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Suspension for Electrathon Vehicle

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Table of Contents

1) Introduction

A) Motivation

The motivation for this project is the suspension for the Central Washington University Electric Vehicle Club's Electrathon Electric Vehicle (EV). In a previous project, the front suspension utilizes lower control arms tied to the vehicle frame by motorcycle air-shocks. The rear of the frame, which is only partially assembled, has solid mounting points tying the electric motor used to drive the rear wheel to the frame. This current design does not allow for any suspension travel, so the rear must be redesigned to accommodate travel for performance. By allowing for suspension travel, there is less vibration and less wear on solid mounted components.

B) Function Statement

A device is needed to suspend the rear of an electric vehicle frame.

C) Requirements

A device is required that:

- allow 3 inches of travel at the axle relative to the ground
- costs less than $1000 to manufacture
- keep the occupant of the vehicle safe in the event of failure
- must conform to Electrathon America guidelines
- with regards to performance, must keep the vehicle upright with no more than 5-degrees of tilt while cornering at 20 mph in a 40-foot radius

D) Engineering Merit

Several engineering concepts are in play for this project. Static equations, dynamic equations, geometry, and trigonometry are paramount to a successful suspension design. To highlight, the spring equation (Force = Spring rate * Displacement) allows for design of the dampening member. Trigonometry plays a vital role, in that it is necessary for determining the correct lengths of members and angles relative to the vehicle frame while the system is both at rest and in travel (this includes the laws of Cosines, Sines, and Tangents).

E) Scope of Effort

As previously stated, this project will only focus on the rear suspension of the electric vehicle.

F) Success Criteria

The success of this project is dependent on the final amount of suspension travel allowed in testing and the ability to support the vehicle without bottoming out. Additionally, safety is paramount. If the system should fail, the weakest point is calculated to be that of the coilover shock. If the shock should fail, the rest of the system should remain intact allowing the vehicle to be driven safely to a stop. If the electric vehicle is completed and assembled prior to the completion of this project, on-road testing would be successful if the suspension kept the vehicle upright with no more than 5-degrees of tilt while cornering at 20 mph in a 40-foot radius.

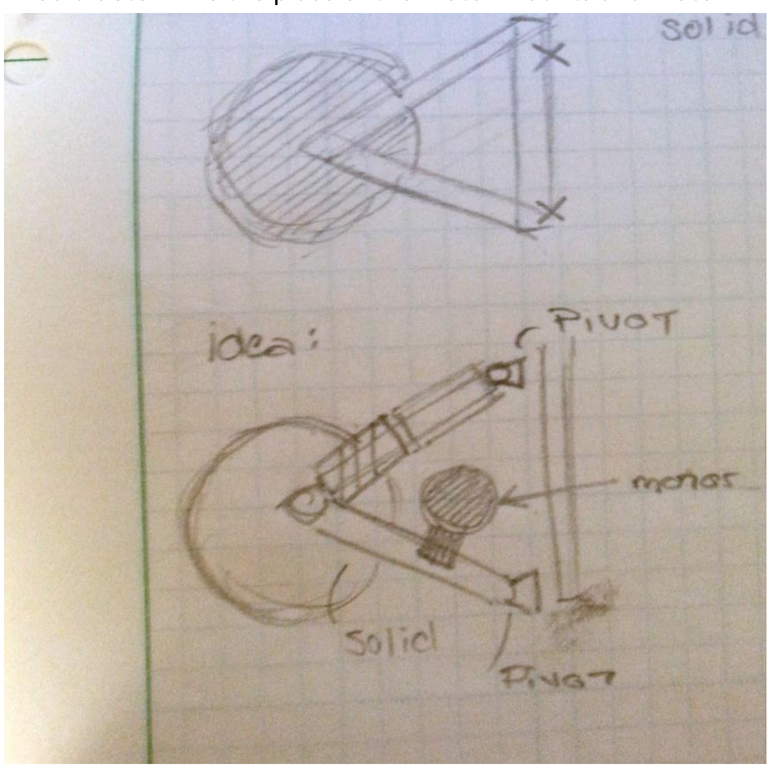
2) Design and Analysis

A) Approach: Proposed Solution

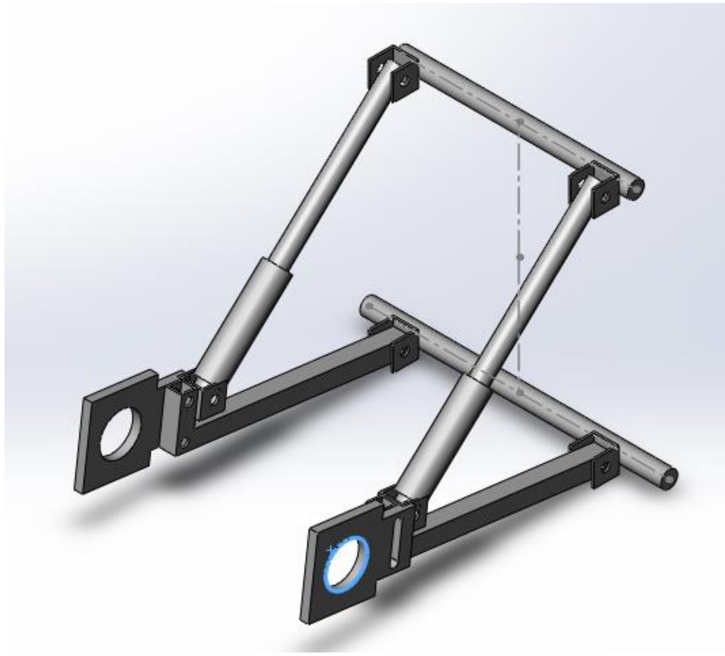
The basic design was based on the existing frame that had been previously built for the vehicle. The electric motor was suspended to a subframe that mounted solidly to the vehicle frame. In the interest of performance and durability, a proper suspension was needed to suspend the motor and support the weight of the frame and driver. An automotive-type coilover shock attached to a lower beam which holds the motor and axle tied to the frame of the vehicle should allow for the necessary suspension travel.

B) Design Description

In the sketch shown above, the basic shape of the system is shown. The lower beams connect to the frame, motor, and dampening unit. This design iteration features a triangulated three-member system, with each member at an almost-equal length in the sprung (half-way loaded) position. The axle mounts, which are pre-made, need to have extra space for mounting at the rear. Additionally, a preexisting chain to connect the motor and axle could be used if necessary. The chain length would determine the place of the motor mounts and motor.



A second design iteration, featuring a fully contained one-piece EMPI coilover and a welded lower control arm was chosen to allow for a greater distance of travel and for practicality in availability of parts. Outsourcing the brackets and dampening units will also save in labor costs.



C) Benchmark

An application of similar layout is in three-wheeled motorcycles, much like the Can-Am Spyder vehicle (produced 2007-current) The rear of the Spyder uses a swing-arm-type suspension with a 145-mm shock. Due to design differences, the engine of such a vehicle is typically mounted underneath the driver. In the electric vehicle project, the layout is similar to a recumbent bicycle, with the driver in a laid-back position instead of upright. However, since the electric motor is to be suspended at the rear of the vehicle, there must be accommodations for the weight of the engine and driver. Additionally, since the vehicle is not completely designed and assembled, there must be assumptions made about the final weight of the vehicle.

D) Performance Predictions

Under these design calculations, the predicted performance is sustaining a load of approximately 300 lb (driver and vehicle) with the spring and shock compressed half-way allowing for a travel of 1.5 inches in either direction. If on-road testing is available, the suspension must keep the vehicle upright with no more than 5-degrees of tilt while cornering at 20 mph in a 40-foot radius.

After design revisions, the updated performance expectations are failure of a shock load of 700 lb to one given coilover. Anticipated vertical distance travelled at the center of the axle is calculated as 6.89 inches from full compression to full extension of the coilover unit.

In testing, the system was predicted to have 6.89 inches of travel at the axle, and a deflection of 1 inch left-to-right.

E) Description of Analyses

The initial design was based on the following:

Making assumptions about the weight of the electric vehicle as a system at 300 lbs and setting arbitrary stationary lengths of 14 inches for each member allowed analysis to be performed.

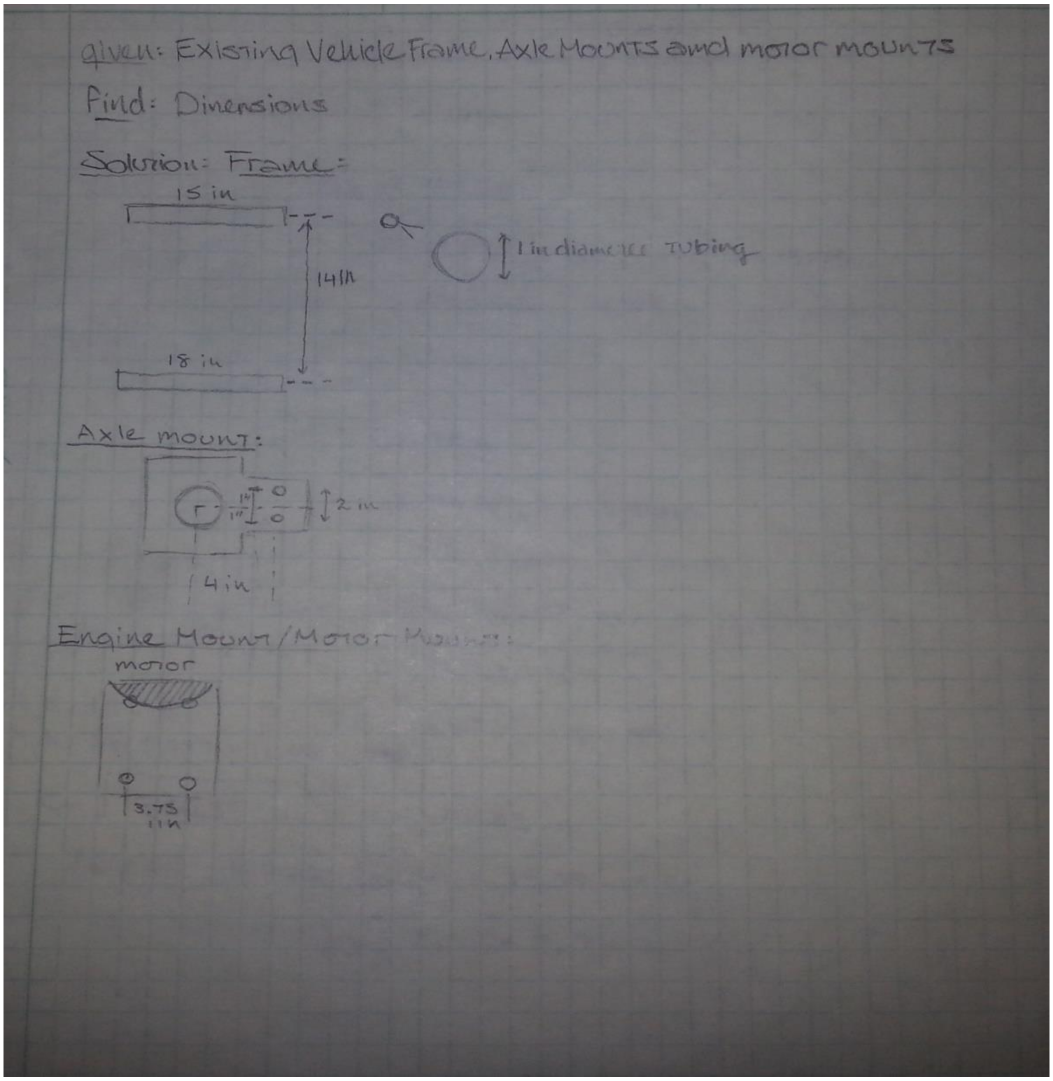
Using basic geometry, the angle of the lower beam relative to the extended line of the vehicle frame was found – ideally varying from roughly 18 degrees to 43 degrees as it travels through its cycle of compression and extension. This will allow the driving engine to travel 1.5 inches in each direction from its neutral position (assuming the neutral position is with the spring half compressed). Knowing this, the length of the dampening unit needed to travel a minimum of 5.35 inches in order to accommodate the full compression of the spring.

Ideally, an exact dampening unit might be manufactured for this system. However, due to manufacturing costs, an aftermarket automotive "coilover" type shock assembly might be a suitable choice for both reliability and availability.

Using the spring equation, force = spring constant * displacement, it was determined that the spring constant was approximately 56 lb/inch. This is an "ideal" spring rate. Understandably, an automotive unit might be designed to accommodate a much larger sprung load. So, using a coilover spring with an adjustable perch would benefit the system in the scenario where the final weight of the vehicle is lighter/heavier than planned.

Design revisions were performed after finding a suitable pre-manufactured coilover shock. EMPI, an aftermarket Volkswagen parts manufacturer, produces a coilover shock for use on Dune-Buggy-type vehicles that fit the initial design figures after adjustments were made.

As demonstrated in the drawing below, the existing dimensions of components that were already manufactured played a large role in analysis and design. The existing frame, with the 14 inch bar spacing dictated the length of the lower control arm. This allows the control arm to operate in a coordinating semi-circle pattern.



With the goal of 3 inches of axle travel, a model was developed in Solidworks, a shock unit had to be found that would allow for adequate compression and extension – which results in the travel of the axle.

Stress calculations using various shapes of material and the failure load of the shock were performed in order to ensure that, under failure, the coilover will remain attached to the control arm and frame to allow for safety of the driver. Appendix A contains several cross sectional calculations to show stress in the lower control arm as a result of shock failure.

Appendix A features a full set of analytical sheets. After building a Solidworks model and adjusting the assembly to function using the commercially sourced parts, the final measurements and calculations were performed. The design was primarily Solidworks-centric, since a true analysis could not be performed until commercially sourced parts were found and documented. Using the commercial measurements, the model was adjusted.

F) Scope of Testing and Evaluation

The suspension will be tested in real world conditions – once the assembly is built and attached to the frame, a load test can be performed by simulating the weight of a driver and applying force to the frame externally. Since the final design iteration will make use of automotive shocks, the anticipated amount of suspension travel should be larger than the initial design allowed. If the vehicle is completed further before the end of the manufacturing of this project, then a road test can be performed to determine its ability to control the vehicle while cornering at race-pace speeds.

G) Analyses

i) Design Issue

The first design issue encountered was the ensuring that the dampening member of the system and the solid member holding the electric motor would not contact while the suspension travelled through its full path. As mentioned above, trigonometric and geometric equations were performed to calculate the predicted path of travel. Once the angles and lengths were calculated, the approximate spring rate needed for the dampening member was calculated.

A second potential design issue was the construction material for the lower control arm. The dimensions should remain similar, but minor adjustments may need to be made to accommodate use of the material that is available.

Finally, the system was adjusted and checked for accommodation of premanufactured parts (the EMPI coilovers, brackets, axle mounts, etc.)

ii) Calculated Parameters

Included below (and featured further in Appendix A) are some sample figures of parameters that were calculated.

Length of Control Arm .... 14 inches

Compressed Length of Coilover .... 11.25 inches

Extended Length of Coilover .... 16.75 inches

Horizontal Distance Travelled at Center of Axle .... 2.92 inches

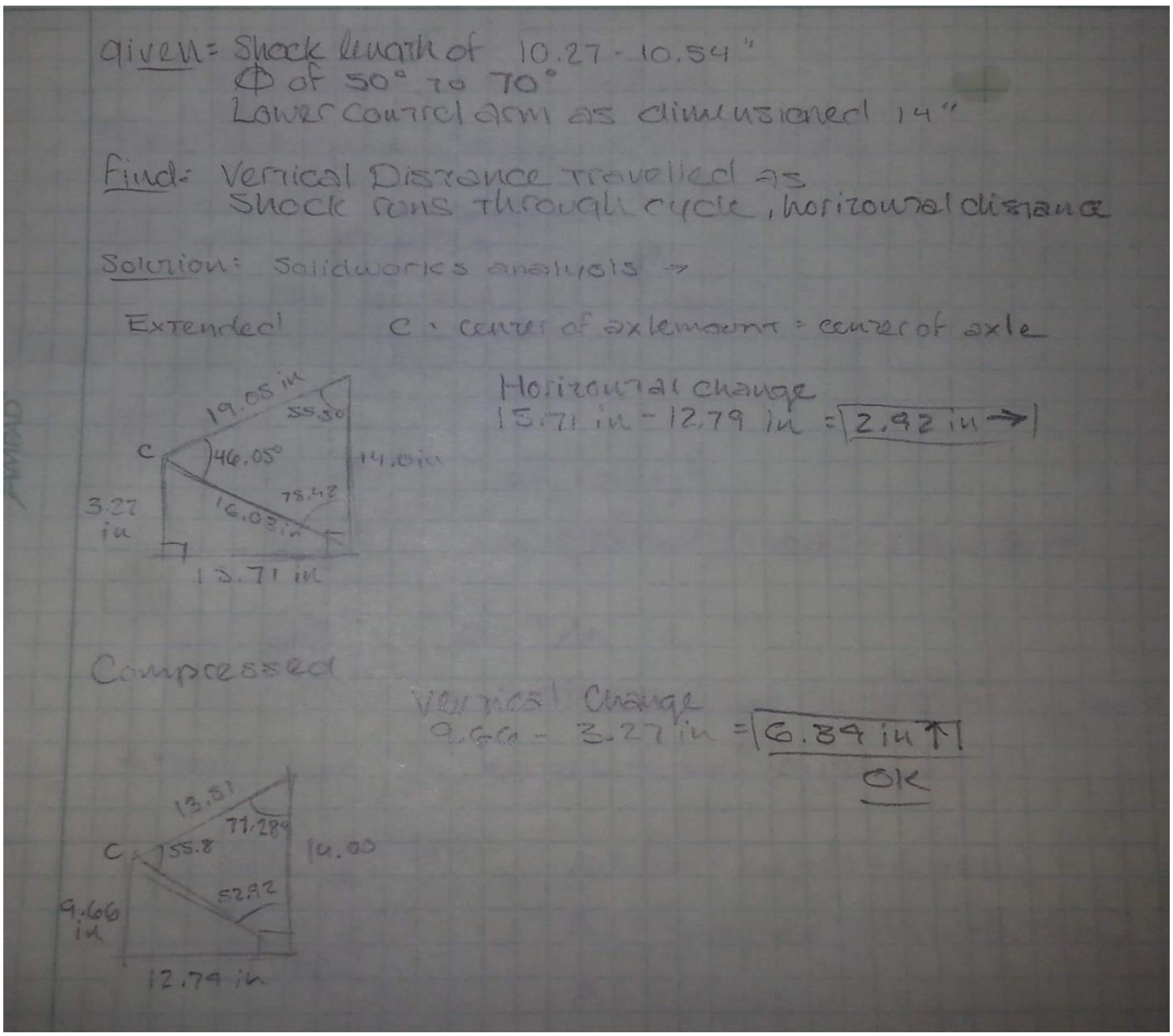
Vertical Distance Travelled at Center of Axle .... 6.89 inches

Failure Load of Shock .... 700 lb

The logic behind shear force applications, featured in Appendix A – 5, is explained below:

> Since safety is paramount, fastening hardware had to have a much higher capacity than the rest of the components. The fastening hardware supplied with the Summit Racing Coilover Brackets is, as specified by the manufacturer, grade 5. Using shear force application, the minimum yield strength for the bolt is 92000 psi. By comparison, the failure of the coilover shock would be at 700 lb. If the entirety of this failure load was applied in shear against the bolt, it would produce 3565 psi. By having a large factor of safety, the failure should not be completely destructive.

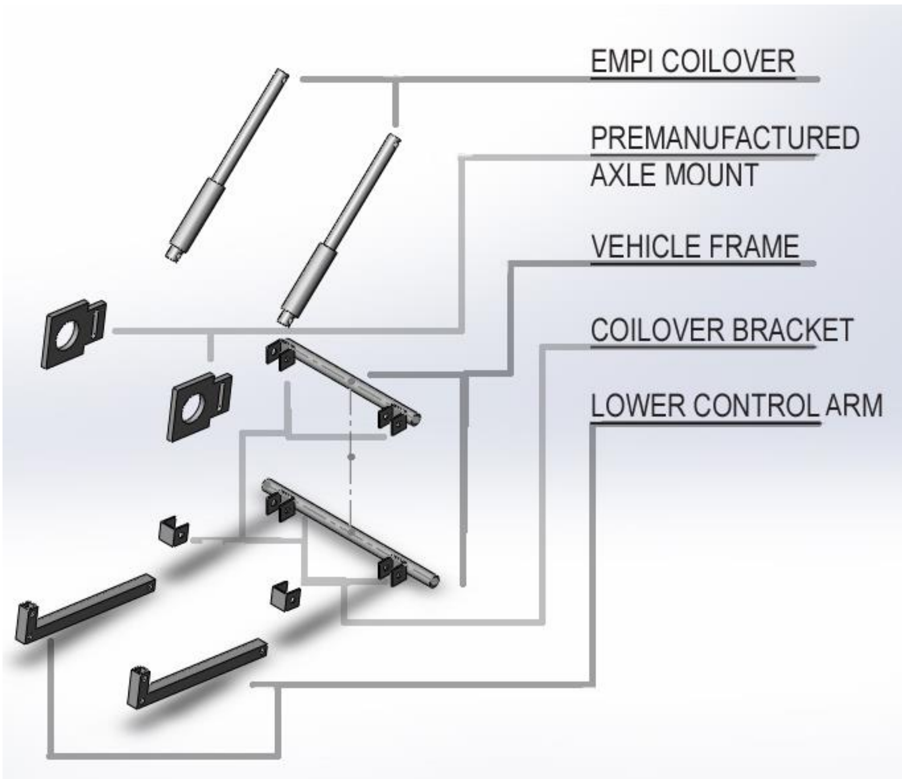
Final calculations regarding travel distances were performed using both Soldiworks modeling and hand calculations, shown here from Appendix A – 12:



iii) Best Practices

As this suspension system is designed for an electric vehicle, it is of the utmost importance that safety for the driver is ensured. First and foremost, the suspension will be designed with a large factor of safety in mind. This is especially important, as the rest of the vehicle is still a work-in-progress, which may lead to the final weight of the vehicle being less or more than what was designed for currently. Additionally, sources of components that are commercially available will lead to easy maintenance and repair, should the vehicle need it. By staying ahead of maintenance, and making the system easy to repair, anticipated failures can be accounted for and minimized.

H) Device: Parts, Shapes, and Conformation



Part 001 – Lower Control Arms

These are the lower control arms that tie the dampening member to the frame and allow for suspension travel, in addition to holding the provisions for mounting the electric engine and axle mounts. There are two lower control arms in this system that remain parallel throughout the range of motion. Construction of the control arms is square steel tubing that is cut to length, notched, and welded. Specific points will then be drilled to allow for connections to brackets.

Part 002 – EMPI Volkswagen Dune Buggy One-Piece Coilover

These are the dampening members in the suspension system. They are produced by an aftermarket parts manufacturer and are designed for use in a dune-buggy-type vehicle. They are self-contained (one piece) coilovers. There is an adjustable ring on the unit itself that allows for some adjustability to pre-load the spring.

Part 003 – Summit Racing Coilover Brackets (Chassis Tab)

These are the provisions for mounting all the points in the system. These points, in specific, are the connection points between the lower control arm and the lower beam of the frame, the connections points between the lower control arm and the coilover, and the connection points between the coilover and the upper beam of the frame. These brackets include the fastening hardware.

Part 004 – Premanufactured Axle Mounts

These mounts were previously created for a different suspension setup for the electric vehicle project.

Per Electrathon America rules, there are no particular guidelines for suspension, and creativity is encouraged. More important than creativity, however, is safety. As such, the design and assembly of parts was carefully performed.

I) Device Assembly and Attachments

Once the parts have been manufactured and the required dampening components are purchased, the assembly is fairly straight forward. The coilover brackets (chassis tabs), provided by Summit Racing), will be welded to six points – 2 on the upper rail of the existing frame, 2 on the lower rail of the existing frame, and 2 on the lower control arms near the pre-made axle mounts. If there are clearance issues between the axle mount and brackets, the mounts can be modified slightly to ensure there are no fitment issues. The coilover units from EMPI will be bolted to the connection points at the frame and at the lower control arms. Then, the lower control arms will be bolted to the frame connection points on the lower rail. All the fasteners required will be included with the coilover brackets, which also supply bushings to prevent premature failure due to friction.

J) Tolerances, Kinematics, and Ergonomics

Several predesigned limitations exist based on the geometry of the frame. The lower member must be long enough to accommodate the axle and motor mounts. The distance between the upper and lower rear bars of the vehicle frame are previously set. Outside of these restrictions, the system has very few limitations. Since the suspension system is designed to have two arms, both must be identical in order to ensure that the rear of the vehicle remains true to the front.

K) Technical Risk Analysis, Failure Mode Analysis, Safety Factors, and Operation Limits

The safety factor for this design was featured in the initial design calculations, with an anticipated safe load of 300 lbs. By choosing to use automotive coilovers, the factor of safety is regulated by the manufacturer (for the weight of a full-size vehicle). The limit, provided by EMPI, is a load of 700 lbs per shock.

Ideally, the point of failure should be the coilover unit itself if it experiences an excessive force (caused by an accident or less-than-ideal conditions). The lower control arm and all mounting hardware should remain intact in the event of coilover failure, ensuring that the structural integrity of the system remains until the unit is able to be driven to a stop.

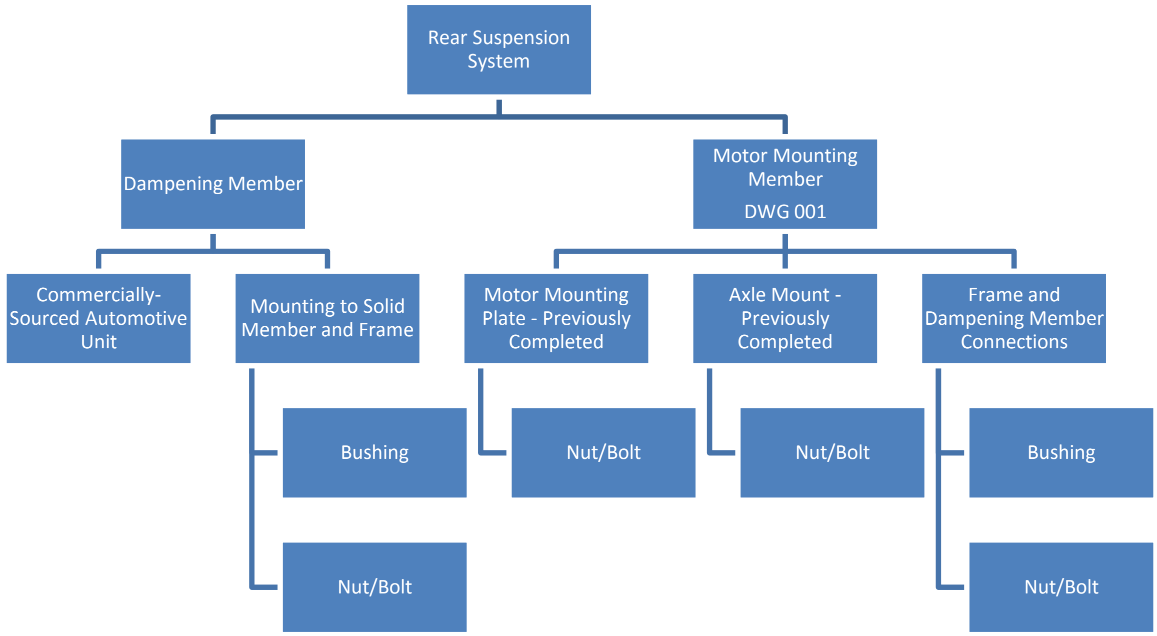
3) Methods and Construction

A) Description

This project is intended to aid the Electric Vehicle club in furthering the construction of the vehicle. Construction and assembly of the components will be a group effort shared by the members of the club. The frame will be made using material on hand in the machine lab, or donated/acquired from a metal supermarket. The dampening unit ("coilover") will be acquired from an automotive parts supplier, in the interest of minimizing cost. Bushings and bolts will be acquired from an automotive parts supplier or hardware store. By minimizing the number of custom-manufactured parts, the suspension will be easier to maintain/repair as time goes on.

The lower control arms will be manufactured off-site by Rod Helmuth of Squire's Machine and Fabrication. Choosing materials that exceed the minimum-strength requirements will ensure that later additions to the vehicle will not cause the system to fail. Once the lower control arms are manufactured, they can be affixed to the rear of the vehicle frame. The dampening system will be fixed to the frame using standard bolts and mounts, and can then be fixed to the lower control arms with bushings and bolts.

B) Drawing Tree and Drawing Identification



C) Parts List and Labels

2x Lower Control Arm (Motor Mounting Member) .... Drawing 001
1x Motor Mount .... Previously Completed
2x Axle Mount .... Previously Completed
6x Coilover Bracket (Mounting Provision)... Purchased
2x EMPI Coilover Unit .... Purchased

D) Manufacturing Issues

Potential manufacturing issues lie in the availability of the square tubing for the lower control arms. 1-in-square tubing may need to be purchased if extra materials from the machine lab are not available. Welding the lower control arm – an angled 45 degree joint – will need to be performed by an experienced welder in order to ensure a correct fit. Any failure in the welds could be a source of danger for an occupant once the vehicle is completed.

Additional manufacturing issues presented themselves as construction progressed, such as the tendency of the system to sway left and right as noted during testing. The solution, in this case, was the installation of a Panhard bar and its subsequent performance during the second testing period.

E) Discussion of Assembly, Sub-Assemblies, Parts, and Drawings

The top level assembly is the rear subframe itself, which connects to the existing vehicle frame. Separating the assembly, the two major components are the dampening member system and the lower control arm/ motor mounting member system. The motor mounting member has provisions for holding the engine, the axle mount, and the necessary mounting hardware for connecting to the dampening member and frame. The dampening member consists of the commercially available EMPI-Coilover shock and mounting provisions for the frame connection and lower control arm connection.

4) Testing Method

A) Introduction

The primary testing method for this project will be comparison between ideal/calculated parameters and experimental/actual data collected. Since the electric vehicle is an ongoing long-term project, the vehicle itself is nowhere near completion. Since testing in movement (that is, movement under its own power) will, most likely, not be available when the testing phase begins, simulated loadings will be used instead. These simulated loads will include the weight of a driver, battery, vehicle body, engine, and other accessories necessary for vehicle control.

In practical testing, the vehicle was analyzed for both horizontal and vertical movement under applied loadings.

B) Method and Approach

Methodology for testing is kept to broad analysis. As previously stated, the vehicle has not been completed. With this in mind, the goal of testing is to study geometry under current conditions of completeness, but with anticipation for later additions that may change the requirements of the total system.

C) Test Procedure

1. Fix the vehicle frame in place by way of ratcheting straps.
2. Position vehicle jack under the axle of the vehicle (use wood blocks as necessary to safely position jack and axle).
3. Take initial measurement of axle relative to the horizontal reference point (ground or vehicle frame horizontal bar).
4. Apply force to the axle by applying known weight
5. Take measurement of axle relative to the horizontal reference point.
6. Repeat as necessary until maximum displacement is achieved.

D) Deliverables

The resultant data will be compared using spreadsheet analysis, showing differences between actual and ideal suspension travel and geometry (lengths of members, relative positioning of the axle, etc.)

If the project is successful, the completed rear suspension will be available for the use of the Central Washington University Electric Vehicle club.

As included in the testing report section of this proposal (Appendix I – Testing Report), the results of the testing showed a vertical axle travel of 4.5 inches, and a left-to-right displacement of less than one inch prior to installation of a Panhard bar. After the installation, the movement was less than one-eighth (1/8) inch.

5) Budget, Schedule, and Project Management

A) Proposed Budget

i) Parts Suppliers, Substantive Costs, and Buying Issues

The coilover dampening shocks will be sourced from EMPI – a company that specializes in aftermarket components for the Volkswagen Beetle. They produce an adjustable coilover shock with an extended length of 16.75 in and a compressed length of 11.25 in. The unit is entirely self-contained and can be purchased for less than $100.00 from various online parts suppliers.

The lower control arms will be donated by Squire's Machine and Fabrication. The tubing will be cut to length, notched, and then the joints will be welded forming the 90-degree angle to accommodate the existing axle mounts. The axle mounts may need to be modified slightly in order to accommodate the frame connections, discussed below.

The frame mounting connections can be purchased, with bushings and bolts, from online supplier Summit Racing for $7.00 including shipping. Six of these connectors will be needed. These connectors will be welded to the frame in the welding technology lab. If necessary, a flat plate may need to be fixed to the frame prior to welding the brackets. At the ends of the lower control arms, nearest to the axle mounts, there may be a small interference between the brackets and the lower edge of the axle mount. If necessary, the end of the axle mount can be milled or cut down to accommodate both the mount and bracket.

Shipping for both the EMPI-sourced shocks and Summit Racing brackets are approximately two weeks from time of payment, according to their respective websites. Square tubing, if not available, can be acquired locally from a metal supermarket, typically the same day as needed.

ii) Labor Rates, Outsourcing Rates, and Estimated Costs

The current estimated labor rate for a qualified welder or machinist is around $100 USD per hour of work. By using outsourced parts, this limits the budget required for labor. A detailed description of costs is as follows:

6x Coilover Brackets... $7.00 USD/ea

2x EMPI Coilover Shocks .... $100 USD/pair

1x 6-feet of 1-in square steel tubing (A513) .... $15.00 USD/6 ft

2x 1 hour - Labor – Welding/Cutting/Assembly .... $100 USD/hr

Estimated Total Cost .... $358.00 USD

In reality, additional costs for various hardware pieces necessary for completion may add to this estimate. By using the machine lab resources, costs may be cut considerably. If hardware is available to be donated, more costs can be minimized.

Once construction was completed, total costs were under the 358.00 USD allotted at the beginning of this project.

iii) Labor

The anticipated tasks that would require additional assistance are as follows

1. Cutting of the square steel stock to build the lower control arms
2. Welding the square stock (MIG/TIG/O.A. welding)
3. Welding the coilover brackets to the existing frame
4. Welding the coilover brackets to the lower control arms
5. Drilling the square steel stock to accept the motor and axle mounts
6. Assembly of the suspension to the frame
7. Modification of the existing axle mounts (if needed)

iv) Estimated Total Project Cost

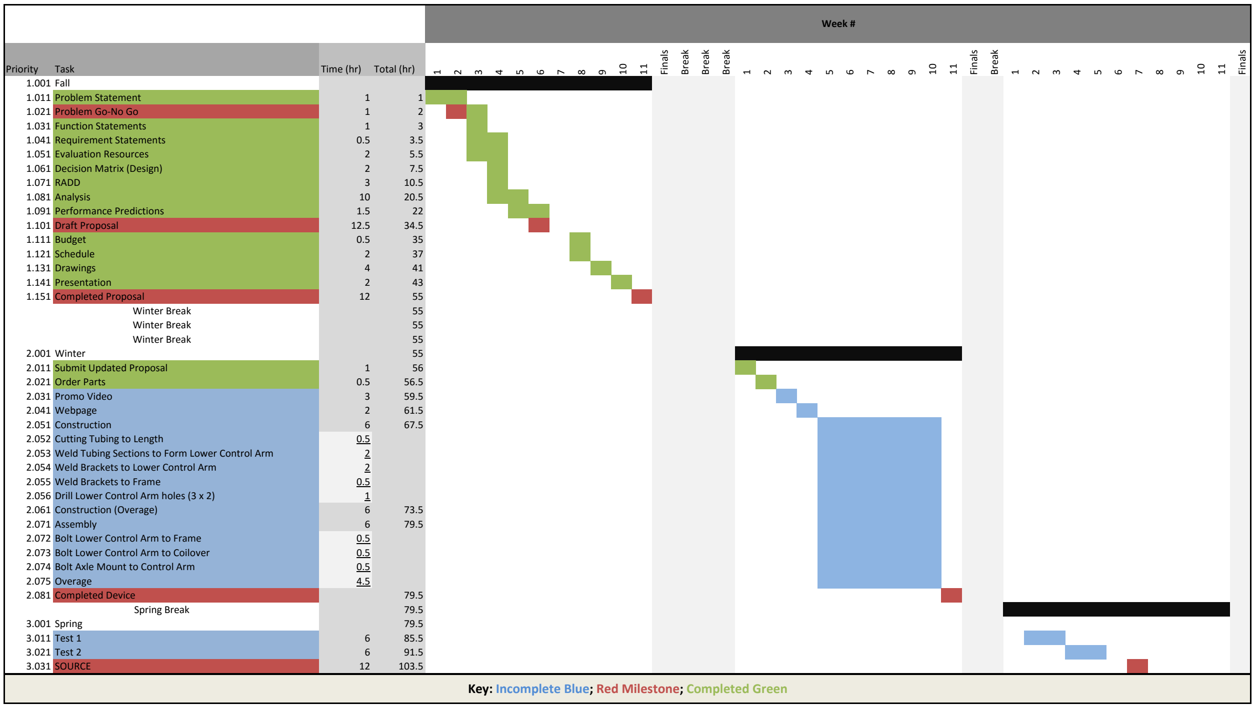
The estimated total project cost, with additional components as necessary, is approximately $400 USD. As stated previously, donated resources will help to reduce this cost.

v) Funding Sources

The majority of the funding required by this project will be provided by the Electric Vehicle club's student account. Any additional resources that are not eligible will be purchased by way of personal monetary funds.

B) Proposed Schedule

i) High Level Gantt Chart



ii) Task Flow and Timing

Further elaboration on the Gantt chart, including a high resolution copy and task breakdown are featured in Appendix E.

iii) Task Dates and Deadlines

Major task dates are shown by week in the Gantt chart above. Significant dates include the submission of the completed proposal at the end Fall Quarter 2015, the completion of construction at the end of Winter Quarter 2016, and the presentation of the project at the SOURCE conference during the 7th week of Spring Quarter 2016.

iv) Deliverables and Milestones

Major deliverables and milestones are highlighted in red on the Gantt chart above. The success of the project is also dependent on the completion of the project proposal, the completion of the construction and assembly, and the presentation of the project at SOURCE.

v) Estimated Total Project Time

Based on the Gantt chart above, the approximate total time invested for the completion of the project is 103.5 hours. It should be noted that this is an estimate for total time invested. Based on unforeseen factors, it is reasonable to suggest an additional 20 hours of work.

C) Project Management

i) Human Resources

The Central Washington University Electric Vehicle club has offered to work on the assembly of the project. Additionally, the Teachers' Assistant in the mechanical engineering department has also offered help on some of the specific manufacturing issues – namely hardware acquisition and welding of the lower control and bracket.

ii) Physical Resources

The physical resources necessary for the project include the machining lab, the senior project room in the Hogue Technology building at the Ellensburg CWU campus, and the welding lab of the same building.

iii) Soft Resources

Software for this project is provided for educational use by the Central Washington University site licensing. The software used includes the Microsoft Office Suite (Word, Excel, Power Point), AutoDesk AutoCAD, and Solidworks.

iv) Financial Resources

Hardware for this project will be purchased at the expense of the Electric Vehicle club and by way of personal monetary contributions. Labor costs, if at all possible, will be minimized by utilizing the on-campus helper staff to complete specific tasks in manufacturing. Through communication with the managing officers of the Electric Vehicle club confirmed that hardware and material purchased for use on the project is eligible for refund provided there is adequate receipt information available for the purchases.

6) Discussion

A) Design Evolution and Performance Creep

The initial design was created based on analysis of the existing frame, axle mounts, and engine mount. The frame had a vertical spacing of 14 inches, which, in order to make most effective use of a dampening system, meant that the lower control arm should also meet that measurement. Outside of basic analysis, the majority of the design was performed after finding suitable components to match the basic needs of the system. While manufacturing a coilover shock may have been a rewarding experience, the amount of time required in engineering such a product greatly outweighed the cost of outsourcing a previously manufactured unit.

In terms of performance creep, the project will undergo a significant amount of planning in hopes that the amount of time spent troubleshooting during construction might be minimized. There may be a lull in progress while waiting for materials and components to arrive after they have been ordered.

B) Project Risk Analysis

Risk analysis, in this case, means ensuring that the project is both safe and complete when delivered and installed on the electric vehicle frame. In terms of financial risk, the monetary investment may be lost if the project is not completed correctly or if the system does not assemble as planned. However, with access to the Central Washington University machining and welding labs, modifications can be made to minimize financial loss.

The point of utmost concern is safety of the passenger of the electric vehicle. By taking the time to adequately analyze, design, construct, and test the system, risk to the passenger can be minimized.

C) Success of the Project

The success of the project is determined by its level of completion. Ideally, the deliverables (the proposal, suspension assembly, etc.) will mark the completion and success of the project. A stretch-success goal is to perform testing on the vehicle and suspension while in motion, but the completeness of the rest of the vehicle project will determine if those testing methods are available.

D) Project Documentation

Project documentation is the body of this proposal, and the appendix of pages that follow, including: analyses, drawings, parts list, budget, schedule, expertise and resources, testing data, evaluation sheet, testing report, and resume / curriculum vitae.

Additional documentation may need to be created to support the project as time progresses.

E) Next Phase

After the completion of this proposal, the process of construction the project begins. This includes the ordering of parts, manufacturing necessary components, and assembly of the system.

Past construction and completion of testing, the subject may be subject to change as the Electric Vehicle Club and its advisors see fit.

7) Conclusion

To conclude, the rear suspension system for use on the Central Washington University's Electric Vehicle club frame is dependent on critical design, analysis, and well-guided construction in order to produce a product that is safe and effective. The system should allow for, at minimum, 3 inches of suspension travel relative to the frame, the coilovers should fail under a load of 700 lb per shock without causing any destruction to the rest of the system, and be safe for the occupant of the vehicle. Support in construction, material costs, and other funding necessities will be provided by the Central Washington University Electric Vehicle Club. .

8) Acknowledgements

The author of this proposal would like to thank the advising professors and assistants in the Mechanical Engineering Technology Department at Central Washington University's Ellensburg Campus, including but not limited to: Professor Beardsley, Professor Johnson, Professor Pringle, Matt Burby, Nathan Wilhelm, Jose Bejar, Rod Helmuth of Squire's Machine, and the CWU Electric Vehicle Club. Without the support of others, this project would not be possible.

9) References

Avallone, E. (2007). *Marks' standard handbook for mechanical engineers* (11th ed.). New York, New York: McGraw-Hill.

Mott, R. (2014). *Machine elements in mechanical design* (5th ed.). Upper Saddle River, New Jersey: Pearson/Prentice Hall.

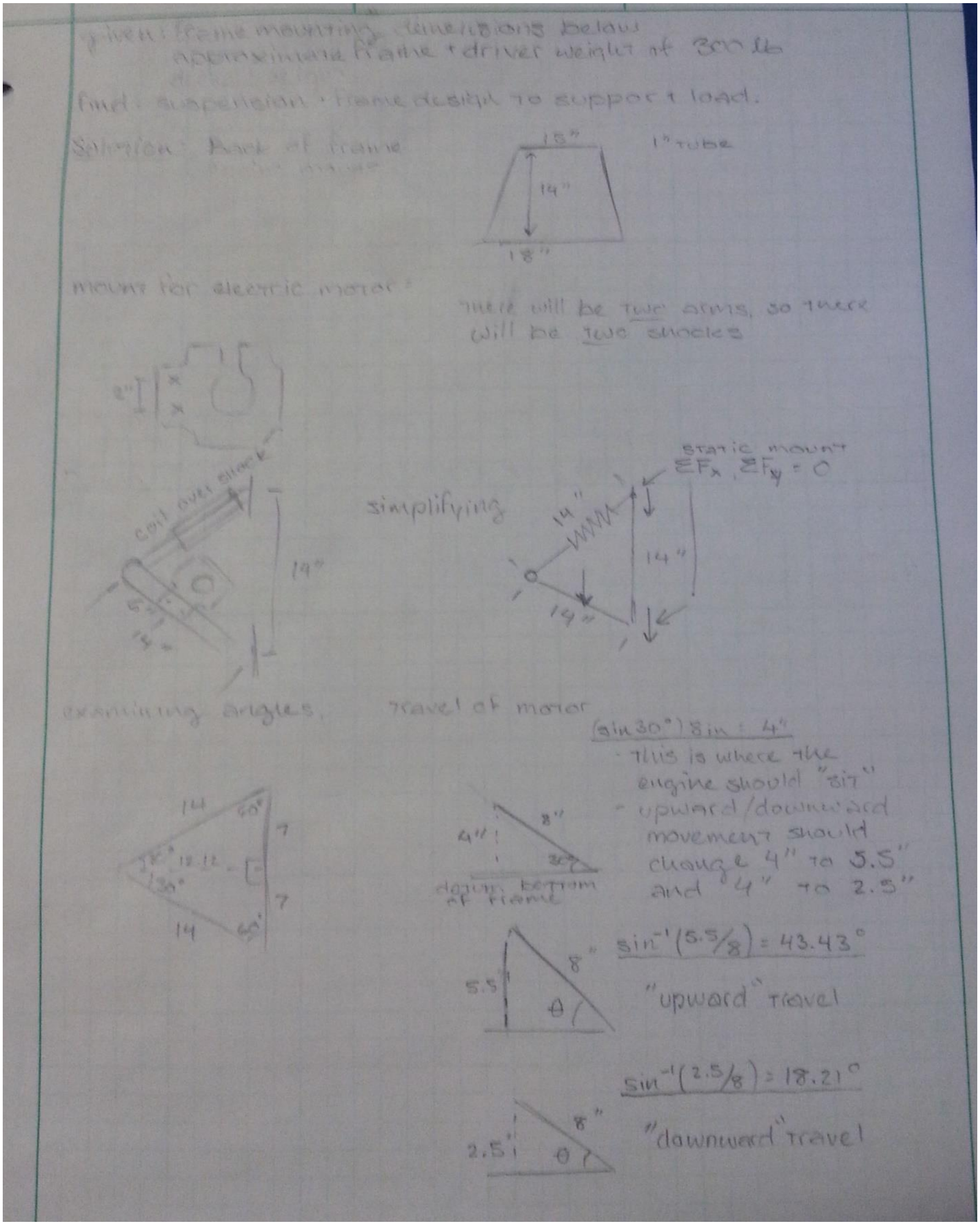
10 key factors in Suspension Design - Racecar Engineering. (2008, May 16). Retrieved December 6, 2015, from http://www.racecar-engineering.com/articles/suspension-design/

Electrathon America 2013 Rulebook. (n.d.). Retrieved December 6, 2015, from http://www.electrathonamerica.org/Rule_Book_&_Forms_files/HANDBOOK 2013.pdf

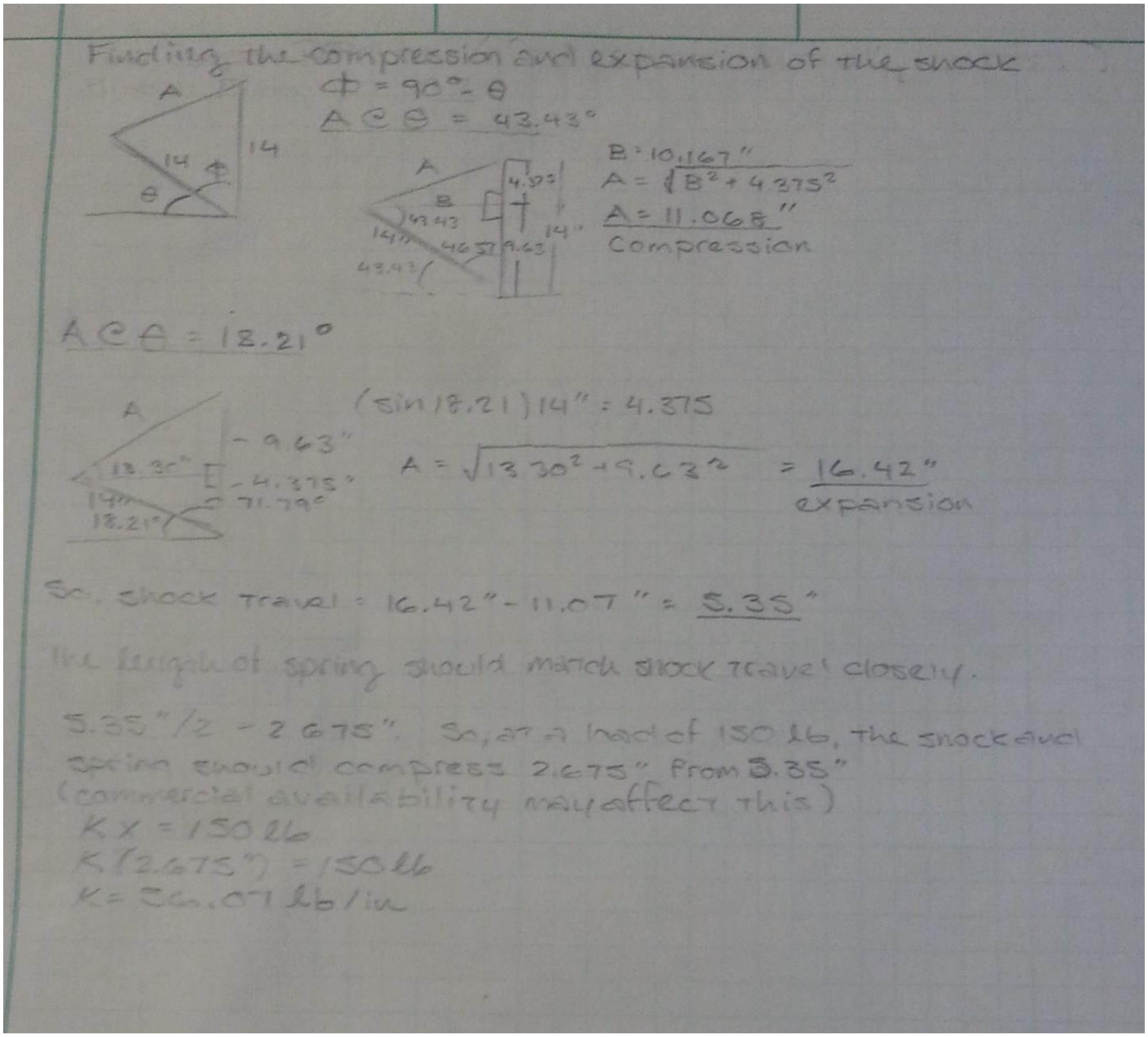
Spyder F3. (n.d.). Retrieved December 6, 2015, from http://can-am.brp.com/spyder/spyder/sport-cruising.html

10) Appendix A – Analyses

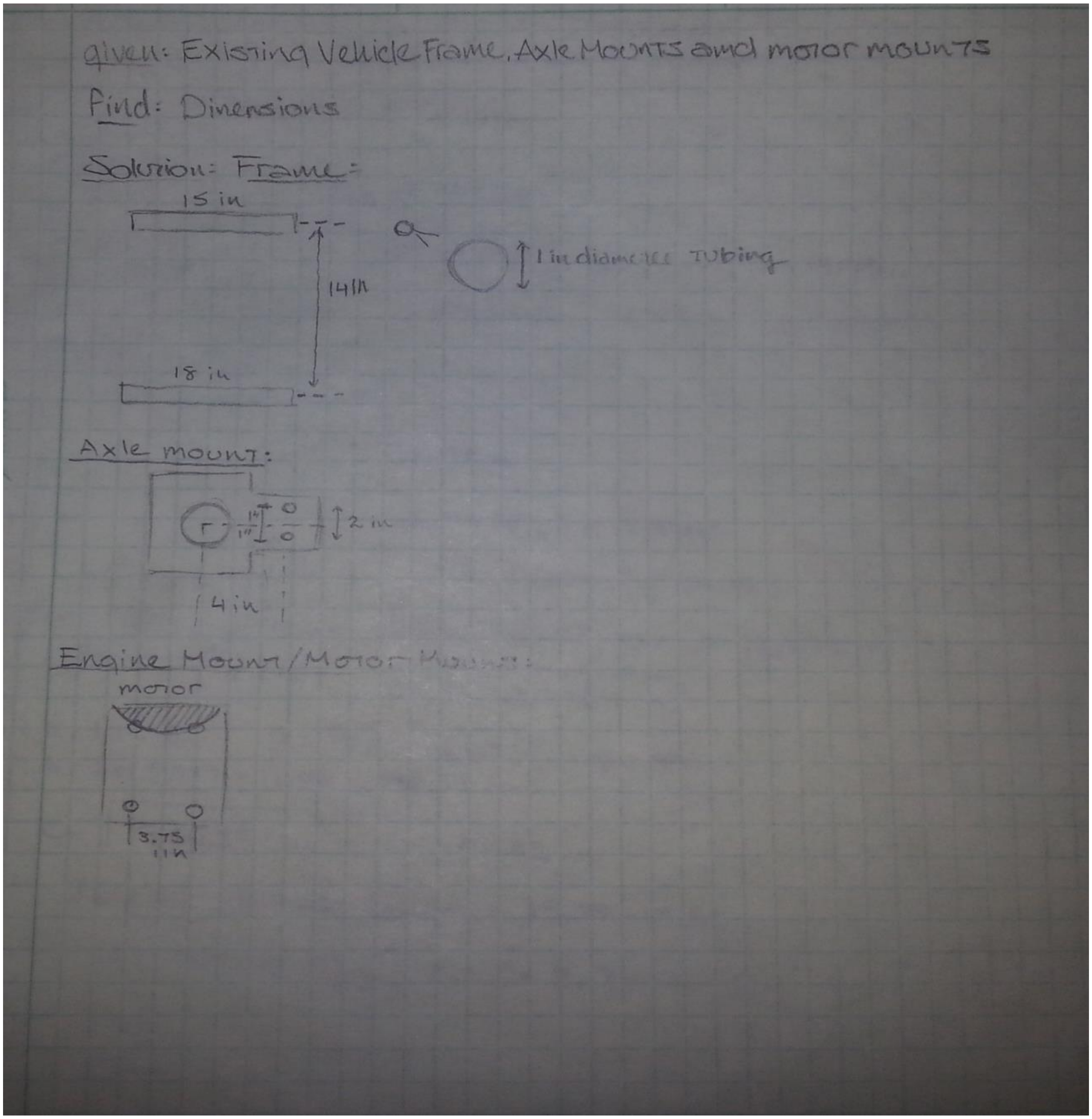
Analysis 1 – Initial Design Idea



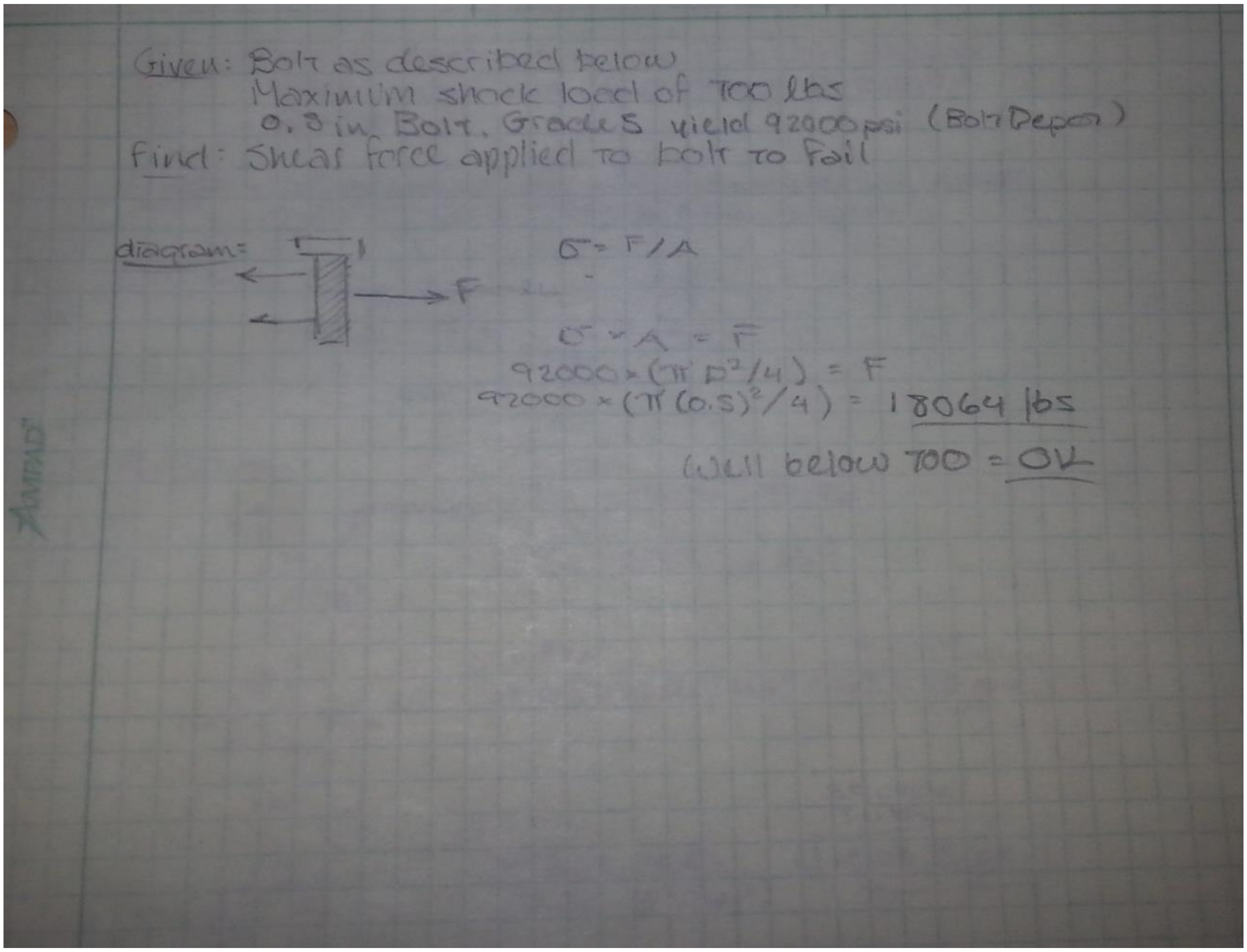
Analysis 2 – Initial Design Idea Continued



Analysis 3 – Existing Measurements



Analysis 4 – Shear Force to Cause Bolt Failure



Given: Bolt as described below
Maximum shock load of 700 lbs
0.5 in Bolt, Grade 5 yield 92000 psi (Bolt Depot)
Find: Shear force applied to bolt to fail

diagram:

$\sigma = F/A$

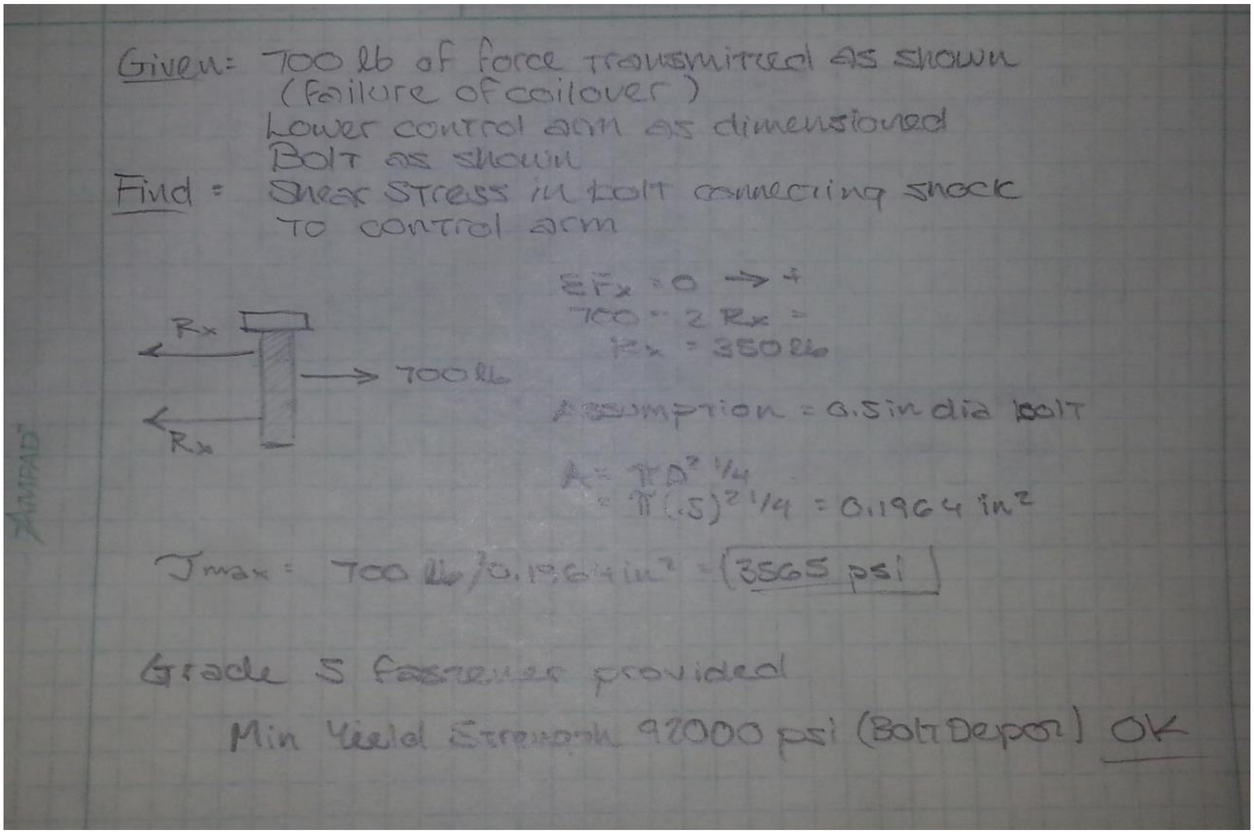
$\sigma \times A = F$

$92000 \times (\pi D^2/4) = F$

$92000 \times (\pi (0.5)^2/4) = 18064 \text{ lbs}$

Well below 700 = OK

Analysis 5 – Shear Force in Bolt Caused by Shock Failure



Given: 700 lb of force transmitted as shown (failure of coilover)
Lower control arm as dimensioned
Bolt as shown

Find: Shear stress in bolt connecting shock to control arm

$\Sigma F_x = 0 \rightarrow +$

$700 - 2R_x =$

$R_x = 350$ lb

Assumption = 0.5 in dia bolt

$A = \pi D^2/4$

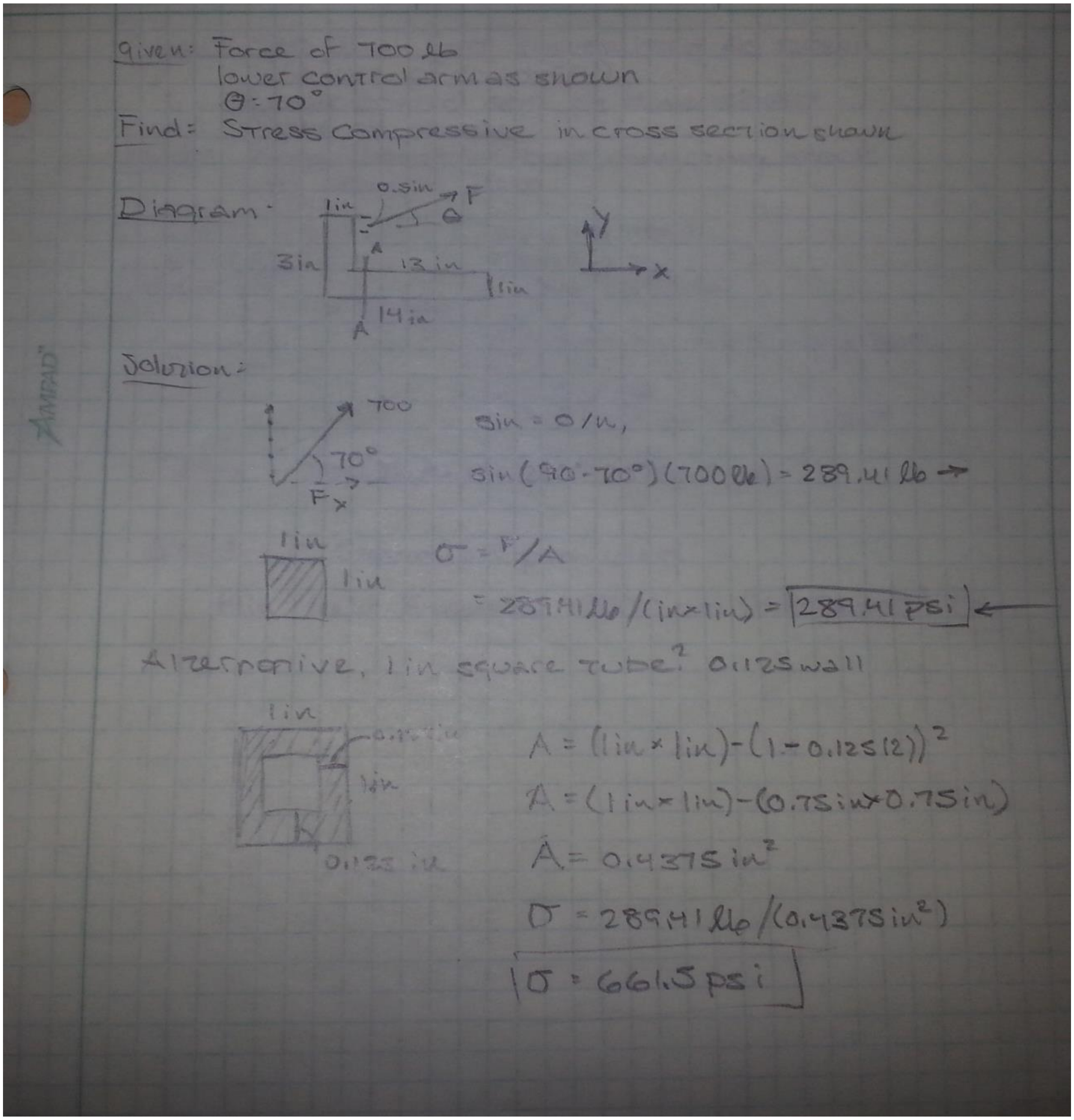
$= \pi(.5)^2/4 = 0.1964\ in^2$

$\tau_{max} = 700$ lb$/0.1964\ in^2 = $ 3565 psi

Grade 5 fastener provided

Min Yield Strength 92000 psi (Bolt Depot) OK

Analysis 6 – Compressive Stress in Lower Control Arm (Horizontal)



Given: Force of 700 lb
lower control arm as shown
$\theta = 70°$

Find: Stress compressive in cross section shown

Diagram:

Solution:

sin = O/H,

$\sin(90°-70°)(700 \text{ lb}) = 289.41 \text{ lb} \rightarrow$

$\sigma = F/A$

$= 289.41 \text{ lb}/(1\text{in} \times 1\text{in}) = \boxed{289.41 \text{ psi}}$

Alternative, 1in square tube, 0.125 wall

$A = (1\text{in} \times 1\text{in}) - (1 - 0.125(2))^2$

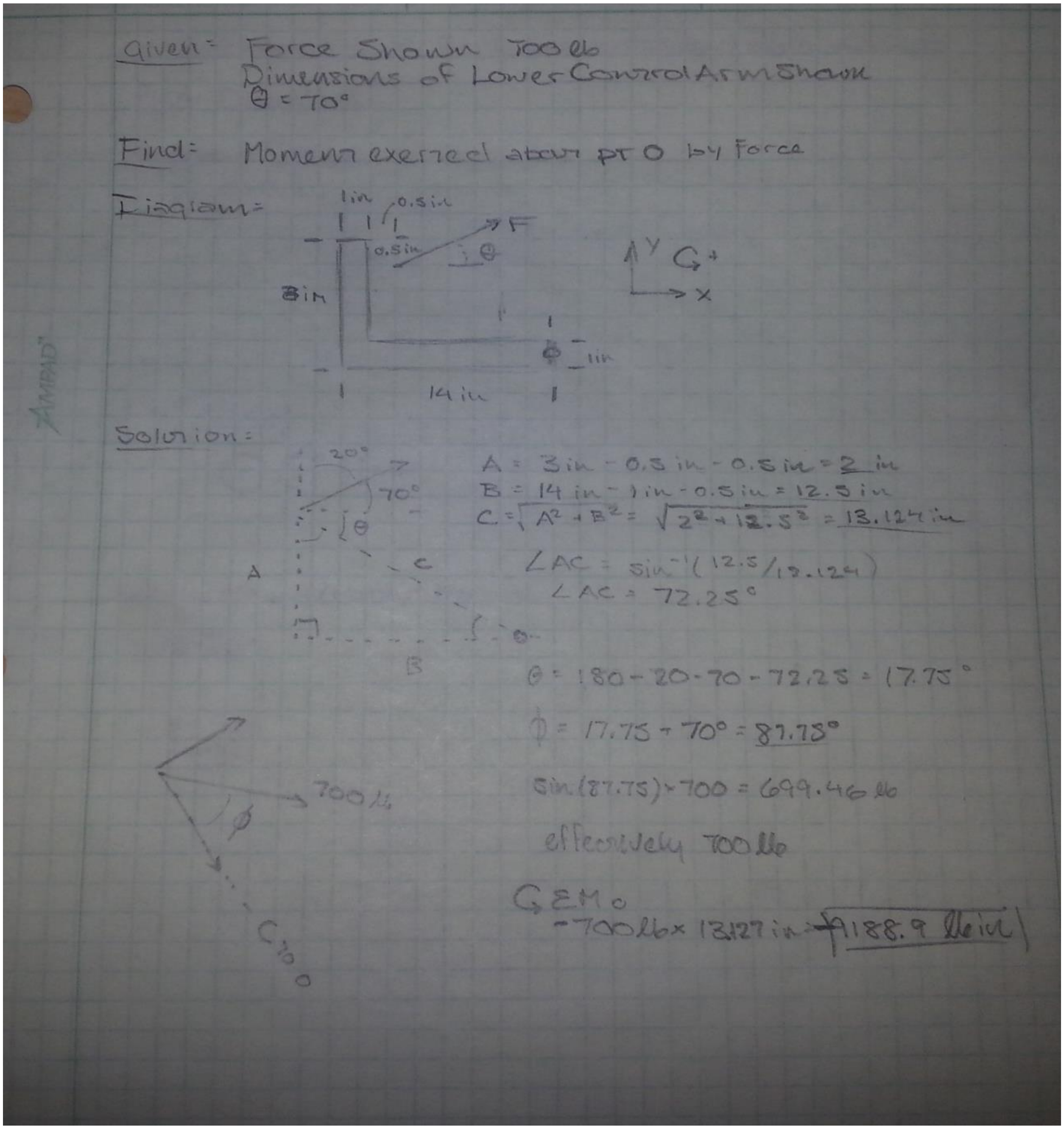
$A = (1\text{in} \times 1\text{in}) - (0.75\text{in} \times 0.75\text{in})$

$A = 0.4375 \text{ in}^2$

$\sigma = 289.41 \text{ lb}/(0.4375 \text{ in}^2)$

$\boxed{\sigma = 661.5 \text{ psi}}$

Analysis 7 – Moment Exerted About Frame to Control Arm Mounting Point



Given: Force Shown 700 lb
Dimensions of Lower Control Arm Shown
$\theta = 70°$

Find: Moment exerted about pt O by Force

Diagram:

Solution:

A = 3in − 0.5 in − 0.5 in = 2 in
B = 14 in − 1 in − 0.5 in = 12.5 in
C = $\sqrt{A^2 + B^2} = \sqrt{2^2 + 12.5^2}$ = 13.124 in

∠AC = $\sin^{-1}(12.5/13.124)$
∠AC = 72.25°

θ = 180 − 20 − 70 − 72.25 = 17.75°

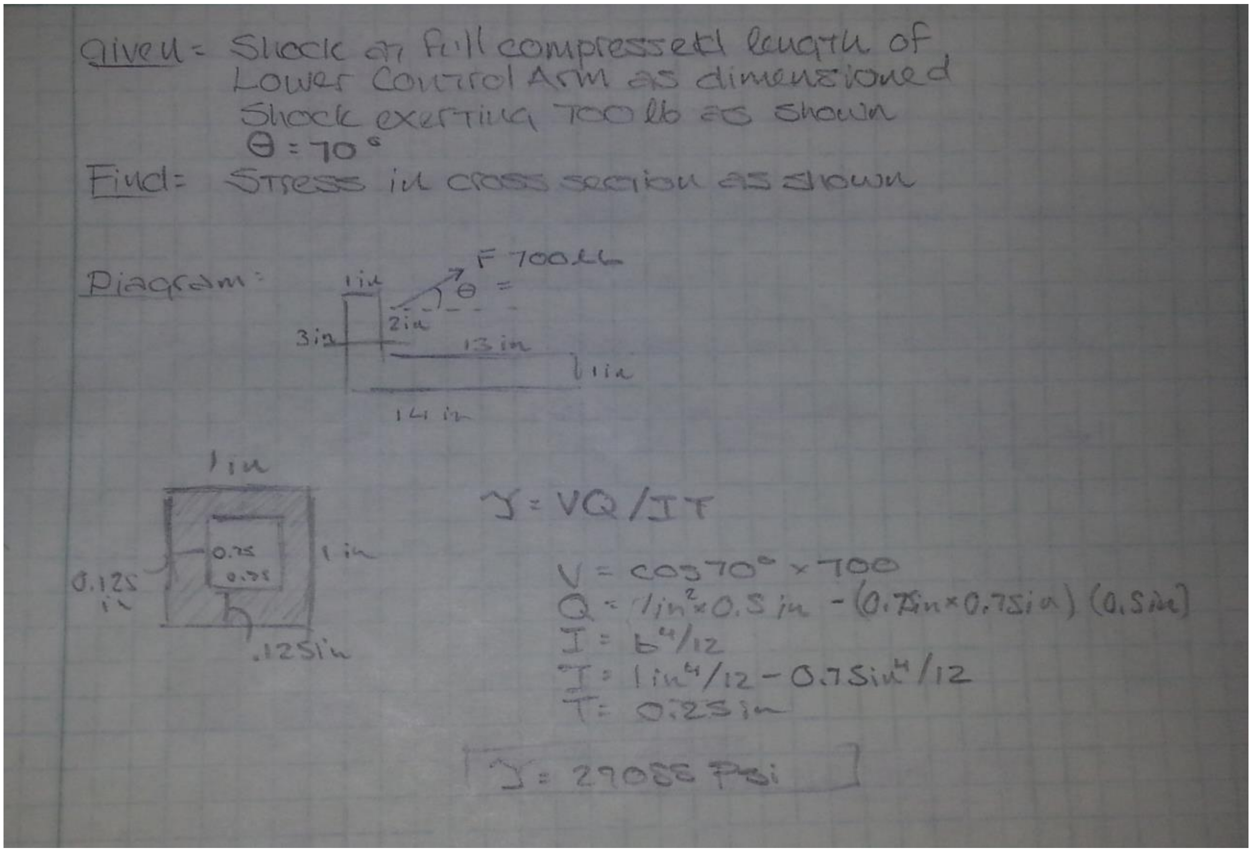
ϕ = 17.75 + 70° = 87.75°

sin(87.75) × 700 = 699.46 lb

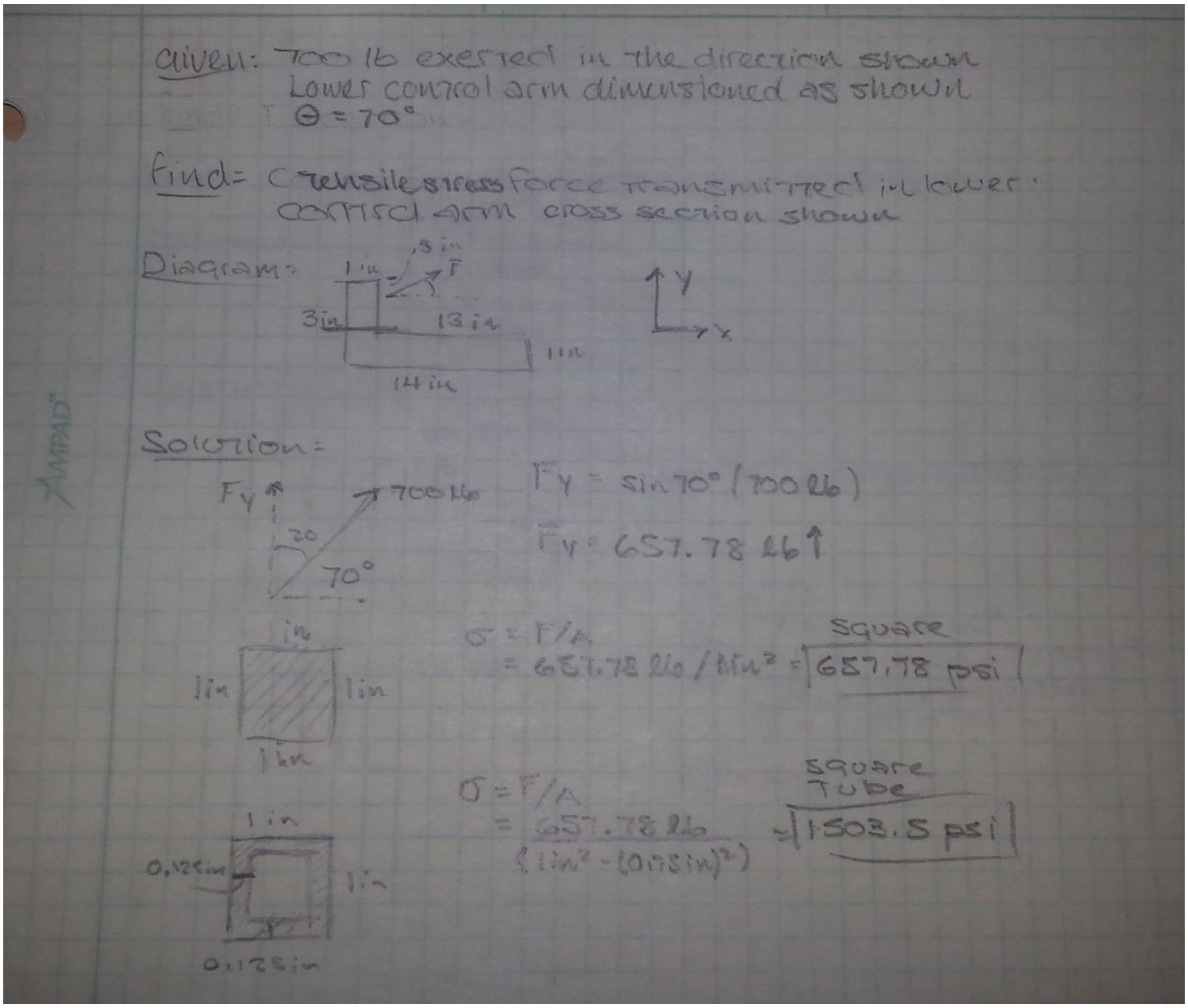
effectively 700 lb

ΣM_O
−700 lb × 13.127 in = −9188.9 lb·in

Analysis 8 – Shear Stress in Upper Section of Lower Control Arm



Analysis 9 – Tensile Stress in Upper Section of Lower Control Arm


Given: 700 lb exerted in the direction shown
Lower control arm dimensioned as shown
$\Theta = 70°$

Find: Tensile stress force transmitted in lower control arm cross section shown

Diagram:

Solution:

$F_y = \sin 70° (700\ lb)$

$F_y = 657.78\ lb \uparrow$

Square

$\sigma = F/A$

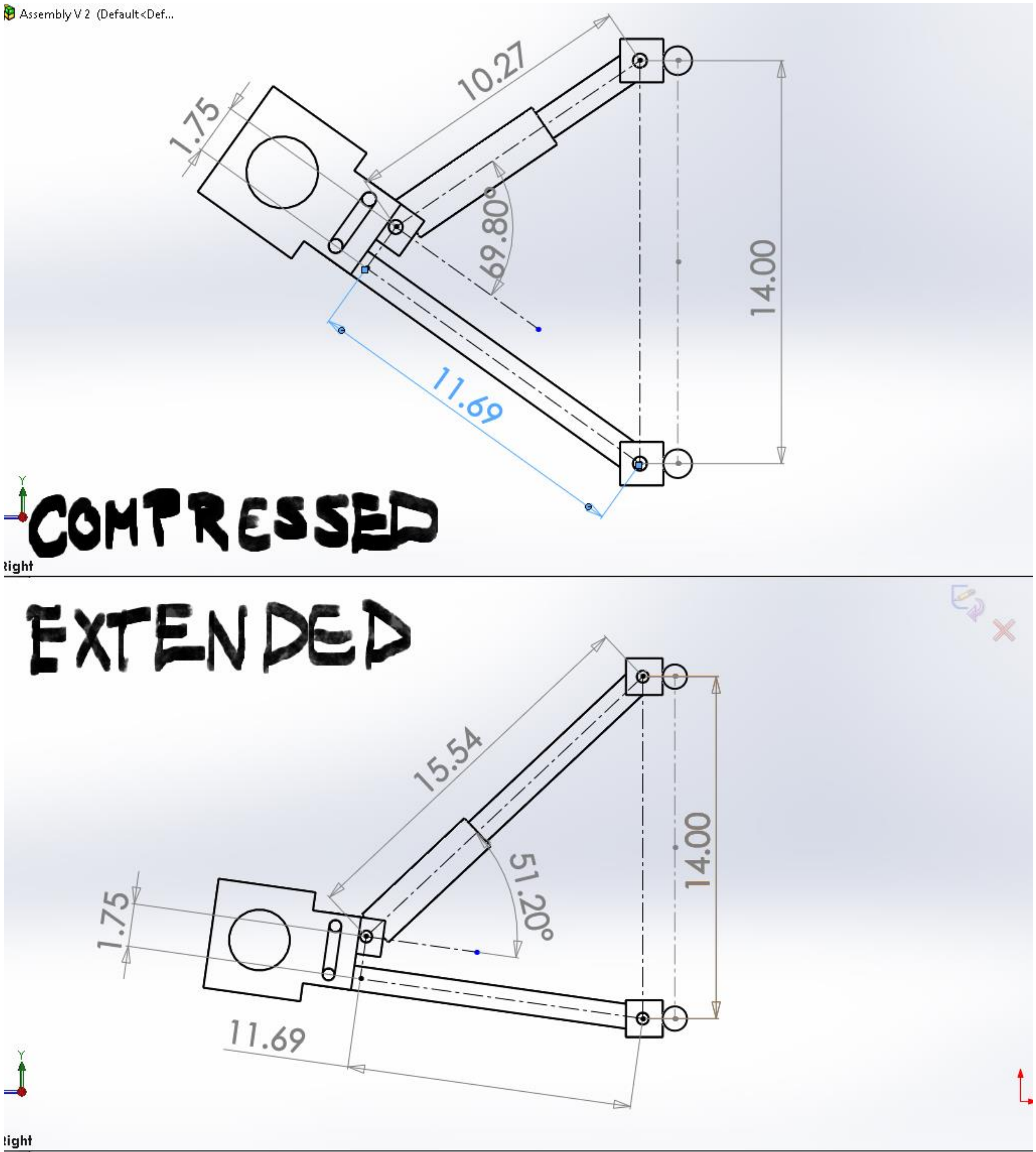
$= 657.78\ lb / 1 in^2 = 657.78\ psi$

Square Tube

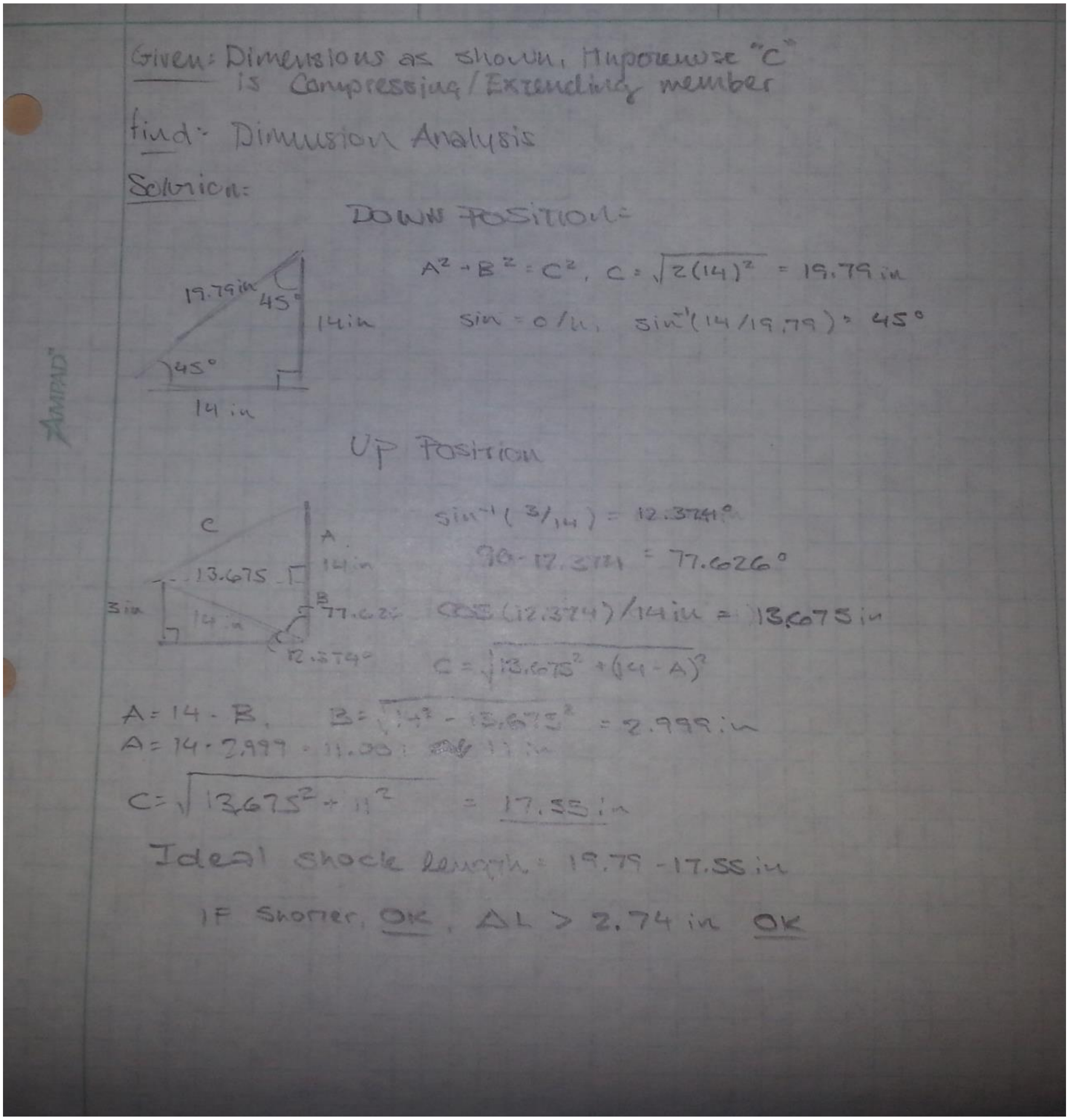
$\sigma = F/A$

$= \frac{657.78\ lb}{(1 in^2 - (0.75 in)^2)} = 1503.5\ psi$

Analysis 10 – Solidworks Measurement Check



Analysis 11 – Angle of Travel Check Using Solidworks Dimensions



Given: Dimensions as shown, Hypotenuse "C" is Compressing/Extending member

find: Dimension Analysis

Solution:

DOWN POSITION:

$A^2 + B^2 = C^2$, $C = \sqrt{2(14)^2} = 19.79$ in

$\sin = o/h$, $\sin^{-1}(14/19.79) = 45°$

UP Position

$\sin^{-1}(3/14) = 12.3741°$

$90 - 12.374 = 77.626°$

$\cos(12.374)/14 in = 13.675$ in

$C = \sqrt{13.675^2 + (14 - A)^2}$

$A = 14 - B$, $B = \sqrt{14^2 - 13.675^2} = 2.999$ in

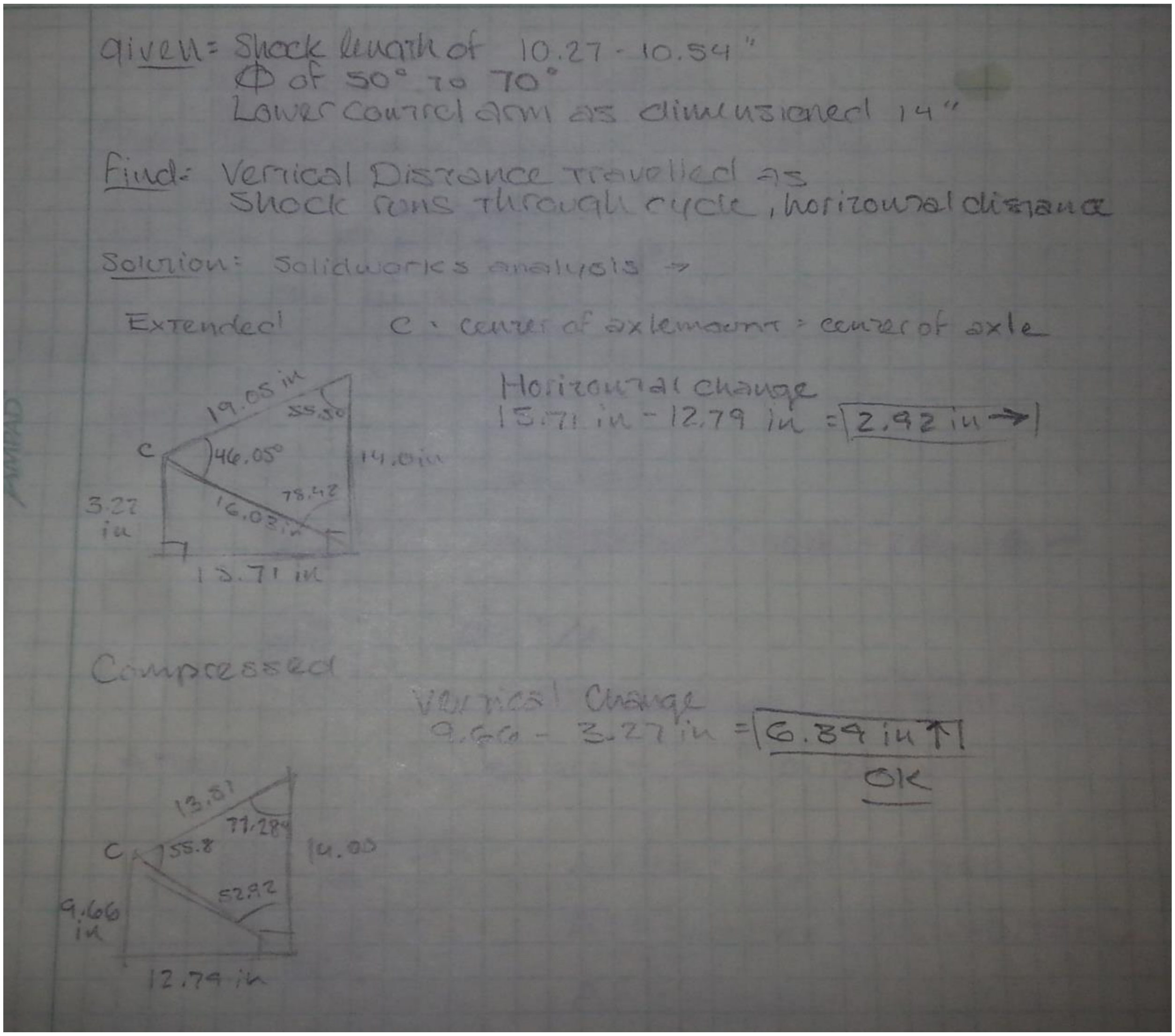
$A = 14 - 2.999 = 11.00 \approx 11$ in

$C = \sqrt{13.675^2 + 11^2} = 17.55$ in

Ideal shock length = 19.79 - 17.55 in

IF Shorter, OK, $\Delta L > 2.74$ in OK

Analysis 12 – Vertical and Horizontal Travel at Center of Axle


given: Shock length of 10.27 - 10.54"
Φ of 50° to 70°
Lower control arm as dimensioned 14"

Find: Vertical Distance travelled as shock runs through cycle, horizontal distance

Solution: Solidworks analysis →

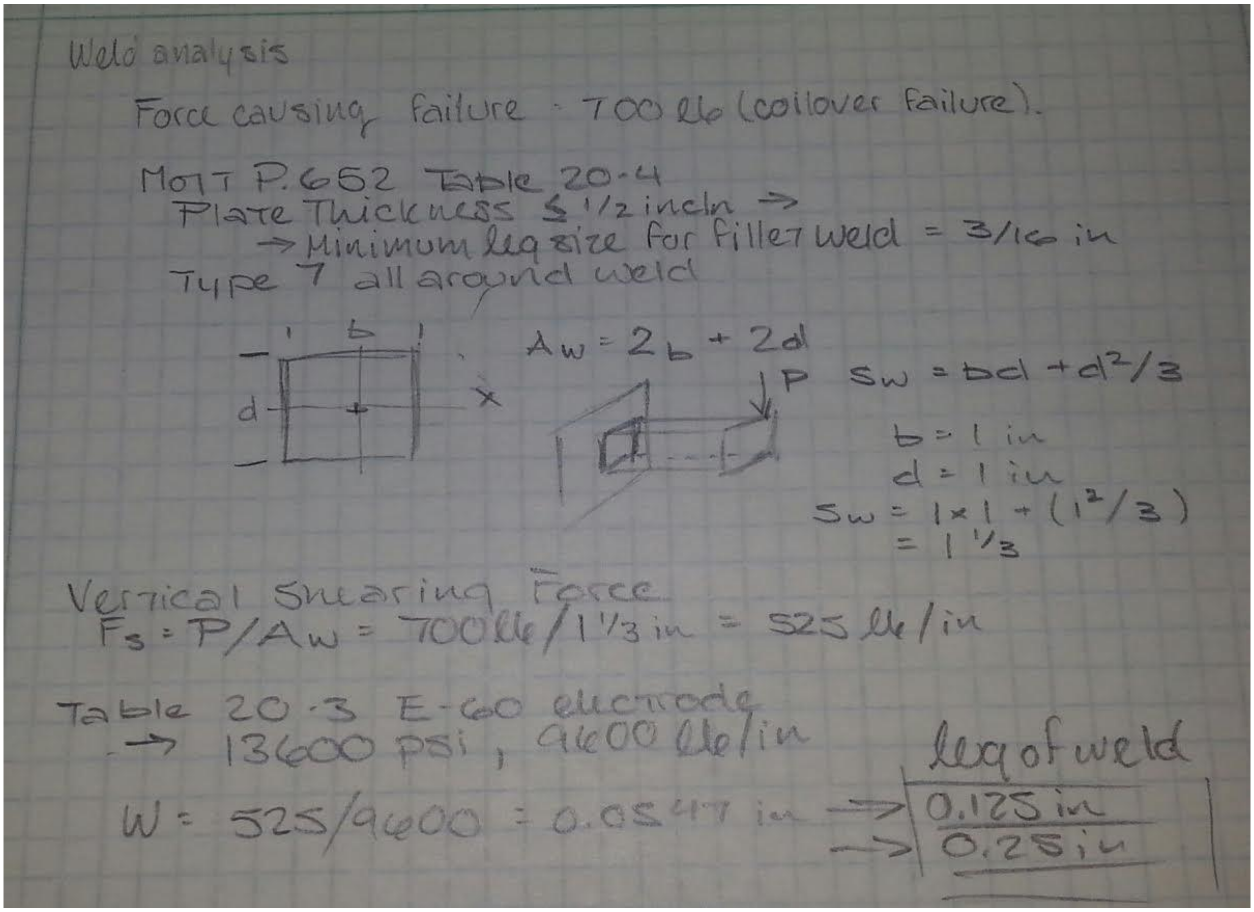
Extended   C : center of axle mount ≈ center of axle

Horizontal change
13.71 in - 12.79 in = 2.92 in →

Compressed

Vertical change
9.66 - 3.27 in = 6.84 in ↑
OK

Analysis 13 – Welding



Weld analysis

Force causing failure - 700 lb (coilover failure).

Mott P.652 Table 20-4

Plate Thickness ≤ 1/2 inch →

→ Minimum leg size for fillet weld = 3/16 in

Type 7 all around weld

$A_w = 2b + 2d$

$S_w = bd + d^2/3$

b = 1 in

d = 1 in

$S_w = 1 \times 1 + (1^2/3)$

$= 1\ 1/3$

Vertical Shearing Force

$F_s = P/A_w = 700\ lb / 1\ 1/3\ in = 525\ lb/in$

Table 20-3 E-60 electrode

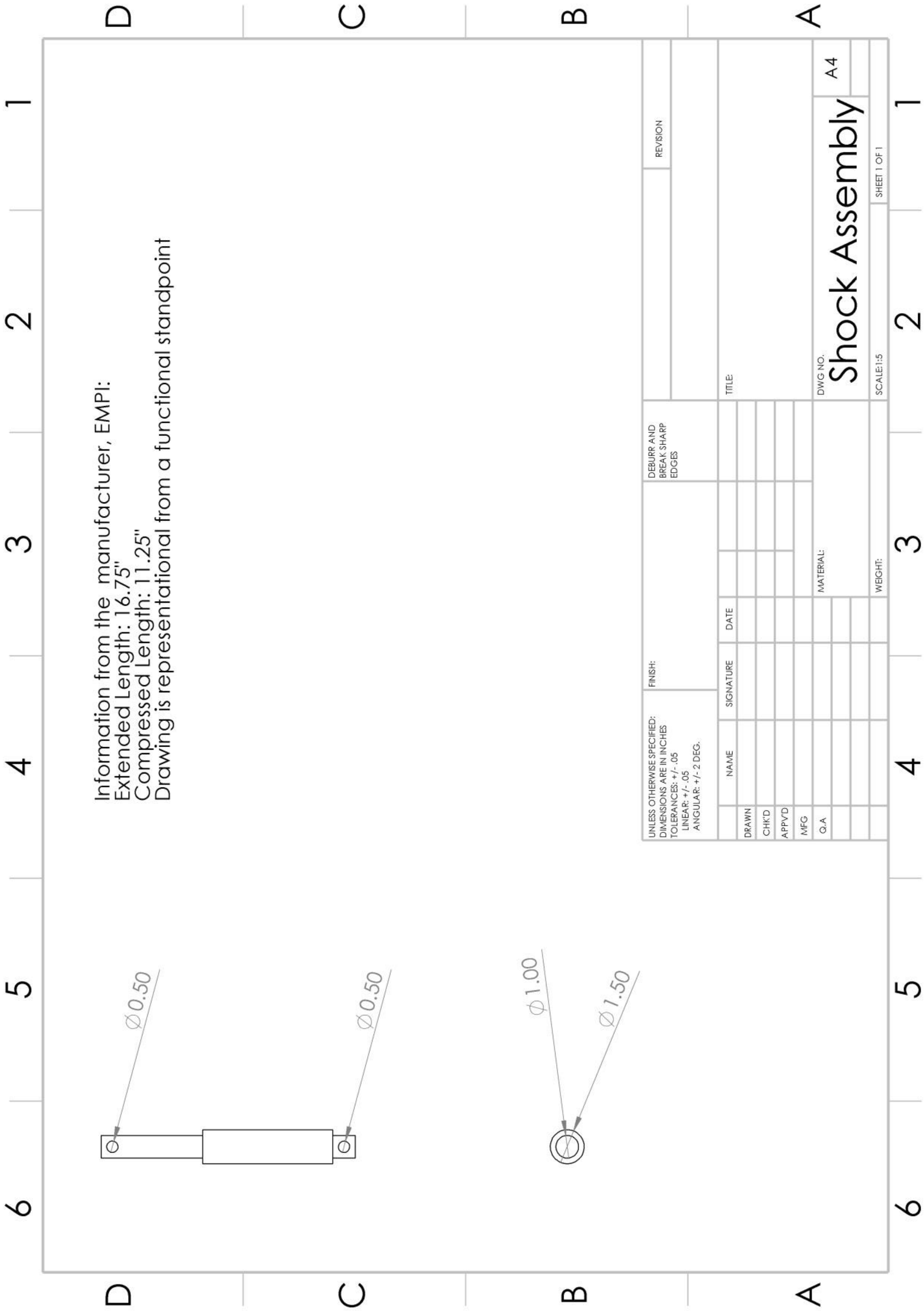
→ 13600 psi, 9600 lb/in

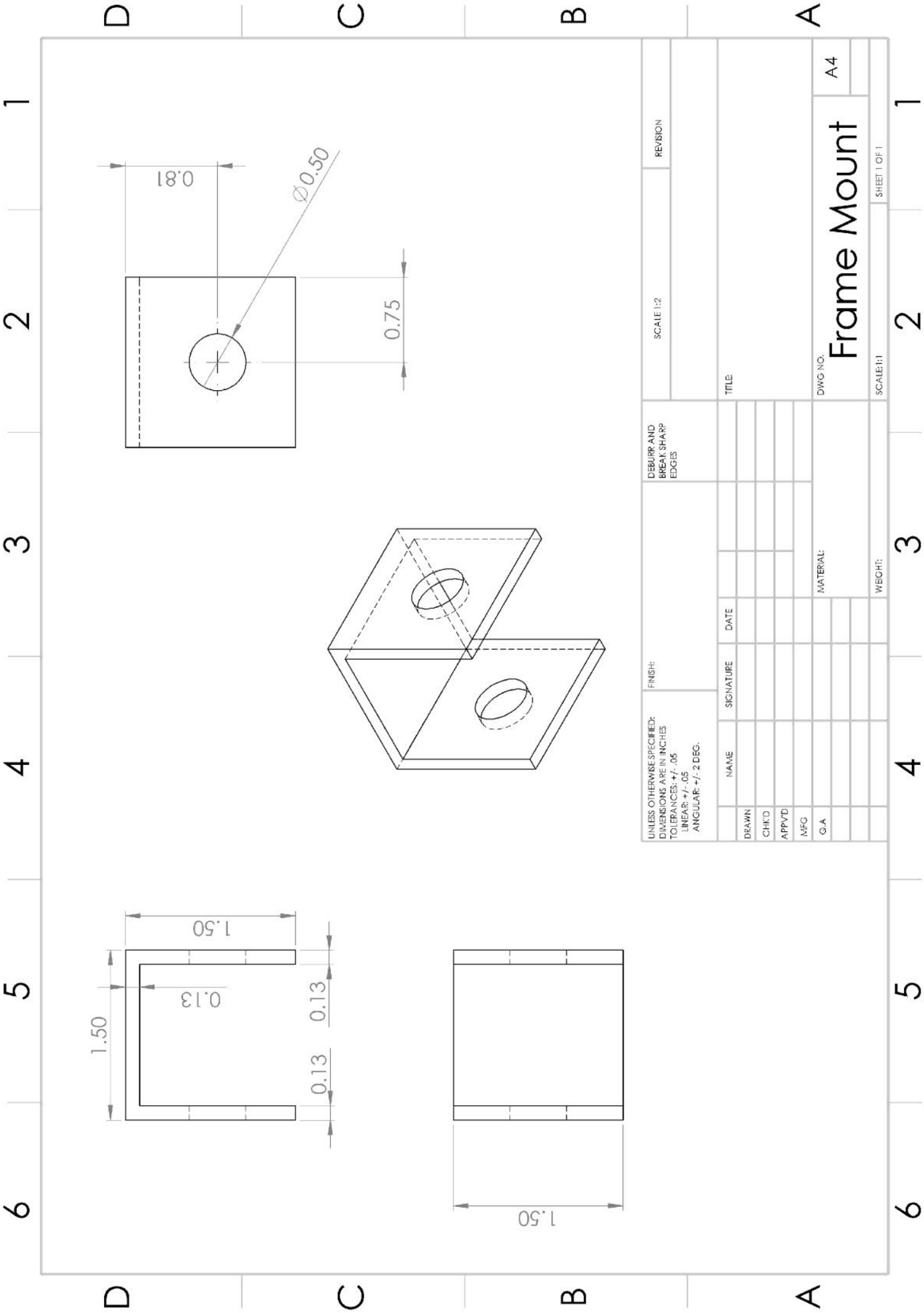
leg of weld

W = 525/9600 = 0.0547 in → 0.125 in

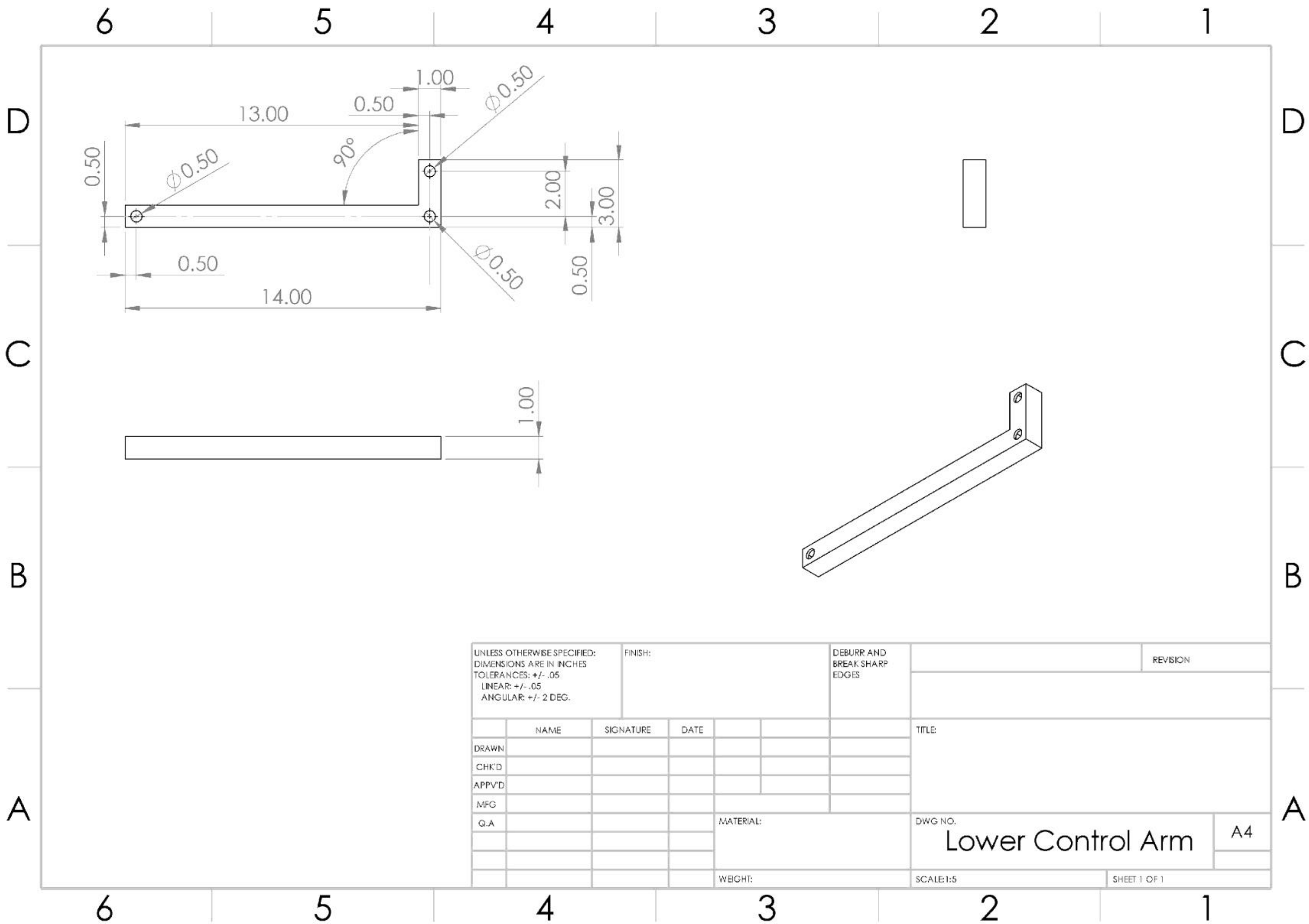
→ 0.25 in

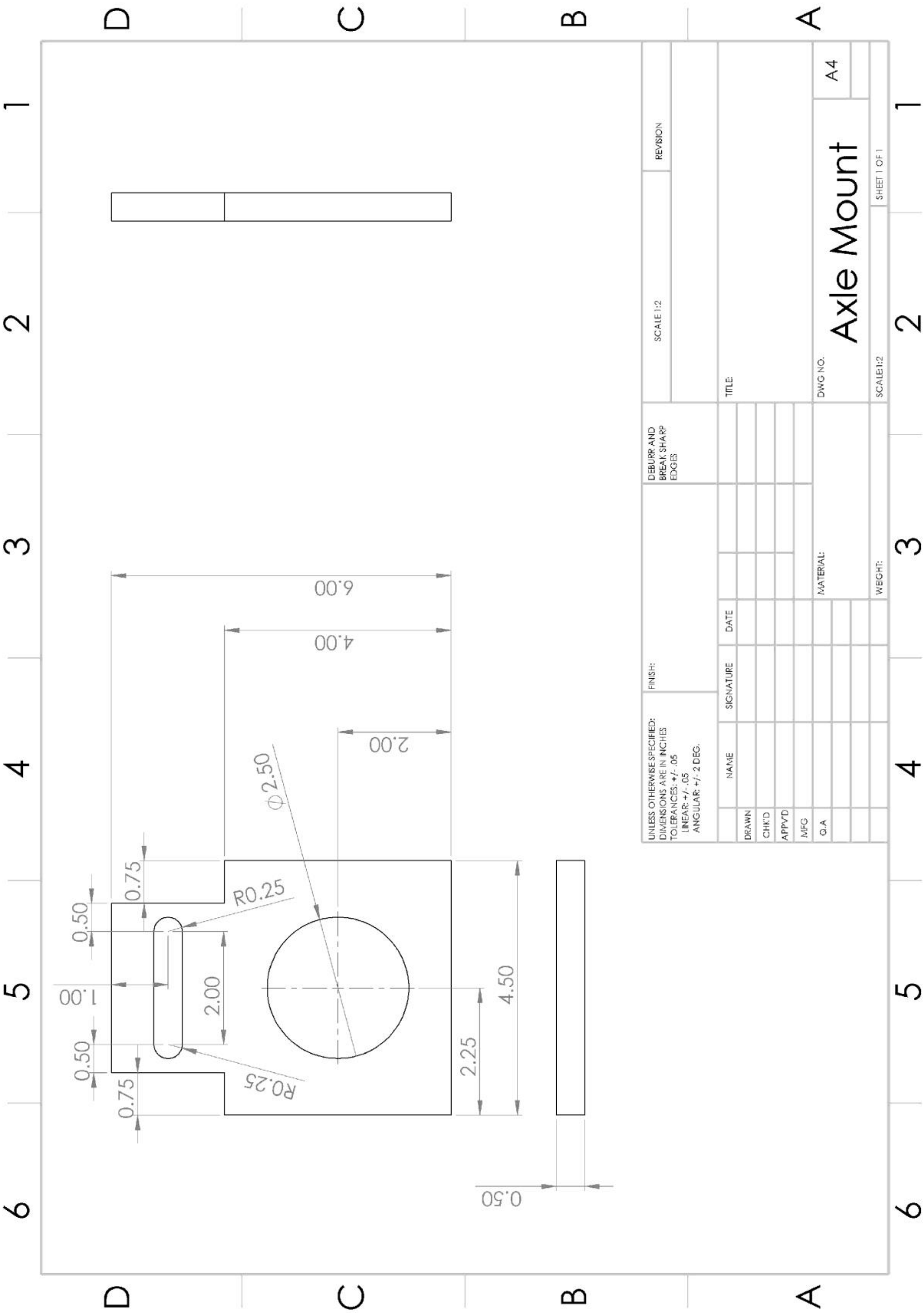
11) Appendix B – Drawings





Frame Mount
0.81
Ø0.50
0.75
1.50
1.50
0.13
0.13
0.13
1.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: +/- .05
LINEAR: +/- .05
ANGULAR: +/- 2 DEG.
FINISH:
DEBURR AND BREAK SHARP EDGES
REVISION
SCALE 1:2
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
TITLE:
DWG NO.
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1


13.00
0.50
1.00
⌀0.50
0.50
⌀0.50
90°
2.00
3.00
0.50
14.00
⌀0.50
0.50
1.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: +/- .05
LINEAR: +/- .05
ANGULAR: +/- 2 DEG.
FINISH:
DEBURR AND
BREAK SHARP
EDGES
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
Lower Control Arm
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1


Axle Mount
6.00
4.00
2.00
⌀2.50
R0.25
R0.25
0.75
0.50
1.00
0.50
0.75
2.00
2.25
4.50
0.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: +/- .05
LINEAR: +/- .05
ANGULAR: +/- 2 DEG.
FINISH:
DEBURR AND BREAK SHARP EDGES
SCALE 1:2
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
DWG NO.
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1

12) Appendix C – Parts List

2x Previously Manufactured Axle Mounts

1x Previously Manufactured Engine Mount

1x Previously Manufactured Vehicle Frame

2x Lower Control Arms (Part 001)

To be Manufactured

6x Coilover Brackets (Part 003)
Allstar Performance Coilover Bracket
Includes grade 5 bolt, nut, washer
848238033632
http://www.summitracing.com/parts/aaf-all60106/overview/

2x EMPI Coilover Shocks (Part 002)
EMPI
00-9750-8
Volkswagen Dune Buggy Aftermarket
eBay Listing from parts supplier http://ebay.to/1YReTCc

1x 6-feet of 1-in square steel tubing (A513)

A513; DOM Mild Steel Tube A513 TYPE 5
http://www.onlinemetals.com/merchant.cfm?pid=7778&step=4&showunits=inches&id=283&top_cat=0

13) Appendix D – Budget

6x Coilover Brackets.. $7.00 USD/ea

2x EMPI Coilover Shocks .... $100 USD/pair

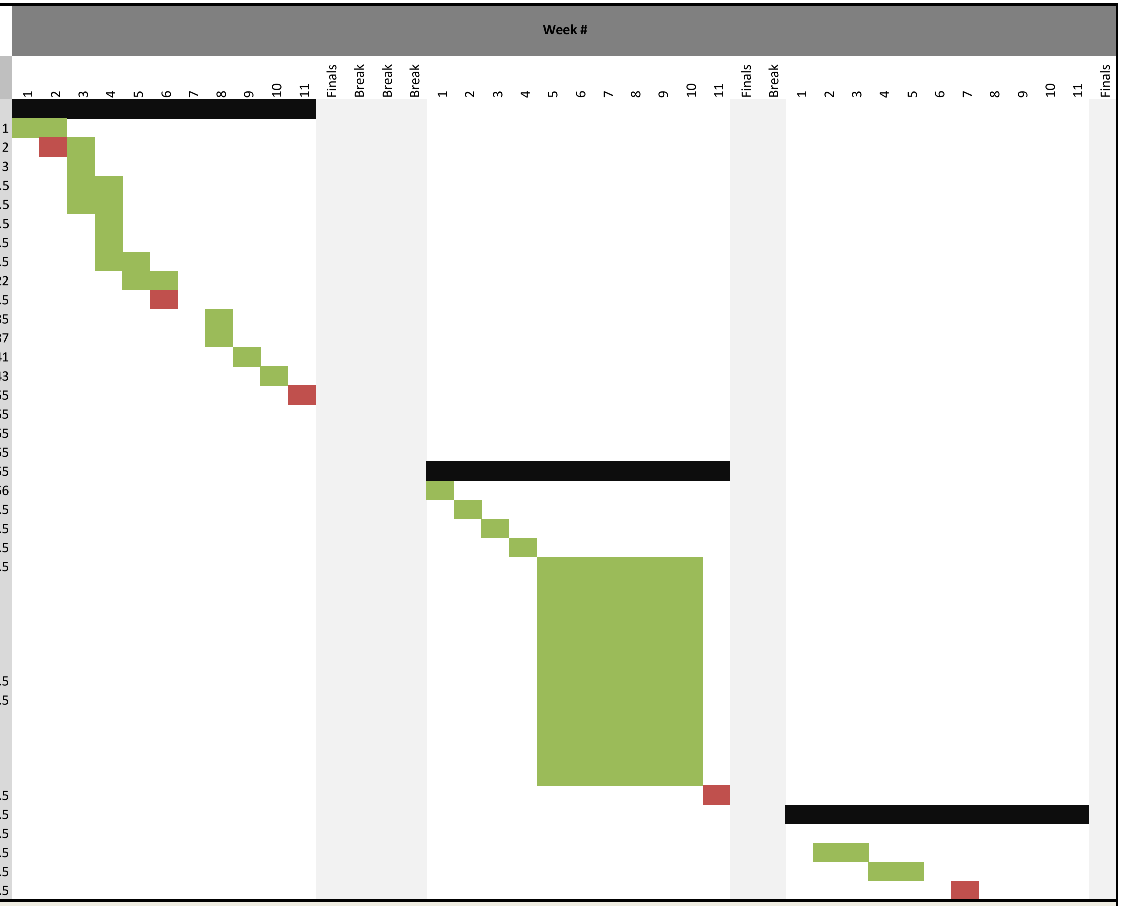
1x 6-feet of 1-in square steel tubing (A513) .... $15.00 USD/6 ft

2x 1 hour - Labor – Welding/Cutting/Assembly .... $100 USD/hr

Estimated Total Cost .... $358.00 USD

14) Appendix E – Schedule

Priority	Task	Time (hr)	Total (hr)
1.001	Fall		
1.011	Problem Statement	1	1
1.021	Problem Go-No Go	1	2
1.031	Function Statements	1	3
1.041	Requirement Statements	0.5	3.5
1.051	Evaluation Resources	2	5.5
1.061	Decision Matrix (Design)	2	7.5
1.071	RADD	3	10.5
1.081	Analysis	10	20.5
1.091	Performance Predictions	1.5	22
1.101	Draft Proposal	12.5	34.5
1.111	Budget	0.5	35
1.121	Schedule	2	37
1.131	Drawings	4	41
1.141	Presentation	2	43
1.151	Completed Proposal	12	55
	Winter Break		55
	Winter Break		55
	Winter Break		55
2.001	Winter		55
2.011	Submit Updated Proposal	1	56
2.021	Order Parts	0.5	56.5
2.031	Promo Video	3	59.5
2.041	Webpage	2	61.5
2.051	Construction	6	67.5
2.052	Cutting Tubing to Length	0.5	
2.053	Weld Tubing Sections to Form Lower Control Arm	2	
2.054	Weld Brackets to Lower Control Arm	2	
2.055	Weld Brackets to Frame	0.5	
2.056	Drill Lower Control Arm holes (3 x 2)	1	
2.061	Construction (Overage)	6	73.5
2.071	Assembly	6	79.5
2.072	Bolt Lower Control Arm to Frame	0.5	
2.073	Bolt Lower Control Arm to Coilover	0.5	
2.074	Bolt Axle Mount to Control Arm	0.5	
2.075	Overage	4.5	
2.081	Completed Device		79.5
	Spring Break		79.5
3.001	Spring		79.5
3.011	Test 1	6	85.5
3.021	Test 2	6	91.5
3.031	SOURCE	12	103.5



Key: Incomplete Blue; Red Milestone; Completed Green

Task 1.011 ....Problem Statement.. (1 hour)

This was the initial problem statement created for the project which drove the design of the suspension.

Task 1.021 ....Problem Go/No Go .... (1 hour)

Initial approval of project from advisors.

Task 1.031 ....Function Statement .... (1 hour)

Function statement to place qualifiers on initial problem statement to drive design.

Task 1.041 ....Requirement Statements.. (0.5 hour)

Requirement Statements to set limits on the extent of the project.

Task 1.051 ....Evaluation Resources.. (2 hour)

Evaluation of resources (manufacturing, labor, etc) available for the project.

Task 1.061 ....Decision Matrix.. (2 hour)

Evaluation of major options for project design and direction.

Task 1.071 ....RADD.. (3 hour)

Process in design and analysis of major systems for the project.

Task 1.081 ....Analysis .... (10 hour)

Analysis performed for design by hand and in Solidworks.

Task 1.091 ....Performance Predictions .... (1.5 hour)

Through analysis, setting performance expectations for the design.

Task 1.101 ....Draft Proposal .... (12.5 hour)

Continued development of the proposal document.

Task 1.111 ....Budget.. (0.5 hour)

Budgeting parts, labor, material, and miscellaneous costs required for the completion of the project.

Task 1.121 ....Schedule... (2 hour)

Continued development of the relative timing as the project goes through various stages.

Task 1.131 ....Drawings .... (4 hour)

Solidworks drawing and assembly development.

Task 1.141 ....Presentation... (2 hour)

Presentation of the current draft of the proposal for critique.

Task 1.151 ....Completed Proposal .... (12 hour)

Peer reviewed proposal.

Task 2.011 ....Submit Updated Proposal..(1 hour)
Make necessary revisions from critique to update proposal.

Task 2.021 ....Order Parts...(0.5 hour)
Place orders with parts suppliers and material warehouses.

Task 2.031 ....Webpage...(2 hour)
Create and update website for project with current information.

Task 2.041/051.............Construction ....(12 hour)
Continued construction of the lower control arms as the parts become available. Lower control arm must be cut to length, notched, welded and drilled to fit the mounting hardware. Mounting hardware must be welded to the lower control arm and existing vehicle frame. It should be noted that the actual time approximated for welding the lower control arms is 2 hours as stated previously. This is a task that is necessary to source a professional welder for safety.

Task 2.061 ....Assembly...(6 hour)
Assembly of the rear subframe and installation of mounting hardware on the existing vehicle frame.

Task 3.011 ....Test 1...(6 hour)
Post-assembly testing to measure axle travel.

Task 3.021 ....Test 2...(6 hour)
If the vehicle state allows it, testing while under movement.

Task 3.031 ....SOURCE ....(12 hour)
Presentation of the completed project at the SOURCE conference.

15) Appendix F – Expertise and Resources

Manufacturing support provided by the following:

Central Washington University Vehicle Club

Rod Helmuth – Owner, Squires Machine of Monroe, WA

Jose Bejar, Lab Assistant

Matt Burby, Lab Technician

Online parts resources:

http://www.summitracing.com

http://empi.com

http://metalsupermarkets.com

Information on Electrathon Vehicle Frames and Suspension:

http://www.electrathonamerica.org

16) Appendix G – Testing Data

Testing Data					
Date performed:					
Location performed:					
Perfomed by:					
Loading (lb)	Vehicle Frame Height (in)	Angle (Control Arm to Frame)	Deflection	Failure?	Comments
0					
100					
200					
300					
400					
500					
600					
700					
800					
900					
1000					

17) Appendix H – Evaluation Sheet

Evaluation			
Axle Travel			Comments
Initial	Calculated	Actual	
Loading			
Initial	Calculated	Actual	
Failure			
Initial	Calculated	Actual	
Initial	Calculated	Actual	
Initial	Calculated	Actual	

18) Appendix I – Testing Report

Testing Report
Suspension for Electrathon Vehicle
MacKenzie Angeledes – CWU ID: 24656877
angeledesm@cwu.edu
Mechanical Engineering Technology – Spring 2016

Introduction:

This testing report is for the rear suspension project for the Central Washington University Electrathon Vehicle. The requirements of the project require that the suspension allows a minimum of 3 inches of travel at the driven rear axle relative to the ground or horizontal reference surface (for example, the lower bars of the vehicle frame). The parameters of interest in this requirement include an application of force to the vehicle axle causing the coil-over shock to be compressed, allowing travel of the axle. Predicted performance, as calculated in the complete project report, the approximate maximum travel under a full shock loading is 6.89 inches (full compression of the shock). Data will be acquired by way of a tape measure and weighted applied loads to the vehicle. Testing for this experiment will occur during the weekend of April 9th 2016.

For Test 2:

The system, as noted during testing of the suspension travel, has a tendency to travel left-to-right (horizontally) in excess. Initial values measured are shown to be 1 inch. After the values for horizontal travel are collected, a Panhard-bar will be created to tie the system together and limit horizontal movement. The goal is to reduce the movement by 50% - or 0.5 inches. Testing for this experiment will occur during the weekend of April 23rd 2016.

Method and Approach:

Resources for this test will be personal equipment provided at no cost. The data, as mentioned above, will be collected by tape measure. Equipment includes ratcheting straps, jack stands, a hydraulic vehicle jack (to apply force), and miscellaneous other tools as needed.

The frame will be fixed using ratcheting straps and jack stands, and a hydraulic vehicle jack will be used to apply force to the vehicle axle to simulate a load. To ensure that the shocks will not fail, a maximum of force of 700 lb per shock will not be exceeded.

While this is not a particularly precise experiment, it will be an accurate representation of what the suspension system is capable of. A simulated vertical load will be similar to what the vehicle would experience under real-world competition settings. Data will be collected by hand using a tape measure, and then recorded into a spreadsheet using Microsoft Excel where it can be stored, manipulated, and analyzed.

For Test 2:

Resources for this test will be personal equipment provided at no cost. The data, as mentioned above, will be collected by tape measure. Equipment includes jack stands, planks of wood, and a tape measure or ruler.

The frame will be suspended under the front of the frame by jack stands, and human weight will be used to apply force to the vehicle axle to simulate a horizontal load. While this is not a particularly precise experiment, it will be an accurate representation of what the suspension system is capable of with and without a Panhard-bar. Data will be collected by hand using a tape measure, and then recorded into a spreadsheet using Microsoft Excel where it can be stored, manipulated, and analyzed.

Test Procedure:

Testing is scheduled to occur during the weekend of April 9th 2016. It will take approximately 2 hours and will be performed in a personal garage in Auburn, Washington. Please note that the Gantt chart shown below has the schedule slated for 6 hours for each test. However, barring any unexpected failures, the actual experiment will take appreciably less time.

1. Fix the vehicle frame in place by way of ratcheting straps.
2. Position vehicle jack under the axle of the vehicle (use wood blocks as necessary to safely position jack and axle).
3. Take initial measurement of axle relative to the horizontal reference point (ground or vehicle frame horizontal bar).
4. Apply force to the axle by using the vehicle jack.
5. Take measurement of axle relative to the horizontal reference point.
6. Repeat as necessary until maximum displacement is achieved.

In order to ensure safety of the test operators, personal protective equipment (safety glasses, gloves, etc.) will be in place. Potential failures could result in flying pieces, though the nature of the experiment should ensure that there are no failures.

For Test 2:

Testing is scheduled to occur during the weekend of April 23rd 2016. It will take approximately 2 hours and will be performed in a personal garage in Auburn, Washington. Please note that the Gantt chart shown below has the schedule slated for 6 hours for each test. However, barring any unexpected failures, the actual experiment will take appreciably less time.

1. Suspend the front of the frame using two jack stands.
2. Apply a force horizontally to the frame causing a horizontal deflection in the initial direction
3. Take initial measurement of the frame relative to a vertical reference point (upright bars of the frame)

4. Apply a force in the opposite direction
5. Take measurement of horizontal travel to the vertical reference point.
6. Repeat as necessary until displacement is recorded.
7. Repeat process using a Panhard-Bar installed on the suspension system.

In order to ensure safety of the test operators, personal protective equipment (safety glasses, gloves, etc.) will be in place. Potential failures could result in flying pieces, though the nature of the experiment should ensure that there are no failures.

Deliverables:

The maximum horizontal axle travel is calculated to be 6.89 inches. The actual value was determined to be 4.5 inches when the vehicle frame bottomed out. This is a difference of 2.39 inches. However, it exceeds the required value of 3 inches by 1.5 inches. This meets the success criteria outlined in the full project report.

To conclude, the purpose of this test was to determine the horizontal displacement of the rear axle of the electric vehicle when under an applied load.

For Test 2:

The horizontal travel measured without the Panhard-bar was measured as 1 inch. To meet the goal of a 50% reduction in travel, the measured distance for a successful trial was calculated to be 0.5 inches. After installing the Panhard-bar onto the system, the measured distance was less than 0.125 inches. This is a 97% reduction, indicating success. The actual measured distance may have been less, but the amount of movement was not measurable – indicating less than one-eight inch of movement

To conclude, the purpose of this successful test was to determine the horizontal displacement of the suspension system with and without a Panhard-bar.

Appendix for Testing Report:

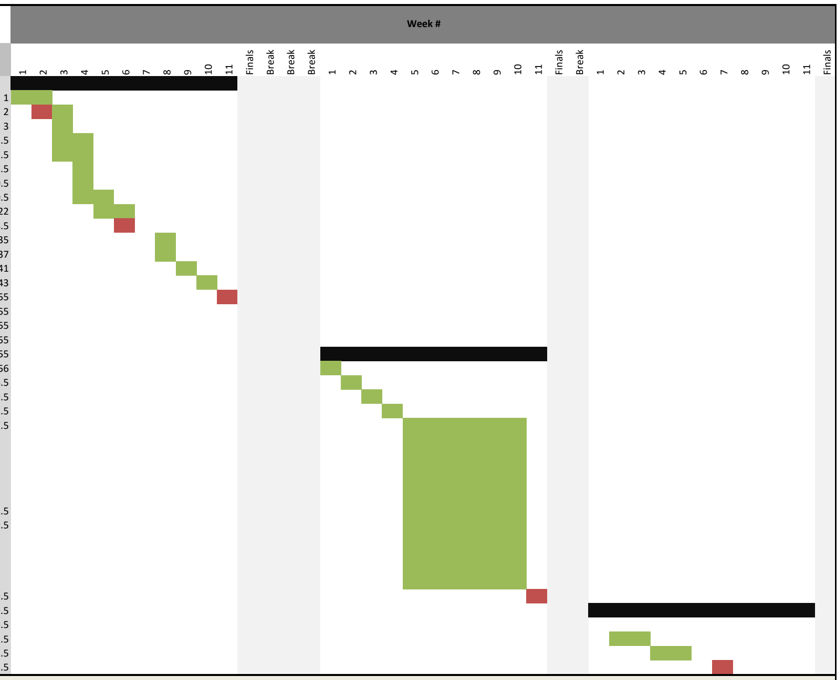
Data forms:

Testing Procedure 1			
All units are in inches unless otherwise stated			
Measurements and Reference Values		Percent Difference (to req'd travel)	Weight (lb)
Required vertical axle travel reference	3	0	
Initial horizontal reference measure	4.5		0
Measurement 1	3.75	25%	140
Measurement 2	3.5	33%	210
Measurement 3	2.2	77%	465
Measurement 4	0	150%	575

Test 2 - Horizontal Displacement of Vehicle Suspension					
Initial Measurement (inches)					
	Trial 1	Trial 2	Trial 3	Average	**System Average**
Passenger Side	1	1	1	1.00	**1.00**
Driver Side	1	1	1	1	
Measurement with Panhard-Bar Installed (inches)					
	Trial 1	Trial 2	Trial 3	Average	**System Average**
Passenger Side	0.125	0.125	0.125	0.125	**0.125**
Driver Side	0.125	0.125	0.125	0.125	

Gantt Chart:

Priority	Task	Time (hr)	Total (hr)
1.001	Fall		
1.011	Problem Statement	1	1
1.021	Problem Go-No Go	1	2
1.031	Function Statements	1	3
1.041	Requirement Statements	0.5	3.5
1.051	Evaluation Resources	2	5.5
1.061	Decision Matrix (Design)	2	7.5
1.071	RADD	3	10.5
1.081	Analysis	10	20.5
1.091	Performance Predictions	1.5	22
1.101	Draft Proposal	12.5	34.5
1.111	Budget	0.5	35
1.121	Schedule	2	37
1.131	Drawings	4	41
1.141	Presentation	2	43
1.151	Completed Proposal	12	55
	Winter Break		55
	Winter Break		55
	Winter Break		55
2.001	Winter		55
2.011	Submit Updated Proposal	1	56
2.021	Order Parts	0.5	56.5
2.031	Promo Video	3	59.5
2.041	Webpage	2	61.5
2.051	Construction	6	67.5
2.052	Cutting Tubing to Length	0.5	
2.053	Weld Tubing Sections to Form Lower Control Arm	2	
2.054	Weld Brackets to Lower Control Arm	2	
2.055	Weld Brackets to Frame	0.5	
2.056	Drill Lower Control Arm holes (3 x 2)	1	
2.061	Construction (Overage)	6	73.5
2.071	Assembly	6	79.5
2.072	Bolt Lower Control Arm to Frame	0.5	
2.073	Bolt Lower Control Arm to Coilover	0.5	
2.074	Bolt Axle Mount to Control Arm	0.5	
2.075	Overage	4.5	
2.081	Completed Device		79.5
	Spring Break		79.5
3.001	Spring		79.5
3.011	Test 1	6	85.5
3.021	Test 2	6	91.5
3.031	SOURCE	12	103.5



Key: Incomplete Blue; Red Milestone; Completed Green

Procedure Checklist:

Test 1:

- Suspend Vehicle Frame
- Place board for use
- Take initial measurement for reference
- Apply weight to frame
- Take measurement
- Repeat measurements with different weights
- Unload vehicle frame from jack stands safely

Test 2:

- Suspend Vehicle Frame
- Take initial measurement for reference
- Apply weight to frame
- Take measurement
- Repeat measurements for validity
- Unload vehicle frame from jack stands safely

19) Appendix J – Resume, Curriculum Vitae

MacKenzie Angeledes

2101 V Street Northwest, Auburn, Washington 98001
MAngeledes@gmail.com (253) 670-1900

Objective

To acquire an internship in a mechanical-engineering related field with opportunities for professional and personal growth.

Educational Experience

Central Washington University - Ellensburg, Washington
September 2013 - Current
Mechanical Engineering Technology (Undergraduate)

Pierce College - Puyallup, Washington
September 2008 June 2010
Associate of Arts Degree (Running Start Participant)

Puyallup High School – Puyallup, Washington
September 2007 – June 2010
High School Diploma

Professional Experience

FedEx Office – Kent, Washington
February 2011 – August 2013
Customer Service Associate (2011-2012)
Handle all aspects of the customer service experience – from manning the entrance to checking shipping logs and customs clearances.
Production Operator and Back-up Courier (2012-2013)
Produce, quality-check, package, and deliver large orders for FedEx Office retail centers. Deliver time sensitive materials and orders directly to clients, some of which require security clearances.

Sign Stop Northwest – Federal Way, Washington
June 2008 – Current
Graphic Designer, Production Operator, and Installer
Family-owned sign company involved in cradle-to-grave graphic installation.

Magik Foods – Seattle, Washington
June 2008 – September 2010
Hawker
Engage customers in fast paced retail sales, manage employees, take inventory counts, and report sales figures.

Skills

- Excellent time management skills
- Comfortable in all work environments – fast-paced retail fronts to isolated production stations
- Proficient in the Microsoft Office Suite, Adobe Creative Suite, SolidWorks, and AutoCAD
- Exceptional language, teaching, and learning abilities
- Practical and conceptual analysis competence

Accomplishments and Community Involvement

- Certified SolidWorks Associate (CSWA, 240/240) - June 2014
- Pierce College Dean's List – Multiple Quarters
- Pierce College President's List – Multiple Quarters
- Central Washington University Dean's List – Spring Quarter 2014
- Volunteer – VEX Robotics Competition at Central Washington University – December 2014
- Outlaw Compact Auto Racing – Board Member (2008 – Current)

- References available upon request -