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Composite Snowmobile Suspension Assembly

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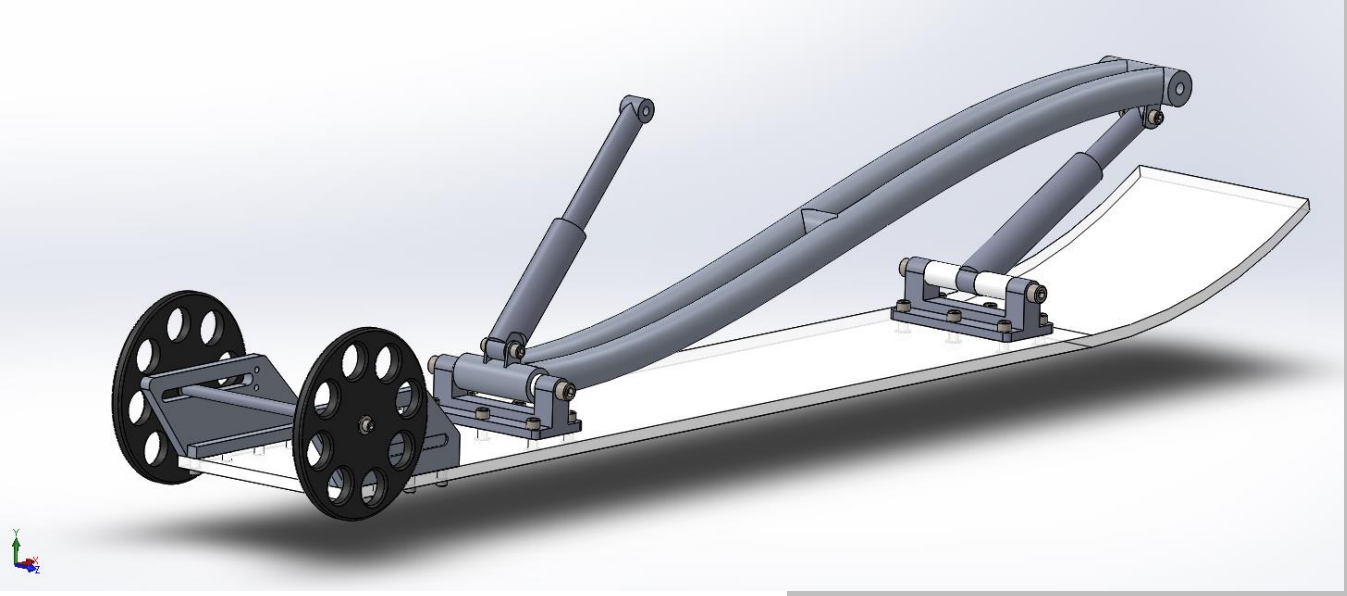
2015

COMPOSITE SNOWMOBILE SUSPENSION ASSEMBLY



Michael Villarma

Central Washington University –
Mechanical Engineering Technology

1/25/2015

ABSTRACT

Snowmobile technology is constantly evolving and incorporating new ideas into products for the consumer to enjoy. After market manufactures are competing among themselves for the top position in suspension technology, yet none have broken the boundaries and really pushed to the next level, until now. The objective of this design was to provide the consumer with a lightweight and simplistic suspension system that would meet the performance demands of the consumer market. In order to meet the strength to weight ratio requirements of this design, composites were implemented to provide the necessary structural strength for the overall system. A one piece carbon fiber sub frame is the first of its kind and provides a foundation for all other components to fasten too. By replacing structural materials that were initially made from a high strength steel with a light weight carbon fiber, the weight savings are substantial and can be observed throughout the system. In order to determine the success of this design, a series of tests both on and off the vehicle were performed to accurately describe the behavior of the material under load. 3 point bending, load analysis, and weight comparison are examples of the test processes that will provide conclusive data on the overall performance of this design.

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INTRODUCTION

Motivation:

This project was motivated by a need for a lightweight rear suspension system that meets snowmobile performance standards without sacrificing strength and dependability. There are several companies producing bolt in aftermarket kits, but none that combine the use of composite materials and alloys. We hope to design a suspension system that will sustain the abuse of heavy impacts and sudden changes of load distribution without the use of a heavy gauge steel.

Function Statement:

This device will allow for a controlled transfer of energy between the ground and chassis of a snowmobile. The applied load from uneven terrain will be distributed along the length of a one piece composite backbone. The forces exerted on the backbone will be transmitted directly to the shock absorber and aluminum link arm assembly through front and rear mounts. The shock absorber will control the rebound and dampening properties associated with the forces. This device needs to perform the above tasks while fulfilling the requirements listed below.

Requirements:

In order for this device to function as designed, there are some basic requirements that need to be fulfilled:

- Must weigh less than the Arctic Cat M Series OEM suspension system of 45 lbs.

- Sustain maximum load in temperatures of 32˚F +/- 32°
- Withstand forces up to 300 Kilo Newton's in vertical drops.
- Must transfer load between ground and chassis smoothly.
- Bolt into existing chassis (2006-2011 Arctic Cat M-Series) without alteration.
- Withstand track speeds of 50+ mph.

Engineering Merit:

Several aspects of this design will require a large amount of calculated analysis. Forces and moments in equilibrium, $\sum \mathbf{F_x=0}$, $\sum \mathbf{F_y=0}$, $\mathbf{\Sigma M=0}$ [1], will be utilized to determine the reaction forces at the given mounting locations. It will be crucial to know the maximum forces applied at these points so that during our design we can determine the dimensioning of mounting brackets. This will ensure the structure will not fail under load. The normal stress, $\boldsymbol{\sigma = P/A}$, that occurs in the backbone sub structure will be calculated and accounted for so that during the construction phase of our backbone, we will know the appropriate material size, layering pattern, and tolerances at which the backbone will need. In addition to normal stress, the shear stress in crucial areas such as the pivot point on the rear arm (*See Appendix A, pg. 24*). The shear stress, $\boldsymbol{\tau = V/A}$, of the hardware used in this pivot point will need to be calculated to determine the quality and hardness of the materials used for the pin. The flexure formula, $\boldsymbol{\sigma = Mc/I}$, will be applied in the design of the composite backbone to account for the bending stress that will occur.

Scope of Effort:

We will be designing all features of this device except for the shock absorber and hardware which will be provided. Modern shock technology is a science in its own and we wanted to focus more on the structural and geometry aspects of this design.

Success Criteria:

The success of this device will be based on the requirements fulfilled and performance of the system during standard vehicle use. Performance of device during use will be observed through Point of View cameras which can be further analyzed to determine components or areas that need improvement. A rider survey will also be conducted amongst people with a riding back ground. A rubric will be constructed where participants can rate performance characteristics 1-10 of the system *(see Appendix pg. 45).*

Benchmark:

There are multiple companies making aftermarket suspension assemblies that improve the performance over the stock ride. K-MOD [2] suspension assemblies is one of the top competitors in the market and provide and excellent product for the consumer. However, they have still retained the scissor style linkage that requires several more components. By eliminating the need for more components, we can construct a lightweight system with the structural properties required to perform adequately.

Optimization:

By incorporating the usage of composite materials, we will replace components that are constructed of allow materials, with a composite, optimizing the strength to weight ratio of the overall structure. We will do this through the use of static, dynamic, and stress analysis methods to determine the proper dimensions of the system.

The geometry of suspension systems on the market require the use of several linkage assemblies which introduce friction, binding, and alignment problems due to use. We plan to optimize the overall geometry of this system by simplifying the linkage systems for a smoother overall transition between maximum and lower limits.

DESIGN & ANALYSIS

Approach:

This design was inspired by the need for a simple, lightweight suspension assembly designed for the backcountry. In order to accomplish this goal, a composite material was required and a simplification of linkage components and geometry alterations would need to occur. The results should yield a lighter overall structure with smoother transitions zones. Multiple sketches were created until a final drawing was approved for analysis.

Description:

Our design will consist of four main components:

The backbone will be made of a carbon fiber reinforced composite, to ensure that we are providing enough rigidity to support the assembly. This component will need to withstand the distributed load due to impact, provide an attachment point for link arm and shocks, and support a rotational track speed up to 70+ mph. Our analysis will be based off a 100 foot or 33 meter drop resulting in a 300 KN impact force, which will be used as a designated impact force the system can withstand.

The mounts that will be machined from a 6061-T6 4” x 3” solid aluminum block. The front and rear mounts will saddle the front and rear shocks and allows the link arm and shock absorbers to be fastened to the backbone. The mounts will be fastened to the backbone using several socket head bolts and bushings (*see Appendix B, pg. 24*).

The link arm, which connects the rear mounting location to the forward mounting location will be made of 6061-T6 1 ½” aluminum extruded tubing. This component will need to be welded using a tungsten inert gas system and will be coated with a corrosion resistant powder coat. The link arm is subjected to axial forces and will be engineered to withstand the maximum force at impact.

For rebound and dampening control, we will be using two Fox Shox Air Float shocks that are adjustable with air pressure. These shocks will provide us with the adjustability and control we will need in order to ensure proper functionality. In order to keep the project within scope, it was best to outsource this portion of the suspension assembly.

Renderings:

Figure 1 shows the original sketch from first brainstorming about the design. From this first initial design, we realized there would be problems with performance characteristics that we needed to meet. We wanted to incorporate a single shock design that allowed the user to dial in his riding style by simply increasing or decreasing preload in the shock.

We soon realized that in order to meet the performance standards set by the market, a dual shock design was necessary. Upon maximum impact, the front mount undergoes approximately a 190,000 N impact force (*Appendix A pg.16).* In order to transfer this intial load smoothly, we are going to need to utilize the full travel length of standard shock in this position. The unibody backbone was essentially altered to accept a dual shock design, and will give us a better transition between fore and aft movement.

Performance Predictions:

This early in the development stage makes it difficult to predict the performance characteristics of our design. However, there are some predictions about the overall performance of the system that I feel there is enough information to provide an accurate prediction.

1. Utilizing the 3D solid modeling program SolidWorks, we were able to determine the approximated mass of each individual component by inputting the density of the material used. If we add the masses of each component we should have a rough approximation of the total weight of our assembly which is 35 lbs. (*See Appendix A, pg. 48*).

2. The suspension assembly will be exposed to temperatures as low as 0˚F. This is a concern because possible damage to the carbon fiber's microstructure could occur resulting in failure of the component. However, carbon fiber is used in several different applications where temperatures are an obstacle to overcome. A thesis paper on "The effects of extreme low temperature on composite materials" [3] was presented at the University of New Orleans which goes into great depth on composite materials at cryogenic temperatures. An example of this was a NASA project for a re-entry vehicle. Composites were used for fuel tanks containing "liquid oxygen and hydrogen at cryogenic temperatures. (e.g. -150˚C)" [3]. I provided a graph that illustrates the effects of cryogenic temperatures on composites *(Appendix F, pg. 43).* An interesting observation was the increase in compressive strength as the temperatures got colder. With the extensive research conducted in Kichhannagari's thesis paper, I am confident in predicting that our backbone, when subjected to 0˚F, a higher temperature than

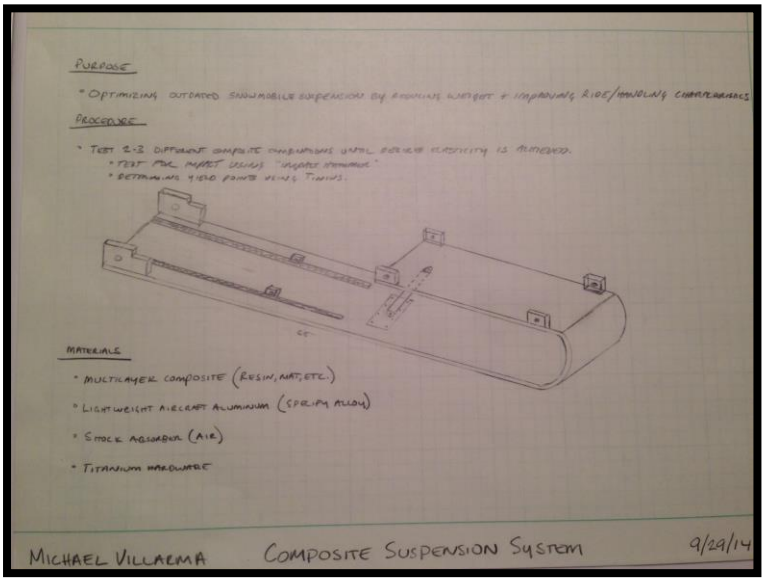


Figure 1: Initial design that was later changed to meet performance requirements.

cryogenic temperatures (-325˚F) will not yield any fracturing in the microstructure of the carbon fiber.

Description of Analyses:

Backbone:

There are several analyses procedures that will occur throughout this process and we first start with determining the maximum impact force at which our suspension assembly will be subjected to. This force can be determined through analysis by utilizing the Energy equation [4], K.E. + U + W = 0 (*Appendix A, pg. 16*) and the relationship between Work and Kinetic energy, W=ΔK.E. The maximum impact force will be calculated from a 33m fall giving us a value for F_{max} of 300 KN. The impact force, is distributed along the bottom side of the backbone which will have 1.65 meters in normal contact with a flat surface. This gave us a 175 KN/m distributed load that we could analyze for internal forces, locations of key point loads, and internal moments.

We constructed a simple static analyses (*Appendix A, pg. 17*) of our suspension assembly to determine reaction forces at mounting locations. We modeled our analysis similar to a beam for simplification purposes. Summing forces in the X and Y direction, we were able to determine the X and Y components of the forces at specific mounting locations. The forward mounting bracket will undergo a 191 KN normal force, while the rear bracket must withstand up to a 98 KN force normal to the backbone.

The maximum shear and moment within the backbone structure is required in order to utilize our stress equation, **σ = Mc/I** [1]**.** Using the Method of Sections [1], a technique used in static analysis, the backbone was sectioned off at specific locations to determine the internal shear and moments at those locations. Our maximum shear (89 KN) and bending moment (29 KN*m) occur at the forward mounting bracket. A shear and moment diagram was constructed (*Appendix A pg. 20*) for a graphical representation of the forces and moments within the backbone.

The top and bottom surfaces will have the highest amounts of stress and gradually decline towards the center of the material (*see Appendix A pg. 21*). We measure this location from the X axis of our backbone and use this as our value for **c** in our stress formula. For a starting point, we are going to first analyze a ½" thick backbone structure, which will give us **c = .25".**

The moment of inertia of the backbone will now need to be determined using the same ½" thickness as used for determining **c.** The backbone is rectangle in shape measuring 9.25" wide (X direction) and .5" tall (Y direction). To calculate the moment of inertia, we use the equation $\frac{1}{12}bh^3$ [5], where "b" is equal to 9.25" and "h" is equal to .5". Plugging these numbers into the equation, we get a result of $I_{B.B.}$=.09635 in^4.

Once all the factors for the stress formula were determined, a maximum bending stress was found equal to approximately 687 KSI (*Appendix A pg. 21*). Using this information, we were able to determine a suitable material to use for the construction of the backbone. Hexcel im7 carbon fiber with a ½" Aramid honeycomb core has an ultimate tensile strength of **747 KSI** [6] which exceeds the maximum bending stress of **687 KSI**. This material in our application with yield a factor of safety of 1.08.

Link Arm:

The link arm will be subjected primarily to axial forces during operation. These forces will induce an axial stress on the link arm and must be accounted for in order to optimize the link arm for weight and strength characteristics. Our analysis begins by examining joint A (*Appendix A pg. 22*) where the link arm, rear shock, and rear mount intersect. Equilibrium equations provided the necessary tools to determine the axial force the link arm is subjected to during maximum impact. The axial force in each member of the link arm is equal to **36 KN**. This force was then used to determine the axial stress, **σ = P/A** in each member of the link arm. 1" O.D. by .125" thick tubing was the first material size we examined and calculated the stress to be **305 MPa** (*Appendix A, pg. 23*). We were interested in using 6061-T6 extruded aluminum tubing for the construction of the link arm due to budget limitations. This material has an ultimate tensile strength of **290 MPa** [7], less than the required value for the 1" tubing. It was necessary at this point to decrease the axial stress in the link arm by increasing the cross sectional area to ensure at least a factor of safety of 1. This was done by increasing the outside diameter of the tubing to 1.5". By increasing the diameter, we managed to lower the stress by **33% to 197 MPa**. This axial stress is below the ultimate tensile strength for 6061-T6 and provides a factor of safety of 1.5.

Front and Rear Mounts:

The purpose of the front and rear mount is to transfer the impact load from the backbone directly to the shocks. We will model the mounts as a rigid component connected to the backbone that is subjected to a shearing force. Our main concern with the mounts is the shear force that is expected to occur at the mount locations. The largest shearing force induced by an impact occurs at the front mount and will result in a **213 KN** force in the normal X direction. There is a total of 6 bolts securing our front mount to the backbone, and each of these bolts will be subjected to a **36 KN** shearing force (*Appendix A, pg. 25*). We used the shearing force in each bolt and divided that force by the area of the bolt to determine the shear stress in each bolt. Using the cross sectional area of a 3/8" and the shear force induced during impact on a single bolt, we determined the shear stress of this bolt to be **758 MPa** or approximately **125 KSI** (*Appendix A, pg. 25*). The stress caused by shear requires the use of 6-3/8"-16 x 1" Grade 8 bolts with nyloc fasteners with a yield stress of **130 KSI**. With this application we will have a factor of safety for the front mount bolts of 1.1.

Failure Modes:

During normal operation of the device, a large amount of stress will be induced to the carbon fiber backbone structure. This was taken into consideration during the design and analysis phase of this project. However, our analysis is simply a prediction of how the component will perform, not the actual performance. There are several variables such as weather conditions the device may experience, terrain obstacles (e.g. rocks, trees), that cannot be accounted for. If the suspension assembly enters failure mode, the first component to fail will be the backbone structure. The component will fail due to exceeding the limit of maximum bending stress of our carbon fiber structure (*see Appendix pg. 21).* Others have conducted similar research by subjected composites structures to bending stress such as S. Kichannagari. In the research conducted by S. Kichannagari's, the composite structure yielded at approximately 100 KSI *(see Appendix F pg. 43).* In our analysis, during maximum impact the backbone would be subjected to nearly 800% more stress than the composite material Kichannagari and his colleagues tested [3]. If our material performs in a similar manner, we would expect a fracture along the tail end of the backbone component after the material yielded at 100 KSI.

METHODS & CONSTRUCTION

Exoskeleton:

We will begin construction of our prototype by first assembling an exoskeleton representing the shape of our backbone. The exoskeleton will be constructed from plywood. It is important that the curvature of the mold matches the curvature of the existing rails that are currently used in the stock rear suspension. This will account for no change in the approach angle of the track allowing us to use the original track. To do so, the curvature of the existing rails will be transferred to a large sheet of paper and cut out. Three runners will be cut out of the ½ inch plywood. These runners will be capped with a sheet of ¼ inch plywood the full length and width of the backbone. In order to produce a clean, smooth and desirable mold, we will need to prepare the exoskeleton for fiberglass. We will do so by following these guidelines:

- All surfaces must be smooth and free of slivers, dimples, or debris.
- Sharp edges and corners should be rounded to ensure the mold will release from the exoskeleton without becoming damaged.
- A wax or similar agent will be applied to the exoskeleton to help with releasing the mold.

Mold:

The mold will be constructed primarily from fiberglass and resin. Two layers of cloth woven mat will be cut in the full length and width of the backbone. These layers of cloth will provide the strength needed to sustain the carbon fiber that will be applied to the mold. Once the fiberglass is cured, it will be removed from the wooden exoskeleton and begin being prepped for the carbon fiber. Any flaws within the mold will need to be sanded and smoothed.

Backbone:

We will be using 3 basic materials in our composite backbone structure.

- Polyurethane Matrix
- Carbon Fiber Cloth
- Aramid Honeycomb Core

In order to develop the strongest bond of our composite materials, we will need to ensure:

- Proper mixing ratios and cure times must be followed
- Carbon fiber cloth must be fully saturated with polyurethane resin
- All presence of air must be removed from system.

The first step to beginning the construction of the backbone is to cut our material to size. The carbon fiber will need to cover the entire length and width of the backbone. When cutting the material, a + ½ inch tolerance will be added to the length and width dimensions *(see Appendix B pg. 33)*. This is required to ensure a full overlap of material around the perimeter of the backbone. We can now begin laying our composite materials into our mold (see footnote [1]). This procedure will begin with a layer of polyurethane resin, followed by a layer of Hexcel IM7 [6], aramid honeycomb core, and another layer of the carbon fiber. Once all cloth has been saturated, the mold will be placed inside the vacuum bag to remove air from system. Allow the mold to remain in the vacuum bag until proper cure time is reached.

[1] Proper ventilation and respiratory precautions must be taken when working with polymer resins.

After curing, the backbone will be removed from the vacuum bag and inspected. We will be looking for imperfections (e.g. air bubbles, unsaturated material) and trimming edges if necessary.

Link arm:

The link arm will be constructed from 6061-T6 1 ½" O.D. x .125 thick extruded aluminum tubing. Tubing will be cut to the required dimensions (*Appendix B, pg. 37*) An AC/DC TIG Welder with a tungsten electrode and 4043 welding rod as a filler will be used to assemble the link arm. All joints require solid welding (no skip or pass) and will need to be properly cleaned before finish coat is applied. Once the link arm passes dimensional inspection, it will be powder coated with a gloss black finish to increase corrosion durability as well as visual appeal.

Mounting Brackets:

In order to securely fasten our backbone structure to the chassis of our snowmobile, we will be machining brackets from a 6061-T6 aluminum alloy for structural and strength purposes. The material will be milled from a solid 4" x 3" block of aluminum. The block will be cut to the approximate size the drawing calls for using a horizontal band saw. We can then apply a layer or layout dye to our part and dimension accordingly. Once the layout lines are scribed onto the material, we will begin milling the mount in one of the milling machines available in the machine lab.

Drawing Tree:

In Figure 2, a breakdown of assemblies and subassemblies is given to illustrate the construction and assembly of our suspension system.

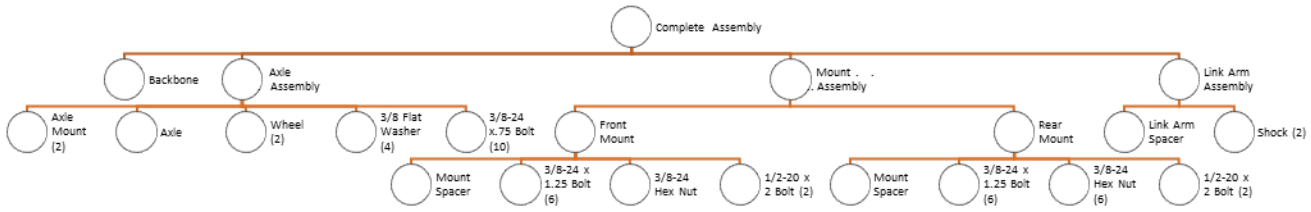
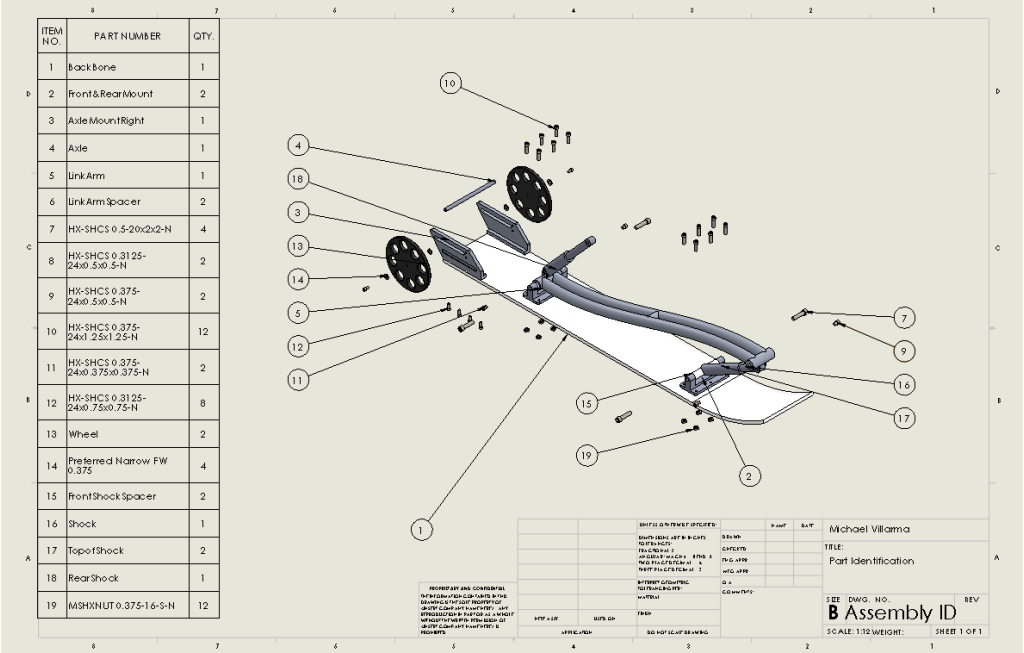


Figure 2: A drawing tree is useful for communication between the designer and the builder. A large scale version can be found in Appendix B.

Parts List and Labels:

A detailed parts list can be found in Appendix C that contains all of the information necessary to complete the build. In Figure 2, assembly and sub-assembly parts are labeled with an ID code and referenced to a table for a detailed description of our system.



ITEM NO.	PART NUMBER	QTY.
1	Back Bone	1
2	Front & Rear Mount	2
3	Axle Mount Right	1
4	Axle	1
5	Link Arm	1
6	Link Arm Spacer	2
7	HX-SHCS 0.5-20x2x2-N	4
8	HX-SHCS 0.3125-24x0.5x0.5-N	2
9	HX-SHCS 0.375-24x0.5x0.5-N	2
10	HX-SHCS 0.375-24x1.25x1.25-N	12
11	HX-SHCS 0.375-24x0.375x0.375-N	2
12	HX-SHCS 0.3125-24x0.75x0.75-N	8
13	Wheel	2
14	Preferred Narrow FW 0.375	4
15	Front Shock Spacer	2
16	Shock	1
17	Top of Shock	2
18	Rear Shock	1
19	MSHXNUT 0.375-16-S-N	12

Figure 3: Individual components are labeled and referenced in a table for easy viewing.

TESTING METHODS

Material Testing:

Prior to construction, a series of bending tests will be conducted using the Instron 1011 equipped with a 3 point fixture used for bending analysis. Three core samples will be tested using different combinations of Hex Cell ½" board, carbon fiber weave, and polymer resins. In order to determine the appropriate combination of mat and resin, the three samples will be subjected to a maximum bending moment that will result in a "failure" point that correlates to that moment. Samples will begin with 1 layer of mat. Our bending moment equation **σ = Mc/I** can now be used to find the maximum bending stress of each sample. The sample with the combination that exceeds the maximum bending stress (687 KSI), will move on to the next testing parameter.

All materials will be subjected to a low temperature environment (32°F $\frac{+0}{-32}$). The approved composite combination will now be placed in a freezing environment for 3-5 hours and monitored. The component will then be removed from the freezer and subjected to the same tests as described above. The results will then be recorded for comparison.

Performance Testing:

Weight Test-

This test will consist of a weight comparison between a standard Arctic Cat OEM suspension assembly vs. the composite suspension assembly we designed. A digital scale accurate to the nearest tenth of a pound will be used for measuring. The scale must be within the last calibration date and have a way to suspend each assembly.

Fitment Test-

This test will be judged based on the ease of installment into a 2005-2011 Arctic Cat M series chassis. One snow machine is available at this time for testing. We are interested in time required for install, clearance issues, and ease of install. To document this data, we will be performing this install while a stopwatch records start to finish time.

Load Testing-

The backbone of our suspension assembly is designed to withstand a 100 foot vertical drop. In some cases, this type of impact occurs in extreme circumstances. However, in order to safely test the durability of our design, we will not be undergoing 100 foot impacts. Several hours of testing will be conducted in various conditions in the Central Washington area wilderness. We will capture footage of the suspension in motion using POV cameras to evaluate the performance of the suspension.

Endurance Testing-

In order to this test to be considered successful, a total of 5 hours of riding time must be achieved without failure.

PROJECT MANAGEMENT

In order to organize this project, a budget and schedule have been implemented to ensure overall success. With a project of this size, there is a risk that is taken which may induce sudden changes to the schedule and or budget. These unexpected changes will be accounted for in our schedule with "catch-up days".

Budget:

An itemized parts list was created with designated call out numbers for reference to establish a tentative budget for this project. The itemized list can be viewed in Appendix C. Call out numbers refer to the number associated with that part in the exploded view of the assembly in Appendix B. There may be small value items (e.g. brushes, containers, misc. fasteners) that have been overlooked in the design phase of this project. A specific dollar amount was set aside to account for these unexpected costs and can be found in the itemized list under "Application Materials". Total material costs for this project are $1627.80 including all components necessary to complete design.

All material processing (e.g. welding, machining, and composite layup) will be conducted in house at the Hogue Technology building. The machine shop and metallurgical lab will provide the necessary tooling and environment to complete these processes. Since no labor will be outsourced, a large portion of the budget will available for other costs. A total of 150.5 hours are estimated from start to finish prototype. If we had to outsource this labor at an average labor rate of $100/hr., an additional $15,050 would need to be incorporated into the budget to accommodate this cost.

Funding for this project will be provided by a board of members that have been asked to donate any materials or parts listed in our itemized parts list. We are hoping to see a positive response from

companies in the industry, encouraging and pushing new technology that will benefit everyone involved. With this positive response and encouragement, we hope to be able to secure several donations that will help with the build phase of this project.

Schedule:

A tentative schedule that is subject to change was created to help organize this project and ensure adequate time for the design, development, and testing of our suspension assembly. This schedule is constrained by the time frames provided by the MET 495 Senior Project Instructors, with a required completion date of June 1, 2015. The schedule is located in Appendix D and can be viewed for further details.

Milestones:

There will be several milestones along the design phase of suspension assembly. The first milestone, which will be the foundation for all processes afterwards, is the completion of the composite backbone structure. This process will be the most crucial process due to the nature of the structure and the material properties (e.g. strength, rigidity) required to continue the assembly. The second milestone will be the completion of the front, rear, and idler wheel mounting brackets. The bulk of material processing time will be used to complete this milestone resulting in four components that will be ready for assembly to the backbone frame. The third milestone will be the completion of the link arm assembly. The completion of the link arm will be the final machined component needed to complete our assembly. Without a complete link arm, other components such as shocks, will not be able to be assembled to our backbone.

DISCUSSION

The initial intent of this project was to design a simplistic, functional, lightweight suspension system for a snowmobile that would be made from strictly composite materials. The first design we created was a one piece composite skid that would utilize the material properties (e.g. elasticity) to perform the transfer of impact from the ground to the rider. After the initial design, analysis of the structure took place. We found that the impact forces the assembly would undergo exceeded the maximum elasticity of the material resulting in a broken component. At this point, a need for a re-design was required and the current assembly found in Appendix B was the solution.

Instead of relying on the material to do the work, we are incorporating 2 Fox Shox to transfer the impact force to the chassis. By integrating the shock work into the system, we were able to drastically change the composite skid design to the “backbone” design we have now. Not only did this adjustment allow the project to continue, we were able to utilize a thinner material for the backbone. This reduction in material negates a portion of the additional weight added to the system by the introduction of 2 shock absorbers.

With the design change came a larger overall suspension assembly. More components were necessary in order for the design to work properly (e.g. link arm, mounts) which made for more design analysis than originally intended. The link arm structure needed to be strong enough to support the structure during a maximum impact load, but light enough to meet the system weight requirement of 45 lbs. or less. In order to achieve this, we optimized the diameter of the tubing as well as the material used to build the

link arm. By using a more affordable material (6061-T6) an increase in weight occurred. Titanium was considered as first but due to budget reasons, we opted to go with the 6061 aluminum tubing.

There was an initial concern about securing the front and rear mounts to our backbone. Our analysis showed, that under maximum conditions the mounts were under a severe amount of shear stress. Such that the thickness of the material required to distribute the stress would interfere with our link arm design. We were able to solve this problem by slightly modifying the mounts themselves. Instead of using 4 bolts for each mount, we increased the amount of bolts to 6. This increase in mounting hardware essentially increased the surface area and distributed the shear force introduced by impact.

CONCLUSION

A snowmobile suspension has been conceived, analyzed, and designed that satisfies the function requirements as described in the opening of this proposal. Parts have further been designated, sourced, and budgeted and are pending acquisition upon receipt of sponsorship funds. With this information, this device is ready to be created. Construction will begin once all funding has been received and materials have been ordered.

This project satisfies the requirements listed in the Senior Project metric and are as follows:

1. Having substantial engineering merit in structural and material analysis.
2. Size and cost of the project is within the parameters for means of completion.
3. Is of great interest to the principal investigator.

ACKNOWLEDGEMENTS

This project will be managed primarily by myself with the guidance from Dr. Craig Johnson, a Professional Engineer who is head of the Mechanical Engineering department at CWU, and Professor Charles Pringle who has a Master's in Mechanical Engineering Technology. Both mentors have an extensive background in engineering design and will be involved in overseeing this project as it continues.

As this project continues, the need for funding will be accomplished through the use of sponsorships. These sponsorships will need to be completed by February 4th, the start of the design phase of our project. If money from a sponsor is not received in time to complete the materials order, the remaining funds will come from myself in order for the project to remain on schedule.

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[7] "MatWeb," 2014. [Online]. Available: www.matweb.com. [Accessed 1 January 2015].

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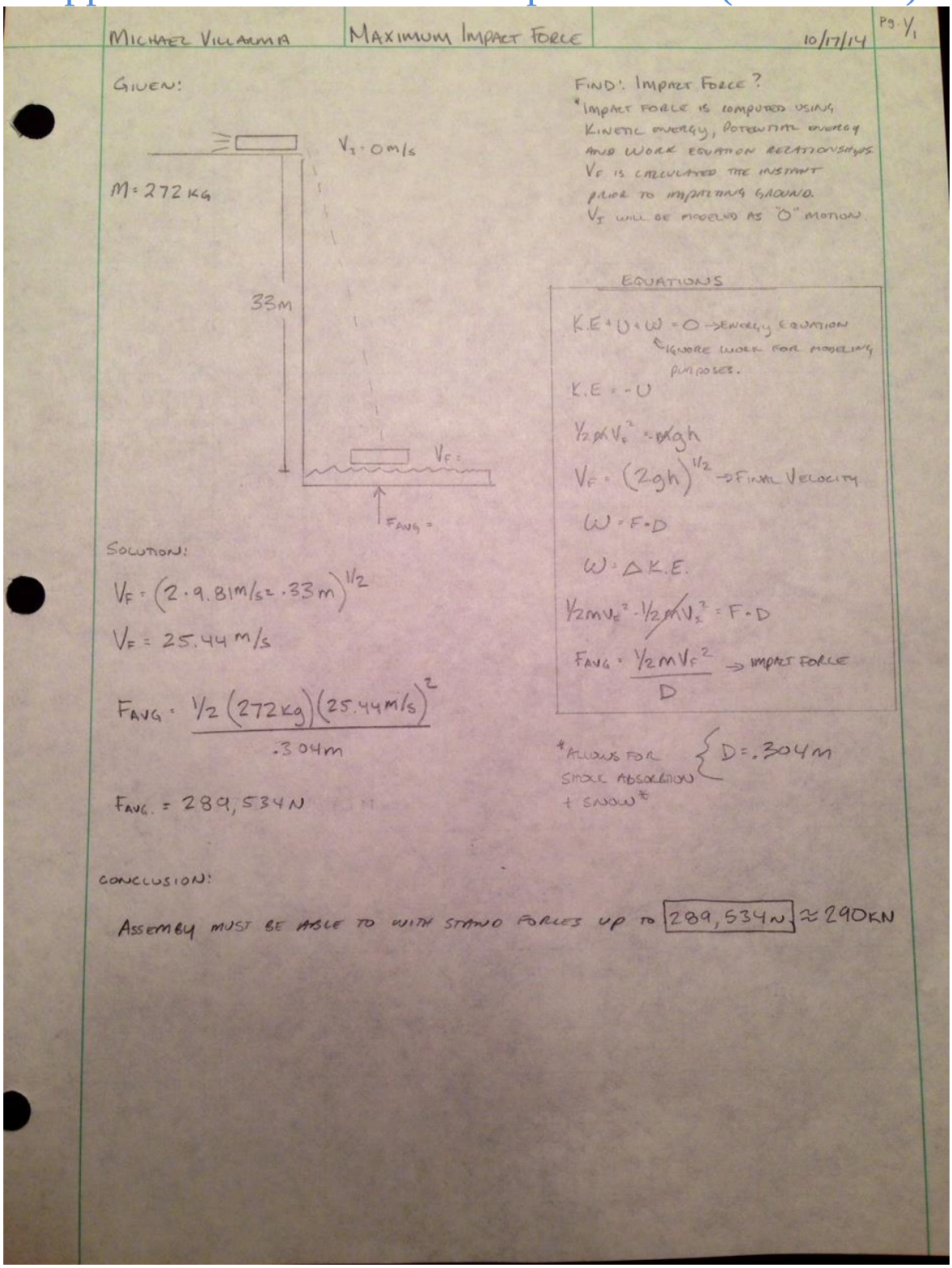
Appendix A – Maximum Impact Force (Backbone)



MICHAEL VILLARMIA | MAXIMUM IMPACT FORCE | 10/17/14 | Pg. 1/1

GIVEN:

$V_I = 0\ m/s$

$M = 272\ kg$

33M

$V_F =$

$F_{AVG} =$

FIND: IMPACT FORCE?

*IMPACT FORCE IS COMPUTED USING KINETIC ENERGY, POTENTIAL ENERGY AND WORK EQUATION RELATIONSHIPS. V_F IS CALCULATED THE INSTANT PRIOR TO IMPACTING GROUND. V_I WILL BE MODELED AS "0" MOTION.

EQUATIONS

$K.E + U + W = 0$ → ENERGY EQUATION
↖ IGNORE WORK FOR MODELING PURPOSES.

$K.E = -U$

$\frac{1}{2} m V_F^2 = mgh$

$V_F = (2gh)^{1/2}$ → FINAL VELOCITY

$W = F \cdot D$

$W = \Delta K.E.$

$\frac{1}{2} m V_F^2 - \frac{1}{2} m V_I^2 = F \cdot D$

$F_{AVG} = \frac{\frac{1}{2} m V_F^2}{D}$ → IMPACT FORCE

ALLOWS FOR SNOW ABSORPTION + SNOW { $D = .304m$

SOLUTION:

$V_F = (2 \cdot 9.81 m/s^2 \cdot .33m)^{1/2}$

$V_F = 25.44\ m/s$

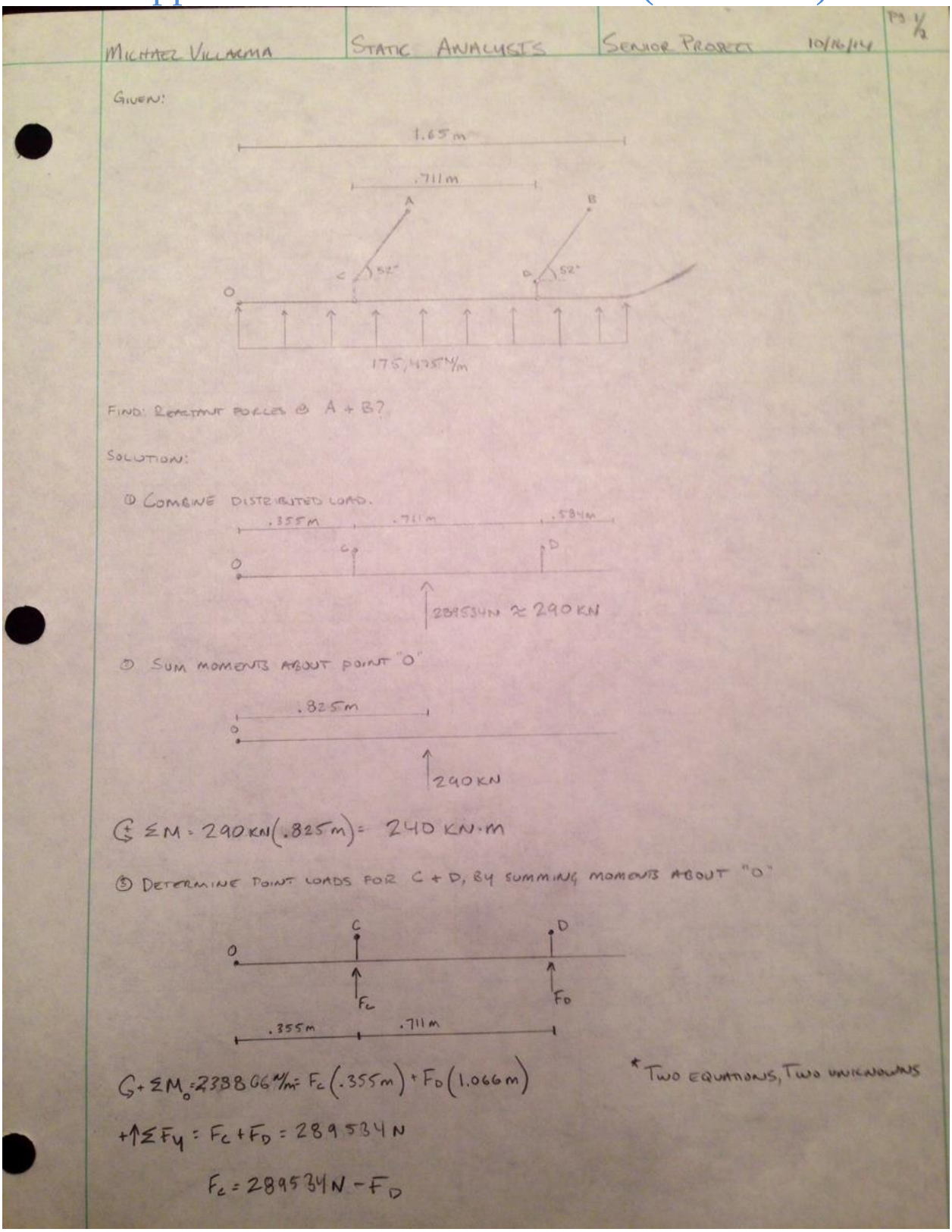
$F_{AVG} = \frac{\frac{1}{2}(272kg)(25.44m/s)^2}{.304m}$

$F_{AVG} = 289,534N$

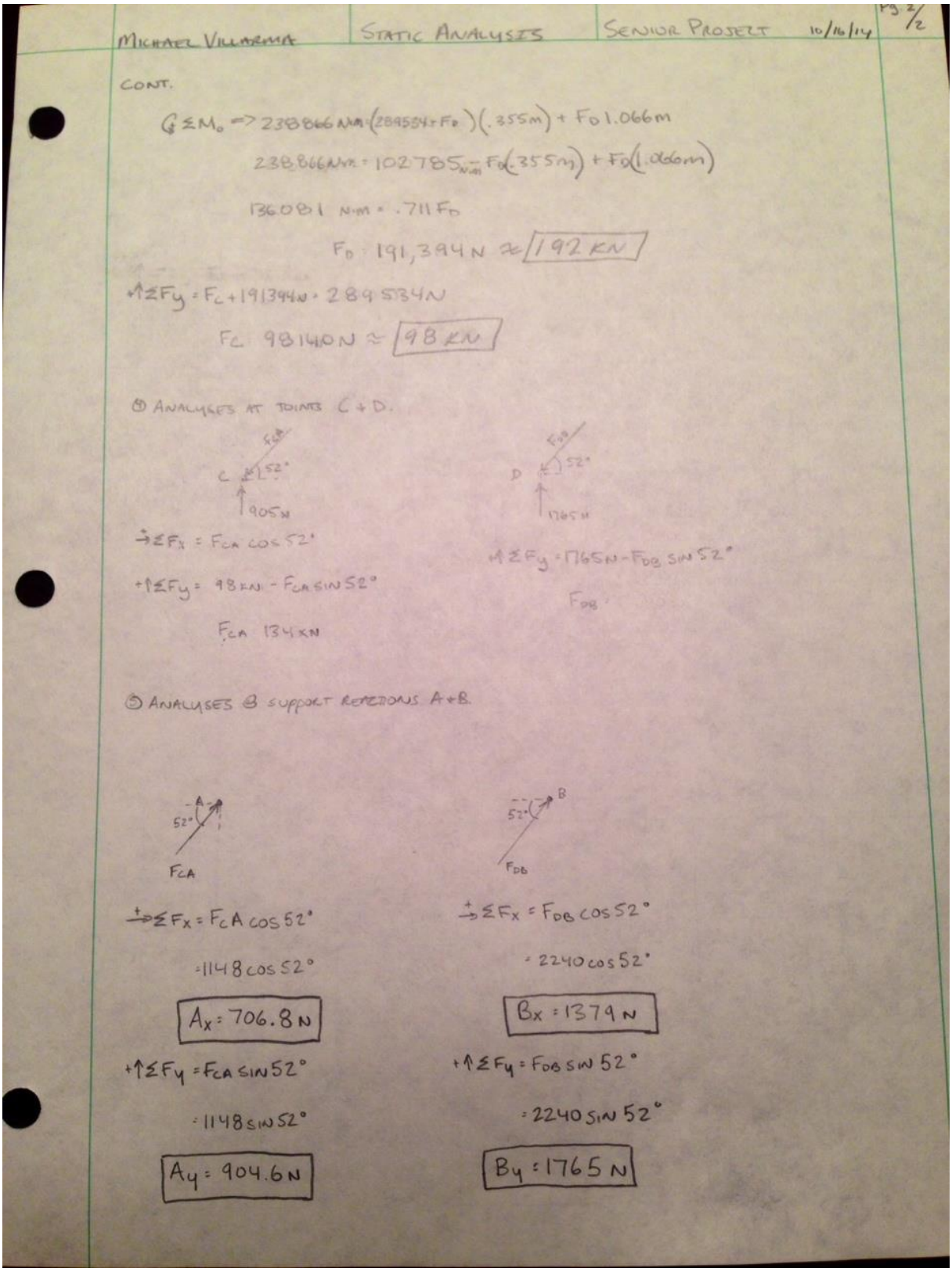
CONCLUSION:

ASSEMBLY MUST BE ABLE TO WITHSTAND FORCES UP TO $\boxed{289,534N} \approx 290kN$

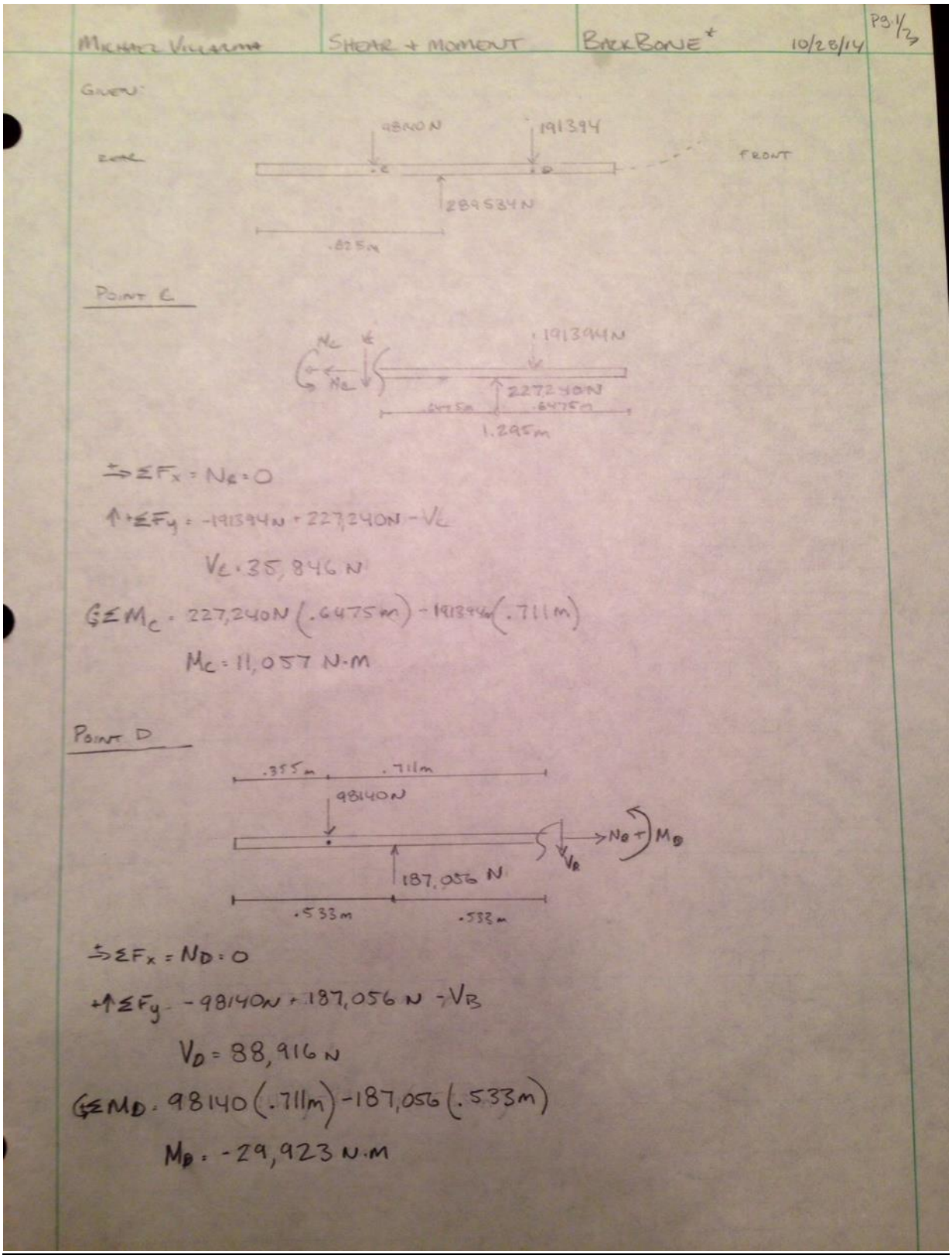
Appendix A - Distributed Load (Backbone)



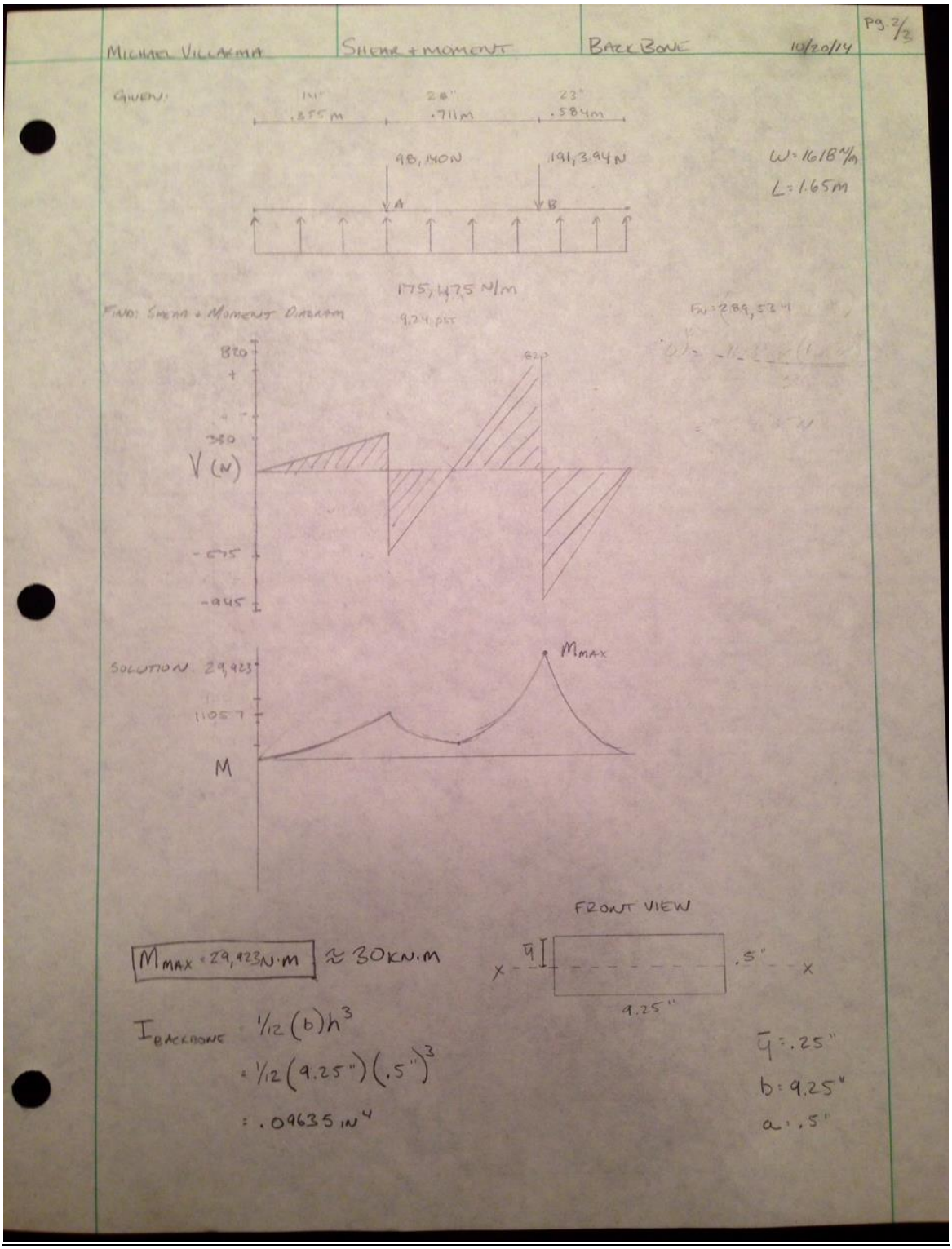
Appendix A – Distributed Load (Backbone) Cont.



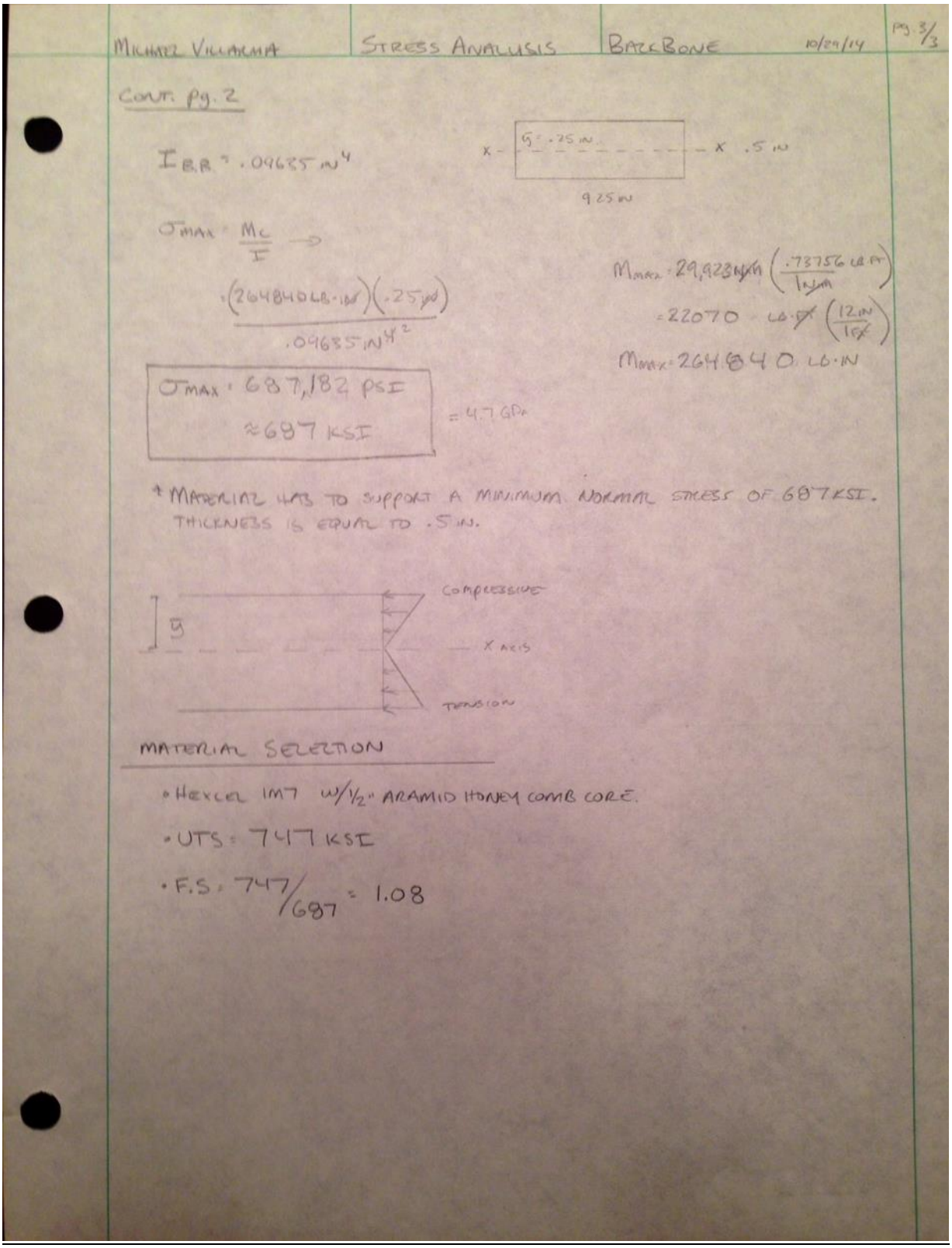
Appendix A – Bending Moment Diagrams (Backbone)



Appendix A – Bending Moment Diagrams (Backbone) Cont.



Appendix A – Bending Moment Diagrams (Backbone) Cont.



MICHAEL VILLARMIA | STRESS ANALYSIS | BACKBONE | 10/29/14 | Pg 3/3

CONT. pg. 2

$I_{B.B} = .09685\ in^4$

$x = \frac{5 = .25\ in}{9.25\ in} \times .5\ in$

$\sigma_{MAX} = \frac{Mc}{I} \rightarrow$

$\frac{(264840\ LB\cdot IN)(.25\ in)}{.09685\ in^4}$

$M_{max} = 29{,}923\ N\cdot m \left(\frac{.73756\ LB\cdot FT}{1\ N\cdot m}\right)$

$= 22070\ LB\cdot FT \left(\frac{12\ IN}{1\ FT}\right)$

$M_{max} = 264840\ LB\cdot IN$

$\sigma_{MAX} = 687{,}182\ PSI$

$\approx 687\ KSI$

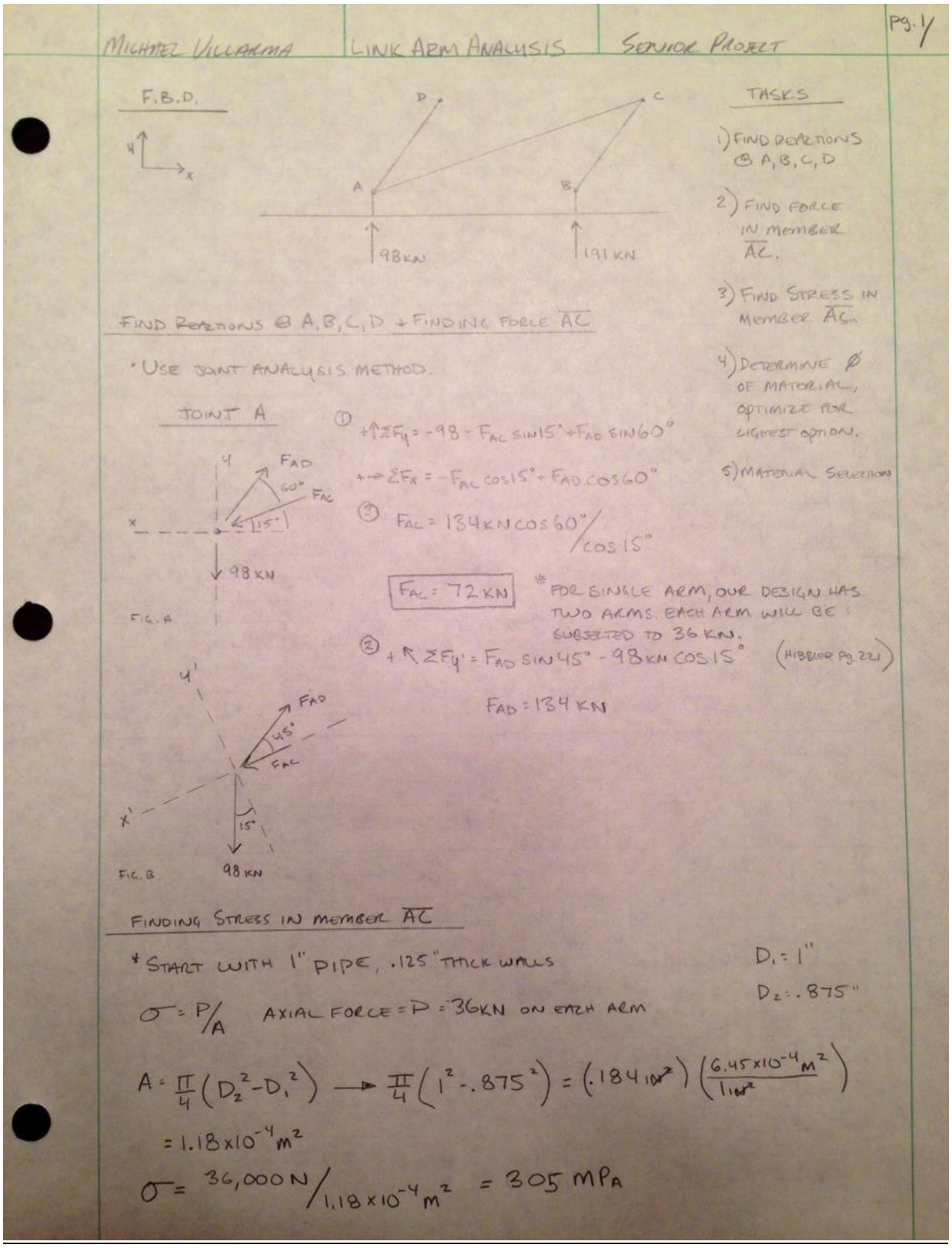
$= 4.7\ GPa$

* MATERIAL HAS TO SUPPORT A MINIMUM NORMAL STRESS OF 687 KSI. THICKNESS IS EQUAL TO .5 IN.

MATERIAL SELECTION

- HEXCEL IM7 w/ ½" ARAMID HONEY COMB CORE.
- UTS: 747 KSI
- F.S: $747/687 = 1.08$

Appendix A – Normal Stress on Link Arm



MICHTEL VILLARMA | LINK ARM ANALYSIS | SENIOR PROJECT | Pg. 1

F.B.D.

TASKS

1) FIND REACTIONS @ A, B, C, D
2) FIND FORCE IN MEMBER $\overline{AC}$.
3) FIND STRESS IN MEMBER $\overline{AC}$.
4) DETERMINE ϕ OF MATERIAL, OPTIMIZE FOR LIGHTEST OPTION.
5) MATERIAL SELECTION

FIND REACTIONS @ A, B, C, D + FINDING FORCE $\overline{AC}$

* USE JOINT ANALYSIS METHOD.

JOINT A

FIG. A

① $+\uparrow \Sigma F_y = -98 - F_{AC}\sin 15^\circ + F_{AD}\sin 60^\circ$

$+\rightarrow \Sigma F_x = -F_{AC}\cos 15^\circ + F_{AD}\cos 60^\circ$

③ $F_{AC} = 134\,KN\cos 60^\circ / \cos 15^\circ$

$F_{AC} = 72\,KN$

* FOR SINGLE ARM, OUR DESIGN HAS TWO ARMS. EACH ARM WILL BE SUBJECTED TO 36 KN.

② $+\nwarrow \Sigma F_{y'} = F_{AD}\sin 45^\circ - 98\,KN\cos 15^\circ$ (HIBBELER Pg. 22)

$F_{AD} = 134\,KN$

FIG. B

FINDING STRESS IN MEMBER $\overline{AC}$

* START WITH 1" PIPE, .125" THICK WALLS

$D_1 = 1"$

$D_2 = .875"$

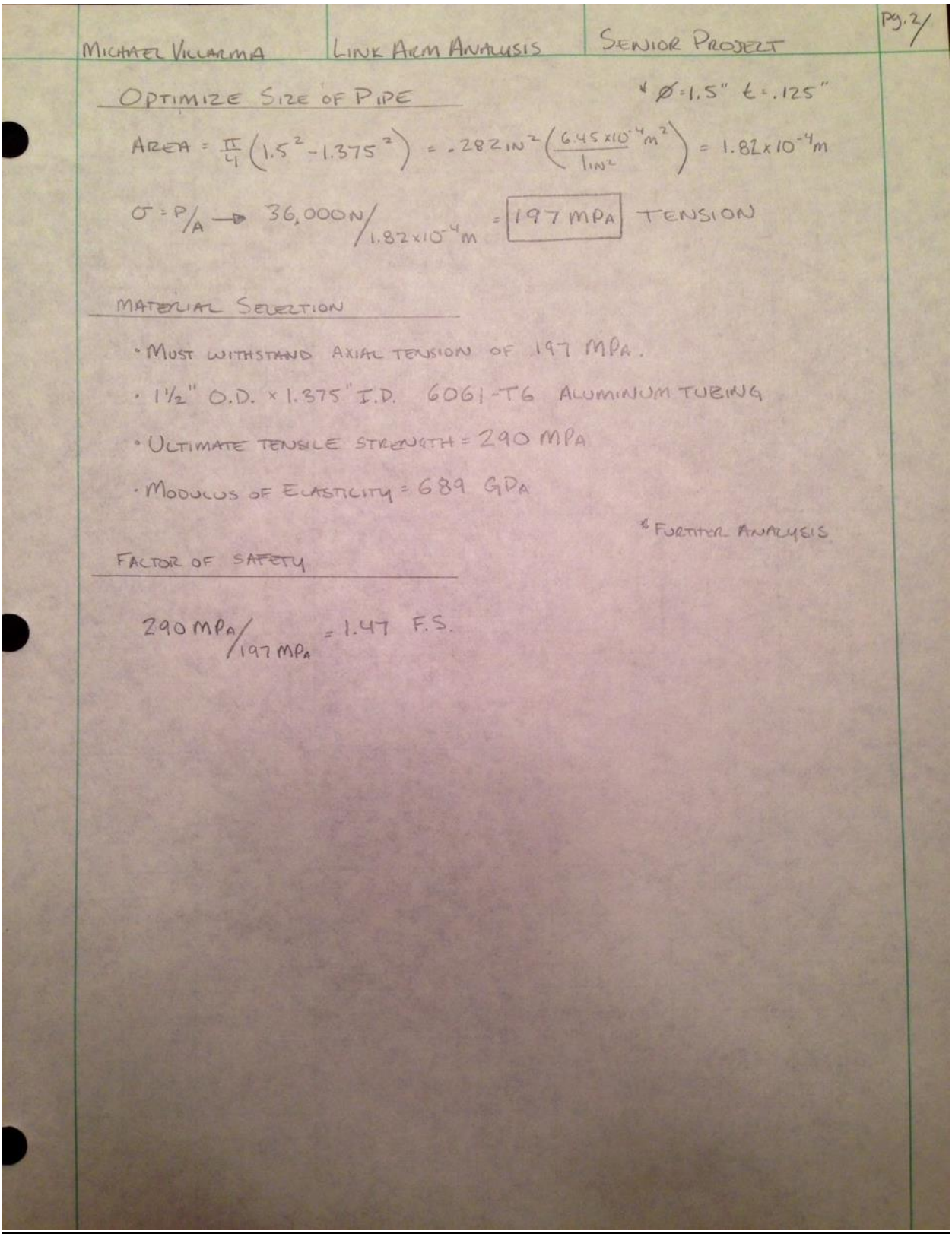
$\sigma = P/A$ AXIAL FORCE = P = 36KN ON EACH ARM

$A = \frac{\pi}{4}(D_2^2 - D_1^2) \rightarrow \frac{\pi}{4}(1^2 - .875^2) = (.184\,in^2)\left(\frac{6.45\times10^{-4}\,m^2}{1\,in^2}\right)$

$= 1.18\times10^{-4}\,m^2$

$\sigma = 36{,}000\,N / 1.18\times10^{-4}\,m^2 = 305\,MPa$

Appendix A – Normal Stress on Link Arm Cont.



Michael Villarreal | Link Arm Analysis | Senior Project | Pg. 2/

Optimize Size of Pipe

* $\varnothing = 1.5"$ $t = .125"$

Area $= \frac{\pi}{4}\left(1.5^2 - 1.375^2\right) = .282 in^2 \left(\frac{6.45 \times 10^{-4} m^2}{1 in^2}\right) = 1.82 \times 10^{-4} m$

$\sigma = P/A \rightarrow 36{,}000N / 1.82 \times 10^{-4} m = \boxed{197 MPa}$ Tension

Material Selection

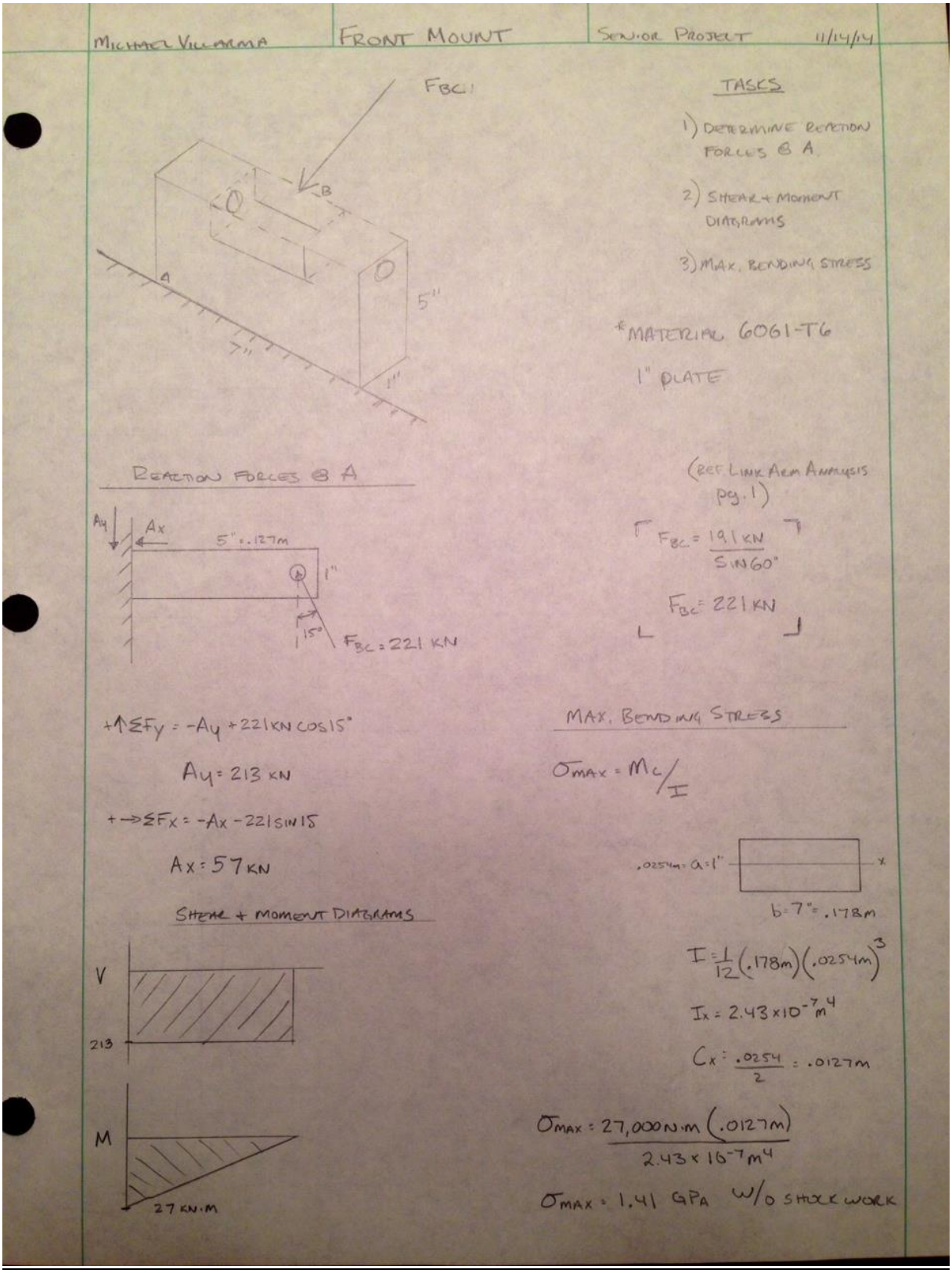
- Must withstand axial tension of 197 MPa.
- 1½" O.D. × 1.375" I.D. 6061-T6 Aluminum Tubing
- Ultimate tensile strength = 290 MPa
- Modulus of Elasticity = 689 GPa

* Further Analysis

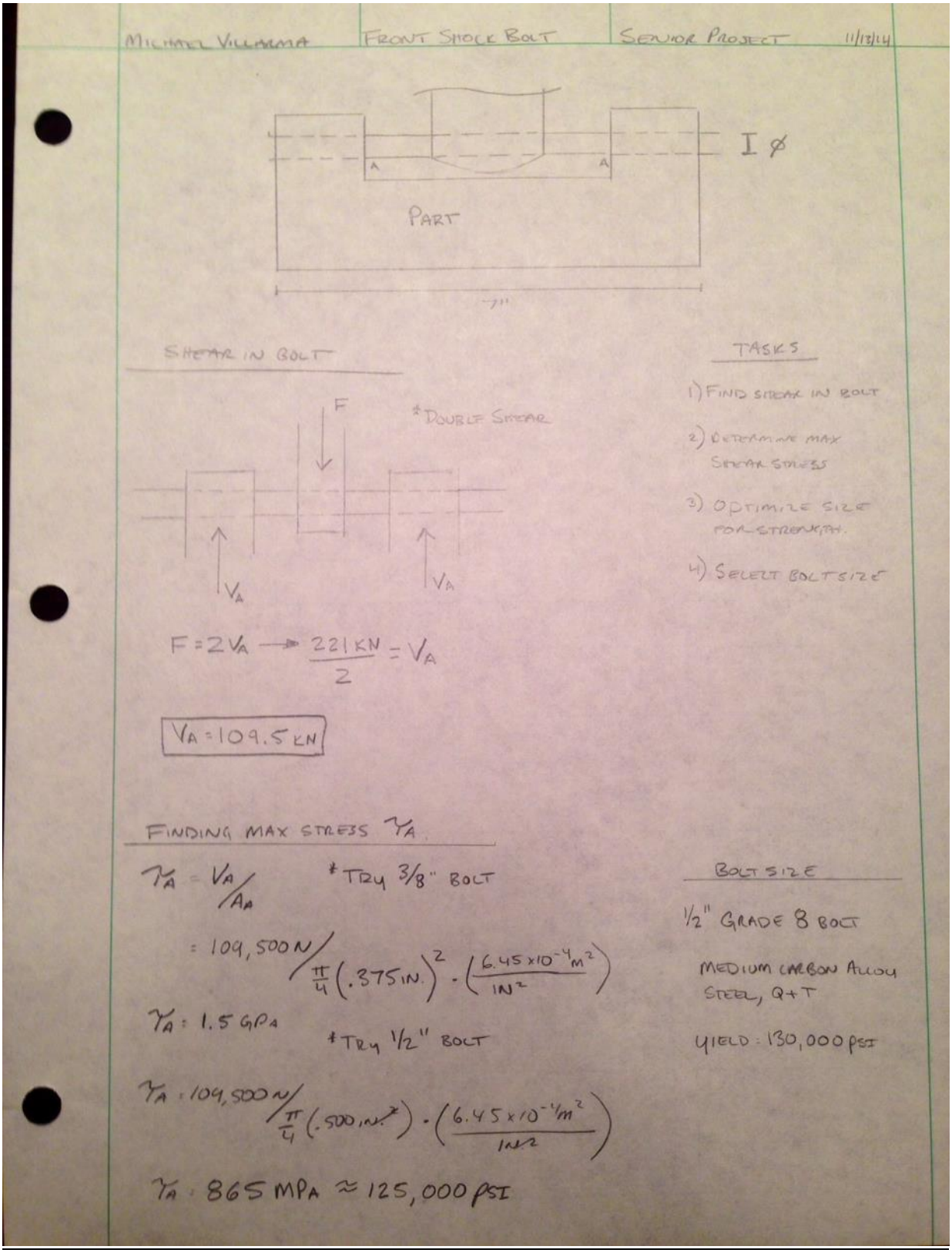
Factor of Safety

$290 MPa / 197 MPa = 1.47$ F.S.

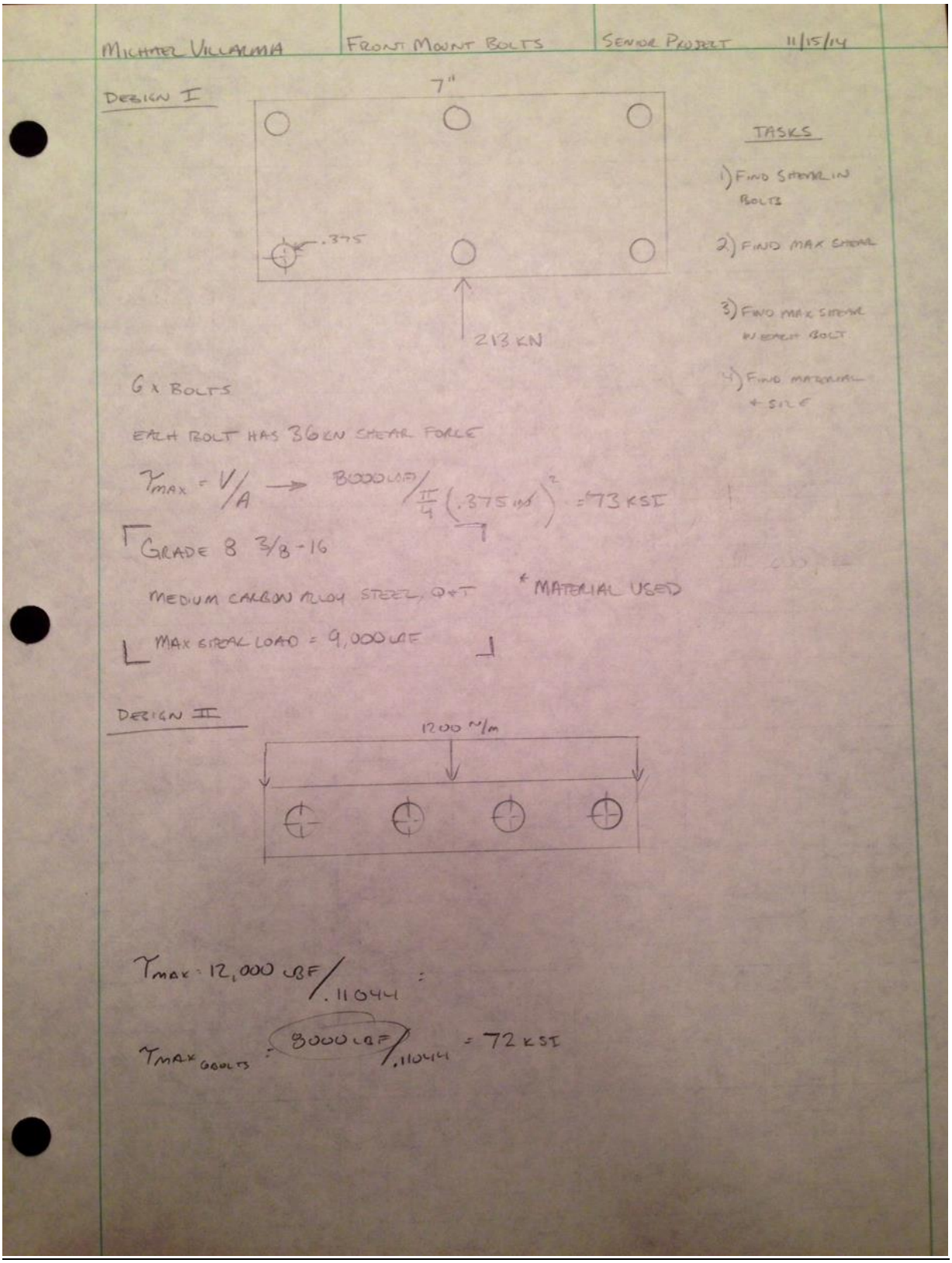
Appendix A – Front Mount Analysis



Appendix A – Front Mount Analysis Cont.



Appendix A – Front Mount Analysis Cont.



Appendix A – Mass Calculations from SolidWorks

Mass properties of Back Bone
Configuration: Default
Coordinate system: -- default --

Density = 0.06 pounds per cubic inch

Mass = 21.94 pounds

Volume = 341.22 cubic inches

Surface area = 1462.71 square inches

Center of mass: (inches)
X = 37.04
Y = 0.49
Z = -0.00

Mass properties of Axle Mount
Configuration: Default
Coordinate system: -- default --

Density = 0.10 pounds per cubic inch

Mass = 0.94 pounds

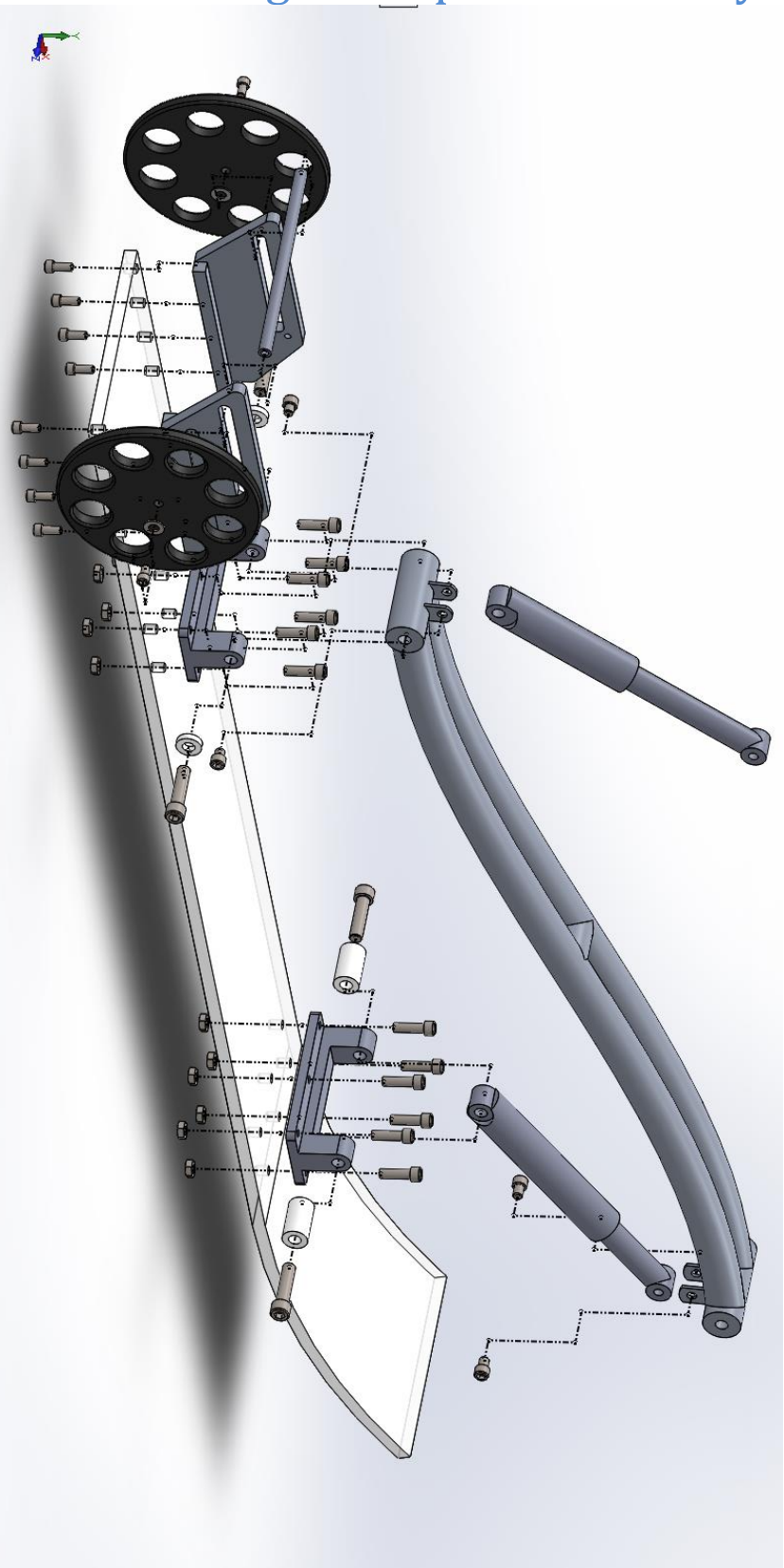
Volume = 9.68 cubic inches

Surface area = 54.98 square inches

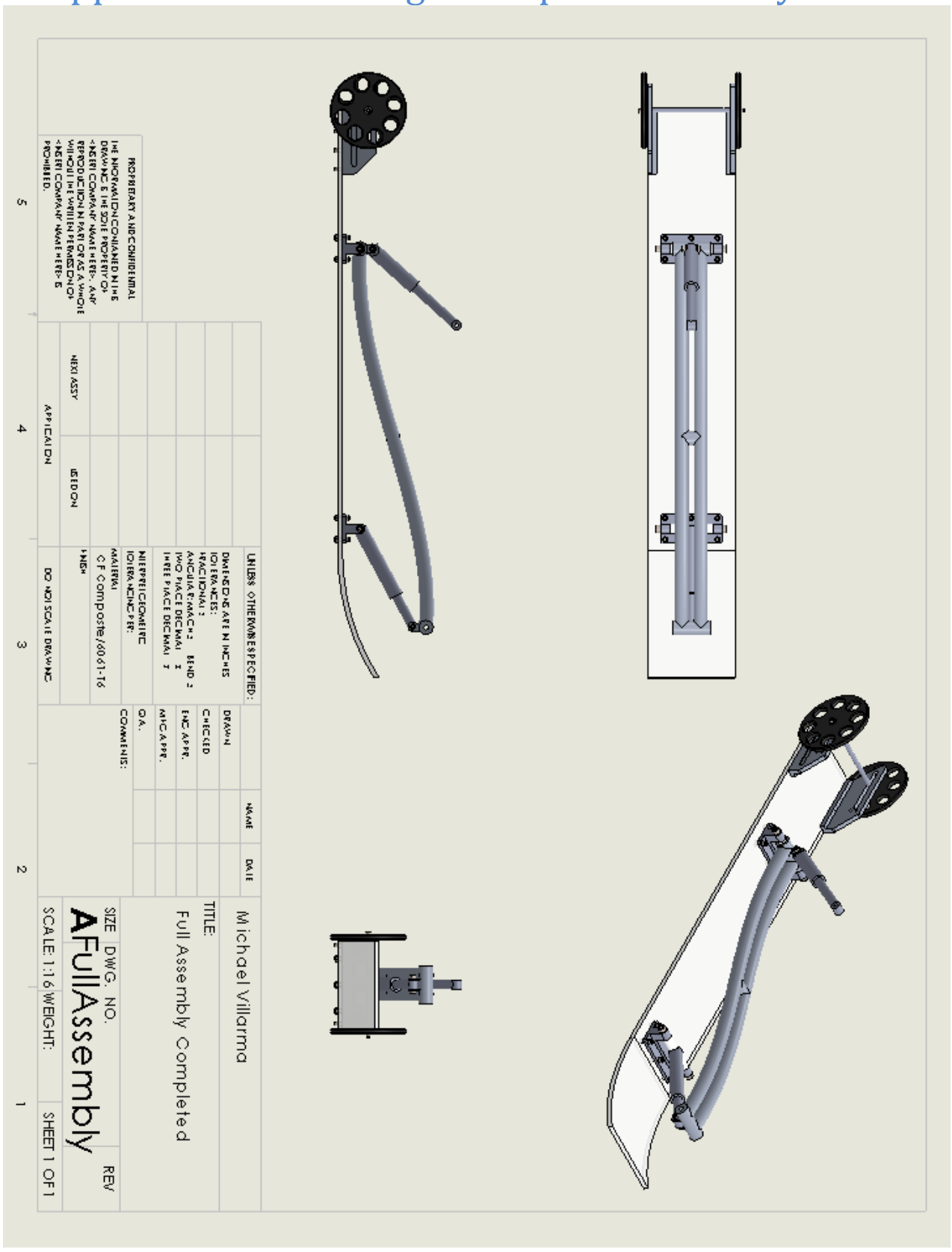
Center of mass: (inches)
X = 0.34
Y = 1.12
Z = -3.40

Appendix B – Drawings: Complete Assembly

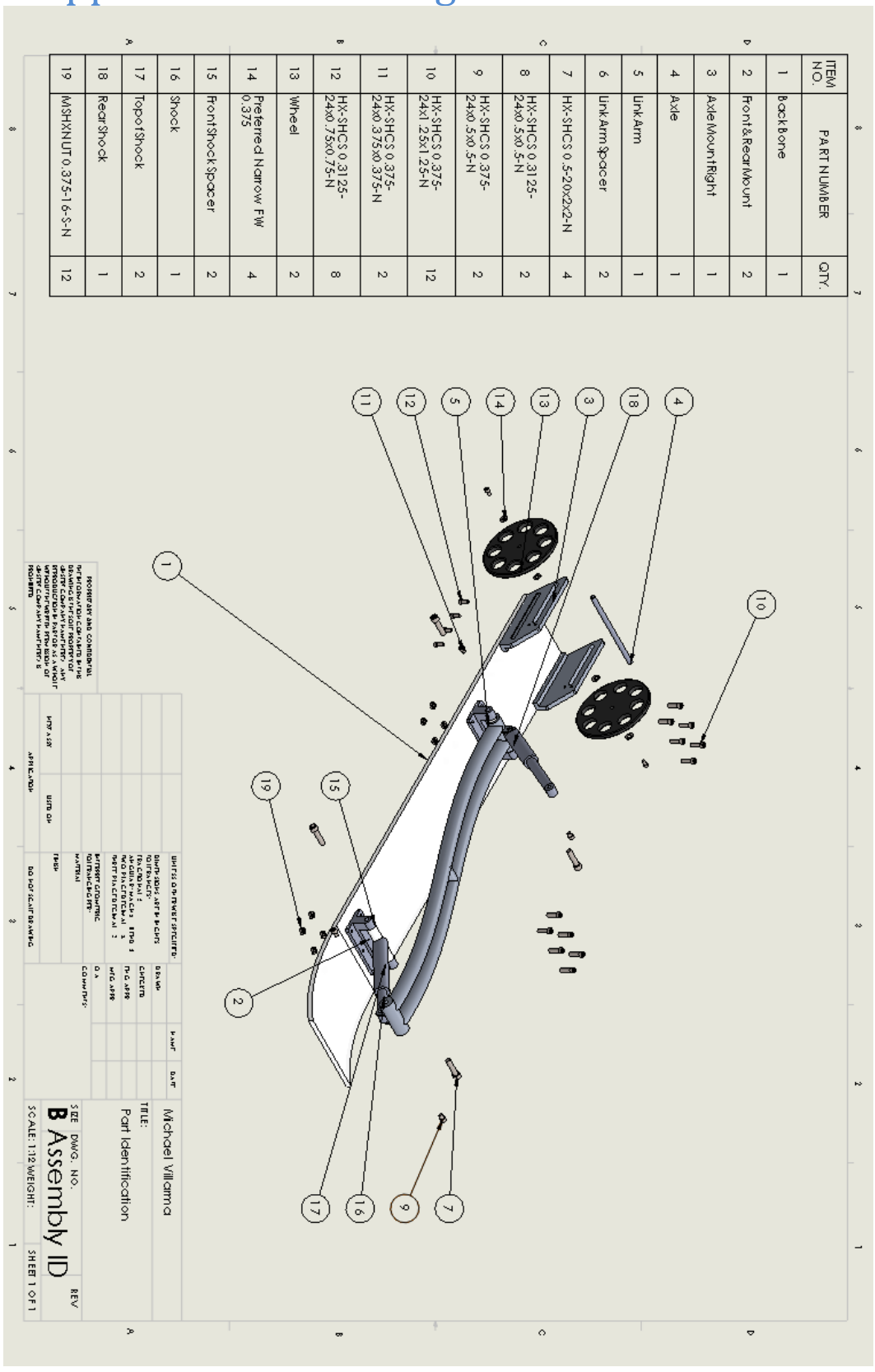
Appendix B – Drawings: Complete Assembly Exploded



Appendix B – Drawings: Complete Assembly Views

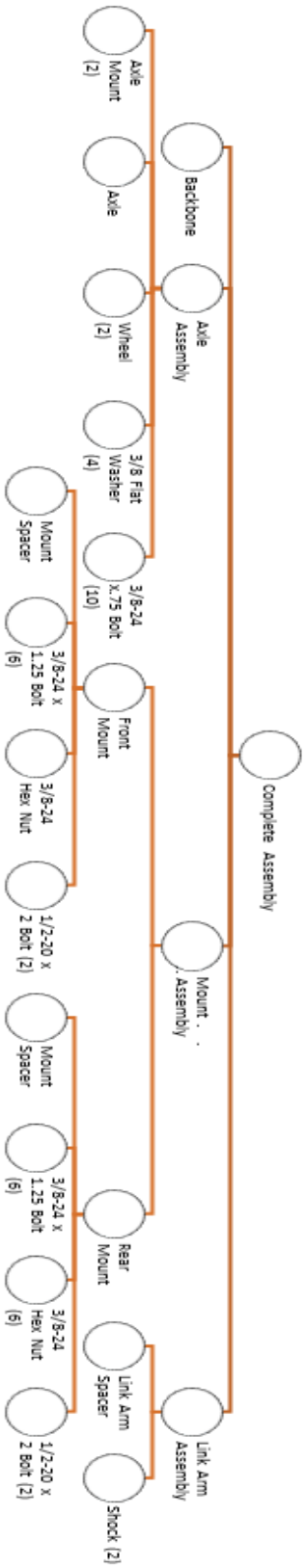


Appendix B – Drawings: Part Identification

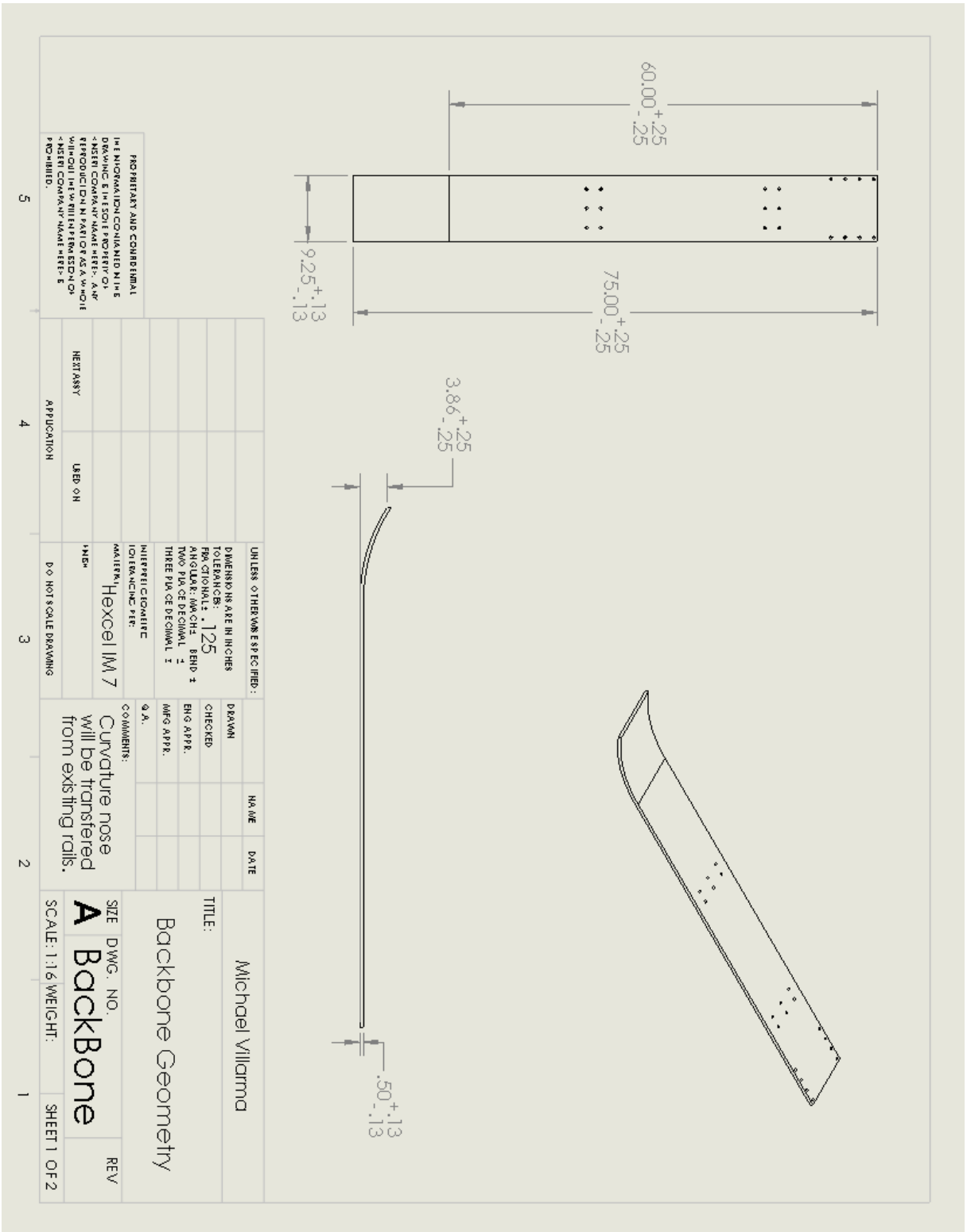


ITEM NO.	PART NUMBER	QTY.
1	BackBone	1
2	Front&RearMount	2
3	AxleMountRight	1
4	Axle	1
5	LinkArm	1
6	LinkArmSpacer	2
7	HX-SHCS 0.5-20x2x2-N	4
8	HX-SHCS 0.3125-24x0.5x0.5-N	2
9	HX-SHCS 0.375-24x0.5x0.5-N	2
10	HX-SHCS 0.375-24x1.25x1.25-N	12
11	HX-SHCS 0.375-24x0.375x0.375-N	2
12	HX-SHCS 0.3125-24x0.75x0.75-N	8
13	Wheel	2
14	Preferred Narrow FW 0.375	4
15	FrontShockSpacer	2
16	Shock	1
17	TopofShock	2
18	RearShock	1
19	MSHXNUT 0.375-16-S-N	12

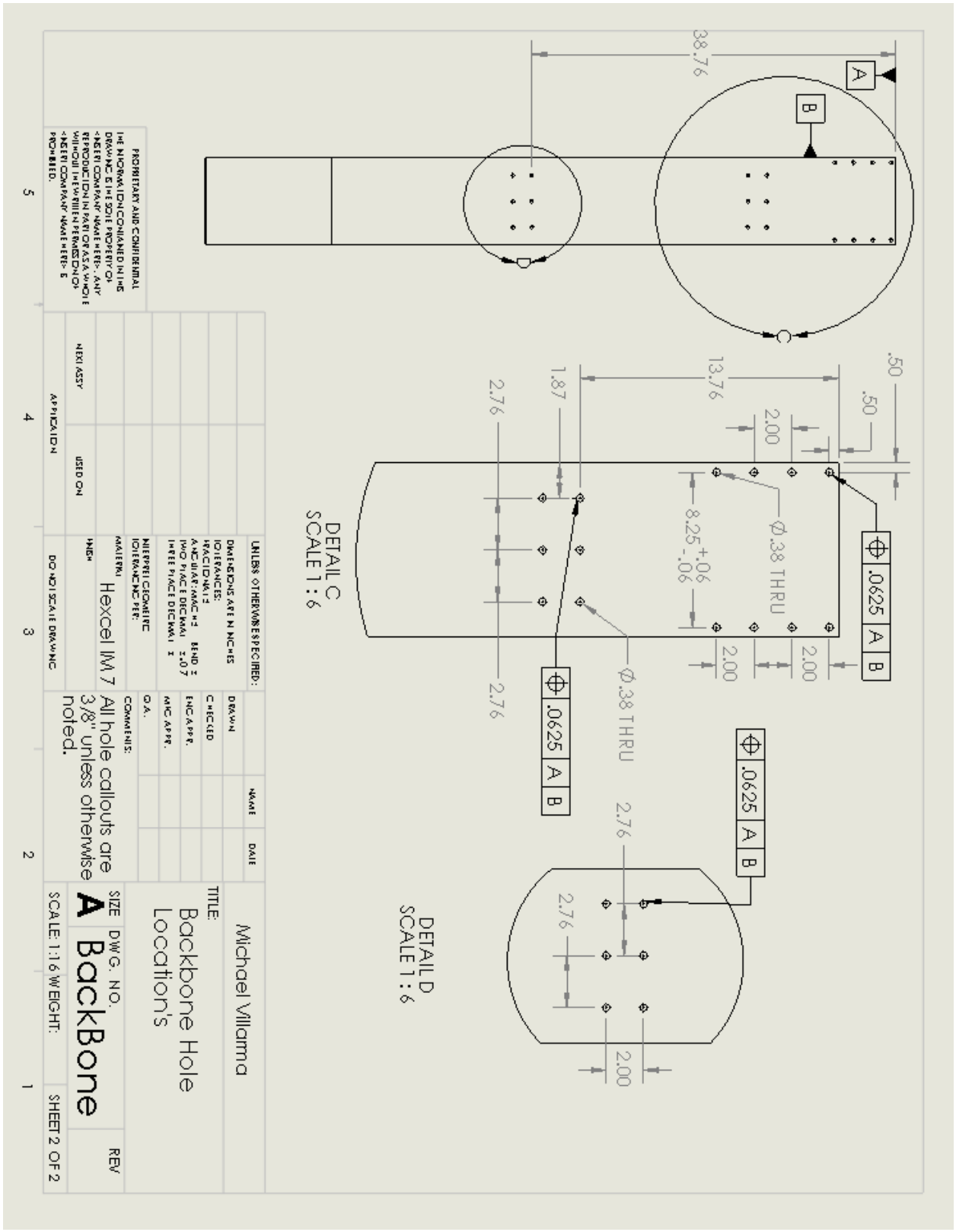
Appendix B – Drawings: Drawing Tree



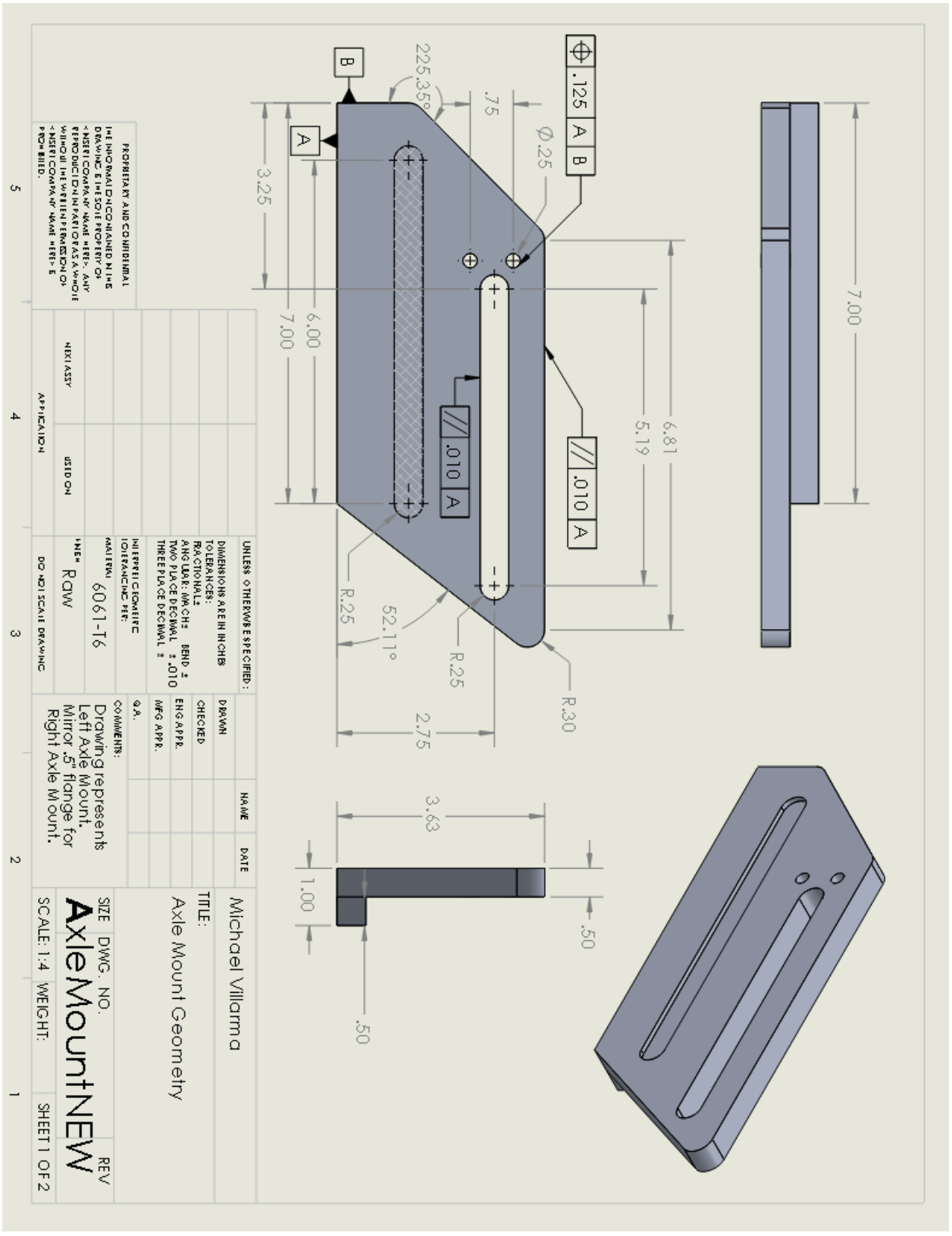
Appendix B – Drawings: Backbone Geometry



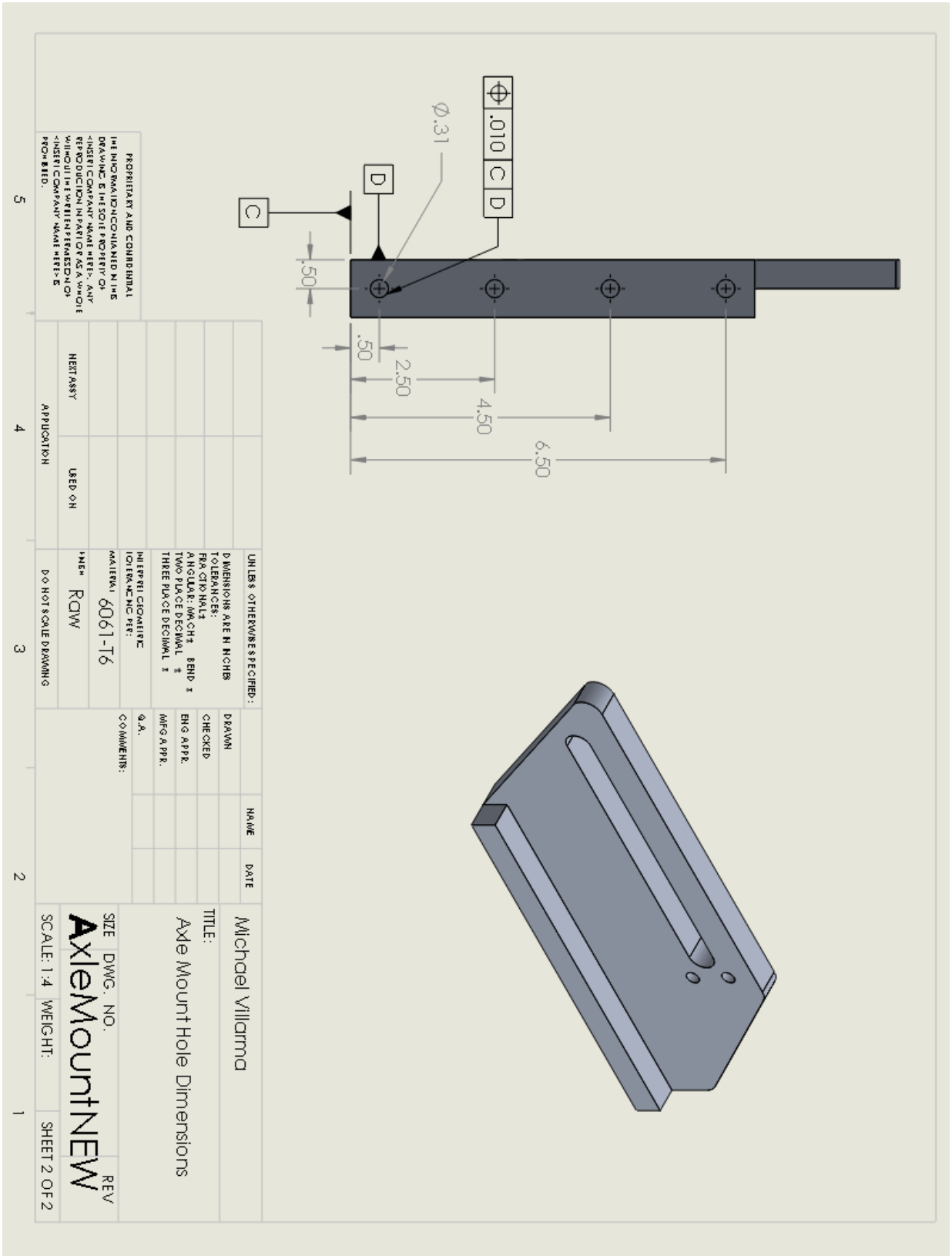
Appendix B – Drawings: Backbone Hole Layout



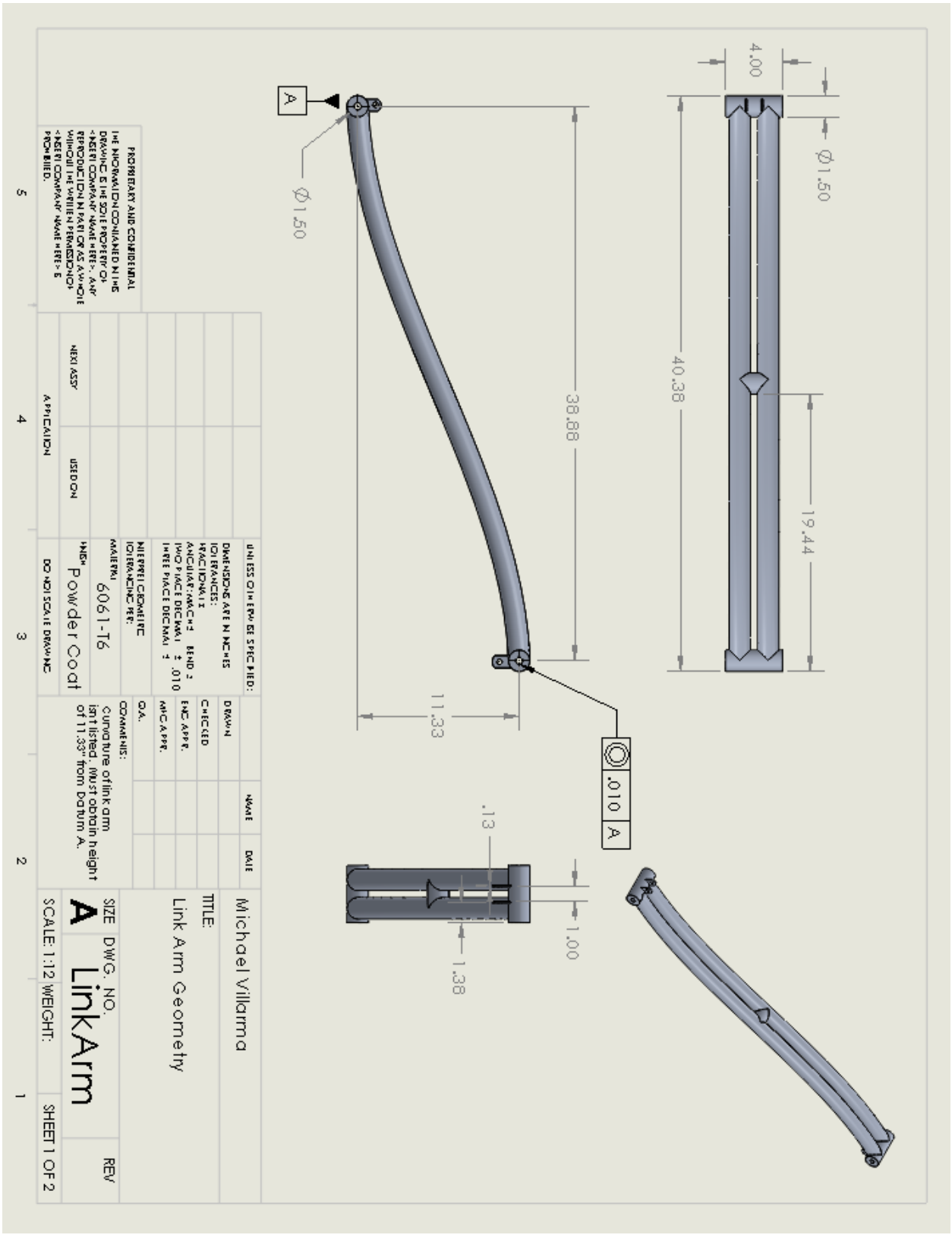
Appendix B – Drawings: Axle Mount Geometry



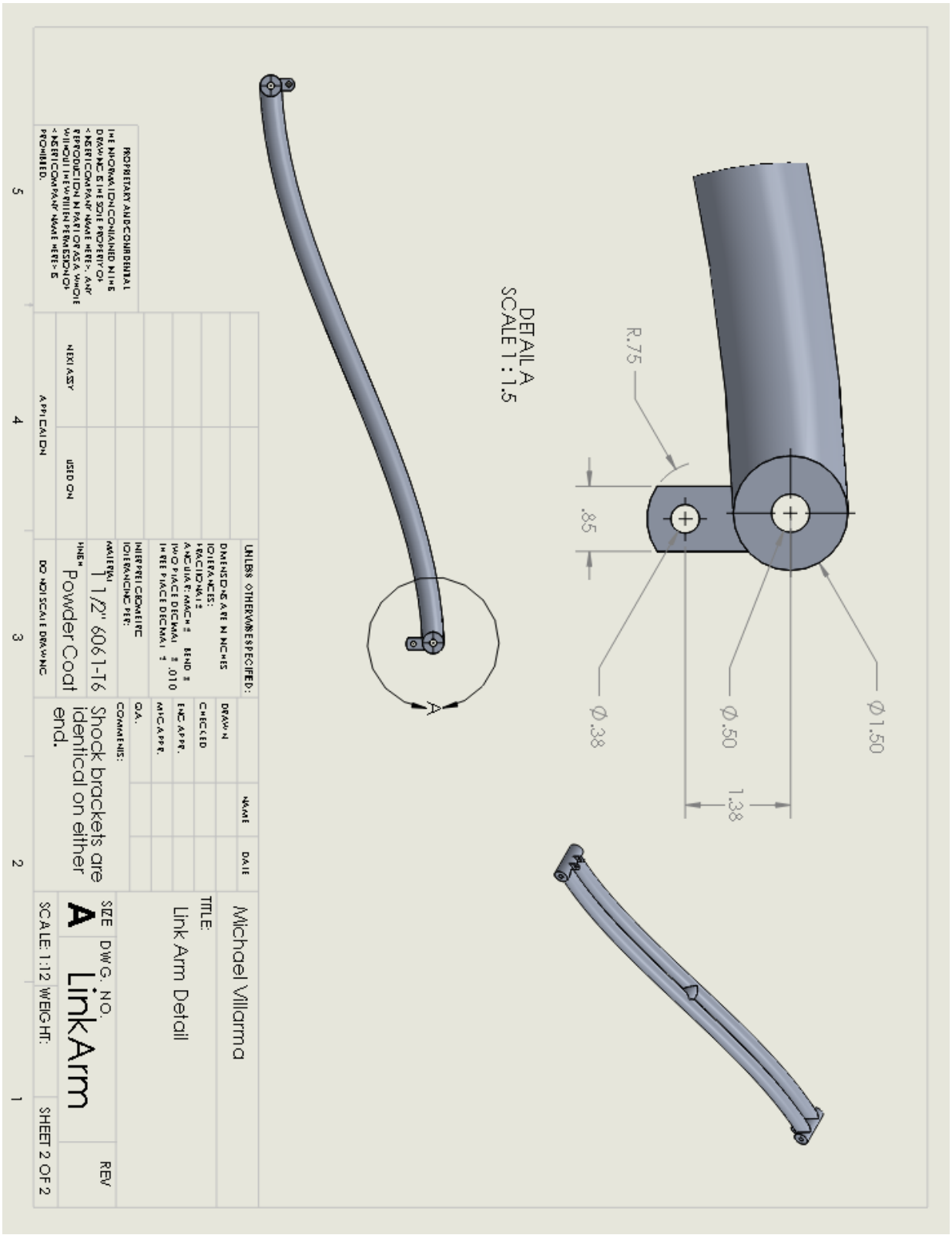
Appendix B – Drawings: Axle Mount Hole Layout



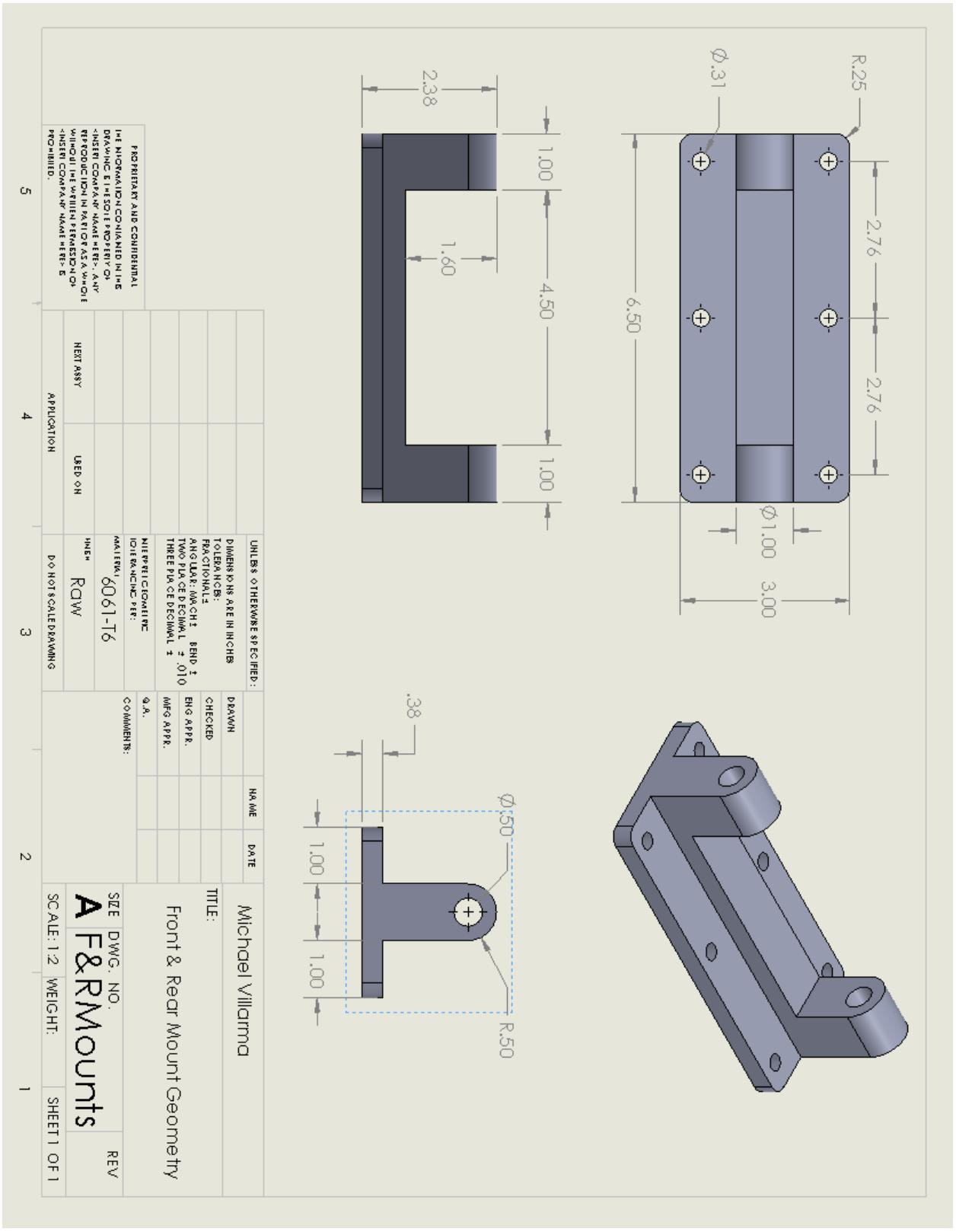
Appendix B – Drawings: Link Arm Geometry



Appendix B – Drawings: Link Arm Detail



Appendix B – Drawings: Front and Rear Mounts



Appendix C – Parts List/Budget

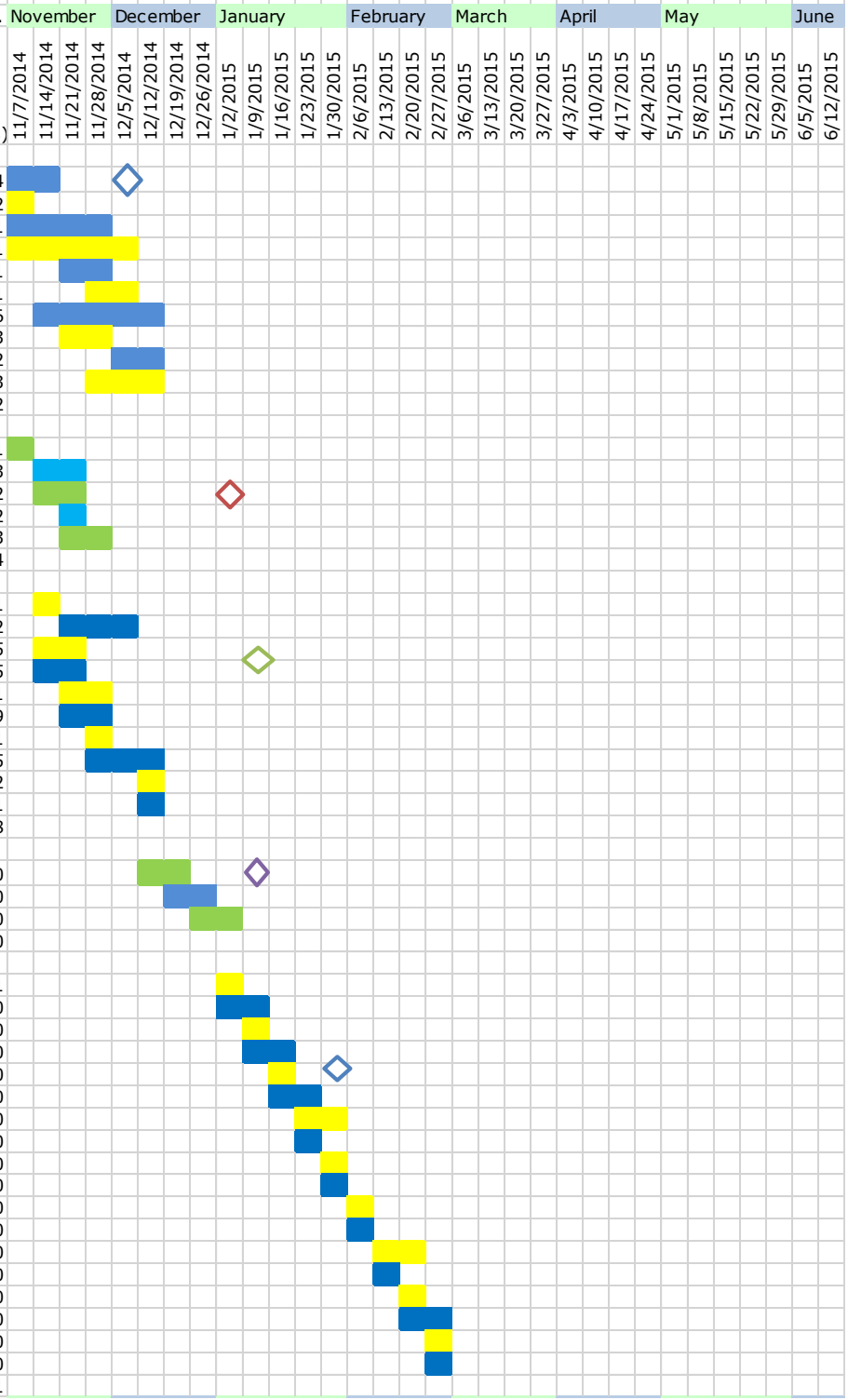
Material	Application	Supplier	Quantity	Price/unit	Total
6061-T6 2" O.D. Aluminum Tubing	Link Arm	Onlinemetals.com	8 feet	$8.26/ft	$66.07
6061-T6 1/2" Aluminum Plate	Idler Wheel Brackets	Onlinemetals.com	12"x24"	$128.28/unit	$128.28
6061-T6 1" Aluminum Plate	Front/Rear Brackets	Onlinemetals.com	8"x8"	$60.20/unit	$60.20
11 oz Twill Carbon Fiber Fabric	Backbone	Uscomposites.com	2 yards	$47.50/yard	$95.00
Nylon Bagging Film	Backbone	Uscomposites.com	2 yards	$4.70/yard	$9.40
Perforated Release Film	Backbone	Uscomposites.com	2 yards	$5.95/yard	$11.90
Sealent Tape	Backbone	Uscomposites.com	2 rolls	$6.95/roll	$13.90
700 Vinyl Ester Resin	Backbone	Uscomposites.com	1 Gallon	$45.50/gal	$45.50
Standard Cell Aramid Honeycomb Core 1/2"	Backone	ACPsales.com	24"x48"	$142.00/unit	$142.00
Application Materials (e.g. brushes, containers, e	Backbone	Local		$100/unit	$100.00
1/2"x4'x8' AC Plywood	Mold	Local	1		
4 oz E Glass Fiberglass Mat	Mold	Uscomposites.com	3 yards	$3.50/yard	$10.50
435 Standard Polyester Lay up Resin	Mold	Uscomposites.com	1 Gallon	$30.50/gal	$30.50
Fox Float 2 Rear Shock Absorber	Assembly	Foxshox.com	1	$469.95/unit	$469.95
Fox Float 2 Front Shock Absorber	Assembly	Foxshox.com	1	$269.95/unit	$269.95
Upper Idler Wheels	Assembly	Countrycat.com	2	$27.95?unit	$55.90
Rear Idler Wheels	Assembly	Countrycat.com	2	$33.95/unit	$67.90
Rear Axle	Assembly	Countrycat.com	1	$8.95/unit	$8.95
Hyfax	Assembly	Countrycat.com	2	$20.95/unit	$41.90
3/8-18 x 1" Grade 8 Socket Cap Bolt	Fasteners		8		
3/8-18 x .75" Grade 8 Hex Bolt	Fasteners		2		
3/8-18 x 4" Grade 8 Socket Cap Bolt	Fasteners		2		
3/8"-18 Nyloc Nut	Fasteners		14		
3/8" S.S. Washer	Fasteners		28		
3/8" Graphite Bushing	Fasteners		8		

Appendix D – Tentative Schedule

PROJECT TITLE: Composite Suspension Assembly

Principal Investigator: Michael Villarma

TASK ID	Description	Duration Est. (hrs)	Act. (hrs)
1	Proposal*		
1a	Outline	2	3.4
1b	Intro	2	2.2
1c	Methods	4	6.1
1d	Analysis	6	11
1e	Discussion	2	1.1
1f	Parts and Budget	2	4.1
1g	Drawings	8	26
1h	Schedule	2	3.3
1i	Summary & Appx	2	2.2
1j	PowerPoint pitch	4	3.3
	subtotal:	34	62
2	Analyses		
2a	Kinematic Analysis (Impact)	2	3.1
2b	Stress Analysis (Bending)	3	5.3
2c	Stress Analysis (Axial)	2	2.2
2d	Stress Analysis (Shear)	2	2.2
2e	Tolerance	0	1.3
	subtotal:	9	14
3	Documentation		
3a	Part 1 Backbone Drawing	3	3.1
3b	Part 2 Link Arm Drawing	3	7.2
3c	Part 3 Front Mount Drawing	2	2.5
3d	Part 4 Rear Mount Drawing	2	2.5
3e	Subassembly Frount Mount	0.5	1.1
3f	Subassembly Rear Mount	0.5	0.9
3g	Assembly Suspension	2	2.1
3k	Kinematic Check	2	1.5
3l	ANSIY14.5 Compl	4	6.2
3m	Make Object Files	1	1.1
	subtotal:	20	28
4	Proposal Mods		
4a	None Yet	1	0
4b	None Yet	1	0
4c	None Yet	1	0
	subtotal:	3	0
7	Part Construction		
7a	Buy Material for mold/cradle	1	1.1
7b	Begin contruction of cradle	3	0
7c	Lay fiberglass for mold	2	0
7d	Order material for backbone	1	0
7e	Inspect mold for flaws	1	0
7f	Prepare mold for carbon fiber	1	0
7g	Lay carbon fiber for backbone	2	0
7h	Order material for mounts	1	0
7i	Order fasteners/hardware	1	0
7j	Remove backbone from mold	1	0
7k	Prepare backbone for assmb.	1	0
7L	Cut material for mounts	0.5	0
7m	Machine mounts to spec.	5	0
7o	Order shock absorbers	0.5	0
7p	Cut material for link arm	1	0
7q	Weld link arm assembly	3	0
7r	Inspect link arm (welds)	0.5	0
7s	Send link arm to powder coat	1	0
	subtotal:	26.5	1.1



Appendix D – Tentative Schedule Cont.

TASK ID	Description	Est. (hrs)	Act. (hrs)	November				December				January					February				March				April				May					June
				11/7/2014	11/14/2014	11/21/2014	11/28/2014	12/5/2014	12/12/2014	12/19/2014	12/26/2014	1/2/2015	1/9/2015	1/16/2015	1/23/2015	1/30/2015	2/6/2015	2/13/2015	2/20/2015	2/27/2015	3/6/2015	3/13/2015	3/20/2015	3/27/2015	4/3/2015	4/10/2015	4/17/2015	4/24/2015	5/1/2015	5/8/2015	5/15/2015	5/22/2015	5/29/2015	6/5/2015	6/12/2015
9	Device Construct																																
9a	Assemble Sub A-A (Mounts)	2	0																														
9b	Assemble Sub B-B (Link Arm)	1	0																														
9c	Assemble Sub C-C (Shocks)	1	0																														
9d	Assemble Suspension	2	0																														
9e	Take Assembly Pictures	1	0																														
9f	Update Website	2	0																														
	subtotal:	9	0																														
10	Device Evaluation																																
10a	List parameters	2	0																														
10b	Design test & scope	2	0																														
10c	Obtain resources	2	0																														
10d	Make test sheets	2	0																														
10e	Plan analyses	3	0																														
10f	Test plan	2	0																														
10g	Perform evaluations	7	0																														
10h	Testing pics/video	4	0																														
10i	Update website	3	0																														
	subtotal:	27	0																														
11	495 Deliverables																																
11a	Get Report Guide	2	0																														
11b	Make Rep Outline	3	0																														
11c	Write Report	4	0																														
11d	Make Slide Outline	3	0																														
11e	Create Presentation	5	0																														
11f	Make CD Deliv. List	1	0																														
11e	Write 495 CD parts	1	0																														
11f	Update Website	2	0																														
11g	Project CD*	2	0																														
	subtotal:	23	0																														
	Total Est. Hours=	151.5	59	=Total Actual Hrs																													
	Labor Rate $100/HR	15150																															
Note: March x Finals																																	
Note: June x Presentation																																	
Note: June y-z Spr Finals																																	
Note	Deliverables*																																
	Draft Proposal																																
	Analyses Mod																																
	Document Mods																																
	Final Proposal																																
	Part Construction																																
	Device Construct																																
	Device Evaluation																																
	495 Deliverables																																

Appendix E – Resources: Sridevi Kichhannagari's Temperature Effects

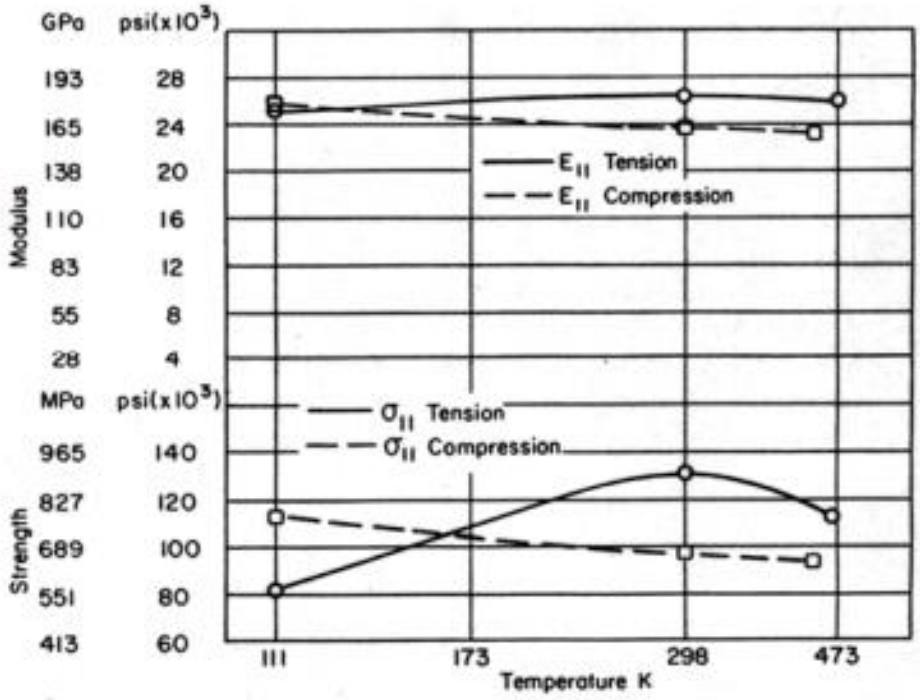


Figure 2.3. AST2002 HMS unidirectional properties versus temperature

Appendix E – Resources: Arctic Cat M8 Snowmachine

This will be the snowmachine used during the testing phase of our suspension system. The existing suspension will be removed and replaced with our design.

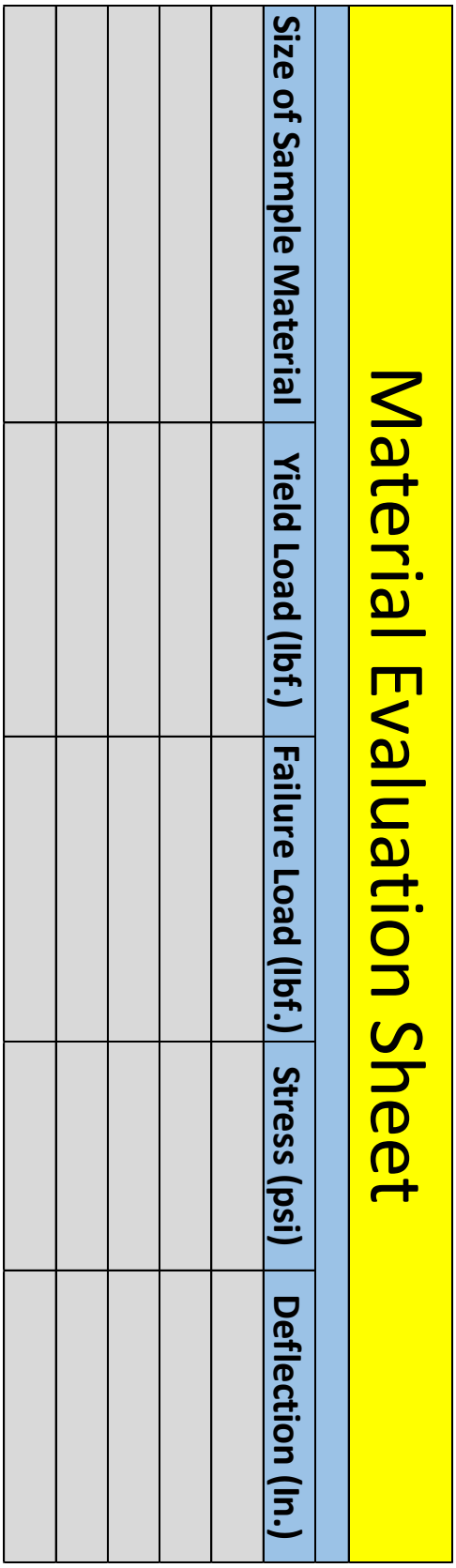
Weight Evaluation Sheet

Manufacturer	Track Size (Inches)	Weight (lbs.)
Arctic Cat **	153	45
Timbersled *	153	42
Kmod *	155	52
Composite Skid **	153	

*Weight based on specs. from manfacturer.

**Actual weight values from testing.

Appendix F – Evaluation Sheet



Appendix F – Evaluation Sheet

Performance Evaluation					
Task	Very Bad (0)	Bad (1)	Good (2)	Very Good (3)	Excellent (4)
Install					
Handling					
Ride Comfort					
Rhythm Section					
Speed Control					
Time To Install	0-10 Minutes	10-20 Minutes	20-30 Minutes	30-40 Minutes	
	4	3	2	1	
Total Score					
Scoring					
0--5	Poor				
5--10	Average				
10+	Good				

Appendix G – Testing Data/Report: SolidWorks Mass Calculations

TESTING REPORT – COMPOSITE SNOWMOBILE SUSPENSION SYSTEM

TESTING PERIOD: 4/1/2015-5/1/2015

MICHAEL VILLARMA

INTRODUCTION:

The purpose of this report is to describe the results from a series of tests that were conducted on a carbon fiber snowmobile suspension design. The results from these tests will define whether we were successful in designing a functional suspension system. There are four tests that we will be collecting this data from: Material testing that involves a 3 point bending test on a sample material of the same construction of our backbone, weight testing that compares our design with some of the current suspension systems, measurement of strain that is naturally induced across the carbon fiber backbone, and overall installation time by user. These tests will determine if the suspension assembly meets the requirements of the project which are as follows:

- Must weigh less than the Arctic Cat M Series OEM suspension system of 45 lbs.
- Sustain maximum load in temperatures of 32˚F +/- 32°
- Withstand forces up to 300 Kilo Newton's in vertical drops.
- Must transfer load between ground and chassis smoothly.
- Bolt into existing chassis (2006-2011 Arctic Cat M-Series) without alteration.
- Withstand track speeds of 50+ mph.

A predesignated list of requirements allowed for easy comparison of test results giving a pass/fail grade to each requirement. There was an area of interest that was not listed in our requirements that we later realized would need to be monitored utilizing a strain gage. We were able to accurately monitor the strain at this given location under various loads using data acquisition software and strain gages.

TESTING METHODS:

Material Testing-
We constructed a sample piece of carbon fiber that was identical to the construction of our backbone used in our design. The Instron 1101 provided us with the platform needed to safely determine the appropriate yield stress and strain, deflection, and modulus of elasticity of our material. The testing procedure occurred as follows:

1) Cut material specimen to size (L=4.00 Inches W=.700 Inches)
2) Attach 3 point fixture into machine
3) Load material specimen into machine, centering upper point over the middle of the specimen.
4) Input material specifications into software
5) Initialize test

Once the test has been completed, a read out is displayed that indicates the values of strain, stress, deflection etc. Using this information, we could solve for the modulus of elasticity of the material used for construction.

Weight Testing-
This test was performed using a digital scale to accurately compare the weight of the existing suspension system to the composite suspension system. Both systems were full loaded with shocks, wear strip, and all idler wheels.

Fitment Test-
The fitment test was based on the ease of install into a 2006 Arctic Cat M7 snowmobile. Factors such as time involved to install, modifications necessary, and adjustability of the suspension will attribute to the overall score of this test.

Load Testing-
This test was accurately performed using strain gages in critical loading areas of the suspension system. A data logger and strain gage monitored the overall change in dimensions of the material as it flexed in compression and tension. A live read out of the strain within the component made it a useful tool to determine the strain at different impact forces. Several static tests were performed where the snowmobile was dropped from different height locations and the strain of the component was measured. Further load testing will be completed in a dynamic situation where the strain in critical areas of the system will be monitored.

Endurance Testing-
Due to scheduling constraints, endurance testing will be completed at a later date in time. An apparatus was not available to perform this type of testing. Outside constraints did not allow for this test to be completed.

RESULTS:

Material Testing:
As a result of the 3 point bending testing, the sample component failed at a load of 400 lbs. with .1826 inches of deflection before it exceeded the elasticity of the material and began to fail. Utilizing the bending stress formula $\frac{MC}{I}$, we calculated a bending stress of 43 KSI when the component failed. This value was used as a limit when testing the actually assembly in the load testing portion of this analysis.

Weight Testing:

Weight Evaluation Sheet			
Manufacturer	Track Length	Weight (lbs.)	Weight Difference vs. Composite
Arctic Cat	153	45	14.4
Polaris	151	41	10.4
Yamaha	153	43	12.4
SkiDoo	154	44	13.4
Timbersled	153	42	11.4
Kmod	153	52	21.4
Composite Suspension	153	30.6	

Fitment Test-
The composite suspension system bolted into the existing chassis without any alterations. The Fox Shox shocks allowed for adjustment of ride height and rebound exactly as the OEM suspension would. Total install time including removal was an average of 14.3 minutes, which was comparable to the stock suspension of 12.1 minutes.

Load Testing-
During load testing, a maximum height of 2 feet was achieved. This height was $1/50^{th}$ of the height the suspension system was designed to sustain impact from. Our strain gage results yielded a maximum strain of 600 micro-inches/micro-inches. This data was collected over a series of 2 foot impact drops. The small amount of strain that was endured during this impact did not carry enough information to accurately determine if the suspension system succeeded during load testing.

Mass properties of Back Bone

Density = 0.06 pounds per cubic inch

Mass = 21.94 pounds

Volume = 341.22 cubic inches

Surface area = 1462.71 square inches

Center of mass: (inches)
X = 37.04
Y = 0.49
Z = -0.00

Mass properties of Axle Mount
Configuration: Default
Coordinate system: -- default --

Density = 0.10 pounds per cubic inch

Mass = 0.94 pounds

Volume = 9.68 cubic inches

Surface area = 54.98 square inches

CONCLUSION:
The success of the device was based on the performance of the principle investigator and the overall performance the device after construction. Throughout this project, several obstacles were presented and solutions had to be derived in order to progress forward. Further testing and modifications will be performed and continued until the desired characteristics are accomplished. This would include on

incorporating a way to raise the bending stress failure load. Overall this project was a success and I look forward to possibly working with industry to further improve this device.

Appendix H – Vita

Michael Villarma
2611 N. Water St. Ellensburg, WA 98926
(858)539-3282
michaelvillarma@gmail.com

OBJECTIVE

To obtain a position as an engineer in a growth-oriented company that will offer diverse job responsibility in mechanical engineering and will fully utilize my technical abilities as well as challenge my skillset.

SUMMARY OF QUALIFICATIONS

- Currently pursuing a BS degree in Mechanical Engineering Technology
- Can adapt quickly to the work environment that is present
- Work well with team oriented tasks
- Utilize my ability to diagnosis and solve problems promptly
- Familiarity with working on heavy machinery

EXPERIENCE

Lead Technician, The Bay Company, Wrangell, AK May 2006 to December 2012

- Received certification as a certified Yamaha Marine technician
- Diagnose and repair problems in the field under extreme conditions
- Rig and install full outboard systems on large marine vessels
- Responsible for all electrical wiring and layout of new navigation systems
- Filed warranty claims and worked with various departments within Yamaha and Mercury marine headquarters
- Generated estimates and worked with customers to provide them with the best quality product possible

Alaska Commercial Fisherman, (part time), F/V Heidi J, Wrangell, AK June 2003 to July 2012

- Fished the commercial Dungeness crab season competing with other vessels
- Worked long hours to remain one of the top fishing vessels in the fleet
- Responsible for maintaining all mechanical systems on board the vessel

Welder/Diesel Technician (part-time), J.A. Welding and Repair, Wrangell, AK May 2001 to September 2003

- Create custom welding projects with both steel and aluminum material
- Installed custom hydraulic and pneumatic systems
- Diagnose and repair heavy machinery and diesel mechanics in the field

EDUCATION

Central Washington University

Bachelors of Science in Mechanical Engineering Technology, Present

Yamaha Marine Technical University

Certification as a Yamaha Marine technician, April 2011

Wrangell High School

High School diploma, May 2003