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RC Mini Baja Car - Suspension and Chassis

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By

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Abstract/Artists Statement: Two students have developed a unique design of the RC Baja Car to optimize functionality and performance. A Baja car is a remote controlled 1/10 scale car that is used for recreation or competition, usually meant for competing in the ASME Baja car competition versus various schools. The competition focuses on the best time achieved in different courses that utilize speed, turns, and jumps. The objective for the project was to create a unique suspension from previous individual's projects by creating a four-link suspension in which allows more travel in the suspension of the car and maintains functionality with the intent to improve overall performance. To integrate this concept, the design process was calculated and modeled carefully after researching the inspiration from competitive trophy trucks. The angle of the suspension arms and tolerances needed to be precise to produce a cohesive functional rear of the car. Upon manufacturing, linkage of the suspension from the rear axle and differential case to the rear strut support and main chassis plate was crucial. Using manufacturing machines such as mills, drill presses, and sheet metal benders, the supports for the struts and the chassis plate which connects the trailing arms were created. With the four-link suspension and allowable adjustments within the design, the RC Baja Car was able to withstand a drop of 1.5 feet and 116 lbf vertically simulating jumps needing to be withstood without failure of the suspension.

Keywords: Suspension, Chassis, Performance

Introduction

1a. Description

The Mini Baja car can be used in contests, recreation, or for sport. The goal would be to compete in the ASME Baja race. The overall design, manufacturing, and analysis of the Baja Car creates an efficient and well-rounded senior project to pursue. The concept of a chassis and suspension on the Baja Car will be explored, manufactured, and tested.

1b. Motivation

The interests and motivation of cars have always been ideal when choosing a senior project, thus choosing a Baja Car that has major components like a car, gives a similar concept to design and test. The need for a Baja Car from Central Washington University to compete in the ASME Baja Race was also taken into effect.

1c. Function Statement

The RC Mini Baja Car's suspension and chassis shall support and hold all its physical parts of the car. The function of the chassis is to support all the major components of the car.

1d. Requirements

The Baja Car must meet the ASME RC Baja Race requirements as well as:

- The cost of parts for the suspension of the Baja car should be limited to $400.
- The Baja Car must be able to withstand being dropped from 1.5 feet.
- The chassis will weigh less than 7 pounds.
- The suspension will be able to handle at least 100 N of force when dropped on its tires.
- Full suspension travel of 2" without interference.

1e. Engineering Merit

This project will require stress analysis on the suspension and chassis, beam flexure on the chassis, dynamic loads and shear calculations on the control arms of the suspension.

1f. Scope of Effect

This portion of the RC mini Baja Car project will focus on the suspension and chassis area of the car.

1g. Benchmark

The benchmark RC Car was The Losi 1/10 Ford Raptor Baja Rey 4WD RC Desert Truck. Made by Losi, model number: LOS03020T1

1h. Success Criteria

The success of this project was determined by a functional Baja Car, competing in the ASME competition, and placing top three in all categories (Acceleration, Slalom, and Baja).

Design and Analysis

2a. Approach

The concept for the suspension and chassis was derived by race trophy trucks. Trophy trucks have independent four-link suspensions and provide an analytical design that varies from suspensions in years past with regards to the RC Mini Baja competition. Something unique and different was desired revolving around the suspension component of the project.

2.b Design Description

Regarding the chassis, weight savings was optimal when trying to design and create a profile. The chassis was designed to hold the necessary components and protect the structure from usage and testing. Wasted space or unused space was made sure to be shaved. The rear suspension was decided to be a four-link independent suspension with the rear axle, then two rods at approximately 45 degrees connected at the mounting posts near the middle of the car. The front end of the chassis was fabricated with a skid plate/bash bar to increase front impact resistance and longevity use of the car. The mid-section of the chassis is flat and needs to have mounting points for the major components to function and work properly in unison. Finally, supports were incorporated into the design of the chassis to attach a shell to protect the internals and make the Baja Car unique.

2.c Benchmark

The benchmark RC Car was The Losi 1/10 Ford Raptor Baja Rey 4WD RC Desert Truck. Made by Losi, model number: LOS03020T1

2.d Performance Predictions

Predictions for the Baja Car include withstanding front impact at 20 mph, being able to withstand a 1.5-foot drop, and to turn at a minimum radius of 2.67 feet. Based off calculations and designs, the Baja car should excel in all these tests being performed.

2.e Description of Analysis

Two analyses are required to be described. The first is the experimentation of the 1.5-foot drop test. The group will have a measured device to reference for a scale during testing. As the car is being drop, a recording via electronic device will capture the test for different trials, to calculate velocity, and to provide ample data to reference in later settings. Before the trials of the drop test will be conducted, the weight of the car will be measured. Visual inspection of any damages will occur after each test, along with the usage of the car to ensure operation is still intact. This test simulates the car jumping off a rock or obstacle that could take place during the ASME competition. The second analysis is the minimum turn radius of 2.67 feet. Using calculations, the team will test and record the turn radius to the left and right side of the car in motion. As the car slow performs its test, tape will be set down to follow the path of the wheels. Once a full 180-degree turn has been conducted to the left and right. Measurements of the radius will be documented. This test simulates sharp turn requirements that will be expected in the ASME competition.

2.f Scope of Testing and Evaluation

The scope of the testing and evaluation touches the aspect of structural integrity and longevity of the car; thus, the drop test being conducted. The scope also touches functionality and performance requirements, conducted in the minimum turn evaluation.

2.g Analyses

Figure A.1 is the calculation of the how much force the Baja car must withstand during a front impact at 20 mph. Regarding design issues, to prevent failure of the body and chassis, a front bash bar and skid plate will be manufactured to withstand most of the impact and diffuse force going into and disrupting the components of the car. Best practices for conducting this test is to ensure the device withstanding the impact of the car will not break, will not cause damage to nearby surroundings and that the test is conducted in a large open area. Figure A.2 is the calculation of the amount of energy the car must withstand upon being dropped from 1.5 feet vertically. The design issues regarding this analysis was the amount of give the shocks will absorb upon contact with the vehicle and the ground. Other analyses were conducting regarding the shocks as individual components as well. Best practices for conducting this analysis would be to ensure the vehicle being dropped is at the correct height and drops straight down every trial. A device or holster would create a controlled setting for maintaining consistency. A visual inspection and operation test will be conducted to make sure the device meets analysis requirements. Figure A.3 is the analysis of the minimum allowable screw diameter in order to not fail based off external forces such as the impact test or the drop test. The minimum allowable screw diameter was found and then converted with a safety factor considered. Once the calculation found the allowable screw diameter based off the given forces being applied, the screw was converted to the next standard size to ensure accessibility, cost efficiency, and durability during building and usage. Best practices regarding screw diameters is to find the minimum allowable with a safety factor converted and reference that value to a standard size if available to do so. Figure A.4 is the preliminary mount point angle for the shock to sit at. There are two orientations that could be explored. The figure analyzed the required angle for the support to mounted from the pin. The calculations will be most important during the manufacturing phase of the project and making sure everything fits cohesively. Best practices include measuring control arm lengths, strut lengths, and proper support heights to minimalize redesign or changes in fabrication once parts are being produced. This best practice will minimalize material costs and labor hours. Figure A.5 is the calculation of max angular velocity of the wheels. Due to torque and power from the motor, ensuring the wheels and linkages can withstand the output is crucial. Best practices regarding the maximum angular velocity of the wheels is to calculate the power going to the wheels and convert the angular velocity to RPM. Figure A.6 calculates the required steering arm angles for the Baja car. During designing and manufacturing phases of the project, getting the steering arm angle correct from calculations, can limit the variables effecting straight line acceleration and overall handling of the car. Best practices to test the effectiveness of the steering arm angles is to have the vehicle go in a straight line and along turns to make sure the car travels in the direction that is desired.

Figure A.7 calculates the spring force if 100 N were applied to the shocks vertically. This analysis simulates a drop or jump test of the vehicle and how it will affect the longevity of the car. The spring must absorb and withstand most of the forces being applied to the vehicle to protect the vitals and structure of the car. Best practices for testing the spring force would be to drop the car at a given height and adjust the spring to different lengths of travel to provide optimal absorption but most efficient specifications. Too soft of a suspension or too stiff of a suspension can limit the overall achievements of the vehicle but adjusting to different testing or terrains reflects real-world applications. Figure A.8 is a crucial analysis. The calculations of minimum allowable hinge pins ensure the pins do not fail or break upon testing and standard operations of the Baja car. Calculations of minimum allowable hinge pins with a safety factor added in based off expected loads, should confirm that the pins will withstand the forces applied on them. Testing phase of the project will analyze this portion extensively. Figure A.9 analyzes the angular moment of inertia for the RC car. These calculations reflect how the car interacts transversely with the wheels and the direction of motion on the ground. In other words, this analysis revolves how the car handles during cornering and turning. It is important that the car does not slip, elevate off the surface, or roll during turns. This analysis can't necessarily be measured but the idea of increasing the width of the car, will negatively affect the angular moment of inertia and can be considered during performance optimization. Figure A.10 calculates the tractive force the tires have on wet and dry concrete conditions. When optimizing speed and handling of a car, the amount of traction received from the tires interacting with the road is essential. A visual inspection of the car slipping during acceleration or turning can be conducted to analyze the amount of traction and grip the RC car has. Figure A.11 regards the allowable weight separately on the front and rear axles which correlates to the maximum allowable amount of weight on one wheel. This analysis can simulate the car going off a jump, becoming off centered and rotating during the time traveling through the air and landing on one axle or one wheel. To prevent suspension failure or malfunction, calculating the allowable force on a singular axle or wheel is important. To test this analysis, applying the calculated loads for a singular axle or a singular wheel and seeing if anything about the suspension breaks or deforms due to the stress. Figure A.12 analyzes the driveline mounting angle needed. This is important to calculate to ensure no rubbing or restraints happen during operation. It is also important for the designing of the linkages and chassis to ensure proper spacing and functionality of the car. During the designing phase, ensuring the driveline/drivetrain does not interact with any other moving part that isn't design to link to it will optimize the operating and usage of the RC car.

2h. Device

The vehicle consists of the drivetrain, chassis, suspension components, power supply, motor, and other body functional components. The device also mimics the shape and functionality at 1/10 of a scale to real trophy trucks. All the components should flow systematically and work cohesively to perform and compete at the ASME competition.

2i. Device Assembly

The device assembly can be found in appendix B of the report. The assembly represents the overall intent of the RC car but will have varying components, designs, and measurements as manufacturing and testing begin.

2j. Tolerances

Overall tolerances dictated for the scope of the project is 0.010 inches because of components having to fit so cohesively and function as intended to be. Screws, pins, and bolts need to hold the components together tightly. The suspension parts have a tolerance range where calculations will be met if manufactured in the designed range.

2k. Risk Analysis

During manufacturing, tolerances and safety during operation of machinery is very important. During testing, the safe practices that are outlined in 2g. should be considered when conducting tests. Safety factors of 1.5 were calculated when deciding allowable sizes and loads to have a buffer of room to limit failure. Calculations that had maximums should be tested below those values to ensure the device wont malfunction or limits the risk of dangers.

Methods and Construction

3a. Description

The project was designed, manufactured, and tested within the city of Ellensburg, utilizing resources and labs on Central Washington University's campus. Major components were fabricated onsite with supplementation of some parts being bought from outside retailers. The various retailers provided tools and parts that cohesively work with the designed and manufactured parts of the group.

3b. Construction

This project was designed in increments and sections. The majority was fabricated on campus with more parts being bought or sent to companies to get manufactured. The process has been broken up into sections. First the chassis which is the main support of the suspension was machined on campus with supplemental holes and billets on a waterjet with an outside retailer. Using Aluminum 6061, the material was band sawed then end milled to get the desired profile. Major issues were using the band saw and getting very precise and small radii. Slowly taking small cuts off each passthrough was conducted to achieve desired results. The surface finish after running the material against the band saw was awful. Milling and using gradual stages of sandpaper allowed for a smoother and more desired surface finish. After efficient machining, marking where mounting points and screws was crucial. Using layout dye and a sketcher, the desired measurements were marked out on the chassis plate. All locations requiring drilling were center punched with a hammer and punch. Using the desired allowable standard drill size, 3mm holes were produced. Issues regarding drilling were getting the proper mounting angle of the part. The parts varied in shapes so getting the device mounted to drill efficiently and safely was crucial. Additional supports followed this same process, like the T post support and trailing flatbed to attached components of the car. The final section of construction was the support struts, shocks, and control arms. These items were bought to ensure structural integrity and reliability. Allowing ample time for the purchased parts was the main issue. Shipping timelines and inventory in stock was something to be considered. The purchased parts were ordered early to try and deter this. The main suspension components, such as the trailing arms and control arms were bought to ensure proper fit and mounts.

3c. Device Operation

The suspension and its components act as an assembly to support the vitals of the car and withstand impact, flexure, and absorption of energy while performing tests and standard operation. The chassis supports the main components and protect the vitals of the vehicle, while the axles link the drivetrain and wheels to provide stability and support for the wheels to the frame of the car. Finally, the struts and shocks absorb the energy and stress while driving to create smoother riding conditions. The device also has electrical components that attach the battery, servo, motor, and provides power so the device can operate. The vehicle has a receiver connected to a remote to control the speed and direction of the car. Once the device is switched to on, power from the ESC and battery goes to the motor, with throttle from the receiver on the remote, the gears begin to spin and provide the power to the drivetrain which goes to the differential. The gears within the differential provide power to the axle and spins the wheels. The turning receiver from the remote reacts to the servo. The servo has turnbuckles that move the hubs on the front wheels and allows the device to turn the desired direction.

3d. Benchmark Comparison

The device has a stronger frame and supports to withstand impacts and jumps at higher speeds. The benchmark device travels at approximately 30 mph, while the team predicted 45 mph per calculations. Due to the difference in speeds, the need for manufacturing and calculating stronger supports to ensure functionality and repeatability when driving the RC car was needed to be in order. The benchmark device also has lots of accessories and pieces that have no performance function and are mostly cosmetic. The vehicle was expected to be lighter than the benchmark due to elimination of accessories and billeting within the material, thus correlating to a faster device. The benchmark device also has many plastic parts that could be at risk of breaking upon impact or collision. The manufactured car has more aluminum supports and parts to obtain stronger mechanical properties.

3e. Performance Predictions

The mini RC Baja car meets ASMEY14.5 tolerancing and drawing requirements while also meeting the ASME Mini Baja Car competition requirements and rules. The vehicle withstands a front impact at 20 mph and a drop at a height of 1.5 feet without failing or manipulating standard operation of the device.

Testing Method

4a. Introduction

The aspect of suspension failure during a drop test and front impact test will be analyzed. These are important tests to simulate due to possibilities during the ASME competition. The vehicle could hit obstacles or go off jumps during the competition so it is necessary to collect data and ensure that the vehicle will withstand the forces being applied.

4b. Method/Approach

During the drop test, the device was at a specific controlled height using a tape measure and then the wall was marked with tape to have consistency when testing. The device had calculations to collect impact velocity and energy for each trial. The device was weighed to meet the 7 lb. weight predictions and to allow for the use of kinematic equations. The actual weight was approximately 6.51 lbs. Per instructed manufacturers procedure, the shocks on the device were filled with the proper fluid and purged to get the air out of the shocks to allow for the shocks to were properly and as intended. The shocks being filled dampened the force and energy sustained upon impact during the drop test and to accurately reflect the test of being able to withstand 14.22 J of energy. The device was then dropped and recorded to gather data and velocity. Ensuring the height of the device being dropped from was important to maintain accurate results. When calculating the deflection distance, the max travel of the springs compressed was used. A visual inspection of the components on the car were also conducted for any failures that restrict the operation of the vehicle. Rolling the device ensured that the device was properly working and the examination of joints, mating materials, and connections were inspected closely. Then, the device was tested during operation to make sure all pieces, connections, and joints are working properly. This test was conducted three times to ensure structural strength is not compromised and to simulate the Baja car jumping off obstacles during the ASME competition. During the front impact test, the device moved at a velocity of 15.6 mph, lower than our required velocity, and hit an obstacle head on to simulate obstacles within the ASME competition. Ensuring that there is enough space for testing is important to limit the dangers of possible debris and proper precautions of protecting the walls or property if testing is conducted within the Hogue Technology building. Obtaining a load cell and attaching the cell to the front of the car would be most ideal but was limited in availability and cost, so it was not included during testing. Also gathering a device such as a radar gun to ensure appropriate velocity is maintained would satisfy testing methods but also was not included due to supply chain lead times and cost. A visual inspection also took place after the vehicle sustained a front collision. The front impact test was conducted three times to confirm that the vehicle could sustain impact and maintain proper operation as intended.

4c. Test Procedure Description

Testing always needs proper procedure and safety equipment. Possibility of pinching and debris were the most concerning obstacles during testing. Proper eye wear was worn during testing. Each test had a controlled variable, such as a set height or mph. The tests were conducted offsite and in a controlled area. Three trials were conducted for each test and recorded or observed.

4d. Deliverables

Based off calculations, the vehicle traveling at 15.6 mph and sustaining a front impact, withstood a force of roughly 842 lb_f. When the device was drop from 1.5 ft or .4572 m, it withstood 13.24 Joules of energy and approximately 116 lb_f.

Budget

5a. Suppliers

Part suppliers included: Traxxas, Losi, and Amazon for most of the components for the RC car. The material for the Aluminum and machined parts came from Amazon. Some components such as the wheels, shocks, battery were sourced from previous projects.

5b. Estimated Outsourcing rates

Most of the rates were shipping and labor rates due to the extensiveness of the manufacturing portion of the project. Most of the costs encountered were the purchased parts that were necessary to the suspension of the car such as the A-Arms, shocks, and trailing arms. The material, aluminum 6061 was a sublevel cost that was required for manufacturing parts but priced fairly. The least costly parts were the miscellaneous bearings, drill bits, and screws but can add up over time. The estimated cost of the project was around $260 with a projected parts list. With the manipulation of sizing and changing manufacturing processes, the overall cost will meet the $260 budget. Two errors occurred when purchasing parts, one beneficial and the other was not a major setback. The first error was purchasing a 1/6 scale trailing arm set instead of a 1/10 scale which was about $70. Fortunately, the parts were returned, and the 1/10 scale trailing arms were about $20, which saved money from the first set as well as the project set within the budget during fall quarter. The second error was the purchase of 6mm OD bearings instead of 7mm OD bearings which were needed. The cost for the set of bearings created a setback of $10 but the use for them could still arise. Due to using only Aluminum 6061 and purchased parts for the suspension and chassis components, the proposed use of 3D printing was no longer needed thus saved money compared to the initial budget. Shipping was a surprising cost and mostly ended up free due to ordering most of the parts and material through Amazon. Stock prices and tax were the main contributors to fulfil the budget. The shock absorbers were $40.99 with $3.40 in tax to a final cost of $44.39. The 7mm OD bearings were $11.49 with $.95 in tax to a final cost of $12.44. The 6mm OD bearings were $10.98 with $.91 in tax to create a cost of $11.89. The A-arms were $29.99 with $2.49 in tax to a final cost of $32.48. The trailing arms were $15.99 with $2.99 in shipping to be a total of $18.98. The aluminum sheet stock was $27.95 for a sheet, two were purchased with $4.64 in tax to create a final price of $60.54. The drill bit was $3.59 with $.30 in tax to an outcome cost of $3.89. The total amount of money spent at this time has been approximately $184.61 which was on track to meet the proposed budget. With testing being conducted, additional material that was needed was very minimal. The cost for poster paper was added for a backdrop that looked professional and could have measurements for the drop test to be conducted. The cost of the poster paper was about $2.19 with $.22 in tax. All other testing materials such as a tape measure, sharpie, and cameras were already obtained and required no additional cost. A few cost issues arose during the process of the RC car project.

If problems occurred, the part was kept or returned, and the correct sized part was then researched and ordered. Ensuring proactive ordering was essential so no task or deadline was exceeded. Luckily, no item was delayed past the expected date. With the testing portion adding very little expenditure towards the budget, the overall budget being used for the RC Baja car came out to $195.30 of the estimated $260, about 75.28% of the budget consumed. If redesigning or upgrading occurred, ample amount of the budget left could be used.

5c. Labor

Labor was calculated as if the group was paying two individuals; the number of students on the project, at a rate of $13.50 (minimum wage in Washington State) in 2020 and was documented on a time sheet for manufacturing all parts and the assembly of the vehicle. Hours were recorded in tenths.

5d. Total Project Cost

The total parts cost was estimated to about $260 and concluded at $195 for all three quarters. Contingencies due to designing a suspension that is unique from previous Baja Car projects adds an element of calculations and designing. The overall list of parts and estimated labor hours changes occurred. The cost for spring testing was minimal and concluded the project cost to $195. The projected overall project goal is $400 or less, so the project was within the projected budget.

5e. Funding Source(s)

All the funding was self-sufficient. Getting donations from ASCWU and outside companies was a goal for the team but was not possible. Some parts were also donated from previous projects or integrated from parts already obtained.

Schedule

6a. Gantt Chart

Appendix E references a high-level Gantt chart an estimated timeline of the project. The Gantt chart has estimated work hours vs actual hours a task took to complete. Categories of how each task was started, such as: started early and ended early or started late and ended early are included in the key section of the chart. Major tasks and deliverables were highlighted in blue to ensure those objectives were met accordingly.

6b. Time Specific Tasks

Several components were time specific or required previous designing and planning before it could be conducted. Thus, a proper timeline and planning is important to stay on an appropriate timeframe. The chassis plate and front support post were high in priority to manufacture first. The chassis plate is the foundation of the RC car and holds major components and connects the front and rear sections of the vehicle. The control arms were purchased first, while the tires and hubs were donated. With the inclusion of Carlton McDonald’s parts, the tie rods and springs were then added for tolerancing and ensuring proper fit. One challenge with the chassis plate and the control arms was the interference of material restricting the control arm to reach full range of motion. Grinding and sanding alleviated this problem quickly. The front support was manufactured per drawing specifications and connected the springs efficiently. The next important manufactured part was the back support which connects the trailing arms, springs, and allows the driveshaft to reach the motor. This part was decided to be manufactured last to allow ample amount of purchased parts to arrive and to ensure all sizes or holes were correct to minimalize redesigning. Part lists are important to know what all needs to be modeled and to be ordered. A parts list was due at the end of Thanksgiving break to allow ample time to model the remaining components and assembly. Completing the Gantt was also important to fill in before the end of the quarter to ensure all tasks were met and allow the manufacturing phase to be conducted. Once the manufacturing phase was able to be pursued, the major components according to the Gantt were manufactured first with supplemental parts such as purchased parts, taps, and screws were ordered next. The manufacturing phase had a strict schedule that was followed closely to meet deadlines. In the spring of the senior project timeline, testing was conducted. The top priority according to the Gantt was to obtain testing materials to conduct the procedures effectively with high-level deliverables. Most of the materials were gathered within the second week of spring quarter. Another time specific task was to create a testing report outline to have direct procedures and variables to be testing. Testing took place in the third and fourth week of spring quarter. Both tests were on track to meet the SOURCE deadline with ample amount of time to double-check procedures, measurements, and calculations. The tightest timeline was the creation of the SOURCE poster that conveyed the information effectively from testing the RC Baja car. Approval was needed from faculty to ensure the poster was concise, then a voice recording was required to be overlaid the slide as if a presentation were being conducted. The voice recording slides had to be submitted to SOURCE by a specific deadline with no forgiveness if missed. The SOURCE poster creation, approval, recording, and submission was about 7 days of allowance.

6c. Task Dates

Parts list was completed by the end of Thanksgiving break. Drawings and assemblies were completed by the end of fall quarter 2019. The remaining section of the report for fall was filled out by the end of Thanksgiving break as well. The appendixes and supporting documents were completed by the end of the fall quarter. All three manufactured parts are finished. All purchased parts have been ordered as well. With the combination of Carlton McDonald's parts and timeline, the drivetrain and rear of the vehicle were completed with amble amount of time to optimize and customize the RC Baja vehicle. All parts were completed and assembled by Wednesday March 11th to meet the requirements to move from 489B to 489C.

6d. Milestones

Milestones include project approval, analysis', testing methods, and completion of report. The project cannot be started without approval and research into a specific problem or task. Approval is the most important milestone to get the ball rolling and start of the project. Analysis are important to ensure designing parameters and testing can be conducted. Testing methods outline risks, locations, and procedure to confirm accurate and safe testing procedures. Finally, the overall completion of the report is a big milestone. Submitting the calculations, assemblies, parts, and budget is a reference for further phases of the project.

6e. Project Time

The exact timeline of the project is hard to calculate, but the estimated time is 100+ hours of manufacturing and optimization. Labor and machine time will fill most of that estimated project time. The fall portion of the project took approximately 37 hours between designing, researching, and reporting. With Fall and Winter added together, the total time has been 95.75 hours for the Baja car project. Spring had about 57 hours accrued, thus bringing the total project time to 152.75 hours.

Project Management

7a. Human Resources

Resources include Carlton McDonald, Lab Technician Matt Burvee, Professor Ted Bramble, Dr. Craig Johnson, Professor Charles Pringle, and Professor John Choi.

7b. Physical Resources

Physical resources include Hogue Technology Building, CNC machines, Engine Lathes, Drill press, and other various tools to complete assembly of the vehicle. The 3D printer is also a physical resource located inside of Hogue.

7c. Soft Resources

Soft resources include senior project report outline, web resources regarding suspension calculations and layouts, and amazon for ordering parts.

7d. Financial Resources

Financial resources include self-supporting funding, ASCWU/Business donation or grant, and donations from previous vehicles.

Discussion

8a. Design Evolution

The initial design of the RC Baja car was to gather ideas and information from previous teams from the past and optimize the vehicle in the group’s unique way. The team saw what was used effectively and where areas could improve. The major design aspect that is unique to the Baja car this year is the four-link suspension that mimics real scale trophy race trucks. As the design for the Baja Car progress, some aspects were manipulated. The rear trunk strut mount was bent in different shapes than projected due to the issue of bending .25” thick aluminum at such an aggressive angle. To compromise, the material was slotted to .125” at the bending joints, then braces were added on the backside to support the material during tension when operating the vehicle. The structural integrity was also compromised during the bending process and caused an “orange peel” effect on the device, but the strength needed for the Baja Car application still meets requirements. The chassis plate was projected to be a solid piece then the intent of optimizing it and make the part lighter was conducted. The main problem was shaving enough material with the pneumatic hacksaw. The hacksaw took large blocks of time to remove material because the part was thick in nature. Once the shaving of material took place, cleaning the slots were conducted with an end mill and Dremel to produce clean surface finishes.

8b. Project Risk Analysis

Risks involved with the RC car include electrical shock from the battery, pinching points from mechanical components, the speed and movement of the car during operation or testing, and the ability to quickly repair if malfunction of the vehicle takes place. Due to complex designing, measuring, mounting, and performance, the manipulation and assembly is important. Manufacturing the support mounts and chassis plate took ample amount of time due to the marking layouts, manufacturing process, setup time, and finishing. Since supplies are limited and costly, ensuring proper lengths are critical to make the overall assembly work. Cutting on the bandsaw can be intimidating but was used to get overall shape desired, then the end mill was used for finishing pass throughs and dimensions. Material is limited and managing the raw sheet stock is important, but the amount ordered combated that efficiently.

8c. Successful

The analysis and design of the vehicle was decided upon the group cohesively. Finding ample deliverables and testing criteria went smoothly as well. The timeline of needed criteria and aspects of the project went smoothly and allowed for items needing prior information or research to be conducted without any delay. The purchasing of material and parts were prioritized and came on time with no issues. Manufacturing of parts are on time according to the Gantt schedule and timeline. One obstacle that created a delay was deciding the most efficient and appropriate manufacturing process regarding the schedule and budget. Like most projects, time and money is a major factor just like in the RC Baja Car project. The obstacle that created the most amount of trouble was being a unique design to other previous RC projects, measurements and resources were limited. Benchmarks allow for visual representation of what the group would like to achieve, but without parts in physical possession, measurements and scale is very hard to obtain. Companies will not put specifications of the parts to reduce copying of products, which is expected. Optimization, best guess, and ultimately the groups decision making is what made the obstacle able to be overcome. The vertical drop test and front impact tests were successful, and the RC car met all the required specifications. The car withstood 842 lbs. of force upon collision with a wall, while withstanding 116 lbs. of force when being dropped vertically from 1.5 feet. A pass/fail inspection was also conducted since there is many mechanical parts that form the assembly of the RC car. To receive a passing grade, the car was turned on to ensure all electrical components were working by controlling the car with the remote to go forward and backwards. The car was then tested to make a left-hand turn and then a right turn. Finally, a visual inspection of all joints, bolts, and manufactured parts was conducted to ensure no nuts came loose, break in materials, or if other nonstandard scenarios took place. If all three criteria were met, the car received a passing grade in which it did.

8d. Project Documentation

Project documentation includes twelve analysis sheets of the vehicle and testing parameters included. Five drawings of physical components are also included in the appendix b section of the report with more to be included. Job hazard analysis documentation was also included to ensure proper safety equipment and testing are used effectively to eliminate risks or injury. The training certification of Hogue Technology Labs is also obtained to confirm that the individuals of the group are trained in the respected labs and the machinery within them.

8e. Next Phase

The next phase of the project includes the overall review of the design, parameters, and testing requirements. Then, a presentation of a chosen testing requirement was to be taken place in front of the senior project class. Following the presentations, in winter quarter, manufacturing begun of the vehicle with any optimization or changes needed during the building phase of the project. The chassis and front strut support post have been manufactured along with all purchased parts. Upon working with Carlton McDonald, the assembly and manufacturing of the rear support was conducted next within the senior project timeline. Once assembly was finished, the optimization and testing of the RC Baja car occurred. Finally, the testing of the vertical drop test and front impact tests were conducted. Some challenges took place when testing the RC car. Trying to keep the data consistent as possible to get accurate results was necessary. During the drop test, ensuring that the car fell near the 1.5 ft height or as close as possible was challenging. A device that held the car at adjusted heights and then unclamped to drop the car would be ideal. During the front impact test, making sure the RC car ran into the stationary object with its nose and not the side of the car. When accelerating the car, so much torque was applied and keeping the device straight was difficult at times. Even though the device did not meet the minimum 20 mph during testing, a very noble 15.6 mph was achieved. With a different battery and weight saving operations within the material, 20 mph velocity could be achieved.

Conclusion

9a. Readiness

The team will focus on the RC Baja Car project with focus on the drivetrain and suspension aspects of the vehicle. The goal for the project was to compete in the ASME Baja Car competition held at Central Washington University in the spring. The overall readiness to begin manufacturing was nearly ready in week 9 of fall quarter. Parts list, schedule, and project proposal had a few aspects needed to be finished and ready to begin the next phase of the project but was finished in time. All materials and parts were manufactured early in winter quarter to streamline the senior project process. Testing was simple during spring and according to the Gantt, the project was finished by week 8 of spring quarter.

9b. Analysis

The two analyses that are of importance that contributes to the success of the project are: front impact test and drop test of the vehicle. These analyses both simulate possible outcomes or events that may take place in the ASME competition. The vehicle may have to sustain jumps and not fail, along with possible collision with obstacles and must not fail as well.

With the suspension being a primary focus, the structural integrity and durability is prioritized to ensure the vehicle does not fail during operation.

9c. Performance

The predicted performances of the car include: to compete in the ASME competition, withstand 125 lb_f upon front impact of the vehicle at 20 mph, and withstand 14.22 J of energy being dropped from 1.5 ft vertically. The actual performance values and criteria were populated upon testing results being received.

Acknowledgements

10a. Resources and Contributors

Acknowledgements and overall appreciation for resources, feedback, and help goes to Carlton McDonald, Dr. Johnson, Professor Choi, and Professor Pringle, Matt Burvee, and Ted Bramble for helping with the senior project. The resource these individuals provided, created a seamless timeline for all elements of the project.

References

Mott, Robert L., Edward Vavrek, Jyhwen Wang. *Machine Elements in Mechanical Design*. [VitalSource Bookshelf].

Hibbeler, Russell C., and Kai Beng Yap. *Statics and Mechanics of Materials*. Pearson, 2019.

“FxSolver.” *FxSolver*, https://www.fxsolver.com/.

Engineering ToolBox, https://www.engineeringtoolbox.com/.

Appendix A - Analysis

RC Baja Car Impact Test

Collin McKenzie

Front Impact Test - Theoretical

Weight of chassis = 2948g = 2.948 kg or 6.51 lbs.

$Fxd = \frac{1}{2} m v^2$

$F = \frac{\frac{1}{2} m v^2}{d}$ D: assumed crumple zone = .75in or .01905 m

$\text{velocity} = \frac{20 \text{ miles}}{\text{hour}} \times \frac{5280 \text{ ft}}{1 \text{ mile}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{1 \text{ min}}{60 \text{ sec}} = 29.3 \text{ ft/s}$

$V = 29.3 \frac{ft}{s} \times \frac{.3048 \text{ m}}{1 \text{ ft}} = 8.93 \text{ m/s}$

$\text{Force of Impact} = \frac{\frac{1}{2}(2.948 \text{ kg})(8.93 \text{ m/s})^2}{(.01905 \text{m})} = 6183.7 \text{ kg} \cdot \frac{m}{s^2}$

$6183.7 \text{ kg} \cdot \frac{m}{s^2} = 6183.7 \text{ N}$

$6183.7 \text{ N} \times \frac{.22481 \text{ lbf}}{1 \text{ Newton}} = \boxed{1390 \text{ lbf}}$

Actual

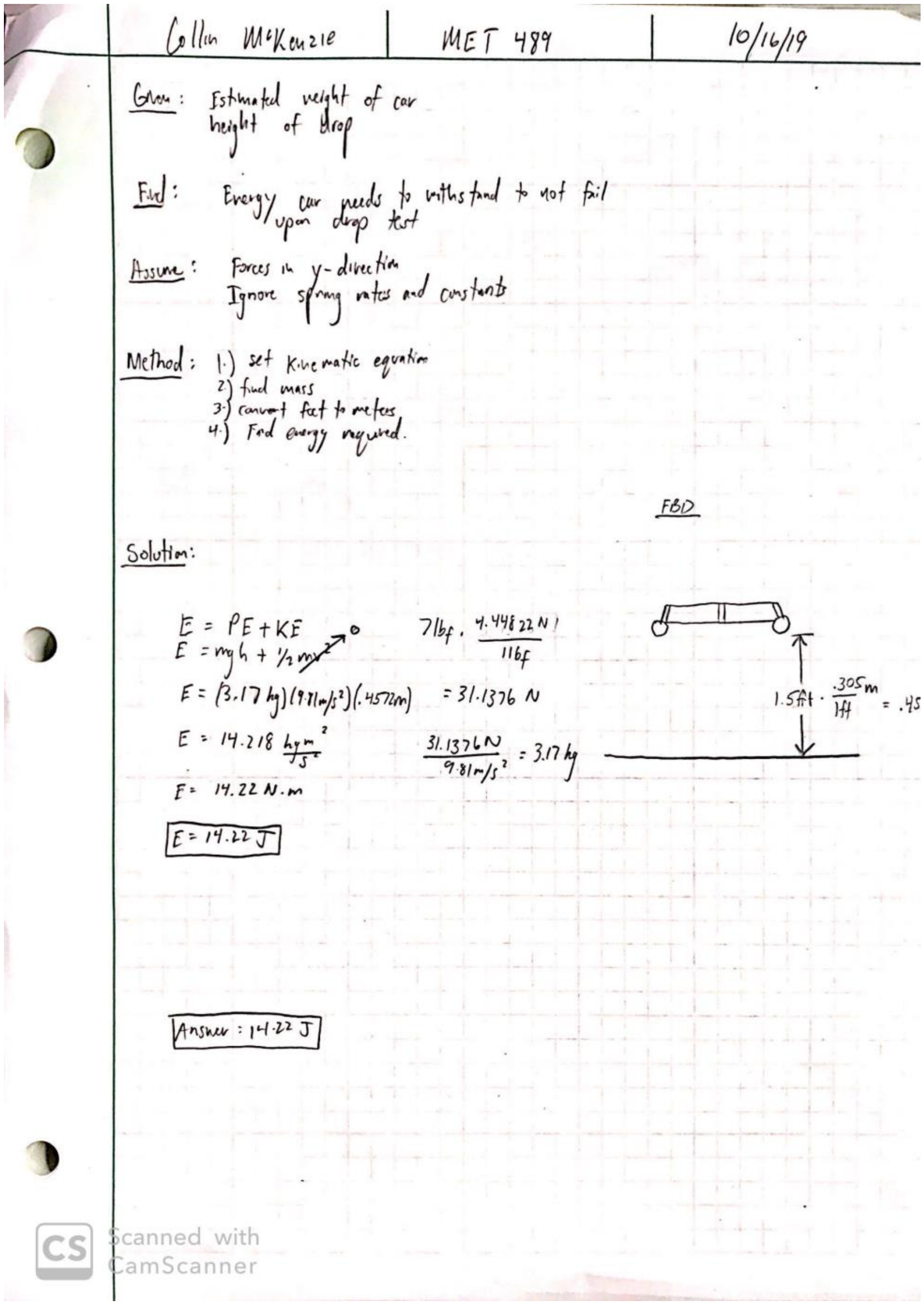
$\text{Avg velocity} = 22.83 \text{ ft/s} \times \frac{.3048 \text{m}}{1 \text{ ft}} = 6.96 \text{ m/s}$

$\text{Force of impact} = \frac{\frac{1}{2}(2.948 \text{ kg})(6.96 \text{ m/s})^2}{(.01905 \text{ m})} = 3{,}748.2 \text{ N}$

$3{,}748.2 \text{N} \times \frac{.22481 \text{ lbf}}{1 \text{ Newton}} = \boxed{842 \text{ lbf}}$ Avgerage

Figure A.1: *Analysis of RC Baja Car sustaining front impact at 20 mph.*

RC Baja Car Drop Test


Collin McKenzie | MET 489 | 10/16/19

Given: Estimated weight of car
height of drop

Find: Energy car needs to withstand to not fail upon drop test

Assume: Forces in y-direction
Ignore spring rates and constants

Method: 1.) set Kinematic equation
2.) find mass
3.) convert feet to meters
4.) Find energy required.

FBD

Solution:

$E = PE + KE$

$E = mgh + \frac{1}{2}mv^2 \to 0$

$E = (3.17\ kg)(9.81\ m/s^2)(.4572\ m)$

$E = 14.218\ \frac{kg\,m^2}{s^2}$

$E = 14.22\ N \cdot m$

$\boxed{E = 14.22\ J}$

$7\ lb_f \cdot \frac{4.44822\ N}{1\ lb_f} = 31.1376\ N$

$\frac{31.1376\ N}{9.81\ m/s^2} = 3.17\ kg$

$1.5\ ft \cdot \frac{.305\ m}{1\ ft} = .45$

$\boxed{\text{Answer} : 14.22\ J}$

Figure A.2: *RC Baja Car energy absorption requirement from being dropped at 1.5 feet.*

Minimum Allowable Screw Diameter

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Given: Energy needed to withstand drop from 1.5 ft.

Find: minimum allowable screw diameter

Assume: Material is Aluminum, homogeneous

Method:
1.) Find σ_{allow}
2.) convert Joules to lbf
3.) solve for diameter

Solution:

$$\sigma_{allow} = \frac{\sigma_{yield}}{S.F.} = \frac{40,000 \text{ psi}}{2} = 20,000 \text{ psi}$$

$$\sigma_{allow} = \frac{V}{A} \qquad A = \frac{\pi d^2}{4}$$

$$\sigma_{allow} = \frac{V}{\frac{\pi d^2}{4}}$$

$$20,000 \frac{lb}{in^2} = \frac{10.49 \text{ lbf}}{\frac{\pi d^2}{7}} \qquad 14.22 \text{ J} = 10.49 \text{ lbf}$$

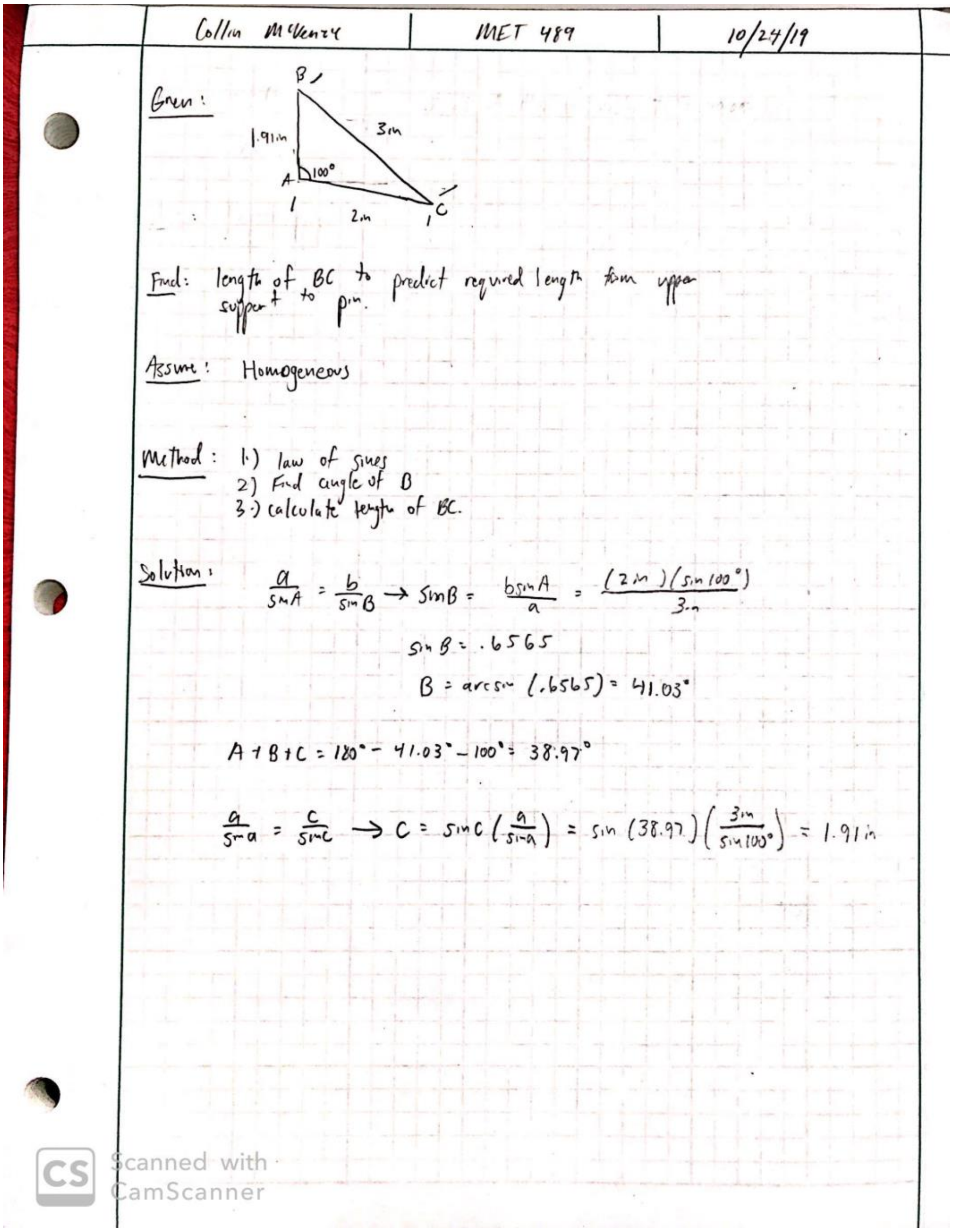
$$\frac{\pi d^2}{4}(20,000) = 10.49$$

$$d = \sqrt{\frac{10.49(4)}{\pi(20,000)}}$$

Answer: $d = .081$ in → min screw diameter

Figure A.3: *Minimum allowable screw diameter to withstand impact and not fail at screws.*

Mounting Angle and Length for struts



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Given:

Find: length of BC to predict required length from upper support to pin.

Assume: Homogeneous

Method:
1.) law of sines
2) Find angle of B
3.) calculate length of BC.

Solution:

$$\frac{a}{\sin A} = \frac{b}{\sin B} \rightarrow \sin B = \frac{b \sin A}{a} = \frac{(2\,in)(\sin 100^\circ)}{3\,in}$$

$$\sin B = .6565$$

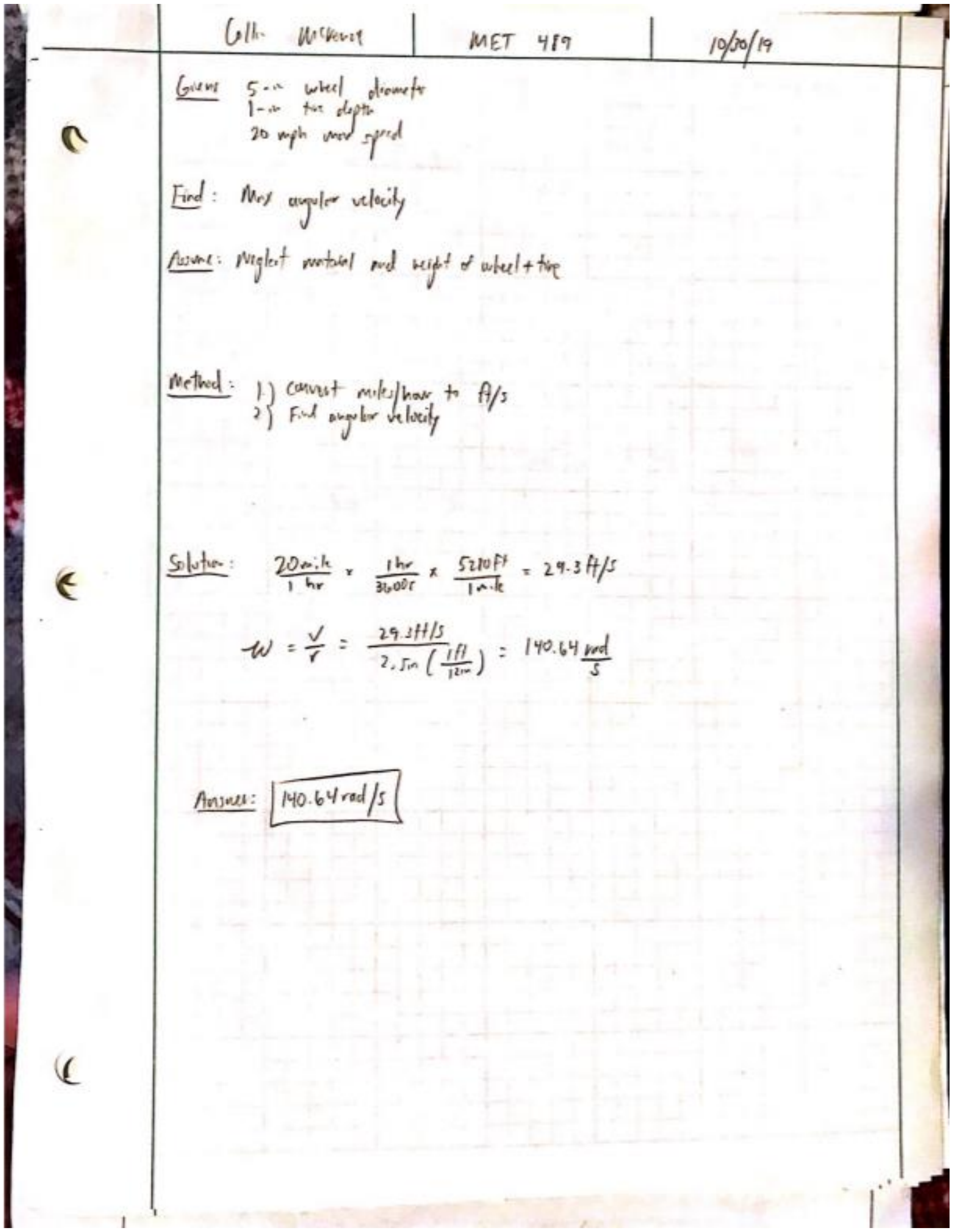
$$B = \arcsin(.6565) = 41.03^\circ$$

$$A + B + C = 180^\circ - 41.03^\circ - 100^\circ = 38.97^\circ$$

$$\frac{a}{\sin a} = \frac{c}{\sin c} \rightarrow c = \sin c \left(\frac{a}{\sin a}\right) = \sin(38.97)\left(\frac{3\,in}{\sin 100^\circ}\right) = 1.91\,in$$

Figure A.4: *Finding the length of mounting supports and angle needed to be attached at.*

Max Angular Velocity of the Wheels



Collin McKeever	MET 489	10/30/19

Given: 5-in wheel diameter
1-in tire depth
20 mph max speed

Find: Max angular velocity

Assume: Neglect material and weight of wheel + tire

Method: 1.) Convert miles/hour to ft/s
2.) Find angular velocity

Solution: $\frac{20 \text{ mile}}{1 \text{ hr}} \times \frac{1 \text{ hr}}{3600 \text{ s}} \times \frac{5280 \text{ ft}}{1 \text{ mile}} = 29.3 \text{ ft/s}$

$$\omega = \frac{v}{r} = \frac{29.3 \text{ ft/s}}{2.5 \text{ in} \left(\frac{1 \text{ ft}}{12 \text{ in}}\right)} = 140.64 \frac{\text{rad}}{\text{s}}$$

Answer: 140.64 rad/s

Figure A.5: *Finding the maximum angular velocity of the wheels.*

Steering Arm Angle

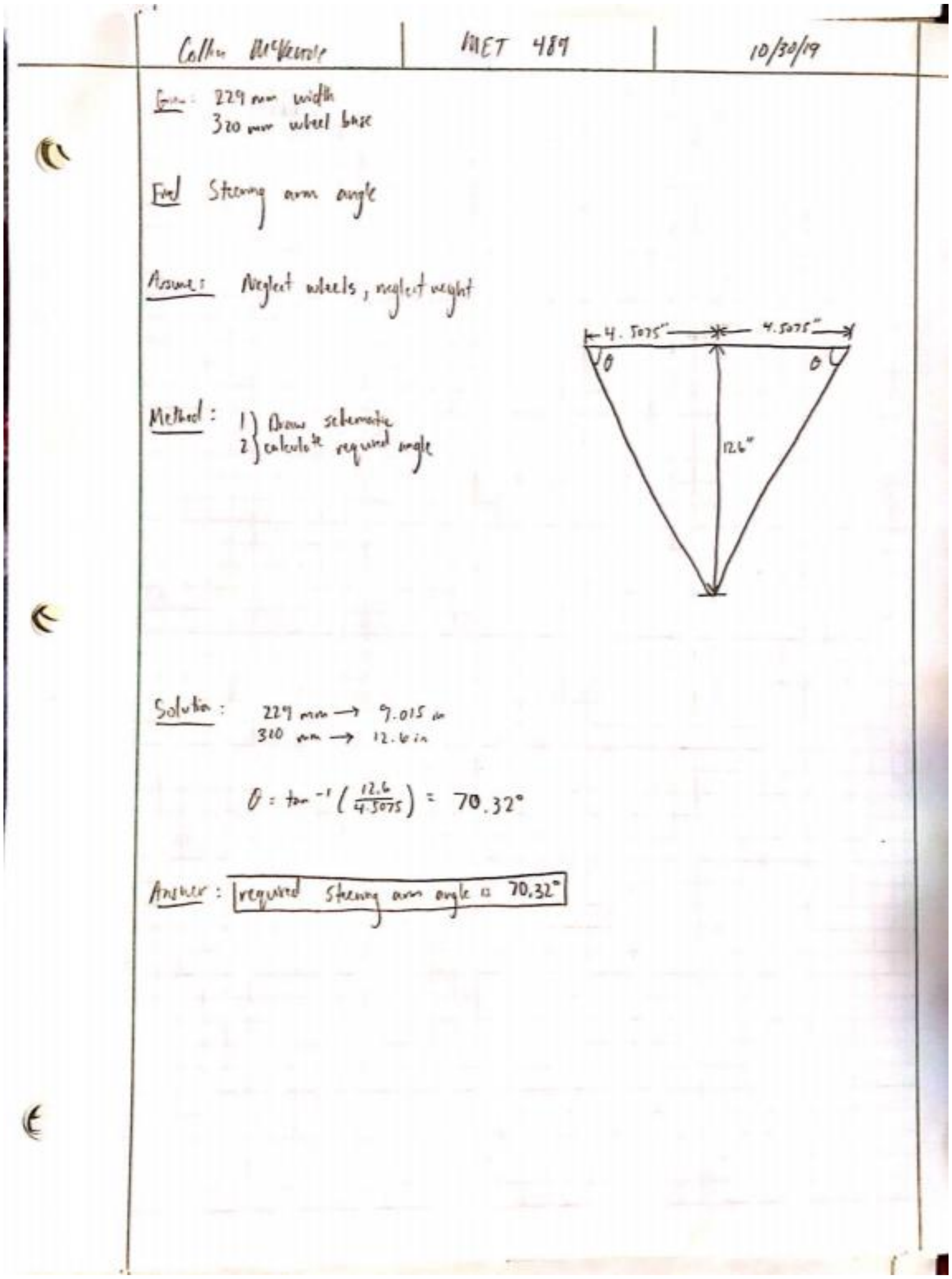


Figure A.6: *Finding the required steering arm angle.*

Spring Force Constant

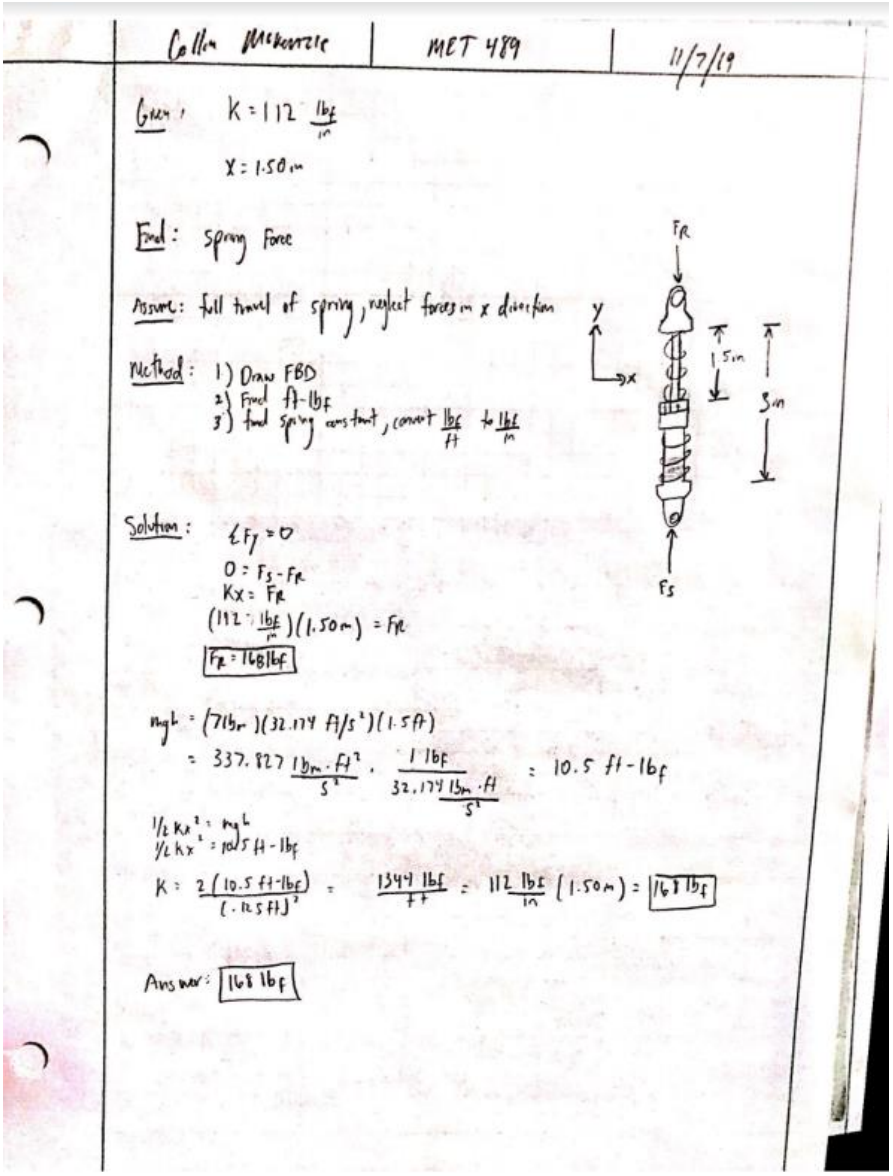
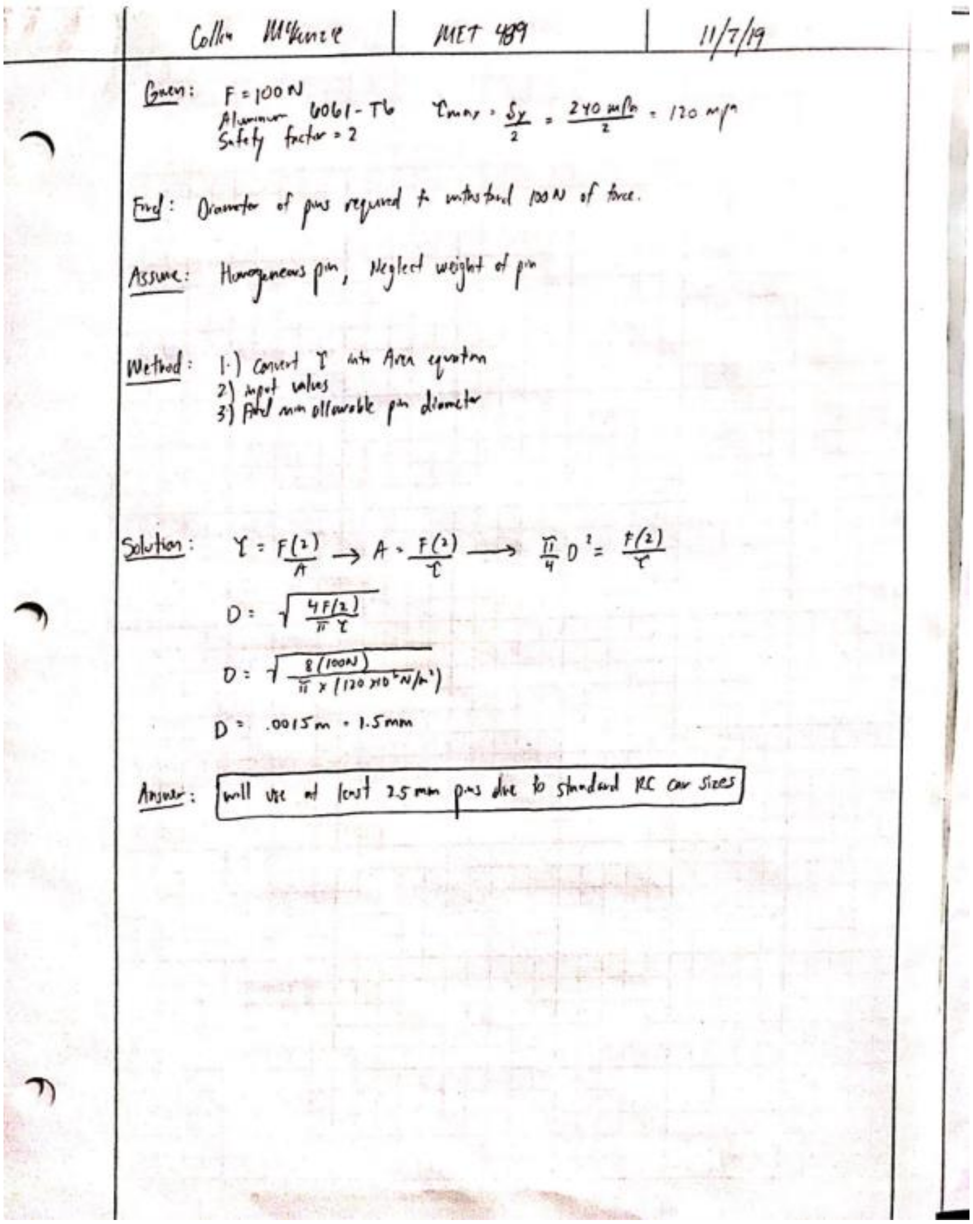


Figure A.7: *100 N of force acting on a spring.*

Minimum Diameter of Pin allowed



Collin McKenzie | MET 489 | 11/7/19

Given: $F = 100\ N$
Aluminum 6061-T6
Safety factor = 2

$\tau_{max} = \frac{S_y}{2} = \frac{240\ MPa}{2} = 120\ MPa$

Find: Diameter of pins required to withstand 100 N of force.

Assume: Homogeneous pin, Neglect weight of pin

Method:
1.) Convert τ into Area equation
2) Input values
3) Find min allowable pin diameter

Solution:

$$\tau = \frac{F(2)}{A} \rightarrow A = \frac{F(2)}{\tau} \rightarrow \frac{\pi}{4} D^2 = \frac{F(2)}{\tau}$$

$$D = \sqrt{\frac{4F(2)}{\pi \tau}}$$

$$D = \sqrt{\frac{8(100N)}{\pi \times (120 \times 10^6\ N/m^2)}}$$

$$D = .0015m = 1.5mm$$

Answer: will use at least 2.5 mm pins due to standard RC car sizes

Figure A.8: Minimum allowable diameter of hinge pins.

Automobile Angular Inertia

Given: m = 3.18 kg, height = .147m, width = .229m

Find: Roll angular inertia (automobile handling)

Assume: uniform mass, neglect friction

Method:
1.) Find mass of car
2.) Find height of car
3.) Find width of car
4.) calculate angular Inertia

Solution:
I = Roll angular Inertia ($kg \cdot m^2$)
M = uniform mass of car (kg)
h = height of car (m)
w = width of car (m)

7 lb = 3.18 kg

$$I = M \cdot \frac{h^2 + w^2}{12}$$

$$I = 3.18kg \cdot \frac{.147m^2 + .229m^2}{12}$$

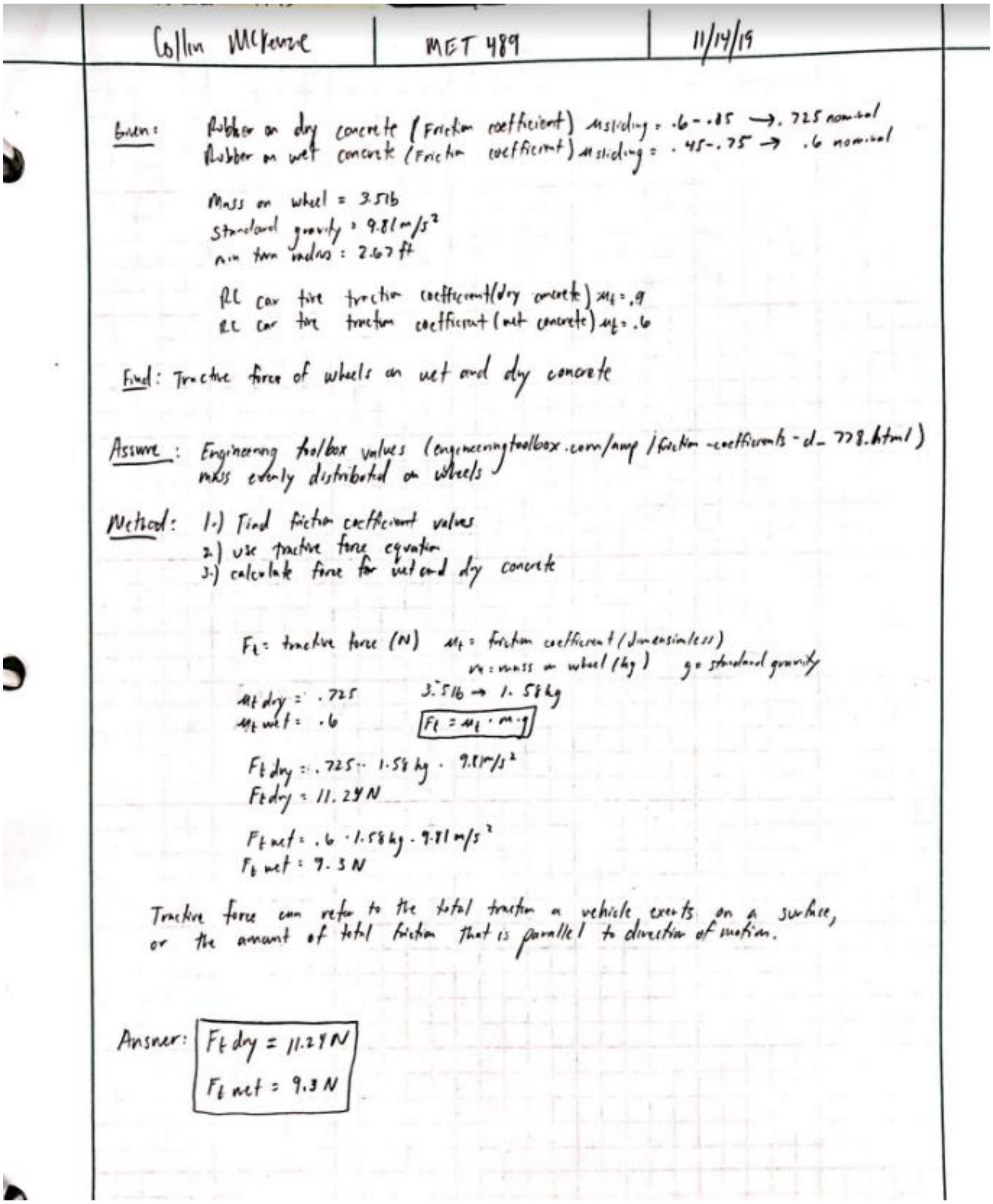
$$I = .0196\ kg \cdot m^2$$

Automobile handling describes the way the wheels perform transverse to their direction of motion, especially during cornering. Greater widths hurts handling by increasing angular inertia.

Answer: $\boxed{I = .0196\ kg \cdot m^2}$

Figure A.9: *Angular moment of inertia for RC car*

Tractive Force of Wheels on Pavement



Collin McKenzie | MET 489 | 11/14/19

Given: Rubber on dry concrete (Friction coefficient) μ sliding = .6 - .85 → .725 nominal
Rubber on wet concrete (Friction coefficient) μ sliding = .45 - .75 → .6 nominal

Mass on wheel = 3.5 lb
Standard gravity = 9.81 m/s²
min turn radius: 2.67 ft

RC car tire traction coefficient (dry concrete) μt = .9
RC car tire traction coefficient (wet concrete) μt = .6

Find: Tractive force of wheels on wet and dry concrete

Assume: Engineering toolbox values (engineeringtoolbox.com/amp/friction-coefficients-d_778.html)
mass evenly distributed on wheels

Method: 1.) Find friction coefficient values
2.) use tractive force equation
3.) calculate force for wet and dry concrete

Ft = tractive force (N) μt = friction coefficient (dimensionless)
m = mass on wheel (kg) g = standard gravity

μt dry = .725
μt wet = .6

3.5 lb → 1.58 kg

$F_t = \mu_t \cdot m \cdot g$

Ft dry = .725 · 1.58 kg · 9.81 m/s²
Ft dry = 11.24 N

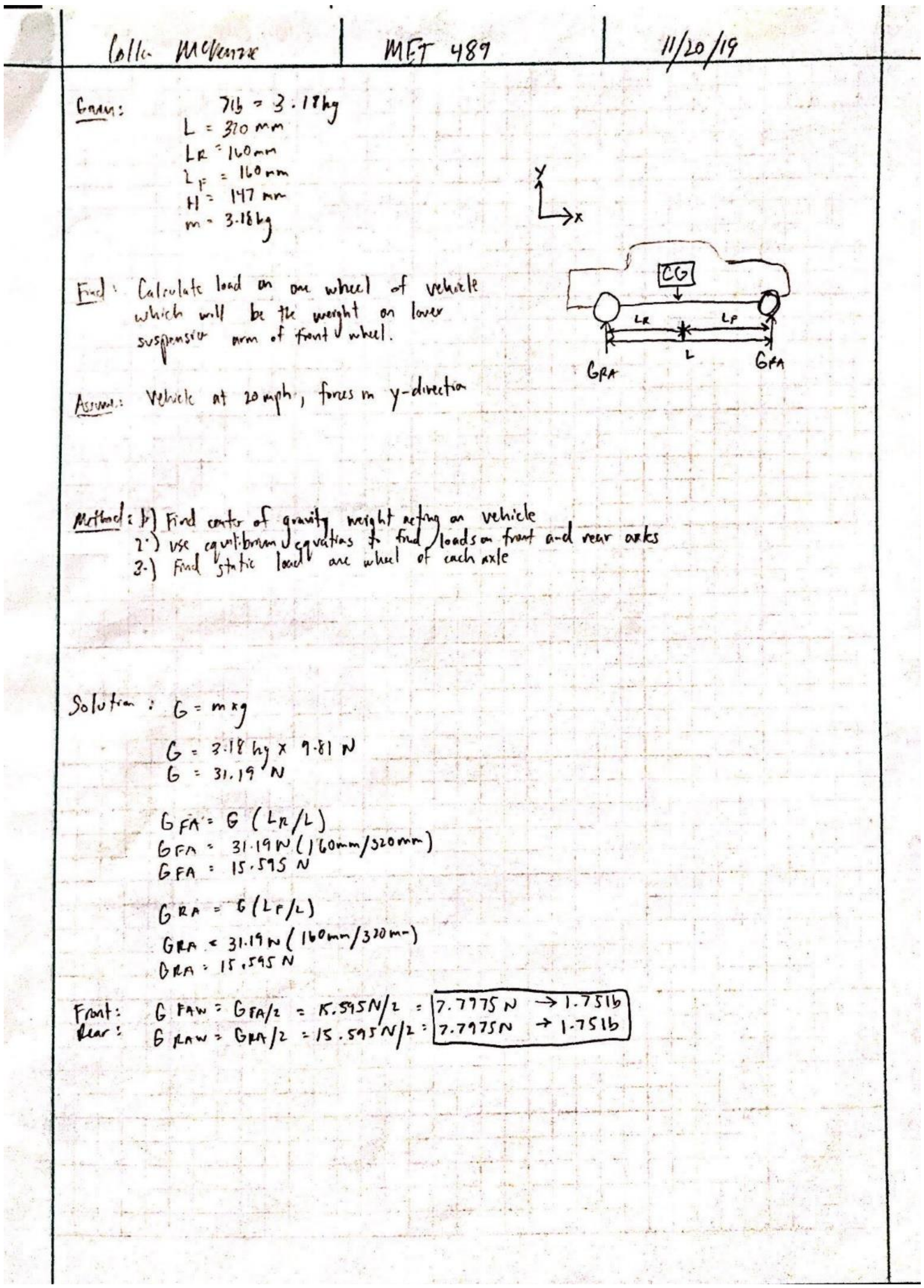
Ft wet = .6 · 1.58 kg · 9.81 m/s²
Ft wet = 9.3 N

Tractive force can refer to the total traction a vehicle exerts on a surface, or the amount of total friction that is parallel to direction of motion.

Answer: Ft dry = 11.24 N
Ft wet = 9.3 N

Figure A.10: *Tractive force of tires on wet and dry concrete.*

Load on one Wheel



Collin McKenzie | MET 489 | 11/20/19

Given: 7lb = 3.18kg
L = 320 mm
LR = 160mm
LF = 160mm
H = 147 mm
m = 3.18kg

Find: Calculate load on one wheel of vehicle which will be the weight on lower suspension arm of front wheel.

Assume: Vehicle at 20mph, forces in y-direction

Method: 1.) Find center of gravity weight acting on vehicle
2.) use equilibrium equations to find loads on front and rear axles
3.) Find static load one wheel of each axle

Solution: G = m x g
G = 3.18 kg x 9.81 N
G = 31.19 N

GFA = G (LR/L)
GFA = 31.19N (160mm/320mm)
GFA = 15.595 N

GRA = G(LF/L)
GRA = 31.19N (160mm/320mm)
GRA = 15.595 N

Front: G FAW = GFA/2 = 15.595N/2 = 7.7975 N → 1.75lb
Rear: G RAW = GRA/2 = 15.595N/2 = 7.7975N → 1.75lb

Figure A.11: *Calculating allowable load on one wheel.*

Drivetrain angle

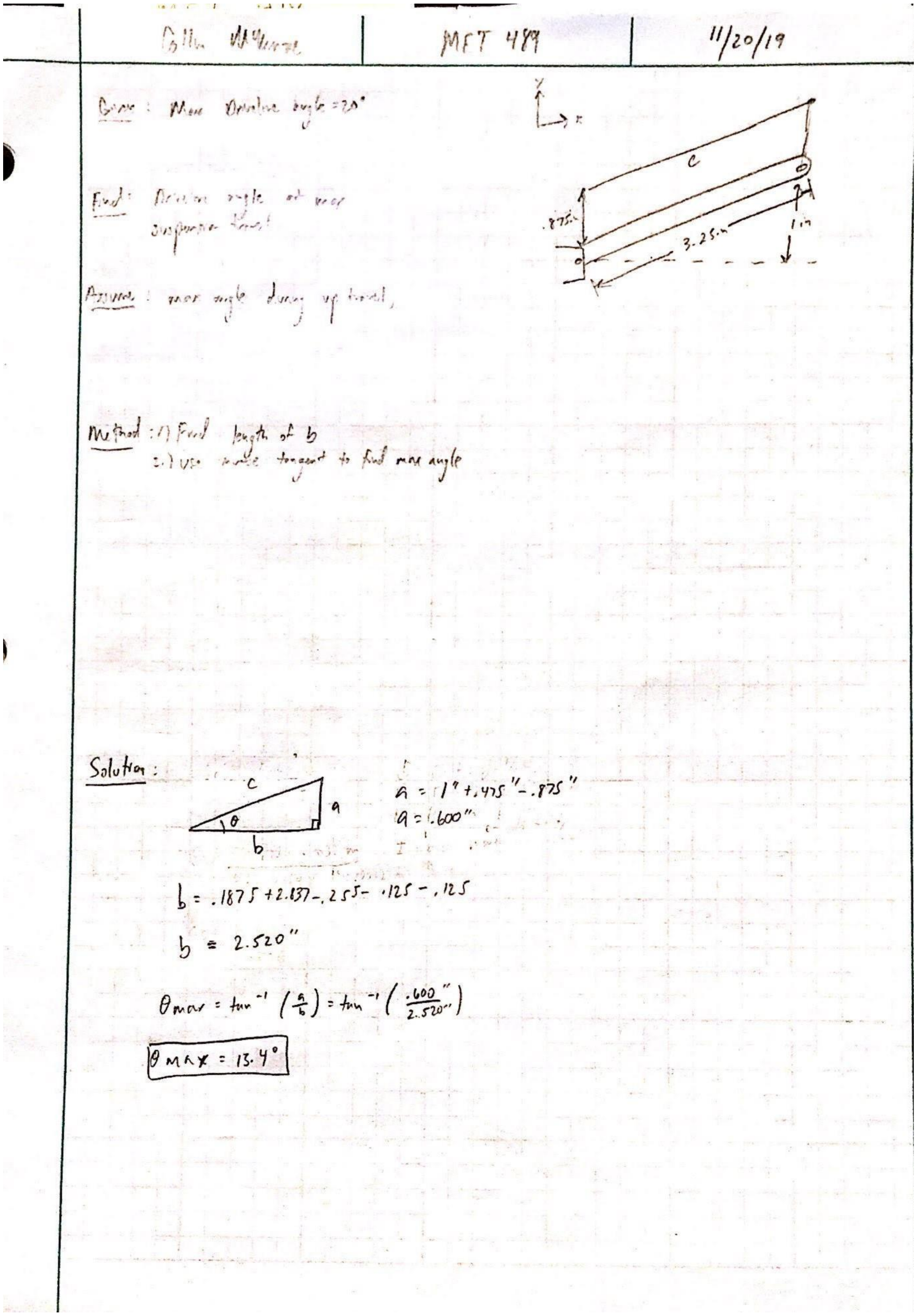


Figure A.12: *Maximum drivetrain angle positioning.*

Appendix B – Drawings

Chassis Plate

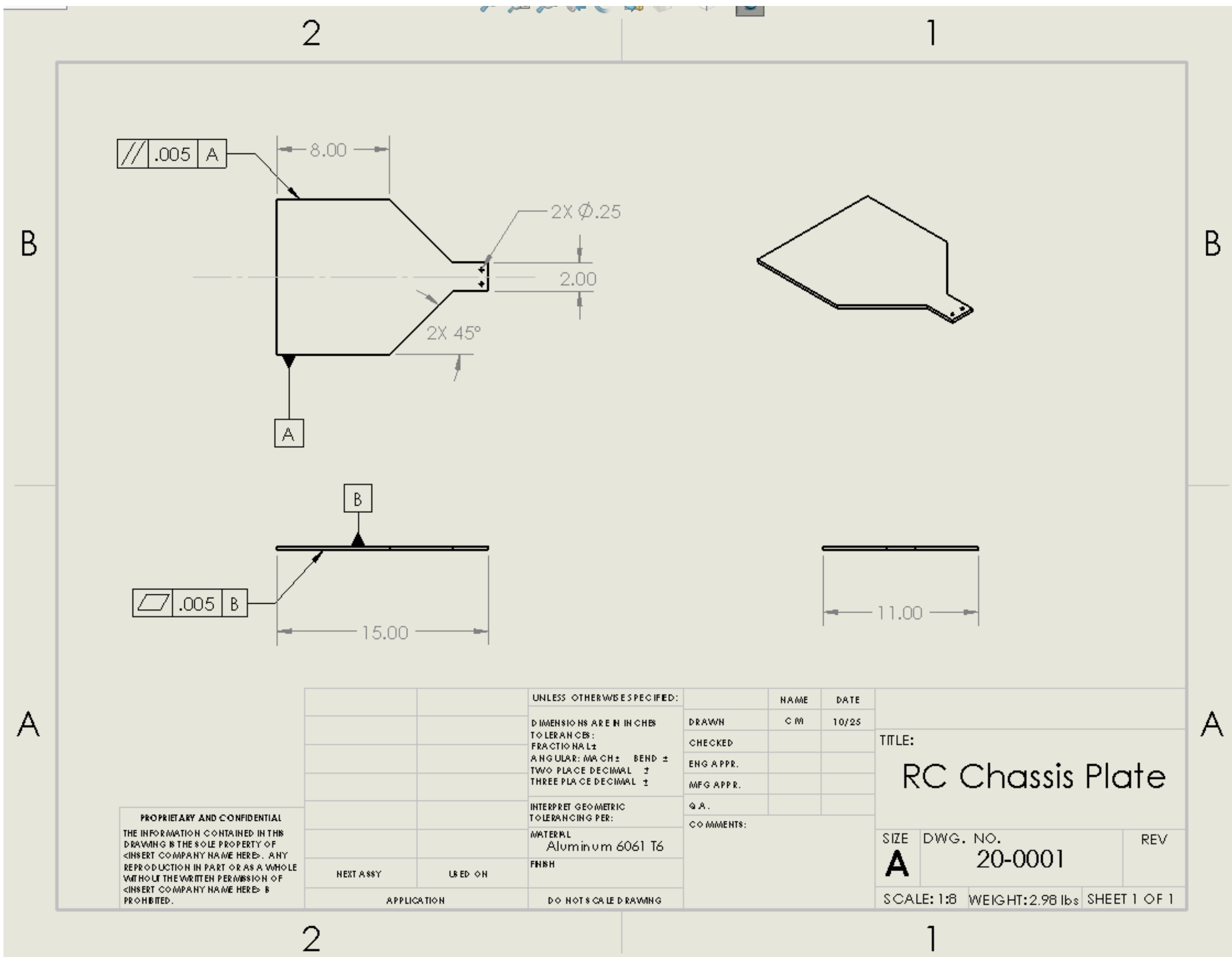


Figure B.1: *Drawing of Chassis support plate with front mounting holes.*

Support Plate

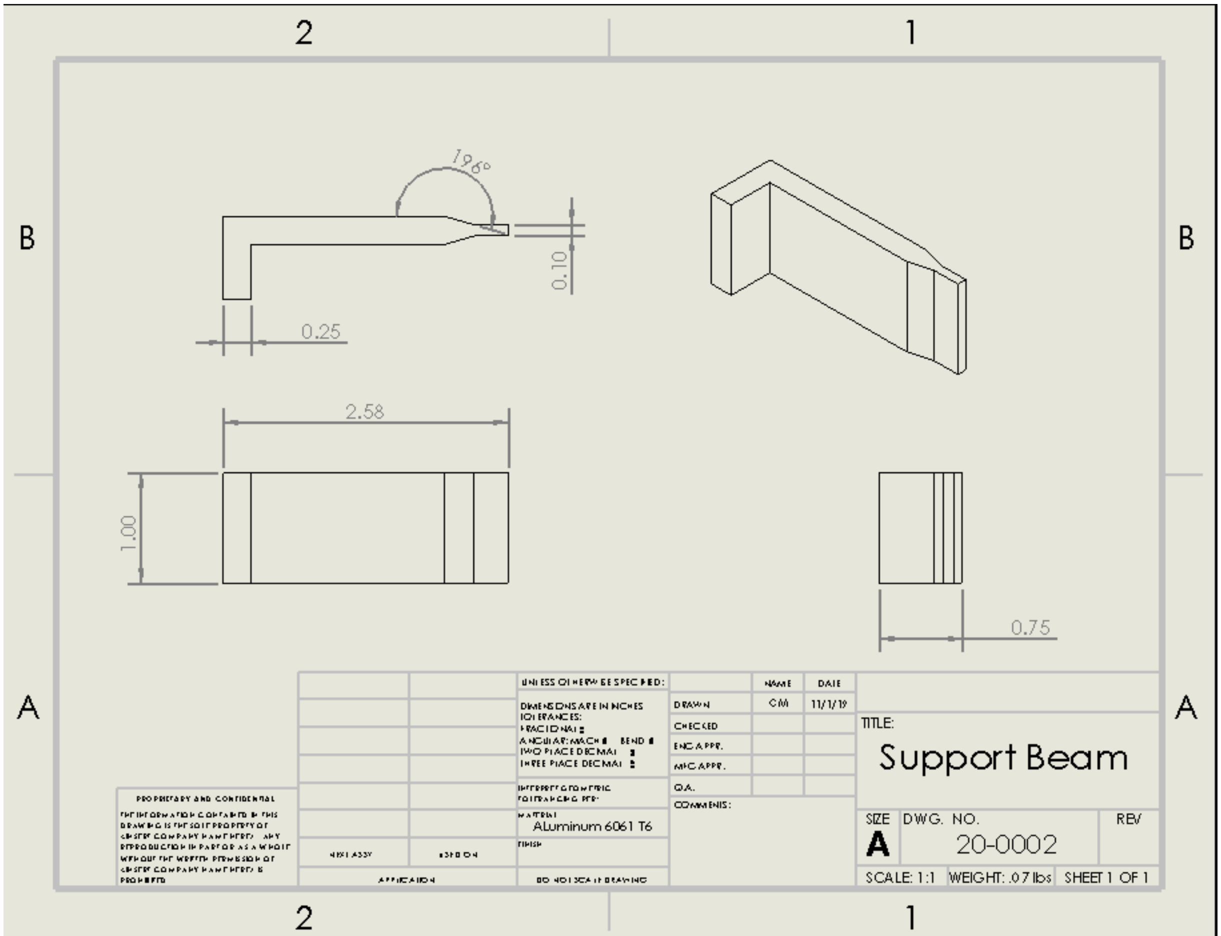


Figure B.2: *Drawing of Front Support for Reinforcement*

Shock

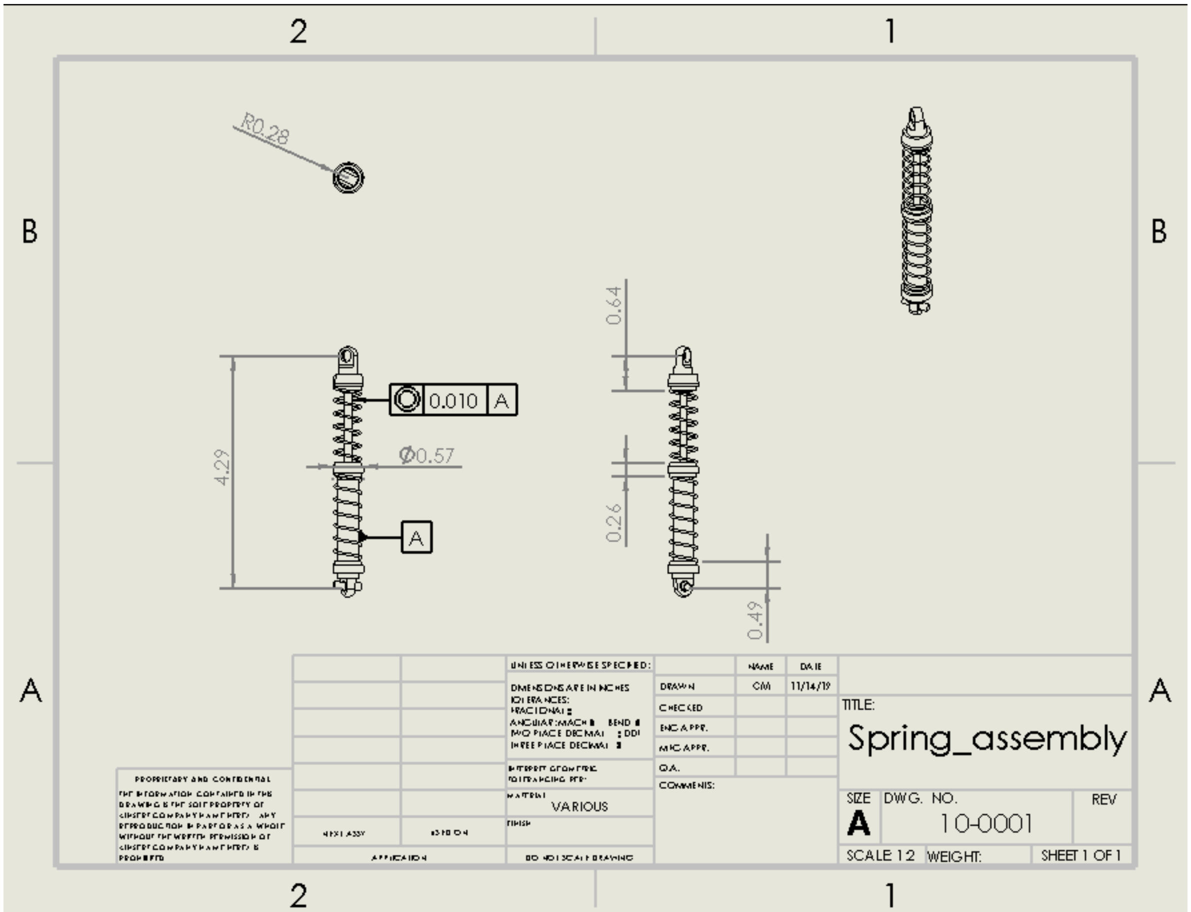


Figure B.3: *Spring assembly of all four shocks.*

Suspension Arm

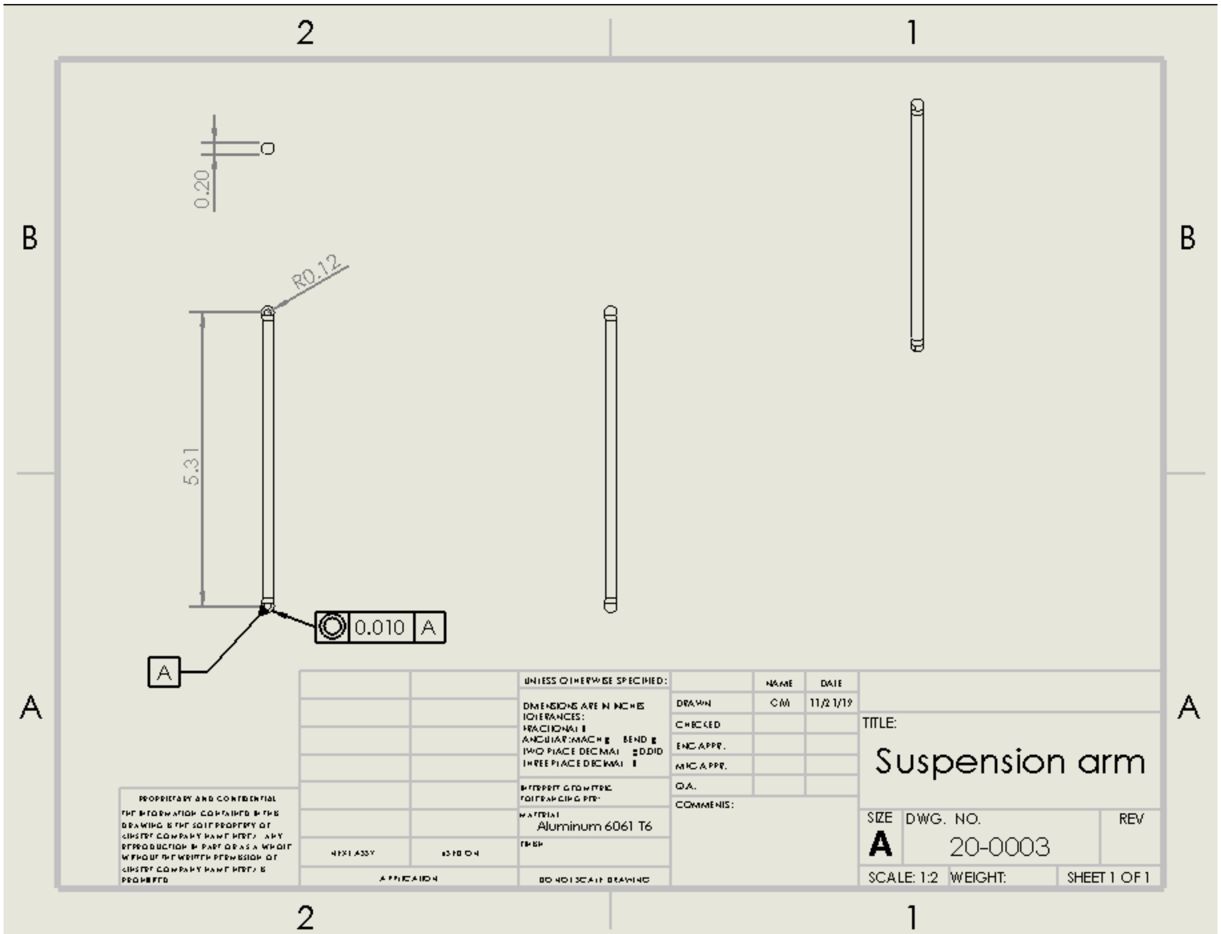


Figure B.4: *Rear suspension arms.*

Trailing Arm

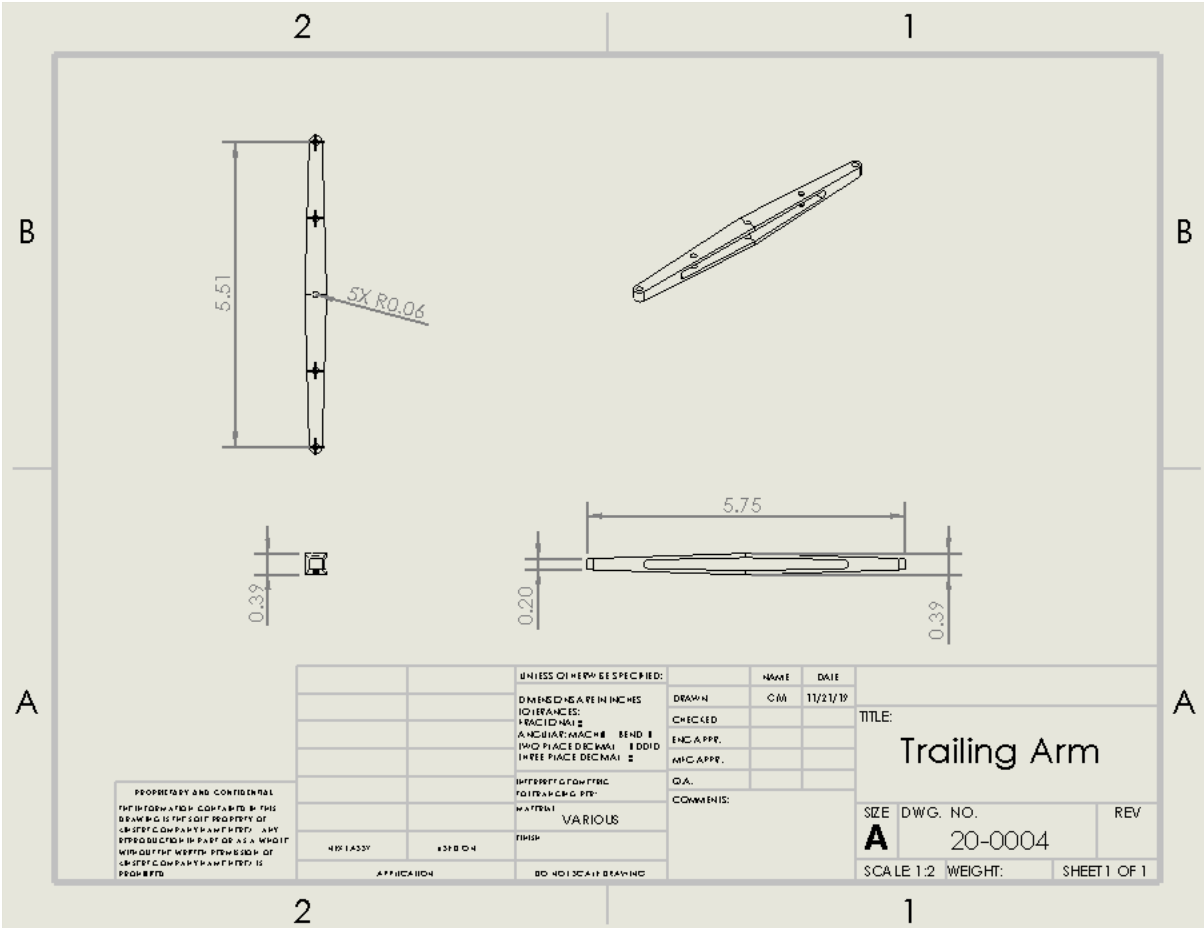


Figure B.5: *Rear trailing arms for shock linkage.*

Full Assembly

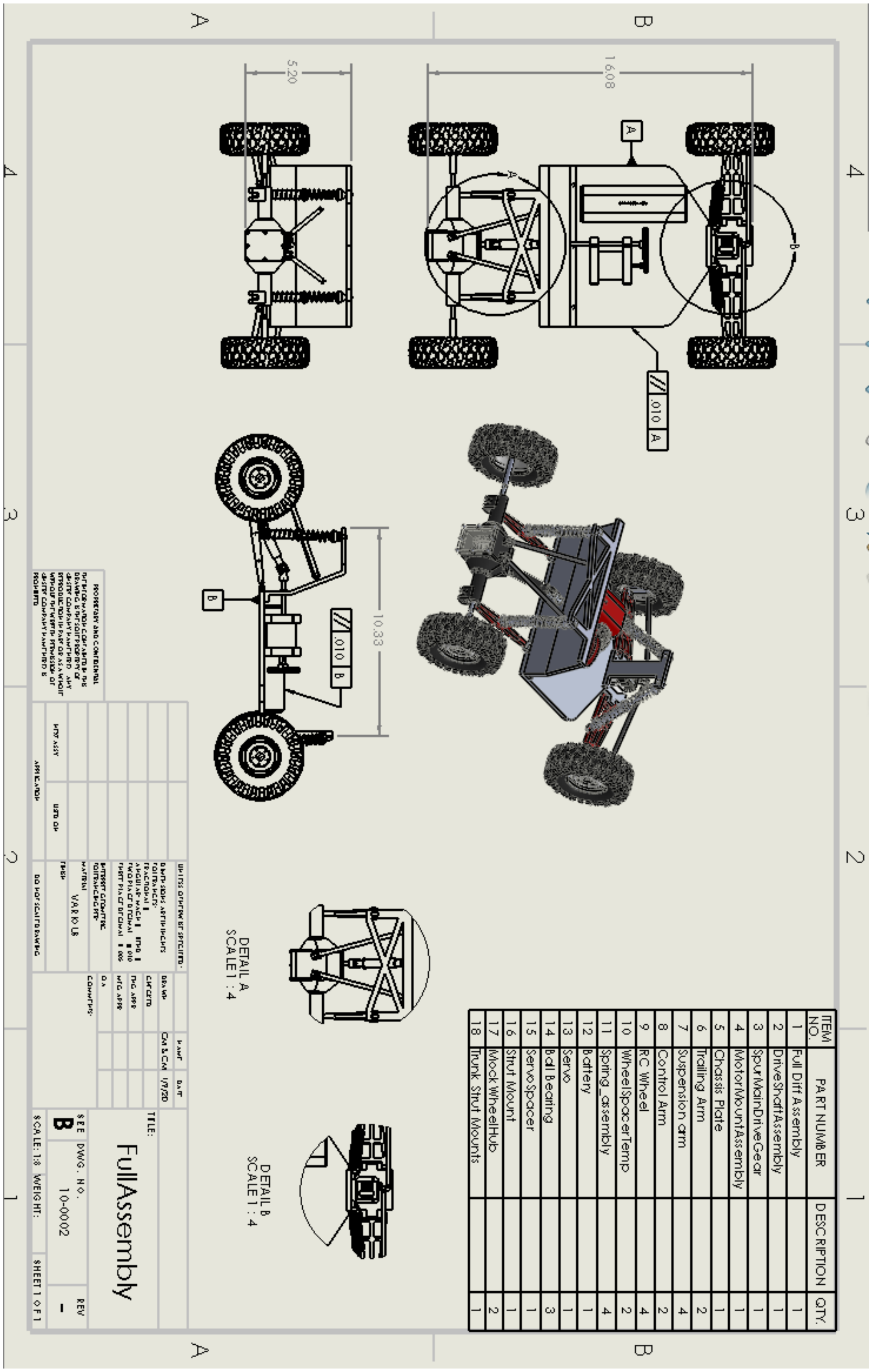


Figure B.6: Full assembly of RC Car.

T Post Strut Mount

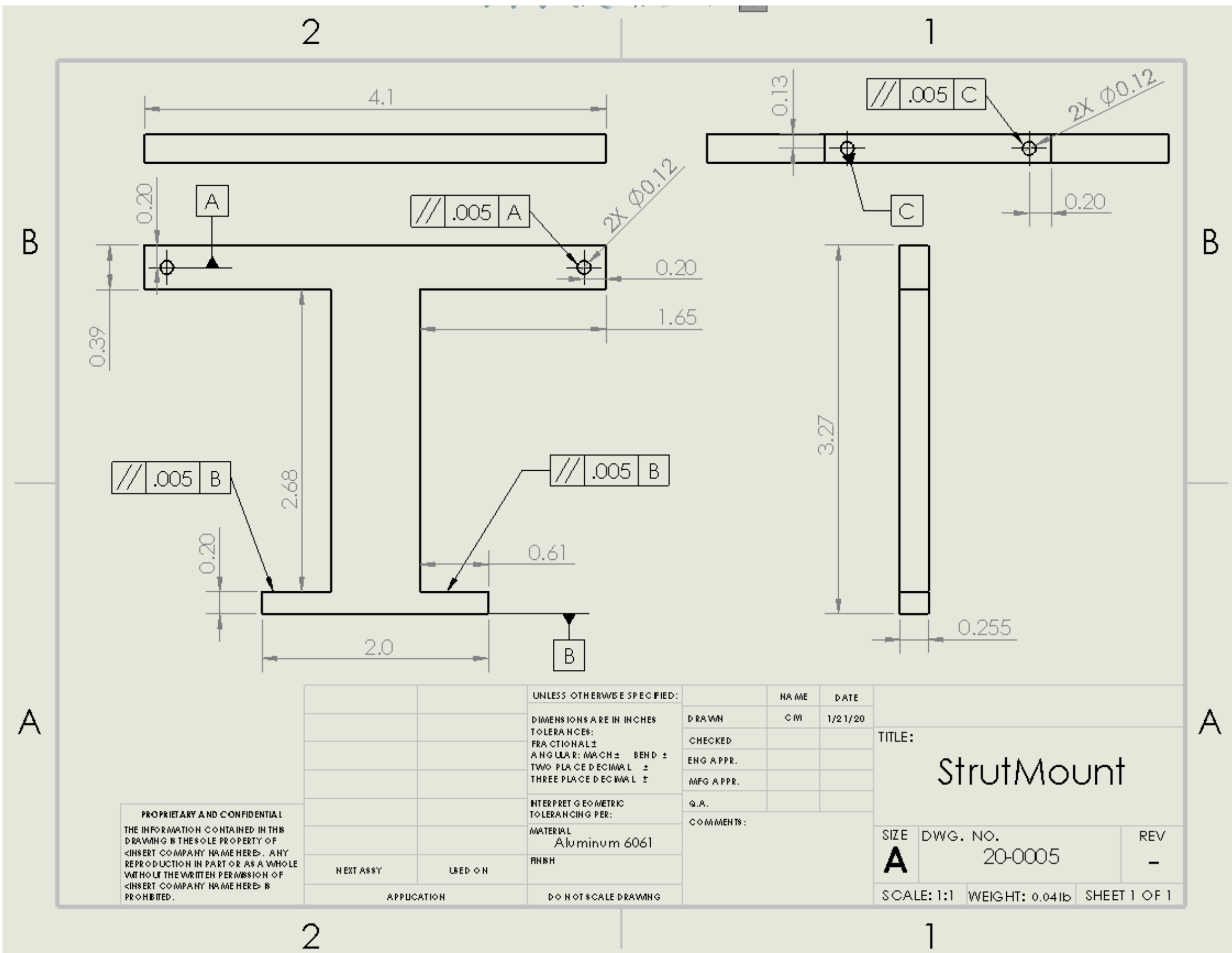
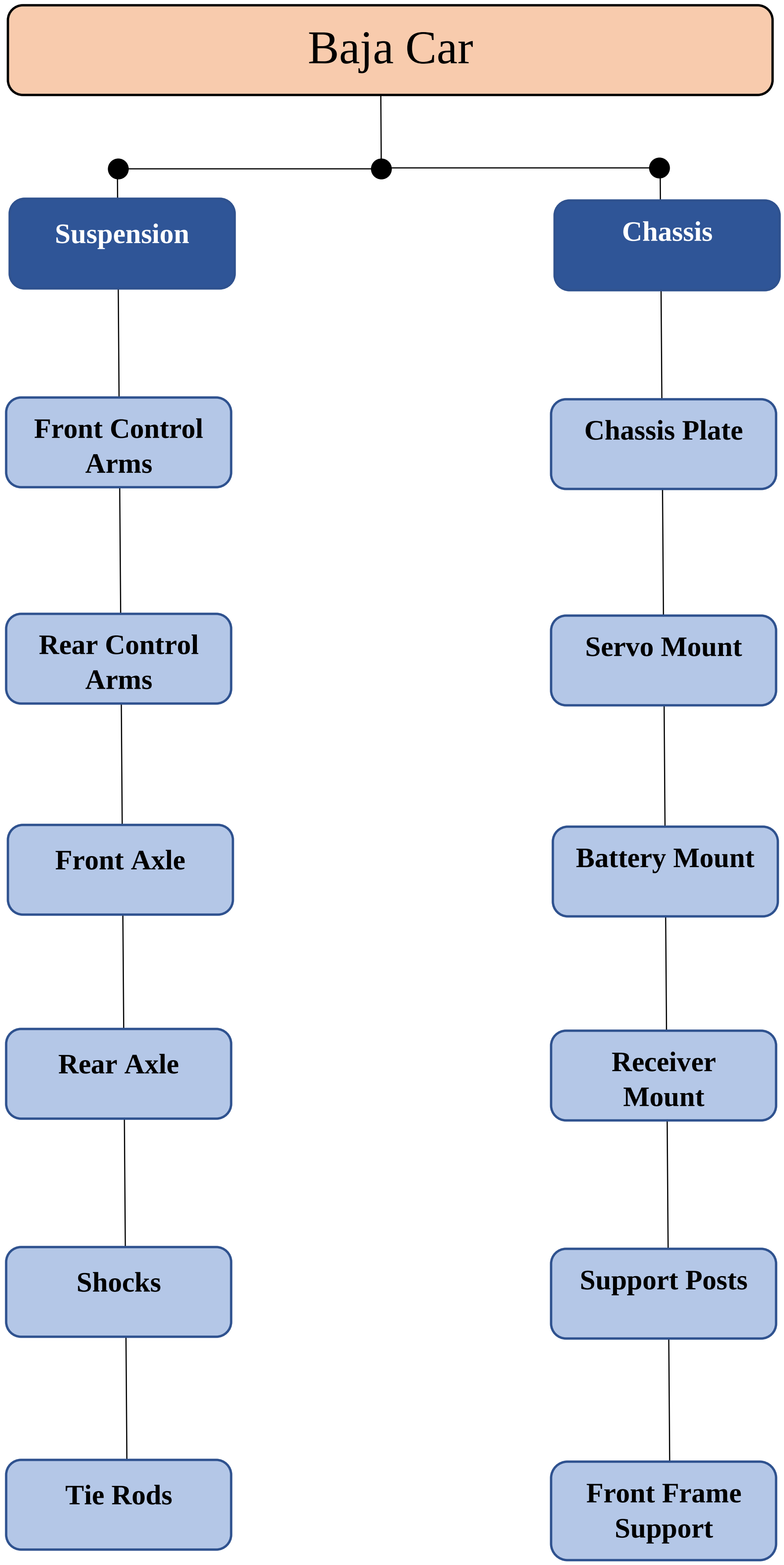


Figure B.7: Drawing of Strut Mount Post.



Baja Car
Suspension
Chassis
Front Control Arms
Rear Control Arms
Front Axle
Rear Axle
Shocks
Tie Rods
Chassis Plate
Servo Mount
Battery Mount
Receiver Mount
Support Posts
Front Frame Support

Appendix C – Parts List

Part ID	Part Description	Material	Manufacture ID
1	4pc 120mm Piggyback Shock Absorber	Aluminum	B07MM1ZC9T
2	Deep Groove Ball Bearing 3x7xmm 10-pack	Chrome Steel	UXCELL 683-2RS
3	Deep Groove Ball Bearing 3mm Bore ID, 6m	Chrome Steel	MR63ZZ
4	4-pack Aluminum A-Arms and Tie Bar	Aluminum	2555 3631 2532
5	Losi Baja Rey Trailing Arm Drag Link Set	Plastic	LOS234003
6	6061-T651 Aluminum Sheet 12"x12"x.25"	Aluminum	OL-400730-12X12
7	Irwin #32 x 2-3/4 High Speed Steel Wire Bit	High Speed Ste	21444
8	Desert Claws Tires	Rubber	LOS43011
9	Wheels (4)	Plastic	LOS43006
10	Bide 3mm Taps set	Steel	B07G5Z5LPX

Appendix D – Budget

Part ID	Part Description	Material	Manufacture ID	Resource	Notes	Quantity	Unit Cost	Tax	Shipping	Total Cost
1	4pc 120mm Piggyback Shock Absorber	Aluminum	B07MM1ZC9T	Amazon		1	$ 40.99	$ 3.40	FREE	$ 44.39
2	Deep Groove Ball Bearing 3x7xmm 10-pack	Chrome Steel	UXCELL 683-2RS	Amazon		1	$ 11.49	$ 0.95	FREE	$ 12.44
3	Deep Groove Ball Bearing 3mm Bore ID, 6m	Chrome Steel	MR63ZZ	Amazon		1	$ 10.98	$ 0.91	FREE	$ 11.89
4	4-pack Aluminum A-Arms and Tie Bar	Aluminum	2555 3631 2532	Amazon		1	$ 29.99	$ 2.49	FREE	$ 32.48
5	Losi Baja Rey Trailing Arm Drag Link Set	Plastic	LOS234003	RC Planet		1	$ 15.99		$ 2.99	$ 18.98
6	6061-T651 Aluminum Sheet 12"x12"x.25"	Aluminum	OL-400730-12X12	Amazon		2	$ 27.95	$ 4.64	FREE	$ 60.54
7	Irwin #32 x 2-3/4 High Speed Steel Wire Bit	High Speed Ste	21444	Ace Hardware		1	$ 3.59	$ 0.30		$ 3.89
8	Desert Claws Tires	Rubber	LOS43011	Donated		2	$ 24.99			$ -
9	Wheels (4)	Plastic	LOS43006	Donated		1	$ 19.99			$ -
10	Bide 3mm Taps set	Steel	B07G5Z5LPX	Amazon		1	$ 7.65		FREE	$ 8.28
11	Royal Brites Poster Board Paper 22 x 28 (3 l	Paper	28408	Fred Meyers		1	$ 2.19	$ 0.22		$ 2.41
Total										**$ 195.30**

Appendix E - Gantt

Fall

RC Mini Baja Car: Suspension
Collin McKenzie

TASK: ID	Description	Note:	Duration Est. (hrs)	Actual (hrs)	%Comp.
	FALL SCHEDULE				
1	Task (Milestone)				
1a	Proposal URL	Turn in Website URL	1	1	
1b	Proprosal Project Approval	Get project approved	0.5	0.5	
1c	Proposal Funtion Statemen	Turn in Function Statement	1	1	
1d	Proposal Requirement State	Turn in requirements	1	1	
1e	Proposal Design/RADD	Turn in section design	2	2	
1f	Proposal Analysis	Turn in analysis section	12	14	
1g	Proposal Methods/Construc	Turn in methods section	1	1	
1h	Proposal Testing Methods	Turn in predictions	1	1	
1i	Proposal Schedule	Turn in schedule section	1	1	
1j	Proposal Budget	Turn in budget section	1.5	2	
1k	Proposal Drawings	Turn in drawings section	10	12	
1l	Proposal Presentation	Turn in PP presentation sec	0.5	0.5	
1m	Complete Proposal	Turn in completed proposal	0.5	0.5	
	subtotal:		33	37.5	

Sept	October				November				Dec			January				February				March			April				May				June		
1	2	3	4	5	6	7	8	9	10	11	Finals	1	2	3	4	5	6	7	8	9	10	nals	1	2	3	4	5	6	7	8	9	10	Finals

Winter

TASK: ID	Description	Note:	Est. (hrs)	Actual (hrs)	%Comp.
	WINTER SCHEDULE		**Est.** (hrs)	**Actual** (hrs)	
2					
2a	Upload Assembly Drawing		8	10	
2b	Order Parts		2	1.75	
2c	Manufacture Needed Parts		15	26	
2d	Assemble Car		8	4	
2e	Redesign/Optimize		10	8	
2f	Test and ensure device functions		5	2	
2g	Upload Report and supporting documents		5	3	
2h	Update Website		5	3.5	
	subtotal:		58	58.25	

Sept	October				November				Dec			January				February				March		
1	2	3	4	5	6	7	8	9	10	11	Finals	1	2	3	4	5	6	7	8	9	10	nals

Spring

TASK: ID	Description	Note:	Est. (hrs)	Actual (hrs)	%Comp.
	FALL SCHEDULE				
	SPRING SCHEDULE				
3	Device Evaluation	Notes			
3a	List Materials Needed		2	2	
3b	Test Plan		4	5	
3c	Test Report		12	10	
3d	Make test sheets		5	2	
3e	Obtain Resources		2	3	
3f	Plan Analyses		8	4	
3g	Perform Evaluation		8	4	
3h	Take Testing Pics/Video		2	2	
3i	SOURCE Project		10	11	
3j	Update Senior Project Report		8	10	
3k	Update Website		8	4	
	subtotal:		69	57	

Sept	October				November				Dec			January				February				March			April				May				June		
1	2	3	4	5	6	7	8	9	10	11	Finals	1	2	3	4	5	6	7	8	9	10	inals	1	2	3	4	5	6	7	8	9	10	Finals

Appendix F – Expertise and Resources

Special help was needed from Lab Technician Matt Burvee and Ted Bramble for manufacturing and recommended practices when fabricating parts for the vehicle in the Hogue Technology labs. Outside resources and funding was also desired for the project to help manage funds and reduce restrictions of capabilities for the project. Unfortunately, no funding was attainable in time.

Appendix G – Testing Report

Introduction

Requirements

- The cost of parts for the suspension of the Baja car should be limited to $400.
- The Baja Car must be able to withstand being dropped from 1.5 feet.
- The chassis will weigh less than 7 pounds.
- The suspension will be able to handle at least 100 N of force when dropped on its tires.
- Full suspension travel of 2” without interference.

Parameters of Interest

The main component being tested is the chassis plate and the suspension components involved. Parameters of interest includes the sustained impact force within the plate. Ensuring the material is thick enough to sustain the required amounts of force while being less than 7 pounds is priority. The impact force of interest can be applied to the drop test and the front impact test.

Performance Predictions

The predicted calculated values for the RC car was to withstand 125 lb_f upon the vertical drop test and an impact force of 1300 lb_f upon the front impact test.

Data Acquisition

All data will be calculated from a recording device and measuring tools. Tape measures, calculations, and scales will allow for ample amount of data to test and record requirements.

Test Schedule

The testing of the vertical drop took place in week 3 of the spring quarter of 2020. The approximated duration of the vertical drop testing was 2.05 hours. The testing had tasks consisting of taping, inspecting, recording, calculating, conducting, and cleaning of the drop test trials. The front impact test took place in week 4 of spring quarter with an approximate duration of 2.5 hours that consisted of finding a rock, practicing velocity, videotaping, conducting the experiment, calculating data, and cleaning the test site.

Method

Resources

The resources needed were widespread but were limited in cost due to most of the needed materials were already processed. Tape measures, tape, a video recorder, scale, and laptop were the main components of the RC car testing. Carlton McDonald was needed for recording, setup, and testing during both procedures.

Data Capture

All the data capturing utilized video recorders, stopwatches, and measurements. The measured controls were the distances needed to reach speed necessary during collision test and a measured height during the drop test. All data and calculations were recorded on green sheets and transferred to Microsoft Excel.

Test Procedure Overview

The testing requires precise procedures to get as accurate results as possible. Following procedures during testing requires understanding of the steps and safety needed to complete the evaluations effectively. The testing environment includes all materials described in the associated procedure along with dry weather. The assumption of dry conditions was calculated to neglect losses or alterations in tractive forces during wet conditions. During both tests, the setup and actual testing consumed most of the time duration. Taking ample amount of time for setting up the evaluation to produce accurate results was emphasized. Clean up and data transferring was quick in comparison.

Operational Limitations

Some limitations arose during testing. From Carlton McDonald's testing, the desired 20 mph was not achievable. The maximum average speed was calculated and used during the front impact force test. An actual speed of 15.6 mph was used but the testing was more focused on the impact portion of the testing. The impact force was calculated to an actual value of 842 lb_f. The analysis of colliding with an object and still properly operate was explored. Another limitation was the ESC would turn the car off during testing on some scenarios, so more tests were conducted to scrap the inaccurate trials.

Precision and Accuracy

Based off the use of kinematic equations, the use of a stopwatch was needed to find time. Manually starting and stopping a stopwatch caused inaccuracies within the testing environment. A tolerance of ±0.50 seconds was used due to the range experienced upon starting and stopping the timer. When measured distances were involved, the tolerance of ±0.25 inches were used due to a tape measure being used along with thick tape. The tape measure is not super precise along with thick tape being used because the precision of the measurement could have been in the exact center of the tape or on either end.

Data Storage

The data was recorded with a video recording device and stopwatch then transferred within a testing table on a green sheet. The data was then populated into Microsoft Excel in a table to be more presentable. The data was manipulated through equations based off varying times.

Data Presentation

The data is presented in a table in Excel with appropriate headers for ease of interpreting data and calculations.

Test Procedure

Vertical Drop Test

Summary
An RC Baja Car is designed to withstand sharp cornering, jumps, and abrupt starts or stops during operation. A main component of testing for the RC Baja Car is the ability to withstand jumps of 1.5 feet or less during competition. A simulation and testing procedure were conducted to analyze a vertical drop of the car to ensure longevity and functionality.

Duration and Location
The location of testing will be at appropriate place of residence or if allowable due to limitations, the Fluke lab within Hogue Technology Building. The date of testing for the vertical drop test was concluded by April 20th, 2020. Setting up the testing scenario per procedure, conducting the trials, recording data with tear down had an approximate duration of 2 hours.

Resources Needed
- 1 Tape Measure
- A device to write with (to record data and mark off height increments)
- 1 Laptop
- Microsoft Excel
- 1 video recording device
- RC Baja Car device
- 1 roll of tape

Procedure
1. Use the tape measure and writing device to mark off 1.5 feet vertically on the piece of tape.
2. Grab RC Baja Car device and hold at the indicated 1.5-foot mark.
3. Start recording on video device.
4. Drop the RC Baja Car, ensuring no horizontal movement as possible.
5. Stop recording on video device once car hits the ground and is stationary.
6. Visually inspect the device for breaks.
7. Record a close-up video of the car rolling using video recorder.
8. Repeat steps 2-7 at least two more trials.
9. Transfer data into Microsoft Excel.

Risks
Ensuring safety during testing is priority. Some risks or hazards that were present during testing included: pinching hazards or debris flying if failure upon dropping RC Car and the electrical shock hazard upon turning the car on. To minimalize risks, wear appropriate eye wear, ensure fingers and feet are clear of the RC Car's drop path, and make sure all electronic devices are off.

Discussion
The testing became easier and more consistent as more trials were conducted. The first trial, following the procedure, took a while to ensure that all steps were met correctly. Trying to keep the testing as consistent and safe as possible was priority. Some challenges were making sure that everything was functioning as intended and lining up the car at the same drop height every trial. The calculations came easily once all data was collected.

Front Impact Test

Summary
A front impact test is crucial to the testing and competition aspect of the RC Baja car. During competition, the device must be able to withstand hitting debris and abrupt stops. To do this, the simulation of a front impact test was conducted to ensure the car can withstand repeated collisions and the functionality is consistent.

During and Location
The location of testing will be offsite from Hogue Technology Building. The project coordinator's place of residence was the location for the front impact test. The date of testing for the vertical drop test was concluded by May 3rd, 2020. Setting up the testing scenario per procedure, conducting the trials, recording data with tear down had an approximate duration of 2.5 hours.

Resources Needed
- RC car device
- 1 large rock
- 1 video recording device
- Microsoft Excel
- 1 writing device
- Tape
- 1 laptop

Procedure
1. Place one large rock in the middle of a long and flat strip of asphalt or concrete.
2. Turn RC car on.
3. Put RC car in line of the rock's pathway based off calculated required distance.

4. Press record on the video recording device (ensure the car's path of travel and collision is emphasized)
5. Accelerate the RC car and gain speed.
6. Take time measurements from when car started until impact.
7. The operator should drive the RC car into the rock and let go of the throttle after the collision.
8. Wait for the car to fully stop and be stationary.
9. Visually inspect the device for breaks and record.
10. Stop the recording device.
11. Repeat steps 3-10 at least two more times.
12. Record/transfer all data into Microsoft Excel once all trials have been conducted.

Risks

The front impact test involved many different possible risks. The collision of the RC car with a stationary object could have caused debris from the RC car or the rock. Being directly in the RC car's path or travel or near the rock during collision would be a risk hazard. Ensuring proper PPE was worn, maintaining 6 feet or more from the collision location, and proper operating experience/knowledge of the RC car device is crucial to assure safety during testing.

Discussion

The front impact test was more efficient as trials were conducted. The car did not quite meet the required 20 mph speed but maintained functionality after collisions which was the main priority of the test, to see the longevity of the device after collision. Calculations based off tested results provided that the RC car had a average velocity of 15.6 mph and had a impact for of 842 lb_{f}. The sustained impact of the RC car was surprising, due to most of the impact area being the rubber wheels which absorbed most of the energy and impact force.

Deliverables

Parameter Values

Based off a fall from 1.5 ft, a device weight of 6.51 lbs. and deformation distance of 1 inch, the sustained impact of the RC car was 116 lb_{f}. During the front impact test, the average speed was found to be 15.6 mph which upon impact created a force of 842 lb_{f}.

Calculated Values

The calculated values for the drop test was based off a predicted 7 lb. car in which the calculated force upon impact required was 125 lb_{f}. During the front impact test, the test was calculated off a baseline speed of 20 mph, which needed to withstand 1390 lb_{f}.

Success Criteria Values

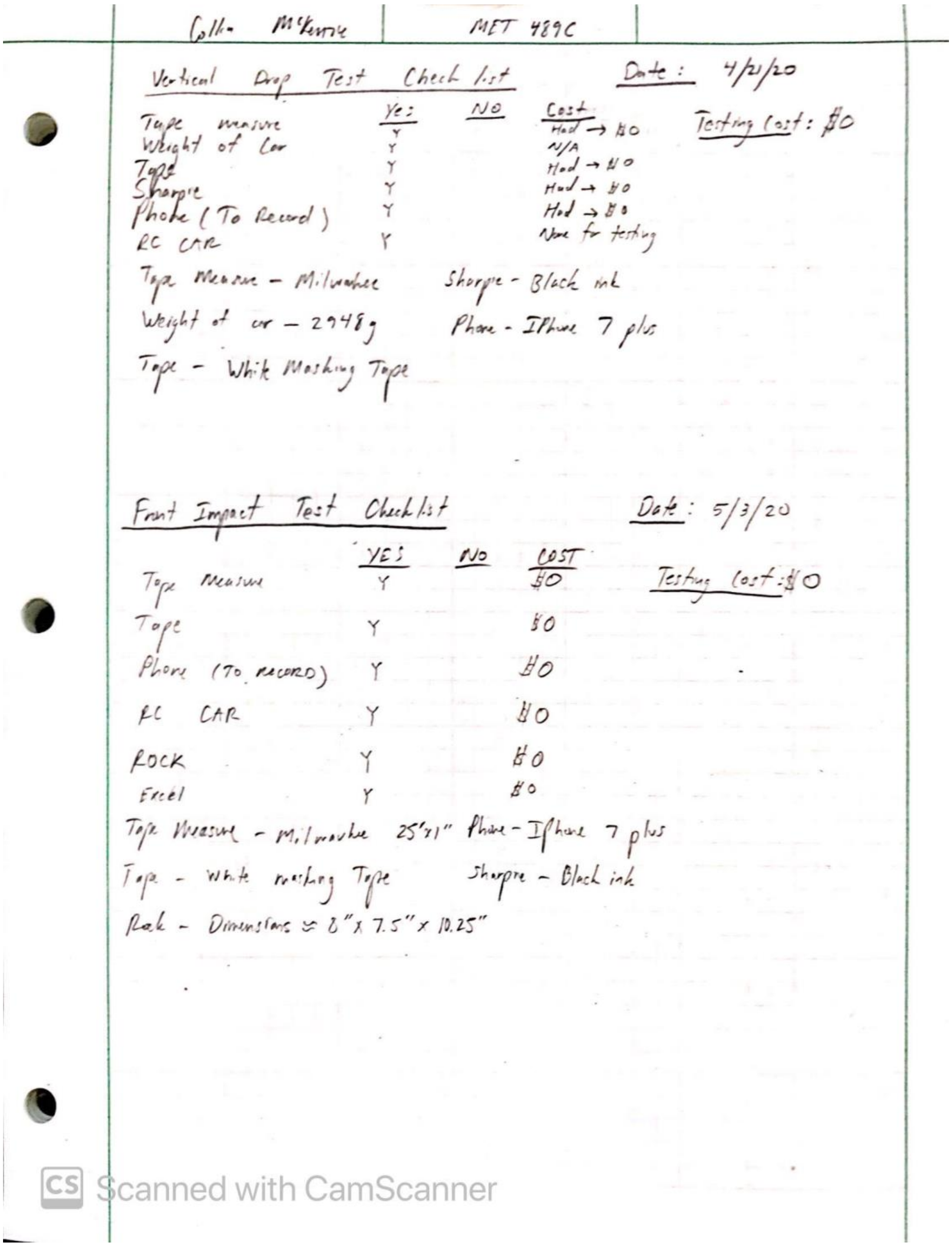
In regards of longevity and functionality of the RC car during testing, the device passed with no failures or breaks. The weight requirement of being 7lbs. or less was met. A full travel of 2" of the suspension with no interference was also met. The requirement of handling 100 N when being dropped was exceeded and the actual valued withstood was 520 N. Overall, the project was well under the $400 dollar budget.

Conclusion

Many aspects of the RC car were explored. After testing, the RC car passed many requirements and predictions with ease. The biggest failure was the 15.6 mph average speed produced. The velocity from calculated values had a 4.4 mph variance. Overall, many in depth tests were analyzed to confirm the material, design, and choices support the output values calculated.

Appendix

Appendix G1



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Vertical Drop Test Check list — Date: 4/21/20

	Yes	NO	Cost
Tape measure	Y		Had → $0
Weight of Car	Y		N/A
Tape	Y		Had → $0
Sharpie	Y		Had → $0
Phone (To Record)	Y		Had → $0
RC CAR	Y		None for testing

Testing Cost: $0

Tape Measure - Milwaukee — Sharpie - Black ink

Weight of car - 2948g — Phone - IPhone 7 plus

Tape - White Masking Tape

Front Impact Test Checklist — Date: 5/3/20

	YES	NO	COST
Tape Measure	Y		$0
Tape	Y		$0
Phone (TO RECORD)	Y		$0
RC CAR	Y		$0
ROCK	Y		$0
Excel	Y		$0

Testing Cost: $0

Tape Measure - Milwaukee 25'x1" — Phone - IPhone 7 plus

Tape - White masking Tape — Sharpie - Black ink

Rock - Dimensions ≈ 8"x 7.5"x 10.25"

Figure 1: *Procedure checklist of drop test and impact test.*

Appendix G2

	Distance (m)	Mass (kg)	Initial Velocity (ft/s)	Final Velocity (ft/s)	Force of Impact (lbf)	Final Velocity (m/s)	Force of Impact (n)
Predicted	0.4572	3.18	0	9.81	126	2.99	560
	0.4572						
	0.4572						
	0.4572						
	0.4572						
	0.4572						
	0.4572						
AVG	0.4572						

Figure 2: *Blank vertical drop test sheet.*

	Distance (feet)	Time (S)	Initial Velocity (ft/s)	Final Velocity (ft/s)	Force of Impact (lbf)	Final Velocity (m/s)	Force of Impact (n)
Predicted	20	0.68	0	29.33	1390	8.94	6184
	20		0				
	20		0				
	20		0				
	20		0				
	20		0				
	20		0				
AVG	20		0				

Figure 3: *Blank front impact test.*

Appendix G3

	Distance (m)	Mass (kg)	Initial Velocity (ft/s)	Final Velocity (ft/s)	Force of Impact (lbf)	Final Velocity (m/s)	Force of Impact (n)
Predicted	0.4572	3.18	0	9.81	126	2.99	560
	0.4572	2.955	0	9.78	116	2.98	517
	0.4572	2.955	0	9.84	118	3.00	524
	0.4572	2.955	0	9.81	117	2.99	520
	0.4572	2.955	0	9.84	118	3.00	524
	0.4572	2.955	0	9.78	116	2.98	517
	0.4572	2.955	0	9.81	117	2.99	520
AVG	0.4572	2.955	0	9.81	117	2.99	520

Figure 4: *Completed vertical drop test sheet.*

	Distance (feet)	Time (S)	Initial Velocity (ft/s)	Final Velocity (ft/s)	Force of Impact (lbf)	Final Velocity (m/s)	Force of Impact (n)
Predicted	20	0.68	0	29.33	1390	8.94	6184
	20	0.85	0	23.53	895	7.17	3980
	20	0.9	0	22.22	798	6.77	3550
	20	0.88	0	22.73	835	6.93	3713
	20	0.93	0	21.51	747	6.55	3325
	20	0.83	0	24.10	938	7.34	4174
	20	0.98	0	20.41	673	6.22	2994
AVG	20	0.86	0	22.83	842	6.96	3747

Figure 5: *Completed front impact test sheet.*

Appendix G4

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Front Impact Test – Theoretical

Weight of chassis = 2948g = 2.948 kg or 6.51 lbs.

$F \times d = \frac{1}{2} m v^2$

$F = \frac{\frac{1}{2} m v^2}{d}$ D = assumed crumple zone = .75in or .01905 m

velocity = $\frac{20 \text{ miles}}{\text{hour}} \times \frac{5280 \text{ ft}}{1 \text{ mile}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{1 \text{ min}}{60 \text{ sec}} = 29.3 \text{ ft/s}$

$V = 29.3 \frac{ft}{s} \times \frac{.3048 \text{ m}}{1 \text{ ft}} = 8.93 \text{ m/s}$

Force of Impact = $\frac{\frac{1}{2}(2.948 \text{ kg})(8.93 \text{ m/s})^2}{(.01905 \text{ m})} = 6183.7 \text{ kg} \cdot \frac{m}{s^2}$

$6183.7 \text{ kg} \cdot \frac{m}{s^2} = 6183.7 \text{ N}$

$6183.7 \text{ N} \times \frac{.22481 \text{ lbf}}{1 \text{ Newton}} = \boxed{1390 \text{ lbf}}$

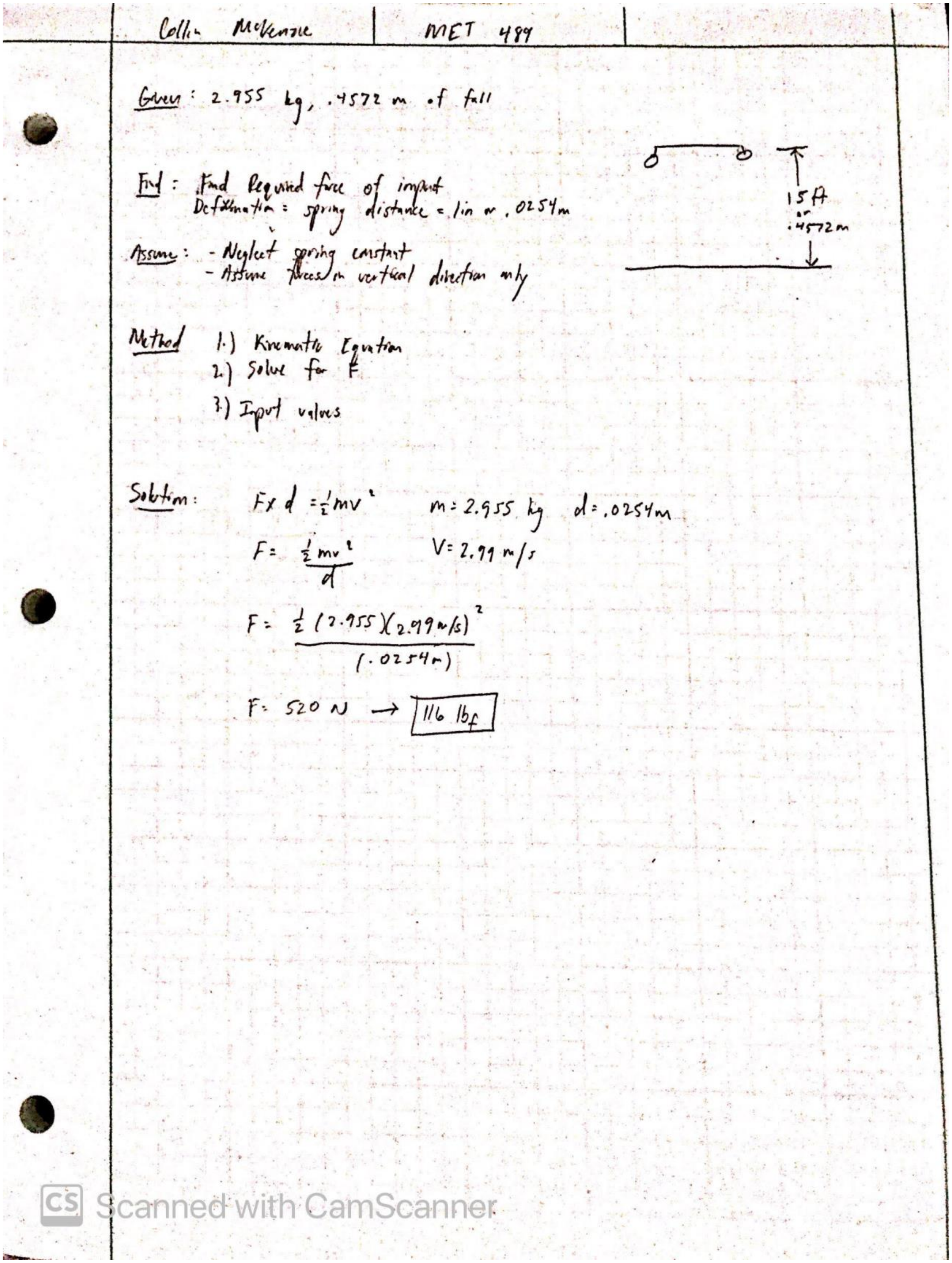
Actual

Avg velocity = $22.83 \text{ ft/s} \times \frac{.3048 \text{ m}}{1 \text{ ft}} = 6.96 \text{ m/s}$

Force of impact = $\frac{\frac{1}{2}(2.948 \text{ kg})(6.96 \text{ m/s})^2}{(.01905 \text{ m})} = 3{,}748.2 \text{ N}$

$3{,}748.2 \text{ N} \times \frac{.22481 \text{ lbf}}{1 \text{ Newton}} = \boxed{842 \text{ lbf}}$ Avgerage

Figure 6: *Green sheet analysis of front impact test.*



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Given: 2.955 kg, .4572 m of fall

Find: Find Required force of impact
Deformation: spring distance = 1 in or .0254 m

Assume:
- Neglect spring constant
- Assume forces in vertical direction only

Method
1.) Kinematic Equation
2.) Solve for F
3.) Input values

Solution:

$F \times d = \frac{1}{2}mv^2$ $m = 2.955$ kg $d = .0254$ m

$F = \frac{\frac{1}{2}mv^2}{d}$ $V = 2.99$ m/s

$$F = \frac{\frac{1}{2}(2.955)(2.99\,m/s)^2}{(.0254\,m)}$$

$F = 520$ N → **116 lbf**

Figure 7: *Green sheet analysis of vertical drop test.*

Appendix G5

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MET 489C								
Testing Gantt								
SPRING			Duration					
Task ID	**Device Evaluation**	**Note:**	**Est. (hrs)**	**Actual (hrs)**	**Week 1**	**Week 2**	**Week 3**	**Week 4**
1a	Tape 1.5 ft in height		0.1	0.1				
1b	Video Tape Test		0.1	0.1				
1c	Visually Inspect Device		0.1	0.1				
1d	Drop Test Calculations		0.5	0.75				
1e	Make Excel Chart		0.5	0.5				
1f	Conduct 3 trials		0.4	0.4				
1g	Clean Testing Setup		0.1	0.1				
Total			**1.8**	**2.05**				
2a	Find/place large rock		0.1	0.1				
2b	Practice needed velocity		0.2	0.2				
2c	Video tape the test		0.1	0.1				
2d	Conduct 3 trials		0.4	0.5				
2e	Impact Test Calculations		0.75	1				
2f	Make Excel Chart		0.5	0.5				
2g	Clean Testing Setup		0.1	0.1				
Total			**2.15**	**2.5**				
Testing Total			**3.95**	**4.55**				

Figure 8: *Testing Gantt schedule.*

Appendix H – Resume

COLLIN MCKENZIE

collinmckenzie2@gmail.com | (360) 631-7237 |

SUMMARY

Innovative student with technological and analytical skills bringing enthusiasm, dedication, and an exceptional work ethic. Self-starting and detail oriented towards workplace while striving for continuous improvement. Strengths and results driven individual. Technology and electronics dedicated, while looking for full-time Mechanical Engineering position after graduating college.

EDUCATION

Central Washington University

Bachelor of Professional Studies in Mechanical Engineering Technology, anticipated June 2020

EMPLOYMENT EXPERIENCE

Student Union Building Manager

Central Washington University, Ellensburg, WA
Apr 2017 – Present

Supervised the operations of the Student Union building at CWU. Greeted and met the demands of clients from the university along with outside organizations. Set up for events hands-on, ranging from job fairs to concerts. Failure analysis was conducted when setting up structures for events. Bill of Materials were provided for client's requests. Oversaw the departments within the building and helped provide quality customer service and maintenance to the facility. Project cost analysis was conducted when accounting for supplies.

Engineering Intern

Pexco Aerospace, Union Gap, WA
May 2019 – Present

Product development and plastics extrusion manufacturing oriented. Provided quotations for customer's drawings. Drafted assemblies and parts using 2D and 3D software. Constantly integrated AutoCAD and Autodesk Inventor to enhance, manipulate, and interact with parts. Analyzed materials to improve understanding, efficiency, and cost for the company. Measured samples and performed calculations for material cooling rate studies. Built die profiles and fabrication parts to be manufactured. Exploring new options for lighter materials and designs for customer profiles was an important overall task.

HONORS

Dean's List – 2017, Wildcat Scholarship Recipient – 2016

SKILLS

SolidWorks CSWA Associate Level Certified, AutoCAD Experience, C++ Coding Experience, Microsoft Office including Outlook, Basic Machining Experience, Technical Writing and Documentation experience, Technology and Electronics efficient, and Supply Chain Experience while at Pexco Aerospace.

Appendix J – Job Hazard Analysis

JOB HAZARD ANALYSIS
Mini RC Baja Car

Prepared by: Collin McKenzie	Reviewed by: Approved by:

Location of Task:	Hogue Technology Building
Required Equipment / Training for Task:	Machining Training, Hogue Labs training, and operation of device training.
Reference Materials as appropriate:	ASME Baja Car Rules https://www.cwu.edu/engineering/sites/cts.cwu.edu.engineering/files/documents/met_2015RC_BajaRules.pdf ETSC Safety Policy https://www.cwu.edu/engineering/department-engineering-technologies-safety-and-construction-etsc-safety-committee

Personal Protective Equipment (PPE) Required (Check the box for required PPE and list any additional/specific PPE to be used in “Controls” section)						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
✓	☐	✓	☐	✓	☐	☐
Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS

Machining Chassis Plate.	**1. Impact** **2. Penetration or Cut** **3. Crush or Pinch** **4. Chemical or Harmful Dust** **5. Heat**	**Person(s) can strike an object, or be struck by a moving or flying/falling object (e.g., fragments, chips, particles, sand, dirt/debris).** **Person(s) can strike an object, be struck by an object, or fall upon an object or tool that would cut or otherwise break the skin.** **An object(s) or equipment/machine may crush or pinch a body or body part** **Exposure to chemicals (i.e., hazardous substances and harmful physical agents), infectious agents from spills, splashing, physical contact, and/ or exposure to dusts, vapors, fumes, or gases that could cause illness, irritation, burns, asphyxiation, breathing/vision difficulty, sensitization, infection, or other toxic health effect** **Exposure to radiant heat sources, sparks, and**	**Wear appropriate footwear and eye protection. Follow SOP machine. Ensure all instructions and operating procedures are read and understood prior to operation. Focus on safety features outlined. Ensure all PPE is worn.**

	6. Light (optical) Radiation 7. Electrical Contact 8. Ergonomic/ Human Factors 9. Environmental	**splashes or spills of hot material** **Exposure to strong light sources, glare, or intense light exposure which is a byproduct or a process.** **Exposure, contact, or proximity to live or potentially live electrical objects.** **Working in cramped spaces, repetitive movements, awkward postures, vibration, heavy lifting.** **Exposure to noisy environments, hot or cold work environments, poor weather conditions, working at a height, and any other conditions in the workplace that could cause danger, discomfort, and/or negative health effects.**	
Machining support mounts.	**1. Impact** **2. Penetration or Cut**	**Person(s) can strike an object, or be struck by a moving or flying/falling object (e.g., fragments, chips, particles, sand, dirt/debris).** **Person(s) can strike an object, be struck by an object,**	**Wear appropriate footwear and eye protection. Follow SOP machine. Ensure all instructions and operating procedures are read and**

	3. Crush or Pinch 4. Chemical or Harmful Dust 5. Heat 6. Light (optical) Radiation 7. Electrical Contact	or fall upon an object or tool that would cut or otherwise break the skin. An object(s) or equipment/machine may crush or pinch a body or body part Exposure to chemicals (i.e., hazardous substances and harmful physical agents), infectious agents from spills, splashing, physical contact, and/ or exposure to dusts, vapors, fumes, or gases that could cause illness, irritation, burns, asphyxiation, breathing/vision difficulty, sensitization, infection, or other toxic health effect Exposure to radiant heat sources, sparks, and splashes or spills of hot material Exposure to strong light sources, glare, or intense light exposure which is a byproduct or a process. Exposure, contact, or proximity to live	understood prior to operation. Focus on safety features outlined. Ensure all PPE is worn.

	8. Ergonomic/ Human Factors 9. Environmental	or potentially live electrical objects. Working in cramped spaces, repetitive movements, awkward postures, vibration, heavy lifting. Exposure to noisy environments, hot or cold work environments, poor weather conditions, working at a height, and any other conditions in the workplace that could cause danger, discomfort, and/or negative health effects.	
Drill press mounting holes on chassis.	1. Clean the table. 2. Load the vise 3. Lock the table in place 4. Load the bit 5. Start the drill	Eye injury from metal debris. Foot injury if the vise falls. Finger pinching while sliding the vise. Back strain Hand injury from the bit None Foreseen Injury caused by breaking the bit Finger pinching while sliding the vise	Wear appropriate footwear and eye protection. Follow SOP of machine. Ensure material is in vise or clamp securely. Ensure PPE is worn. Ensure area is clear of all tripping hazards. Be aware of hand and finger location at all times. Rotate job tasks when

	6. Feed the drill with the feed 7. Unload the vise 8. Clean the table	Eye injury from metal debris	possible. Ensure table is at proper ergonomic level.
Drilling bolts and fastening screws	1. Clean the table. 2. Load the vise 3. Lock the table in place 4. Load the bit 5. Start the drill 6. Feed the drill with the feed 7. Unload the vise 8. Clean the table	Eye injury from metal debris. Foot injury if the vise falls. Finger pinching while sliding the vise. Back strain Hand injury from the bit None Foreseen Injury caused by breaking the bit Finger pinching while sliding the vise Eye injury from metal debris	Wear eye protection and keep fingers away from location of drilling. Ensure area is clear of all tripping hazards. Be aware of hand and finger location at all times. Rotate job tasks when possible. Ensure table is at proper ergonomic level.

	Operation of Car during testing/competition	Fast moving devices can cause injury if struck.	Stay at least 10 feet away while testing and wear appropriate footwear to minimalize risk of injury. Closed toe shoes. Wear proper PPE when handling or adjusting device in both on or off state.
	Operation of Car during testing/competition	Moving gears and shocks can cause injury or pinch appendages.	When modifying or picking up car, ensure device is off and fingers are away from potential moving parts. Wear proper PPE such as gloves and eye protection.