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Catmobile Front Suspension

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By

Adam Romine

Chapter 1 Contents

Table of Figures

Abstract

Each year electric vehicles become more and more popular. The electric vehicle that the Central Washington University Electric Vehicle Club is building needs a front suspension. The vehicle is being built to compete in the Electrathon America Race in May of 2015. The suspension attaches to the wheels and attaches to the frame of the vehicle and provides bump dampening. The suspension was built was using a single swing arm type design. This design consists of six parts that are welded and bolted together to connect the wheel to the frame. The shock absorber that is attached to the single swing arm that absorbs the shock of the vehicle's weight as it goes over irregularities in the road. The design of the suspension had to fit within the constraints of the preexisting frame. The suspension was manufactured using the tools in the Central Washington University Machine Shop and Power Lab for under $140. The suspension weighs 9.6lbs per side and is made of steel. Initial tests so far have shown that it is strong enough to hold the static load of the vehicle plus the driver. The suspension provides the wheels with the 50ft turning diameter requirements. The shock travel requirement will need some modifications before it meets the desired specification. The suspension is operational and is ready to undergo testing and eventually be ready to compete in the Electrathon America Race.

Introduction

Engineering Problem

The engineering problem is the electric vehicle called the 'Catmobile" does not currently have any sort of front suspension. The Catmobile is being built by the Electric Vehicle Club for the Electrathon America Competition. The design of the suspension must be able to attach to spindles that were created last year by a senior in the MET department, and the frame of the vehicle.

Motivation

The reason this project was chosen was because I have always enjoyed working on cars so this will be a special opportunity to explore this more. Gaining more experience in design, calculations, building, and writing proposals will help give me my first real world type project. Gaining skills in this will only help with future jobs that I hope to someday get. The motivation for the Catmobile is that without a front suspension attaching the wheels and transferring the load from the wheels to the chassis, the vehicle will not be able to function. It would just be a frame with a motor attached to it with no way to move.

Function

The function of the suspension will be a means to secure the two wheels to the front of the vehicle and attach a shock for a smoother ride. The suspension will also need to resist travel that would occur in the wheels and to smoothly transfer the load that happens during a corner.

Requirements

The design of my suspension system depends on two major factors. The first factor is whether or not the suspension will hold up to the forces that are going to be put upon it from the weight of the vehicle, and the forces acted upon it during corners. The next factor in the design is the requirements in the rule book for Electrathon America Competition. There are rules on how the suspension must be designed and the performance requirements that must be met.

- The suspension needs to support the driver and vehicle of up to 500 pounds.
- Must have the strength to not buckle the arm during maximum cornering force of 450lbf.
- Must weigh less than 20 pounds per side.
- The distance between the left and right wheel that is supported must be larger than 2 feet.
- Needs to provide wheels with enough turning space for a 50 foot diameter turn.
- Brackets installing the suspension need to withstand the force of 750 lb.
- Must bolt onto the chassis that is already built.
- Brackets must attach to the 1 in diameter bar of chassis.
- Needs to provide a ground clearance of more than 2 in while trying to keep the vehicle as low as possible.

Success Criteria

A success for this project would be for the vehicle to run and have the suspension hold up and perform well. Perform well as being able to take a 1 g corner and be reliable. It would also be a success if the entire electric vehicle was ready to race in the Electrathon America Competition.

Scope

The scope of this project is designing the suspension so that it connects the wheels to the vehicle. The scope will also involve all of the analyses to see what the dimensions and materials the parts should have. This project will also include the construction of the suspension as well as the assembly. The last thing that will need to be done is testing the suspension to make sure all criteria was met and that it works well.

Engineering Merit

Engineering merit will be shown through constant improvements of the design of the suspension. There will always be room for improvement for the design such as making it more rigid, lighter, or less expensive. Several equations will be used in the design of the suspension. The shear equation $\tau_{avg} = \frac{V}{A}$ will have to be used for the bolts to make sure they do not shear off, and to see the type of material that could be used so it does not shear off. The use of the flexure formula $\sigma_{max} = \frac{Mc}{I}$ will be needed as well.

Benchmark

The following picture is a swing arm front suspension on a go kart. This is a similar solution to a front suspension of a similar vehicle. This picture was taken from the Home Shop Machinists website. If I run into problems I can refer back to this picture to see what others have done.

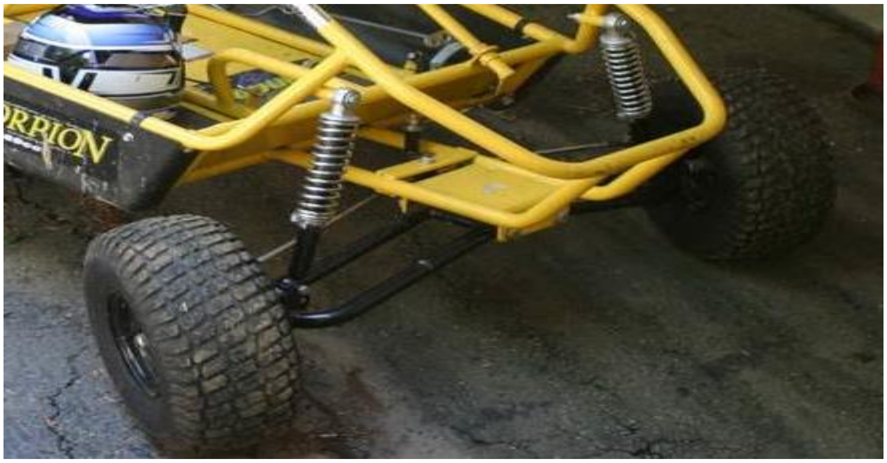

Figure 1 Benchmark Design of Front Swing Arm Suspension

Design and Analysis

Approach

The approach to this problem is to design a swing arm front suspension. There are multiple ways of doing this but for this case the best way to do this is to make it as simple as possible. The intended design for the suspension is a swing arm suspension. It will attach the wheels to the frame using a single swing arm that attaches from the frame to the wheels. As the arm holds the wheels to the vehicle there will be a float shock that attaches from the frame to the arm to smoothly transfer the weight of the vehicle during turns. Throughout the process of designing this part there will be a need for modification to the design.

Optimization

This design will be optimized for simplicity, cost, and weight. Since there is limited time and man hours to complete this project keeping it simple will be of upmost importance. This project is on a limited budget so the price needs to be kept as low as possible. This can be optimized by choosing the least expensive material that will still meet the requirements stated in the requirement section. The weight of the suspension will also be optimized for. Since when it comes to going as fast as possible the more weight the vehicle has will slow it down. Optimizing this and the cost will be the hardest part. The reason is because light weight material that meets the design requirements normally is expensive. There will have to be a medium that is reached between cost and weight.

Description

The swing arm suspension will be connected to the front of the chassis. It will be mounted on the outside of the frame that is built and needs to stick out only a few inches. It would be ideal if it could stick out more but there is limited space for it. The swing arm that comes out will be pin connected to the brackets that are welded to the frame. The arm will be an arch shape and the far end will attach to the steering spindle. It must allow the steering spindle to still be able to turn the wheels. The suspension must leave the wheels enough space to allow the wheels to rotate enough for a 50ft diameter turn. The shock will come down from an attachment point that is higher up on the frame and attach to the end of the swing arm.

The float shock that will be used in this design is made by Fox Racing. It is a Fox Float RL Racing Shock. This is an air shock and will both dampen and rebound the weight of the vehicle while it is in motion. The shock has a two position lockout lever, which changes the shock between the lockout and open positions. The lockout position makes the shock stiff and not compress virtually at all. When the shock is in the open position that is when it will compress and is best for bump absorption and weight transfer during corners. You can also set how fast the shock rebounds. Rebound is the rate in which the shock goes back to normal position after it compresses. The rebound should be set to rebound as quickly as possible while not allowing the vehicle to spring into the air. The illustration below shows an example swing arm design.

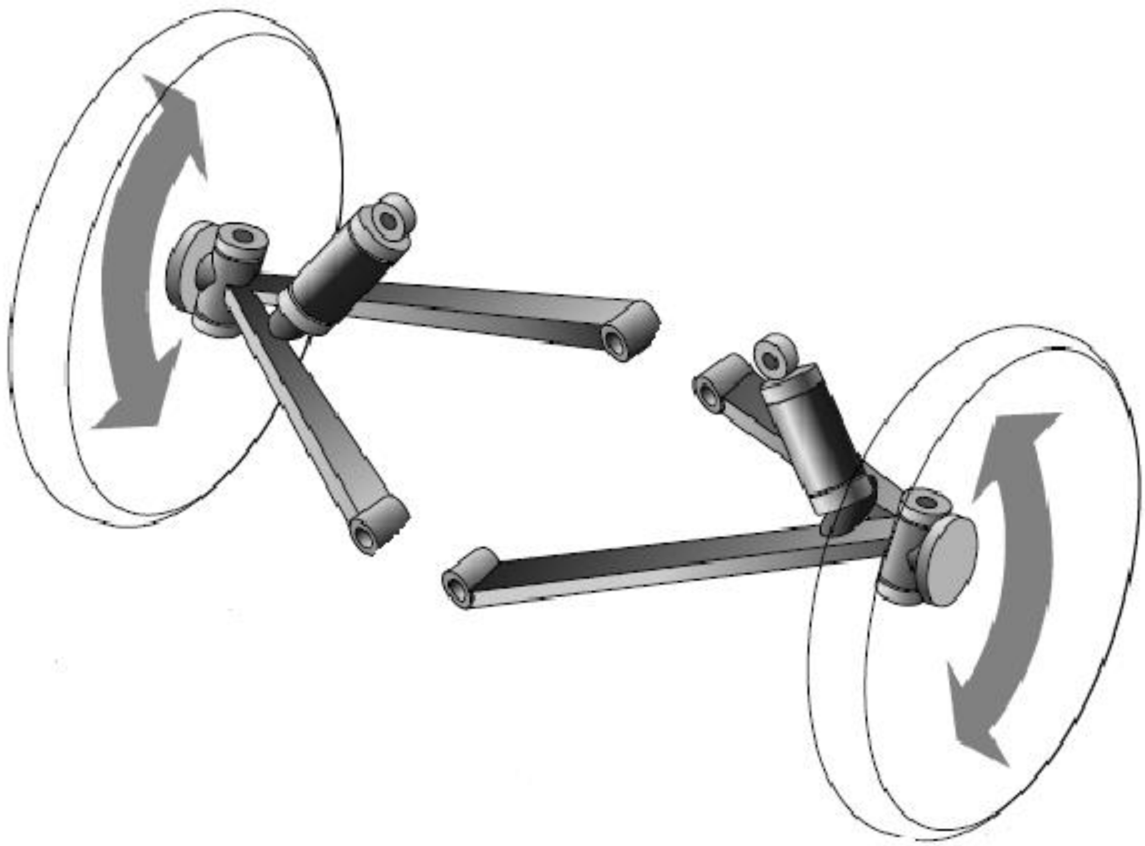

Figure 2 Drawing Example of Swing Arm Suspension

This is the first hand drawn drawing of the swing arm suspension. This will be changing throughout the rest of the design process hopefully not to drastically.

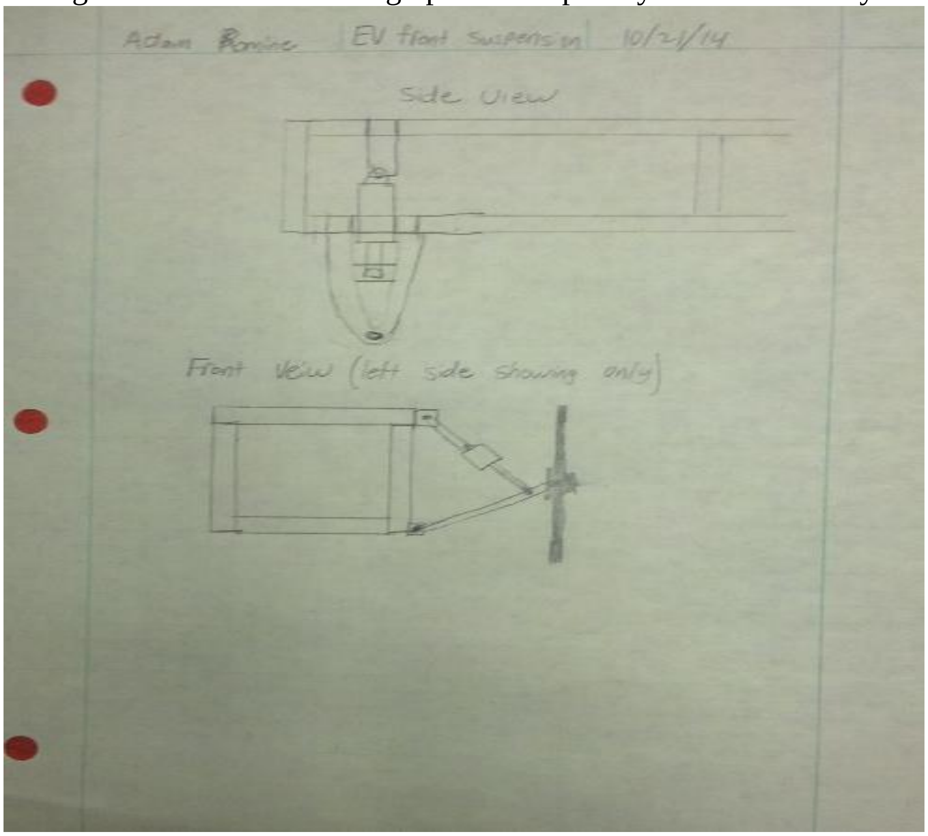

Figure 3 Hand Drawing of Swing Arm Design

Performance Predictions

The performance predictions for the suspension will allow the wheels to have enough space to make a 30.6ft diameter turn. It will also be sturdy enough to hold the weight of the vehicle and person when the vehicle is in motion and at rest. Each side of the suspension will weigh about 4.9 pounds. The suspension will not fail during a corner where the friction force that the wheels can hold is 1426lbs assuming that the corner is taken on dry pavement.

Description of Analyses

The first thing that was analyzed was the static forces that were acting on the suspension arm and the shock. The requirement was that they need to hold the static weight of 500 pounds. Since there are two sides each one will have to hold at least 250 pounds of static weight. Using the equations of equilibrium $\sum F_x=0$, $\sum F_y=0$ and $\sum M_o=0$. (Reference Appendix A-1).

Once that the static forces are found it should be noted that these forces are the minimum forces that the suspension needs to hold. The maximum forces that the suspension will be subject to are the forces that the suspension will be designed for. To find the maximum force acting on the suspension was found by finding how much force the wheels could hold before they slipped. This was found using the equation $f_{s=}\mu_s N$. μ_s was found online at TheEngineeringToolbox.com. The total force that the suspension will be subjected to is 450 pounds (reference Appendix A-3). Using the safety factor of 3 the total force the suspension will be designed for is 1350 pounds.

The next thing that will be analyzed is if the brackets will attach to the chassis. The way that the design calls for will be to attach them to the chassis by welding them to the 1 in steel bar. Design for the brackets will be explored using the average shear equations and then test them by attaching them to the vehicle and loading the vehicle how it normally would. The equation that was used was $\boldsymbol{\tau_{avg}} = \frac{\boldsymbol{V_{Bolt}}}{\boldsymbol{A_{Bolt}}}$ this shows that there needs to be at least 1/4in aluminum bolt. The shear force on it with this size bolt is 25ksi with a safety factor of 3 (reference Appendix A-4).

After analyzing the wheels and how much they must rotate in order to provide a 50ft diameter turn, the result was the wheels need to rotate at least 13.5 degrees (reference Appendix A Pg. 20). The reason this needed to be analyzed was because in order to design the length of the swing arm the amount of wheel clearance to the outer frame had to be calculated. A design requirement was to provide a 50ft diameter turn this requirement was set because it is a requirement to compete in Electrathon America. After finding the maximum angle the wheels can turn a value of 23 degrees. The car will have a turning diameter of 30.6 ft. (reference Appendix A-6).

After doing the analysis of the buckling of the arm during a 1g corner. It was shown that it would not come anywhere close to the critical force that the arm needs in order to buckle. The buckling equation $P_{cr} = \frac{\pi^2 EI}{KL^2}$ was used to analyze the buckling force in the arm. It was determined that the K factor to be used is 2 (reference appendix A pg. 19). The critical load that was gotten here was much less than the cornering load that would be applied to the arm during a corner. The force applied to the arm during a corner was determined by two equations. The first equation used was the tangential acceleration equation $a_n = \frac{V^2}{r}$ and with this the force was found using$\sum F_x = ma_x$ (reference Appendix A-8).

The weld bar was analyzed for bending. The bar was determined to be 1”x1”x1/8” (reference Appendix A Pg. 25-26). The bar will be resisting the force of the shock determined from the max forces calculation (reference Appendix A-11).

Scope of Testing and Evaluation

To test this device to make sure that the design works and that the calculations were done correctly for the suspension we will put it into the electric vehicle. When it is put into the vehicle we will load it to the standard weight of the vehicle plus the driver to see if it holds up. This will check to see if the arms are buckling, how much deflection there is, and how much it will travel, and to see the sheer forces in the connecting points.

Analysis

I. Approach: Analysis will begin with the testing of the sag and travel of the suspension as load is slowly applied to the arm and shock assembly. Then analysis will shift to seeing deflection and measuring stresses that are occurring in the members of the suspension assembly.

II. Design: The first step to designing the suspension will be selecting a proper safety factor. Since this vehicle is going to be carrying a person at high speeds a safety factor of 3 should be used. There will also be dynamic forces that are going on in the suspension so the load of the 500 pound vehicle plus driver will be greater. When the vehicle is going around the maximum corner that it can handle to suspension needs to be able to stand up to 1350 pounds. Since there are two wheels in the front of the vehicle when static hold roughly the same amount of weight there will only be a 250 pound load on each suspension. Therefore, the suspension should be designed to hold at least 750 pounds. After this there will need to be calculations for, deflection on the arms that are the suspension, the shear forces in the mounts, bending in the arms and shock, the amount of pressure the shocks piston will load into the cylinder at full load, and buckling forces in the arms. There will be special consideration to the design of the lengths of the arm to assure there will be adequate space for the wheels to rotate.

III. Calculated Parameters: Most of the parameters were calculated using the equations discussed in the description of analyses section. It was determined that the swing arm will be made out of A36 Steel, and the arm will have a diameter of 1.125 in. This was calculated by the maximum bending moment and comparing that to the yield strength of A36 Steel (reference Appendix A-9, 10). This material is ideal because it is commercially available and is fairly low in cost. The buckling showed that it would not buckle with this diameter. The 3/8 in hole was determined from the shear stress that was calculated in the bolt. The bolt needed to be larger than .24 so the closest standard size is 1/4in. The bolt will be made from 6061 T6 aluminum to keep it as light as possible (reference Appendix A-4). The weld bar that the shock will be bolted onto will be made form 6061 aluminum and be 1x1x1/8 in this is the smallest commercially available tee bar out there. The bar will hold maximum bending stress of 3805 psi (reference A-11,12). The bolts that will connect both sides of the shock to the brackets will are 11/32in diameter bolts. They are under 11.9ksi in direct shear so aluminum 6061 T6 will be used (reference A-5).

IV. Device Assembly: To mount the suspension to the frame the brackets will first need to be welded to the lower section of the frame. The shock mount will be welded onto the arm. Then the swing arm will have to be welded to the bracket mount. The bracket mount will then be bolted into the bracket with the arm welded on to it. Next the shock bracket will need to be welded to the upper portion of the frame and the shock will be bolted into it. Then the shock and the swing arm will need to be bolted together to form the assembly. Next the steering spindles will be bolted into the swing arm. After that the wheel will be bolted into the steering spindle and the vehicle will be ready to roll.

V. The tolerances for the assembly will be crucial in the angle at which the swing arm is mounted to. If there is more angle or less angle it will affect the camber of the wheels. The angle needs to be as close as possible to 18 as possible because that is the zero camber angle. The tolerances of the individual parts need to be precise enough to make sure every part fits correctly. The tolerances for the holes and locations need to be within a tenth of an inch. The tolerances for mounting need to be precise enough to make sure the 18 degree angle is within a half of degree.

Failure Modes

The failure modes for the suspension is in the control arm. The force that is acting on it during a corner is trying to bend the arm. For this aspect a safety factor of 3 was used which seems to be a common safety factor for most automobiles regarding suspensions and stability. The operational constraint for this vehicle is to not put a driver or a load into the vehicle that is more than 250 pounds. Another operational constraint for the suspension is the tires that need to be used must be 17in diameter tires. If smaller or larger tires are used then they will be sitting at a positive or negative camber and negatively affect the performance.

Risk

There is risk that goes along with this device because if it fails it can cause the vehicle to lose control and crash. Since the vehicle will be traveling at relatively high speeds of about 40 MPH and is being driven by a person it could lead to injury of the driver that would be involved in the crash. To prevent crashes from occurring careful precautions must be made in the design to make sure that no failures occur during the use of this vehicle. Also proper maintenance of the shock will help make sure it stays in operational shape.

Methods and Construction

This project was designed to be constructed at Central Washington University, using the limitations of what is available for use this entire project will be built here. The project will be constructed in the machine shop and in the foundry.

Construction

I. Description: The device will be built in smaller parts and then assembled together. Most of the parts will be manufactured and assembled together here on campus. There are two parts that are going to be bought from suppliers, the tee bar and the Fox Racing Shock. There are 26 parts in whole for this project and will be assembled into 3 assemblies.

II. Drawing Tree/ IDs: For drawing tree please reference Appendix F. For ANSI Y14.5 standard drawings and assemblies reference Appendix B.

III. Parts List and Labels: For the parts list please reference Appendix C.

IV. Manufacturing Issues: Issues with manufacturing started with bending the bar for the arms of the suspension. Originally 6061 T6 aluminum wanted to be used but putting that into the bar bender would cause too much residual stress, so steel had to be used. Another issue was hitting tolerances on the holes made from the drill press. The drill bits were worn down to the point where they were giving holes that were out of tolerance for my part. Another issue was coping the ends of the arms. There was no good way to hold them in the milling machine and that caused them to chatter excessively and not able to hit tolerance.

V. Discussion of Assembly, Sub-Assemblies, Parts and Drawings: Once all of the single parts of the suspension are completed the sub-assemblies will start to be put together. The arm assembly is the most complex assembly that will be made. The arm needs to be welded to the bracket attachment first. Then the bracket will need to be welded onto the frame of the vehicle. The shock bracket will then be welded onto the control arm and the bracket attachment will be bolted onto the bracket. The next thing that needs to be done is weld the weld bar to the frame. Once it is welded to the frame the upper shock attachment needs to be welded to it. Then the shock is bolted to the lower and upper shock attachments and the suspension is fully put together. Once the suspension is put together the steering spindle will be bolted onto the control arm.

Device Operation

How the suspension operates is that it uses a lower control arm that attaches from the frame of the vehicle to the steering spindles to hold them in place in the horizontal direction. The suspension also uses a shock that is also attached to the frame of the vehicle and is attached to the lower control arm to hold the steering spindles in place in the vertical direction. The shock will also allow for the vehicle to dampen the shock of the vehicle as it encounters bumps and irregularities on the surface that it is operating on.

Benchmark Comparison

The suspension compared to the benchmark go-kart suspension is 33% as large. It also weighs a considerable amount less since the suspension will be made out of aluminum and the benchmark suspension is made from steel.

Testing Method

Introduction

For testing the suspension on this vehicle assuming that the vehicle is functional when the suspension is put onto the vehicle an empty parking lot or racetrack will be needed to test out the vehicle and how it performs. What the tests will be looking for on the part is if the suspension transfers the load of the vehicle smoothly, if the parts break, and if it can last an hour of running time.

Method/Approach

The first thing that will need to be done when the full suspension assembly is mounted onto the vehicle is configure the shock so that it performs appropriately. The shock will be tested using the methods described by the Fox Racing Company who are the manufacturers of the part. The next thing that will be tested is the strength of the suspension. The first thing that needs to be done is to test to make sure the suspension holds the weight of the driver and vehicle. The next test that will be done is a turning diameter test. The height of the vehicle will be tested by measuring the lowest part of the vehicle to the ground. The distance between the wheels will also be measured using a measuring tool.

Testing Documentation and Deliverables

How the testing will be documented is using a form that will be made up to record the results of each test. The form will only be used for tests that might give different results each time such as, the turning diameter test and the maximum cornering force test. A form will not be needed for measurements such as the vehicle height and the distance between the tires because they are just simple measurements and should not change. For testing the vehicle while it goes around corners an accelerometer will be used to measure the centrifugal acceleration. This test will also use a camera to see what is going on with the suspension during these corners.

Test Procedures

1. Turning test: The procedure for this test is to attach a compass to one of the wheels and turn the wheel until it is interfered by the frame or the shell of the vehicle. The test needs to measure the maximum angle that the wheels can achieve from the straight position to both the right and left position. The angle needs to be at least 13.5 degrees from straight for both left and right turns or modifications need to be made.
2. Weight test: This test involves putting all of the parts of the suspension onto a scale and weighing them to see how much weight the suspension will add to the vehicle. The weight needs to be under 20 pounds per side.
3. Shock test: The shock test will be performed using a dial indicator and a shock pump. First the shocks need to be pumped up using the pumped to a desired psi and then the vehicle needs to be loaded to static conditions. Then the dial indicator will read how far the shock travels from the load. The shock needs to travel .438 inches. Repeat until the right psi reads the right shock travel.

Testing Deliverables/Discussion

It was determined that with the weight of the vehicle and the amount of travel that needed to occur in the shock under the static load was .438in. The closest psi number that gave this value was 135 psi. This gave an average travel value of .451in. The shock test data has a lot of errors in it because of how it was measured and the way the shocks were acting. The pump was tested to see how precise the readings were and while the readings were precise when the pump was unscrewed from the shock it would cause the shock to lose 5-10 psi. This was really affecting how accurate the readings were in the test. Another thing that was affecting the accuracy of the readings was the shocks would rebound to a different height each time. For information on this test refer to Appendix F figure 30. The rebound height would jump around by an average of .01in from the last reading. The wheel angle/ turning diameter test showed that the angle the wheels could make was 23 degrees which is much larger than the required 13.5 degree angle. Refer to Appendix F figure 31. The weight of the suspension was measured to be 12.3 pounds per side which is less than the required 20 pounds per side. Refer to Appendix F figure 32.

Budget

Part Supplies

For this project there will be raw supplies that need to be bought as well as a few pieces of hardware. The hardware that will be bought will be purchased online through McMaster-Carr and from the local hardware store. The raw materials to make the arm and the brackets will be purchased online at OnlineMetals. The aluminum Tee-bar will be bought from Orange Aluminum. For a part list refer to Appendix C Parts List.

Estimated Total Cost

The total estimated cost is $637.49 dollars. The total money that will need to be spent is only $99.49. This is because the two shocks worth $538 dollars have already been paid for. The actual value for which the shocks were bought for is unknown this value is the value of the shocks now from Fox Racing website. The total overall budget was $**123.27.** Refer to Appendix D Budget.

Labor

There will not be any outsourcing labor done. There will be considerable labor hours needed in the manufacturing process of the suspension. Machining will be done to make the swing arm and to drill the holes. There will also be some bending of the sheet metal to make the brackets and the mounts for the arm and the shock. Considerable amount of welding will be done to weld all of the parts together and to mount the brackets to the frame.

Funding Source

The funding for the hardware and raw materials will come out of pocket but will be reimbursed by the Electric Vehicle Club. The funding for the shocks have already been purchased by the Electric Vehicle Club.

Schedule

Description

The schedule is shown in the Gantt chart in Appendix E Pg. 31. The proposal part of this project needs to be turned in by December 10, 2014. The suspension needs to be built by March 16, 2015. The whole project needs to be completed by June 6, 2015. The total estimated hours is 158 hours. So far most of the estimates are lower than the actual time spent. This is because lots of problems have come up while trying to complete the project and the lack of experience in estimating how long certain things take. Most of the time spent so far was writing up the proposal which took 65.2 hours. The next big thing will be device construction. There are 21 hours estimated for the construction and only 14 hours estimated to put it all together. Overall the project was estimated at 158 hours but was able to be completed in 135.3 hours.

Project Management

Human Resources

The lead investigator and machinist of this project needs to construct the project, and work out all of the analyses. This person is in charge of meeting deadlines and making sure everything works out.

Physical Resources

This project will need the use of machines to manufacture it. It will need a drill press to cut the holes, and a mill to cut out parts and shapes. It will also need a TIG welder to weld the aluminum. The machines that will be used will be at Central Washington University in the machine shop. The TIG welder will also be used at Central Washington University in the foundry.

Soft Resources

The soft resources that will be used are the CAD labs at Central Washington University. The software that will be used is Solidworks. Solidworks is what will be used to create the 3D part, drawing, and assembly files. MasterCAM will also be used to create CNC code for the mill machines to cut out parts.

Discussion

The design of the front suspension has evolved greatly throughout the whole process. When the design started it was much more complicated than it had to be. There was a major design change that made the design much simpler. The original design was drawn up on SolidWorks just fine the problem was it appeared there was no efficient was to construct the parts. There was also way too much going on for a suspension that is only holding a 500 pound vehicle. The design was changed from a double a-arm suspension to a swing arm suspension. The differences between a swing arm suspension and a double a-arm suspension is that the swing arm suspension uses only a lower control arm, that is hinged mounted, to hold the wheel and then uses a shock to transfer the weight of the vehicle. The double a-arm suspension is similar to the swing arm except that it uses two control arms to hold the wheel in place. After tweaks were made the design now looks possible to be able to construct. One of the biggest thing that was done to make the design simpler was to make the left and right suspension identical.

The design has seven major parts that need to be made for each side of the suspension. The drawings for each of these parts can be found in Appendix B. There are also assemblies describing how these parts will go together in Appendix B. A drawing tree was also made to see how each part goes together chronologically. After all the tweaking the final design looks like it has a single control arm that bolts from the chassis to the steering spindles. There is a shock that is bolted to the welded bracket on the control arm that is also bolted to the bracket that is welded to the weld bar. The weld bar is welded to the inside of the frame and spans from the upper part of the frame to the lower part of the frame.

Conclusion

The results of this project are: 1) it functions as the function statement says that it should, 2) it doesn't break when it is in use, and 3) the part is completed and tested in time for the Electrathon America Competition. Since the purpose of the suspension is to be bolted onto the electric vehicle so that it can race in the Electrathon America Competition these are reasonable results that would indicate a successful project. The Electrathon America Competition is going to take place in the spring of 2015.

Acknowledgements

I would like to thanks Dr. Johnson, Professor Pringle, and Professor Beardsley for help throughout the project with questions that I had. Also would like to thank Mr. Burvee for help with the machines and the manufacturing of the suspension. I would also like to thank the Electric Vehicle Club for help with ideas and funding of the project. I also would like to thank Central Washington University for the use of their labs and shops to complete this project. Without the help of everyone this project would not have been able to happen. Thank you again!

Sincerely,

Adam Romine

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Appendix A Analyses

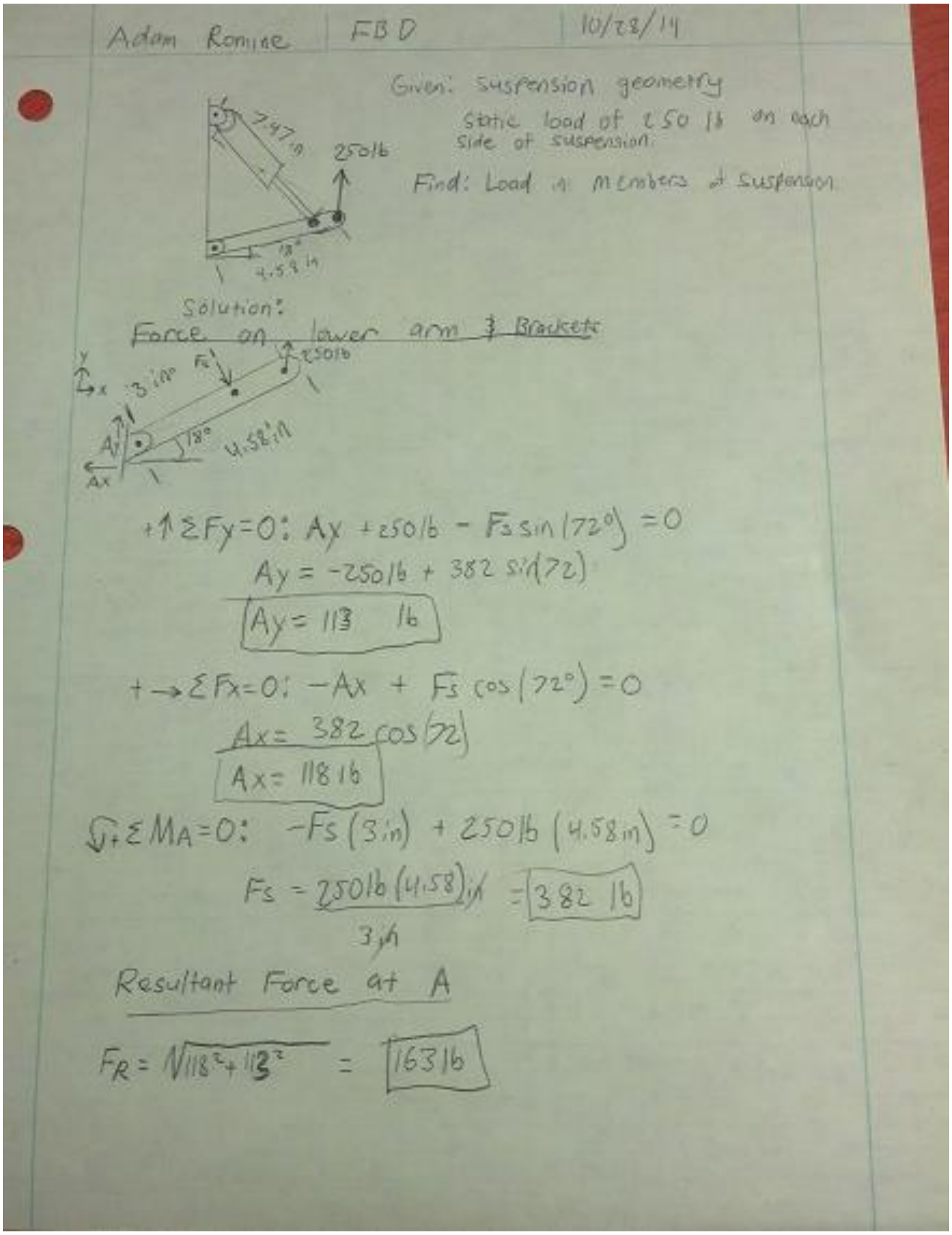


Figure 4 A-1

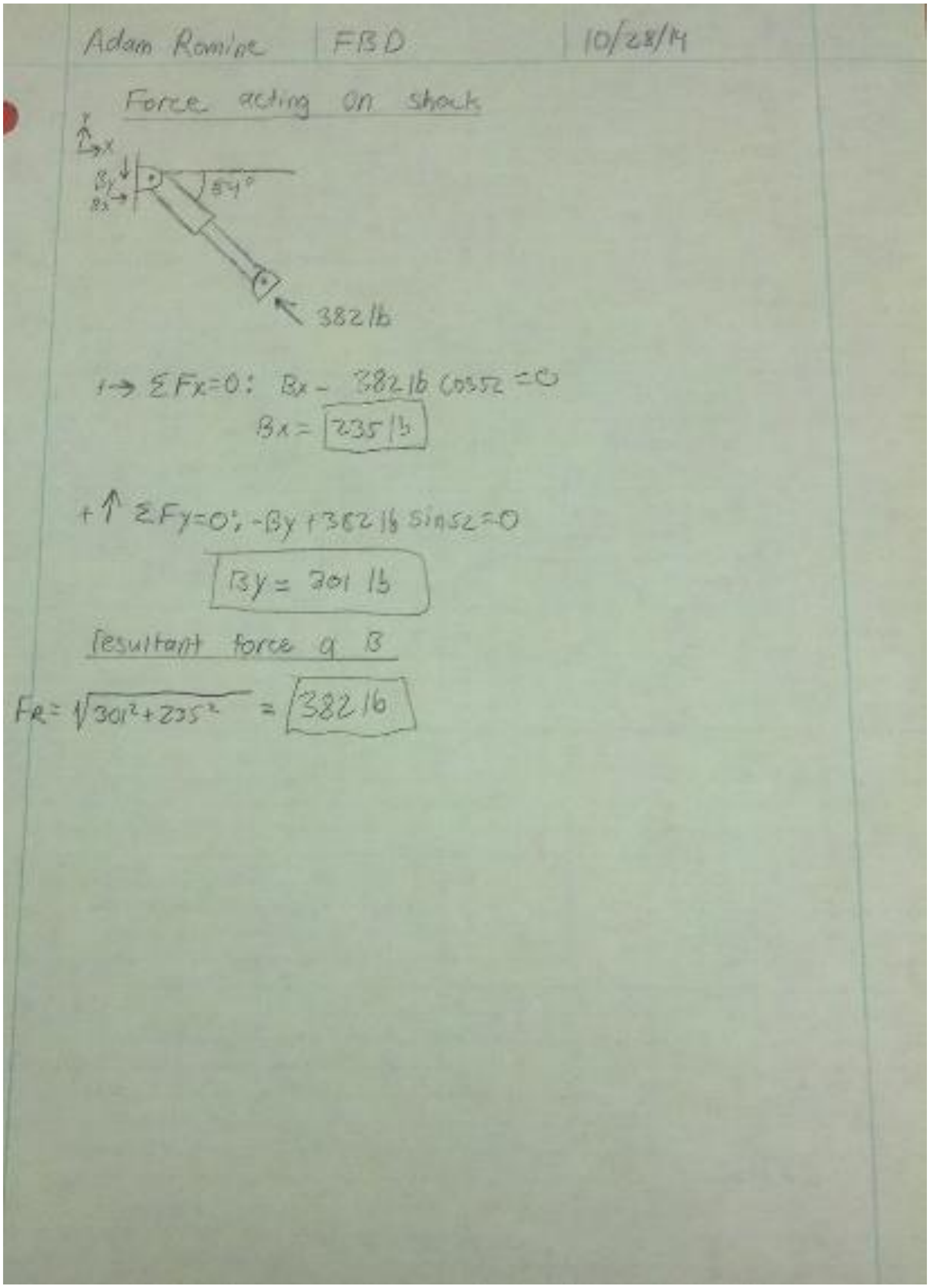
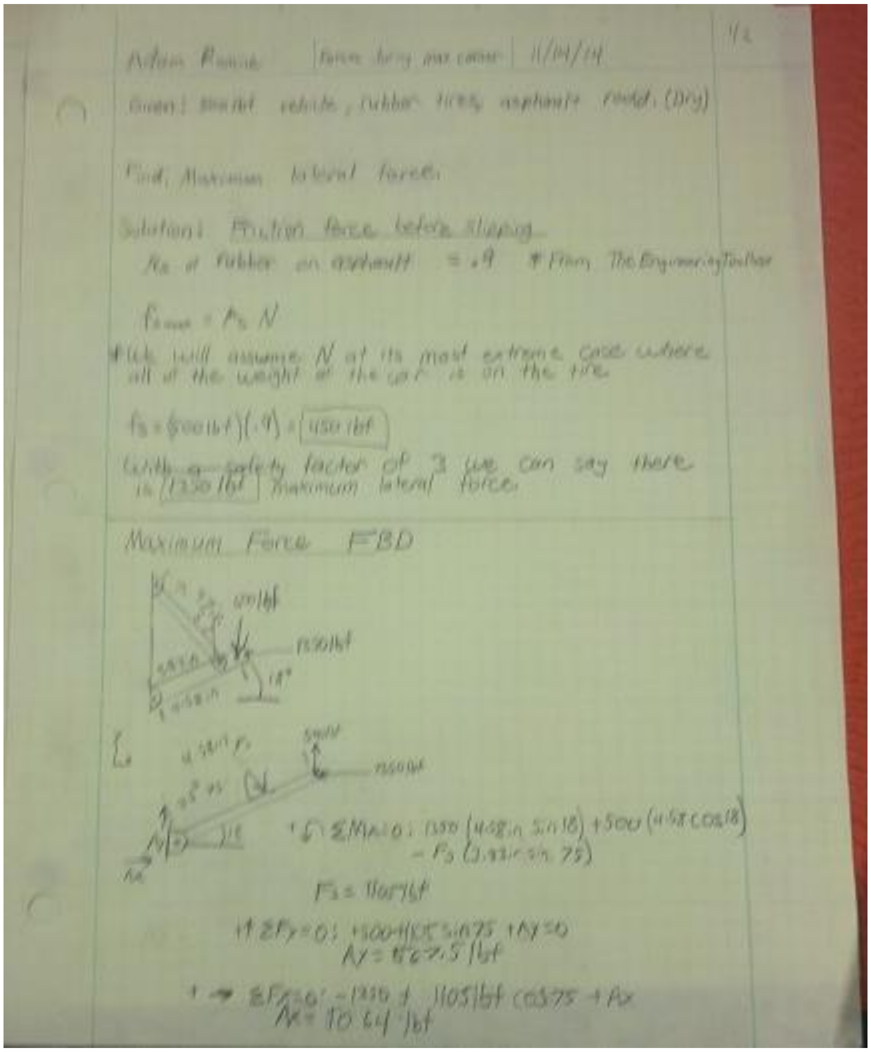

Adam Romine
FBD
10/28/14
Force acting on shock
84°
382 lb
ΣFx=0: Bx - 382 lb cos52 = 0
Bx = 235 lb
ΣFy=0: -By + 382 lb sin52 = 0
By = 301 lb
resultant force @ B
FR = √(301² + 235²) = 382 lb

Figure 5 A-2


Find: Maximum lateral force.

Solution: Friction force before slipping

With a safety factor of 3 we can say there is 1350 lbf maximum lateral force.

Maximum Force FBD

Figure 6 A-3

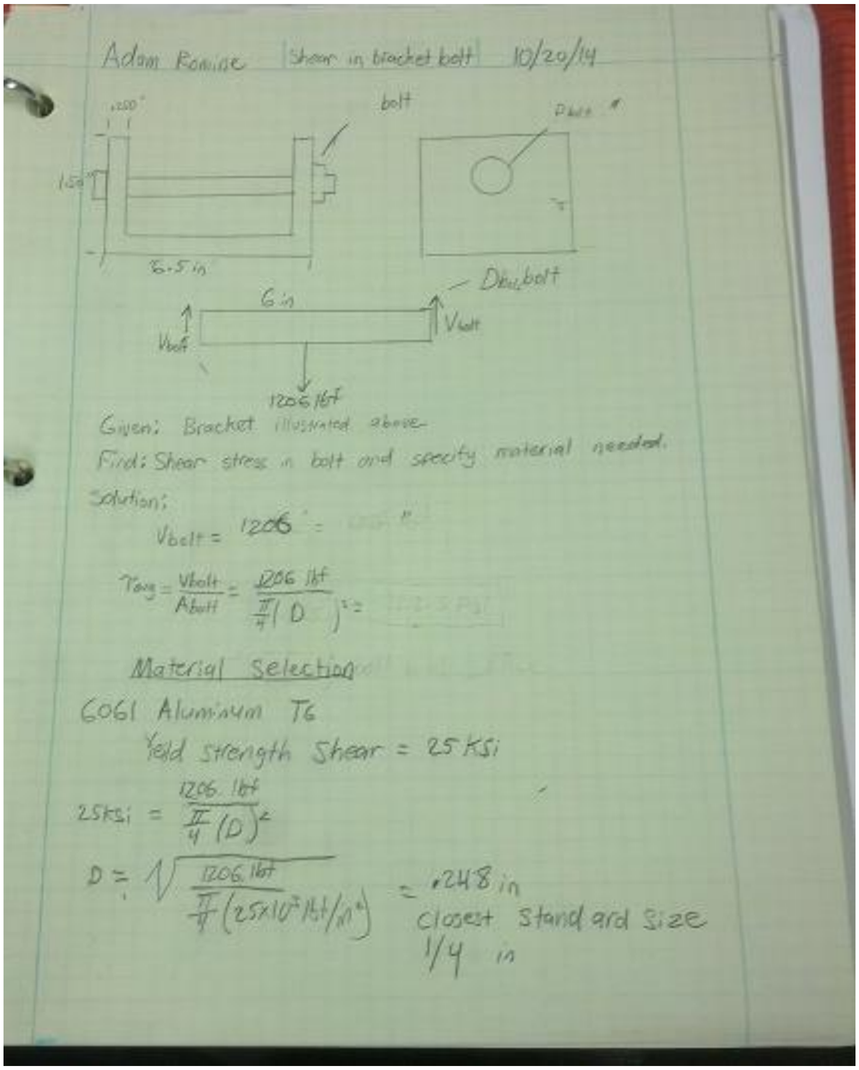
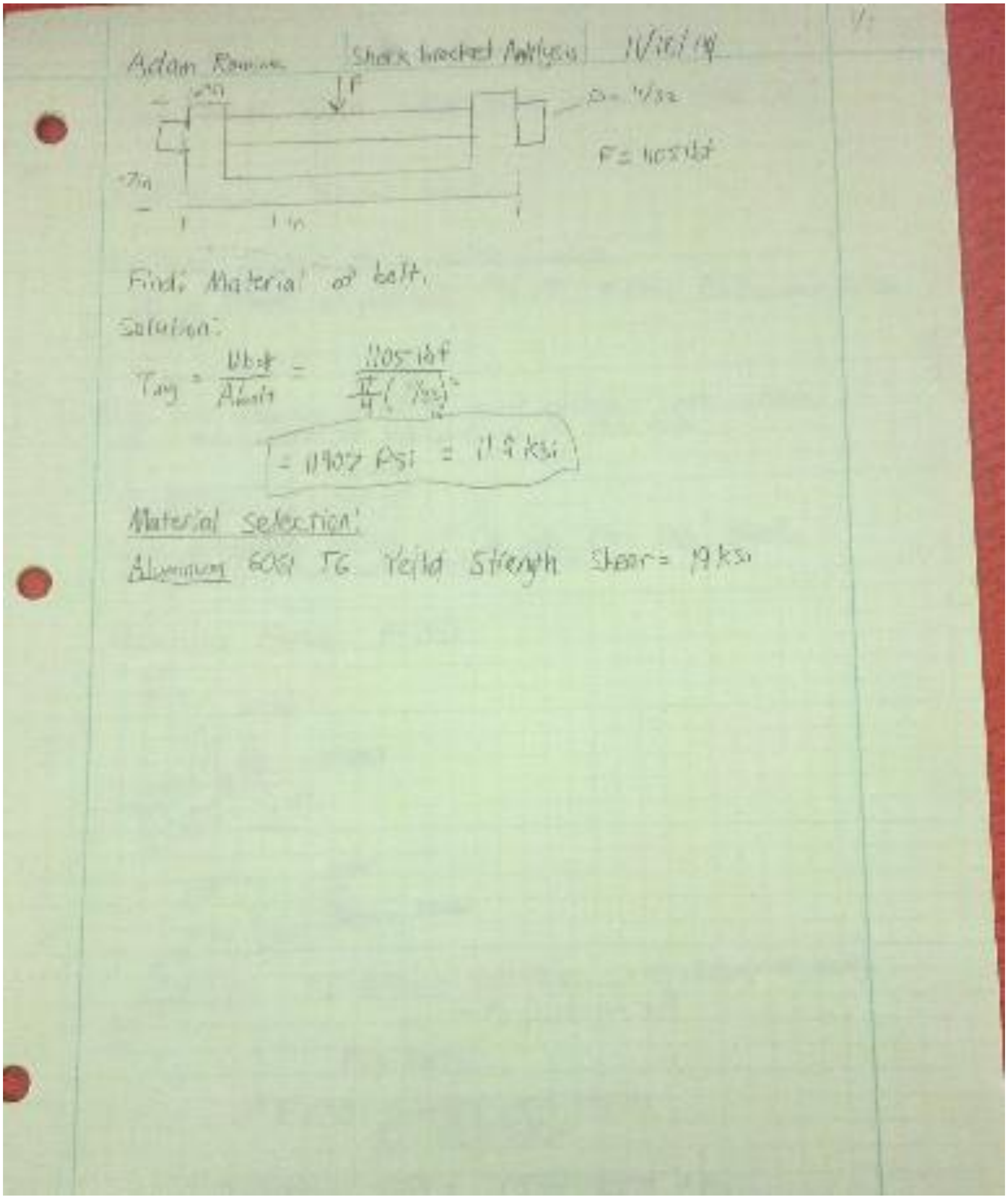
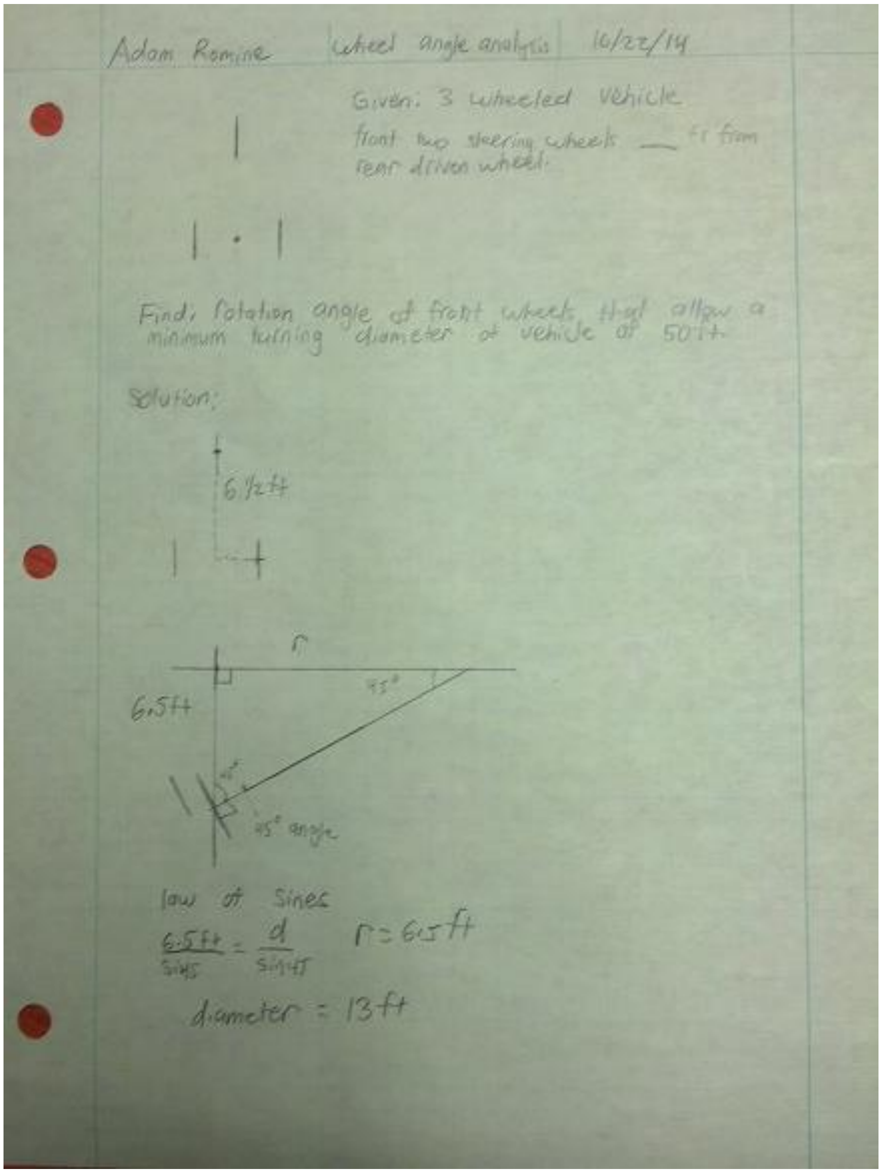

Adam Romine
Shear in bracket bolt
10/20/14
bolt
6.5 in
Dbu bolt
6 in
Vbolt
Vbolt
1206 lbf
Given: Bracket illustrated above
Find: Shear stress in bolt and specify material needed.
Solution:
Vbolt = 1206
Material selection
6061 Aluminum T6
Yeild strength Shear = 25 Ksi
= .248 in
closest standard size
1/4 in

Figure 7 A-4



Adam Rouman
Shock bracket Analysis
F = 1105 lbf
Find: Material of bolt.
Solution:
= 11907 psi = 11.9 ksi
Material selection:
Aluminum 6061 T6 Yield Strength Shear = 19 ksi

Figure 8 A-5


Adam Romine
wheel angle analysis
10/22/14
Given: 3 wheeled vehicle
front two steering wheels ___ ft from
rear driven wheel
Find: rotation angle of front wheels that allow a
minimum turning diameter of vehicle of 50 ft
Solution:
6 1/2 ft
r
45°
6.5ft
45° angle
law of Sines
6.5 ft / sin45 = d / sin45
r = 6.5 ft
diameter = 13 ft
Figure 9 A-6

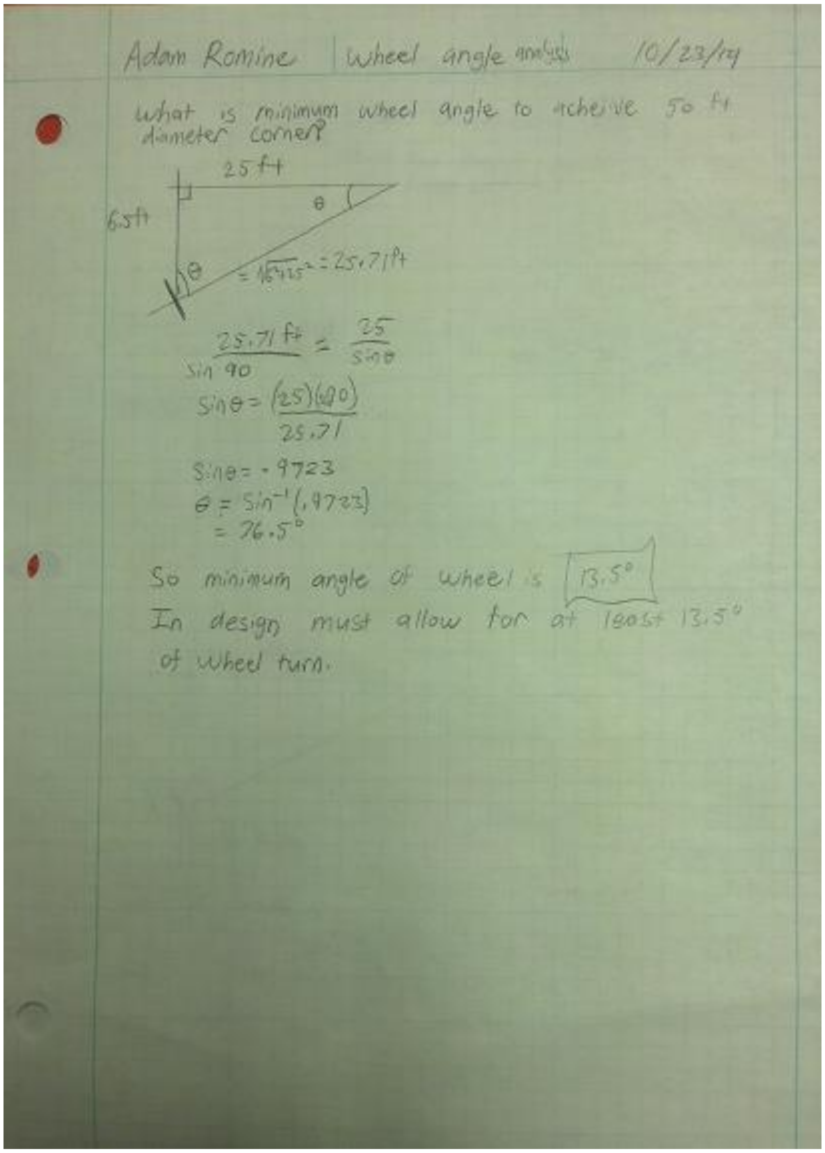

Adam Romine | Wheel angle analysis 10/23/14
what is minimum wheel angle to acheive 50 ft diameter corner?
25 ft
6.5 ft
θ
= 25.71 ft
25.71 ft / sin 90 = 25 / sin θ
sin θ = (25)(sin 90) / 25.71
sin θ = .9723
θ = sin⁻¹(.9723)
= 76.5°
So minimum angle of wheel is 13.5°
In design must allow for at least 13.5°
of wheel turn.

Figure 10 A-7

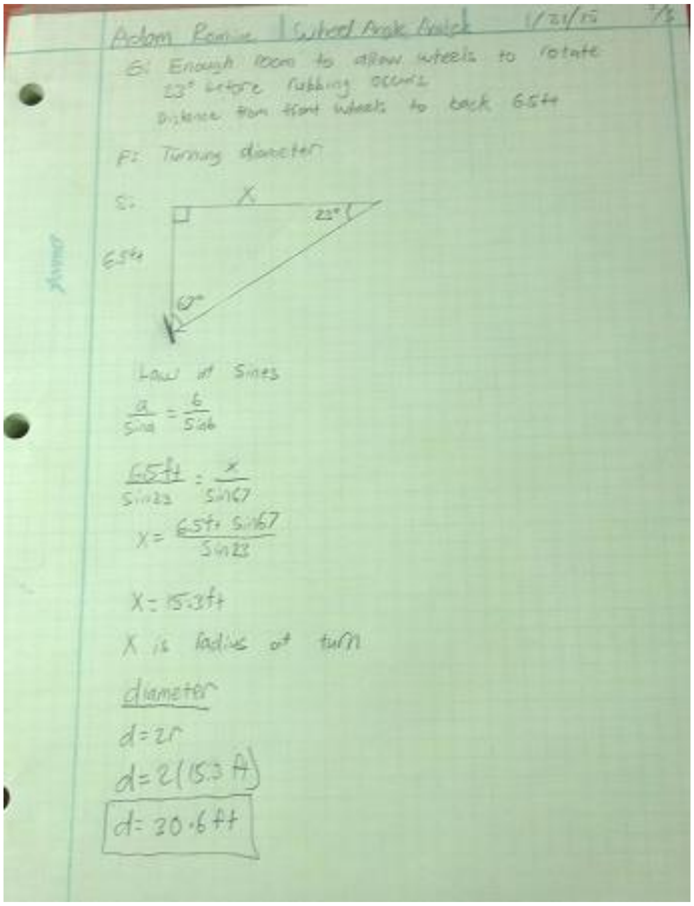
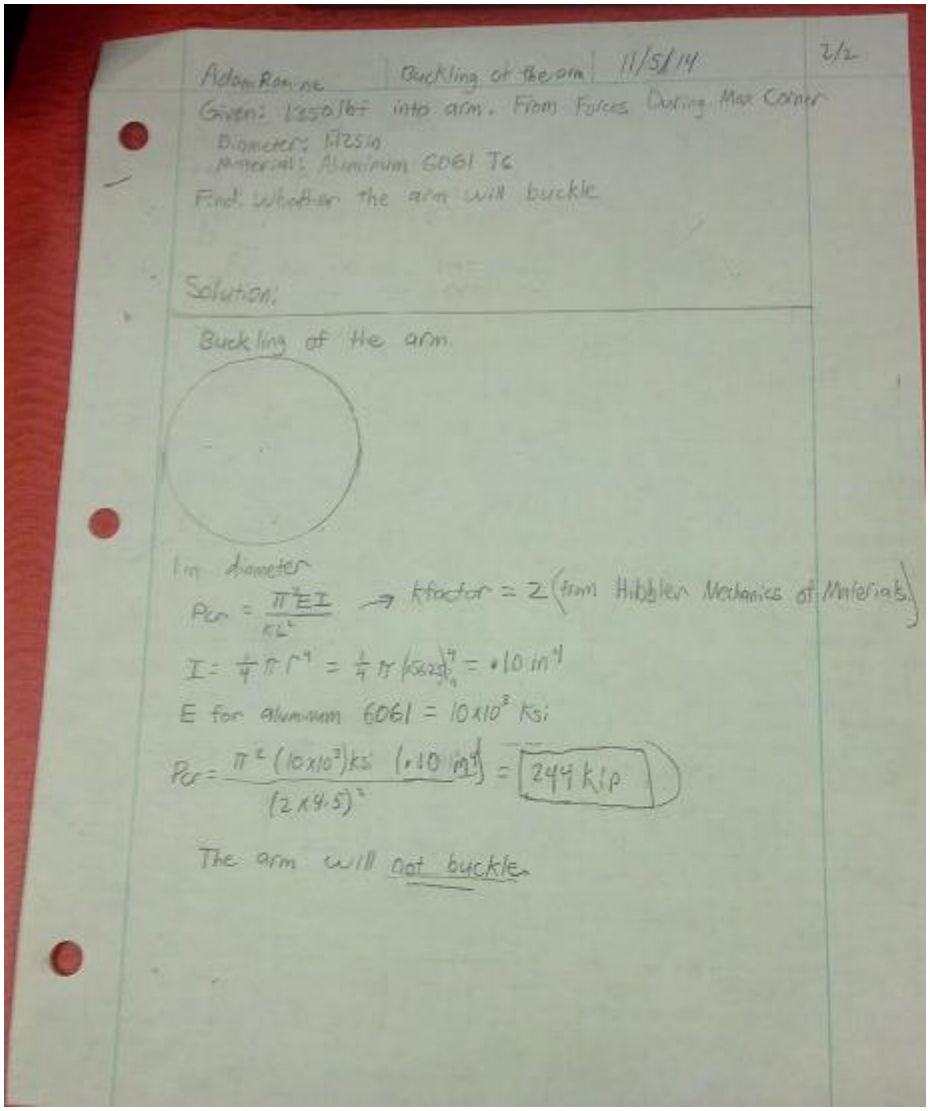

Adam Romine | Wheel Angle Analysis 1/21/15
G: Enough room to allow wheels to rotate 23° before rubbing occurs
Distance from front wheels to back 6.5ft
F: Turning diameter
S:
X
23°
6.5ft
67°
Law of Sines
X = 15.3ft
X is radius of turn
diameter
d = 2r
d = 2(15.3 ft)
d = 30.6 ft

Figure 11A8



Adam Romine | Buckling of the arm | 11/5/14 | 2/2

Given: 1350 lbf into arm. From Forces During Max Corner

Diameter: 1.125 in

Material: Aluminum 6061 T6

Find: Whether the arm will buckle

Solution:

Buckling of the arm

1 in diameter

$P_{cr} = \frac{\pi^2 E I}{K L^2}$ → Kfactor = 2 (from Hibbler Mechanics of Materials)

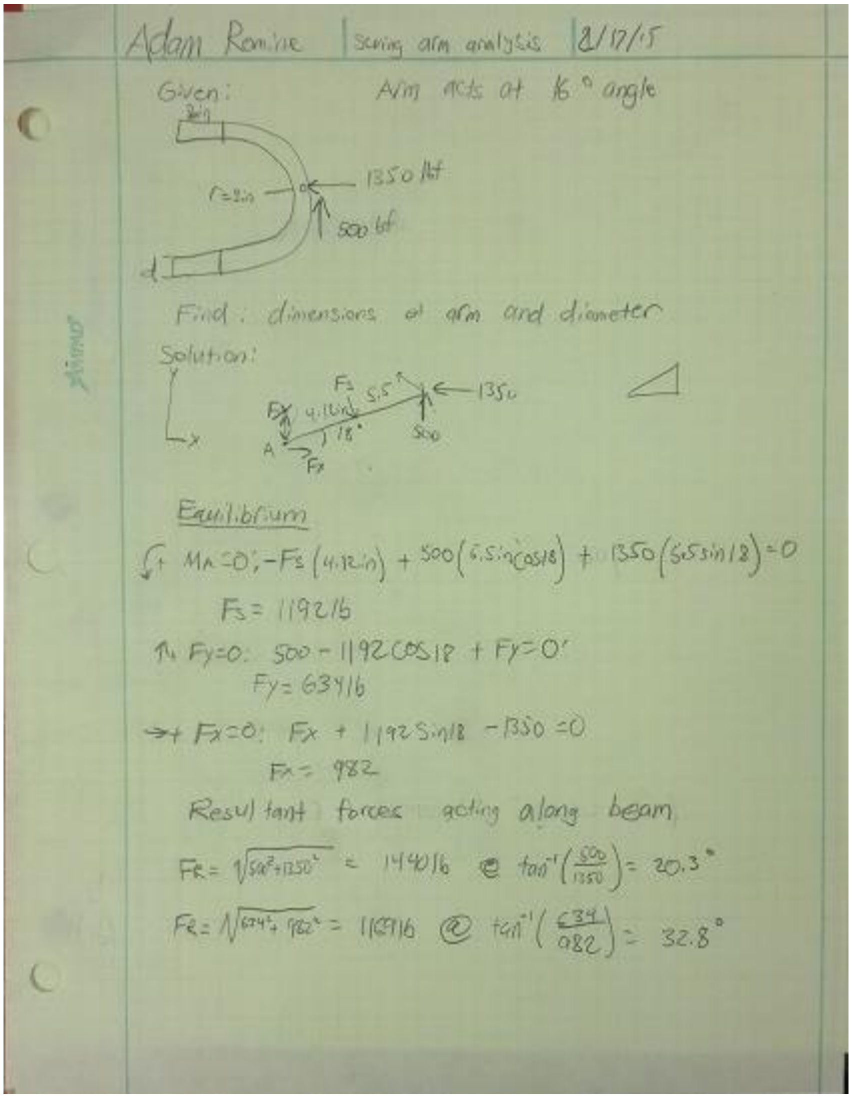
$I = \frac{1}{4}\pi r^4 = \frac{1}{4}\pi (.5625\ in)^4 = .10\ in^4$

E for aluminum 6061 = 10×10^3 ksi

$P_{cr} = \frac{\pi^2 (10 \times 10^3)\,ksi\ (.10\ in^4)}{(2 \times 4.5)^2} = 244\ kip$

The arm will not buckle.

Figure 12 A-9



Adam Romine | Swing arm analysis | 8/17/15

Given: Arm acts at 18° angle

Find: dimensions of arm and diameter

Solution:

Equilibrium

$\circlearrowleft + M_A = 0;\ -F_s(4.12in) + 500(5.5in\cos 18) + 1350(5.5\sin 18) = 0$

$F_s = 1192 lb$

$\uparrow + F_y = 0:\ 500 - 1192\cos 18 + F_y = 0$

$F_y = 634 lb$

$\rightarrow + F_x = 0:\ F_x + 1192\sin 18 - 1350 = 0$

$F_x = 982$

Resultant forces acting along beam

$F_R = \sqrt{500^2 + 1350^2} = 1440 lb \ @ \ \tan^{-1}\left(\frac{500}{1350}\right) = 20.3°$

$F_R = \sqrt{634^2 + 982^2} = 1169 lb \ @ \ \tan^{-1}\left(\frac{634}{982}\right) = 32.8°$

Figure 13 A-10

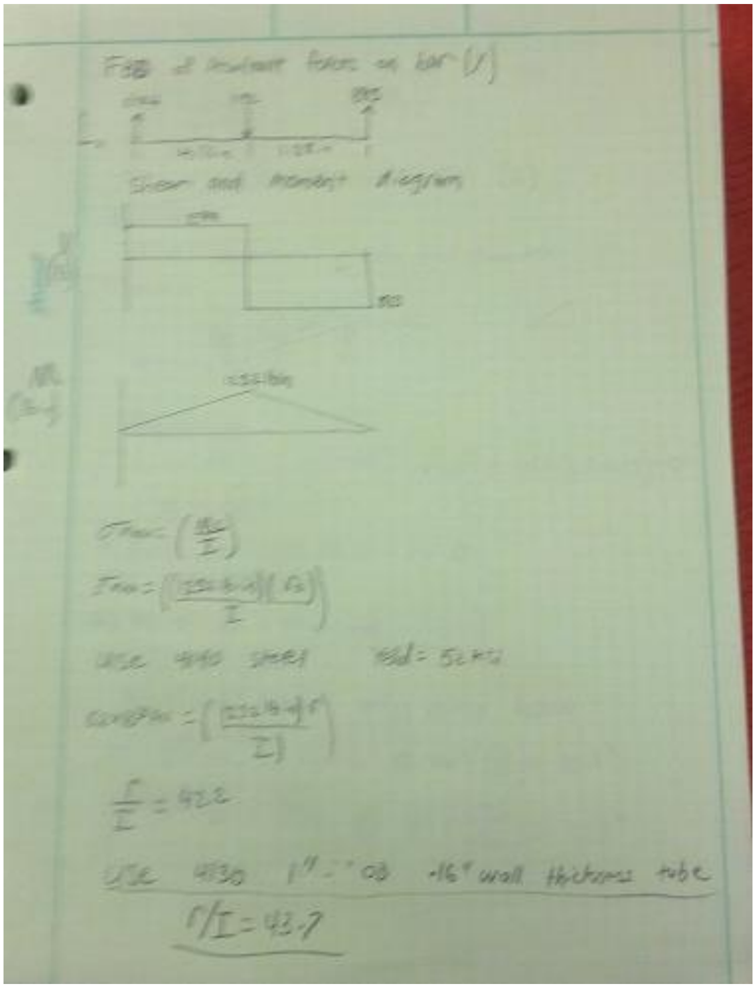


Figure 14 A-11

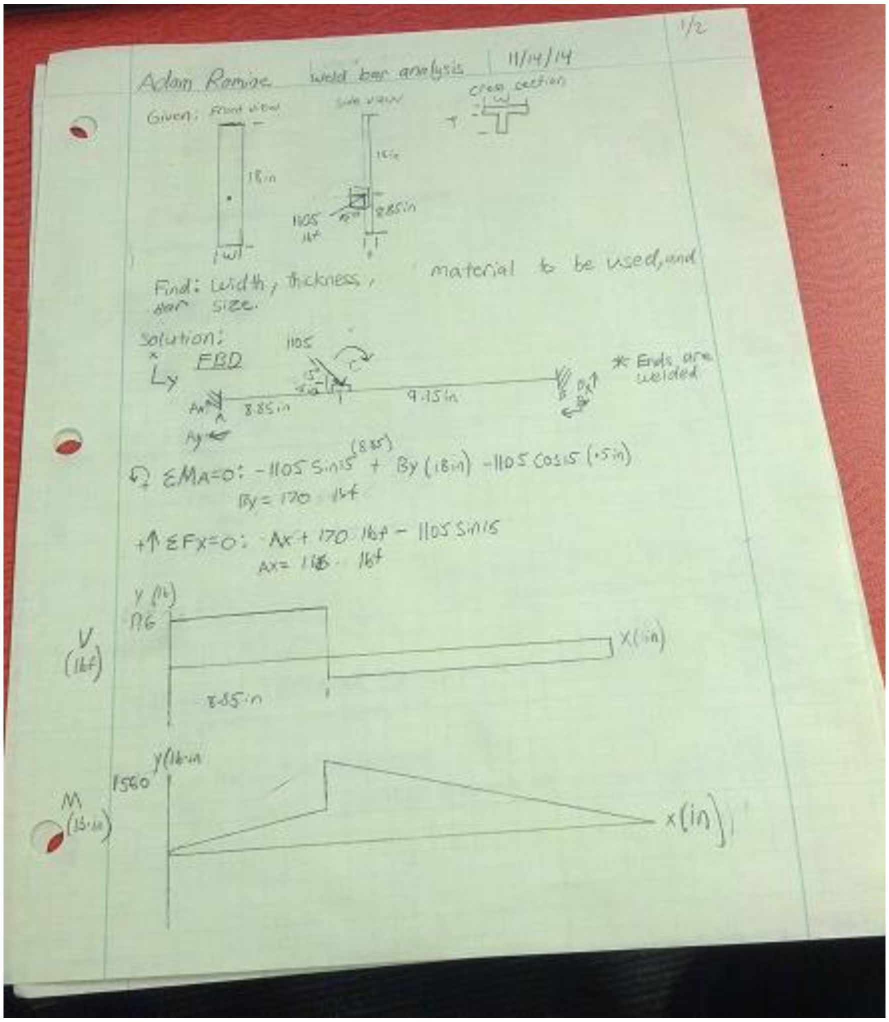
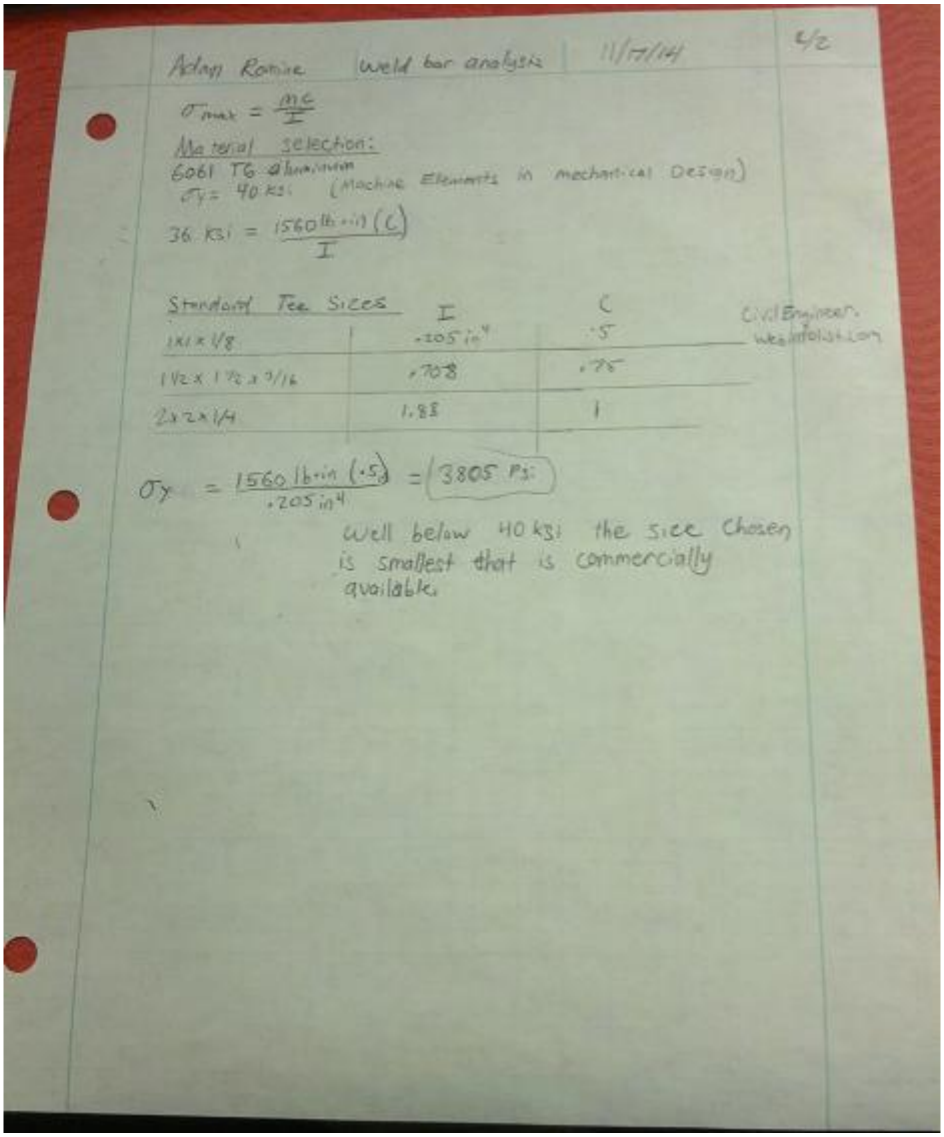


Figure 15 A-12


Adam Romine | Weld bar analysis | 11/17/14 | 1/2

$\sigma_{max} = \frac{Mc}{I}$

Material selection:
6061 T6 aluminum
σ_y = 40 ksi (Machine Elements in Mechanical Design)

$36\ ksi = \frac{1560\ lb\cdot in\ (c)}{I}$

Standard Tee Sizes

	I	C
1x1x1/8	.205 in⁴	.5
1 1/2 x 1 1/2 x 3/16	.708	.75
2x2x1/4	1.88	1

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$\sigma_y = \frac{1560\ lb\cdot in\ (.5)}{.205\ in^4} = 3805\ psi$

Well below 40 ksi the size chosen is smallest that is commercially available.

Figure 16 A-13

Appendix B Drawings

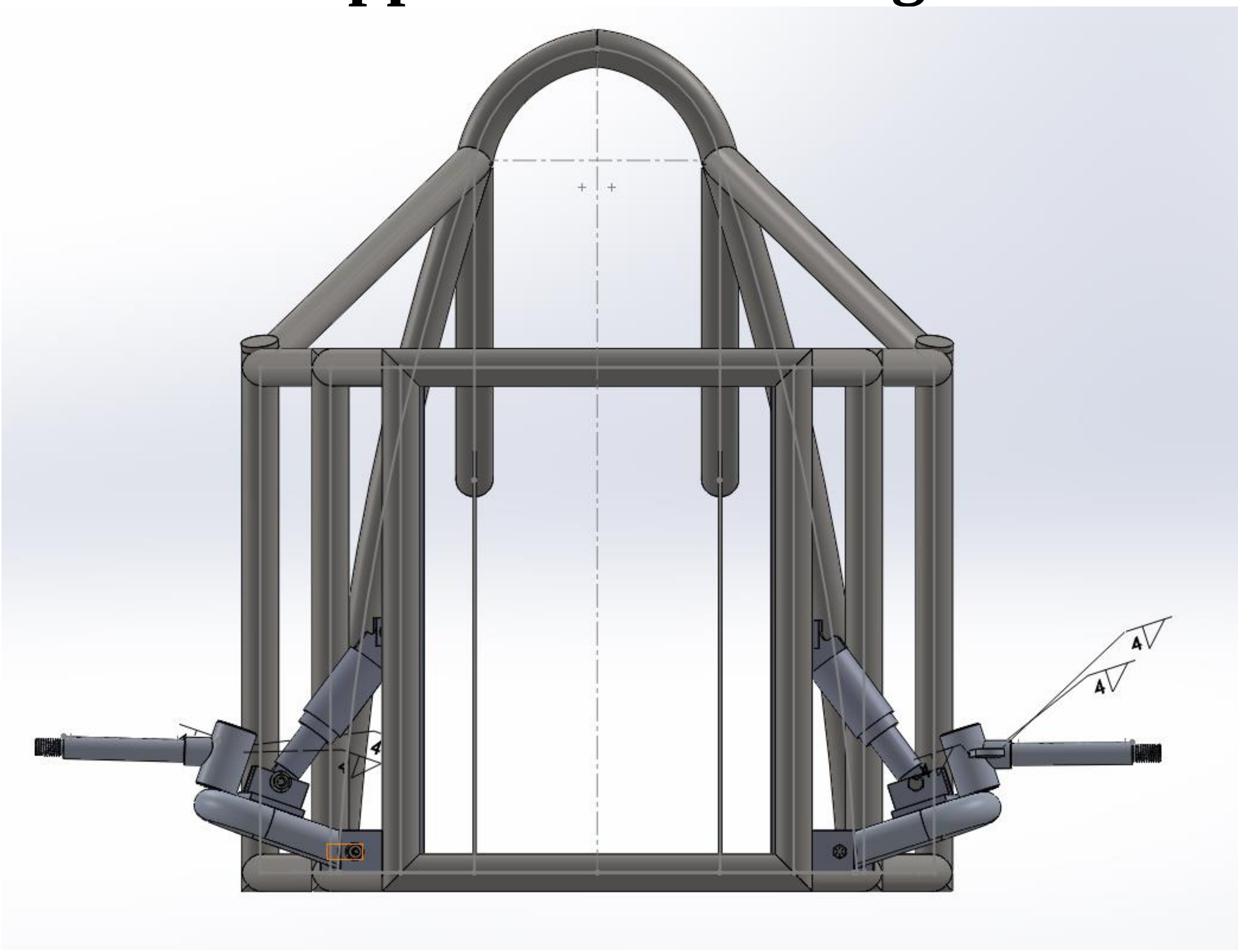
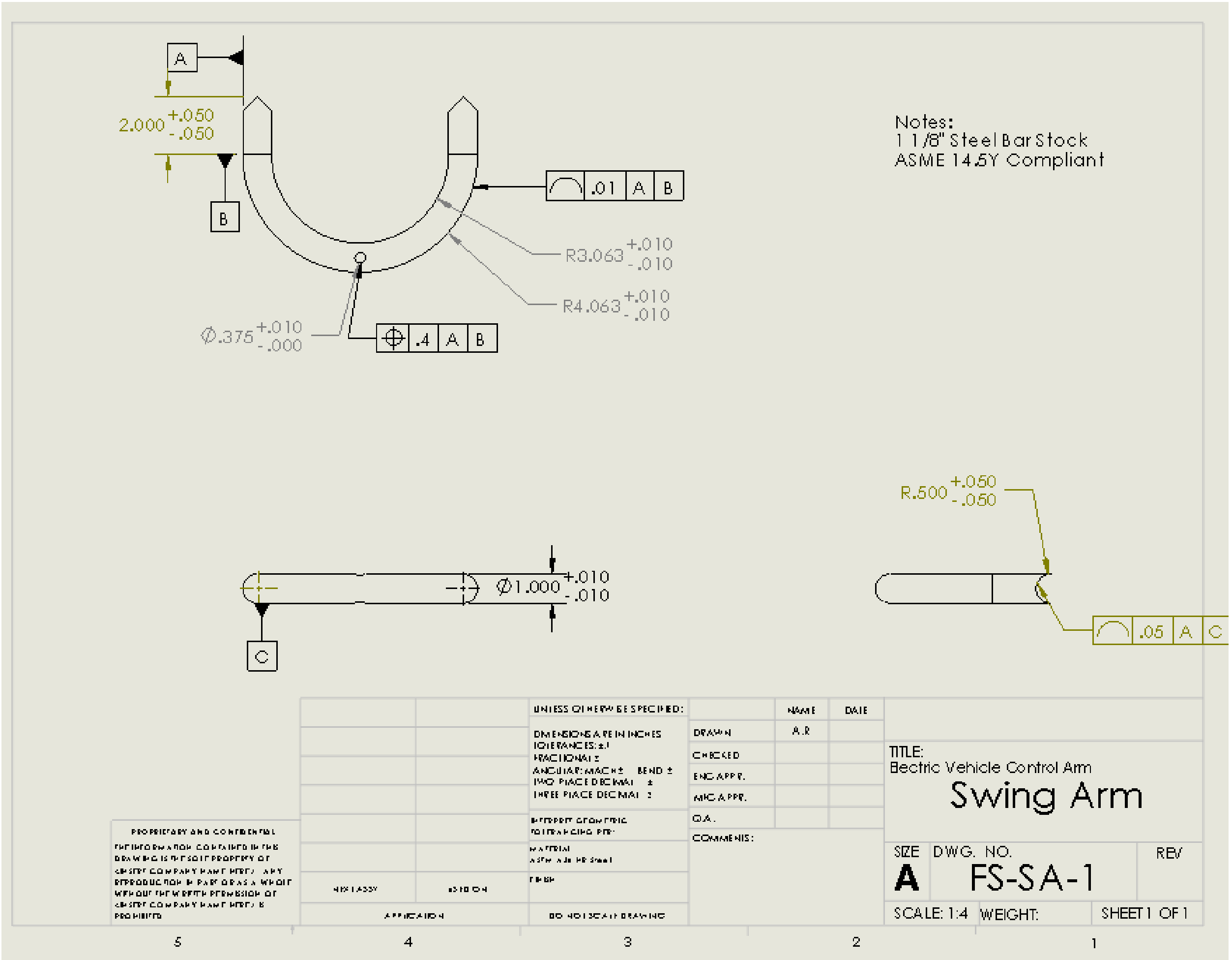


Figure 17 B-1



A
2.000 +.050 -.050
B
.01 A B
R3.063 +.010 -.010
R4.063 +.010 -.010
∅.375 +.010 -.000
.4 A B
Notes:
1 1/8" Steel Bar Stock
ASME 14.5Y Compliant
R.500 +.050 -.050
∅1.000 +.010 -.010
C
.05 A C
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
A.R
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Electric Vehicle Control Arm
Swing Arm
SIZE
A
DWG. NO.
FS-SA-1
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

Figure 18 B-2

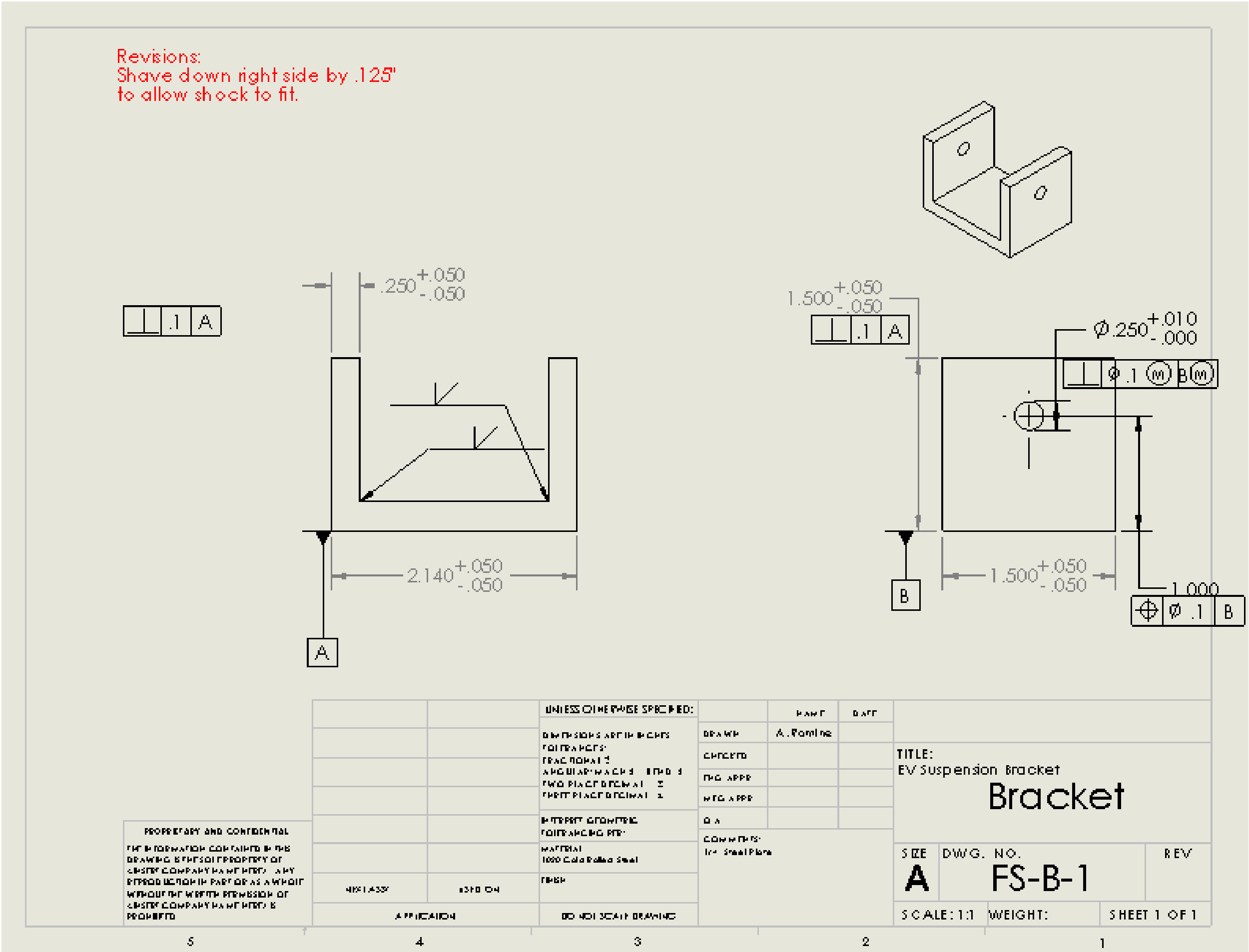
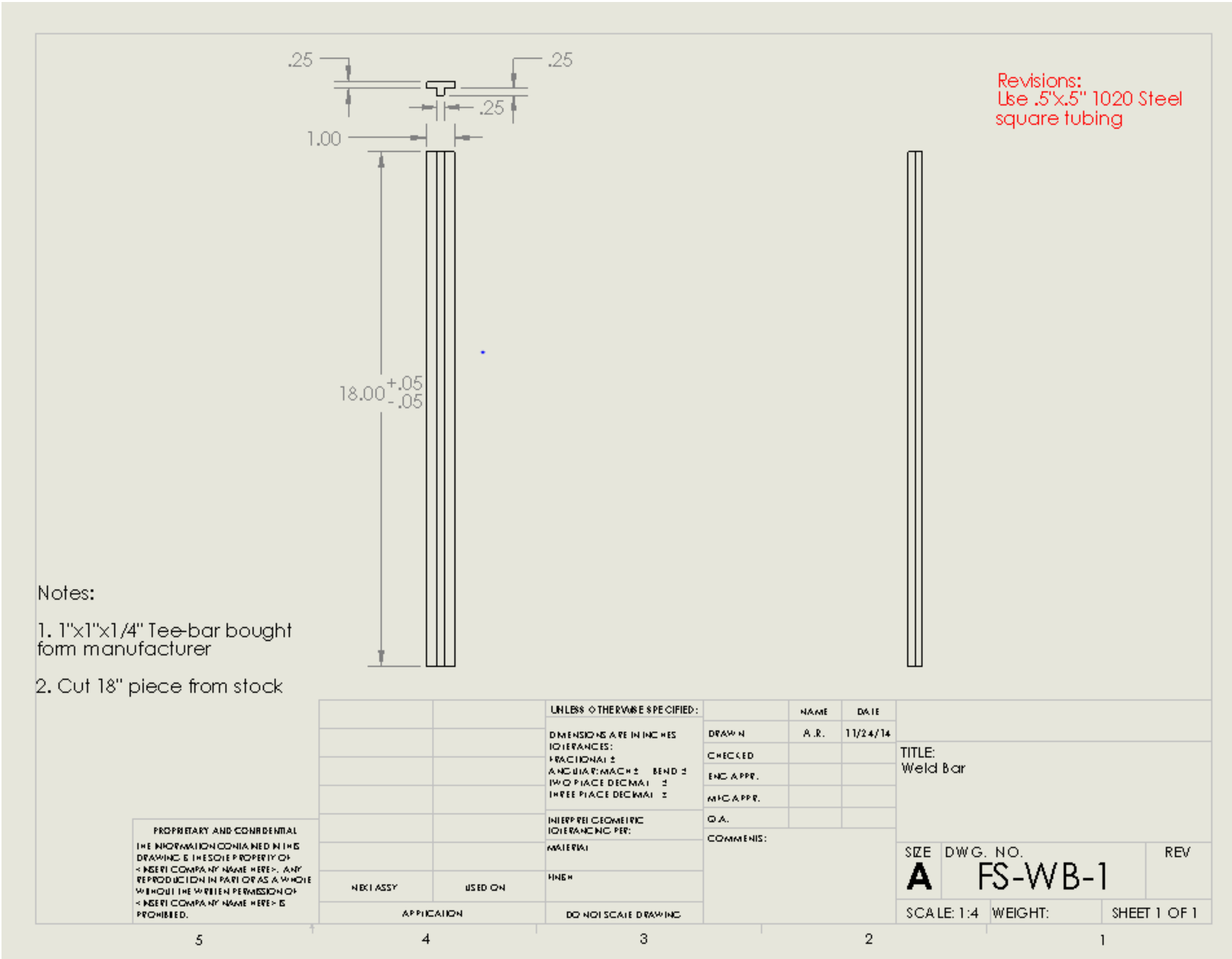

Revisions:
Shave down right side by .125"
to allow shock to fit.
.250 +.050 -.050
2.140 +.050 -.050
1.500 +.050 -.050
Ø.250 +.010 -.000
1.000
A
B
UNLESS OTHERWISE SPECIFIED:
DRAWN
A. Romine
TITLE:
EV Suspension Bracket
Bracket
SIZE
A
DWG. NO.
FS-B-1
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
APPLICATION
DO NOT SCALE DRAWING

Figure 19 B-3



.25
.25
.25
1.00
18.00 +.05 -.05
Revisions:
Use .5"x.5" 1020 Steel
square tubing
Notes:
1. 1"x1"x1/4" Tee-bar bought form manufacturer
2. Cut 18" piece from stock
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
A.R.
11/24/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Weld Bar
SIZE
A
DWG. NO.
FS-WB-1
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

Figure 20 B-4

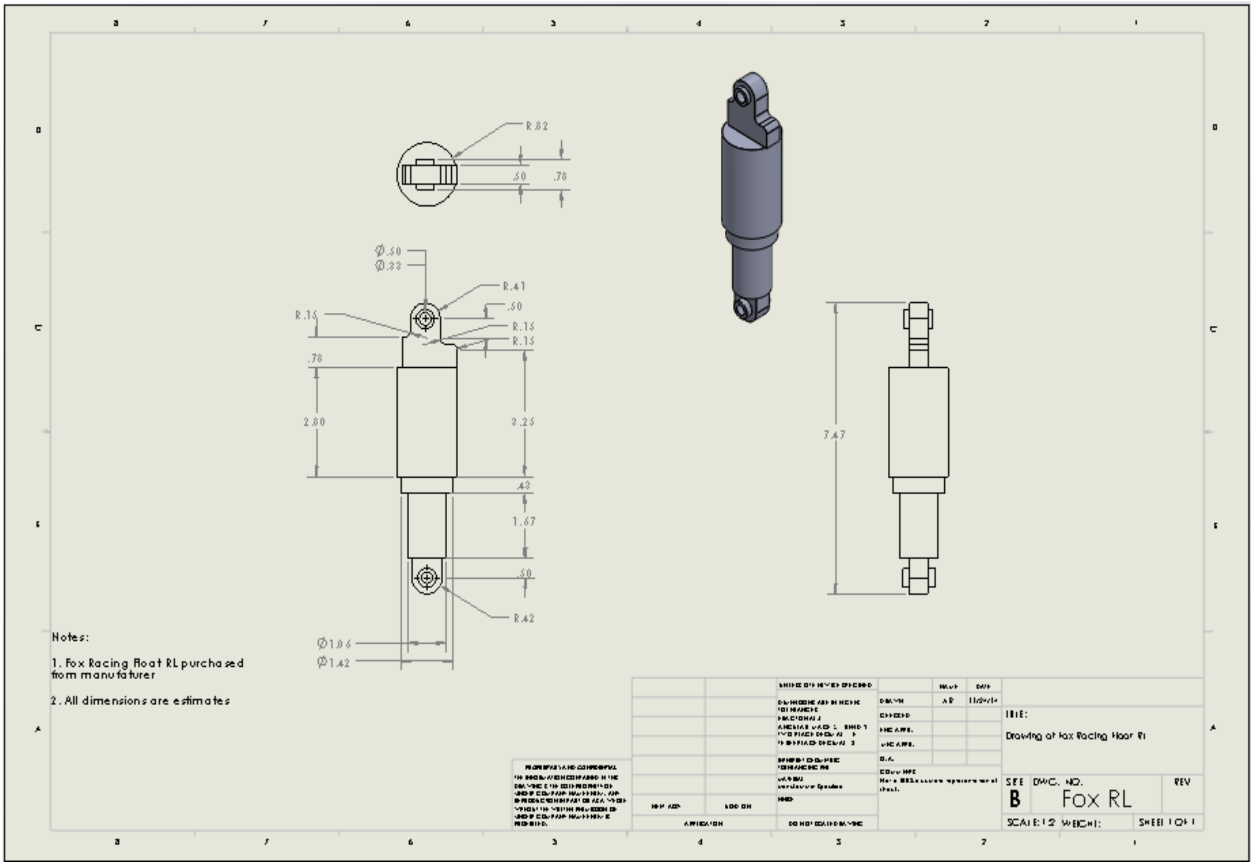

R.82
.50
.78
Ø.50
Ø.33
R.41
R.15
.50
R.15
R.15
.78
2.80
3.25
7.47
.43
1.67
.50
R.42
Ø1.06
Ø1.42
Notes:
1. Fox Racing Float RL purchased from manufaturer
2. All dimensions are estimates
DWG. NO.
Fox RL
SIZE
B
REV
WEIGHT:

Figure 21 B-5

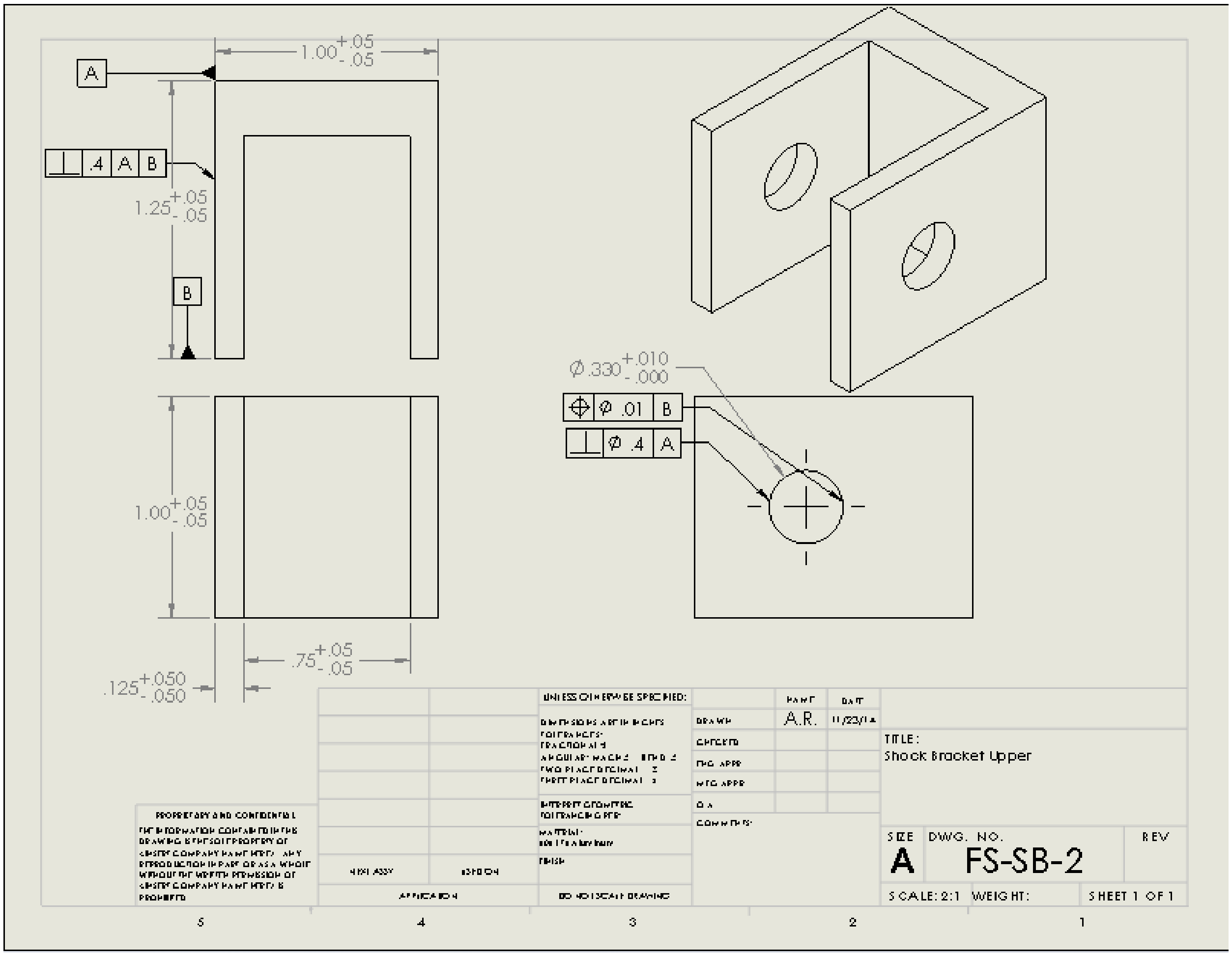

1.00 +.05 -.05
A
.4 A B
1.25 +.05 -.05
B
1.00 +.05 -.05
.75 +.05 -.05
.125 +.050 -.050
Ø.330 +.010 -.000
Ø .01 B
Ø .4 A
UNLESS OTHERWISE SPECIFIED:
DRAWN
A.R.
TITLE:
Shock Bracket Upper
SIZE
A
DWG. NO.
FS-SB-2
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
DO NOT SCALE DRAWING

Figure 22 B-6

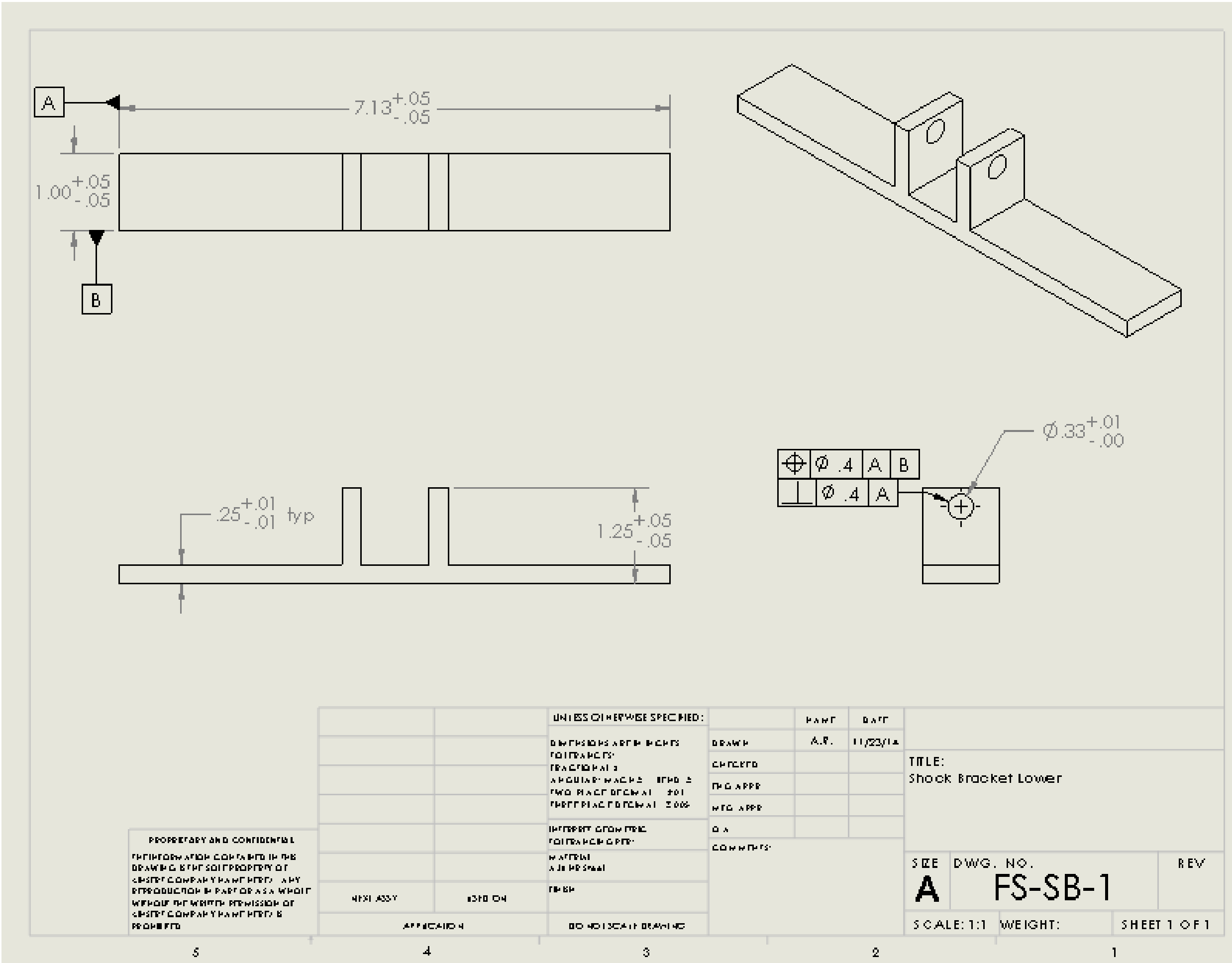
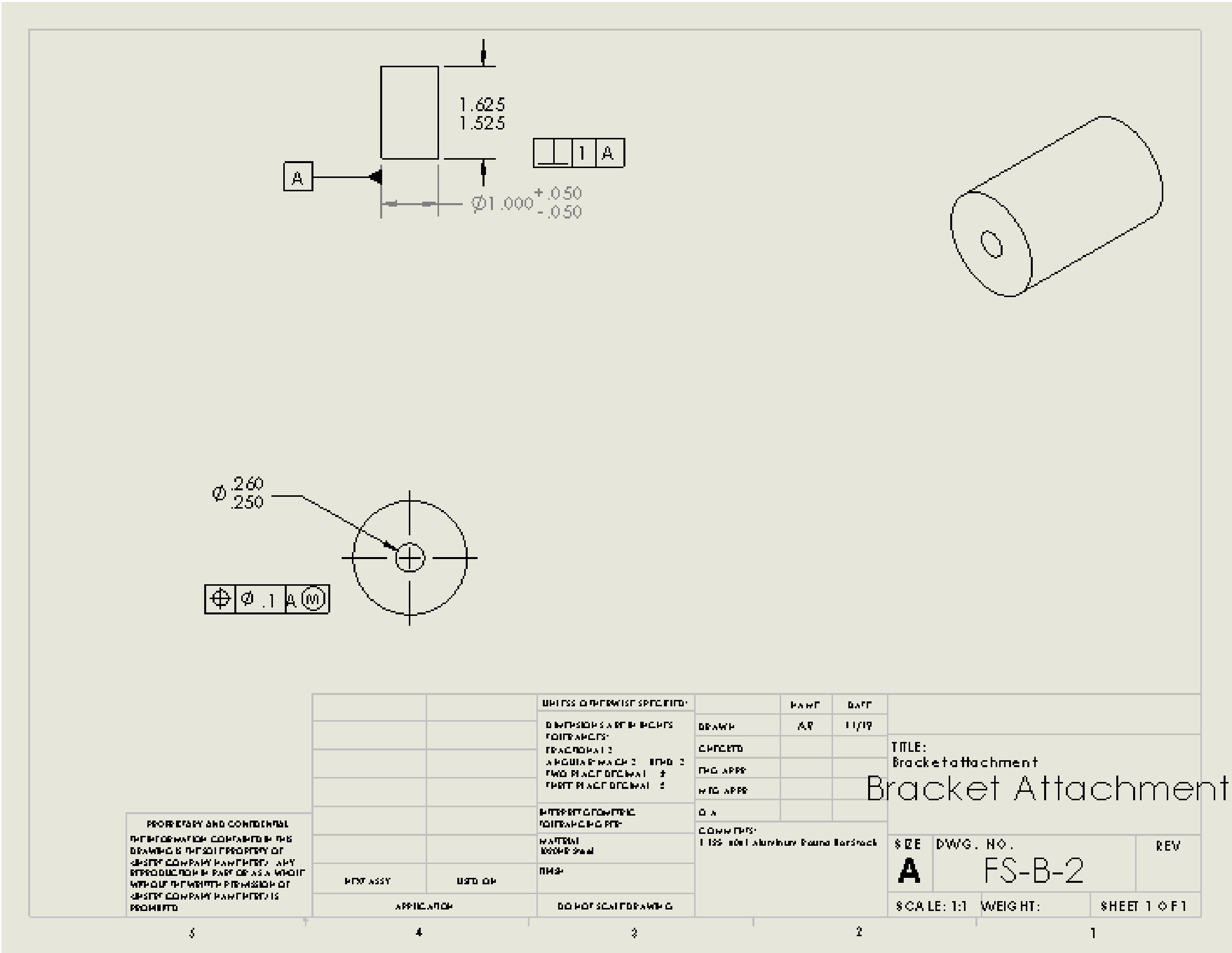

7.13 +.05 -.05
1.00 +.05 -.05
A
B
.25 +.01 -.01 typ
1.25 +.05 -.05
Ø.33 +.01 -.00
Ø .4 A B
Ø .4 A
UNLESS OTHERWISE SPECIFIED:
DRAWN
A.R.
11/23/14
TITLE:
Shock Bracket Lower
SIZE
A
DWG. NO.
FS-SB-1
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

Figure 23 B-7


1.625
1.525
A
Ø1.000 +.050 -.050
Ø.260 .250
TITLE:
Bracket attachment
Bracket Attachment
SIZE
A
DWG. NO.
FS-B-2
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
APPLICATION
DO NOT SCALE DRAWING
Figure 24 B-8

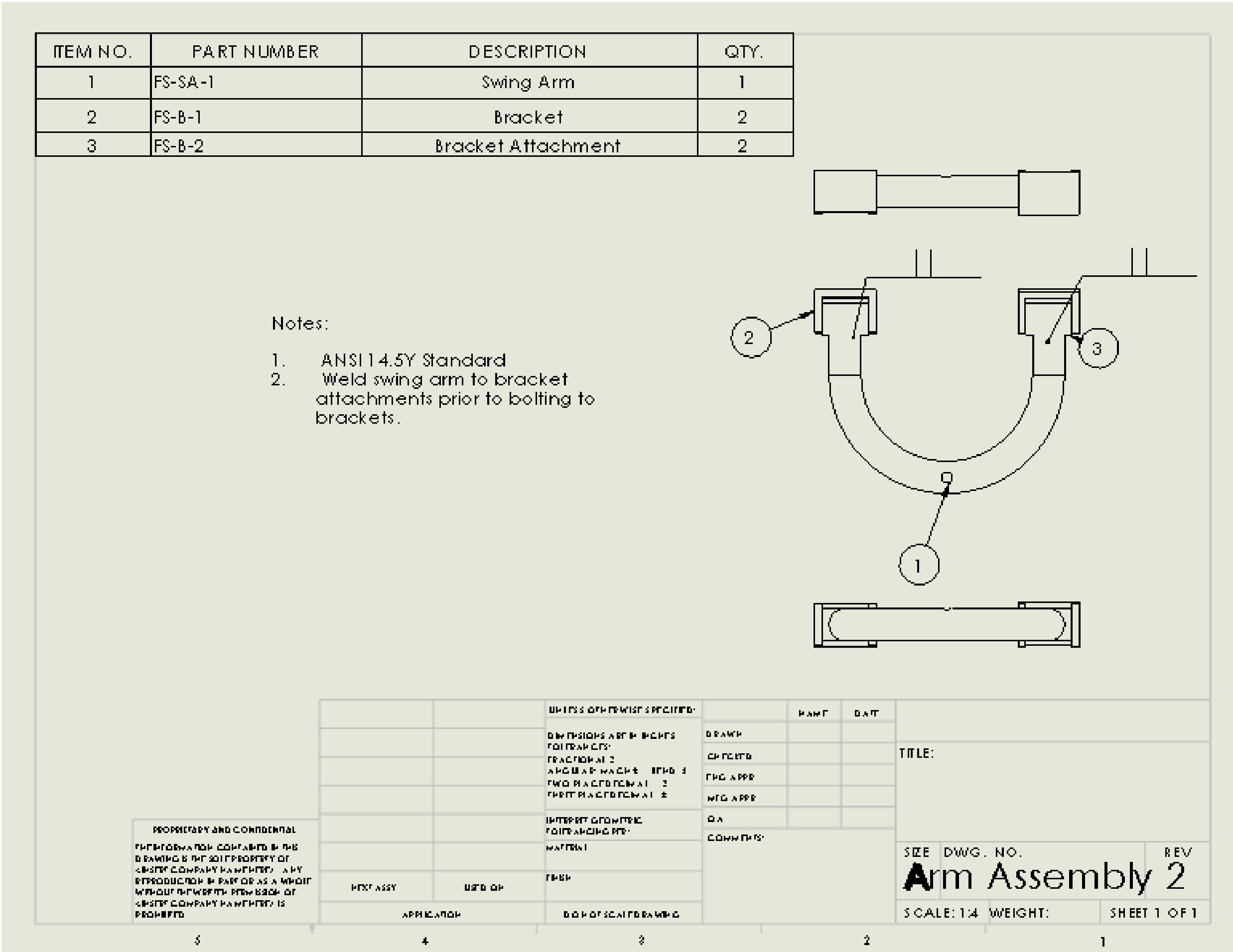

ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
1 | FS-SA-1 | Swing Arm | 1
2 | FS-B-1 | Bracket | 2
3 | FS-B-2 | Bracket Attachment | 2
Notes:
1. ANSI 14.5Y Standard
2. Weld swing arm to bracket attachments prior to bolting to brackets.
1
2
3
TITLE:
SIZE DWG. NO. REV
Arm Assembly 2
SCALE: 1:4 WEIGHT: SHEET 1 OF 1

Figure 25 B-9

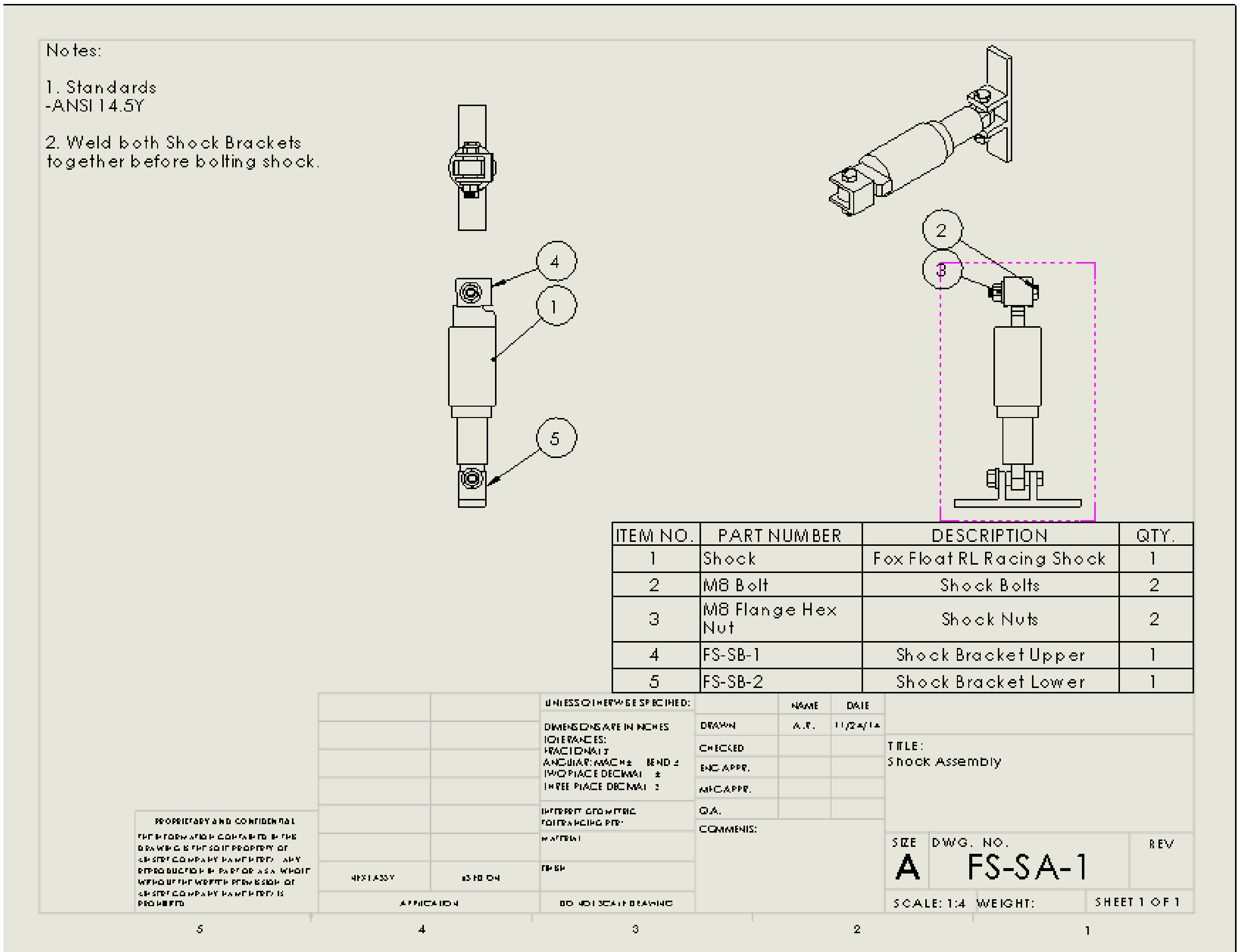


Figure 26 B-10

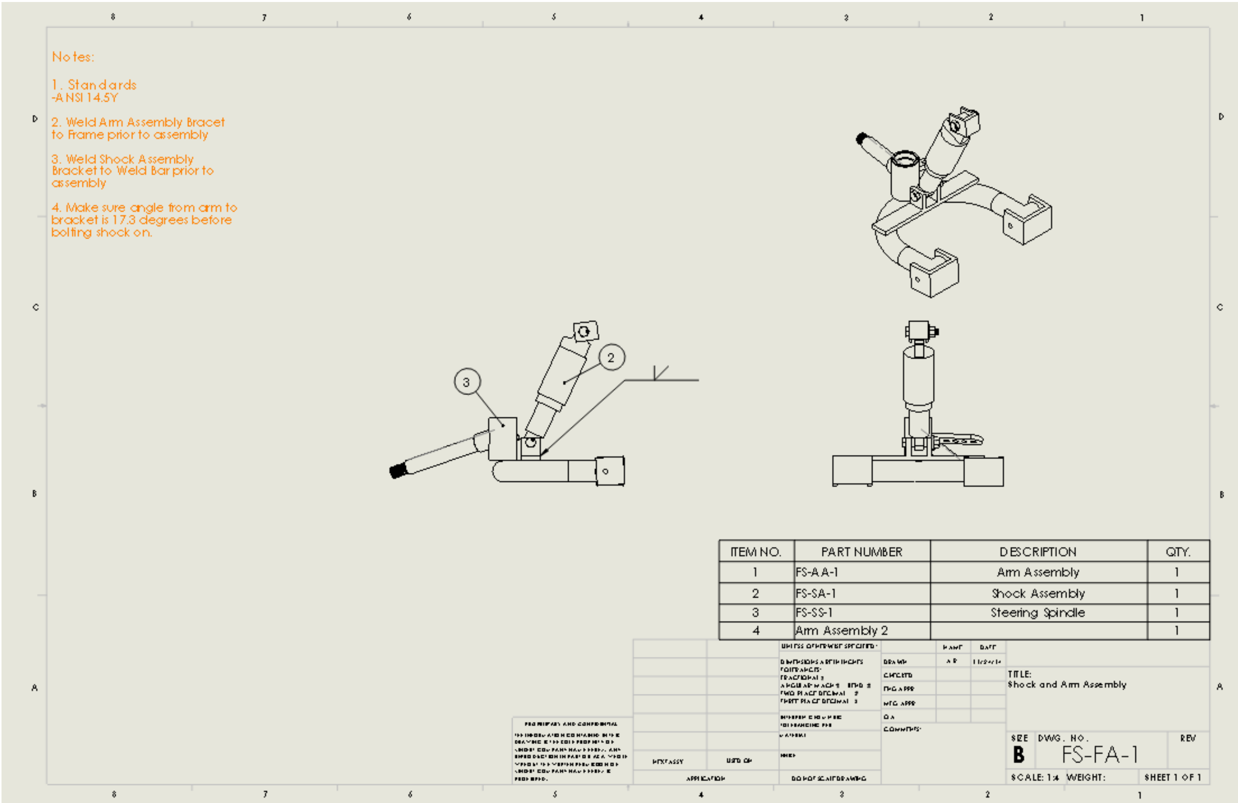


Figure 27 B-11

Appendix C Parts List and Drawing Tree

		Front Suspension Parts List			
Item Number	Part Number	Description	Quantity	Weight per part (lbs.)	Total Weight
1	FS-SA-1	Swing Arm	2	1.12	2.24
2	FS-B-1	Arm Bracket	2	0.96	1.92
3	FS-B-2	Arm Bracket Attachment`	2	0.55	1.1
4	FS-SB-1	Upper Shock Bracket	2	0.14	0.28
5	FS-SB-2	Lower Shock Bracket	2	0.45	0.9
6	Shock	Fox Float RL Racing Shock	2	0.9	1.8
7	M8 Bolt	M8-40mm 1.25mm Pitch Bolt	4	0.04	0.16
8	M8 Flange Hex Nut	M8 1.25mm Pitch Hex Nut	4	0.02	0.08
9	1/4"x20 UNC Bolt	1/4"x20 UNC Bolt 6in Long	2	0.04	0.08
10	1/4"x20 Flange Hex Nut	1/4"x20 Flange Hex Nut	2	0.02	0.04
11	FS-WB-1	Weld Bar	2	0.55	1.1
Total			26		9.7

Figure 28Parts List

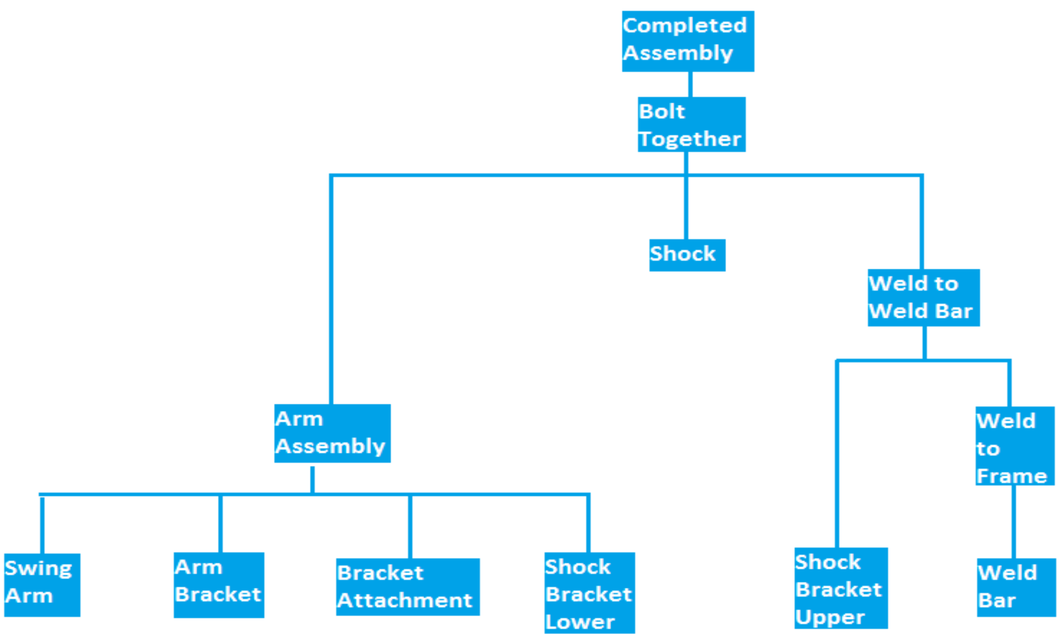


Figure 29 Drawing Tree

Appendix D Budget

Item ID	Item Description	Item Source	Material	Price (US Dollars)	Quantity (# or hours)	Cost Subtotal	Actual Cost
FS-SA-1	Swing Arm	Online Metals	1.125" A36 Steel	$10.90/ft	2ft	$21.80	$45.66
FS-B-1	Arm Bracket	Online Metals	.25"x1.5" 1020 HR Steel Flat Bar	$4.17/ft	2ft	$8.34	$15.22
FS-B-2	Bracket Attachment	Online Metals	.25"x1.5" 1020 HR	$10.90/ft	1ft	$10.90	$7.61
M8 Bolt	Shock Bolts	McMaster Carr	M8-40mm 1.25mm pitch Metric High Strength Steel Class 10.9	$8.48/pack	1 Pack	$8.48	$6.79
M8 Flange Hex Nut	Shock Nuts	McMaster Carr	M8 1.25mm pitch Black Oxide Case Hardend Steel	$2.54/each	4 nuts	$10.16	$4.56
FS-SB-1	Shock Bracket Upper	Online Metals	.25"x1.5" 1020 HR	$3.22/ft	1ft	$3.22	$7.61
FS-SB-2	Shock Bracket Lower	Online Metals	.25"x1.5" 1020 HR	$3.22/ft	2ft	$6.44	$15.22
Shock*	Fox Float RL	Fox Racing		$300/shock	2 shocks	$600	Donated
1/4"x20 UNC	Bracket Screw	McMaster Carr	High Strength Steel Grade 8	$8.29/pack	1 Pack	$8.29	$5.67
1/4"x20 Flange Hex Nut	Bracket Nut	McMaster Carr	Black Oxide Case Hardened Steel	$1.93/each	2 nuts	$3.86	$2.37
FS-Weld	Welding Cost	CWU Foundry	Time		10 hours	$0	0
FS-Machine	Maching Cost	CWU Machine Shop	Time		20 hours	$0	$0.00
FS-WB-1	Weld Bar	Orange Aluminum	6061 T6 Aluminum Tee-Bar	$17.98/8ft	1 8ft section	$18	$12.56
					Total	699.49	$123.27

*Float RL Shocks have been already purchased by the Electric Vehicle Club the price listed is the current value of the shock it does not represent the value that it was actually purchased for.

Figure 30 Budget

Appendix E Schedule

Note: March 16-19 Finals
Note: June 11 Presentation
Note: June 8-11Spr Finals

Electric Vehicle Front Suspension
Principal Investigator: Adam Romine

November | Dec | January | February | March | April | May | June

TASK: ID	Description	Duration Est. (hrs)	Actual (hrs)
1	Proposal*		
1a	Outline	1.0	1.8
1b	Intro	3.0	5.6
1c	Methods	3.0	8.2
1d	Analysis	8.0	7.4
1e	Discussion	4.0	2.0
1f	Parts and Budget	1.0	3.2
1g	Drawings	8.0	11.9
1h	Schedule	1.0	3.0
	subtotal:	29.0	43.1
2	Analyses		
2a	Static Forces	1.0	2.1
2b	Shear in Brackets/Bolts	2.0	3.0
2c	Turning Diameter	2.0	1.1
2d	Maximum Cornering Force	2.0	2.4
2e	Bending in Swing Arr	1.0	1.1
2f	Bending in Weld Bar	1.0	0.8
	subtotal:	9.0	10.5
3	Drawings		
3a	Swing Arm	1.0	2.8
3b	Shock bracket Lowe	1.0	0.5
3c	Shock Bracker Upper	1.0	0.5
3d	Arm Bracket	1.0	1.5
3e	Arm Bracket Attachment	1.0	1.0
3f	Weld Bar	1.0	1.0
3g	Arm Assembly	1.0	1.0
3h	Frame and suspension Assembly	2.0	3.0
	subtotal:	9.0	11.3
4	Proposal Mods		
4a	Schedule	1.0	2.0
4b	Part List	1.0	1.2
4c	Review	20.0	7.3
4d	Propose w/ Movie	3.0	4.6
	subtotal:	25.0	15.1

7	Part Construction		
7a	Buy Materials	3.0	2.1
7b	Cut and bend Swing Arm material	2.0	3.6
7c	Drill 3/8" Hole Into Arm	1.0	1.0
7d	Mill Out End Radius Swing Arm	2.0	1.8
7e	Cut sheet metal for Shock Brackets	2.0	1.3
7f	Drill Holes Into Shock Brackets	1.0	0.5
7g	Cut sheet metal for Arm Brackets	2.0	2.3
7h	Drill Hole Into Swing Arm Brakets	1.0	0.5
7i	Manufacture Plan*	3.0	2.4
	subtotal:	17.0	15.5
9	Device Construct		
9a	Construct Welding Jig for task 9b	1.0	0.8
9b	Weld Arm to Arm Bracket Attachment	2.0	0.5
9c	Construc jig for task 9d	1.0	0.5
9d	Weld Weld Bar to Frame	1.0	0.2
9e	Construct welding jig for task 9f	1.0	0.8
9f	Weld Arm Bracket to Frame	2.0	0.5
9g	Make welding jig for task 9h	1.0	0.2
9h	Weld Upper Shock Bracket to Weld Bar	1.0	0.3
9i	Weld Lower Shock Bracket to Swing Arm	1.0	0.4
9j	Attach Shock to Upper and Lower Shock Brackets	1.0	0.2
9k	Attach Swing Arm to Swing Arm Bracket	1.0	0.1
9l	Update Website	2.0	2.4

10	Device Evaluation			
10a	List Parameters	1.0	0.7	
10b	Design Testing Shee	3.0	0.6	
10c	Set Up Test Track	1.0	1.1	
10d	Plan analyses	3.0	2.6	
10e	Perform Test	2.0	3.4	
10f	Perform Evaluation	5.0	2.5	
10g	Take Testing Pics	1.0	0.2	
10h	Update Website	2.0	1.2	
	subtotal:	18.0	12.3	
11	495 Deliverables			
11a	Get Report Guide	1.0	1.3	
11b	Make Rep Outline	1.0	0.9	
11c	Write Report	15.0	11.5	
11d	Make Slide Outline	4.0	2.6	
11e	Create Presentation	5.0	3.1	
11f	Make CD Deliv. List	2.0	1.6	
11e	Write 495 CD parts	2.0	1.2	
11f	Update Website	2.0	2.4	
11g	Project CD*	1.0	0.5	
	subtotal:	33.0	25.1	
	Total Est. Hours=	154	135.3	=Total Actual Hrs
Labor$	100	15400		
Note:	Deliverables*			
	Draft Proposal			
	Analyses Mod			
	Document Mods			
	Final Proposal			
	Part Construction			
	Device Construct			
	Device Evaluation			

Appendix F Testing Evaluation

	Date: 4/28/2015	Test: Shock Travel Test
	Project: EV Front Suspension	Adam Romine
	PSI	Average Inches of Travel
	105	1.75
	110	1.75
	115	1.1
	120	0.753
	125	0.592
	130	0.515
	135	0.451
	140	0.413

Figure 31Shock Test Results

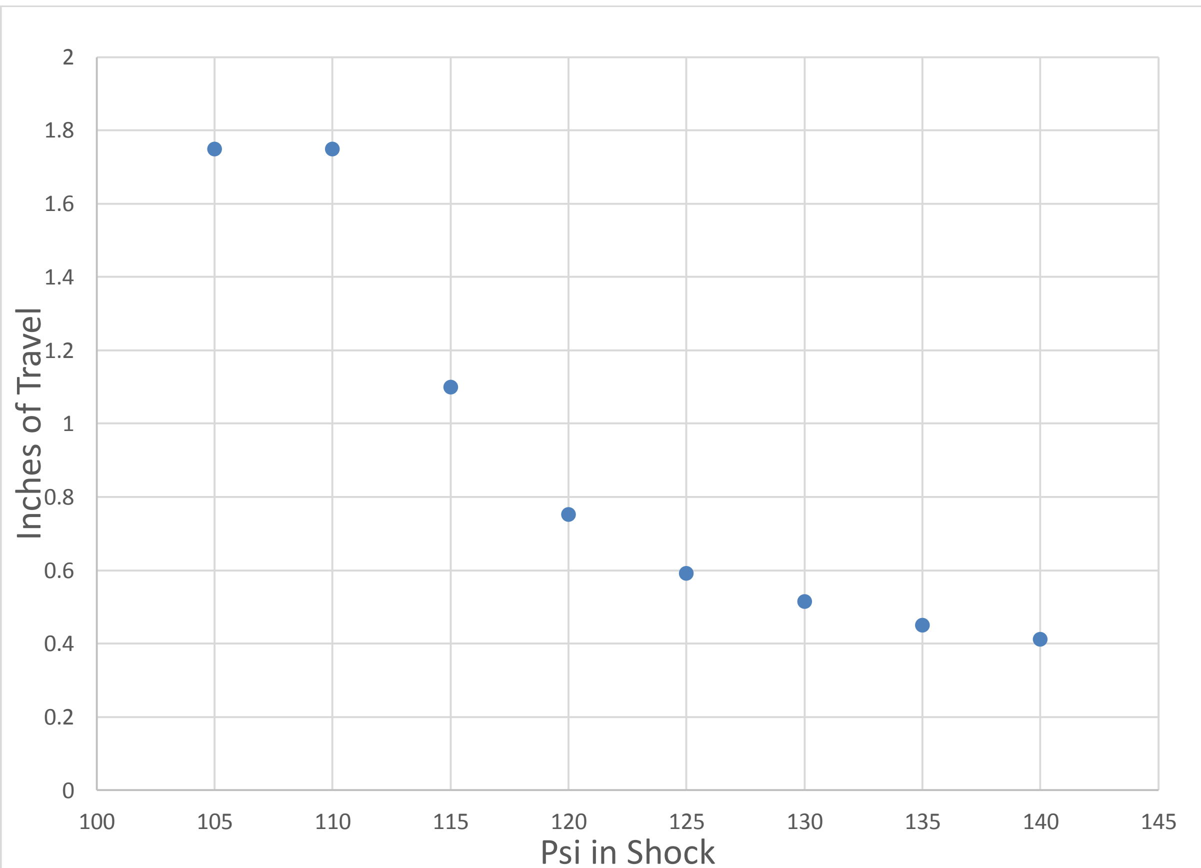


Figure 32Shock Test Results Graph

Weight Left Side	Weight of Right Side
12.31lbs	12.29lbs

Figure 33Weight Test Results

Angle of Right	Angle of Left	Diameter of turn
23 degrees	23.1 degrees	30.62 ft.

Figure 34Turning Angle Test Results

Appendix G Resume

Adam Romine

2104 N. Yellowstone Unit A., Ellensburg, WA 98926, (206) 450-0156, rominea@cwu.edu

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Objective: My objective is to find a position in the mechanical engineering field, and to be able to keep developing my skills and have the ability for promotion.

Work Experience:

RIVER RAFTING GUIDE June 2014- present
Wildwater River Guides Throughout WA State

- Be a leader in the raft. Instructing the others in the raft on what to do to in order to make the raft go where it is needed to go within the river.
- Be outgoing and personable. Make connections with new people inside the raft in order to ensure that everyone is having a good time and to develop return customers.
- Be able to deal with pressure. Coping with high pressure situations when unforeseeable incidents happen on the river and making sure that everyone is safe.

FARM HAND September 2011- present
River Bottom Sheep Farm Ellensburg, WA

- Feed, water and attend to the general health of the farm's sheep.
- Perform regular maintenance on fence lines, feeder and water boxes, irrigation canal, sheds and other structures around the farm as well as the sprinkler system's pumps, tubes, valves and sprinkler heads.

MOTOR POOL ASSISTANT June 2013- September 2013
Central Washington University Ellensburg, WA

- Washed, fueled, and checked fluid levels of cars in the University motor pool.
- Stuck to a schedule to make sure that the right cars were going out when they were needed.

LAB TECHNICIAN ASSISTANT (Biology Lab) February 2009-June 2011

South Seattle Community College Seattle, WA

- Helped set up and break down biology labs and sanitized lab equipment for the next use.

Education:

Diploma Evergreen High School Seattle, WA
9/2007-6/2011
Running Start South Seattle Community College Seattle, WA
9/2009-6/2011
University Central Washington University Ellensburg, WA
9/2011-present

- Anticipate completing my BS, Mechanical Engineering Technology in June 2015.

Skills:

Computer Skills: Proficient with Microsoft Office, Auto CAD, Master CAM, CSWA certified in Solid Works.

College Activities: I am active in Central Washington University's American Society of Mechanical Engineers club (ASME), as well as the CWU Wakeboard Team where I competed in the Regional Collegiate Wakeboard Competition in Boise, ID in 2013.