d.10. The analysis showed that the 0.25”x0.50”x3.00” (BxHxL) 6061 aluminum beam was more than sufficient to resist deflection under an 8.5-pound load.

Requirement: less than 0.0625” of deflection under an 8.5-pound load at the center of the trailing arm.
Analysis: finding deflection from an 8.5-pound load in the center of the trailing arm
Design Parameter: Size of cross section in order to resist deflection.
Documentation: In the green sheet for analysis 2 in appendix A.02 the design is determined to be sufficient (0.25”x0.50”x3.00” 6061 aluminum).

iii. Analysis 3- Tie rod buckling

The tie rods had to resist buckling in order for the steering system to function properly. The tie-rods were designed to be 0.158” in diameter with a maximum length of 6”. Each tie-rod was custom and slightly different length, however maximum buckling occurred on the longest tie-rod. Therefore, the analysis was performed on a 6” long column. The analysis showed that the 0.158” diameter at 6” long tie-rod was more than sufficient to resist buckling with a safety factor of 2 (Appendix A.03 Figure A3.1-A3.2).

Requirements: The tie-rod was required to resist buckling from a 20lb axial load as listed in 1d.11.
Analysis: Finding the critical point for the axial load where the column begins to buckle.
Design Parameter: The analysis determined a suitable diameter for a 6” column made from mild steel.
Documentation: The green sheet for analysis 3 in appendix A.03.1-A.03.2 determined that the 0.158” diameter was suitable for a 6” column.

iv. Analysis 4- Shear on control arm/bulkhead bolt

The shear stress for the control arm/bulkhead mounting bolt was calculated to ensure that the bolt could withstand the shear. The design was originally a 0.125” bolt that held together the bulkhead and control arm. The analysis in appendix A.04 figure A4 shows that the design was sufficient.

Requirements: The shear stress on the control arm/bulkhead bolt must not exceed 42,500psi. as listed in 1d.12
Analysis: The shear analysis was done using the double shear equation and then comparing the shear into the bolt to the max shear of that material (appendix A.04 figure A4).
Design parameter: This analysis determined that the 0.125" bolt was suitable for the application.
Documentation: In appendix A.04 figure A4 the green sheet can be seen that documents the appropriate size for the mounting bolt.

v. Analysis 5- Deflection of lower control arm

Deflection of lower control arm was required to be less than 0.0625" under 20lb load. The deflection was found to be 0.00022" (A.05 Figure A5) which shows that the 0.25"x0.3125"x3.38" beam was a sufficient design

Requirement: Lower control arm was required to deflect less than 0.0625" under a 20lb load as according to requirement 1d.03.
Analysis: In appendix A.05 figure A5 the analysis was done using the deflection formula found in Mott A14-1a pg.801.
Design parameter: The analysis determined an appropriate cross sectional size for the component. The appropriate size chosen was 0.25"x0.3125".
Documentation: Appendix A.05 figure A5 (green sheet) and Appendix B.04 figure B4 (final part drawing).

vi. Analysis 6- Shear on caster block pin

Shear on caster block pin was calculated to find the minimum pin size required. The shear load was assumed to be 20lbs. The analysis in appendix A.06 figure A6 shows that a 0.125" pin is sufficient.

Requirement: As listed in 1d.14 the shear on the caster block pin could not exceed 42,500psi.
Analysis: In appendix A.06 figure A6 the analysis was shown that used the double shear equation to solve for cross section area of the pin. Then using the area of a circle, the diameter of the pin was solved for.
Design parameter: The diameter of the pin was solved for in appendix A.06 figure A6 the minimum size found was 0.012" and the actual size that was used was 0.125".
Documentation: Appendix A.06 figure A6 (green sheet).

vii. Analysis 7- Column buckling of trailing arm

Analysis 7 determined if the design parameter found in analysis 2 was sufficient at resisting buckling from the 100lb axial load. The 0.5"x0.25"x6" beam design was found to be sufficient.

Requirement: According to the requirement in 1d.15 the trailing arm was required to resist buckling under a 100lb axial load.
Analysis: In appendix A.07 figures A7.1-A7.2, the column buckling analysis was shown that used the Johnson formula for a short column.

Design Parameter: This analysis verified that the original 0.5”x0.25”x6” design was sufficient enough at resisting column buckling under a 100lb axial load.
Documentation: The analysis was documented in appendix A figures A7.1-A7.2

viii. Analysis 8- Column buckling of upper long arm

The Column buckling analysis for the upper long arm was done to find the minimum diameter to resist buckling. The engineer opted to use an 8mm rod because he had 8mm female hiem joints already available and 8mm was larger than the minimum size found in the analysis from A.08 figure A8.1-A8.2.

Requirement: according to the requirement in 1d.15 the upper long arm must be able to resist buckling under 40lb axial load.
Analysis: In appendix A.08 figures A8.1-A8.2 the analysis was done to determine the minimum diameter of the upper long arm. The engineer assumed the upper long arm was a long column and used the Euler equation.
Design Parameter: The minimum diameter found was 3.3mm the engineer chose to use an 8mm rod because he had 8mm female hiem joints available.
Documentation: The analysis was documented in appendix A figures A8.1-A8.2

ix. Analysis 9- Shear on shock eyelets pins

The shocks would pull and push on the shock eyelet pins as the car went over terrain. The engineer assumed that the force max shear force at the pins was 40lbs.

Requirement: The requirement in section 1d.1 states that the shock eyelet pins were required to not yield under 40 lbs. of shear force in double shear.
Analysis: The analysis in appendix A.09 shows the double shear calculation being used to solve for the size of the pin as well as the max force allowed through the pin.
Design parameter: The pin diameter was found to be a minimum of 0.0245 inches, the engineer decided to size up to a common size of 0.125 inches.
Documentation: The analysis is documented in appendix A.09, figure A9.

x. Analysis 10- Compression of shocks after drop

The suspension system was designed to perform well when being dropped form 2 feet. To achieve this the engineer assumed that when being dropped from 2 feet the shocks would compress a max of 3 inches.
Requirement: The requirement in 1d.7 states that the shock must compress less than 3 inches after a 2-foot drop.
Analysis: The analysis in appendix A.10 equates potential energy and work to solve for the force at impact.
Design parameter: The analysis determined a suitable spring rate of 8lbs/in for each shock.
Documentation: The analysis is documented in appendix A.10 figure A10

xi. Analysis 11- Steering Rack connecting bar buckling

The steering rack connecting bar is responsible for turning the rotational motion of the arms to liner motion of the tie rods.
Requirement: As listed in 1.d.17 the steering rack connecting bar must resist buckling under 25kgf load.
Analysis: Appendix A.11 assumes that the cross bar is a long column and uses the Euler equation to solve for the minimum thickness of the bar.
Design Parameter: The minimum thickness was found to be 0.045" and the engineer decided to use 0.125" for the thickness.
Documentation: The analysis is documented in appendix A.11 figure A11.

xii. Analysis 12- Deflection of rear shock tower arm

The rear shock tower is responsible for connecting the shocks on the trailing arm to the rest of the chassis, while also absorbing the force transferred through the shock.
Requirement: As listed in 1.d.18 the deflection of the rear shock tower arm had to be less than 0.0625" under a 24lbf load
Analysis: The analysis listed in appendix A.12 shows the use of the cantilever beam deflection equation to solve for the height of the arm.
Design Parameter: The minimum height for the arm was found to be 0.14" and the engineer decided to use 0.25" for the actual thickness.
Documentation: The analysis is documented in appendix A.12 figure A12.

h. Device: Parts, Shapes, and Conformation

Many of the parts on the RC Baja car were designed to a specific cross-sectional size, the cross sections were determined by material selection, requirements of deflection and bending, max material stresses, reaction forces/moments, and safety factors. For most of the analyses the reaction forces and moments were first found, then an arbitrary cross section was chosen, then the deflection, bending, and internal stresses were determined and compared to the requirements set by the engineers.

The safety factors were determined by which parts the engineers were least confident in based on their own experiences and assumptions in the analyses. The engineers were aware that some of the parts would experience more wear and tear than other parts, and they wanted to make sure that these parts would stand up to the abuse. The parts that were in high wear and high impact environments received higher safety factors.

The safety factor for the tie rods was decided to be 2.0, this is a relatively high safety factor, however, the engineers felt that it was necessary. This high of a safety factor was necessary because if the tie rods failed then the vehicle would lose control and be rendered useless.

The safety factor for the upper long arms (rear suspension component designed to add stability) was 1.2. This safety factor was slightly lower because the upper long arms shouldn't have experienced much force being transferred through them; This is because the rear shocks are absorbing most of the impacts and the long arms are simply providing stability.

Often the original design of a part would have to be changed all together after performing an analysis. This is because some designs created very abrupt stress concentrations or didn't take advantage of a materials properties. Some discarded part designs had essentially horizontal cantilever beams resisting a vertical force on the end. These designs looked okay on the drawings, but once the analysis was done the moment created at the fixed end of the beam was so extreme that in order to resist bending and failure the beam would have to have a one-inch square cross section when made out of 6061 Aluminum.

Tolerances for most of the hardware were based on common hardware sizes. The mechanics of materials analysis was done in order to determine the stresses in the hardware. Then a minimum size would be calculated and the hardware that was chosen was usually the next common size up from the minimum. The exception to this was when the minimum size was very close to the next size up in common sizes, in these cases, the hardware would be over sized by two standard sizes. This ensures that the hardware won't fail even if there were defects in materials.

Ergonomics were considered when designing the RC car as well. For example, all burrs and sharp edges were smoothed out so that the car could be picked up without cutting a person's hands. Also, all of the wires were properly managed so that they did not get caught on hands when the car was being picked up.

i. Device Assembly

The RC Baja was designed to compete in an ASME RC Baja competition consisting of a drag race, slalom race, and Baja course. The suspension was designed to be a solid rear axle and independent front suspension. The front suspension consisted of an upper and lower control arm connected to the servo housing. The servo connects to a tie rod on each side that runs between the control arms to the back side of the wheels spindle. The shock tower was attached to the top of the servo housing and the shocks went from the lower control arm, in front of the tie rods, and up to the shock tower. The rear suspensions consist of one solid axle with two trailing arms. The rear shock tower was mounted to the rear of the frame, and the rear shocks connected form the trailing arms to the top of the shock tower.

j. Technical Risk Analysis

Associated with the RC car was many technical risks, for example every design choice was made with durability in mind, but with durability comes larger and heavier components. With the heavy components the suspension system became difficult to adjust while still maintaining the required amount of travel. This is because the weight of the car compressed the shocks so much that there was very little travel left. To combat this the shocks had to be adjusted to be more stiff, but when the suspension system became too stiff the system began to not function ideally.

Another design choice that created a technical risk was that the ground clearance requirement was originally too high (3”). With more ground clearance the angle of the tie rod became steeper; With a steeper tie rod angle the servo had to work harder to turn the wheels, this was because most of the force created by the servo was being transferred in the vertical direction and very little was being transferred in the horizontal direction. Not only did this design put more load on the servo but it required a greater amount of force to go through the tie rods, meaning that the tie rods had to be strengthened to resist deflection.

k. Failure Mode Analysis

The failure mode of the tie rods was dynamic, because when the servo wasn’t moving there wasn’t much internal stress inside of the tie rod. However, when the servo oscillated and moved the tie rods, one side of the system was in compression and one side was in tension. As the tie rods repeatedly experienced tension and compression, they could have failed due to fatigue.

The shock tower mounting points experienced shear stress in line with the long axis of the shocks. This shear stress dynamically changes based on how much force the shock is resisting, each shock will be resisting different amounts of force depending primarily on the form of the terrain and the speed of the vehicle. The maximum shear of the 6061-aluminum shock tower was determined using the direct shear equation (Hibbeler EP1 pg 911). Then the calculated shear stress was compared to the maximum shear stress of 6061-aluminum.

l. Operation Limits and Safety

To protect the electronic servo responsible for actuating the tie rods, the endpoints of the servo were properly adjusted. Adjusting the endpoints of the servo ensures that the servo only attempts to turn the tires to the maximum turn angle the vehicle is capable of, instead of trying to turn past the maximum turn angle and overloading the servo.

The suspension and steering was designed to withstand dropping the car from 3’ directly on to the tires. The car had a safety limit of 2.5’ for the height of any drop or jump. This safety limit was put in place to ensure that the components wouldn’t experience plastic deformation or fracture during normal operation, even if there were to be defects in the materials.

3. METHODS & CONSTRUCTION

a. Methods

The RC Baja was created using a variety of manufacturing techniques including outsourcing to "send cut send" as well as in house machining and 3D printing, all of the machines and tooling needed to perform the in-house manufacturing was available at the Hogue engineering building.

i. Process Decisions

The shock tower was to be made from either steel, aluminum, or PLA. The decision matrix in appendix F.02 figure F2 showed the comparison between weight, ease of manufacturing strength, and cost. Weight and ease of manufacturing were weighed the heaviest and cost was weighed the lightest. The 3D printed PLA version was the cheapest, easiest to manufacture, and the lightest. For these reasons the 3D printed shock tower had the highest number of points in the decision matrix.

The control arms could be manufactured using either a plasma cutter, band saw, or send cut send. The decision matrix in appendix F.03 figure F3 showed the comparison between each option. Accuracy, ease of manufacturing, time, and cost were all considered in the decision matrix. The control arms were a relatively important part for the success of the car, for this reason the engineer was less worried about time and cost and more concerned with accuracy; Ease of manufacturing was also very important because the engineer was not a professional machinist. For these reasons "send cut send" was chosen for the method of manufacturing for the control arms. "Send cut send" was the easiest method for manufacturing as well as the most accurate, in addition to these reasons, the turnaround time for "send cut send" was about a week when the engineer had these parts manufactured.

b. Construction

i. Description

The main assembly (NMS-10-001) consisted of 4 sub-assemblies, the sub-assemblies provided by the principle engineer were the front suspension (NMS—10-002) and steering rack (NMS-10-003). The partner engineer was responsible for a rear axle assembly and a chassis assembly and the principle engineer created trailing arms (NMS-20-006) and upper long arms (NMS-20-005) to connect the chassis to the rear axle. The parts created by the principle engineer were manufactured in the following manner; For the front suspension the shock tower (NMS-20-004) and bulkhead (NMS-20-001) were 3D printed. The two control arms (upper NMS-20-003 and lower NMS-20-002) were sent to send cut send to be cut using a water jet. The shocks (NMS-55-002) were purchased. For the steering rack (NMS-10-003) the base (NMS-20-007) was 3D printed, the bearings (NMS-55-001) were purchased. The two arms (NMS-20-008 and 009) as well as the connecting bar (NMS-20-010) were sent to send cut send to but water jet cut. The

upper long arms (NMS-20-005) and trailing arms (NMS-20-006) were made using a lathe and a milling machine in the CWU machine shop. All part numbers are referenced in the drawing tree in appendix B.01.

ii. Drawing Tree, Drawing ID's

First the front suspension assembly was assembled (NMS-10-002) this assembly was done by install the control arms on the bulk head, then attaching the shock tower to the bulk head. Then the steering rack was assembled (NMS-10-003), this was done by press fitting the bearings on to the shaft then pressing the arms on to the bearings then the connecting arm connected both arms. Both of the previous sub assemblies were then attached to the chassis along with the trailing arms and upper long arms. This method of assembly was chosen because the sub assemblies were easiest to assemble when they were not installed on the chassis.

iii. Parts

- Send cut send
    - Control arms
        - NMS-20-002
        - NMS-20-003
    - Steering arm and connecting arm
        - NMS-20-008
        - NMS-20-009
        - NMS-20-010
- 3D printing
    - Shock tower
        - NMS-20-004
    - Bulk head
        - NMS-20-001
    - Steering rack base
        - NMS-20-007
- Mill machine
    - Trailing arms
        - NMS-20-006
- Lathe
    - Upper long arm
        - NMS-20-005
- Purchased parts
    - Shocks
    - Steering knuckles
        - Custom "C" bracket to attach control arms to knuckle
    - Joints and fasteners
    - Bearings

iv. Manufacturing Issues

A potential risk the engineer faced for manufacturing was having access to a 3D printer, the engineer did not own a 3D printer and did not always have access to the printing room. Another

manufacturing risk was the turn around time for send cut send, the engineer had no control over how long the outsourced parts took and there for had to order parts ahead of schedule to ensure that hey were on time. Access to milling and lathe machines was another potential risk because the engineer had to share the machine shop with fellow engineers and with the machining classes at CWU.

v. Discussion of Assembly

When beginning assembly of the device the engineer began with the sub assembly of the front end (NMS-10-002) as seen in appendix B figure B.01. The first step of this assembly was attaching the bottom face of the shock tower to the top face of the bulk head (NMS-20-004 and NMS-20-001). The next step was to attach an upper and lower control arm to either side of the bulkhead (NMS-20-002 and NMS-20-003). Finally the shocks (NMS-55-002) were able to be installed by attaching the lower end to the lower control arm and the upper end to the top arm of the shock tower, this step concluded assembly of the front end.

4. TESTING

a. Introduction

The intentions of the tests were to ensure that the RC car would perform well in a drag race, slalom race, and Baja race. The drag race was on concrete, and the team expected that the car would make it to the end of the 25 foot drag strip in 4 seconds. To do this the engineer responsible for steering had to ensure that the car could hold a straight line at high acceleration. The slalom race required that the car could effectively turn between a series of cones, for this race the engineer tested the maximum steering angle to ensure that the car could make it through the cones. For the Baja race the car needed to accelerate quickly and turn sharply just as in the previously mentioned races; However, this race also included three jumps where the RC car was likely going to experience a fall from 2 feet.

The drag race required that the car was able to hold a straight line at high accelerations. To ensure this the engineer tested the slop in the steering system. If the slop in the steering system was less than 3-degree, then the car passed the test. If the car did not pass the test, then the engineer would have modified the system until the car passed. The car was required to have a minimum turn angle of 50 degree for the slalom race, the car was predicted to be able to turn at an angle of 55 degree. To test this the engineer planned to measure the radius of a 180 degree turn to determine what the true turn angle was. The car was predicted to experience frequent drops from 2 feet during the Baja race, therefore the engineer required that the shocks would not compress more than 3” when falling from this height. To test this the engineer used a slow-motion camera and a ruler to see and record how much the shocks compressed after a drop.

b. Method/Approach

The method and approach for testing each requirement in section 1d-1-10 was as follows:

- Shock eyelet pins were required to not yield under 40 lbs. of shear force in double shear.
    - The shock eyelet pins were placed on the Instron machine with each blade placed 0.25” apart. Once the test was set up a 40lb load was applied slowly four times. After this the pin was checked for deformation; No deformation clearly demonstrated that the pin did not yield under the load.
- Car needed to have a 50-degree minimum turn angle.
    - When performing this test, the engineer measured the radius of a 180-degree turn, then used this measurement to calculate the effective turn angle.
- Lower control arm had to deflect less than 0.0625” under 20lb load.
    - To perform this test the engineer used the Instron machine to apply 20 pounds of force to the beam and measure the deflection at the same time.
- Trailing arms and rear axle had to actuate at least one inch up or down.

    - To test this the engineer the engineer used a ruler to measure the length of travel of the rear axle
- Shock tower had to weigh less than 4oz.
    - To test this the engineer weighed the shock tower
- Needed a minimum of 3” of ground clearance at static ride height.
    - To test this the engineer measured the ground clearance at the front of the chassis when the cars suspension was supporting the weight.
- Needed to not compress shocks more than 3” after a 2’ drop.
    - To test this the engineer dropped the car from two feet in front of a yard stick, he also used a slow motion camera to see how many inches the suspension deflects.
- Arm of shock tower must not deflect more than 0.0625” under 8 pound total static load (2 pound load at each tire).
    - To test this the engineer held a ruler to the shock tower and repeatedly lifted and set down the car to monitor the change in static deflection under load.
- Tie rods and control arms needed to not deflect more than 0.0625” during a front-end impact at 5 mph.
    - To test this the engineer fixed a ruler to the side of the car and recorded a 5mph front end collision with a slow motion camera to monitor the deflection of the tie rods and control arms.
- Trailing arms had to deflect less than 0.0625” under a 8.5 pound point load at the center of the long axis.
    - To test this the engineer used the Instron machine to test the force and deflection of the beam.

Measurement tools

- Yard stick and ruler
- Slow motion camera
- Measuring tape
- Instron machine
    - 3D printed Jig for each part being tested
- Scale

c. Test Process

The engineer conducted his testing mostly on flat ground in good lighting in the Hogue fluke lab. Flat ground was important for consistent turning angles, drop tests, and ground clearance measurements. The lighting in the fluke lab was important for seeing ruler measurements on the slow-motion camera during drop tests. A large portion of the engineers requirements were dependent on deflection of a part and to perform these tests the engineer used the Instron deflection machine in the materials lab.

d. Deliverables

The engineer created a spreadsheet with a different page for each test to record the testing results and requirements. At the top of each page was listed the part and the parts requirements along with testing procedure and a dedicated spot for observations. All deflection tests had data of deflection and force listed in columns and converted to a graph. The steering angle and drop tests had 5 trials and the result of each trial was recorded in a table. Weight of the front shock tower was recorded on its own page with observations of how accurate the requirement was. Each page had photos of the testing being performed along with a statement about the failure or success of the test.

When performing the deflection test for the rear trailing arm the engineer ran into a few issues. The requirement for the rear trailing arm was defined in section 1.d.10 which stated "Trailing arms had to deflect less than 0.0625 inches under a 8.5 pound point load at the center of the long axis". The analysis for the rear (Appendix A.02 Figure A2) was done using the deflection equation for a simply supported beam (Mott A-14-1(a) pg. 801). Since there was a 0.25" slot in the center of the 0.5" wide trailing arm, the engineer simplified the beam to be 0.25"x.5"x3". Under an 8.5lb load the aluminum trailing arm was predicted to deflect 0.00018" which was less than the 0.0625" requirement. In actuality this was a hard analysis to verify because the deflection was so small that at 8.5 lbs their was a large margin of error just based on the where the engineer set the zero point at. Because of this the engineer decided to push the test a little farther the results were 0.0399" at 26.01lbf, 0.0624" at 253.5lbf, and 0.0314 at 55.89lbf. These tests resulted in more usable data but one glaring issue did arise after the 253.5lbf test; the trailing arm was slightly deformed permanently. The deformation did not effect the performance of the part so it was still usable, but the deformation was not expected.

5. BUDGET

a. Parts

The following parts were listed in tables C1-C3 in appendix C. Part numbers NMS-20-002 and NMS-20-003 (Appendix C, Table C1) were the upper and lower control arms, these parts were sent to send cut send for manufacturing; The order total after shipping and tax for a total of four parts was $50.00. Purchased parts consisted of two steering spindle assemblies for a total of $20.00, part number NMS-55-001 (Appendix C, Table C2). The steering spindle assemblies were received on 10/21/2023. Hardware to assemble the suspension and steering consisted of part NMS-50-001 (Appendix C, Table C3), which was a shoulder screw that was used as a pivot point for the control arm as well as NMS-50-002 (Appendix C, Table C3) which was a nut used to hold the shoulder screw in place. Part NMS-50-003 (Appendix C, Table C3) was a 2.5” 4-40 socket head screw used to hold the bulk head to the frame.

b. Outsourcing

The front suspension assembly required the upper and lower control arms (NMS-20-002 and NMS-20-003, Appendix C Table C1) to be outsourced to send cut send. This decision was made because send cut send was cheaper than the cost of labor to manually machine the four components in house. The entire send cut send order was $80.00 and the estimated in-house cost was 20 hours at $37 per hour, which is equivalent to $740.

c. Labor

The average hourly wage for a level one mechanical engineer was $37 in 2023 (Salary.com), this wage was used to estimate labor costs for the project. The labor time used for estimating manufacturing was the total hours dedicated to manufacturing parts in the schedule (appendix, E), which was 120 hours, which costed $4,400 (Appendix D, Table D1). Design time was estimated to be 100 hours which was slightly more than 8hours per part, this total cost came out to $3,700 (Appendix D, Table D1).

d. Estimated Total Project Cost

The estimated total project cost was $8,950 (Appendix D, Table D1). This was broken down as $4,400 for manufacturing hours, $3,700 for design time, and $850 for all of the parts. The cost for all purchases included the cost of tax and shipping. This total cost seemed excessive however, $8,950 was simply an estimate had the engineers in charge of this project been paid. The only money actually spent on the project was for parts, hardware, and outsourcing.

e. Funding Source

This project was funded by money the engineers made at their summer internships, as well as a $150 donation from family.

f. Winter Updates

5a: The engineer previously expected that the parts outsourced to send cut send would cost a total of $80. However, once the order was placed the total came to almost $40. NMS-20-002 costed $8.48 for two parts, NMS-20-003 costed $3.26 for two parts, NMS-20-008 costed $2.37 for a single part, NMS-20-009 costed $1.90 for a single part, NMS-20-010 costed $3.07 for a

single part, and finally NMS-20-011 costed $17.38. On top of the individual price of each part there was also $3.06 paid in sales tax, the order also qualified for free shipping bringing the order total to $39.52. This change in cost opened up a little extra money in the budget for the engineers to use at their discretion.

5b: In winter quarter the engineer ordered the servo from amazon on January 22nd and was not expected to receive the servo until late February or early March. Not having this servo restricted the engineers from completing the assembly of the steering assembly. Also, with the outsourced parts from send cut send there was a lot of clean up work left to be done when the engineer received the parts, this was not a huge issue but it was time consuming and in the future the engineer would pay for a more finished product.

5c: The engineer estimated in the schedule (appendix E) that he spent 65 hours manufacturing parts. The major items for time manufacturing were machining the rear trailing arms which took 25 hours and machining the upper long arms which took 20 hours. For device assembly the engineer estimated that each assembly took 8 hours for a total of 48 hours. Using an estimate of $37 per hour for labor cost the engineer estimates that manufacturing would cost $2,405 and assembly would cost $1,776. The budget in appendix D was updated to reflect the labor cost of manufacturing and assembling time during winter quarter.

g. Spring Updates

5a: During spring quarter the device failed a shock compression test and required stiffer shock springs to correct the issue. The stiffer shock springs costed $35.26 after shipping and tax. The part number for the stiffer shock springs was NMS-55-004 listed in appendix C table C2. This was the only extra cost acquired during spring quarter as the engineer had access to all other necessary resources to complete testing.

5b: The engineer estimated in the schedule (appendix E) that there was about ten hours spent on performing tests and fixing the device from testing, Fixes that had to be performed were replacing the rear shock tower bracket and the front steering assembly. The parts breaking occurred during the RC baja and the drop test, both parts had to be fixed to resume testing.

5c: The rear shock tower bracket broke during the drop test and had to be fixed, had the engineer not had access to free 3-d printers at Hogue then he would’ve had to pay for someone else to print the new part or buy a new 3-d printer and print the part himself. This cost would have been a few dollars to pay for a print or several hundred dollars to buy a printing setup.

6. SCHEDULE

a. Design

Fall: During the Fall quarter 12 analyses were completed, each analysis was scheduled 5 hours to complete. However, some analyses took more or less time; The tie-rod column strength (Appendix E, Figure E1, 2b) calculation took 6 hours because the engineer had to do more research to determine a suitable method of analysis (Johnson or Euler). The shear analysis on the bulkhead (Appendix E, Figure E1 2c) pins took about 3 hours because shear calculations are relatively simple and the part was already designed at the time, so there was less assumption to navigate. The schedule in appendix E outlines completion of the proposal during the fall. The proposal was kept on schedule by dedicating a substantial amount of time each day to working in the computer lab. The time spent in the computer lab ranged from 5-8 hours on an average day. Obtaining purchased part dimensions prior to designing a mating part created a schedule risk. When the engineer was designing the control arms, he didn't know the dimensions of the steering knuckle that they attached to, this meant that the engineer had to guess and change the design when the part arrived. To avoid this the engineer started ordering parts in advance so that the dimensions were already on hand. Another risk to the schedule was that when the engineer made the Gantt chart, he knew very little about how each phase would be completed, this meant the some of the time estimations and dates stated in the schedule were wrong. To overcome this risk the engineer updated the Gantt chart as he acquired new knowledge of each phase and process.

b. Construction

Fall: During fall quarter very little construction took place, what did take place was considered "getting ahead" because almost every part and device manufacturing task (Appendix E, Section 4-5) was scheduled for the winter. This excludes buying the servo which was scheduled to take place in November (Appendix E, Figure E1, 4a). The engineer also purchased spindles, tie-rod joints, spindle joints, and tie-rod material during the fall. Purchasing these items ahead of schedule was done to give the engineer more tangible dimensions for designing parts.

Winter:
During winter quarter the engineer faced several scheduling issues, for example when the engineer placed his order for his servo (Appendix E, Figure E2, task 4a) on Amazon, he expected it to arrive during the week starting January 29th, however due to shipping issues with amazon the part was estimated to arrive sometime between February 16 and March 7. This servo was an integral part to the steering of the device and the engineers had to wait to finish assembly of the device during winter quarter. All other parts in the Amazon order previously mentioned arrived during the week of January 29th just as the engineer had anticipated. To make do when the part was missing the engineer acquired a 3D model of the part, this allowed him to 3D print a non-working servo. This 3D print allowed the engineer to create a non-working prototype of the steering system so that when the part arrived everything was ready for it to be added in to create a functioning device. To remedy this issue in the future the engineer decided to place online orders ahead of time so that long wait times would affect the project less.

The engineer had no issues with meeting manufacturing deadlines, especially with 3D printed parts. The engineer had 24/7 access to a 3D printer and this allowed him to create parts whenever

it was convenient for him which led to parts being finished ahead of time. 3D printed parts included the front shock tower, bulk head, rear shock tower bracket, and steering base (Appendix E, Figure E2, tasks 4c, 4i, 4j, 4k). For the engineers second manufacturing deadline most parts were outsourced to send cut send, and the parts arrived January 30th (Appendix E, Figure E2, tasks 4d, 4e, 4l, 4m, 4n, 4o). This arrival date was cutting it close for the February 2nd deadline, and the engineer learned that outsourced parts should be ordered even farther in advance than just two weeks

After the outsourced parts arrived the engineer anticipated that finishing work for all for all of the parts would take about 3 hours (Appendix E, Figure E2, task 4p). However, this estimation was wrong, the engineer spent close to 6 hours in the machine shop finishing the parts to prepare for the manufacturing deadline. Other time estimates like the ones for 3D printing were more accurate, because the engineer wasn't actively working on the parts, he only had to account for the time that it took to slice the STL files, which never took longer than an hour.

c. Testing

Fall: During the fall quarter device evaluation was scheduled to take place in spring (Appendix E, section 6). During analysis the engineer took note of seemingly unreasonable results and planned to test these results during the spring quarter. For example the tie rod Column analysis (Appendix A.03 Figure A3.2) showed that the critical point for the tie rod was above 2400lbs.The engineer decided that this was a result that should be tested later on as seen in the schedule (Appendix E, 6g).

Spring:
During spring quarter the engineer was tasked with testing his device, the engineer chose to perform three tests which were the rear trailing arms deflection, drop test (suspension compression), and front control arms deflection (Appendix E Figure E3 Line 6d 6f and 6a). The engineer struggled with access to the Instron machine and if he did not get an admin code before the professors left the building then he could not perform his deflection tests that day. The first time the engineer attempted to use the Instron he was unaware of needing an admin code, so he couldn't do any deflection testing on the rear trailing arm that day. This pushed back the testing for that part an extra day. From that point forward all deflection tests were performed early in the day when several professors were present to input an admin code. Missing the one day for doing the deflection test was only a slight set back and the very next day the engineer performed the test and was back on track with his testing. Each test was estimated to take about an hour and a half and that estimate was fairly accurate because each test took about an hour to perform.

7. PROJECT MANAGEMENT

The engineer funding the project planned to receive extra funding during the winter quarter from already obtained scholarships and grants. However, if the engineer didn't keep his GPA above a 3.5, he would have lost the $2,500 from his WSOS scholarship, and that extra money was what funded the $1,000 budget. The schedule was put at risk when the engineer sent off parts to send cut send in the 7th week of winter quarter. The parts were delayed by "send cut send" and the engineer almost didn't finish the car by the end of the manufacturing and assembling deadline. The engineer became concerned with the safety of the car when he realized that his cars top speed was pushing 60mph and had a solid aluminum frame and weighed 8lbs, if this car would have hit someone or something there could have been severe injuries and damages. The materials for the car were provided by the CWU engineering department, the engineer was concerned that other engineers were going to reserve all of the necessary materials for other senior projects, leaving this project with no material. If there were no materials to manufacture parts then the engineer would have had to either buy material, outsource manufacturing, or 3d print more parts. The concerns of the engineer worked themselves out because the engineer kept his GPA above a 3.5 and materials ended up being plentiful and there was no risk of running out. However, the safety of the car had to be address by choosing to only run the car on lower voltage batteries except for when on a sufficient track. The lower voltage batteries led to a top speed of around 30 mph that was much more controllable and safer to use on campus. Risks were controlled by diligent studying, reserving required materials early, and by reducing the power of the car. The project ultimately succeeded due to the engineer having the appropriate technical expertise and resources.

a. Human Resources

The principal engineer was the main human resource that provided expertise in mechatronics and computational analysis to create a functional design and verify that the design was appropriate for the application and their resume is shown in appendix H. The partner engineer provided expertise in mechanics of materials and material selection to ensure that the chassis and drive train of the car was made out of the most optimum materials. Professor Pringle provided guidance to the principle engineer for analysis, material selection, and design decisions. Professor Pringle was not always available and the engineer had to ensure that he was in contact with the professor a few days in advance so that there was available time in the professors schedule to help the engineer before deadlines.

b. Physical Resources

The engineer required access to milling machines, lathes, taps and dies, horizontal band saw, soldering irons, and fasteners in order to complete the manufacturing of the project. However, all of these resources were located in the labs at the Hogue engineering building, these labs were not open all day and somedays the labs closed early due to staffing issues. Also, the engineer shared these labs with all of the other students in the building, meaning even if the labs were open the engineer didn't necessarily have access to the required resources. These risks had the potential to delay the engineer past his deadlines for milestones. The engineer

responded to these risks by always starting manufacturing a week before the part was needed, this ensured that the engineer had access to several open lab hours and had the time to wait for certain machines or tools while other students used them.

c. Soft Resources

The engineer required access to SolidWorks, Microsoft project, Wix website builder, and Microsoft word in order to complete this project. The engineer found that SolidWorks worked best on the school computers and opted to do all of the CAD work at school. The computer lab hours at Hogue fluctuated throughout the design portion of the project, this fluctuation created an availability risk for SolidWorks. If the engineer didn't have SolidWorks available to him with a part drawing deadline shortly after, then the engineer would have likely fallen behind schedule. To manage this risk the engineer started part drawings early and downloaded SolidWorks on his personal computer to use as a last resort. Wix website builder and Microsoft office products were at risk of crashing while working on the project. If these software's' were to crash while the engineer was doing last-minute work for a class deadline, then the deadline would have likely not been met. To manage this risk the engineer used these software's in advance to create a time buffer for software crashes.

d. Financial Resources

This project is entirely funded by the engineer and his scholarship, as well as small amounts of funding from friends and family. The engineer has the WSOS scholarship that he received towards the end of high school, this scholarship paid $2,500 per quarter to the engineer and the engineer used the left-over money to fund the project. The engineer's friends and family helped out with funding when they could, contributions from friends and family totaled $200. If the engineer had gone over budget, there was no stakeholder for him to answer to other than himself because all funding was provided with relatively open-ended terms. No equipment or tools were donated or purchased for the engineer; However, all necessary tooling and equipment was already available at Hogue.

8. DISCUSSION

a. Design

The design for the suspensions and steering system underwent some minor changes during the design quarter. Originally the engineer planned to design a car with a solid front and rear axle. However, after doing research and talking with other engineers, the decision was made to use independent front and solid rear. The issue with a solid front axle was that at higher speeds the car would be more likely to lose control over various terrain. This is because when one of the front wheels moved up or down, the other wheel would have to move as well, causing the front end to get thrown around at high speeds. The independent front suspension allowed the front wheels to move independently of one another, making the car more controllable of terrain at high speeds.
The updated front suspension design meant that the engineer had to create a front shock tower control arms. Originally the engineer planned to print an aluminum shock tower and use PLA to print the control arms. However, the engineer decided to switch the front shock tower from being 3D printed out of aluminum to the tower being printed out of PLA. To do this the shock tower had to be made much more hefty, because PLA isn't as strong as aluminum. This change was made because not only was aluminum printing very expensive, but it was a very new process and not many companies were providing this service.

Once the engineer finished the front shock tower design he printed the part to perform some informal testing. One of the tests the engineer performed was dropping the part on the ground. When he did this, one of the shock tower arms broke off. To resolve this issue the engineer added fillets to the inside of the arms to reduce stress concentrations.

After designing the front control arms, the engineer realized that the parts were flat and could easily be cut using a water jet, which meant the parts would be aluminum instead of PLA. The engineer decided that this would be good to implement into the design, because aluminum remains light weight while still being very strong. The strength for These parts were reflected in the analysis for control arm deflection, shown in appendix A.05 figure A5.

Completing the design of the project faced several risks, ranging from scheduling, cost, to acquiring purchased part dimensions.

The time allotted for designing the suspension and steering components was 10 weeks. While this would have been ample time if the engineer only had the RC project to complete but this wasn't the case. Often times the engineer had to juggle deadlines between the project and other classes. The engineer had to consistently make choices on what to work on first because sometimes there just simply wasn't enough time to complete everything, especially when approaching midterms and finals. The engineer at first let project deadlines slip by and then

would complete the work at a later date, while the work was still being completed this was not a good process, nor did it result in good scores when the deadlines would pass. To overcome this risk the engineer started to dedicate more time to school especially over the weekends for classes unrelated to the project. Doing this meant that during the week when the engineer had access to the necessary resources at Hogue (SolidWorks, 3D printers, computer lab, ect.), he could focus on project related tasks instead of his other classes.

The cost of the project was another risk that the engineer faced, and the cost had to be kept in mind during the design phase. The engineer often wanted to buy the most expensive parts or outsource manufacturing, but doing this was not cost effective. To overcome these risks the engineer would redesign parts to make them easier to machine, and sometimes the redesigned parts were even designed so that they could be 3D printed. An example of this was when the engineer originally wanted to 3D print the bulkhead out of aluminum, but the quote for this service was over $300, the engineer decided this cost was not worth it and redesigned the part to be strong when printed out of PLA. To overcome the cost of parts the engineer searched for deals and comparable parts, this way function wasn't sacrificed for cost.

Often times the parts that the engineer was designing had to interface with other purchased parts. The engineer struggled with obtaining the dimensions of purchased parts and would often guess what the dimensions were. To overcome this, the engineer began purchasing parts in advance to so that when a related part needed to be designed he already had all of the dimensions available to him. Often times design work was done with a purchased part in hand as a reference.

b. Construction

During the construction quarter there were a couple changes to manufacturing and assembly of the device. The first change in construction came about when the engineer dropped the front shock tower and the mounting arm for the shocks broke off. The engineer knew that the part had to be stronger so he increased the infill when printing from 60% to 90% and used 3 wall layers instead of 2.

Also, when the engineer was assembling the front end of the RC car, he noticed that the bulkhead did not have a very tight fit on the chassis. To remedy this the engineer added washers to take up the excess space and create a tighter more precise fit. This tight fit was important to ensure the alignment and controllability of the car.

During construction quarter the engineer faced several risks, these included ensuring that purchased parts and outsourced manufacturing arrived on time, covering the cost of manufacturing, and the risk of ruining outsourced parts during finishing work.

To ensure that purchased parts and outsourced parts arrived on time, the engineer had to stay ahead of schedule with his orders. This was especially important with the winter weather during the construction phase. The weather often times would cause delays in shipping in the engineer's area, and he had to make sure that these delays did not effects his deadlines.

To cover the cost of outsourced parts the engineer used project money that was already set aside as well as picked up a part time gig as a delivery driver for an independent contracting company. In combination, the two sources of money allowed the engineer to pay for the outsourced parts easily.

The largest risk that the engineer faced was ruining outsourced parts during finishing work. These parts costed a lot of money and the engineer could not afford to replace them if he ruined them. To avoid ruining these parts the engineer used high quality and sharp tooling to perform all milling, drilling, tapping, and reaming. In addition to using good tooling the engineer ensured that feeds and speeds were correct and that the operations were being performed precisely. Even with the engineer's own checks in place to ensure that parts were not ruined, he still had other engineers look over his process plans to ensure that there weren't any potential issues that would arise during finishing work.

3D printing complex parts worked well for the engineer and saved money and time on manufacturing. The engineer realized early on that not every part needed to be made from the strongest materials, especially if it was designed properly. With that in mind the engineer created the bulkhead, steering rack base, front shock tower, and rear shock tower bracket from 3D printing.

What did not work well was the orientation of 3D printing the front shock tower. The engineer decided to print the part laying flat on it's back to reduce the amount of PVA support material needed. However, the print did not turn out very good in this orientation, the print warped and began separating from the print bed. This led to an inaccurate part that had to be re-printed and ultimately used more much more material than had the engineer printed it in the vertical orientation to begin with.

The finishing of the outsourced parts was completed relatively quick and with ease. The only issue the engineer faced was when drilling one of the mounting holes on the bottom of the rear shock tower. While the engineer was being very careful and abiding by all rules of machining, the drill bit unfortunately broke inside of the part. The engineer added more mounting provisions to the center of the shock tower bracket to make up of the missing hole and has decided to proceed with using the part.

The engineer machined his own trailing arms and ran into an issue with finding .5"x.5" aluminum stock. This meant that the engineer had to machine down a different piece of aluminum to size. He did this by cutting a thin layer off of a small aluminum block and then cutting that layer into strips and then machining those strips down to size. This burned up a lot

of time and the engineer had to a lot more time to machining these parts in order to complete them on time.

The original steering rack base that the engineer printed was not tall enough to keep the tie rods inline with the servo. With the original height the tie rod joints were at too steep of an angle to function properly, the height was increased slightly and the new design allows for all tie-rods to function properly.

When completing the control arms that were ordered from “send cut send” the engineer noticed that the slots for the shocks and the openings for the casters were too tights to fit the mating parts. To remedy this the engineer filed down the parts slightly until everything fit properly.

The engineer learned from the manufacturing phase that outsourced parts should be ordered early, high quality tooling should be used on all parts, and to pay attention to hardware limitations during the design phase. The design of a few parts had to change slightly to achieve better fitment but overall, the original designs that the engineer created worked well and proved his concepts. Overall, the manufacturing phase was a success, and even after all of the issues discussed above the device was completed on time.

c. Testing

When testing the deflection of the rear trailing arm the engineer originally planned to load the piece with only 8.5 pounds at the center. However, during testing the engineer realized that the part was much too strong for an 8.5-pound load to deliver any relevant data. Because of this the engineer decided to push the test past the load requirement and up to 30 then 50 pounds then pushed the test all the way to the deflection limit which was 0.0625” and had a load of 250 pounds. The data with higher loads gave more information about plastic and elastic deformation and was overall more useful than data at 8.5 pounds and 0.0002” deflection.

During the trailing arm deflection test the engineer had to be careful not to damage the part, because the part needed to be used on the device still. To avoid damage the engineer kept the test within the deflection specification of the part. Anything beyond 0.0625” of deflection could have caused permanent damage that would affect the performance of the device. A small amount of plastic deformation did occur when the deflection was pushed to 0.0625” however, the part was not damaged beyond use nor did the damage effect performance.

Another risk the engineer faced when trying to use the Instron was having access to an admin to enter their admin code. If no one was present to enter the admin code then it was not possible to use the Instron. To avoid this issue the engineer performed Instron tests during dedicated class time so that professors were present to enter their admin code.

The trailing arm deflection test was a success because the part met its specifications and did not break. However, the engineer would have liked to of avoided plastic deformation during

this test. If the engineer were to perform this test again, he would slow the head speed down and pay attention to the applied force as the head was moving. When the rate at which the force was increasing slowed down, he would stop the test. This method would have minimized plastic deformation due to the behavior of the stress-strain curve between the elastic and plastic zone.

The drop test was done by dropping the device in front of a tape measure from two feet and recording in slow motion the impact of the device. Originally the engineer planned to measure compression of the shocks using the tape measure in the video. However, since the shocks compressed completely each time the device was dropped the engineer was able to assume 3.5” of compression at each shock on each drop.

This test risked breaking the rear and front shock towers after each drop because a majority of the force from the drop was transferred to the shock towers. The rear shock tower did end up breaking and the engineer re-printed it to fix the device. To protect the rear shock tower from breaking in the future the engineer increased the infill to 90%.

If the shocks hadn’t compressed all the way and the engineer had been forced to use the tape measure for measuring compression it would have been difficult to read because of parallax and the device blocking the measuring tape. 3-D printed measuring sticks mounted to the top of each shock would have worked better because the sticks would have been mounted close to and in line with the shocks.

When testing the deflection of the front control arm the engineer risked permanently deforming the part. To avoid this the engineer did not allow the test to exceed the specified deflection limit of 0.0625”.

9. CONCLUSION

a. Design

The RC Baja, suspension and steering was designed to be implemented in part with the drive train and chassis that was created by another engineer. The function of the steering and suspension was to work together to make the RC car controllable. The analyses done, especially the ones covering spring rates and buckling of steering components, along with principals of mechanical design, led to a system that worked well enough to satisfy the function statement. The spring rate analysis was important because without proper spring rates the suspension would have been either too stiff or too soft, both would have led to the car not being controllable. The buckling analyses of the steering components were important because if a component were to buckle slightly when the car turned then each wheel would not have turned the same amount, making the car less controllable. More requirements were listed in section 1d-1-18 to ensure reliability and functionality of the systems, these requirements were analyzed and met in the analyses listed in appendix A. The designs are listed in appendix B that meet the design parameters listed in section 2G. This project displays engineering merit because of the use of mechanical design when designing the steering system, using mechanics of materials when solving for stresses, deflections, and buckling of components, as well as statics and kinematics when solving for resulting forces from an impact or drop. Parts were specified, components were sourced and budgeted for future sourcing, with all of the work completed at the end of the design quarter, the suspension and steering system was ready to be created.

b. Construction

The RC Baja suspension and steering was designed to absorb terrain and make the device controllable. The engineer opted for an independent front and solid rear axle for the suspension system. Changes to this design included opening up the slots for the shocks on the front control arms using a file, increasing strength and adding fillets to the front shock tower, the height of the steering rack base had to be increased, and there were holes added to the base of the rear shock tower bracket to allow for another mounting location. What led to the manufacturing phase being a success was ordering parts ahead of time, diligently working to stay ahead of manufacturing due dates, and conversing with other engineers to quickly solidify process plans and methods. The manufacturing phase was a success because the end of the phase resulted in a completed and functioning device.

c. Testing

10. ACKNOWLEDGEMENTS

The principal engineer would like to thank his partner, Beni Filemon, for his diligent work in completing his half of the project. The engineer would also like to thank his friends and family for being supportive when the project was not going well. The engineer would also like to thank the WSOS scholarship program, the extra funding that they provided made this project possible. The engineer also gives a special thanks to Caden Harris and Chayce Williams for always providing new ideas, advice, and mentorship.

References

APPENDIX A - Analysis

Appendix A.01 – Shock tower arm deflection

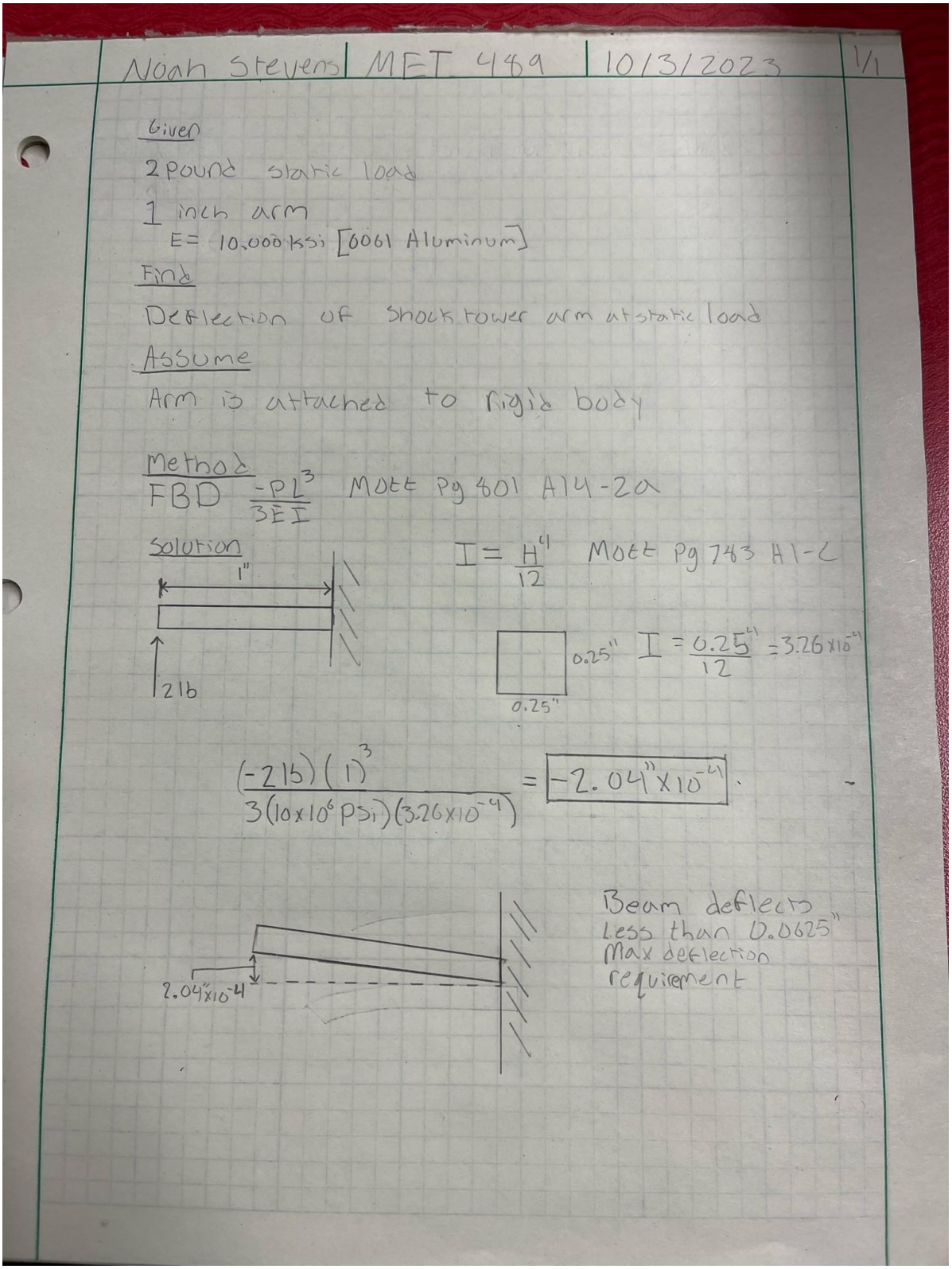

Figure A1: Shock tower arm deflection

Appendix A.02 – Trailing arm deflection

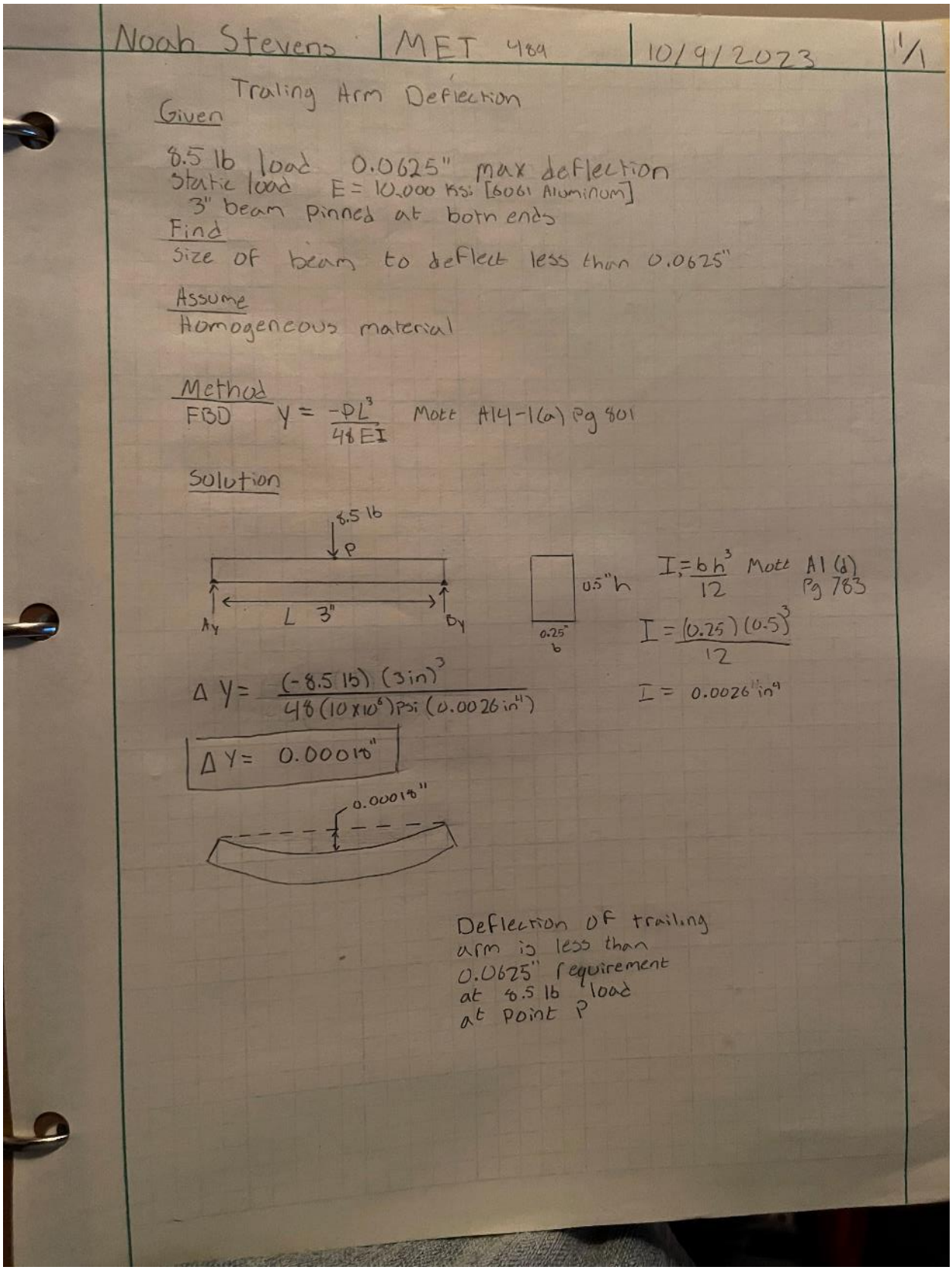

Figure A2: Trailing arm deflection.

Appendix A.03- Tie-Rod buckling analysis.

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Tie Rod

given

Low Carbon Steel Astm a-108 — MatWeb Low carbon steel

$\sigma_y = 60$ ksi ; $E = 202$ GPa $= 29{,}300$ ksi

6" Long 4mm Solid rod = 0.157"

Both ends pinned $K = 1$ — 2016 Axial load Safety Factor of 2

Find

Buckling Force "P_{cr}"

Buckling Stress "σ_{cr}"

Assume

Homogeneous material

Method

Compare slenderness ratios to determine valid column formula

Johnson (short column) $= P_{cr} = AS_y\left[1 - \frac{S_y S_r^2}{4\pi^2 E}\right]$ Mott Pg 225 6-9

Euler (long column) $= P_{cr} = \frac{\pi^2 EI}{(L_e)^2}$ Mott Pg 221 6-5

$\frac{L_e}{R_g}$ > transition slenderness ratio use Euler

Fairfield.edu Machine design notes 07

Solution

$R_g = \sqrt{I/A} = \sqrt{\frac{[\pi D^4/64]}{[\frac{\pi}{4} D^2]}} = \sqrt{\frac{(3.04 \times 10^{-4})\,in^4}{0.0196\ in^2}} = 0.039$ in

Mott Pg 16

$L_e = LK = 6" \times 1 = 6"$

$\frac{L_e}{R_g} = \frac{6\text{ in}}{0.039\text{in}} = \boxed{151.9}$ = slenderness ratio

Transition slenderness ratio $= \sqrt{\frac{2\pi^2 E}{\sigma_y}} = \sqrt{\frac{2\pi^2 (29300\text{ ksi})}{60\text{ ksi}}} = \boxed{98.1}$

$\boxed{151.9 > 98.1 \therefore \text{Use Euler}}$

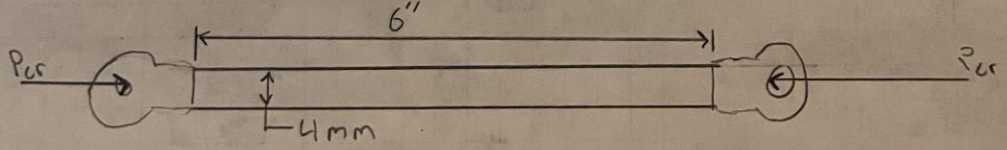


Figure A3.1: Tie Rod Buckling force and stress Pg1.

Appendix A.03- Tie-Rod Buckling analysis Cont.

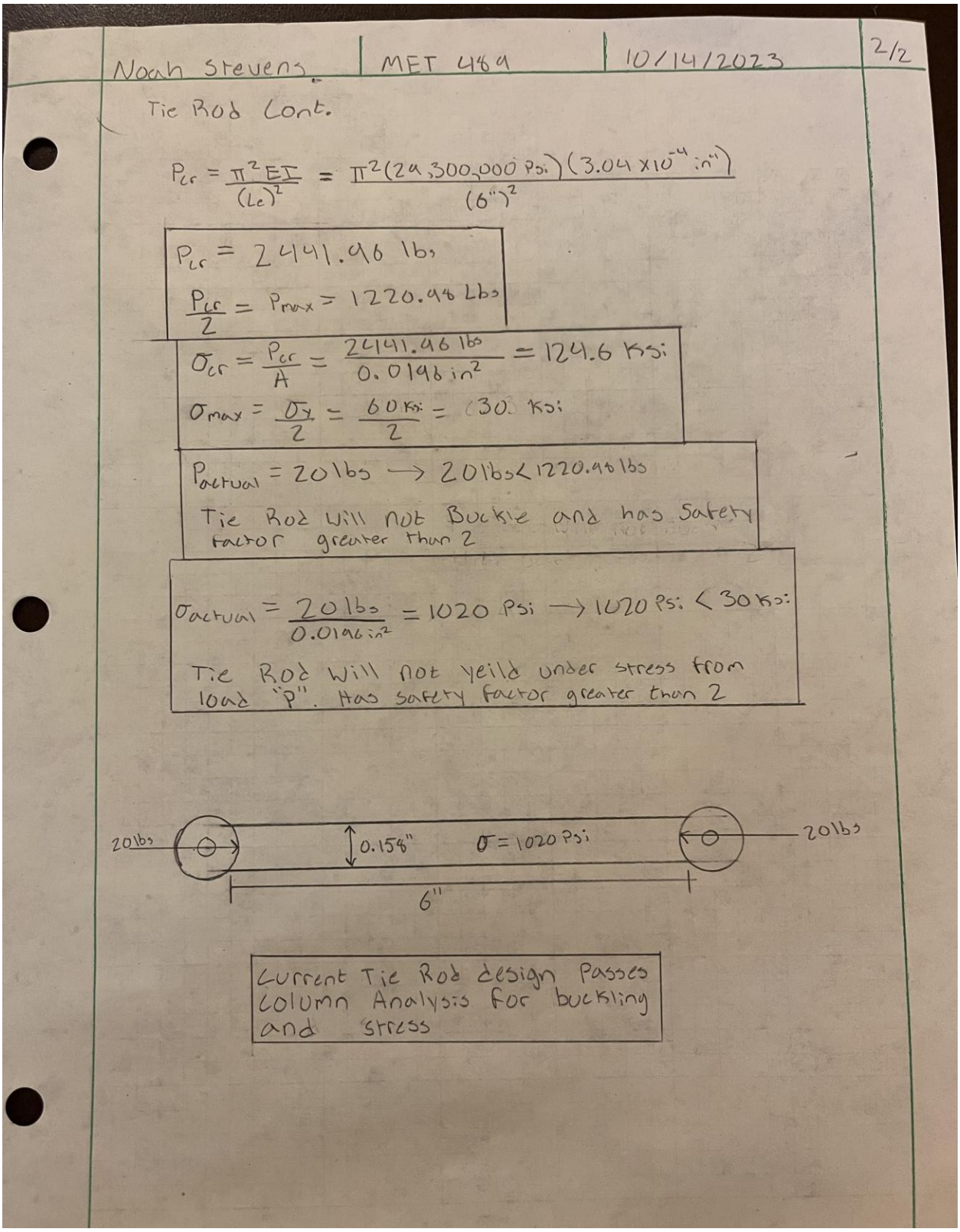


Figure A3.2: Tie-Rod Buckling force and stress Pg2.

Analysis A.04- Bulkhead Bolt shear and bearing stress

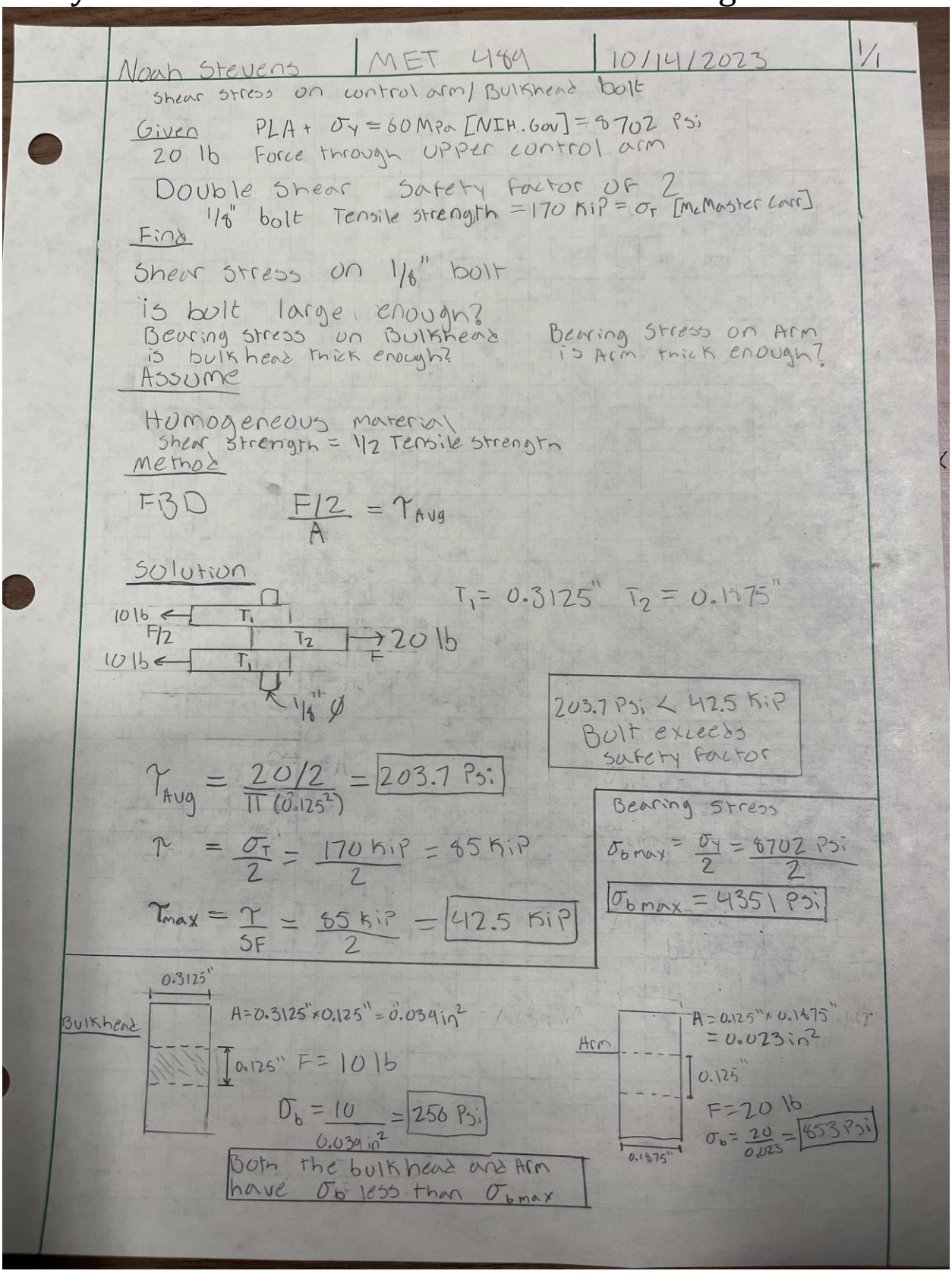


Figure A4: Shear and bearing stress from control arm mount.

Appendix A.05- Deflection of lower control arm

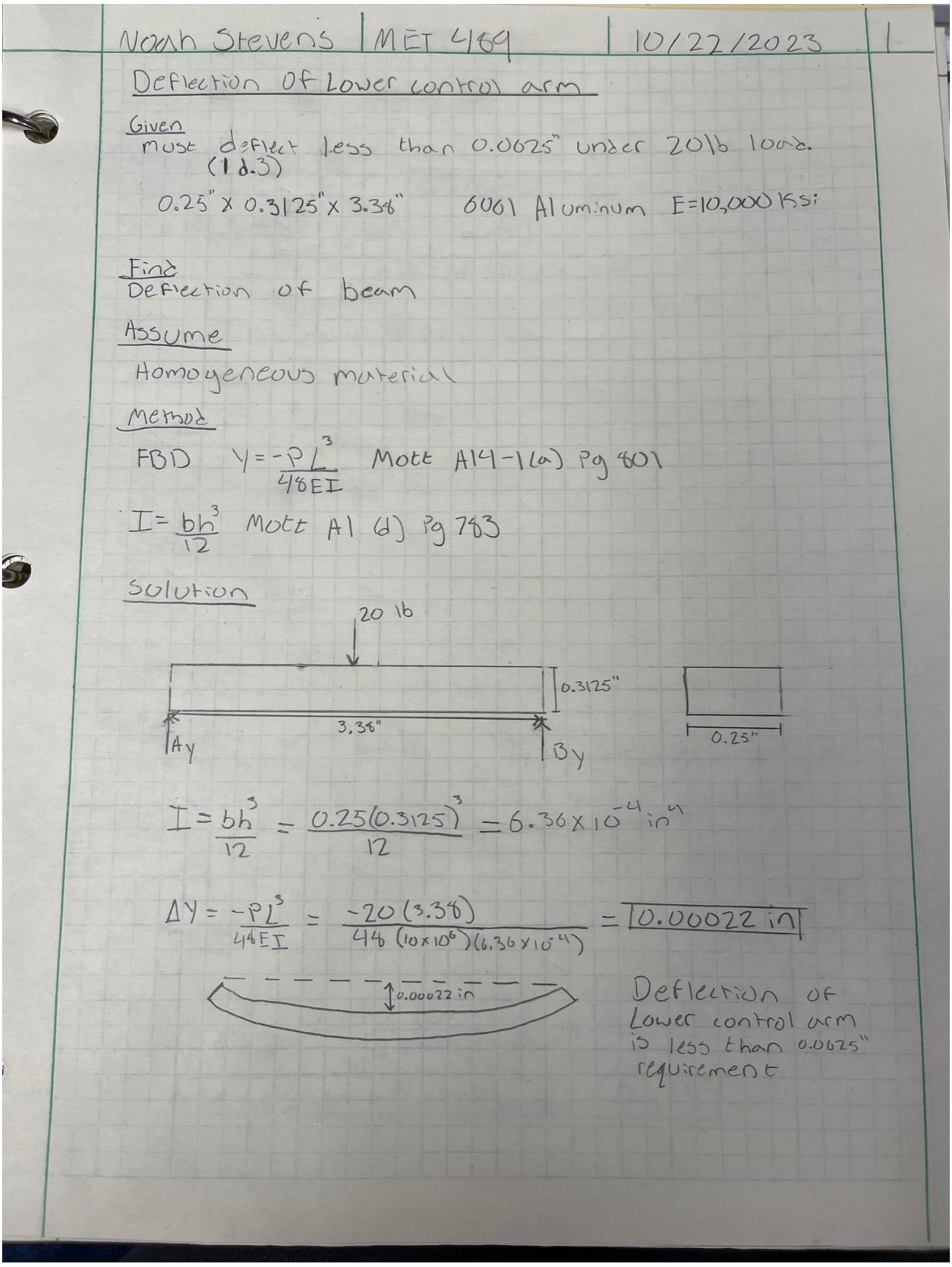
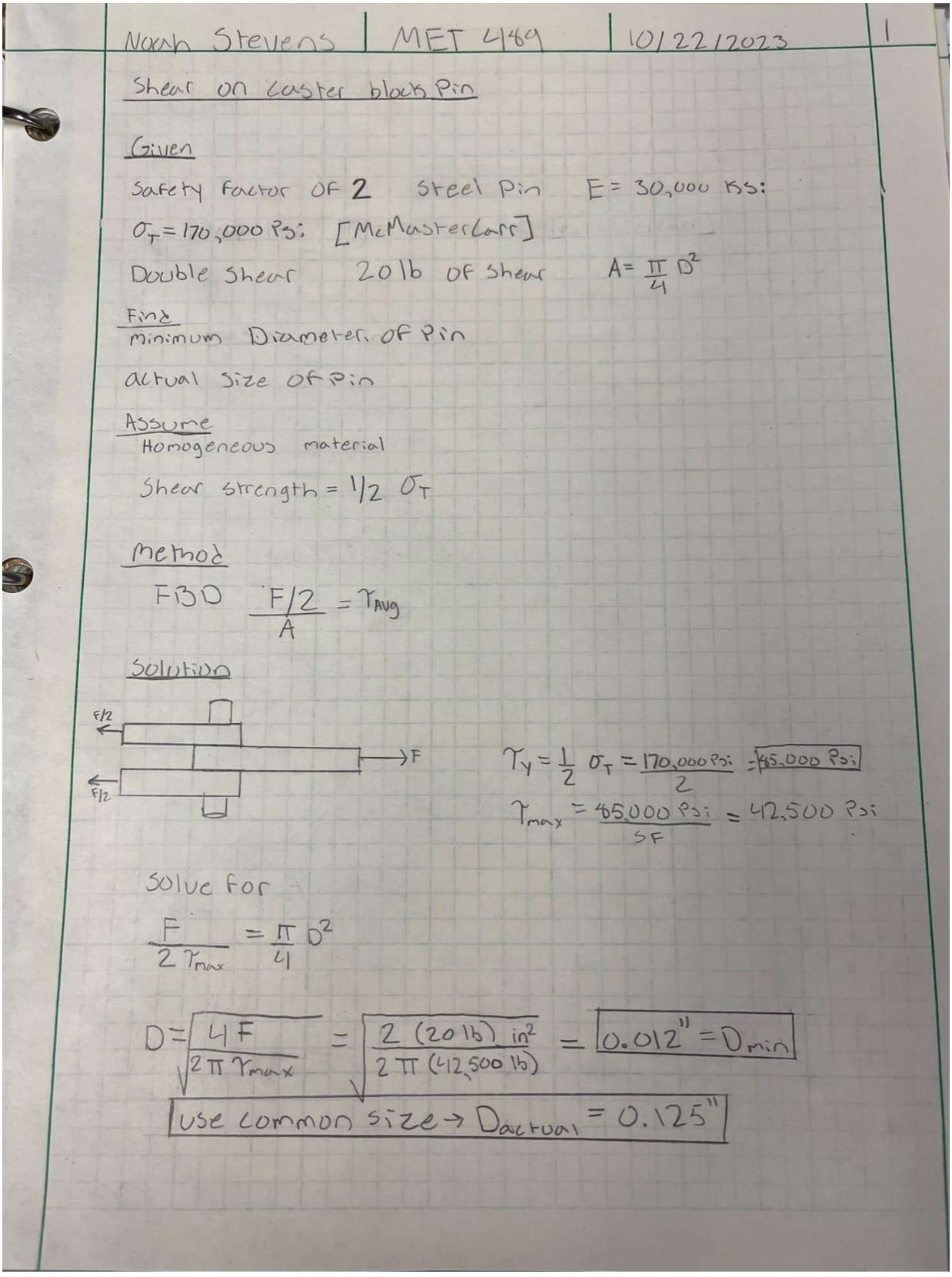


Figure A5: Lower control arm deflection

Appendix A.06- Shear on caster block pin



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Shear on caster block Pin

Given

Safety factor of 2 steel pin $E = 30{,}000$ ksi

$\sigma_T = 170{,}000$ psi [McMasterCarr]

Double shear 2 lb of shear $A = \frac{\pi}{4} D^2$

Find

minimum Diameter of Pin

actual size of pin

Assume

Homogeneous material

Shear strength = 1/2 σ_T

Method

FBD $\frac{F/2}{A} = \tau_{Avg}$

Solution

$\tau_Y = \frac{1}{2}\sigma_T = \frac{170{,}000\text{ psi}}{2} = 85{,}000$ psi

$\tau_{max} = \frac{85{,}000\text{ psi}}{SF} = 42{,}500$ psi

Solve for

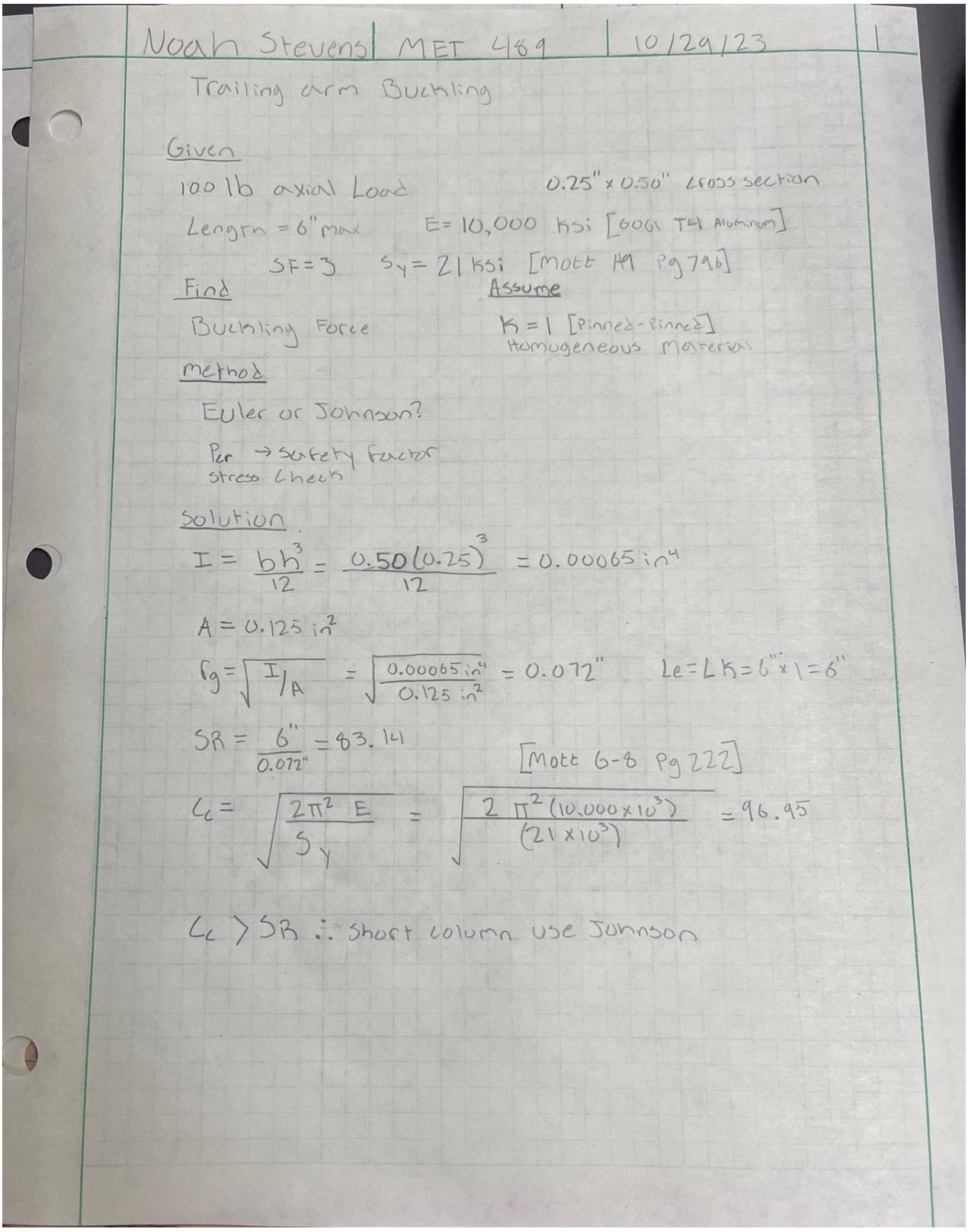
$\frac{F}{2\tau_{max}} = \frac{\pi}{4} D^2$

$D = \sqrt{\frac{4F}{2\pi\tau_{max}}} = \sqrt{\frac{2(20\text{ lb})\text{ in}^2}{2\pi(42{,}500\text{ lb})}} = 0.012" = D_{min}$

use common size → $D_{actual} = 0.125"$

Figure A6: Shear on caster block pin

Appendix A.07- Trailing arm Column Buckling



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Trailing arm Buckling

Given

100 lb axial Load — 0.25" x 0.50" cross section

Length = 6" max — E = 10,000 ksi [6061 T4 Aluminum]

SF = 3 — S_y = 21 ksi [Mott A9 Pg 796]

Find — Assume

Buckling Force — K = 1 [Pinned-Pinned] Homogeneous material

Method

Euler or Johnson?

Per → safety factor stress check

Solution

$$I = \frac{bh^3}{12} = \frac{0.50(0.25)^3}{12} = 0.00065\ in^4$$

$$A = 0.125\ in^2$$

$$r_g = \sqrt{I/A} = \sqrt{\frac{0.00065\ in^4}{0.125\ in^2}} = 0.072" \qquad Le = LK = 6" \times 1 = 6"$$

$$SR = \frac{6"}{0.072"} = 83.14$$

[Mott 6-8 Pg 222]

$$C_c = \sqrt{\frac{2\pi^2 E}{S_y}} = \sqrt{\frac{2\pi^2 (10{,}000 \times 10^3)}{(21 \times 10^3)}} = 96.95$$

$C_c > SR$ ∴ short column use Johnson

Figure A7.1- Trailing arm column buckling

Appendix A.07- Trailing arm buckling cont.

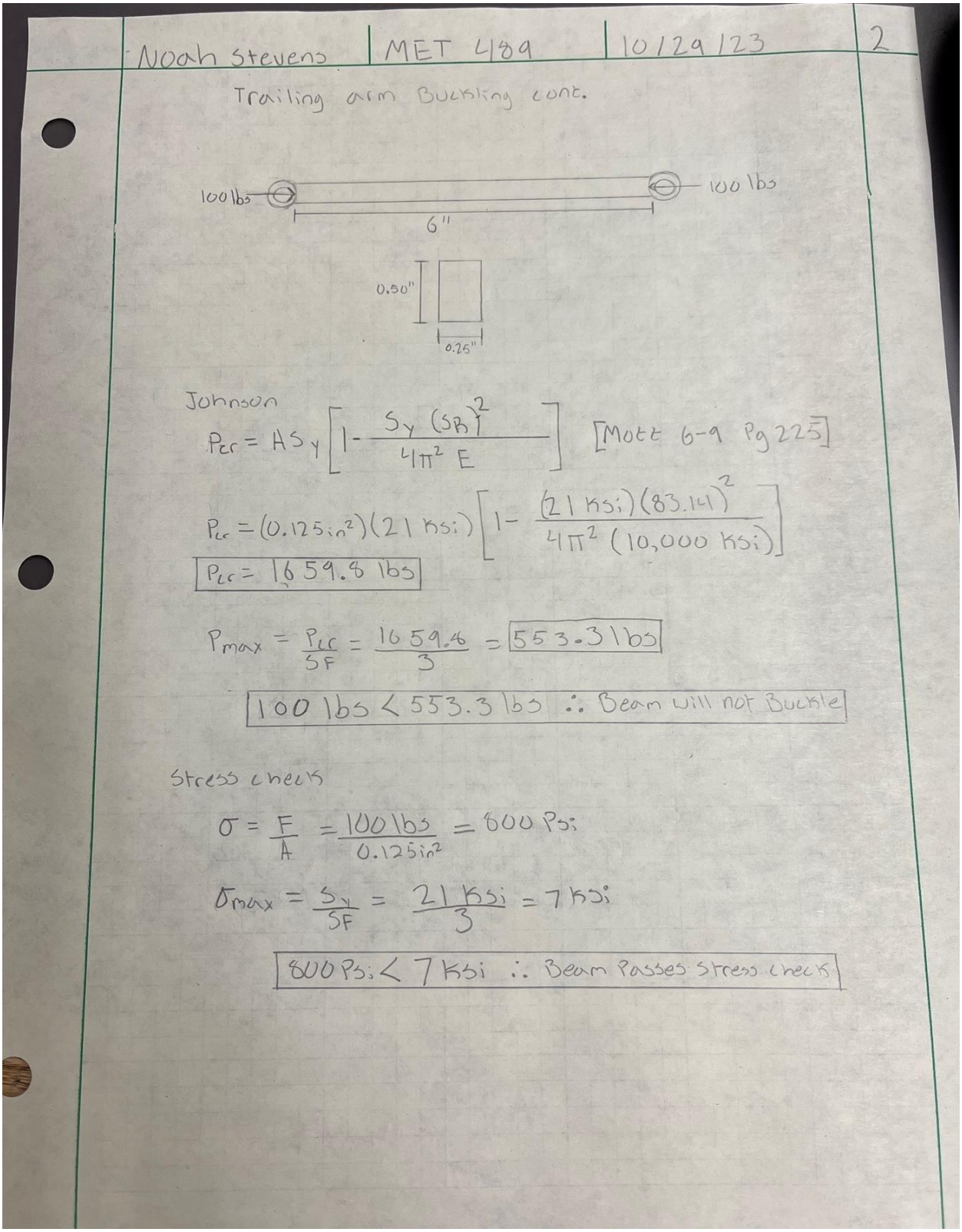
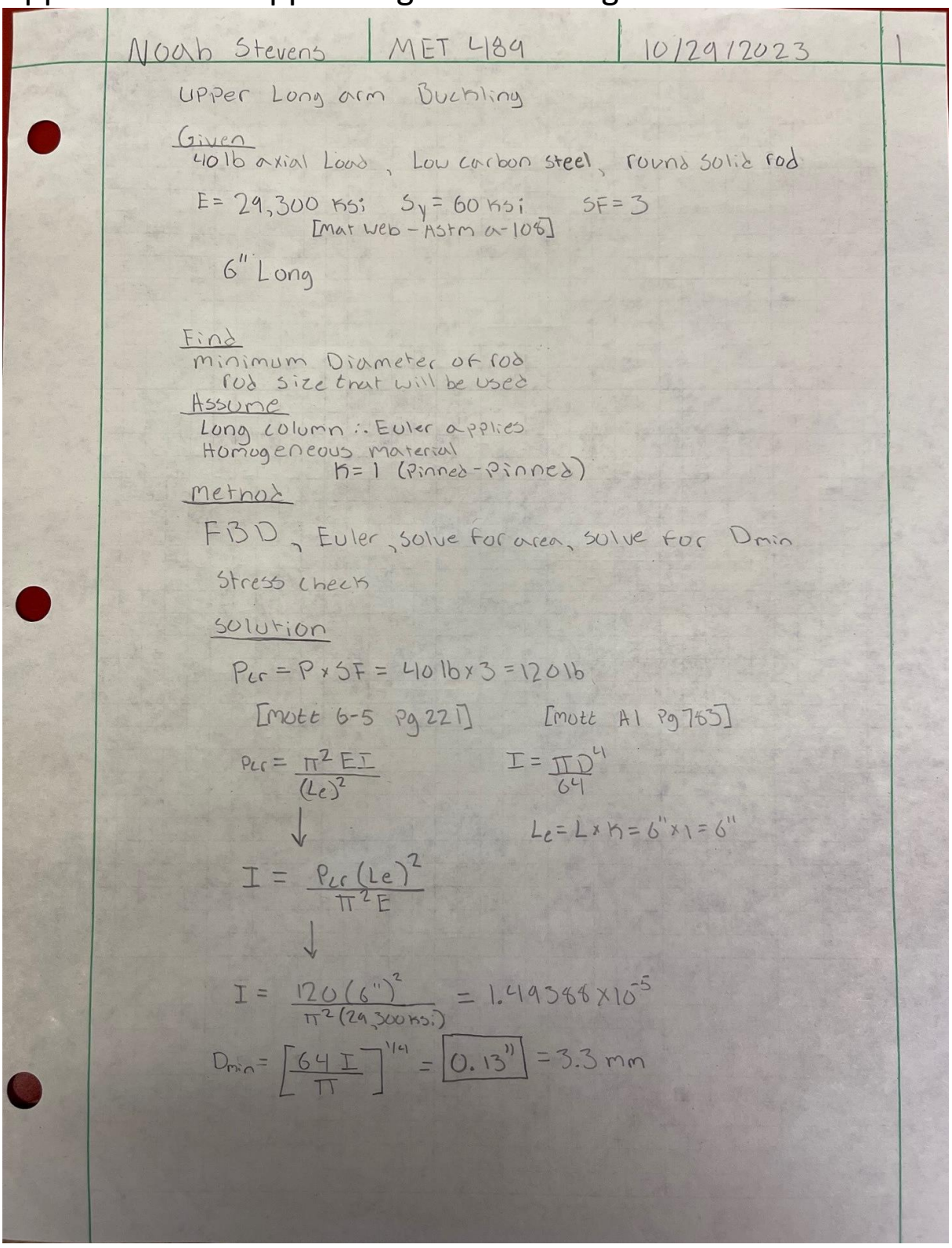


Figure A7.2- Trailing arm column buckling continued

Appendix A.08- Upper long arm buckling



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Upper Long arm Buckling

Given

40lb axial Load, Low carbon steel, round solid rod

$E = 29{,}300$ ksi $S_y = 60$ ksi $SF = 3$

[Mat Web - Astm a-108]

6" Long

Find

minimum Diameter of rod

rod size that will be used

Assume

Long column ∴ Euler applies

Homogeneous material

$K = 1$ (Pinned-Pinned)

Method

FBD, Euler, solve for area, solve for Dmin

Stress check

solution

$P_{cr} = P \times SF = 40\text{lb} \times 3 = 120\text{lb}$

[Mott 6-5 Pg 221] [Mott A1 Pg 765]

$P_{cr} = \frac{\pi^2 E I}{(L_e)^2}$ $I = \frac{\pi D^4}{64}$

$L_e = L \times K = 6" \times 1 = 6"$

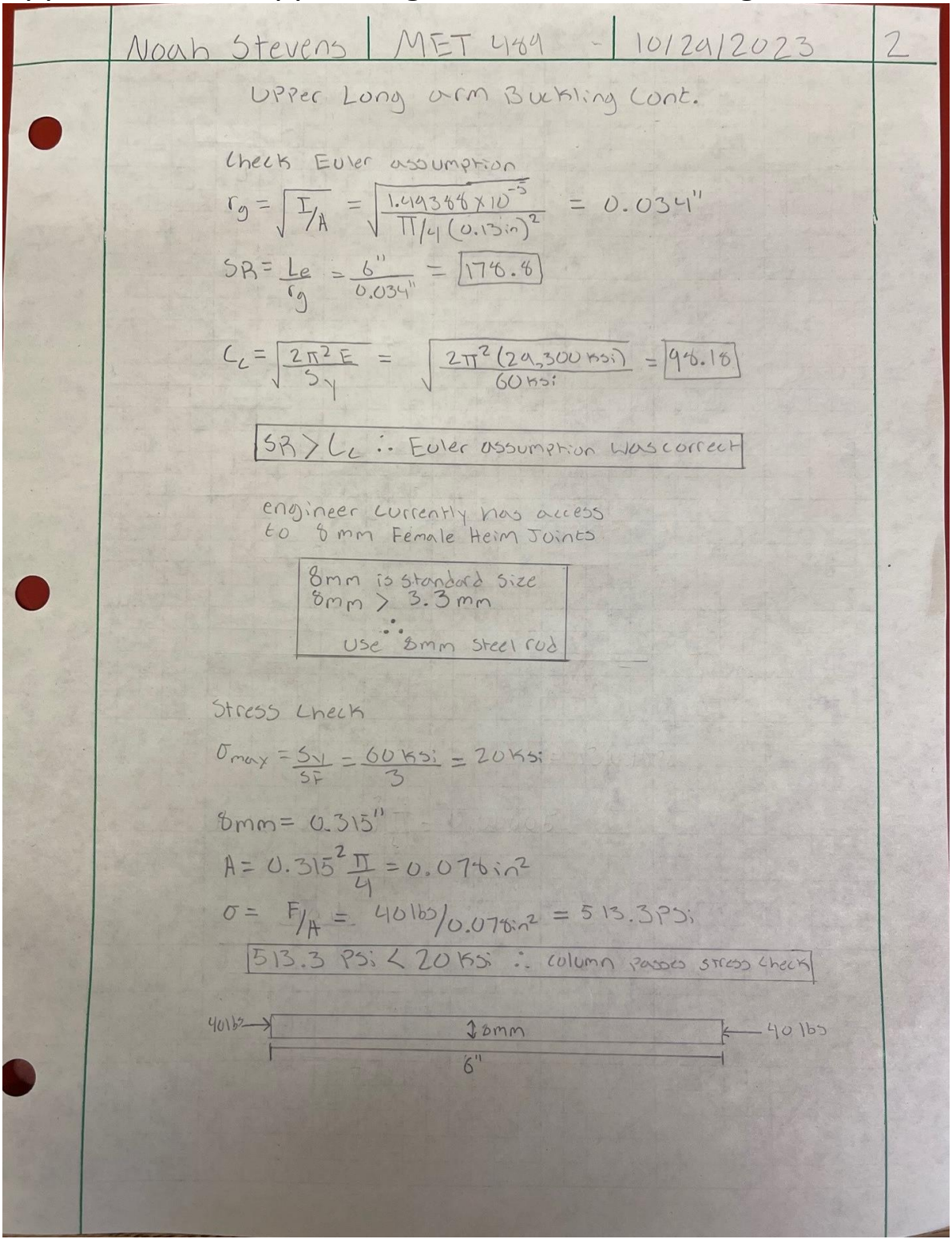
$I = \frac{P_{cr}(L_e)^2}{\pi^2 E}$

$I = \frac{120(6")^2}{\pi^2(29{,}300\text{ ksi})} = 1.49388 \times 10^{-5}$

$D_{min} = \left[\frac{64 I}{\pi}\right]^{1/4} = \boxed{0.13"} = 3.3\text{ mm}$

Figure A8.1- Upper long arm buckling

Appendix A.08- Upper long arm column buckling cont.



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Upper Long arm Buckling Cont.

Check Euler assumption

$r_g = \sqrt{I/A} = \sqrt{\frac{1.49348 \times 10^{-5}}{\pi/4 (0.13in)^2}} = 0.034"$

$SR = \frac{Le}{r_g} = \frac{6"}{0.034"} = 176.8$

$C_c = \sqrt{\frac{2\pi^2 E}{S_y}} = \sqrt{\frac{2\pi^2 (29,300 ksi)}{60 ksi}} = 98.18$

$SR > C_c$ ∴ Euler assumption was correct

engineer currently has access to 8mm Female Heim Joints

8mm is standard size
8mm > 3.3mm
∴ use 8mm steel rod

Stress Check

$\sigma_{max} = \frac{S_y}{SF} = \frac{60 ksi}{3} = 20 ksi$

8mm = 0.315"

$A = 0.315^2 \frac{\pi}{4} = 0.078 in^2$

$\sigma = F/A = 40 lbs / 0.078 in^2 = 513.3 psi$

513.3 psi < 20 ksi ∴ column passes stress check

Figure A8.2- upper long arm buckling

Appendix A.09- shear on shock eyelet pins

Noah Stevens | MET 489 | 11/5/2023 | 1

Shear on shock eyelet pins

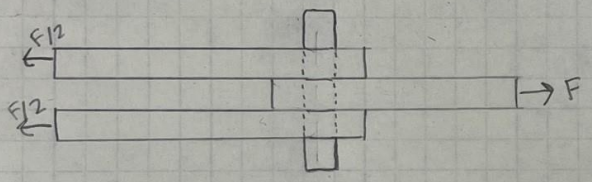
Given
40 lb shear load, double shear, safety factor of 2
Steel pins, tensile strength = 170 kip = σ_T [McMaster Carr]

Find
suitable pin diameter
Force allowable

Assume
shear strength = $\frac{1}{2}\sigma_T$
Homogeneous material

Method
FBD, $\frac{F/2}{A} = \tau_{Avg}$

Solution



$$\tau = \frac{1}{2}\sigma_T = 0.5\,(170\ \text{kip}) = 85\ \text{kip}$$

$$\tau_{Avg} = \tau_{max} = \frac{\tau}{SF} = \frac{85\ \text{kip}}{2} = 42.5\ \text{kip}$$

$$\frac{F/2}{A} = \tau_{Avg} \rightarrow A = \frac{F/2}{\tau_{Avg}} = \frac{\pi}{4}D^2$$

$$D_{min} = \sqrt{\frac{2F}{\pi\tau_{Avg}}} = \sqrt{\frac{2\,(40\,\text{lbs})\,\text{in}^2}{\pi\,(42.5\times10^3)\,\text{lbs}}} = 0.0245''$$

Use standard size → 0.125" pin

$$F_{allow} = 2A\tau_{Avg} = (2)\left(\frac{\pi}{4}\right)(0.125^2)\,(42.5\times10^3)\,\frac{\text{lbs}}{\text{in}^2}\,\text{in}^2$$

$$F_{allow} = 1043\ \text{lbs}$$

Figure A9- Shear on shock eyelet pins

Appendix A.10- Suitable spring rate

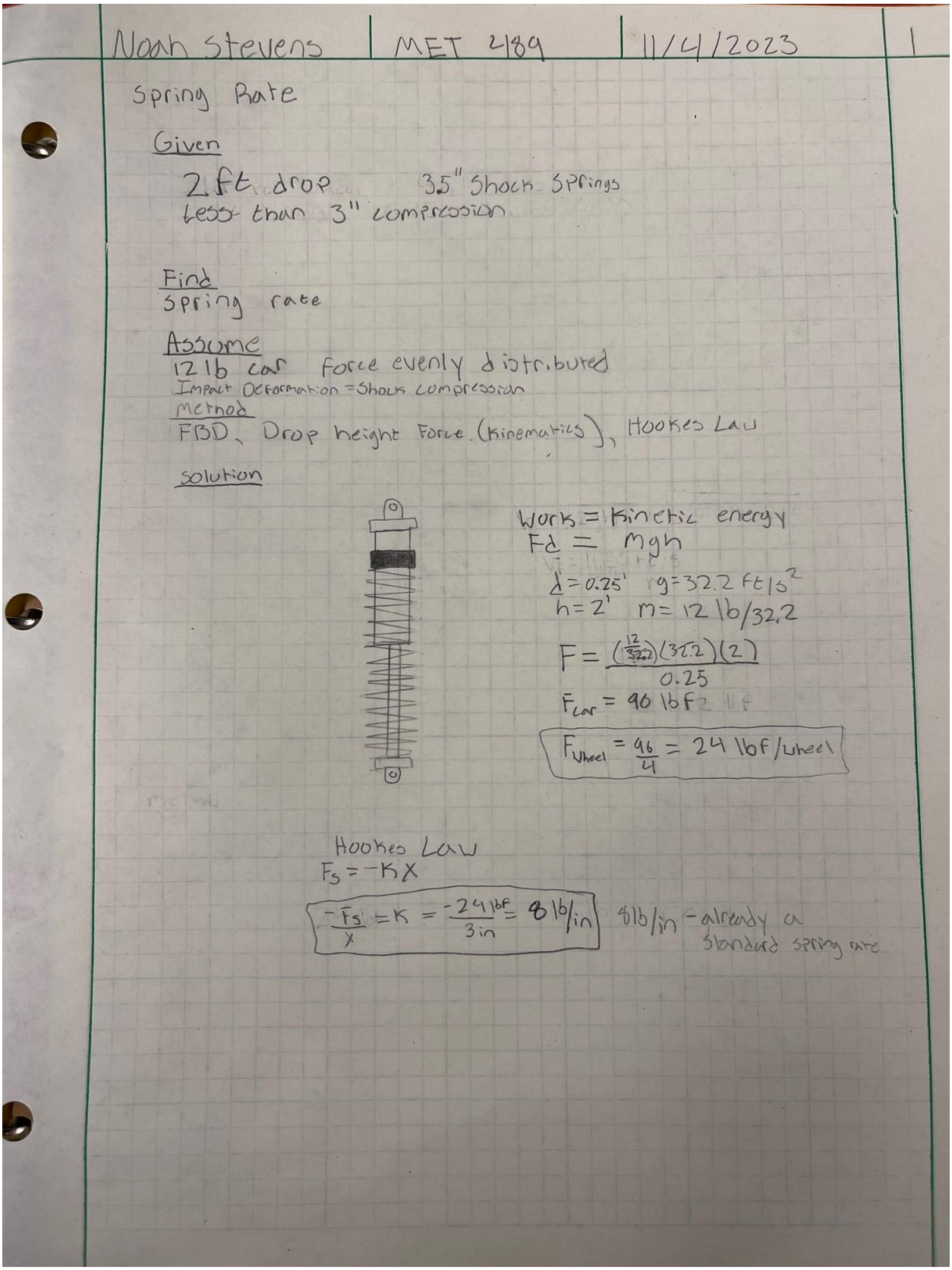


Figure A10- Suitable spring force

Appendix A.11- Steering Rack Cross Bar Buckling

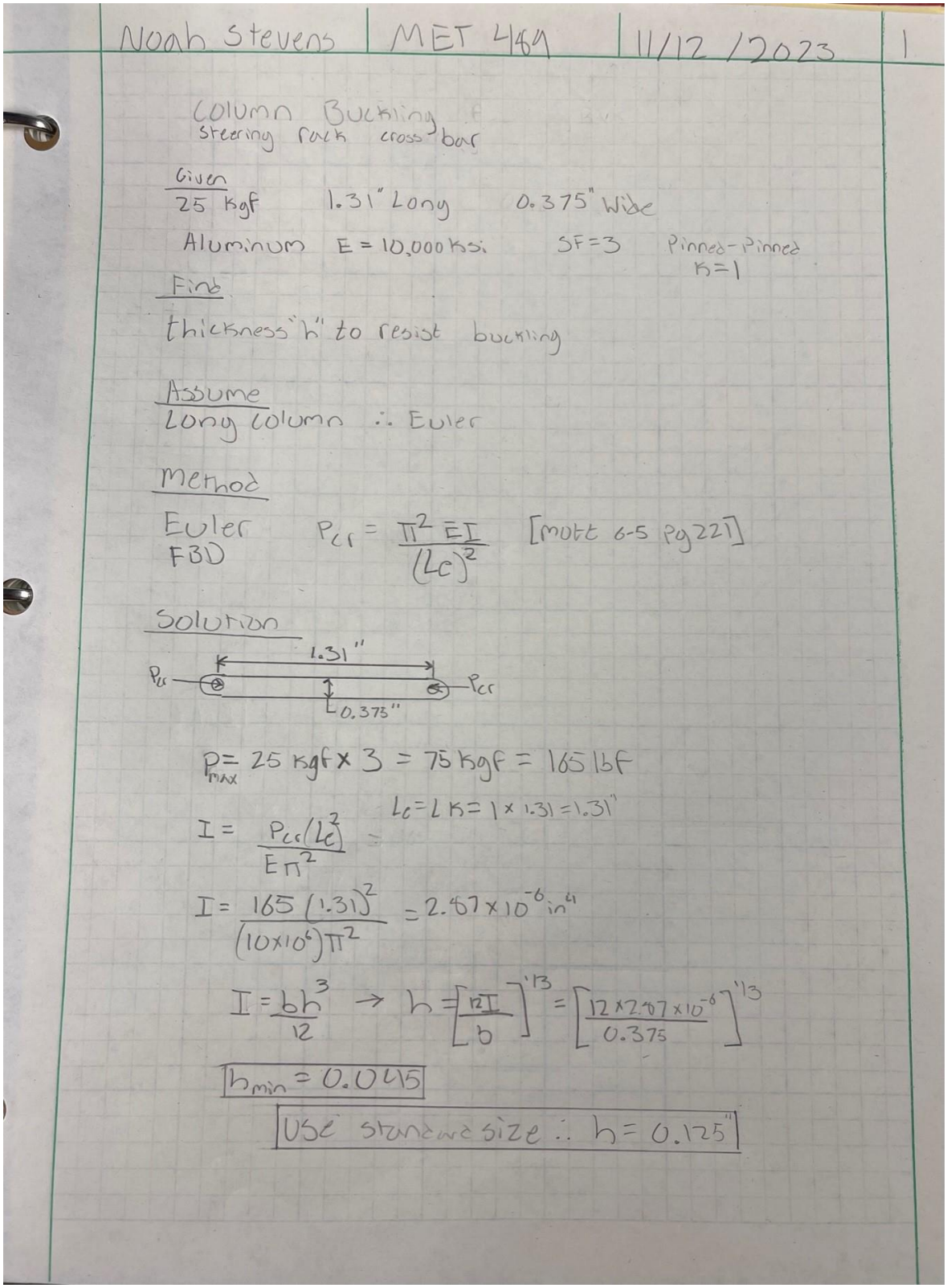
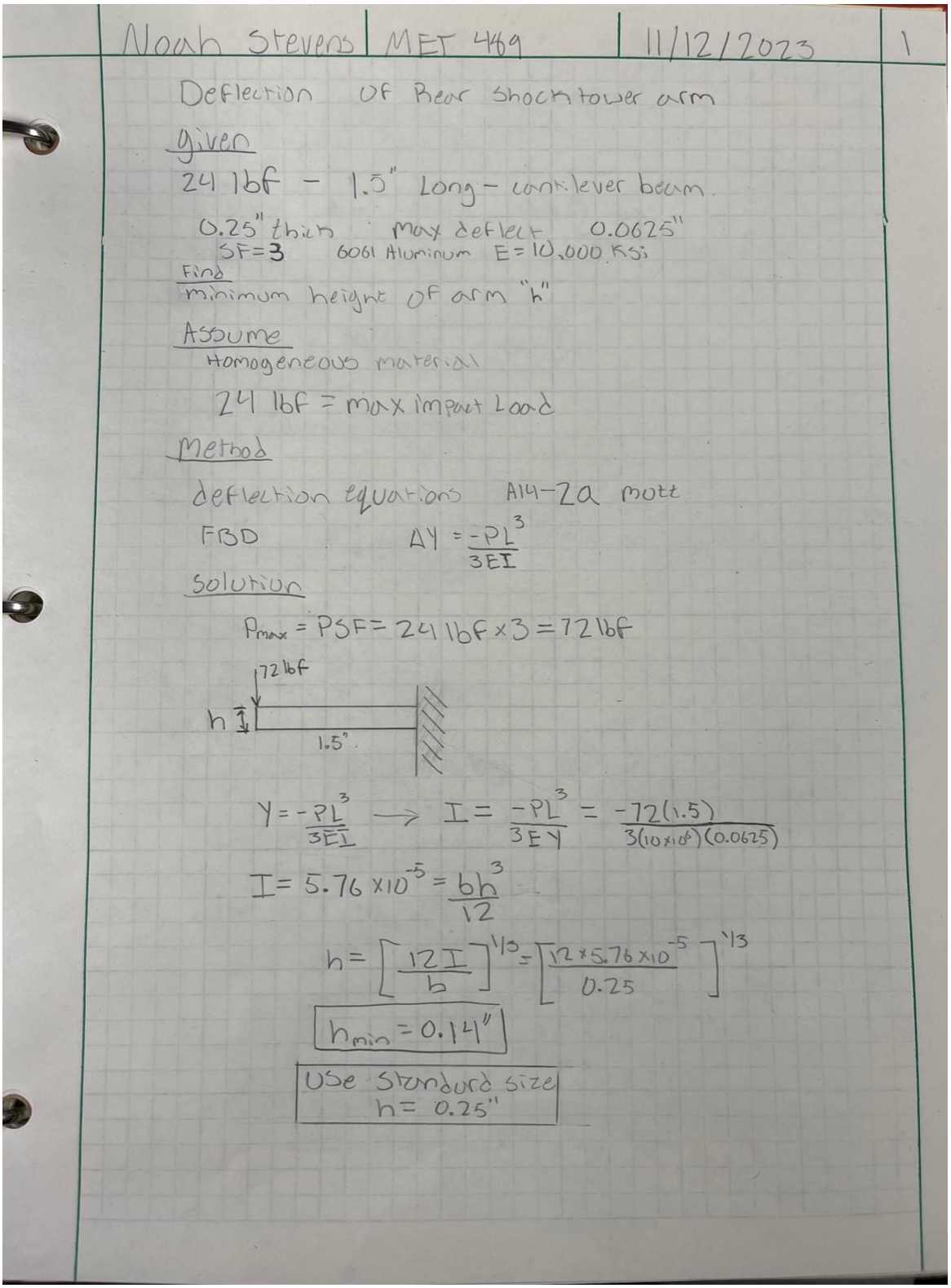


Figure A11- Steering Rack Cross bar buckling

Appendix A.12- Deflection of Rear Shock Tower Arm



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Deflection of Rear shock tower arm

given

24 lbf - 1.5" Long - cantilever beam.

0.25" thick max deflect 0.0625"

SF=3 6061 Aluminum E=10,000 KSi

Find

minimum height of arm "h"

Assume

Homogeneous material

24 lbf = max impact Load

Method

deflection equations A14-2a mott

FBD $\Delta Y = \frac{-PL^3}{3EI}$

Solution

$P_{max} = PSF = 24\,lbf \times 3 = 72\,lbf$

$Y = \frac{-PL^3}{3EI} \rightarrow I = \frac{-PL^3}{3EY} = \frac{-72(1.5)}{3(10\times10^6)(0.0625)}$

$I = 5.76 \times 10^{-5} = \frac{bh^3}{12}$

$h = \left[\frac{12I}{b}\right]^{1/3} = \left[\frac{12 \times 5.76 \times 10^{-5}}{0.25}\right]^{1/3}$

$h_{min} = 0.14"$

Use Standard size
h= 0.25"

Figure A12- Deflection of Rear shock tower

APPENDIX B – Drawings

Appendix B01 – Drawing Tree

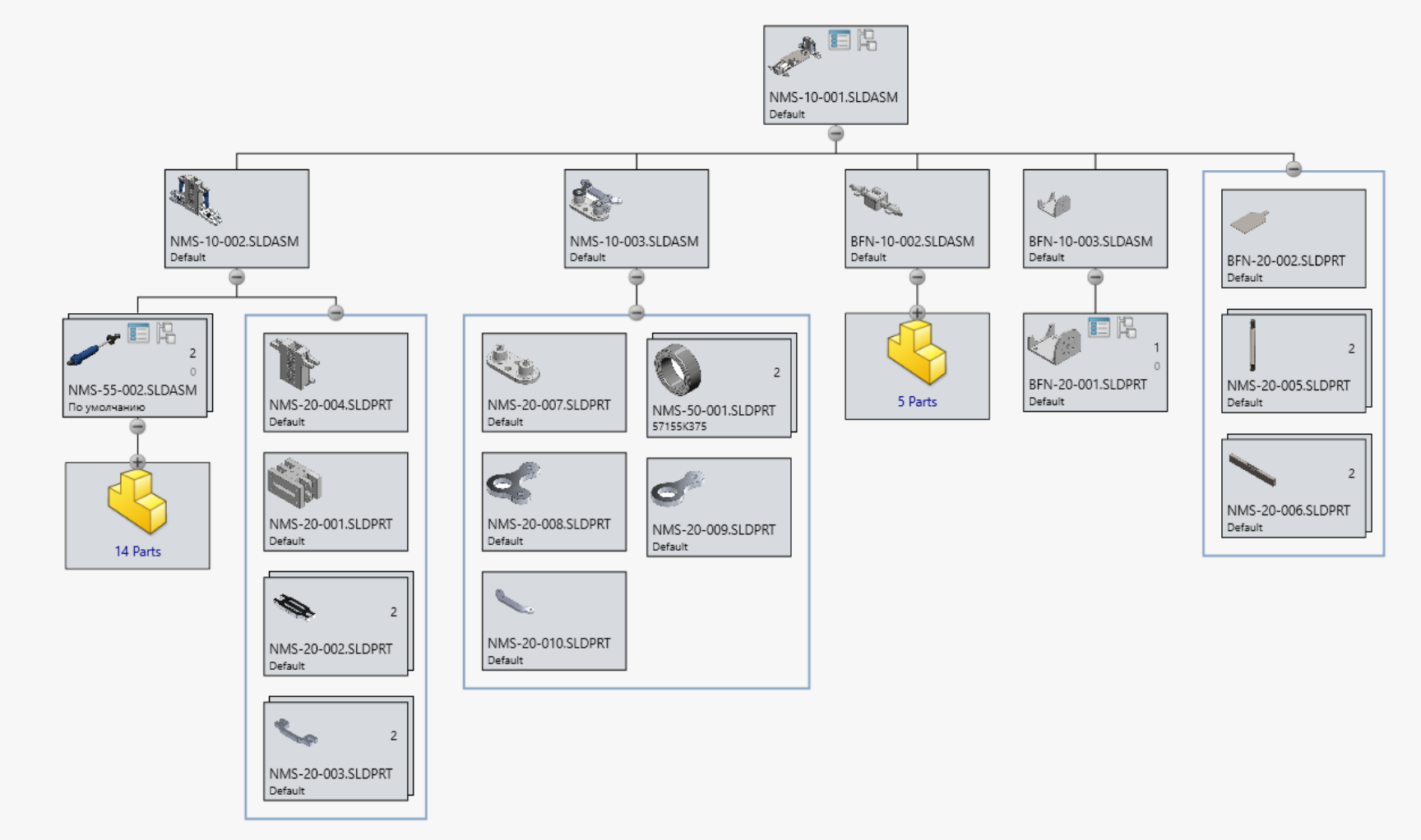


Figure B.01 drawing tree

Appendix B02 – Drawing Index

Table B.02 Drawing Index

Drawing Assignment Num.	**Drawing #(s)**	**Date submitted**
Upload: DWG 1	NMS-20-001	10/11/2023
Upload: DWG 2	NMS-20-002	10/18/2023
Upload: DWG 3 & 4	NMS-20-003 & NMS-20-004	10/25/2023
Upload: DWG 5 & 6	NMS-20-005 & NMS-20-006	11/01/2023
Upload: DWG 7 & 8	NMS-20-007 & NMS-20-008	11/08/2023
Upload: DWG 9 & 10	NMS-20-009 & NMS-20-010	11/15/2023
Upload: DWG 11 & 12	NMS-20-011 & NMS-20-012	01/18/2024
Upload: ASSY DWG 1 & 2	NMS-10-001 & NMS-10-002	11/29/2023

Appendix B.03- NMS-20-001 Bulkhead

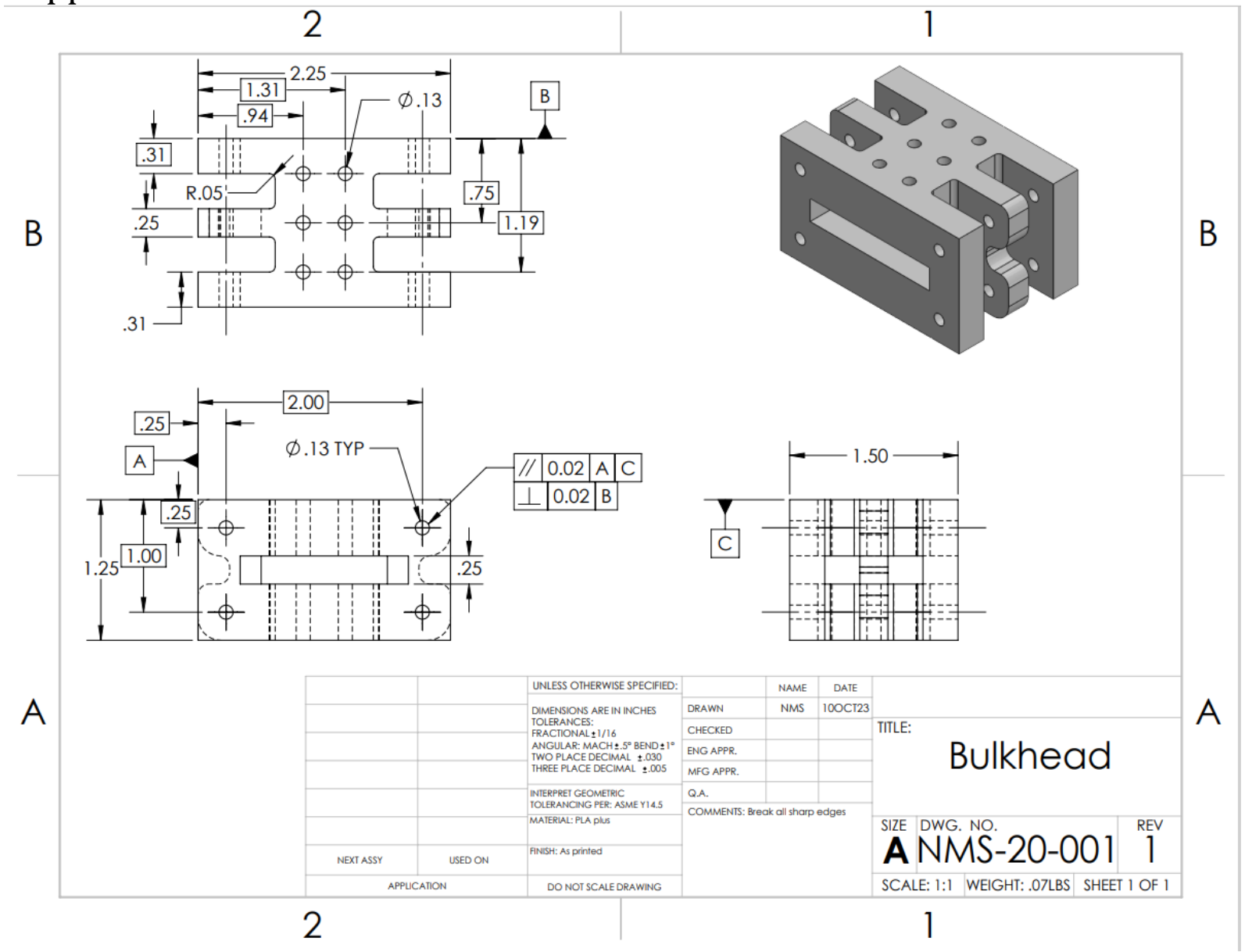


Figure: B3 Control arm bulkhead

Appendix B.04-NMS-20-002 Lower Control Arm

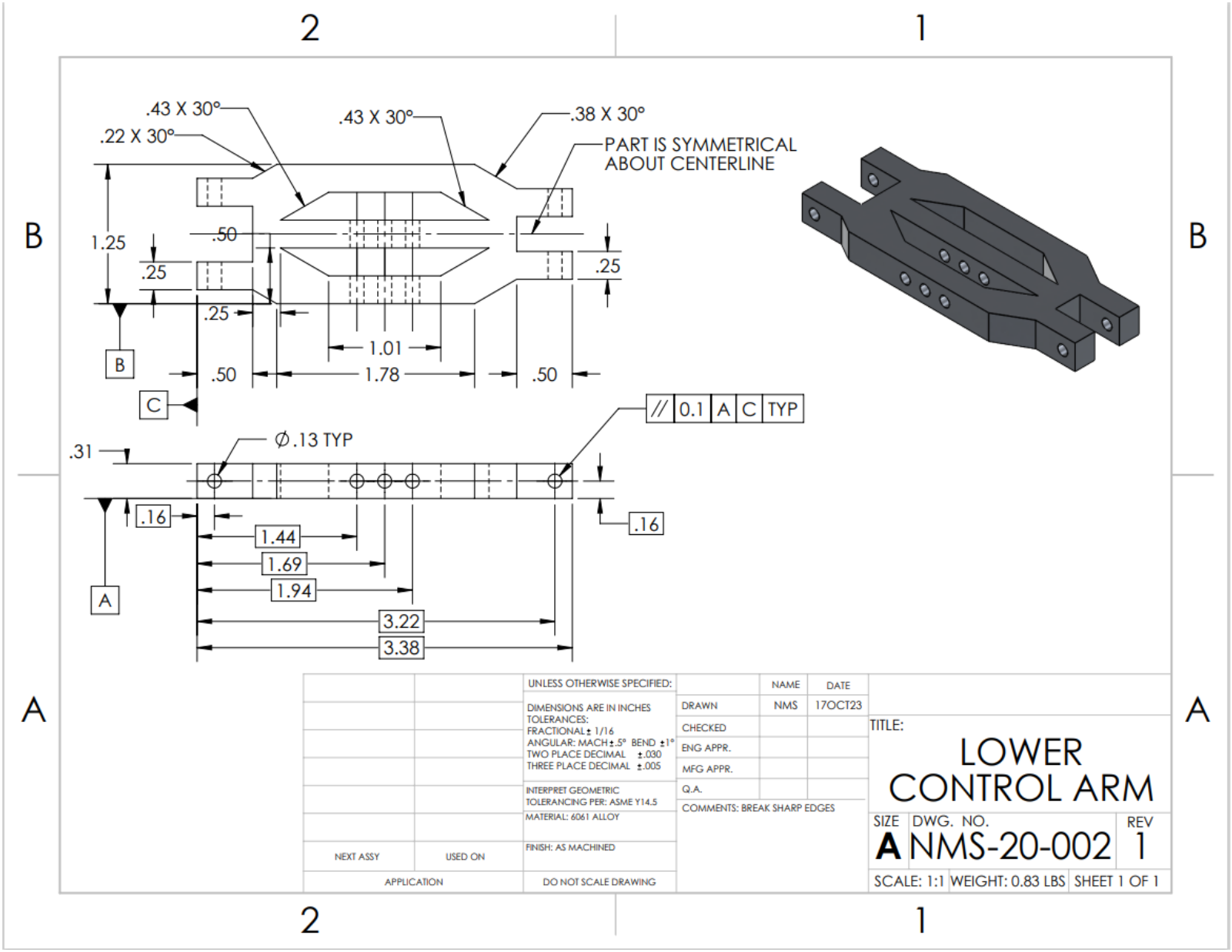


Figure B4: Lower Control arm

Appendix B.05-NMS-20-003 Upper Control Arm

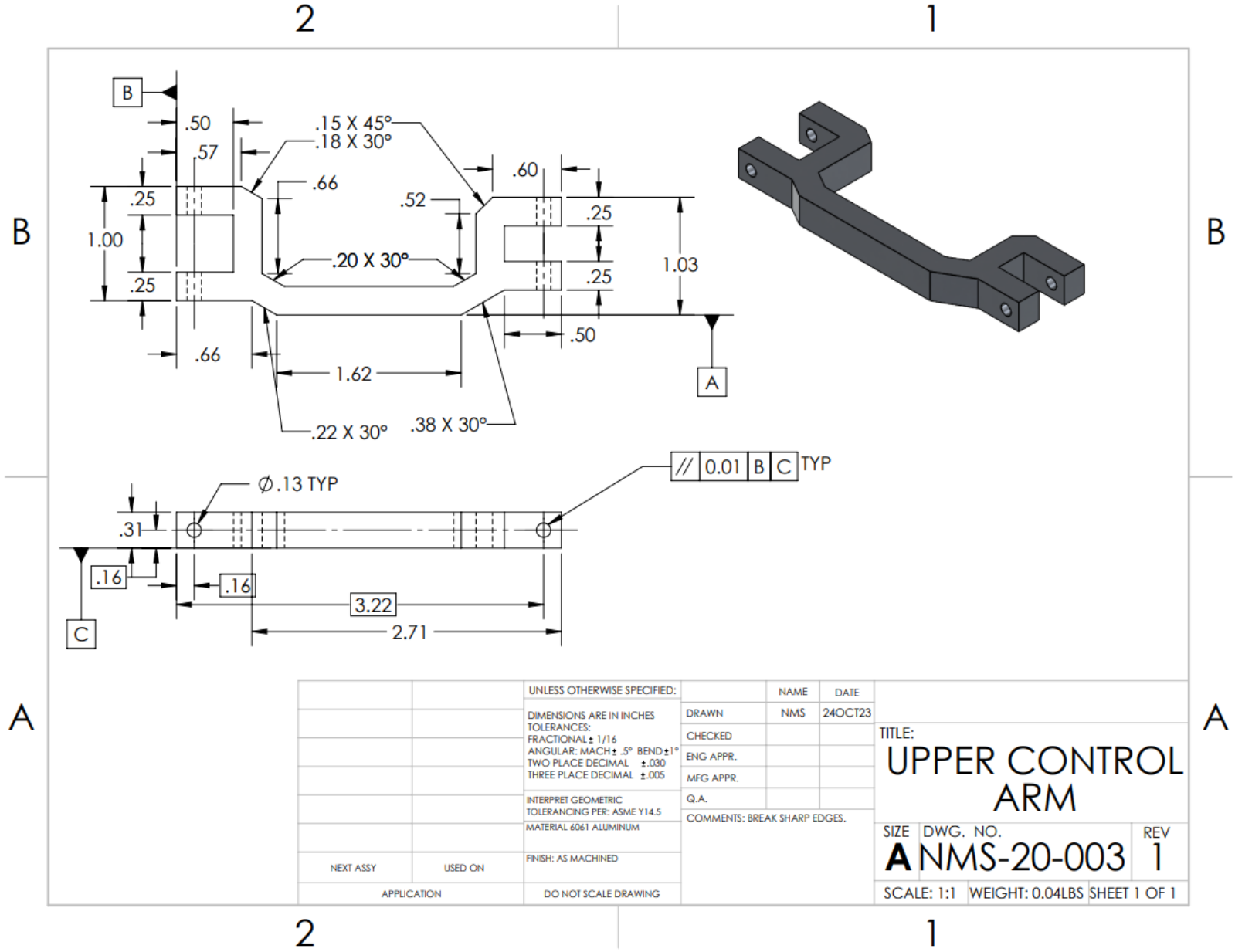


Figure B5: Lower control arm

Appendix B.06-NMS-20-004 Shock Tower

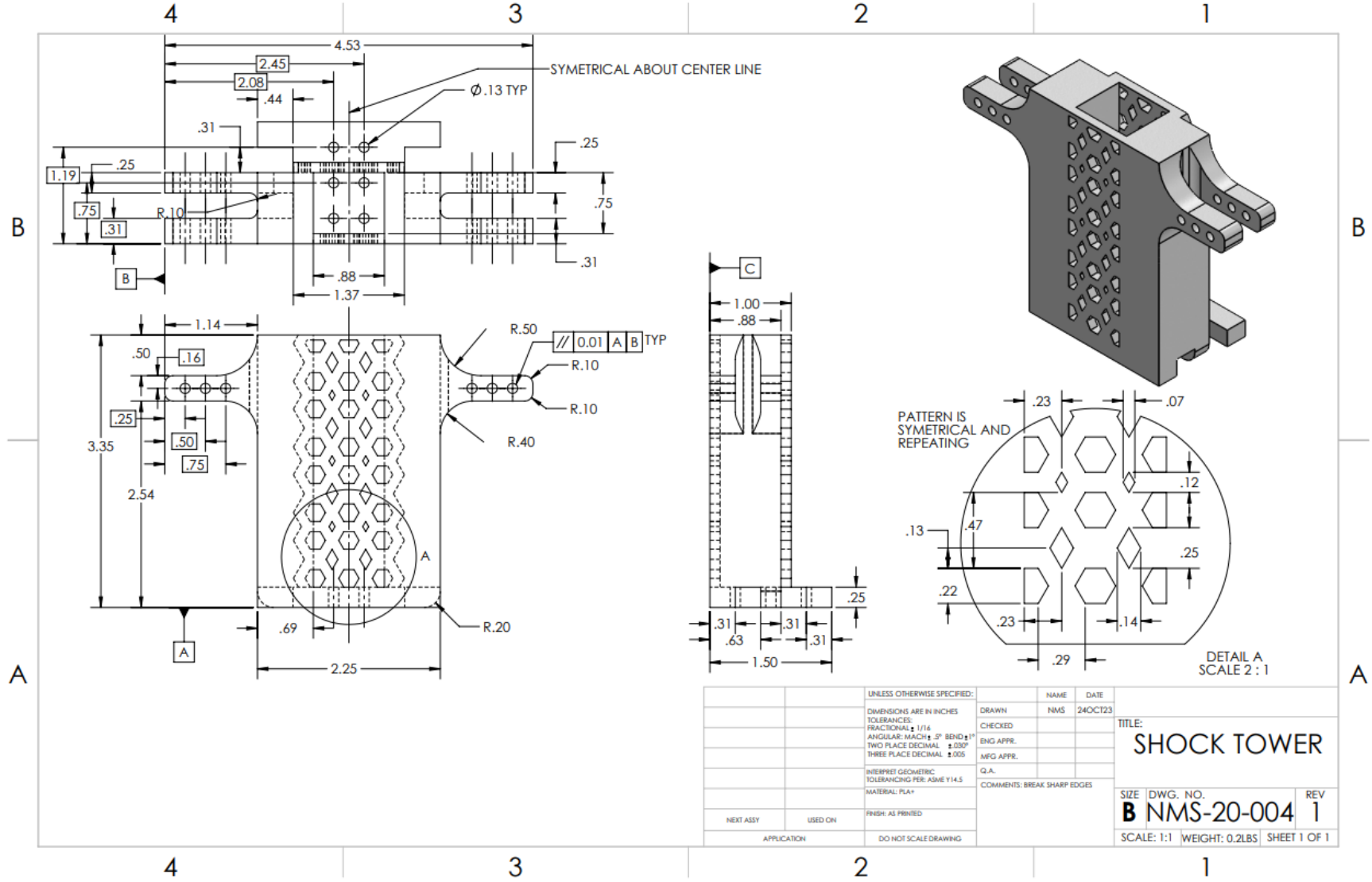


Figure B6: Shock Tower

Appendix B.07- NMS-20-005 Upper Long Arm

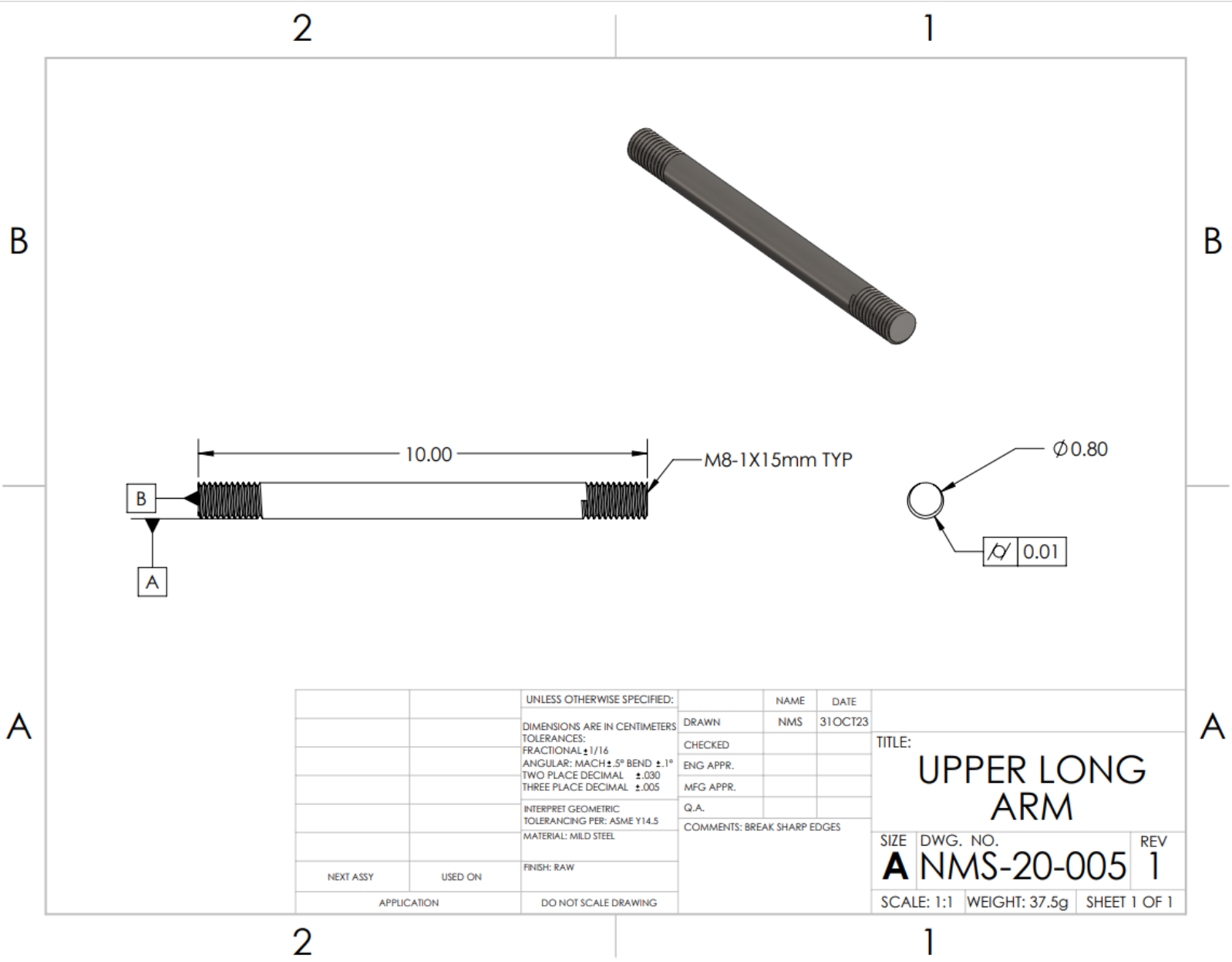


Figure B7: Upper Long Arm

Appendix B.08- NMS-20-006 Trailing Arm

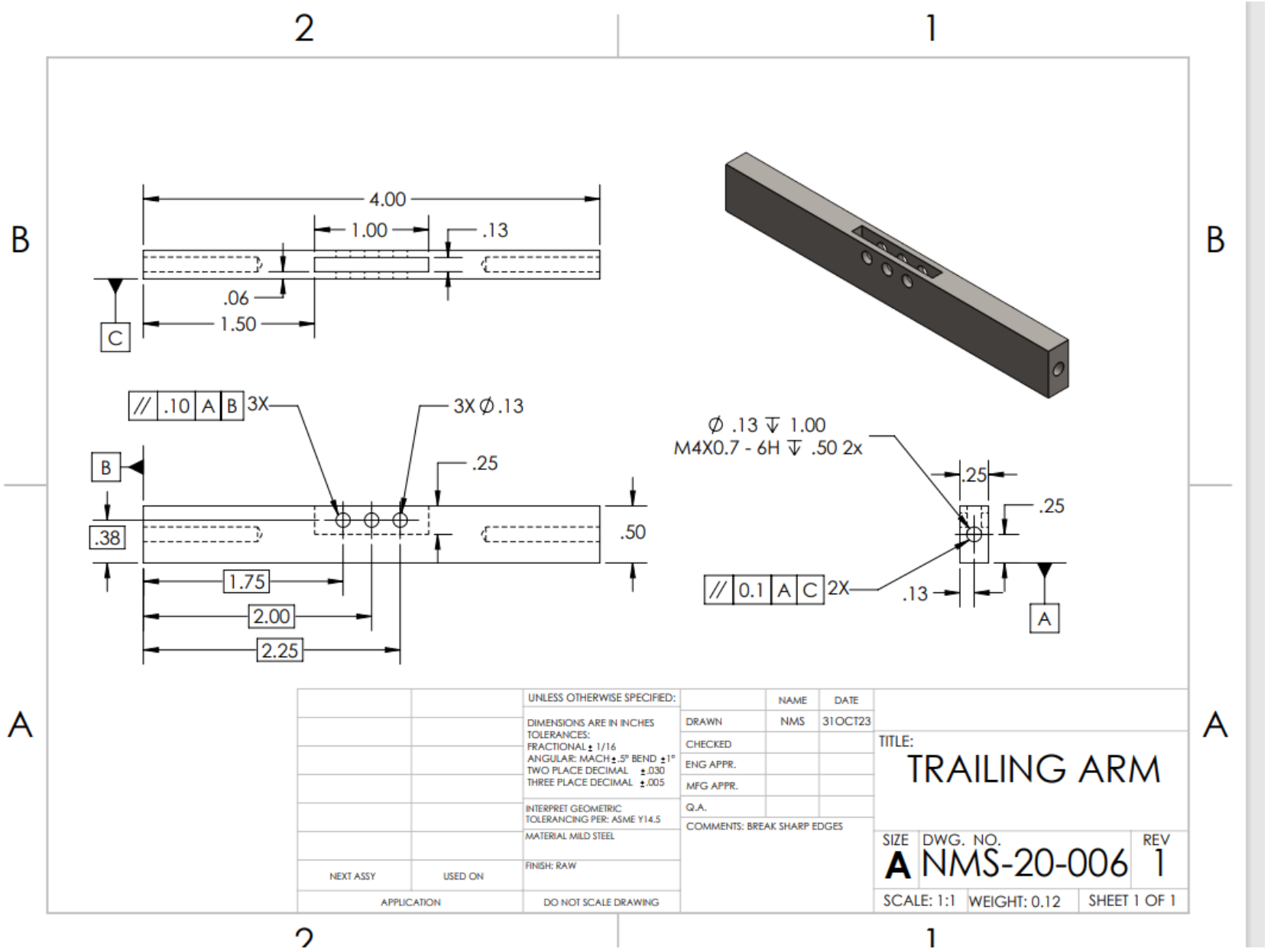


Figure B8: Trailing arm

APPENDIX B.09- NMS-20-07 Steering Rack Base

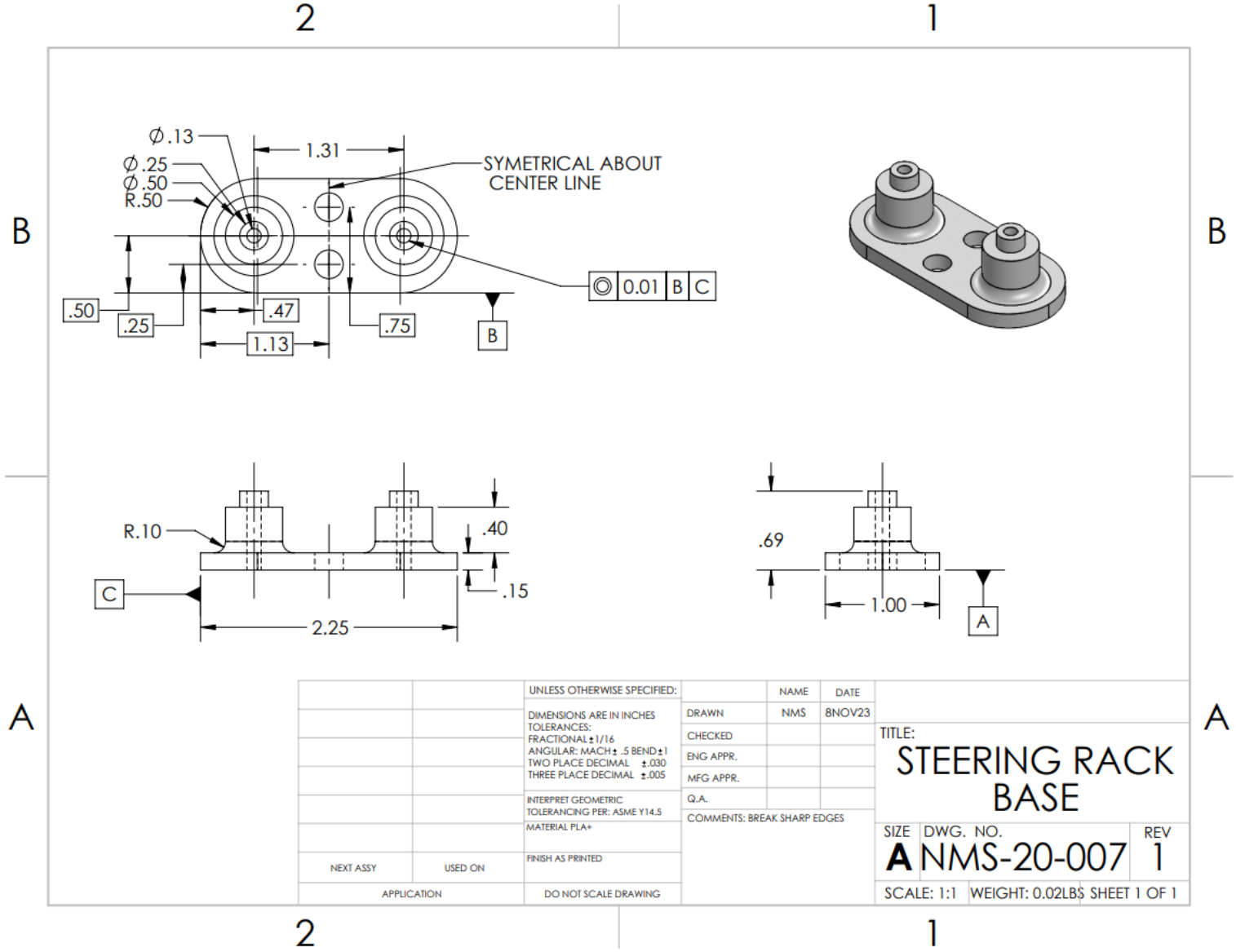


Figure B9: Steering Rack Base

Appendix B.10- NMS-20-008 Steering Rack Arm

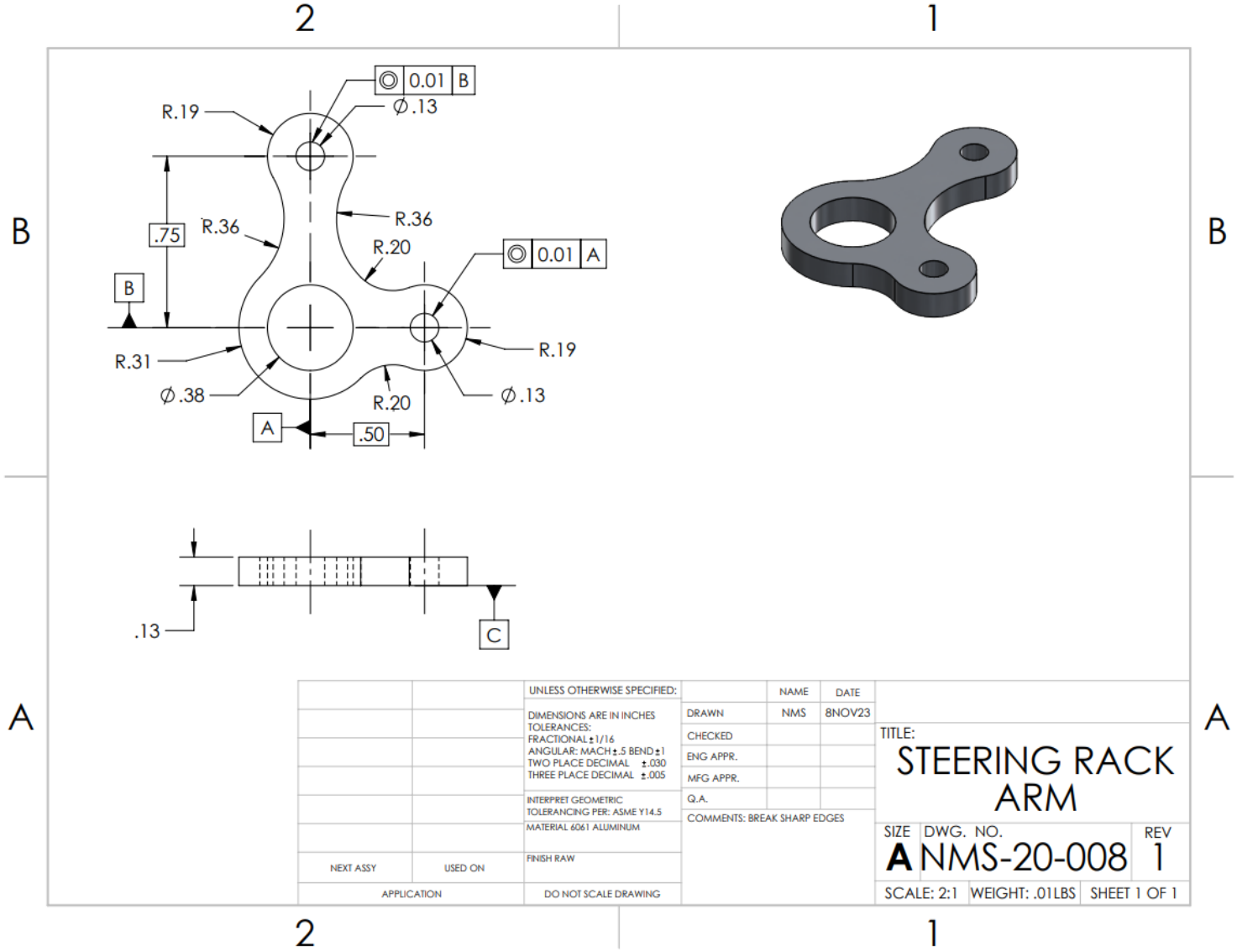


Figure B10: Steering Rack Arm

Appendix B.11- NMS-20-009 Steering Rack Arm 2

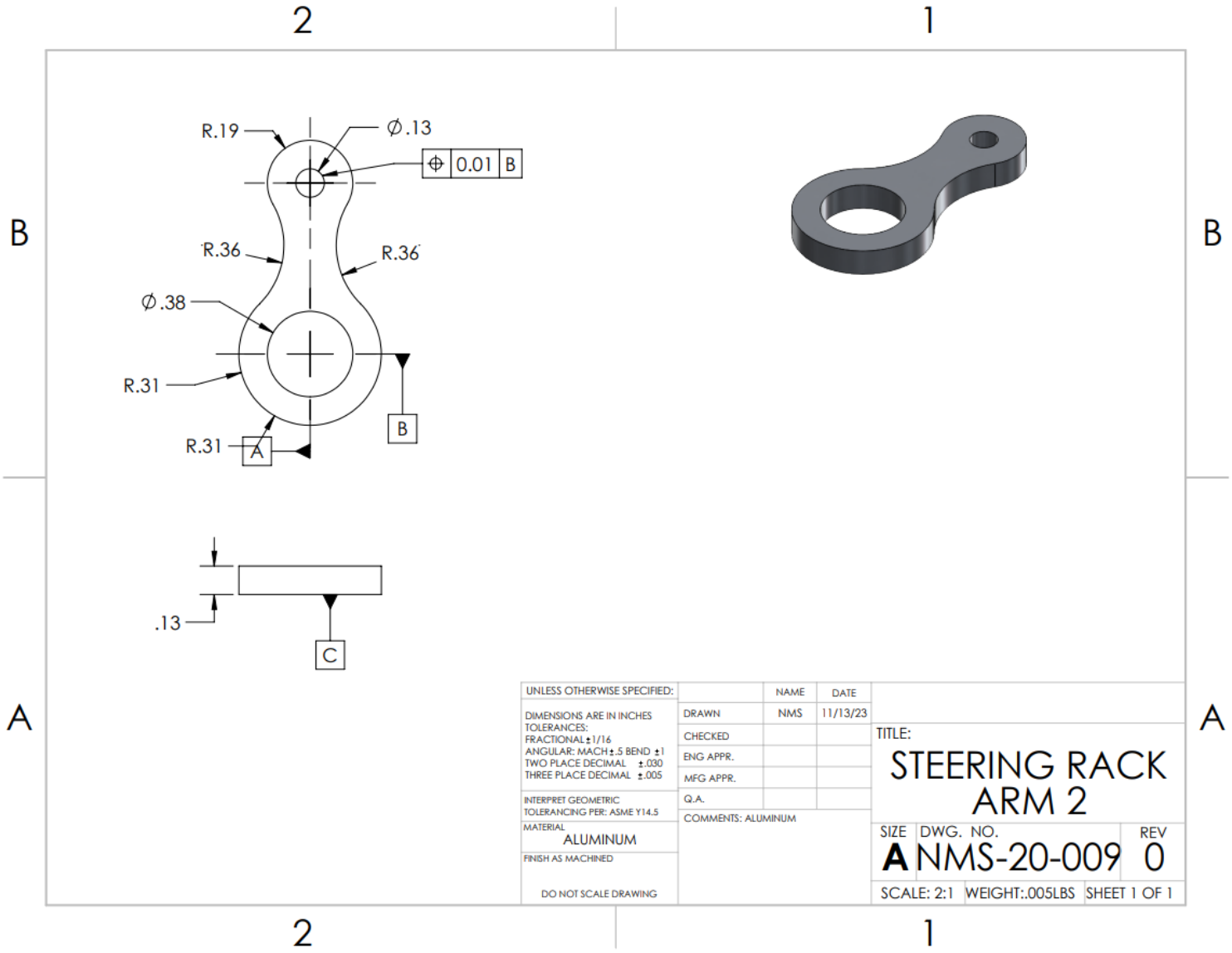


Figure B11: steering rack arm 2

Appendix B.12- NMS-20-010 Connecting Bar

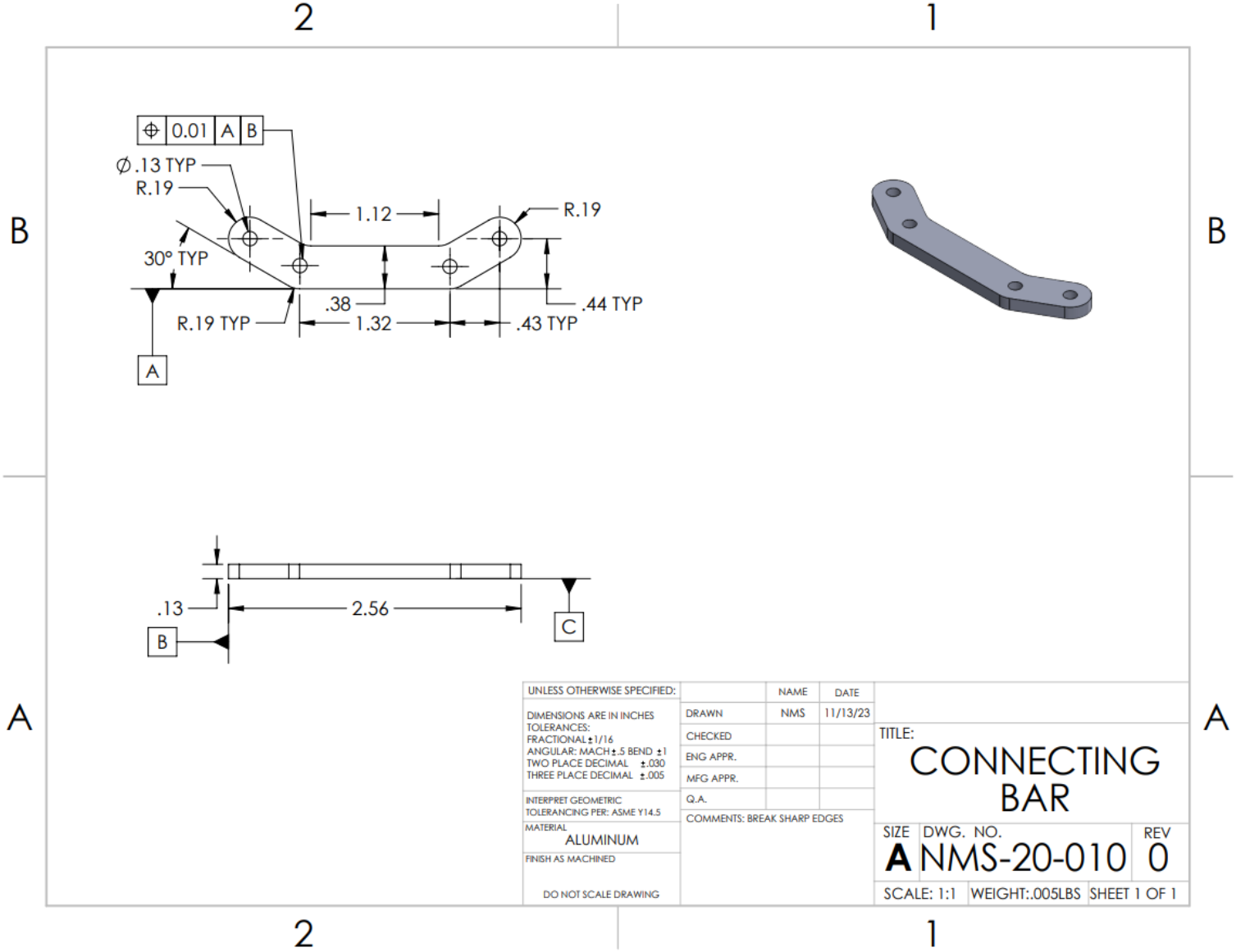


Figure B12: Steering connecting bar

Appendix B.13- NMS-20-011 Rear shock tower

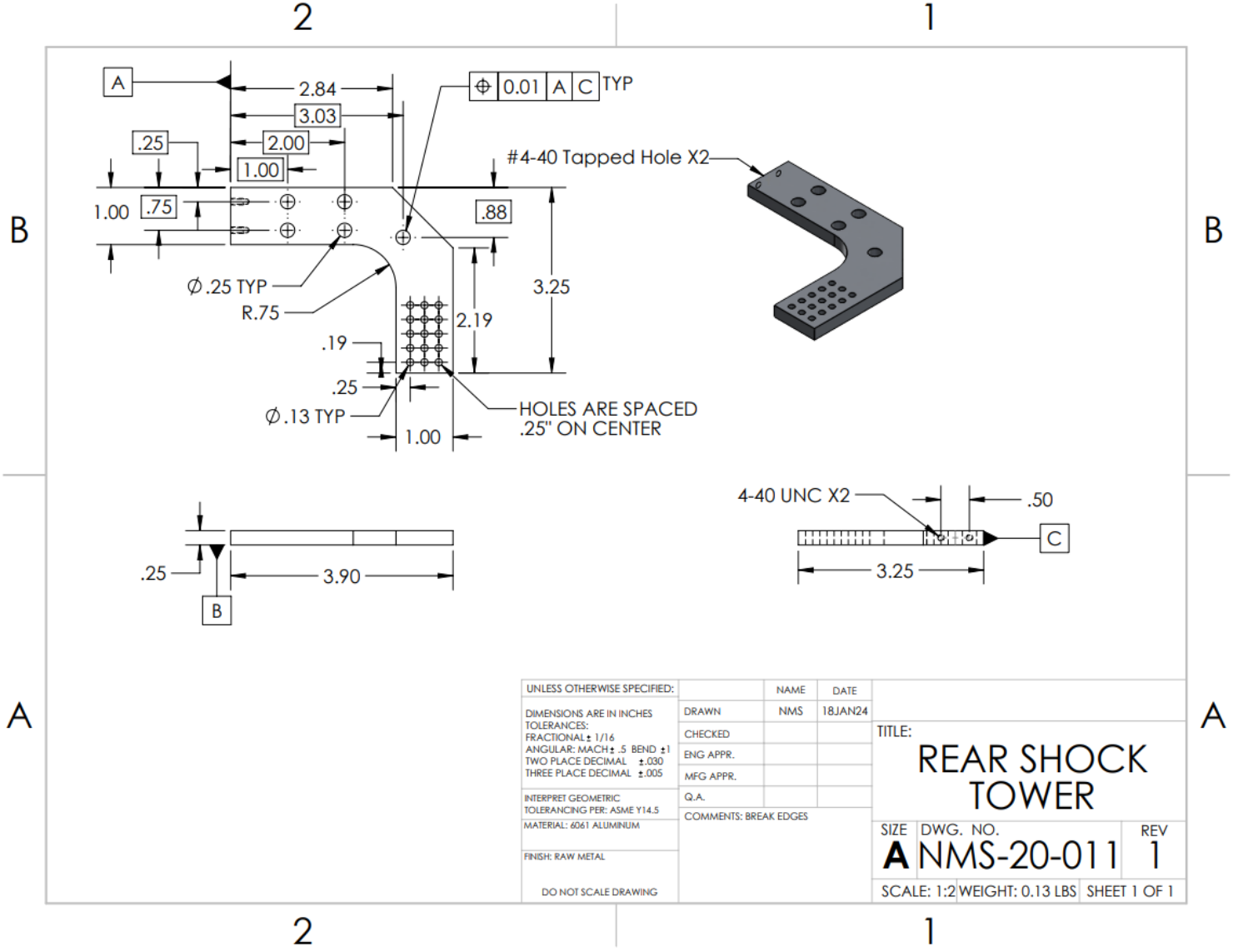


Figure B13: Rear shock tower

Appendix B.14- NMS-20-012 Rear shock tower bracket

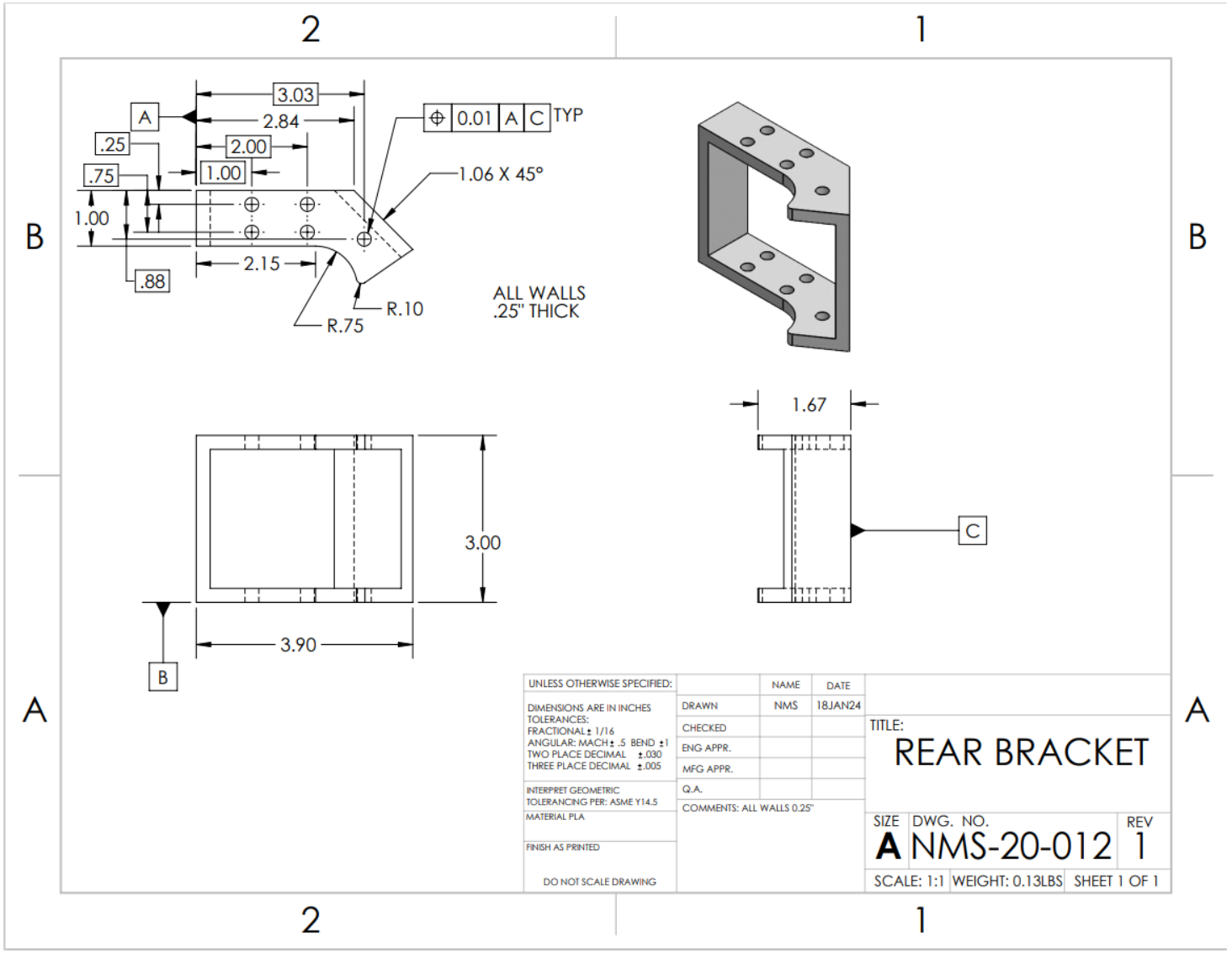


Figure B14: Rear shock tower bracket

Appendix B.15-NMS-10-001 Total Car Assembly

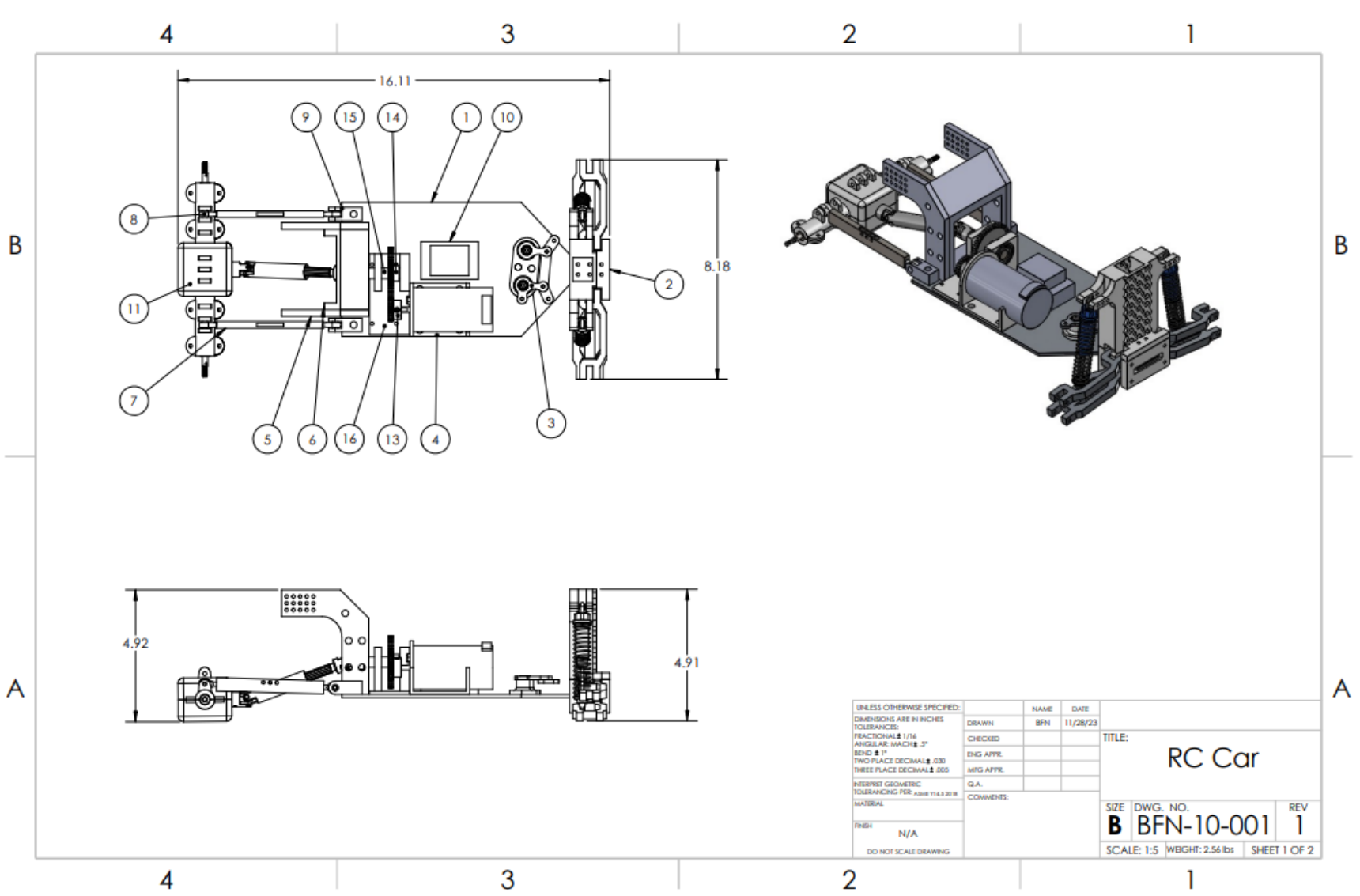


Figure B15: Car Assembly

Appendix B.15-NMS-10-001 Total Car Assembly Cont.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	BFN-20-002	Chassis	1
2	NMS-10-002	Front Suspension	1
3	NMS-10-003	Steering Rack	1
4	BFN-10-003	Motor Mount Assembly	1
5	NMS-20-011	Rear Shock Tower	2
6	NMS-20-012	Rear Shock Tower Bracket	1
7	NMS-20-006	Trailing Arm	2
8	NMS-50-002	Ball Joint Rod End	4
9	BFN-20-009	Trailing Arm Tabs	2
10	BFN-50-004	ESC	1
11	BFN-10-002	Rear Axle Sub Assembly	1
13	BFN -55-002	25T Spur Gear	1
14	BFN-55-002	61T Spur Gear	1
15	BFN-20-004	Gear Axle	1
16	BFN-20-005	Gear Mount	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± .5°
BEND ± 1°
TWO PLACE DECIMAL ± .030
THREE PLACE DECIMAL ± .005
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5 2018
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	BFN	11/28/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE: RC CAR

SIZE B | DWG. NO. BFN-10-001 | REV

SCALE: 1:5 | WEIGHT: | SHEET 2 OF 2

Figure B15: Car Assembly Cont.

Appendix B.16-NMS-10-002 Front suspension Assembly

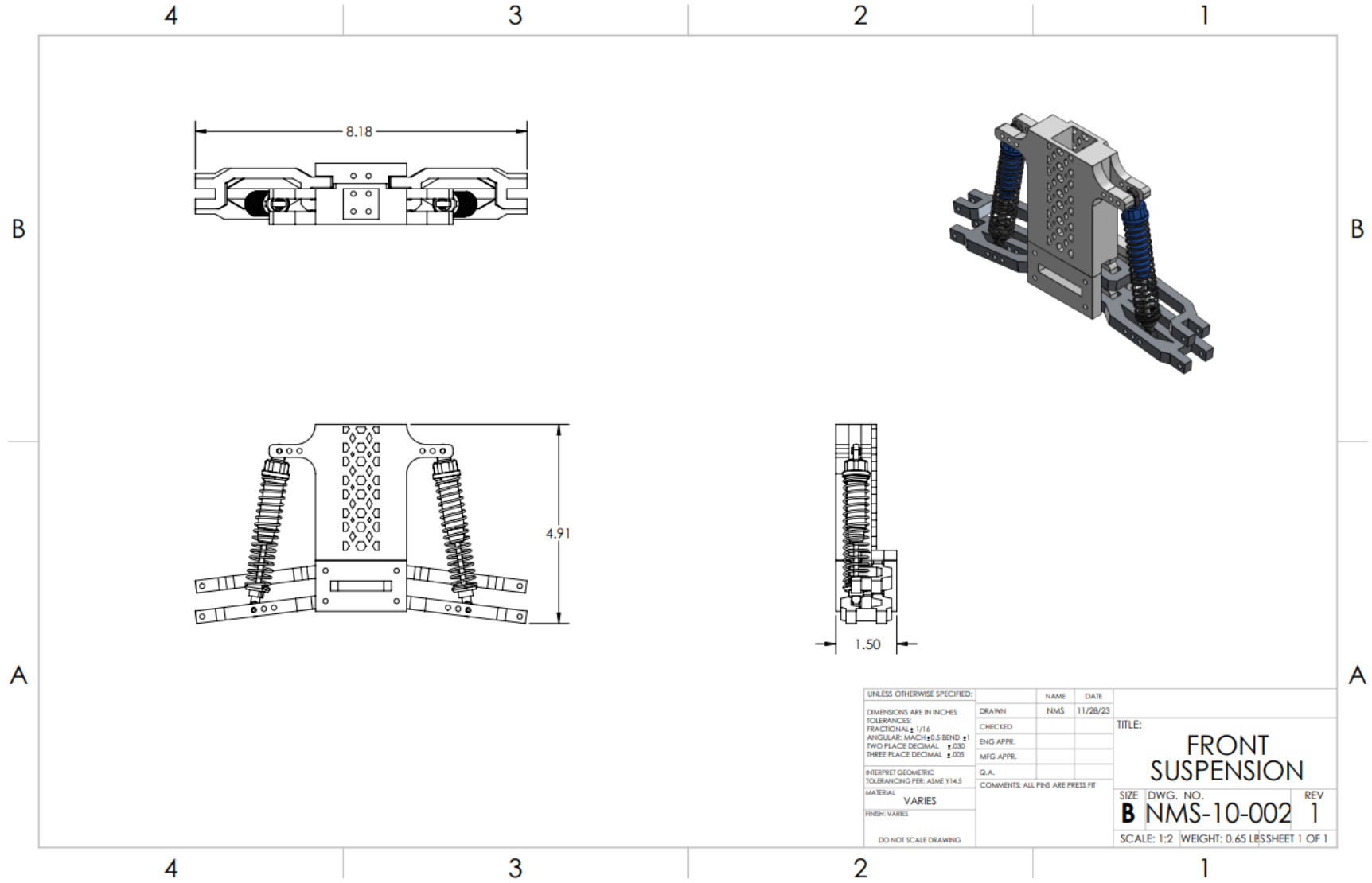


Figure 1 Front Suspension assembly

APPENDIX C – Parts List and Costs

Table C1-Manufactured Parts

Parts					
Part Number	Qty	Part Description	Source	Cost	Disposition
NMS-20-001	1	Bulkhead	3D printed	$0	01/06/2024
NMS-20-002	2	Lower control arm	Send Cut Send	$8.48	01/27/2024
NMS-20-003	2	Upper control arm	Send Cut Send	$3.26	01/27/2024
NMS-20-004	1	Shock Tower	3D printed	$0	01/17/2024
NMS-20-005	2	Upper Long arm	Machined	$25	02/01/2024
NMS-20-006	2	Trailing arm	Machined	$25	02/01/2024
NMS-20-007	1	Steering rack base	3D printed	$0	01/17/2024
NMS-20-008	1	Steering rack arm	Send Cut Send	$2.37	01/27/2024
NMS-20-009	1	Steering rack arm 2	Send Cut Send	$1.90	01/27/2024
NMS-20-010	1	Steering connecting Bar	Send Cut Send	$3.07	01/27/2024
NMS-20-011	2	Rear shock tower	Send cut send	$17.38	01/27/2024
NMS-20-012	1	Rear shock tower bracket	3D printed	$0	01/17/2024
			Total:	$86.46	

Table C2- Purchased Parts

Purchased Parts					
Part Number	Qty	Part Description	Source	Cost	Disposition
NMS-55-001	2	Steering Spindle assembly Hobby Park MPN-8230-8231	Amazon	$20.00	10/21/2023
NMS-55-002	4	110mm Shocks	Amazon	$30.00	01/29/2024
NMS-55-003	2	Steering rack Bearings (0.375” OD 0.25” ID)	Amazon	$10	02/09/2024
NMS-55-004	1	Steering servo	Amazon	$35	02/18/2024
NMS-55-004	1	Stiffer spring kit for shocks	Rc 4wd	$35.26	4/11/2024
			Total:	$130.26	

Table C3- Hardware and Fasteners

Hardware/Fasteners					
Part Number	Qty	Part Description	Source	Cost	Disposition
NMS-50-001	4	18-8 Shoulder Screw, 1/8" Shoulder Diameter, 1-1/2" Shoulder Length	Local Hardware	$5.00	01/16/2024
NMS-50-002	4	4-40 steel nut	Local Hardware	$2.00	01/16/2024
NMS-50-003	6	Socket Head Screw, 4-40 Thread Size, 2-1/2" Long	Local Hardware	$6.00	01/16/2024
			Total:	$13.00	

APPENDIX D – Budget

Table D1- Total budget

Item	Qty	Description	Cost
Manufacturing Time	70 hrs	Time spent actively manufacturing parts	$2,590
Design Time	100 hrs	Time spent designing and redesigning parts	$3,700
Total part cost	40 parts	All parts needed to complete car	$850
		Total Cost	$7,140

APPENDIX E – Schedule

Task Mode	Task Name	Duration	Start	Finish
	PROPOSAL/REPORT WRITING	**189 days?**	**Wed 9/20/23**	**Sat 6/8/24**
✓	1a Intro	8 hrs	Mon 9/25/23	Mon 9/25/23
✓	1b Analysis	40 hrs	Mon 10/2/23	Fri 10/6/23
	1c Methods	8 hrs	Wed 2/14/24	Wed 2/14/24
✓	1d Testing	12 hrs	Mon 10/2/23	Tue 10/3/23
✓	1e Budget	2 hrs	Tue 10/24/23	Tue 10/24/23
✓	1f schedule	4 hrs	Tue 10/17/23	Tue 10/17/23
✓	1g Project Management	6 hrs	Wed 11/8/23	Wed 11/8/23
✓	1h Discussion	8 hrs	Wed 5/1/24	Wed 5/1/24
✓	1i Conclusion	3 hrs	Tue 9/12/23	Tue 9/12/23
✓	1j Drawings	82 hrs	Wed 11/1/23	Wed 11/15/23
✓	1k Appendix	232 hrs	Wed 11/29/23	Sun 1/7/24
✓	1l Abstract	1 hr	Wed 3/27/24	Wed 3/27/24
	SUBTOTAL	185 hrs		

Task Mode	Task Name	Duration	Start	Finish
✓	**ANALYSIS**	**45 days**	**Wed 9/20/23**	**Tue 11/21/23**
✓	2a shock tower arm deflection	5 hrs	Tue 10/3/23	Tue 10/3/23
✓	2b Tie rod Column strength	6 hrs	Fri 10/13/23	Fri 10/13/23
✓	2c Bulk Head shear stress	5 hrs	Sat 10/14/23	Sat 10/14/23
✓	2d deflection of trailing arm	5 hrs	Sun 10/1/23	Sun 10/1/23
✓	2e shear on caster block pins	3 hrs	Sun 10/22/23	Sun 10/22/23
✓	2f column analysis of trailing arm	2 hrs	Sun 10/29/23	Sun 10/29/23
✓	2g Shock spring rates	3 hrs	Sat 10/28/23	Sat 10/28/23
✓	2h deflection of lower control arm	2 hrs	Sun 10/22/23	Sun 10/22/23
✓	2i Column analysis of upper long arms	2 hrs	Sun 10/29/23	Sun 10/29/23
✓	2j rear shock tower arm deflection	1 hr	Sun 11/12/23	Sun 11/12/23
✓	2k shear on shock eylets	2 hrs	Sun 11/5/23	Sun 11/5/23
✓	2l steering rack connecting bar buckling	2 hrs	Fri 11/17/23	Fri 11/17/23
✓	SUBTOTAL	38 hrs	Wed 9/20/23	Tue 9/26/23

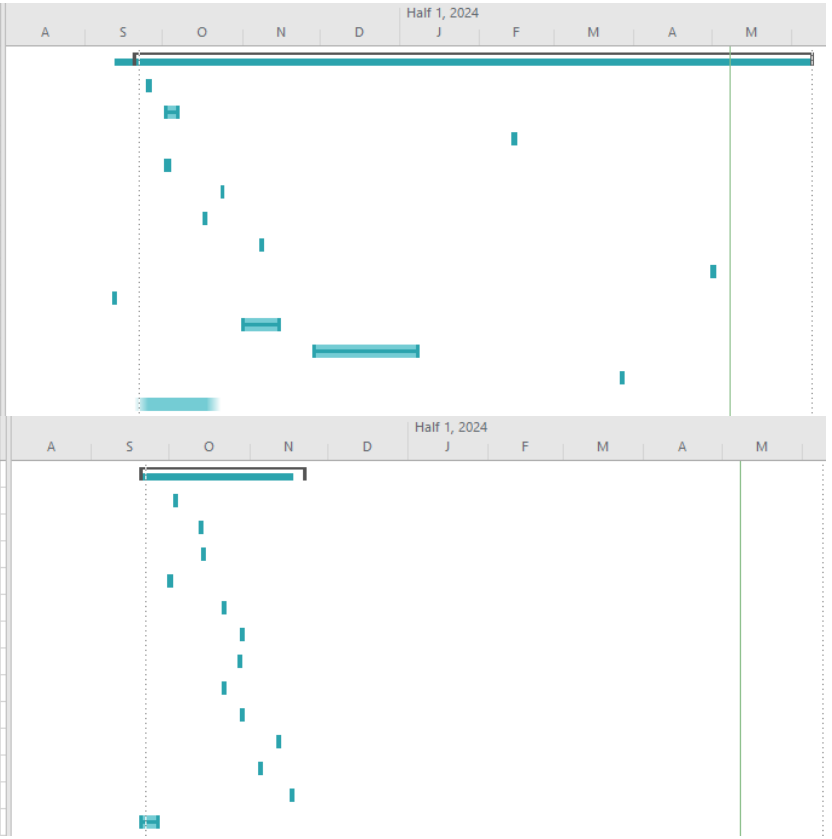
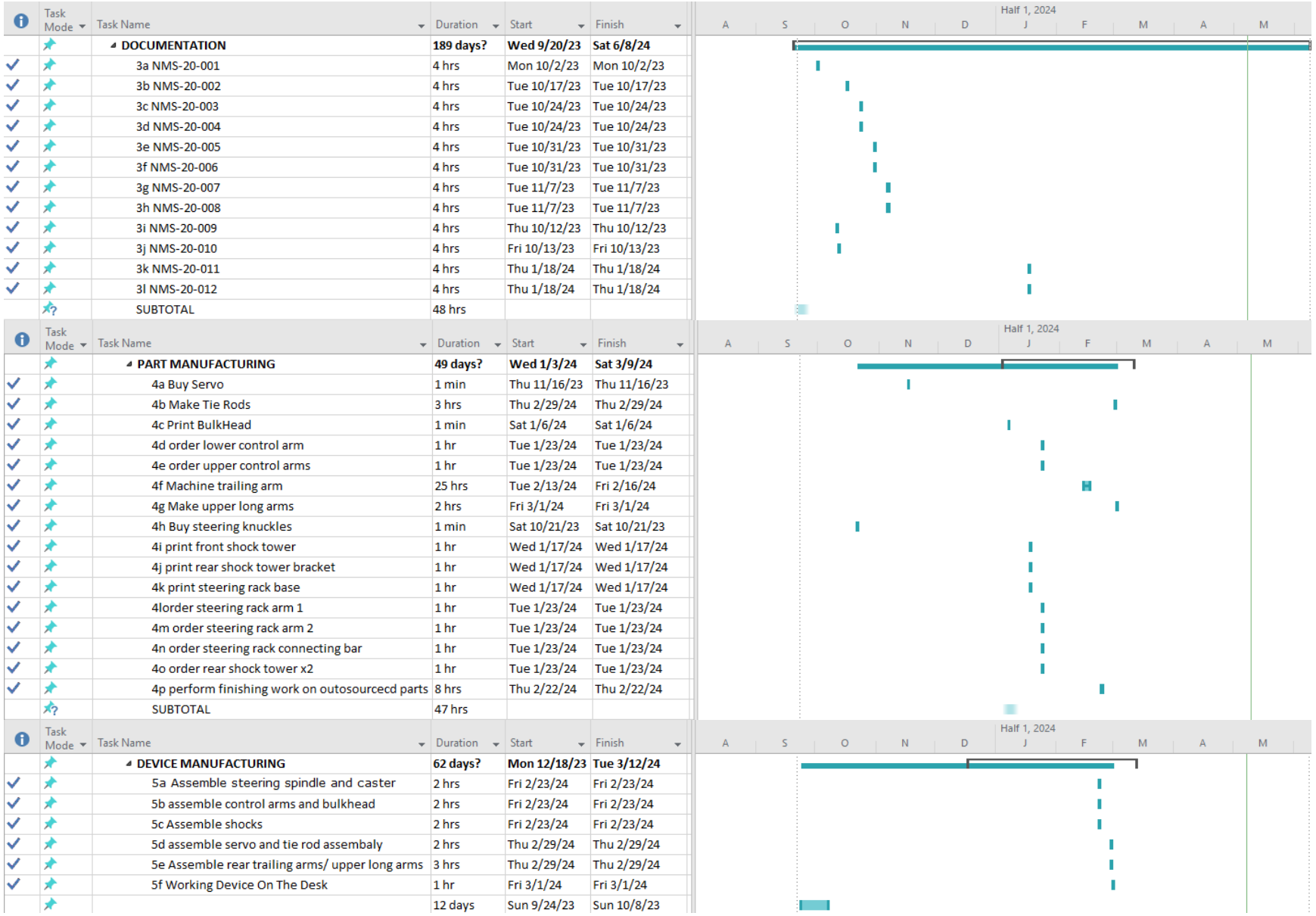


Figure E1- Schedule for section 1-2

Appendix E- Schedule Cont.



Task Mode	Task Name	Duration	Start	Finish
	DOCUMENTATION	**189 days?**	**Wed 9/20/23**	**Sat 6/8/24**
✓	3a NMS-20-001	4 hrs	Mon 10/2/23	Mon 10/2/23
✓	3b NMS-20-002	4 hrs	Tue 10/17/23	Tue 10/17/23
✓	3c NMS-20-003	4 hrs	Tue 10/24/23	Tue 10/24/23
✓	3d NMS-20-004	4 hrs	Tue 10/24/23	Tue 10/24/23
✓	3e NMS-20-005	4 hrs	Tue 10/31/23	Tue 10/31/23
✓	3f NMS-20-006	4 hrs	Tue 10/31/23	Tue 10/31/23
✓	3g NMS-20-007	4 hrs	Tue 11/7/23	Tue 11/7/23
✓	3h NMS-20-008	4 hrs	Tue 11/7/23	Tue 11/7/23
✓	3i NMS-20-009	4 hrs	Thu 10/12/23	Thu 10/12/23
✓	3j NMS-20-010	4 hrs	Fri 10/13/23	Fri 10/13/23
✓	3k NMS-20-011	4 hrs	Thu 1/18/24	Thu 1/18/24
✓	3l NMS-20-012	4 hrs	Thu 1/18/24	Thu 1/18/24
	SUBTOTAL	48 hrs		

Task Mode	Task Name	Duration	Start	Finish
	PART MANUFACTURING	**49 days?**	**Wed 1/3/24**	**Sat 3/9/24**
✓	4a Buy Servo	1 min	Thu 11/16/23	Thu 11/16/23
✓	4b Make Tie Rods	3 hrs	Thu 2/29/24	Thu 2/29/24
✓	4c Print BulkHead	1 min	Sat 1/6/24	Sat 1/6/24
✓	4d order lower control arm	1 hr	Tue 1/23/24	Tue 1/23/24
✓	4e order upper control arms	1 hr	Tue 1/23/24	Tue 1/23/24
✓	4f Machine trailing arm	25 hrs	Tue 2/13/24	Fri 2/16/24
✓	4g Make upper long arms	2 hrs	Fri 3/1/24	Fri 3/1/24
✓	4h Buy steering knuckles	1 min	Sat 10/21/23	Sat 10/21/23
✓	4i print front shock tower	1 hr	Wed 1/17/24	Wed 1/17/24
✓	4j print rear shock tower bracket	1 hr	Wed 1/17/24	Wed 1/17/24
✓	4k print steering rack base	1 hr	Wed 1/17/24	Wed 1/17/24
✓	4lorder steering rack arm 1	1 hr	Tue 1/23/24	Tue 1/23/24
✓	4m order steering rack arm 2	1 hr	Tue 1/23/24	Tue 1/23/24
✓	4n order steering rack connecting bar	1 hr	Tue 1/23/24	Tue 1/23/24
✓	4o order rear shock tower x2	1 hr	Tue 1/23/24	Tue 1/23/24
✓	4p perform finishing work on outosourcecd parts	8 hrs	Thu 2/22/24	Thu 2/22/24
	SUBTOTAL	47 hrs		

Task Mode	Task Name	Duration	Start	Finish
	DEVICE MANUFACTURING	**62 days?**	**Mon 12/18/23**	**Tue 3/12/24**
✓	5a Assemble steering spindle and caster	2 hrs	Fri 2/23/24	Fri 2/23/24
✓	5b assemble control arms and bulkhead	2 hrs	Fri 2/23/24	Fri 2/23/24
✓	5c Assemble shocks	2 hrs	Fri 2/23/24	Fri 2/23/24
✓	5d assemble servo and tie rod assembaly	2 hrs	Thu 2/29/24	Thu 2/29/24
✓	5e Assemble rear trailing arms/ upper long arms	3 hrs	Thu 2/29/24	Thu 2/29/24
✓	5f Working Device On The Desk	1 hr	Fri 3/1/24	Fri 3/1/24
		12 days	Sun 9/24/23	Sun 10/8/23

Figure E2- Schedule for section 3-5

Appendix E- Schedule Cont.

	Task Mode	Task Name	Duration	Start	Finish
		DEVICE EVALUATION	**50 days?**	**Tue 4/2/24**	**Sat 6/8/24**
		6a Test control arm deflection	1 hr	Tue 4/2/24	Tue 4/2/24
		6b Test tie rod column strength	1 day?	Fri 4/19/24	Fri 4/19/24
		6c Test suspenion travel	1 day?	Tue 4/23/24	Tue 4/23/24
✓		6d Test trailing arm defelction	1 hr	Fri 4/5/24	Fri 4/5/24
		6e Frontal impact testing	1 day?	Fri 5/3/24	Fri 5/3/24
✓		6f Drop Test	1 hr	Sat 4/13/24	Sat 4/13/24
		6g Tie rod tensile test	1 day?	Thu 4/25/24	Thu 4/25/24
		6h Steering angle test	1 day?	Mon 5/6/24	Mon 5/6/24
		6i Bulk Head shear test	1 day	Mon 6/3/24	Mon 6/3/24

	Task Mode	Task Name	Duration	Start	Finish
		DELIVERABLES	**189 days?**	**Wed 9/20/23**	**Sat 6/8/24**
✓		7a Fall Presentation	1 hr	Fri 11/24/23	Fri 11/24/23
		7b SOURCE	1 hr?	Fri 5/17/24	Fri 5/17/24
✓		7c Winter Presentation	1 hr	Mon 3/4/24	Mon 3/4/24
		7d Spring Presentation	1 hr?	Thu 5/16/24	Thu 5/16/24
✓		7e Rc Baja Competition	3 hrs	Sat 4/20/24	Sat 4/20/24
		7f Make USB Drive	1 hr?	Wed 5/22/24	Wed 5/22/24
		7g Final Presentation	1 hr?	Fri 6/7/24	Fri 6/7/24
		7h Final Report Submission	1 hr?	Fri 6/7/24	Fri 6/7/24

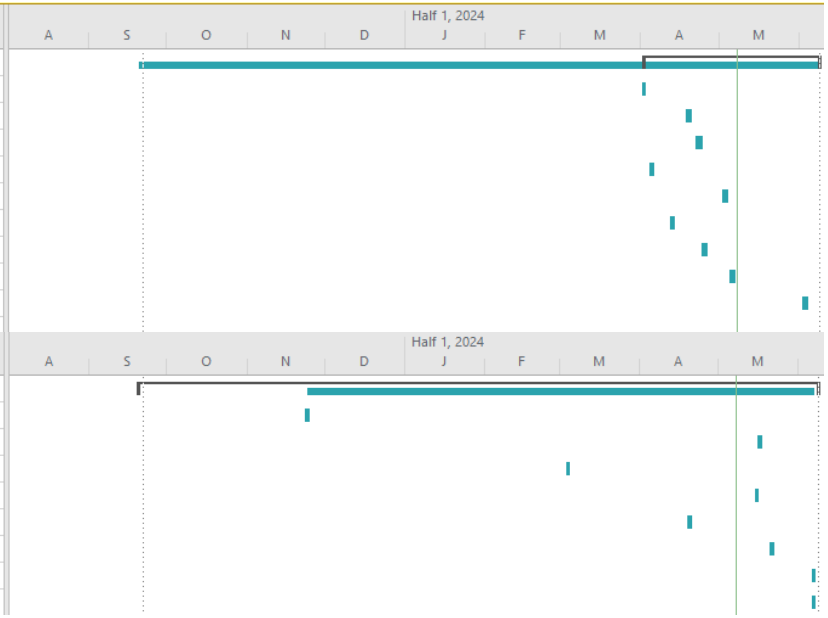


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Figure E3- Schedule for section 6-7

Appendix F.01 Suspension design decision matrix

Criterion	Weight	Best Possible	Independent front/ Solid rear	Score x Wt	Independetn front and rear	Score x Wt	Solid front and rear	Score x Wt	
	1 to 3	3							
Cost	1	3	3	3	2	2	3	3	
Ability to absorb terrain	3	9	2	6	3	9	1	3	
suspension travel	3	9	3	9	3	9	1	3	
ease of manufacturing	3	9	2	6	1	3	3	9	
Total	10	30	24		23		18		
NORMALIZE THE DATA (muliply by fraction, N)		3.33	80.0		76.7		60.0		Percent
Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits			Good? Then done.		72.2		Average
	Poor Bias:	Standard Deviation is one or less digits			Poor? Change something!!!		11		Std Dev.
		You can change the criteria, weighting, or the projects themselves…							

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

Criterion	
Cost	High cost of components makes the car more expensive, and the engineers have a limited budget
Ability to absorb terrain	Ability to absorb terrain effects the performance of the car
suspension travel	Suspension travel directly effects how large of terrain differences the suspension can handle.
ease of manufacturing	The engineers have limited time and must be able to manufacture these parts efficiently.

Comments:

Cost was analyzed by how many parts would need to be purchased and how much time the engineers would spend on it.
Ability to absorb terrian was analyzed by knowledge of rear suspension systems on off road vehichles
Suspension travel was analyzed by how far the shocks can travel and by if they can travel independently
ease of manufacturing was analyzed by how long it would take to make the components

Figure F1: Suspension design decision matrix

Appendix F.02 Material Choice for Shock Tower

Criterion	Weight	Best Possible						
Material choice for shock tower	1 to 3	3	Steel	Score x Wt	Aluminum	Score x Wt	PLA	Score x Wt
Weight	3	9	1	3	2	6	3	9
Ease of manufacturing	3	9	1	3	1	3	3	9
strength	2	6	3	6	2	4	1	2
Cost	1	3	1	1	2	2	3	3
Total	9	27		13		15		23
NORMALIZE THE DATA (muliply by fraction, N)		3.70		48.1		55.6		85.2 Percent

Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits	Good? Then done.	63.0 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...		

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	
Strength	highest yeild stress scores the highest
Weight	Light weight scores better on the success equation
Cost	Cheap material score best
Manufacturability	Is it simple to produce? Are there multiple process for a single component?

Comments:
PLA was the cheapest to manufacture
Part was desined to have strength in the critical areas
Material decision was largly based off of what was going to be easiest

Figure F2 Material decision matrix for front shock tower

Appendix F.03 Manufacturing Method for control arms

Criterion	Weight	Best Possible							
Control arm manufactuirng	1 to 3	3	Plasma cutter	Score x Wt	Band Saw	Score x Wt	Send Cut Send	Score x Wt	
Accuracy	3	9	2	6	1	3	3	9	
Ease of manufacturing	3	9	3	9	1	3	3	9	
Time	2	6	3	6	1	2	3	6	
Cost	1	3	2	2	3	3	2	2	
Total	9	27		23		11		26	
NORMALIZE THE DATA (muliply by fraction, N)		3.70		85.2		40.7		96.3	Percent
Decide if Bias is Good or Bad	Good Bias:	Standard Deviation is two or more digits				Good? Then done.		74.1	Average
	Poor Bias:	Standard Deviation is one or less digits				Poor? Change something!!!		29	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	
Strength	highest yeild stress scores the highest
Time	Light weight scores better on the success equation
Cost	All costs considered the cheapest method scores the best
Manufacturability	How much work does the process take on the engineers part?

Comments:
PLA was the cheapest to manufacture
Part was desined to have strength in the critical areas
Material decision was largly based off of what was going to be easiest

Figure F3 Manufacturing Method decision matrix for control arms

APPENDIX G – Testing Report

Appendix G1 Deflection of rear trailing arm

Introduction

The deflection of the rear trailing arms was important because if the rear trailing arms were to deflect to much and become severely deformed then the devices driving ability would be greatly affected and the device would be nearly impossible to keep straight. This is why the engineer created a deflection requirement for the part in 1.d.10 of the engineering report that stated “trailing arms had to deflect less than 0.0625 inches under a 8.5 pound point load at the center of the long axis”. This requirement was crafted based on an estimate of a max operational load of 8.5 pounds at the center of the trailing arms and any deflection less than a sixteenth of an inch would be negligible to the performance of the device. The requirement stated a threshold for deflection under a given load, meaning that the parameter that was being tested using the Instron machine was deflection. The deflection prediction was 0.00018 inches, found in the green sheet that was shown in appendix A.02 figure 2 of the engineering report. This deflection based on the moment of inertia of the beam, Youngs modulus for the aluminum, and length of the beam. The data was collected using the force vs deflection graph produced by the Instron. This test was completed on May 5th from 9 to 10am as seen in the schedule shown in appendix G1.5 figure 1.5 and also shown in the engineer report appendix E figure E3.

Method/Approach

The engineer identified various resources required for the testing process, including disassembly tools for the RC car (such as a crescent wrench and standard Allan keys), the Instron machine along with its power source and three-point bending apparatus, a phone equipped with a camera, and a thumb drive for data storage. Data capture and processing were facilitated by the Blue Hill application, which controlled the Instron and generated a graphical representation depicting force versus deflection, including maximum force values. The test procedure provided an overview of the testing process, specifying the time, location, required resources, associated risks, detailed steps, and a data table for result recording. Operational limitations highlighted that the device was designed for a maximum fall height of 2 feet. A noted constraint of the testing apparatus was it could only apply a perpendicular load to the beam and in practice the load being applied would not always be perpendicular. Precision and accuracy of the results was dependent on the Instron machine's capabilities, measuring up to the ten-thousandth of an inch and hundredth of a pound. Data storage and manipulation involved capturing a screenshot of the generated graph, which the engineer then emailed to themselves. For data presentation, the original graph produced by the Instron and Blue Hill application was utilized to convey the test results effectively.

Test Procedure

Summary

The deflection of rear trailing arms test determined whether or not the rear trailing arms met the requirement specified in section 1.d.10. This requirement stated “Trailing arms had to deflect less than 0.0625” under a 8.5 pound point load at the center of the long axis”. This requirement was to ensure that the rear trailing arms were strong enough to withstand the forces resulting from suspending the chassis. The following is the test information and procedure.

Time

This test was conducted 4/5/2024, from 1:00 pm to 2:00 pm. There was a half hour of disassembly and equipment set up time and the rest of the time was for the test.

Place

Hogue hall, Room 127 materials lab, Central Washington University, Ellensburg, WA

Required Equipment includes

- RC car Disassembly tools
    - Crescent wrench
    - Standard Allan keys
- Instron machine
    - Power source
    - And 3 point bending apparatus
- Phone with camera
- Thumb drive

Risks

The Instron machine requires power and an admin code. The phone camera requires the battery to have a charge. Risks would be if the power went out or there was no admin to input the code then the Instron would be unusable or if the operator did not have a charged phone they would not be able to take pictures to document the test.

Test procedure

1. Disassemble rear trailing arm assembly
2. Acquire required equipment and set on table near Instron machine in Hogue 127

a. Smart phone (With camera)
b. Thump drive
c. Rear trailing arm
d. 3 point loading apparatus (if not at station request from professor Pringle or Capovilla)

3. Install 3 point loading apparatus
4. Login to computer next to Instron machine and turn on Instron

a. Select the blue hill application
b. have an admin input the admin code

5. Choose the “test” and then the “quick-test” option

a. Set speed to 0.125”/min

6. Place trailing arm in testing apparatus and center the part (see appendix G1.0 figure G1.0)
7. Select “Setup” and use the downward arrow on Instron machine to jog head toward the part until contact is made at the center.
8. Once the machine is in contact with the part start the test using the start button on the Instron
9. Run the test until the force is 8.5lbs
10. Press the stop button on the Instron as soon as the force hits 8.5lbs
11. Screen shot the force-displacement graph
12. Save test as test 1 and move on to trials 2 and 3
13. Save screen shots and data points to thumb drive for each trial
14. Input data into data table in appendix G1.2 table G1.2.0

Appendix G1.0 set up of 3 point loading

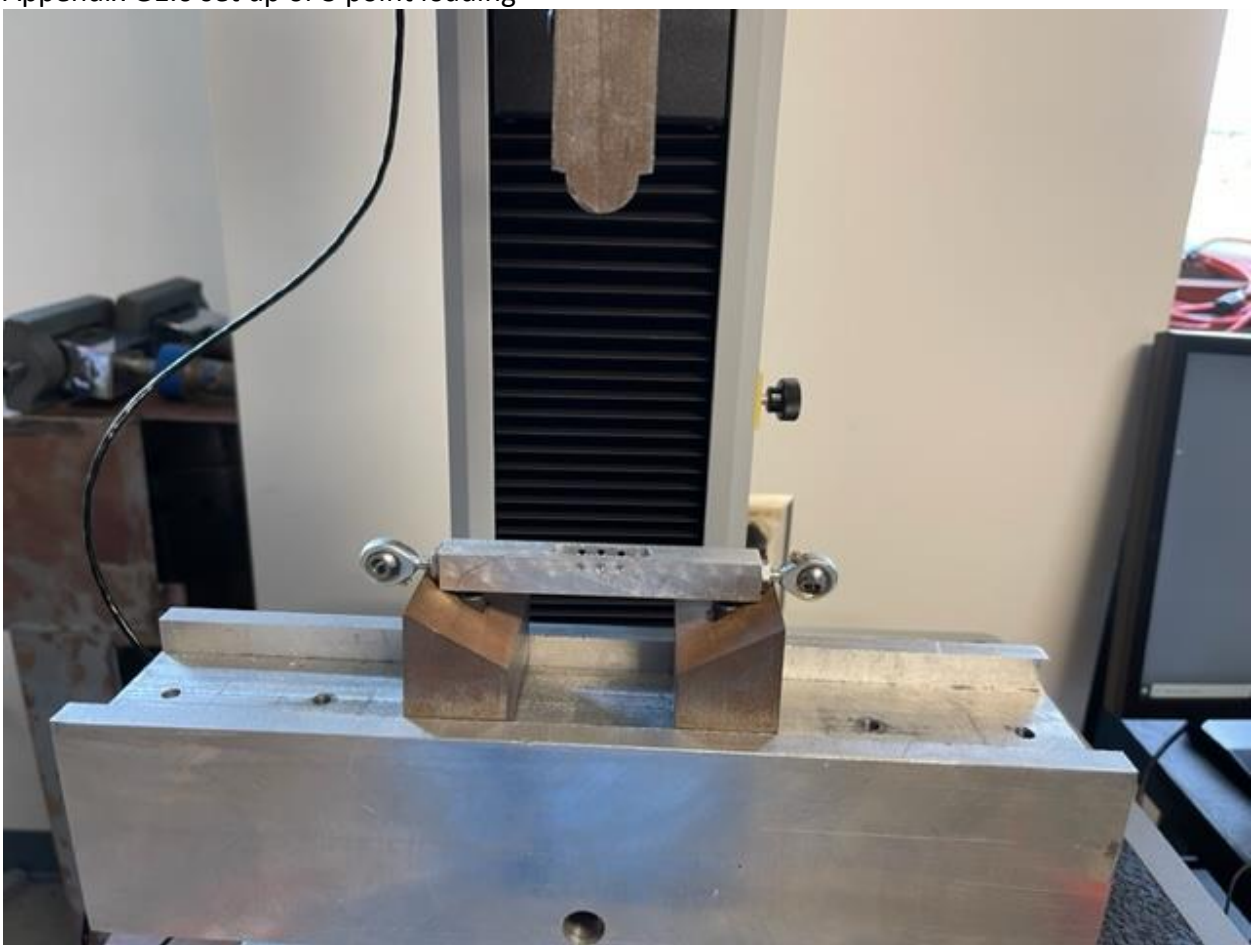

Figure G.10 Set up of test

Deliverables

The parameter being tested was deflection at (or even above) 8.5 lbs and the data was collected an compiled in the following table. The data was collected from the blue hill application and shown in figures G1.3.1, G1.3.2, and G 1.3.3

Table G1.1- results of test

Trailing arm Deflection Data		
Trial Number	**Force (lbf)**	**Deflection**
Trial 1	26.01	.0399”
Trial 2	253.5	.0624”
Trial 3	55.89	.0314”

The calculated value for deflection was 0.00018” under an 8.5 pound load, the requirement was less than 0.0625” of deflection at the 8.5 pound load. This requirement guided the success criteria which was any deflection less than 0.0625” at or above an 8.5 pound load. Given that each result shown in the table above is less than 0.0625” and greater than 8.5 pounds, the rear trailing arm passed the deflection test.

Appendix G1.1 – Procedure Checklist+

1. Smart phone (With camera)
2. Thump drive
3. Rear trailing arm
4. 3 point loading apparatus (if not at station request from professor Pringle or Capovilla)
5. Access to Instron
6. Admin present to input admin code

Appendix G1.2 – Data Forms

Table G1.2.0- Data collection table

Trailing arm Deflection Data		
Trial Number	**Force (lbf)**	**Deflection**
Trial 1		
Trial 2		
Trial 3		

Appendix G1.3 – Raw Data

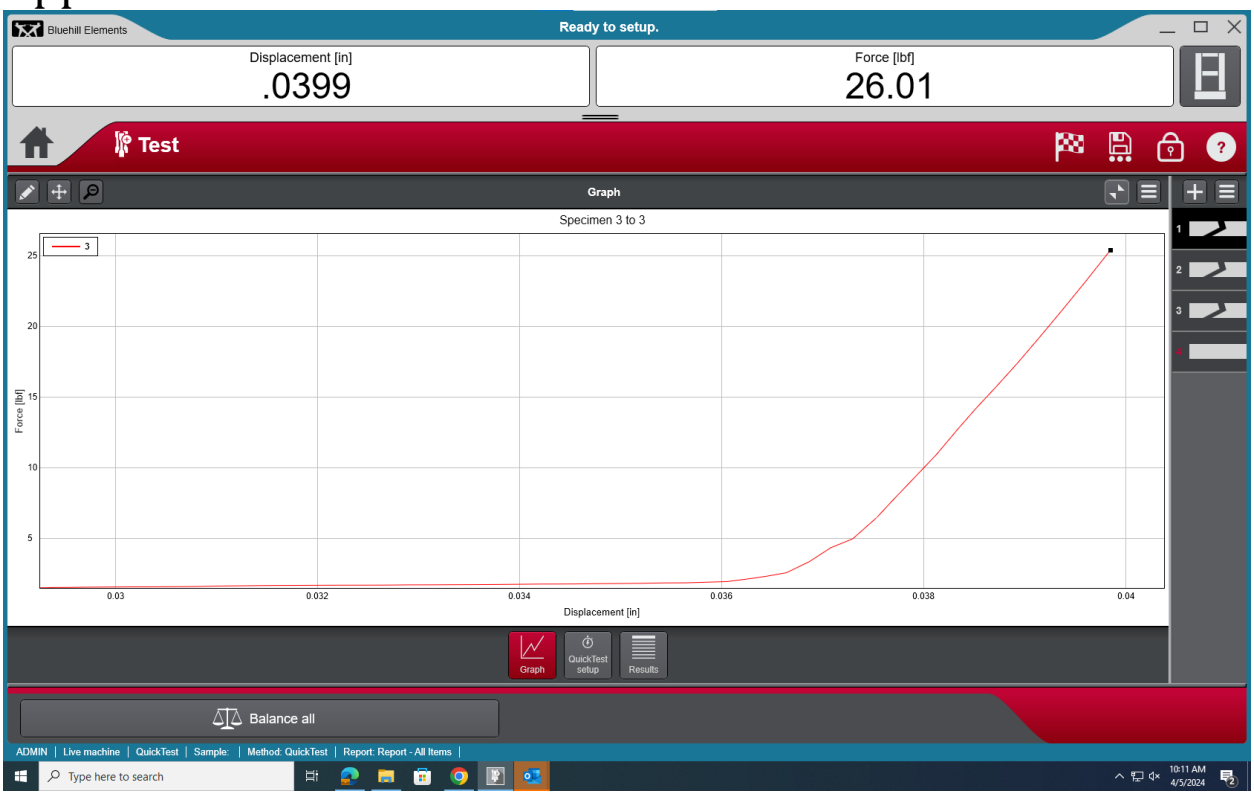

Figure G.1.3.1 First trial

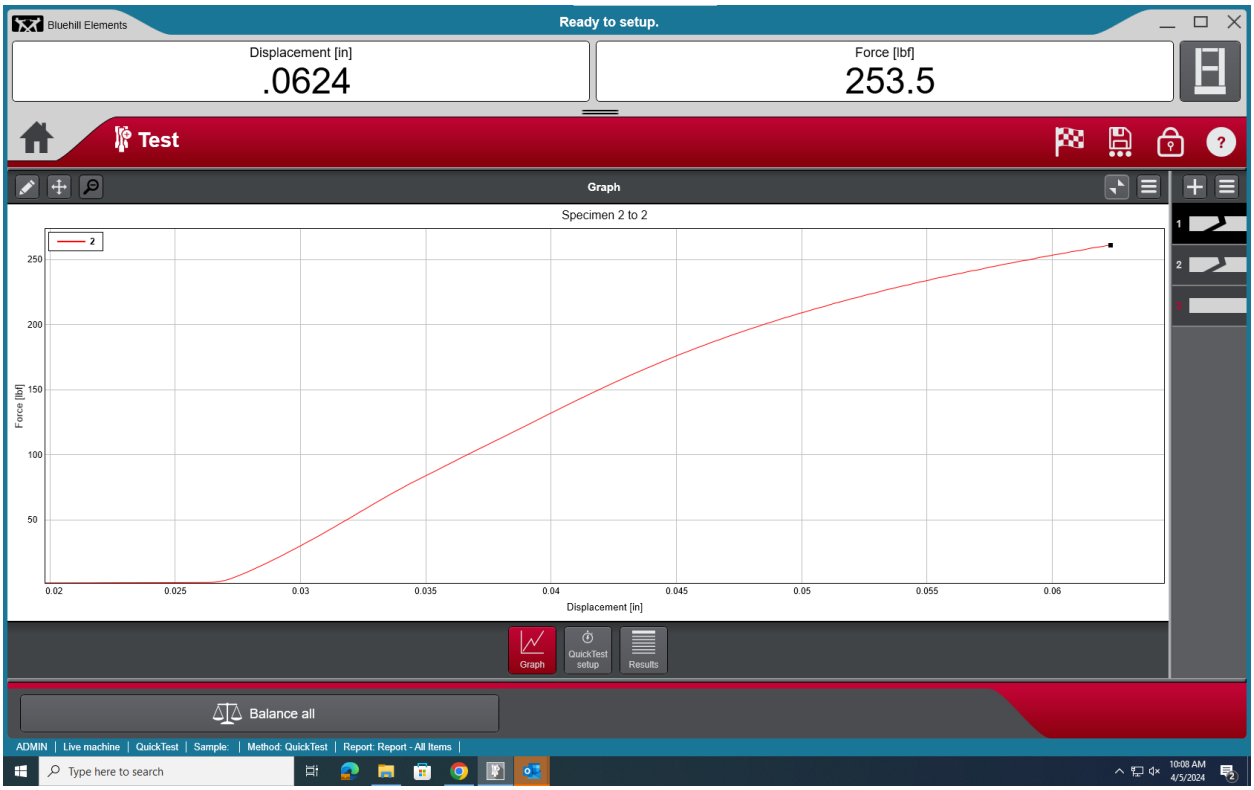

Figure G.1.3.2 second trial

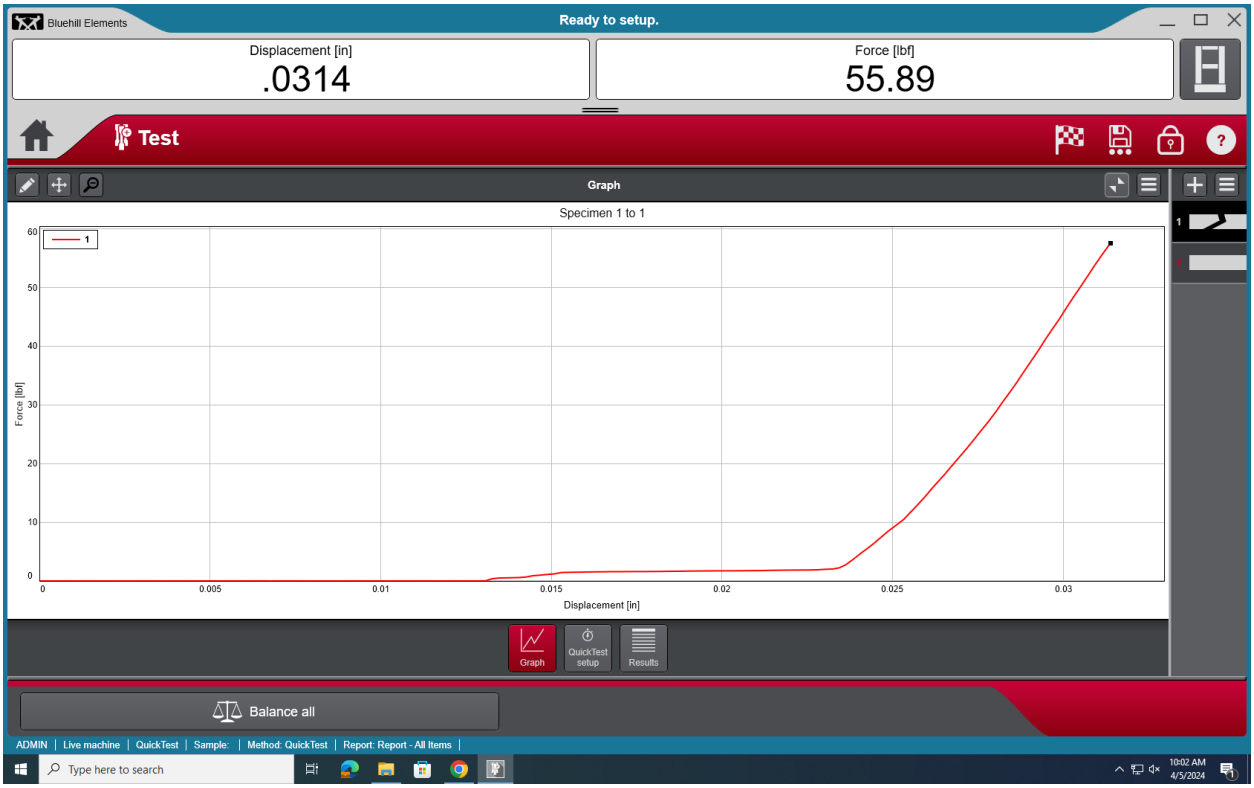

Figure G1.3.3 third trial

Appendix G1.4 – Evaluation Sheet

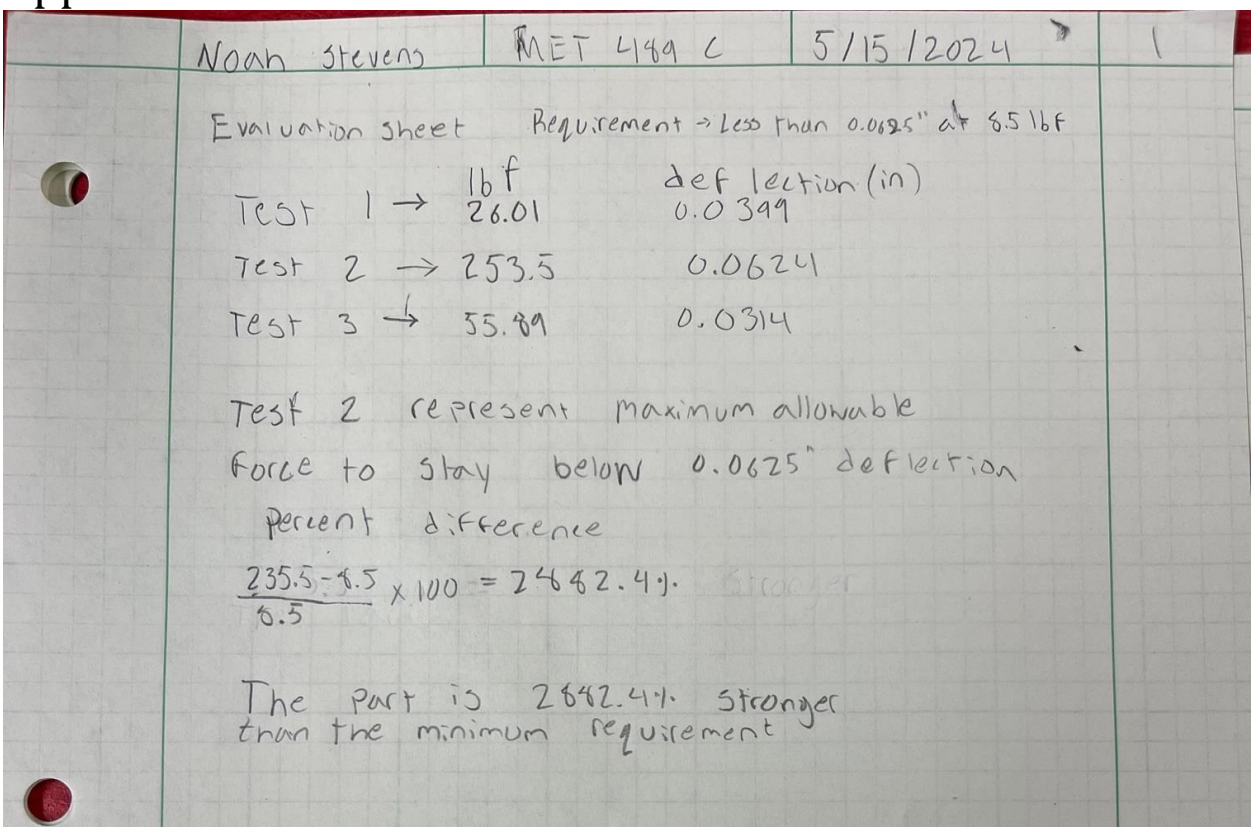

Figure G1.4.0- evaluation of data for trailing arm deflection

Appendix G1.5 – Schedule (Testing)

	Task Mode	Task Name	Duration	Start	Finish
		DEVICE EVALUATION	**50 days?**	**Tue 4/2/24**	**Sat 6/8/24**
		6a Test control arm deflection	1 hr	Tue 4/2/24	Tue 4/2/24
		6b Test tie rod column strength	1 day?	Fri 4/19/24	Fri 4/19/24
		6c Test suspenion travel	1 day?	Tue 4/23/24	Tue 4/23/24
✓		6d Test trailing arm defelction	1 hr	Fri 4/5/24	Fri 4/5/24
		6e Frontal impact testing	1 day?	Fri 5/3/24	Fri 5/3/24
✓		6f Drop Test	1 hr	Sat 4/13/24	Sat 4/13/24
		6g Tie rod tensile test	1 day?	Thu 4/25/24	Thu 4/25/24
		6h Steering angle test	1 day?	Mon 5/6/24	Mon 5/6/24
		6i Bulk Head shear test	1 day	Mon 6/3/24	Mon 6/3/24

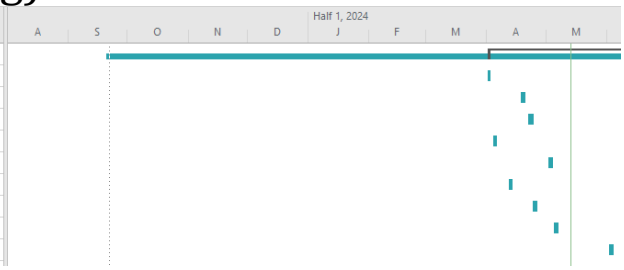

Figure 1.5- Schedule for testing

Appendix G2 Suspension drop test

Introduction

Method/Approach

Test Procedure

Summary

The suspension drop test was performed to determine weather or not the device met the requirement listed in section 1.d.07 which stated “Needed to not compress shocks more than 3” after a 2’ drop”. This requirement was to ensure that the suspension shocks were stiff enough (high enough spring rate) to support the weight of the car under standard and excessive operation.

Time

This test was performed on 4-23-2024 at 7pm and took 45 minutes to complete.

Place

Fluke lab in the Hogue engineering building at CWU Ellensburg.

Required equipment

- Tape measure
- Slow motion camera (cell phone worked well)
- An assistant to drop the device

Risks

This test risked damaging the device. And the test was at risk if the engineer could not get access to a slow motion camera or a tape measure. When the device was dropped the rear suspension put a lot of force on the rear shock tower and the 3-d printed bracket was at risk for breaking. Had the engineer not been able to gain access to the slow motion camera and tape measure then he would not of been able to perform the test. To avoid these risks the engineer ensured that the camera being used has slow motion capabilities and that he had access to a tape measure. Also, the engineer printed an extra rear shock tower bracket so that if the testing damaged the device there would have been an extra to continue the test with.

Deliverables

Test procedure

1. Allow measuring tape to hang from table and press against the floor
2. Have assistant hold the device at two feet (measured to the bottom of the wheels)
3. Camera person should lay close to the ground holding slow motion camera facing the tape measure where when the car drops the entire device would be in frame.
4. Drop device
5. Replay video and determine the deflection of the front and rear shocks.
6. Repeat for a total of three trials

7. Input data into table below

Trial	Front shock deflection	Rear shock deflection
1	3.5”	3.5”
2	3.5”	3.5”
3	3.5”	3.5”
Average	3.5”	3.5”

Appendix G2.1 – Procedure Checklist

Appendix G2.2 – Data Forms

Appendix G2.3 – Raw Data

Appendix G2.4 – Evaluation Sheet

Appendix G2.5 – Schedule (Testing)

Appendix G3 (Replace with test title here)

Introduction

Method/Approach

Test Procedure

Deliverables

Appendix G3.1 – Procedure Checklist

Appendix G3.2 – Data Forms

Appendix G3.3 – Raw Data

Appendix G3.4 – Evaluation Sheet

Appendix G3.5 – Schedule (Testing)

APPENDIX H – Resume

NOAH STEVENS

PROFILE

I'm a self-motivated student looking to further my professional skill set. In addition to furthering my professional skill set I hope to find a potential career.

CONTACT INFO

PHONE:

EMAIL:
2noahstevens@gmail.com

TOP THREE STRENGTHS

Tenacity
Outgoing
Patient

HOBBIES

Camping
Motorcycles
Car audio
Fishing
Car maintenance

EDUCATION

Graduated from East Valley High School in 2019
Graduated as a distinguished Scholar with a 3.98 G.P.A

Central Washington University
Currently attending CWU seeking a degree in Mechanical Engineering with a mathematics minor.

OBJECTIVE

My objective is to obtain a career as a design engineer in the automotive industry.

SKILLS

- Engine Rebuilds
- Car audio wiring
- Associates Certification in Solidworks
- Member of ASME engineering club
- Perform well in group settings
- Constructive criticism is a driver for me

EXPERIENCE

HF Hauff
Engineering Intern
Supervisor Neil Hauff
hfhauff@gmail.com

Description: In charge of assembling and designing parts for an 18ft fixture and an 18ft polyurethane mold. I installed vacuum lines into the mold that are used to hold down a wind machine blade on a router table.

Solar-Decathlon
Team Solar Cats
Instrumentation Officer
Advisor Darryl Fuhrman
Darryl.Fuhrman@cwu.edu

Description: competing in a nationwide competition to build an energy independent home.

Wendy's
Crew Member
2706 W Nob Hill Blvd
Yakima, WA 98902
Manager Brandon or Crystal