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CatMobile EV Front Suspension

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Electric Vehicle Braking and Suspension

By

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Abstract

The Central Washington University (CWU) Mechanical Engineering Technology (MET) program owns an electric vehicle called the “Cat-Mobile” designed to be entered into an Electrothon America race. The Cat-Mobile is a collaborative project, various aspects of which are built by CWU MET students in the capstone sequence of the senior year. For the Cat-Mobile to operate safely and effectively, it was necessary to design and build a proper front suspension system. The suspension needed to meet Electrothon America Handbook rules dictating a minimum ground clearance of 2” and optimize material usage to keep added weight at or below 20lbs. Loading and stress analysis was used to design the suspension system, and FEA analysis assisted with optimization. The final design modeled a typical “double-wishbone” or “double A-arm” style suspension. A spindle assembly was mounted between the A-arms with the use of ball-joints. The spindles included provisions for steering, and potential mounting locations for braking components. A coil-over style shock absorber is used which can allow for height and dampening adjustments. The total mass of parts added to the Cat-Mobile was just 12.7 lbs. The ground clearance of the Cat-Mobile can be adjusted and at minimum height adjustment, conforms to the Electrothon America requirement of 2”.

Keywords: EV, Electric Vehicle, Electrothon America, Suspension

Introduction

Description:

Central Washington University has an electric vehicle (EV) that students have worked on various aspects of in the past. The intended use of this EV is competing in a race hosted by Electrothon America. This organization is a donation-based entity that establishes guidelines and rules for the vehicles and races in which they perform. This project aims to build a braking system for the EV currently at the university. The original project has been modified from this original intent to address an issue with the front suspension. The resolution of which is necessary for successful design and implementation of a braking system.

Motivation:

This project was motivated by a need to safely and effectively operate the EV. The EV currently has no complete braking system installed and thus, cannot be operated safely.
The EV is capable of up to 60 mph in some cases and needs to be able to slow itself down to avoid damage or injury. The front suspension needs to be able to maintain stability and geometry.

Function Statement:

A device is needed to allow the driver of CWU's electric vehicle to control slowing of the vehicle to a complete stop from normal operating speeds.
Prior to achieving this goal, a device is needed to support the vehicle mass, wheel mount, steering, and brake caliper mounts.

Requirements:

Electrothon America dictates several design requirements in order to use the EV in a race. As per the most recent handbook released by Electrothon America, the braking system must:

- Comply with Electrothon America Handbook
- Apply braking force to at least two of the vehicle's wheels
- Be fitted to two wheels sharing the same axle
- Include separate actuation cables for each brake
- Stop the vehicle from rolling when pushed by hand
- Stop the vehicle from a speed of 25 MPH in less than 40 ft.
- Add no more than 20lbs to the vehicle
- Provide velocity reduction intermittently for one hour
- Suspension must clear 2"

Success Criteria:

The braking system design will be successful if it can achieve slowing the vehicle to a complete stop.
The suspension system will be successful if it maintains suspension geometry and stability during operation.

Engineering Scope:

This project will include a complete design, installation and testing of the braking system and suspension system. This will include designing the mounts for calipers, actuation system and pedal/lever assembly. This also includes designing a spindle assembly and mounts with control arms. The project will require force calculations and evaluation of design for optimization.

Benchmark:

A company called Evelo Electric Bikes creates effective braking systems for their bikes, such as The Evelo Aries Mid-Drive which features a cable system like the one intended for use on this project and thus is a suitable benchmark to use.

The suspension will be benchmarked to common wishbone style suspension systems.

Success:

The project will be successful when it successfully can be used under normal operating conditions on the EV.

Design and Analysis

Approach

Brakes:
The proposed solution to complete a braking system will include the use of industry brake calipers from a recumbent or mountain bike. These calipers will be mounted on aluminum mounts designed to carry the tangential loads caused by braking safely and effectively.

Currently there is no place for a driver to rest their legs or operate power or brake actuation. To remedy this, a floorboard must be designed and assembled to allow the actuation of the brake cables. Brake cables will be actuated via a pedal by the foot of the driver.

Suspension:

The proposed solution will include the addition of upper control arms and the use of ball-joints to allow for stability through motion.

Design Description

The caliper mounts will be aluminum brackets mounted onto the spindle and position the caliper onto the rotor. Cables will route to a pedal on the floorboard assembly. To allow for comfortable and effective brake actuation, the pedal will be a lever style pedal.

The suspension will add a frame rail to allow for the addition of upper control arms. The spindle assembly will sit perpendicular to the ground and maintain this position through use of ball-joints.

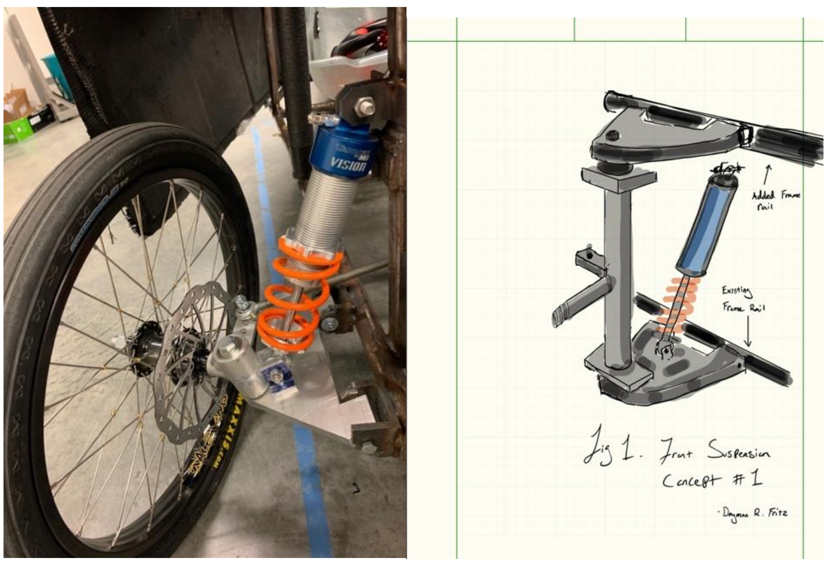


Figure 1- Current Suspension/New suspension concept

Benchmark

The benchmark bike used in this project will provide details on how to effectively mount the calipers and route cables. The EV brake system will be compared to the effectiveness of braking on the benchmark during testing.
The suspension will be modeled after typical “double-wishbone” style suspension.

Performance Predictions

The EV braking system will perform in accordance to the requirements set. Upon completion, the EV will be able to be held steady upon application of the brakes when pushed by human force. Testing will need to be devised to test the moving requirement of stopping within 40 ft. from a speed of 25mph as there is no operational power actuation on the vehicle as this time.

Description of Analysis

Analysis will include: braking force requirements, friction forces from tire to road surface, tangential braking force on caliper, existing mount bracket stress analysis, main caliper bracket stresses, and pedal design analysis.

Analysis/Device

Braking Force

Preliminary analysis shows the braking force required to stop the EV from 25mph within the given distance of 40 ft. would be 1161.69 N. *(Appendix A, Figure 2)*

Friction and Caliper Force

The friction coefficient between the tire and the common road surface is reported in Jones & Childers, *Contemporary College Physics*, 3rd ed., 2001. For dry surfaces, this value is reported to be .7. As the project requirements are stated for dry conditions this value will be sufficient in determining friction force.

Analysis shows the friction force between the tire and road to be 519.12 N *(Appendix A, Fig. 4)*. This force equates to a force of 1498.37 N at the brake caliper. For two calipers on the front of the EV, it can be stated that the total braking force at the calipers is 2996.7 N. *(Appendix A, Fig. 5)*. This information will help in the design of the brake pedal.

A University of Michigan study, “Brake Force Requirement Study: Driver-Vehicle Braking Performance as a Function of Brake System Design Variables” describes various metrics about braking systems. The study found that the braking force applied from female drivers ranged from 311.38N and 444.82 N, and male braking force ranged from 622.75N- 822.92N.

Pedal Dimensions

The overall dimensions needed from a pedal for the minimum human applied force of 311.84N to be able to express 1498.37N of braking force are .20cm from foot applied force to pivot, and 5.4cm from pivot to braking force. *(Appendix A, Figure 3)*

A minimum cross-sectional area of approximately 13mmX10mm is required for the pedal. Analysis can be seen in Appendix A, Figure 6. For practicality, the final pedal assembly will have a much larger cross-section as seen in Appendix B, Fig 15.

Analysis of the forces acting on the pivot of the pedal assembly show the minimum diameter must be at least 3.39mm *(Appendix A, Fig 8)*. For practicality, the final pivot diameter will be as shown in Appendix B, Fig. 17.

Caliper Mount

The main caliper bracket analysis can be seen in Figures 8 and 11. Final dimensions will be similar to those seen in Appendix B, Fig. 20.

Analysis of the brake caliper mounting location shows that the current mounting location would be insufficient for the loads it will experience and would fail under braking load.
A bracket with a thickness of 12.7mm will be sufficient to support the loads for this project as can be seen in Appendix A fig. 7.

Suspension: Reaction forces

The lower control arm experiences reaction forces due to the shock absorber and the pinned mounts. The load of the mass of the vehicle and an average driver weight of 500lbm is assumed to be evenly distributed between the wheels of the vehicle. With this assumption the reaction forces at the mount and from the load are 43.5 lbf in the x and 22.6 lbf in the y. The reaction force from the shock absorber is 58.8lb at 24.5 degrees. With this information, FEA analysis was performed to optimize the design of the lower control arms. Principle stresses can be seen in figures 15 and 16 of the original lower control arm design and the optimized design respectively. The optimized design reduced the weight of the control arm by 40% and maintained a safety factor of at least 4.

Risk Analysis

There will be several risks involved in the process of manufacturing and assembling the project components. However, many of these can be prepared for by use of proper training and safety equipment.

All aluminum parts will be machined via use of Central Washington University's machine shop. The processes included in this will be lathing, milling, drilling, surface finishing, and sawing. Each of these tasks presents unique dangers to the operator. To prevent injury or damage, the student has been trained in this use of these machines and will be using proper PPE during these processes.

Assembly of these components will require welding. The risks associated with welding include topical and flash burns. The student has experience in welding and will be using proper PPE when welding, as well as seeking assistance from more experienced personnel on Central Washington University's staff.

Methods and Construction

Methods

The objectives of this project will be met by utilizing resources provided by Central Washington University, as well as by modest investment from the student. With this limitation, parts will be sourced through inexpensive means or donation.

For the braking system on the EV to be effective, it must satisfy the requirements stated in the introduction. This will be achieved by using mountain bike disc brakes.

The system will consist of a floorboard for the driver to rest their legs, a pedal to actuate the brakes, and two individual caliper brackets with purchased calipers and cables, new spindles and upper control arms.

The floor-board design can be seen in fig. 16. It will mount between the chassis rails and contain the mechanism for the pedal. It will be secured to the EV chassis via 4 M10X1.5 metric bolts. The floorboard will be large enough to accommodate future project's needs for power actuation.

The design for the pedal can be seen in Fig. 15 in appendix B. The length dimensions were determined from analysis of the braking force exerted on the caliper. A minimum cross-sectional area of the pedal can be seen in Fig. 6 in appendix A. The final cross-section is much larger as the minimum dimensions required are too small to comfortably and safely actuate the calipers. Grooves are to be cut at the top of the pedal as shown to provide grip.

The pedal is secured to the floorboard via a pin and cap as seen in the assembly drawing fig. 19. The pin and cap can be seen in fig. 17 and 18 respectively.

The redesigned spindles will include an upper and lower ball joint. The lower ball joint will mount to the current lower control arm and an upper control arm will need to be machined for the upper ball joint to mount to. This upper control arm will need to be mounted to a new piece of tube steel welded onto the frame. This can be seen in Appendix B Fig. 26.

The Calipers themselves will be mounted using the redesigned spindle assembly. Brackets will be welded onto the spindle the calipers will bolt to. The current spindle, however, is unsuitable for this and a redesign of the spindle is required.

Due to this, the scope of the project has been adjusted to include only the redesign of the front suspension.

The spindles have been machined from 1-inch aluminum round stock. The diameters were all machined using a lathe with a live center. The 5/8-11 machine threads were then cut using a standard die. The end of the spindle that will be coped to the spindle tube was then radiused using a 1" end mill.

The spindle tubes were cut to length in the machine shop from 1" aluminum round tube. Cut to length via a band saw.

Mounting the ball-joint will require manufacturing mounting plates. Four mounting plates were machined from ¼" aluminum plate via the use a mill.

The steering arms were cut to length from ¼" aluminum via the band saw. Tie rod end holes were then drilled in the arms for variability of steering.

The new upper control arms were machined from ½" aluminum plating. The overall dimensions were cut to length via use of the bandsaw. The notches were then cut out using an end-mill. The three mounting holes were drilled using the drill press. The sides were then shaped via the bandsaw. Finally, the ball-joint ends were radiused to remove sharp edges.

The new upper control arms required the addition of an upper frame mount. The upper frame mount was cut to length from 1” steel tube via a band saw. For fitment, the ends were radiused using a 1” end mill to match the profile of the current frame pieces.

The upper control arms further required the addition of mounting brackets. A total of four mounting brackets were made. The brackets were made from 2” square steel tubing. The tube was cut to length and halved via the band saw. Once halved, the mounting holes were drilled using a drill press. The mating end of the mount was then radiused using a 1” end-mill to match the profile of the upper frame mount for better mating.

The new upper frame mount and control arm mounts were welded onto the existing chassis Dave’s Exhaust in Ellensburg Washington. Dave’s Exhaust donated the time, labor, and materials to the project.

Construction

All parts aside from the purchased calipers, cables and ball joints will be machined from purchased aluminum at Central Washington University’s facilities. Following machining they will be weighed and assembled to the EV chassis. Aluminum stock will be sourced from online suppliers for machining of components.

All components needed to ensure the success of the braking system can be seen via the drawing tree shown in Appendix B. Fig. 14.

Parts needed for successful completion of the braking project include:

- 20-0001-Pedal
- 20-0003-Pivot Cap
- 20-0004-Pivot
- 10-0001-Floorboad Assembly
- 20-0011-Caliper Bracket
- 20-0009-Caliper Sub-mount

Initial analysis shows that a redesign of the front spindles will be necessary in order to facilitate mounting the brake calipers. The new spindles will need to include upper and lower ball joints as well as add an upper control arm for stability. Parts necessary for this operation include:

- 20-0012-Upper Control Arm Frame Mount
- 20-0008-Spindle
- 20-0007-Steering Arm
- 20-0006-Spindle Tube
- 20-0010-Ball-joint Mount

- 12-0002-Spindle Assembly
- Control Arms (previous design may be used)

Assembly of the machined components will proceed beginning with the new spindle assembly parts.

Assembling the spindle components required the use of a TIG welder. As the university's foundry was shut down, this operation needed to be carried out by a third party.

All components necessary for the spindle were welded in place as shown in fig. 24.

Manufacturing Issues

The largest manufacturing hindrance was the lack of overall experience using the machinery in the shop. This lack of experience led to higher labor times and potential for mistakes.

One such mistake was during the machining of the spindles. One of the spindles that was discarded, was so because of an error turning the lathe table feed the incorrect way during the final cut of the OD. This resulted in a gouge in the shaft and rendered it unusable. Greater care was taken during subsequent lathe operations.

The manufacturing of the upper control arms was performed appropriately, and no issues were encountered. The existing lower control arm ball joint mount needed to be modified to accept the new ball-joints. The mounting hole diameter was increased from ½" to ¾".

Manufacturing of the control arm bracket was a time-consuming endeavor due to the manufacturing process. Three separate attempts to make the parts were attempted. First, due to lack of properly sized material, a larger bracket was attempted. However, this change would have required a modification to the upper control arms and was discarded. A second attempt was made to cut the bracket from steel stock. This process, however, was labor intensive and ended up breaking an end-mill. The final manufacturing process used 2" square tubing that simplified the process and didn't require modifications to any other part.

Upon a test assembly, a clearance issue was found between the ball-joint mount and the shock absorber. To remedy this, four new control arms will be manufactured widening the track width by 4". This allows for the shock mount to remain the same location and ensures clearance between the wheels turning and the body. However, for better turning clearance it is recommended to cut fenders into the body.

Final assembly of the front suspension proved to be a simple task. All components mated as intended and suspension is ready for testing.

Device Operation:

Brake system:

The driver of the EV will press on the pedal, creating the required tension in the cables to effectively depress the caliper pistons.

Suspension:
The device will be mounted to the chassis and suspend vehicle from the ground. The suspension will be adjustable.

Benchmark Comparison:
Brake system:
The braking system will be able to slow the EV to a stop in the same fashion as the benchmark device.

The device is expected to stop within 100% of the stopping distance required.

Suspension:
The suspension will model a typical double-wishbone style suspension.

Testing Method

Proposed Tests:

The design will be tested by evaluating its adherence to the requirements set forth in the introduction.

The added components will be weighed to ensure a mass addition of 20lbs or less. Following assembly, the brakes will be applied while stationary to resist a push by hand. Finally, the brakes will need to be shown to stop the vehicle within the 40 ft distance limit from a speed of 25 mph.

Testing of the proposed new spindle and suspension will include three tests:

- Verification of minimum ground clearance allowed by Electrothon America
- Camber angle deviation for steering sweep
- Adjustability of suspension
- Mass requirement

Tests:

Currently, operating the vehicle will not be possible as no driver controls exist to operate the drive and braking. Testing, therefore, will consist of methods that do not require full operation
.

Due to the frame mounts needed to be welded in, the mass of the suspension components needed to be weighed prior to welding. A total of 18 parts were manufactured for this project. When weighed, the parts were found to add only 12.2 lbs. to the mass of the vehicle. This is just over half of the maximum allowed weight addition. However, welding filler mass was neglected as the mass of the fill is negligibly small. The final weight addition will be only slightly more than 12 lb. after the addition of 2” length to the control arms.

After initial mock-up, it was found that the steering sweep was greatly improved. Prior to the redesign, the steering was inconsistent and caused jerking motions and drastic change in suspension geometry. Furthermore, the location of the steering arm on the existing suspension creates an approximately 30-degree angle between the plane of motion and the force of the steering wheel, dividing the force into x and y components. This is inefficient as not all of the force used to turn is planar with the component it's acting on.

The new system places the steering arms in plane with the existing tie-rods. This places all the force required to move the steering wheel, linear with the motion of the steering arms. The addition of the upper control arms also ensure that suspension geometry is maintained throughout the sweep of the steering motion.

Test: Ground Clearance

The ground clearance test verified compliance with a key Electrothon America requirement. The requirement states that the EV must be able to pass over a 2X4 piece of wood that has been milled to 1.5" while in operation. It suffices to say that the vehicle will be in compliance if it is able to safely pass over any object with this height dimension. In absence of a 2X4, a 1.5" garden brick was used. The requirement states that it must clear the dimension while in operation, to satisfy this, the vehicle will be loaded with a *test driver for weight.

*The ground clearance test was performed on the second floor of the Hogue Technology Building on the CWU campus. Due to recent social distancing measures enacted by the State of Washington's COVID-19 response, the test was unable to be performed as originally intended. A test driver could not be used while safely maintaining social distancing. In lieu of a test driver, the weight of the test administrator was used to simulate normal operating condition.

Prior to beginning the test, the suspension coil-overs were set to the minimum height adjustment. The ground clearance while loaded and stationary was measured and found to be 2.9" from the bottom of the EV chassis to the top of the brick, while the EV chassis measured 4.4" from chassis to ground. It was predicted the EV would pass over the brick while in operation without issue.

To verify a ground clearance of at least 1.5", the EV passed over the garden brick for 3 operations; forward motion, left turn, and right turn. The 3 operations were video monitored for analysis.

Video analysis of the 3 operations showed a minimum clearance from EV chassis to brick occurred on the left turn. This was a clearance from the brick of 2.2", a total clearance of 3.7", yielding a safety factor of 1.7.

This test yielded a successful verification of the Electrothon America requirement.

Test: Camber Deviation

Camber deviation was tested by holding the steering in three positions: forward, full left-lock, and full right-lock, and measuring the camber angle at these locations.

The previous suspension design allowed for a maximum camber angle deviation of 3.4 degrees. The new suspension design only allows for a maximum deviation ($\Delta\theta$) of .6 degrees. Well below the required maximum of 1 degree.

Test: Adjustability

A key component to automotive racing is tuneability of the racing vehicle's various systems. This includes suspension systems. The front suspension of the EV therefore, must be adjustable. To test the adjustability of the front suspension, the coil-over spring-preload/height adjustment collar was raised and lowered to the extremes of allowable travel. Ride height measurements were made while the vehicle was loaded and unloaded. Dampening effects were be observed. The suspension will be considered adequately adjustable if the high preload setting allows for less than ½ of the ride height deflection allowed at no preload.

The minimum preload deflection upon loading was .6" . The maximum preload deflection was only .3", meeting the requirement factor of ½.

Budget

This project consisted of few purchased components and several machined parts from aluminum stock. All components were purchased by the student or donated by suppliers.

Brake calipers sufficient for the project were obtained from Ellensburg Washington local bike store, Recycle, with the advice of the store owner, Fred Johnston. Mr. Johnston provided the calipers for $20.

The spindle redesign requires the use of ball joints. Ball joints for a small compact car will be used and are to be purchased from an online supplier. The total cost for all four ball joints with shipping will be $70 .

The majority of the parts for this project will be sourced from online industrial suppliers. Several pieces of aluminum stock will need to be purchased. At least 1 12"X12"X.25" plate, a 4"X12"X.5" plate, 3' of 1" steel round stock, and a 3' section of 1.5" round stock. The total cost of aluminum stock is roughly $200.

This cost was mitigated by being allowed to use the on-hand supply of materials at Central Washington University's Machine Shop.

The labor will be donated time by the student but will be logged for records and tracked by a rate of 1$/hr.

Total project cost will be a summation of hours of labor and total cost of parts and supplies. Making the assumption the student will work 60 hours, the total estimate for project cost is approximately $500.

Most of the project cost was intended to be paid for by student club funds, however, this was found to not be an option as club senate cannot fund anything with a grade attached to it. This presented an issue at the beginning of the manufacturing schedule as funds had not been secured so parts could not be ordered.

The student used his own money to purchase ball-joints from an online supplier for the amount of $70, however without funding to order raw materials, the manufacturing process was delayed.

During manufacturing process review, this budget concern was addressed and found to be a non-issue. The facilities on campus contained enough excess material that ordering new material was not necessary. All raw material was sourced from campus facility stock at no cost to project budget. This reduced the project cost significantly as the only items left to pay for are welding services to be outsourced. Much of this welding cost has already been deferred by donations as well. Under Pressure Racing Development out of Tacoma Washington donated the welding of the spindle assemblies. The upper control arm frame mount additions will need to be welded by a local shop.

The steel welding was completed free of charge by Dave's Exhaust of Ellensburg WA.

Testing of the project added unforeseen costs to the project, however these were small amounts that had little impact on the total project cost.

The ground clearance test required the purchase of a 1.5" garden brick costing approximately five dollars, as well as a roll of duct tape costing $3.

100% of material stock was donated by Central Washington University, saving $196 in total project cost. Welding services provided by Under Pressure Racing Development and Dave's Exhaust saved approximately $300 in labor costs for welding.

The total project cost was $98, only 19.6% of the projected project cost. The cost of the project was largely deferred thanks to generous donations by local businesses and campus facilities.

Schedule

This project is subject to the constraints set for Central Washington University's MET 495 Senior Project course. A general outline can be seen in the project Gantt Chart in Appendix E.

There will be three main phases with milestones the project will need to follow in order to be successful.

Phase one will consist of the preparation for the project's completion. Phase one will be complete by the end of a 3-month period. This will be the first milestone and entails completion of all the elements present in this report. Analysis for design parameters will be completed at the rate of 2 per week culminating in at least 12 by the first milestone. Present in this report will also be part and assembly drawings for the device.

Phase two will consist of the device construction. Parts and materials will be ordered by first week of the second phase. Parts will be manufactured within the next three-month period, culminating in a complete working device as the second milestone.

Phase three will consist of device testing and presentation. A successful device will be presented at a SOURCE conference at Central Washington University. This will serve as the third and final milestone.

During phase two of the project, all the manufacturing needed was performed to produce the parts required for the suspension. Manufacturing was scheduled to begin in early January but was delayed due to an inadequate manufacturing plan and lack of funds to order raw materials.

The manufacturing schedule was largely dictated by the course schedule in the senior project class at Central Washington University. A deadline was set of January 24th 2020 to have manufactured at least 5 parts from the project. Fortunately, raw materials were donated on time, however, the delay in a manufacturing plan meant that production couldn't begin until January 17th. A manufacturing plan was devised with assistance from Matt Burvee January 17th and production began that same day.

To maintain the deadline of January 24th, the student worked diligently in the machine shop with Matt Burvee to refamiliarize with equipment and execute machine processes effectively. Due to the inexperience of the student, mistakes were made early during the manufacturing of the first spindle and that part needed to be remade twice causing about a 3-hour delay in delivery of that component. This delay meant working longer hours to achieve the deadline.

On January 24th, the deadline was met and a total of 12 parts out of 18 were complete.

The parts made were components of assembly 10-0002 (Appendix B. Fig. 24). Task 7a, as mentioned above took several hours longer to accomplish largely due to inexperience with shop equipment. This learning curve would be quickly overcome however, as most manufacturing tasks maintained on schedule, the exception being the control arms.

Task 7e, the upper control arm production was intensive as 6 total control arms were made to address fitment issues.

Assembly of 10-0002 required the use of TIG welding. The on-site welding services at the campus are unavailable due to a lead contamination in the engineering departments foundry. As such, welding services were outsourced. Under Pressure Racing Development out of Tacoma Washington generously donated time, skill and materials to weld the components to the assembly.

Task 7b, manufacturing of the ball-joint mounting plates, was accomplished on schedule without delay. This task may have taken longer but due to the revelation that the bolt holes needed to be custom matched to each ball-joint, use of a coordinate system was negated and time was saved.

Welding the frame components to the existing frame took more time than expected. However, this extra time was valuable in the knowledge gained. Dave of Dave's Exhaust generously donated his time and experience to welding the frame components at no cost. Dave has several years' experience in racing and took the opportunity to share his knowledge of racing suspension systems.

Final assembly of the completed components showed successful and the device is ready for testing.

During the testing phase of the project, scheduling testing proved to be more difficult than

Project Management

This project will succeed in part due to the effort of the student, but also the support of the staff and facilities located at Central Washington University. The machine shop located in Hogue will serve as the main facility for manufacturing of parts with the assistance of machine shop faculty to serve as guides and safety officers. The instructional staff within the engineering program will provide expertise and guidance on design and analysis to help ensure quality, safety and completion of the project. The principle engineer of the project will be the student who has several years of hands on project experience within the automotive industry as a technician and has experience in vehicle projects, as well as experience that has been dictated by the curriculum within the MET program at CWU.

Financial resources include funding from the student and donations from CWU Electric Vehicle Club.

Discussion

The braking system for the EV has been considered, analyzed and designed fully for the requirements of this project.

First, the pedal assembly was considered as a means of brake actuation. Since the EV does not have a structural floorboard, one will need to be made for the operator to rest their legs and utilize the brakes. The pedal itself was then designed to withstand the forces acting on it and for comfort and practicality.

The next concern was determining how to mount the brake caliper such that it would articulate with the motion of the wheel and stay in location to the rotor during a full sweep of the steering system. The current steering arm has room for mounting a caliper bracket and would allow for the caliper to remain in sync with the wheel movement. However, analysis showed this steering arm would be unable to withstand the tangential braking force from the caliper and would fail. Thus, a new mount location on the hub needs to be considered. This presented a challenge as it was found that the current hub assemblies were not identical and were welded at different angles to the spindle. The current design of the hub also allows for the camber angle to vary by as much as 15 degrees during steering sweep. Because of this, a new hub assembly would need to be built to fix these issues before proceeding the mounting the calipers.

However, prior to being able to proceed with mounting the calipers, another issue needs to be addressed in order for the project to be successful.

During investigation into the caliper mounting location, it was determined that the front suspension design is insufficient to work with and will need to be redesigned in order to have an effective braking system. The current design places the spindles at random angles to the hub and there is insufficient support for the hub which would cause an unsafe bump-steer condition. This renders the vehicle essentially inoperable.

Due to this revelation, the scope for the initial project has grown substantially. New designs will be needed for a spindle, hub, upper and lower control arms, and finally the brake caliper brackets. Examples of a potential hub assembly redesign can be seen in Appendix B Fig. 22.

This design will incorporate upper and lower control arms, upper and lower ball joints and mounts for the ball joints to the spindle such that front end alignment can be maintained, as well as the spindle, steering arm and brake caliper. Further analysis will be required to properly design these, but examples can be seen in Appendix B.

Manufacturing the components for the new front required several processes in the machine shop. Due to inexperience in the machine shop, this presented a challenge as great care needed to be taken to ensure correct operation of machines, and safety. The inexperience led to mistakes being made and parts had to be made more than once.

During the turning process for the spindles, not enough cutting oil was used and the aluminum shavings welded to the tool. This caused a very rough cut and chattering to occur. The spindle was left with a rough finish that was variant in diameter. The solution to this issue was to regrind the cutting tool and use more cutting oil on the lathe. However, the first spindle needed to be scrapped and manufacturing was restarted from the beginning. During the second attempt a mistake was made during the last cut of the smallest diameter. The feed table was accidentally turned the wrong way, gouging the main diameter of the spindle, rendering it unusable. The second spindle was discarded, and the process was restarted once again. Finally, with the potential errors accounted for and care taken, both spindles were machined properly.

During manufacturing the mounts for the ball joints, it was found that the purchased ball-joints mounting holes were not symmetrical. This meant the ball joint mounting plated needed to be matched to the ball joint as special hole locating was needed. Due to this, identifying marks were stamped into the ball-joint mounting plates and their respective ball-joint. This was to assist in future maintenance.

Once manufacturing was complete, the components of the spindle assembly were welded together by Under Pressure Racing Development based in Tacoma Washington. The time, expertise and material for welding was donated by Under Pressure Racing Development.

The upper control arm frame mounts were welded in place courtesy of Dave's Exhaust of Ellensburg, Washington. The time, expertise and material for welding was donated by Dave's Exhaust.

Upon mounting the new control arms, it was found the ball-joint plates interfered with the mounting location of the shock during the steering sweep. This was an anticipated problem that several solutions were considered to remedy. The solution chosen was to widen the track of the car by 4". This meant manufacturing 4 new control arms, relocating the ball-joint mount location further from the shock mount to ensure no interference. The new suspension was temporarily mounted to confirm no further interference occurred.

Upon final assembly, the suspension was found to operate as expected and is ready for testing.

Testing was performed on the second floor of the Hogue Technology building at CWU. Four tests were completed: a ground clearance test, steering camber angle deviation, adjustability, and mass requirements.

The ground clearance test initially required the use of a data recorder and an operator. Due to COVID-19, the test was all performed by a sole test administrator and adjustments to the testing procedure were changed. The ground clearance test was performed on an approximate 10-degree incline such that with little assistance, the vehicle could be pushed by hand and propelled by gravity further. The test was recorded and analyzed via software following the test. This allowed the test administrator to perform the test without assistance.

The ground clearance test yielded successful results. The minimum ground clearance was found to be 4.4" at lowest preload. A factor of 2.9 above the requirement. In all operation scenarios, the EV cleared the 1.5" requirement without issue.

The camber deviation test was designed to be a metric for stability in steering motion. The previous design lacked upper support and caused the camber to deviate greatly during the steering motion, allowing for a deviation of 3.4 degrees. The test utilized a digital inclinometer via iPhone application. Camber measurements were taken in forward, left, and right steering positions. The suspension is considered stable if a change in degree is less than 1.

The maximum camber deviation allowed with the new front suspension was .6 degrees. The addition of the upper ball-joint greatly improved the stability of the front suspension.

Adjustability is important in automotive racing suspensions. Racing is comprehensive sport that includes not only vehicle design and talent, but also the ability to tune the racing vehicle to support the needs of the race. The adjustability test evaluated the front suspension's ability to be customized. The shock absorber preload was adjusted to safe maximum and minimums and suspension deflection was recorded during loading. The suspension will be considered adequately adjustable if the high preload setting allows for less than ½ of the ride height deflection allowed at no preload.

The maximum ride height deflection during lowest preload was .6" of travel. The maximum ride height deflection during the highest preload was .3. This is exact the required factor of ½.

The mass test evaluated the total weight added to the vehicle as it is important to keep this as low as possible. A total of 18 parts were manufactured for this project. When weighed, the parts were found to add only 12.2 lbs. to the mass of the vehicle. This is just over half of the maximum allowed weight addition. However, welding filler mass was neglected as the mass of the fill is negligibly small.

Conclusion

Given the discovery of the need for a complete spindle and front suspension redesign, it was unlikely that the electric vehicle brake project could be completed in the timeframe allotted. Due to this, the scope of the project was adjusted to focus on the redesign of the front suspension.

The new suspension design benefitted the EV race car greatly:

- The redesign allows future engineers to complete the braking system as analysis has been complete and this goal has been kept in mind for the entirety of the project, simplifying it for future students.
- The redesign maintains suspension geometry throughout motion of the steering
- The newly designed suspension allows for safer operation of the vehicle and would provide stability in steering such that it can be operated for the race without uncontrollable bump-steer conditions.

The manufacturing phase of this project has been a success. The suspension system is installed on the vehicle and awaiting testing. Initial inspection instils confidence in testing. The vehicle still needs more systems before it will be ready for a race, but with the front suspension finished, and a brake-system designed, it is likely to be ready within one year if these tasks are pursued.

While the suspension system is a success, it brought to light an issue with the steering. The steering system is quite difficult to operate. The force to move the spindles is scaled by a lever arm creating a moment that is difficult to overcome at the steering wheel. Were this design changed to incorporate a rack and pinion style steering system, vehicle control would be greatly improved.

Acknowledgments

This project has been supported by several community members and the faculty/staff of Central Washington University:

- The Recycle Bike shop in Ellensburg WA supplied the brake calipers at a discount, thanks to owner, Fred Johnston.

- The Electric Vehicle Club at CWU supported this project as vehicle sponsors.

- Under Pressure Racing Development Tacoma Washington welded the spindles together. Thank you to founder, Zach Leitzke for his expertise and time.

- Dave’s Exhaust Ellensburg WA, thank you for welding the frame mounts.

- Thank you to professor Charles Pringle for assistance/guidance with several analysis, design discussions, general motivation and support for this project. His guidance was a valuable resource.

Appendices

Appendix A – Analysis

Braking Force Analysis:

Dayman R. Fritz | Braking force

Given: Mass (m): 201.5lb
Max Velocity (v): 25 mph
Max stopping distance (S): 40 ft

S.I.
$m_t = 226.796\ kg$
$V = 11.176\ m/s$
$S = 12.192\ m$

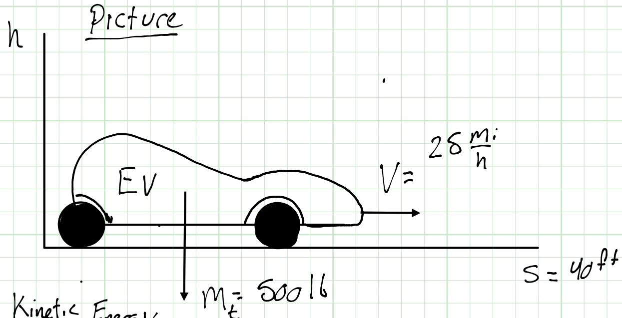
Find: Straight Line stopping force needed

assume: motion in one plane
Total mass of vehicle + Driver
$M_t = 500\ lb \approx 226.796\ kg$
Neglect friction

method:
Energy + Work Eq,s

Solution: in metric

Picture



Kinetic Energy

$$KE = \frac{1}{2} m V^2 = \frac{1}{2}(226.79\ kg)\left(11.176\ \tfrac{m}{s}\right)^2 = 14163.373\ \tfrac{kg\,m^2}{s^2}\ (J)$$

Work

$$W = FD \longrightarrow F = \frac{W}{D} = \frac{14163.373\ \tfrac{kg\,m^2}{s^2}}{12.192\ m} = \boxed{1161.69\ \tfrac{kg\,m}{s^2}\ (N)}$$

for reference: 261.09 Lbf

Figure 2-Braking Force Analysis

Brake Pedal Side Profile Analysis

Daymon Fritz | Pedal Side dim.

Given: Braking force required $F_B = 1161.64N$

Minimum Driver Braking force, $F_E = 311.48N$

average Female foot size = .25m

Find: Pedal-Lever Side dimensions

Assume: Uniform Force

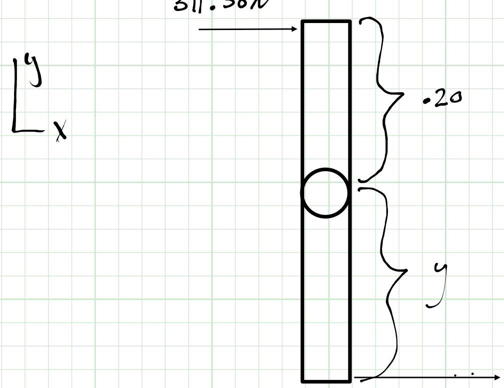
Let dimension $x = .20m \rightarrow 20cm$

(Distance From Heel to ball of foot)

Method: First order Lever

Force Balance

Solution: $F_E = 311.38N$



$F_B = 1161.69\,N$

Moment Balance

$$F_E(x) = F_B(y)$$

$$\rightarrow y = \frac{F_E(x)}{F_B}$$

$$\rightarrow y = \frac{311.38N(.20m)}{1161.69N}$$

$$\boxed{y = .054m}$$

$\rightarrow 5.4cm$

Figure 3-Pedal Assy. Side profile Analysis

Friction Force Analysis

Dayman Fritz | Friction Force @ tire

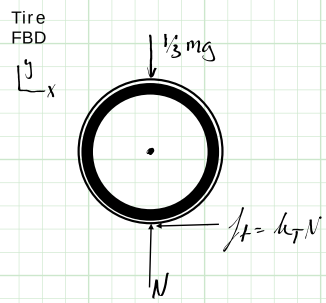
Given: Coefficient of Friction
From tire to Road surface
$\mu t = .7$ M = 226.79kg

Find: friction force Between tire and road

ASSUME; Evenly distributed mass,
Neglect air resistance

Method: FBD. Equilibrium Eqs.

Solution:



$$\Sigma F_y = N - \tfrac{1}{3}mg = 0$$

$$\rightarrow N = \tfrac{1}{3}mg = \tfrac{1}{3}(226.796\,kg)(9.81\,m/s^2) = 741.60\,N$$

$$f_f = (741.60)(.7) = \boxed{519.12\,N}$$

Force Between tire and road surface $\boxed{Ff = 519.12\text{ N}}$

Fig. 4- Friction Force on Tire

Tangential Braking Force on Caliper

Dayman R. Fritz | Caliper Tang. force

Given: Friction force Between tire and Road ff= 519.12 N

radius of rotor r1= 88mm

radius of Tire r2= 254mm

Required force to stop EV, F2=1161.12 N

Find: Tangential Braking Force on caliper. Fc

Assume: Steady Force application

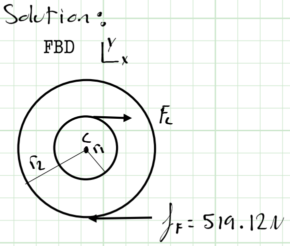
neglect air resistance

Braking force evenly distributed

Method: F. B. D. . Moments

Solution:

FBD



$$\Sigma M_c = (519.12N)(.254m) = F_c(.088m)$$

$$\longrightarrow F_c = \frac{(519.12N)(.254m)}{(.088m)} = \boxed{1498.37N}$$

The tangential Braking force on The caliper is 1498.37N

$\boxed{\text{X 2 calipers = 2996.74N}}$

Fig. 5-Tangential Force on Caliper

Pedal Cross-Section Analysis

Given: FE = 311.38N; FB = 1161.69N

Aluminum - 6061

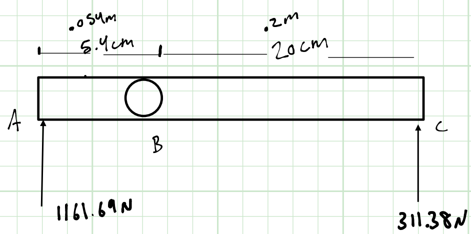
Flexural yield - 40KSI → 255 MPa

Find: minimum cross-section
For Brake Pedal

Assume: Isotropic and Homogenous

Method: FBD
moment
section
modulus

Solution:



MAX Moment $= (1161.69N)(.054m) = 62.73 Nm$

$(311.38)(.2) = 62.27\ Nm$

$$S = \frac{M}{\sigma_d} = \frac{62.27\ Nm}{255E6\ Pa} = 2.44E\text{-}7$$

For rectangular cross-section

$$S = \frac{HB^2}{6} \rightarrow$$

Let $B = .0127m$ (12.7mm)

$$H = \frac{6S}{B^2} = \frac{6(2.44E\text{-}7)}{(.0127m)^2} = \approx 9.08mm$$

Answer:
Min. Pedal cross-section

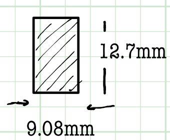


Fig. 6-Cross-Section

Existing Mount Option Analysis

Existing mount Stress

Given: Existing mount Dimensions
Tangential Braking force
FB= 1498.37N

Find: Can Existing mount Location handle stress From Braking.

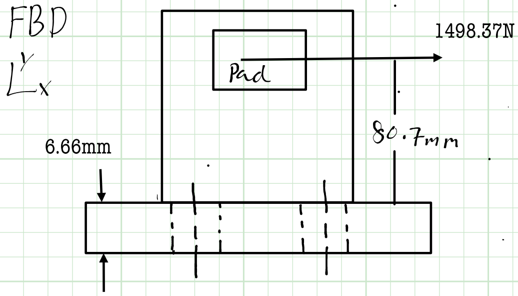
Assume: Aluminum T6-6061

yield = 225 Mpa

Method: FBD
Moment
σ

Solution:

FBD



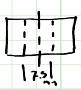
moment

$$(\text{Max } m = 1498.37N)(.0807m)$$
$$= 120.92Nm$$

Side

Mount $A = (.00666m)(.020m) = .0001332$

$\sigma = \frac{mc}{I}$ $\qquad C: \frac{(.00666m)}{4} = .001665$



$I = \frac{1}{12}(12.5E\text{-}3m)(.00666m)^3 = 3.077E\text{-}10m^4$

$B = (20-7.5) = 12.5mm$
Width-Hole

$$\sigma = \frac{(120.92Nm)(.001665)m}{3.077E\text{-}10m^4} = 654311992.2\frac{N}{m^2} = \boxed{654.3Mpa}$$

Conclusion: The stress on the Existing mount Bracket option Would be Be too Great and would Fail. New Bracket design is needed

Fig. 7-Brake caliper mount analysis

Pedal Pivot-Pin Analysis

Pin - Diameter

Given: Forces Acting on Pin

$\tau_{max} = 131mpa$

D.F. = 2.0

Find: Minimum Pedal Pin Diameter.

Assume: Homogeneous, Isotropic material

Aluminum 6061 T6

Force acting on Pin Equal To cable Force.

Method: F.B.D.

Double Shear

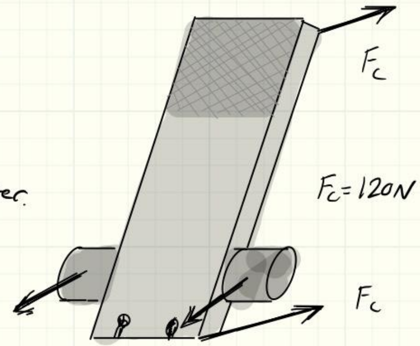
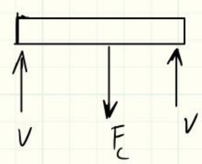


Fig 1) Pedal assy.

Solution:



$V = \frac{1}{2} F_c$

$$\tau_{allow} = \frac{131E6pa}{2} = 65500000\ pa$$

$65.5mpa$

$$\rightarrow \tau_{allow} = \frac{V}{A} \rightarrow A = \frac{V}{\tau_{allow}}$$

$$A = \pi r^2 \rightarrow r = \sqrt{\frac{V/\tau_{allow}}{\pi}}$$

$$r = \sqrt{\frac{\frac{60N}{65.5E6pa}}{\pi}} = .0016m$$

$$D = (.001696) \times 2 = .00339m$$

minimum required Pin diameter

$\boxed{\approx 3.39mm}$

• final dimensions

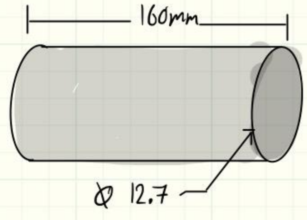


Fig. 8-Pedal Pin

Caliper Bracket Extension Analysis

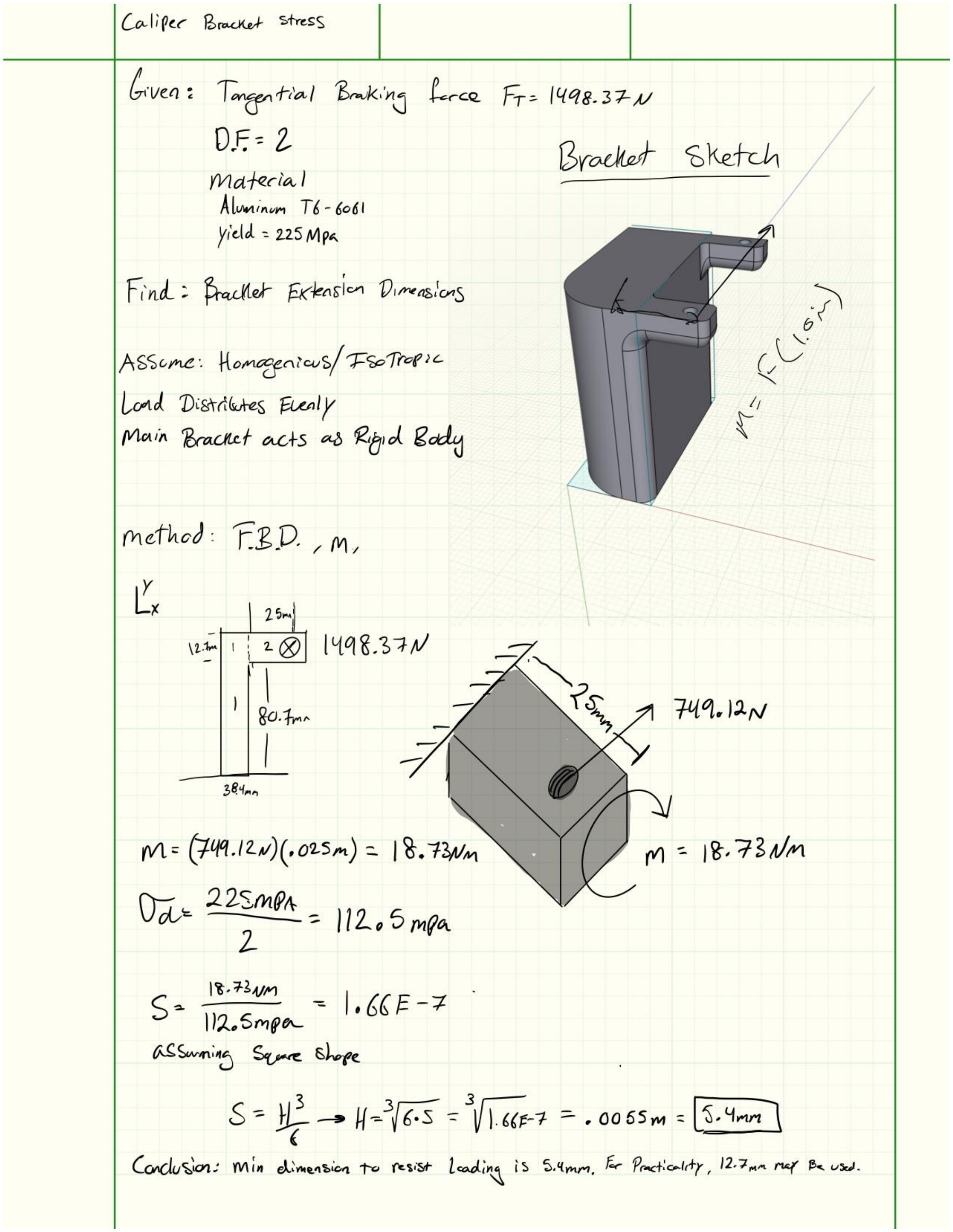


Fig. 9-Bracket Ext.

Caliper Sub-Mount Analysis

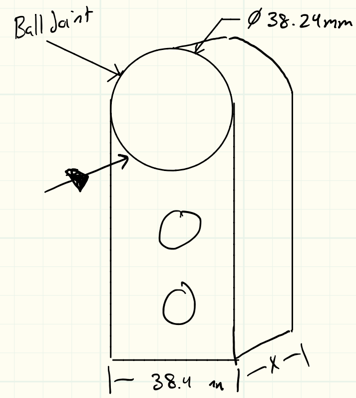
Caliper Sub-mount

Given: Tangential Braking force Moment

$DF = 2$

find: Minimum Cross-Sectional Area/Dimensions for Caliper sub-mount

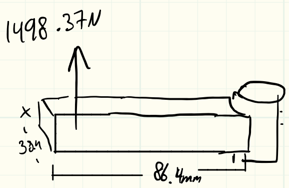
Assume: Aluminum T6-6061
yield = 225 Mpa



Method: F.B.D.
Stresses
Section modulus
required min. Dimensions

Solution:

F.B.D.

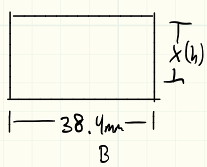


$$\sigma_d = \frac{225\,Mpa}{2} = 112.5\,mpa$$

$$M = (1498.37N)(.0864m) = 129.46Nm$$

$$S = \frac{129.46Nm}{112.5mpa} = 1.151E\text{-}6$$

Cross-Section



$$S = \frac{BH^2}{6} \rightarrow H = \sqrt{\frac{6S}{B}} = \sqrt{\frac{(6)\,1.151E\text{-}6}{38.4mm}} = \boxed{.00042\,mm}$$

Conclusion: The minimum required height of .00042mm Would Be impractical, as such, A common size of 12.7mm Will Be Suggested.

Fig. 10-Caliper Sub-Mount

Caliper Mount Extension Torsional Shear

τ_{max} - Extension

Given: Caliper Extension Dimension

$\frac{F_t}{2} = 749.12N$

Find: τ_{max} on Bracket Extension

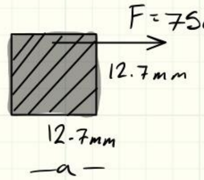
Assume: Isotropic & Homogenious material

6061-T6 $\tau_{max} = 207\,mpa$

Method: T, J, c, Z_p

Solution:

$F = 750N$ $\quad T = (750)(.0127m) = 9.53Nm$



Polar moment

$$J = \frac{a^4}{6} = \frac{12.7E\text{-}3m^4}{6} = 4E\text{-}8m^4$$

$$C = \frac{12.7mm}{2} = .00635m$$

$$Z_p = \frac{4E\text{-}8m^4}{.00635m} = 6.8E\text{-}7m^3$$

$$\tau_{max} = \frac{T}{Z_p} = \frac{9.53N \cdot m}{6.8E\text{-}7m^3} = 13954559.8\,N/m^2$$

Conclusion: 140mpa < 207mpa ✓

Fig 11-Torsional Shear on bracket Extension

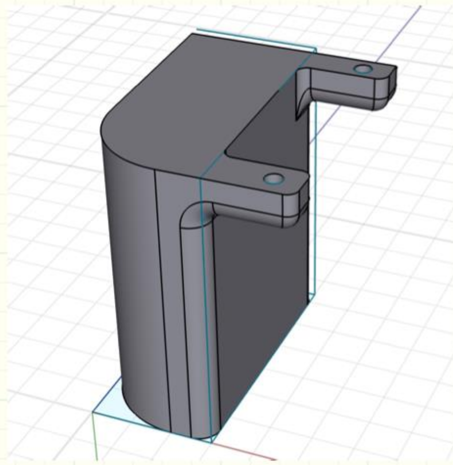
Main Caliper Bracket Torsional Shear

Main Bracket τ

Given: Main - Bracket - Dimensions

$F_T = 1498.37 N$

Find: τ_{max} on main Bracket

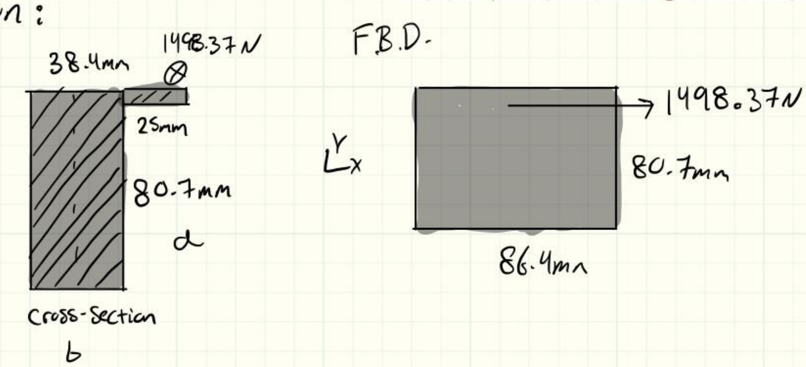


Assume: T-6 6061

$\tau_{allow} = 207 mpa$

Method: FBD, T, Z_p

Solution:



$$T = (1498.37N)(44.6E{-}3m) = 66.83 Nm$$

$$Z_p = \frac{b d^2}{\left(3 + 1.8\frac{d}{b}\right)} = \frac{(.0384)(.0807)^2 \ m^3}{\left(3 + 1.8\left(\frac{.0807}{.0384}\right)\right)} = 3.69E{-}5 \ m^3$$

$$\tau_{max} = \frac{66.83 Nm}{3.69E{-}5 m^3} = 1811111.11$$

$$\boxed{1.81 Mpa < 207 Mpa}$$

Figure 12-Main Bracket Torsional Shear

Main Caliper Bracket Direct Shear Stress

Bracket Stress

Given: Bracket Dimensions
$F_t = 1498.37N$

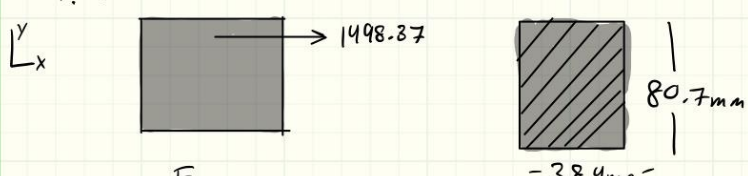
Find: Direct stress

Assume: Axial Loading
Homogenious/Isotropic

method: F.B.D.
Area
Shear

Solution:

F.B.D. Cross-Section



$$\sigma = \frac{F}{A}$$

$$A = (.0384m)(.0807m) = .00309m^2$$

$$\sigma = \frac{1498.37N}{.00309m^2} = 483{,}519.8pa$$

$$\boxed{.48MPa < 207MPa}\ \checkmark$$

Fig. 13-Main Bracket Shear

Lower Control Arm Analysis:

Dayman R. Fritz	Lower Control arm	Analysis

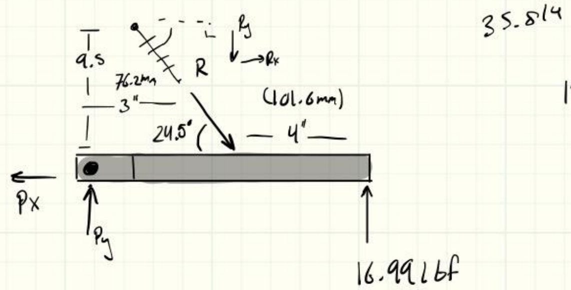
Given: Lower Control arm, Force From mass

find: Reaction force at shock

Assume: Vehicle mass distributed Evenly among wheels

Method: FBD, Equillibrium

Solution:



$$\circlearrowleft \sum M_p = \varnothing = (16.99^{Lbf})(7in) - R_y(8") = \varnothing$$

$$\rightarrow R_y = \frac{(16.99)(7in)}{3in} = 39.6^{Lbf} = R_y$$

$$\cos(24.5) = \frac{R_y}{R_x} \rightarrow R_x = \frac{R_y}{\cos(24.5)} = \frac{39.6^{Lbf}}{\cos(24.5)} = 43.5 Lbf$$

$$\sum F_y = \varnothing = 16.99 - 39.6 = P_y = 22.61$$

$$\sum F_x = \varnothing = 43.5 - P_x = \varnothing \rightarrow P_x = 43.5^{Lbf}$$

$$|R| = \sqrt{39.6^2 + 43.5^2} = 58.8^{Lbf}$$

Answer:
$R_y = 39.6^{Lbf}$
$R_x = 43.5 Lbf$
$P_y = 22.61^{Lbf}$
$P_x = 43.5^{Lbf}$
$|R| = 58.8^{Lbf}$

Figure 14-Lower Control Arm Analysis

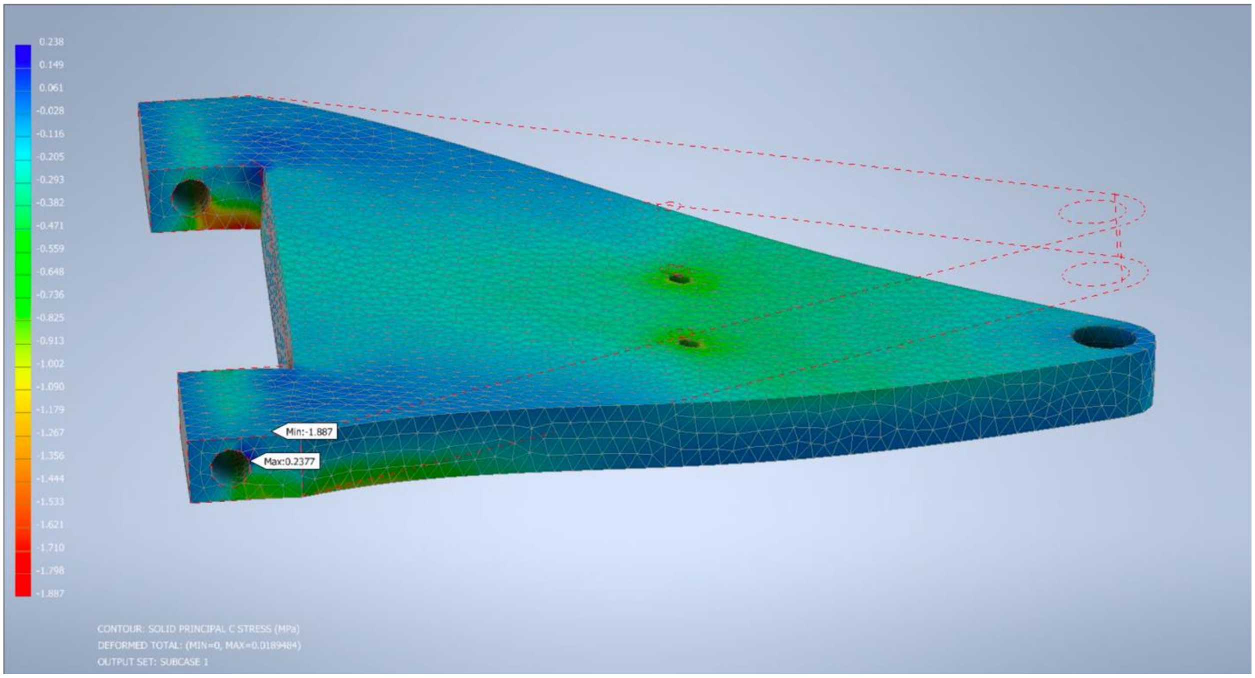


Figure 15-Lower Control Arm FEA – Stress

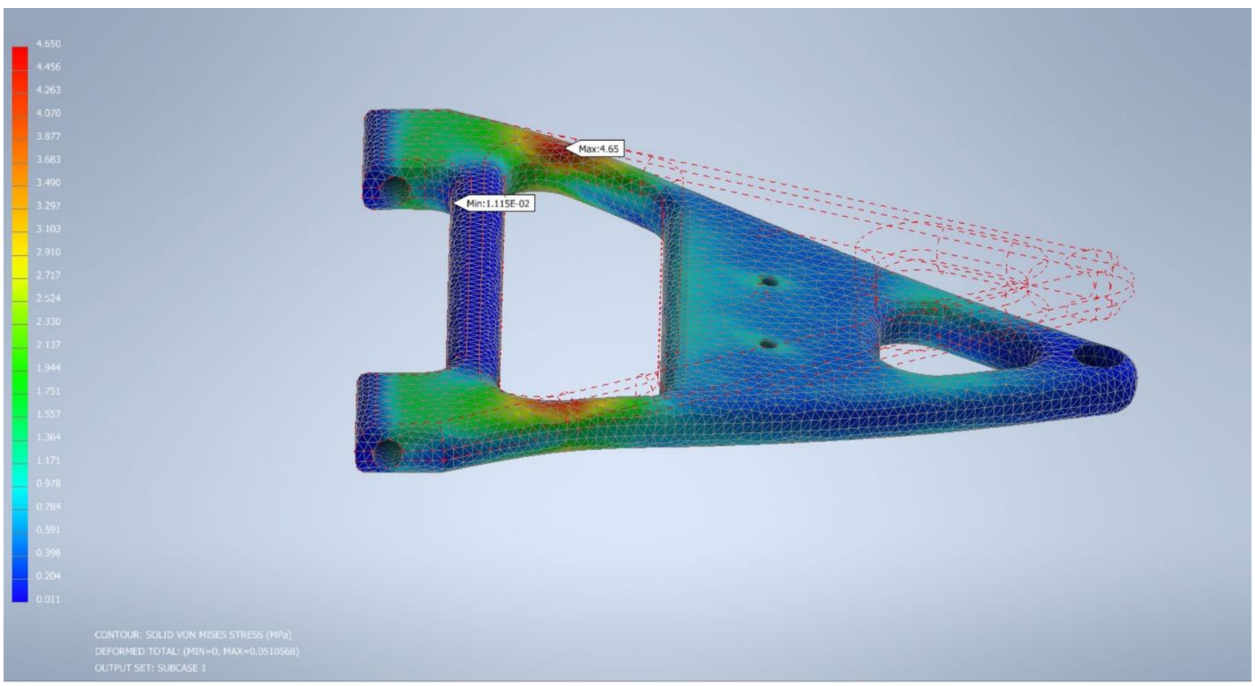


Figure 16-Optimized Control Arm FEA-Stress

Spindle Tube Analysis:

Spindle Tube		1-27-2020

Given: Load - 166.7 Lb axial

Spindle Tube Dimensions $N = 3$

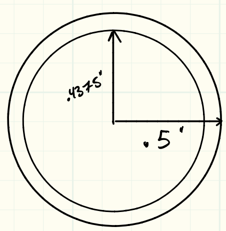
find: Critical Buckling Load
max allowable Load

T6-6061 $E = 10000\,KSI$
$S_y = 35000\,PSI$

Assume: mass Distributed Equally among Wheels of EV.
Column in compression

method: Mott's Flow chart

Solution:



$I = \frac{\pi}{64}(1^4 - .875^4) = .04909$

$A = \pi(.5^2 - .4375^2) = .7854$

$r = \sqrt{\frac{.049}{.7854}} = .25$

using Practical K

$L_e = (.65)(6) = 3.9$

$S_r = \frac{3.9}{.25} = 15.6$

$C_c = \left(\frac{2\pi^2\,10000}{35000}\right)^2 = 31.8$

$P_{cr} = \frac{(\pi^2)(10{,}000\,KSI)(.04909)}{3.9^2} = 318{,}539.7^{lb}!$

$15.6 < 31.8$

∴ Column is Long!
use Euler!

Design factor not necessary
∴ allowable Load $= P_{cr}$

Appendix B- Drawings

Drawing Tree

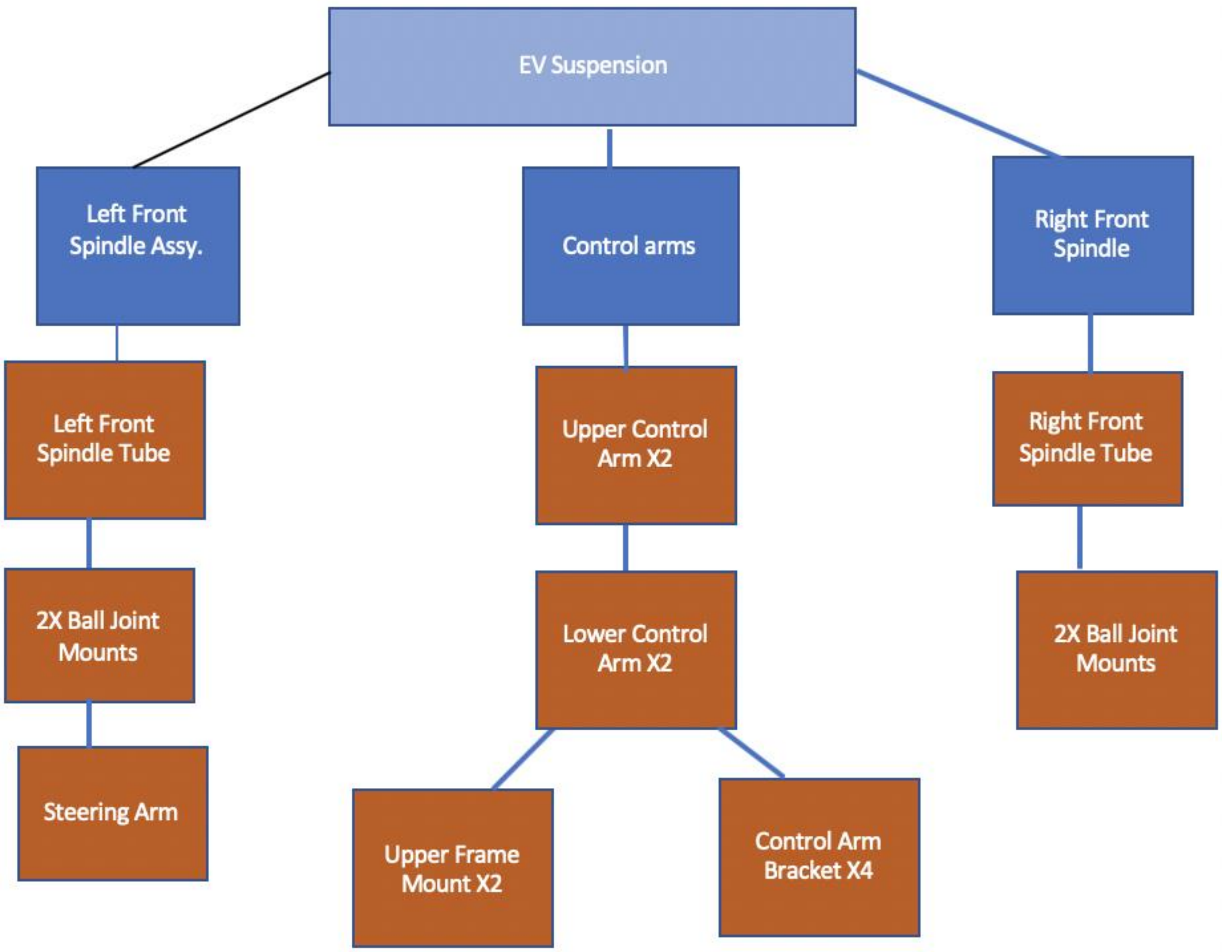


Figure 17-Drawing Tree

Upper Control Arm Mount Brackets

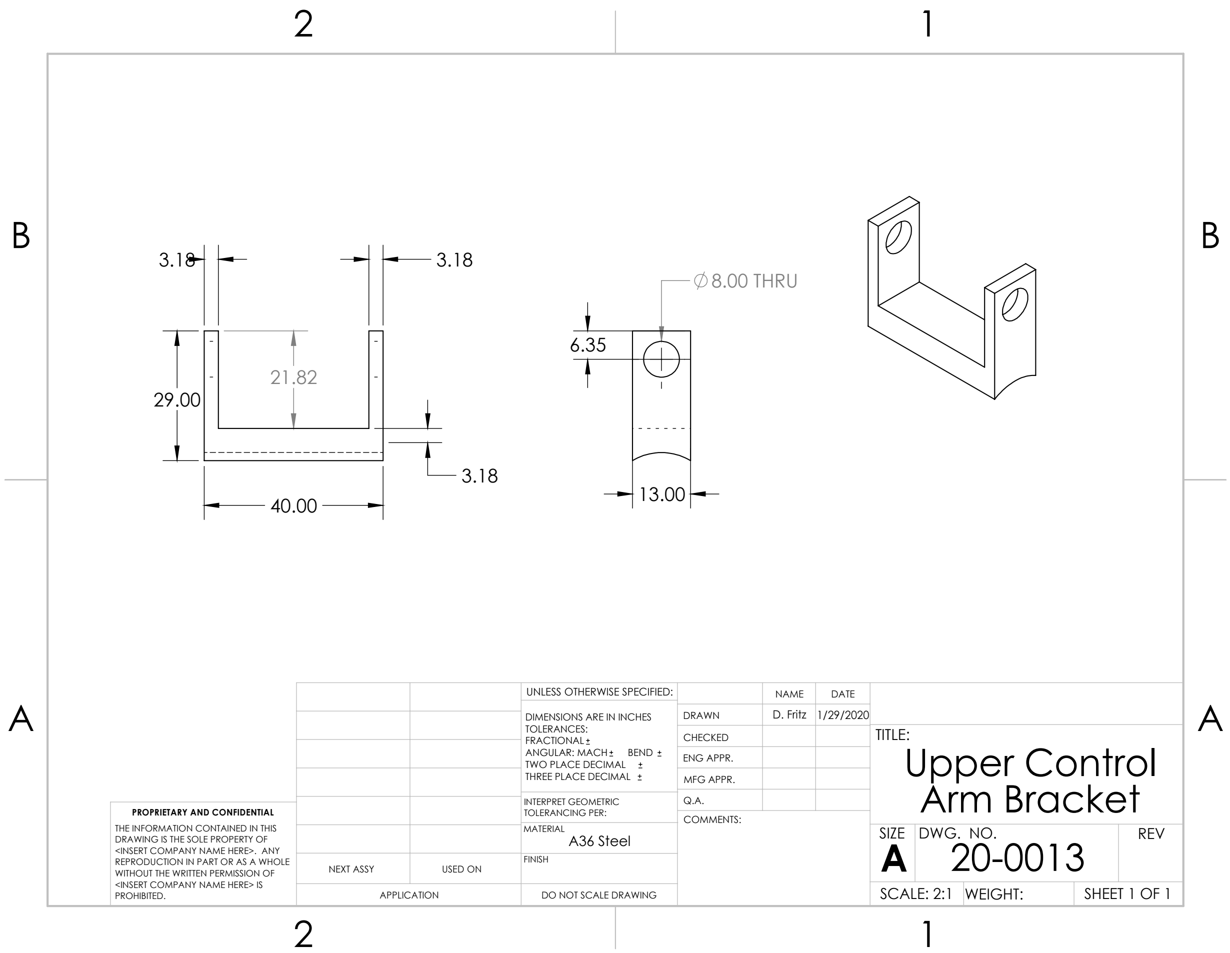


Figure 18-UCA Mount Bracket

Spindle Tube Redesign Drawing

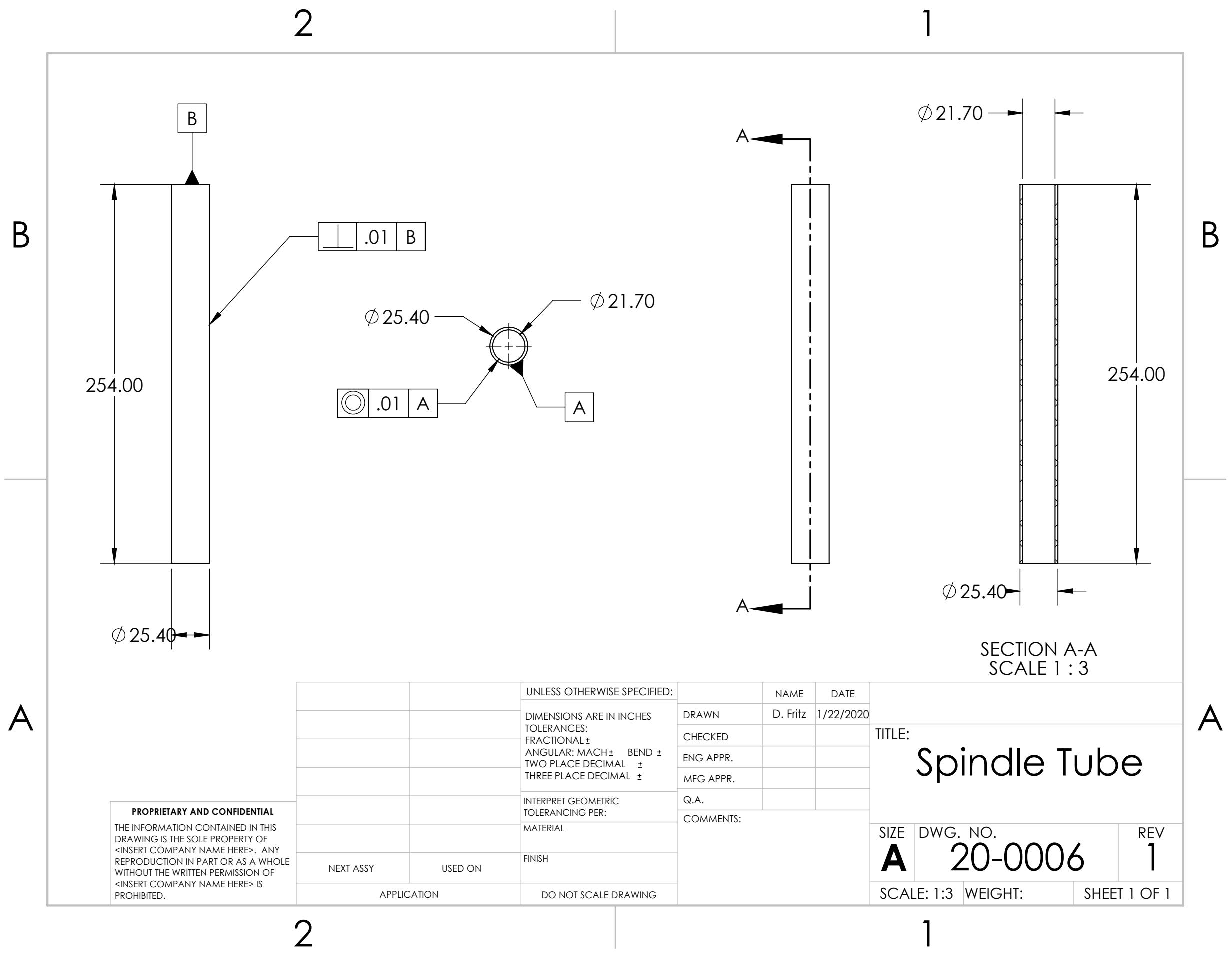
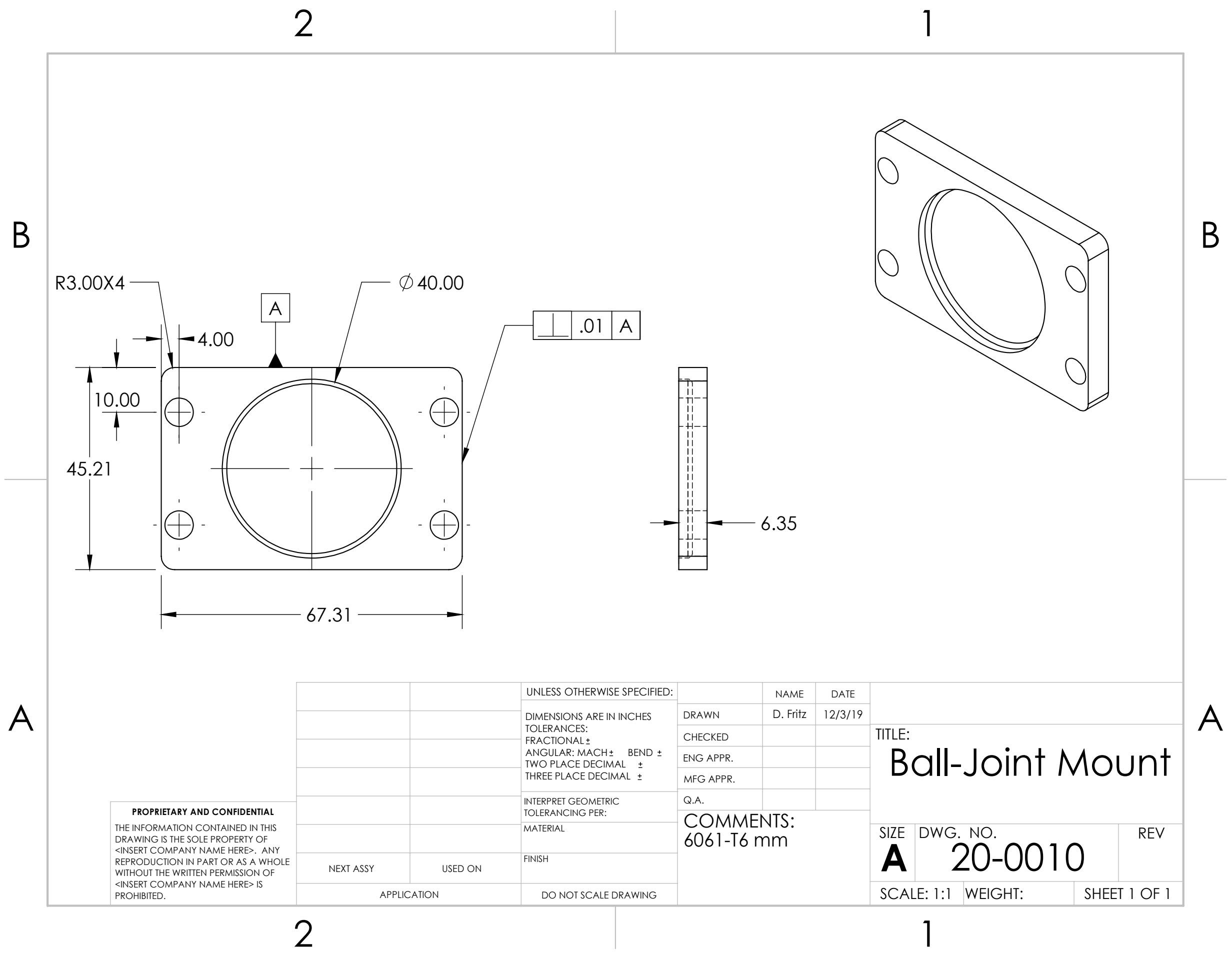


Figure 19-Spindle Tube

Ball Joint Mount Plate



Steering Arm Drawing

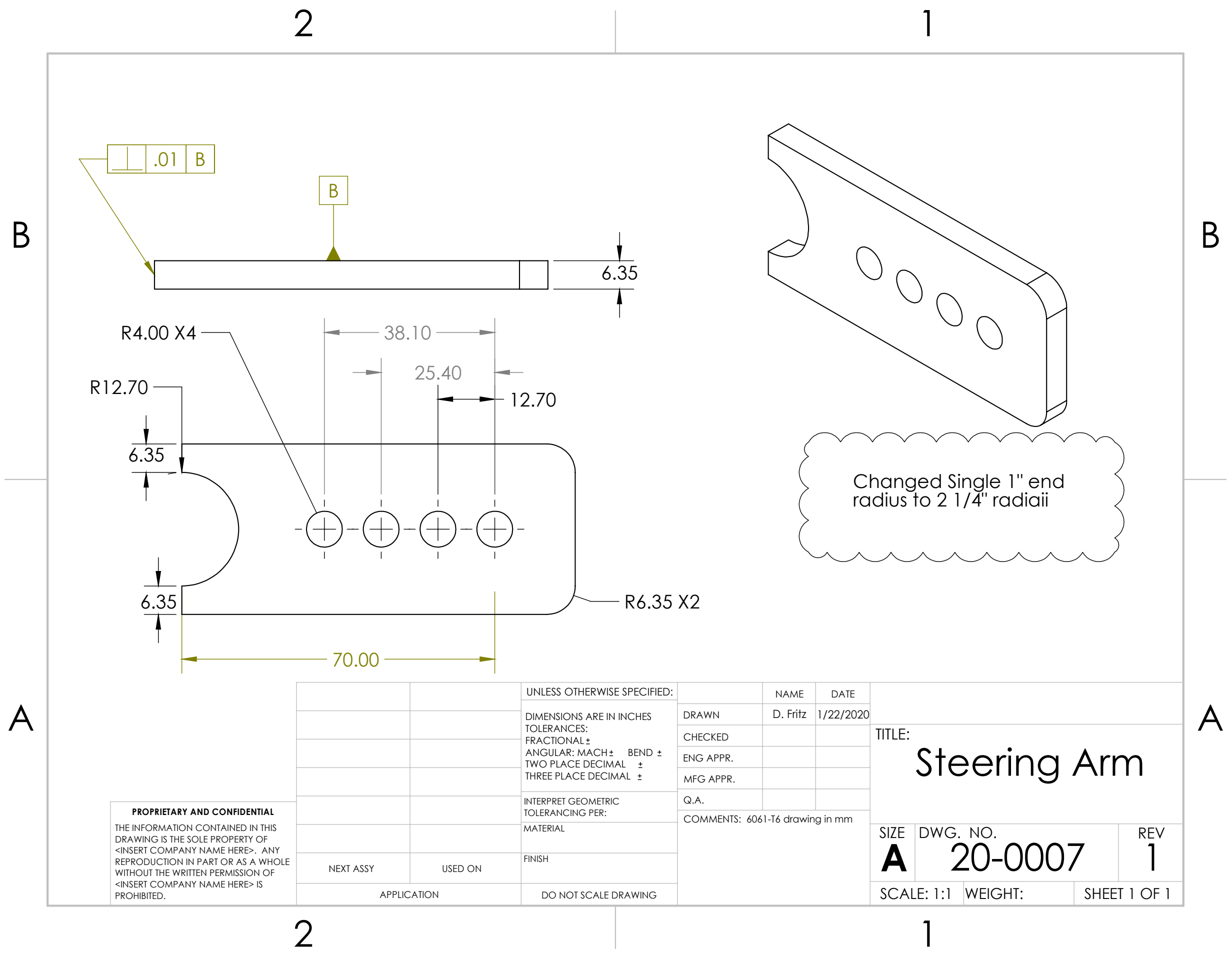


Figure 20-Steering Arm

Spindle Hub Drawing

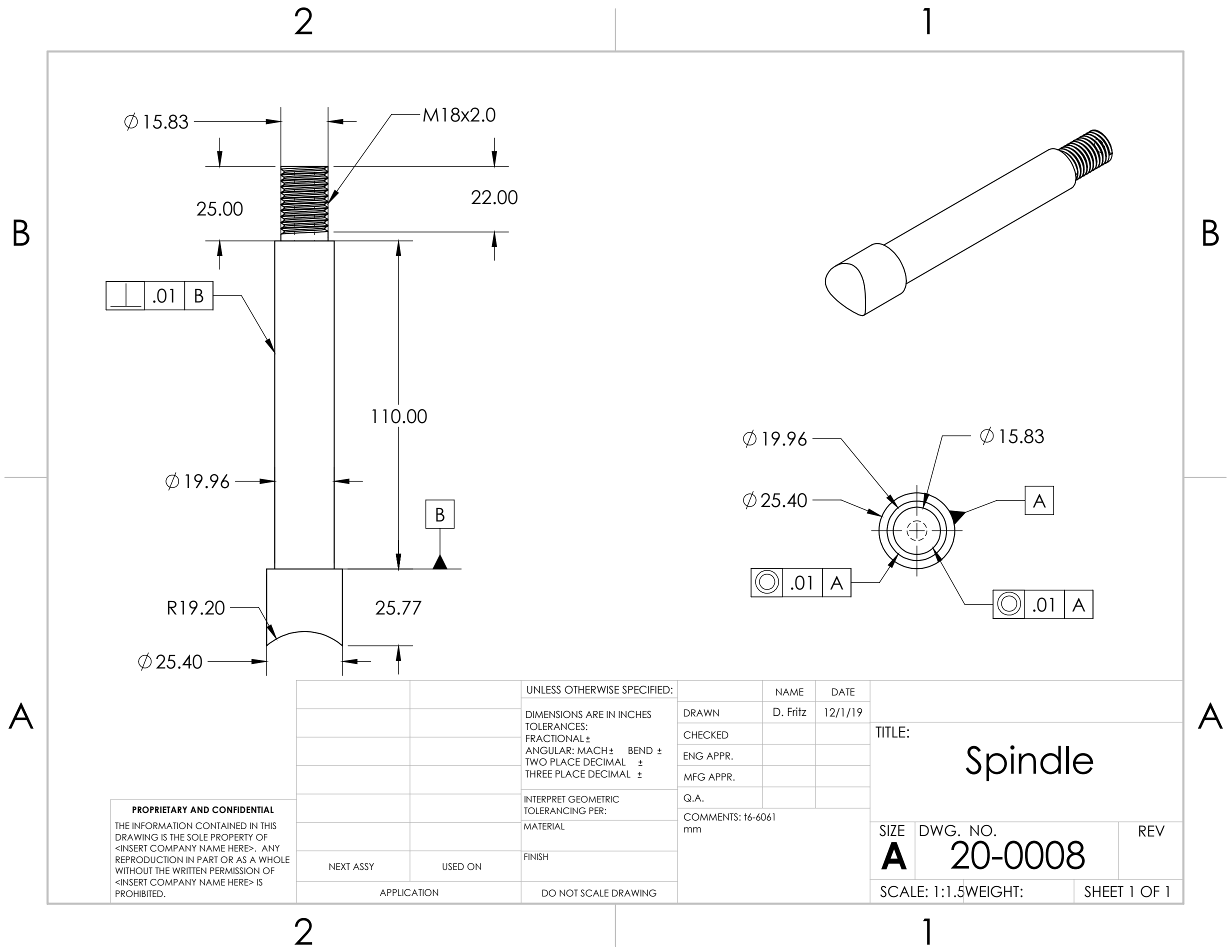


Figure 21-Spindle

Suspension Spindle Assembly Drawing

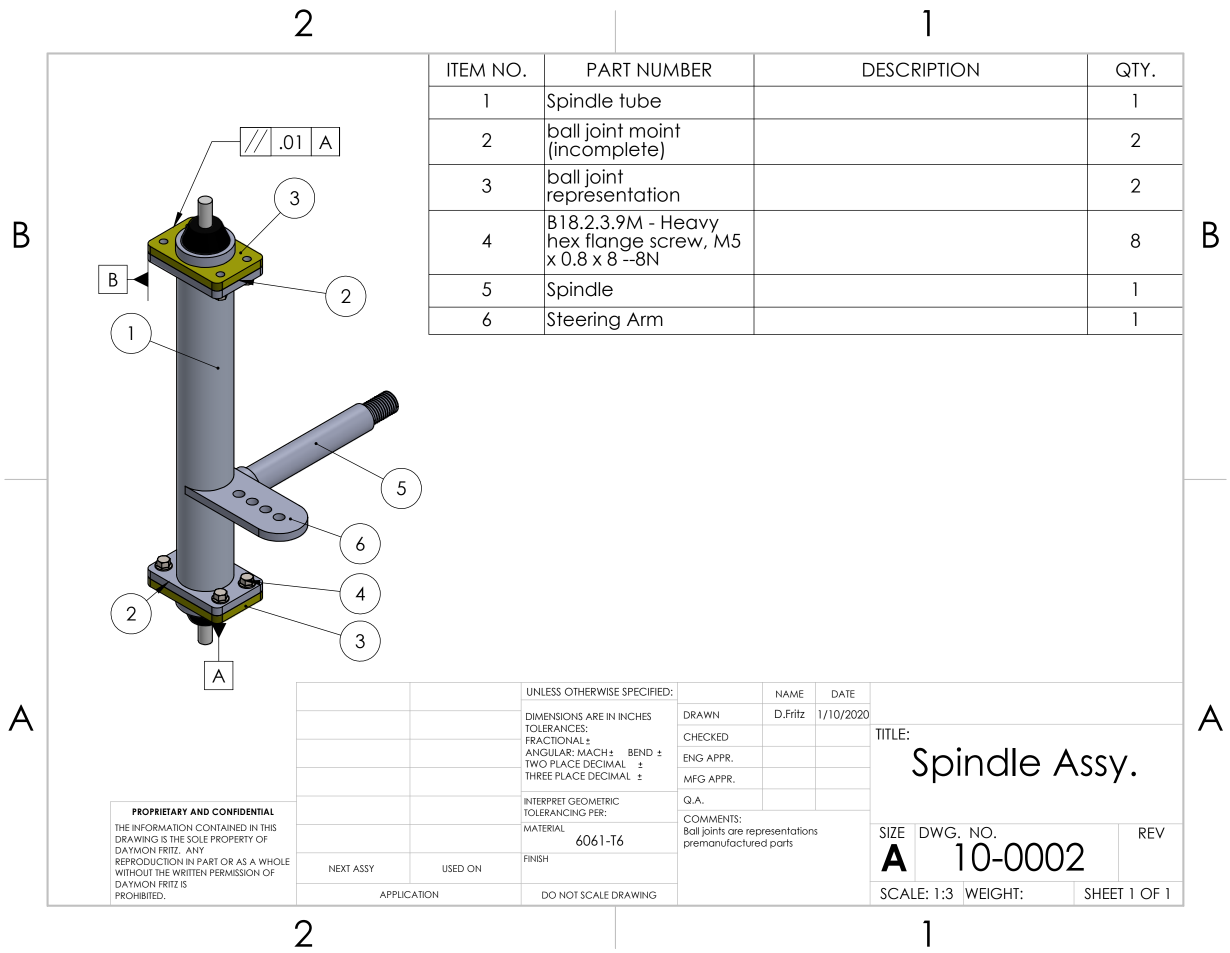


Figure 22-Potential Hub rendering

Control Arm

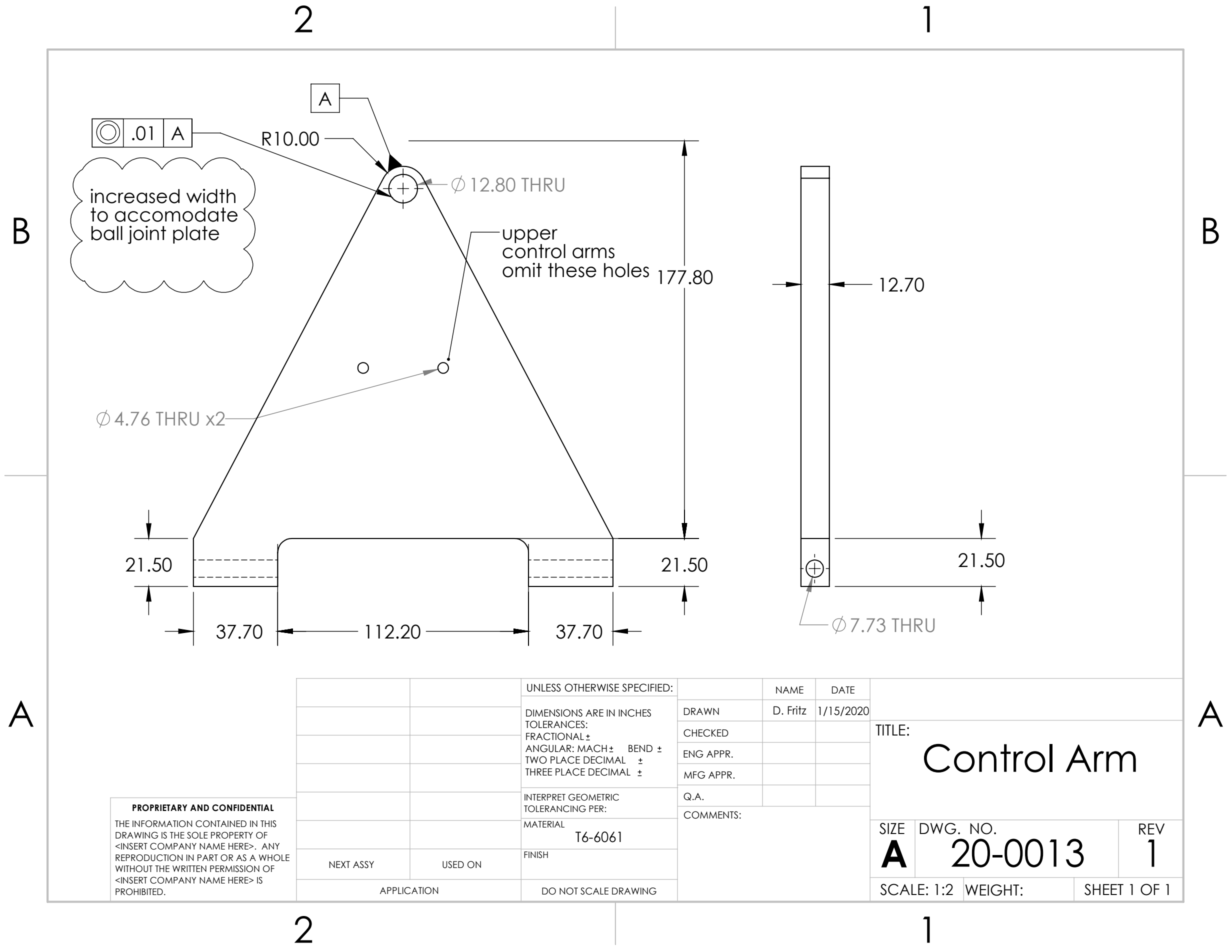


Fig. 23-Control Arm

Upper Control Arm Frame Mount

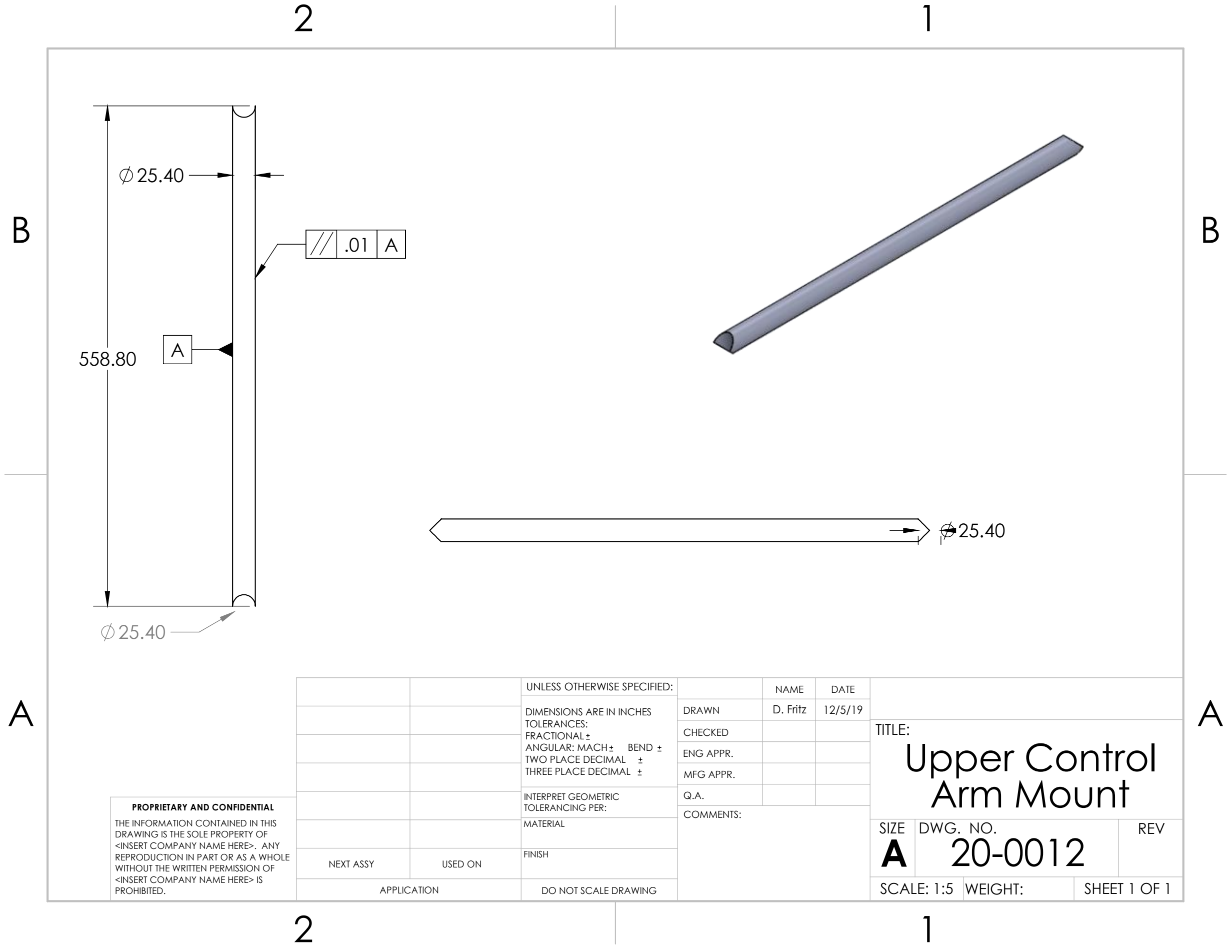


Figure 24-Frame Piece

Appendix C-Parts

Ball Joints:

Fig. 25-Ball Joints from retailer

Appendix D- Budget

Parts List/ Budget EV Braking System								
Item ID	Description	Source	Brand	Model	Cost ($)	Qty.	Subtotal$	Actual
1	Brake Caliper	The Recycle Shop	Tektro	Mira	$10	2	$20	
2	Brake Cable	Amazon	Shimano		$10	2	$20	
3	1/2" 4X12 Plate	Grainger Industrial	NA	6061	$55	1	$55	
4	1/4" 12x12 Plate	Grainger Industrial	NA	6061	$70	2	$140	
5	1" round	Grainger Industrial	NA	6061	$11	1	$11	
6	1.5" round	Grainger Industrial	Na	6061	$40	1	$40	
7	Ball Joint Kit	Ebay	NA	civic/EG	$27	2	$54	
8	Labor	Student	NA	NA	$1	116	$116	
9	Tube Steel	Grainger Industrial	NA		$20	1	$20	
					Total		$476	

Appendix E- Schedule

Gantt Chartt:

PROJECT TITLE: EV Front Suspension
Principal Investigator.:Daymon Fritz

TASK: ID	Description	Duration Est. (hrs)	Actual (hrs)	%Con	S	October				November				Dec		January				February				March				April				May				June	
1	Proposal*																																				
1a	Outline	2	1				X	X	X																												
1b	Intro	2	2				X	X																													
1c	Methods	3	1							X	X	X																									
1d	Analysis	4	1				X	X	X	X	X	X	X																								
1e	Discussion	4	3							X	X	X																									
1f	Parts and Budget	1	1							X	X	X																									
1g	Drawings	2	2								X	X	X																								
1h	Schedule	2									X																										
1i	Summary & Appx	4										X	X	X																							
	subtotal:	24	11																																		
2	Analyses																																				
2a	Braking Force Analysis	0.5	0.5				X																														
2b	Friction Force Analysis	0.5	0.5					X																													
2c	Caliper Force Analysis	0.5	0.5					X																													
2d	Pedal Side Profile Analysis	0.5	0.75						X																												
2e	Minimum Pedal Cross-section	0.5	0.5						X																												
2f	Exisiting mount option Analysis	0.5	0.5							X																											
2g	Pedal Pivot Analysis	0.5	0.5							X																											
2h	Caliper Sub-mount Analysis	0.75	0.75								X	X																									
2i	Caliper bracket Flexure stress	0.75	0.5									X	X																								
2J	Caliper bracket twist analysis	0.75	0.5									X	X																								
2K	Lower Control Arm Force analysis	1	1									X	X																								
2L	Soindle Column Analysis	1	1																																		
	subtotal:	7.75	7.5																																		
3	Documentation																																				
3a	Pedal Drawing	3	2						X																												
3b	Floor-Board	3	2							X	X																										
3c	Pivot Pin Drawing	4	0.5								X	X																									
3d	Floor-Board assy.	0.5	2								X																										
3e	Main Caliper Bracket Drawing	2	2								X	X	X																								
3f	Spindle Tube Drawing	2	1									X	X	X																							
3g	Ball Joint Mount Plate Dwg.	4	0.75									X	X	X	X	X																					
3h	Steering Arm Dwg.	2	1									X	X	X																							
3i	Spindle Hub Dwg.	1	3										X	X																							
3j	Upper Control Arm Dwg.	0.5	1										X	X																							
3k	Caliper Sub-mount Dwg.	2	1										X	X																							
3l	Frame Support Dwg.	1	1											X																							
3m	Control Arm Mount Dwg.	1	1											X																							
3n	ANSI Y14 Assembly Dwg.	2	2											X	X	X																					
	subtotal:	28	18.25																																		
7	Part Construction																																				
7a	Machine Spindles (2)	3	3													X	X																				
7b	Machine Ball-joints mounts (4)	3	3													X	X																				
7c	Machine Spindle tube (2)	0.5	0.5														X																				
7d	Machine Steering Arms (2)	2	1														X	X																			
7e	Machine Control Arms (4)	4	10																X																		
7f	Machine Upper Control Arm Mount frame (2)	1	1																	X																	
7g	Machine Control Arm Mounts (4)	2	3.5																	X																	
	subtotal:	15.5	22																																		
9	Device Construct																																				
9a	Current Suspension Dismantle	1	1																X																		
9b	Weld Components to Spindle Tubes	2	6																X	X	X																
9c	Welding Upper Control arm mounts	1	3																		X	X															
9d	Weld Upper Control arm mounts to frame	0.5	2																			X															
9e	Mount Front Suspension	1	2.5																			X	X														
	subtotal:	5.5	14.5																																		
10	Device Evaluation																																				
10a	Chassis Clearance Test	1	1																				X														
10b	Steering camber Test	1	1																				X	X													
10h	Adjustment test	0.5	2																						X	X	X	X	X								
10i	Mass Requirements	0.25	0.25																													X	X				
	subtotal:	2.75	4.25																																		
11	495 Deliverables																																				
11a	Get Report Guide	1	0.25																			X															
11b	Make Rep Outline	1	1																			X	X	X													
11c	Write Report	15	28																			X	X	X	X	X	X	X	X	X	X	X	X	X	X		
11e	Create Presentation	4	4																														X	X			
11f	Update Website	5	6																												X	X	X	X			
11g	Project Thumb Drive	3	10																														X	X			
	subtotal:	29	49.25																																		
	Total Est. Hours=	112.5	126.8							=Total Actual Hrs																											
Labor:	1	113																																			
Note:	Deliverables*																																				
	Draft Proposal																																				
	Analyses Mod																																				
	Document Mods																																				
	Final Proposal																																				
	Part Construction																																				
	Device Construct																																				
	Device Evaluation																																				
	495 Deliverables																																				

Appendix F- Expertise and Resources

- The Recycle Bike shop in Ellensburg WA. Supplied the brake calipers at a discount thanks to owner, Fred Johnston.

- The Electric Vehicle Club at CWU supported this project as vehicle sponsors.

- Under Pressure Racing Development Tacoma Washington welded the spindles together. Thank you to founder, Zach Leitzke for his expertise and time.

- Dave's Exhaust Ellensburg WA, thank you for welding the frame mounts.

- Thank you to professor Charles Pringle for assistance/guidance with several analysis, design discussions, general motivation and support for this project. His guidance was a valuable resource.

Appendix G-Testing Report

Electric Vehicle Braking and Suspension: Testing Report

By

Daymon Fritz

Introduction

This testing report evaluates the newly designed and built “Cat-Mobile” EV front suspension system. The front suspension operation must adhere to the requirements dictated by the engineering report and Electrothon America.

This report will evaluate the following requirements:

1. The Electrothon America handbook dictates the EV chassis must maintain a ground clearance of 1.5” while in operation.
2. The front suspension components added must weigh no more than 20lbs.
3. The camber angle must deviate no more than 1 degree during the steering sweep
4. Must have sufficient adjustability (ride height and preload).

To evaluate these requirements, a series of tests were performed to measure minimum ground clearance in inches, total added mass in lbs. , camber deviation in degrees, and adjustability in inches of deflection.

Due to COVID-19, testing was completed by a sole test administrator and thus, data was acquired via video analysis of tests and individual measurement recording.

Initial inspection predicted successful testing; measurements of stationary, un-sprung, ground clearance, indicated a minimum clearance of 1.5” would be observed without issue. Mass property evaluation on Solidworks predicts under 15lbs were added to the vehicle, indicating actual measurements were likely to be under 20lbs. Visual inspection of the camber angles after installation showed minor deviations from left sweep to right sweep. From this it was predicted that deviation would be within desired range. Finally, the coil-overs used contain adjustability and thus, final suspension was predicted to be adjustable.

Methods

The requirement testing was performed on site at the Hogue Technology Building at Central Washington University. Testing and gathering of data occurred in one day and the following resources were used; one test administrator, a caliper, video recording device, a 1.5” garden brick, a cardboard box, and digital tools (I.E. digital inclinometer, Vernier video physics).

There was very little cost associated with testing. The resources needed were already owned by the test administrator, the garden brick being the exception. The cost for the garden brick was approximately $5.00.

Each test required unique testing procedures; To test ground clearance, the EV will be operated rolling forwards, turning left, and turning right, passing over the garden brick to ensure at least

1/5” of ground clearance; the additional suspension components added were weighed and mass recorded; the camber angle was measured via the inclinometer at all extremes of the steering sweep and camber deviation was calculated; and finally, the suspension was verified to be adjustable by measuring ride height deflection at the minimum and maximum preload settings.

The ground clearance test initially was designed to utilize an operator and a test administrator to record data. The operator sitting in the vehicle would more accurately represent the distributed weight of the racing driver. However, Due to COVID-19, one test administrator was permitted to perform the test. This limitation meant the test administrator needed to operate the vehicle. This meant the distribution of mass on the vehicle was uneven for the test. This likely will not affect the outcome of the test as stationary ground clearance was well above the required 1.5”.

The EV currently contains no drive or braking mechanisms and thus cannot be safely operated as a self-propelled vehicle. This limits the camber test to being stationary only and limits the ground clearance test to being performed only while being pushed by the operator/test administrator.

Precision will be dictated by the instruments in use. The limiting instrument is the Vernier Video Physics application which reports distance measurements to ± 0.1. Thus, all measurements will be to this significant digit. Measurements were recorded digitally, and results were reported in tables and graphs.

Testing Procedures

Ground Clearance

Ground clearance is tested by rolling the vehicle over an obstacle of known height 1.5”. The test will be performed in Hogue Technology Building, will require 1 hour to complete, and will require the Vernier Video Physics app, digital caliper, and an iPad.

The vehicle currently not containing a functional braking system presents a risk of being unable to stop the vehicle once propelled over the brick. This could lead to collisions and injury. The brick will be used to slow the vehicle by allowing the rear wheel to contact the brick and stop the motion of the vehicle.

Procedure:

1- Verify height dimension of brick. Electrothon America Handbook dictates 1.5” must be cleared.
2- Secure brick to level driving surface with duct tape. Place 3 strips of duct tape on the brick, spaced evenly apart. This duct tape will secure the brick to the driving surface.

3- Load the vehicle with the average weight of driver. For this test, use 190 lb.
4- Align the vehicle such that if propelled forward, it will pass over the brick on the ground.

Figure 26-Forward Testing Position

5- With the vehicle, and brick in position, push vehicle forward over brick.
6- If vehicle clears brick when fully loaded with driver. The test is passed. If the vehicle and brick come into contact. Adjust suspension components and perform Ground Clearance Test again.
7- Repeat steps 4-6 for a left turn and right turn of the vehicle, for a total of 3 directions of motion.

To facilitate performing this test without assistance, the rolling was assisted by pushing the EV down a slight incline located on the second floor of Hogue. This allowed the test operator to spend more time in control of the vehicle rather than pushing. Following this, the test progressed as expected. Testing consisted of approximately 15 minutes of set-up, 10-15 minutes of testing, and an additional 30 minutes of evaluation and reporting.

Camber Deviation

Camber deviation is tested by holding the steering in three positions: forward, full left-lock, and full right-lock, and measuring the camber angle at these locations. The test will be performed in the Hogue Technology building, will require 30 minutes to complete, will utilize a digital inclinometer, and an I-pad. The measurements will be compared to measurements taken from the original front suspension.

There is a pinch point risk to be observed with this test. During the sweeping motion of the steering, it is important to ensure all body parts are clear from the steering and suspension mechanisms.

Procedure:

1. Place steering in forward position.
2. Place digital inclinometer on wheel brake rotor.

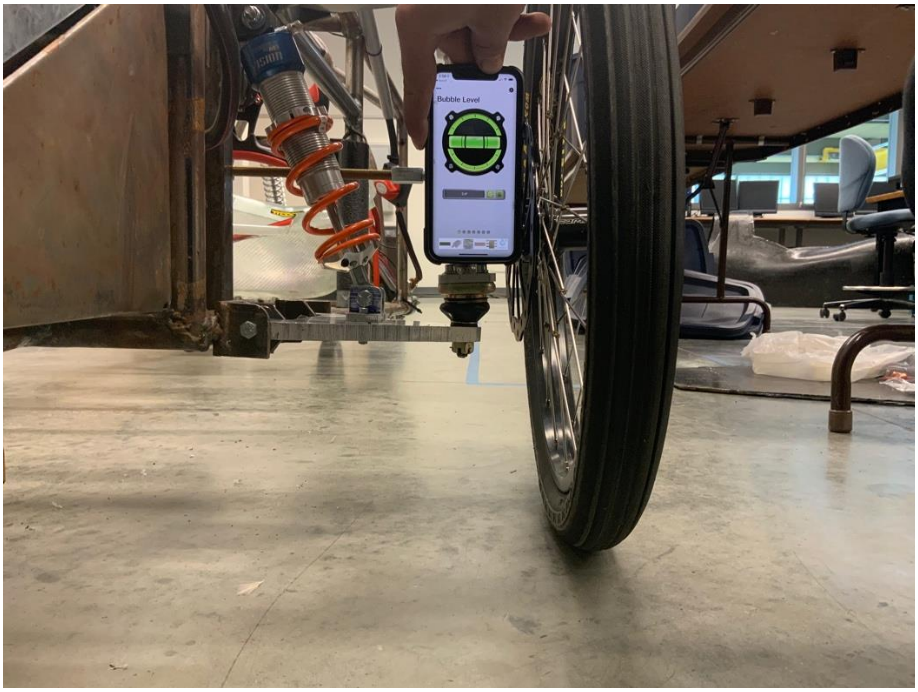


Figure 27-Inclinometer Positioning

3. Record camber angle.
4. Repeat Steps 2 and 3 for full left-lock and full right-lock steering positions.
5. Calculate the change in camber angle from forward position to both left and right-lock positions.

The camber test proceeded as intended without incident. Testing occurred on the second floor of the Hogue Technology building. Testing time from set up to clean up took approximately 30 minutes.

Adjustability

A key component to automotive racing is tuneability of the racing vehicle's various systems. This includes suspension systems. The front suspension of the EV therefore, must be adjustable. To test the adjustability of the front suspension, the coil-over spring-preload/height adjustment collar will be raised and lowered to the extremes of allowable travel. Ride height measurements will be made while the vehicle is loaded and unloaded. Dampening effects will be observed. The suspension will be considered adequately adjustable if the high preload setting allows for less than ½ of the ride height deflection allowed at no preload. This test will take approximately 30 minutes to complete.

There is a risk of cut injury during suspension adjustment. Use proper PPE and equipment while performing test. The maximum preload was measured 2” from the end of the threads on the collar as adjustment becomes difficult and unsafe to attempt to further tighten the spring.

Procedure:

1. Position vehicle on flat surface for test, ensuring to block wheels from rolling.
2. Adjust suspension such that the upper spring perch on both sides is positioned approximately 2” above bottom of shock. (Position 1)

Figure 28-Upper Spring Perch position 1

3. Record ride height from the ground to the bottom of the chassis rail both while vehicle is loaded and unloaded.
4. Adjust suspension such that the upper spring perch is approximately 3.5” above bottom of shock absorber. (Position 2)

Figure 29-Upper Spring Perch Position 2

5. Record ride height from the ground to the bottom of the chassis rail both while vehicle is loaded and unloaded.
6. Use the following formula to calculate change in ride height:

$$\Delta H = H_f - H_o$$

Where ΔH is allowed deviation, H_f is the ride height at max preload, and H_o is the ride height at minimum preload.

The test was performed on the second floor of Hogue Technology building. The test progressed as intended and took approximately 20 minutes to complete.

Mass addition

In automotive racing, mass of the vehicle is a metric that is closely monitored and carefully considered. The front suspension was not to add more than 20 lbs. to the EV. This will be measured using a standard bathroom scale. This test should not take more than 15 minutes.

There is a lift risk associated with this test, however, the masses of components are such that they are unlikely to cause injury if dropped or lifted in any manner.

Procedure:

1. Obtain a cardboard box large enough to contain all added components.
2. Measure and record mass of box.
3. Measure and record mass of box with components.
4. Calculate total component mass.

This test was performed prior to final assembly of the suspension system as some components needed to be welded in place on the chassis. The test was performed on the second floor of the Hogue Technology building. The initial test took 10 minutes to complete, however, it was discovered the scale used was faulty and an additional 10 minutes was needed to complete the test with a newly calibrated scale.

Results

Ground Clearance

The unloaded, stationary ground clearance of the EV was 4.4”. This value was a good predictor that the EV would clear the 1.5” requirement without issue. The results from the test confirmed the prediction. Seen below in fig.5, the operational clearance for each motion was above 4” at the EV’s lowest ride height.

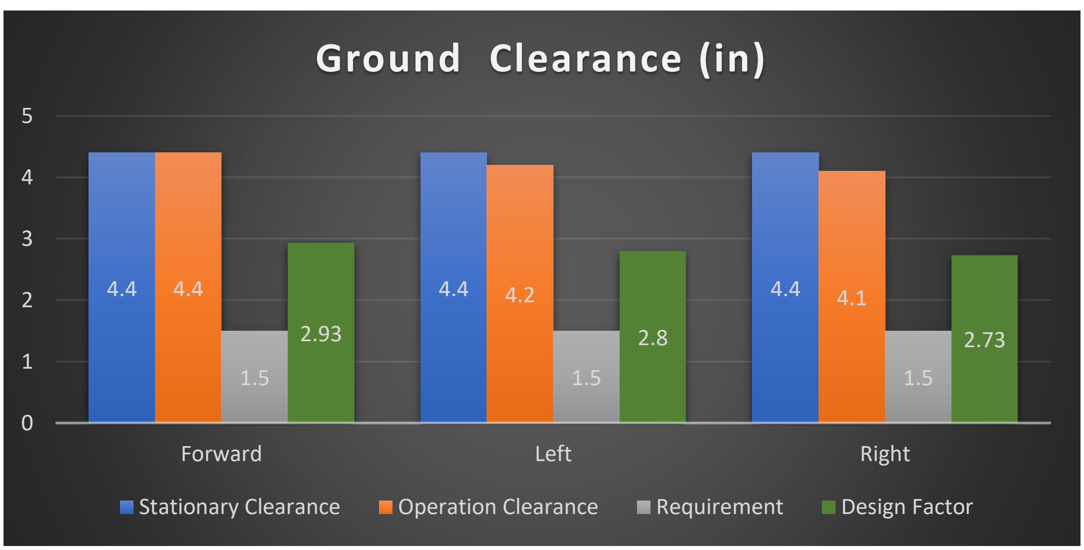


Figure 30-Ground Clearance

Camber Deviation

The previous suspension design allowed for a maximum camber angle deviation of 3.4 degrees. This was attributed to the lack of an upper support for the spindle. The new design added an upper support and was predicted to stabilize this deviation greatly. The new suspension design only allows for a maximum deviation ($\Delta\theta$) of .6 degrees. Well below the required maximum of 1 degree.

$$\Delta\Theta_{camber} = \Theta_{camber_f} - \Theta_{camber_o}$$

Figure 31-Change in angle formula

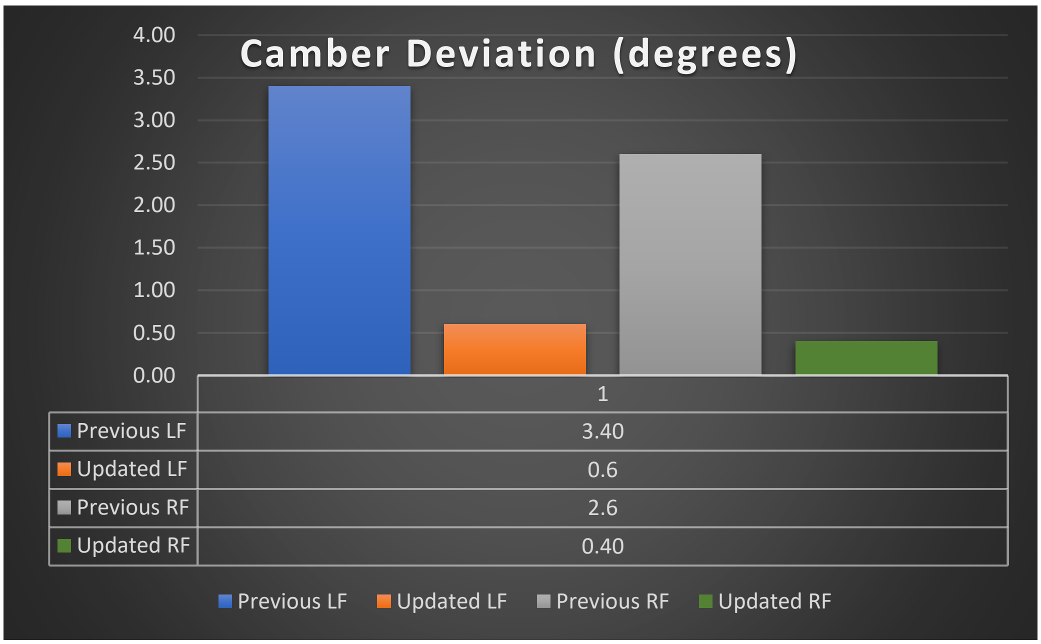


Figure 32-Camber Deviation Chart

Adjustability

The minimum preload deflection upon loading was .6” . The maximum preload deflection was only .3”, meeting the requirement factor of ½.

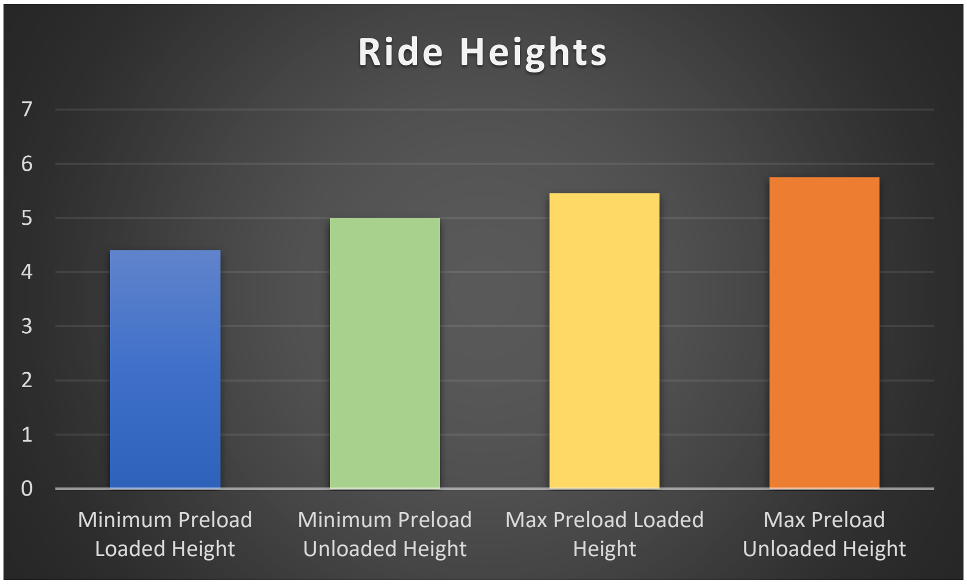


Figure 33-Preload Height Differences

Mass addition

The measured total mass of added components was found to be only 12.2 lbs. This is well below the requirement maximum of 25 lbs.

Conclusion

The tests have shown that the Cat-Mobile Ev front suspension has performed as required and further optimization can be considered. Each test was performed without issue despite the COVID-19 adjustments needing to be made. The mass added to the vehicle was well below the target maximum of 25lbs. at only 12.2lbs. . The maximum camber deflection is well below the 1 degree maximum at only .6 degrees. This has increased maneuverability, stability, and safety of the EV. The suspension has shown that it will be well suited to the racing environment and will be able to be adjusted and tuned to the preference of the operator.

Appendix
Procedural Checklists
Supplies

Supplies

✓	1	Garden Brick
✓	1	I PAD
✓	1	Inclinometer
✓	1	Digital Caliper
✓	1	Bathroom scale
✓	1	Cardboard Box
☐		
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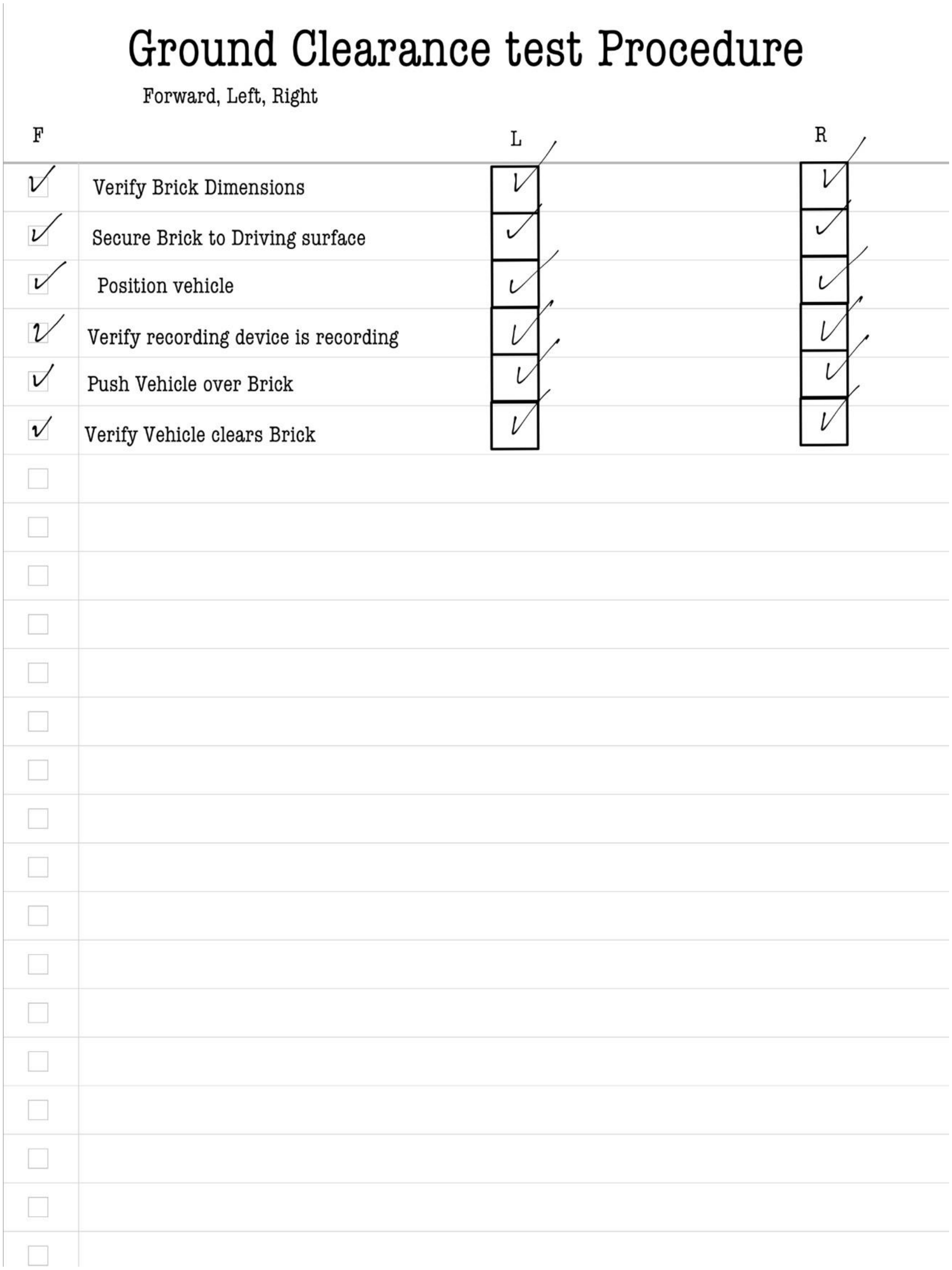
Figure 34-IPAD Supplies Checklist

Ground Clearance Test Procedures



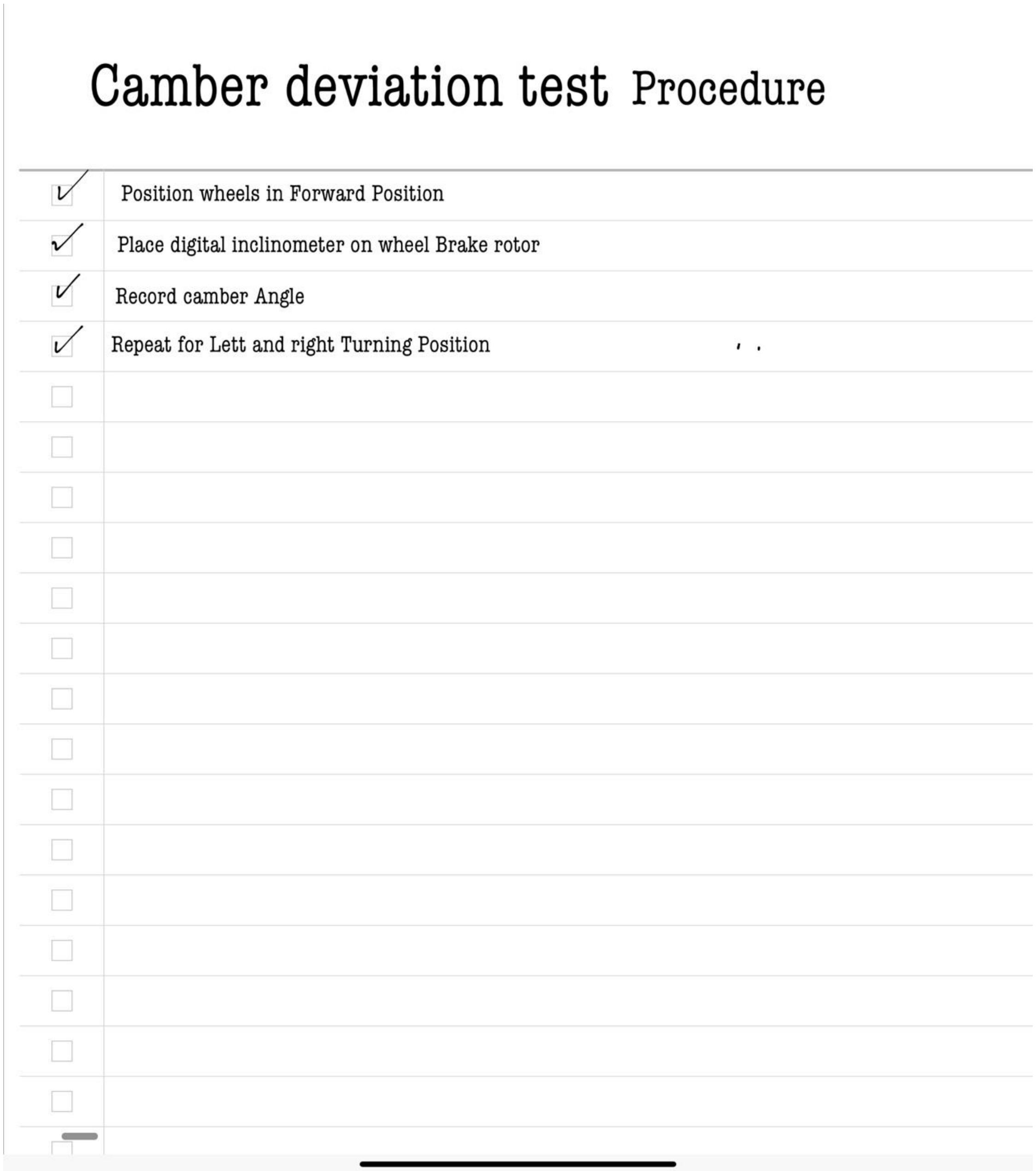
Ground Clearance test Procedure

Forward, Left, Right

F		L	R
✓	Verify Brick Dimensions	✓	✓
✓	Secure Brick to Driving surface	✓	✓
✓	Position vehicle	✓	✓
✓	Verify recording device is recording	✓	✓
✓	Push Vehicle over Brick	✓	✓
✓	Verify Vehicle clears Brick	✓	✓

Figure 35-IPAD ground clearance checklist

Camber Deviation Test Procedure

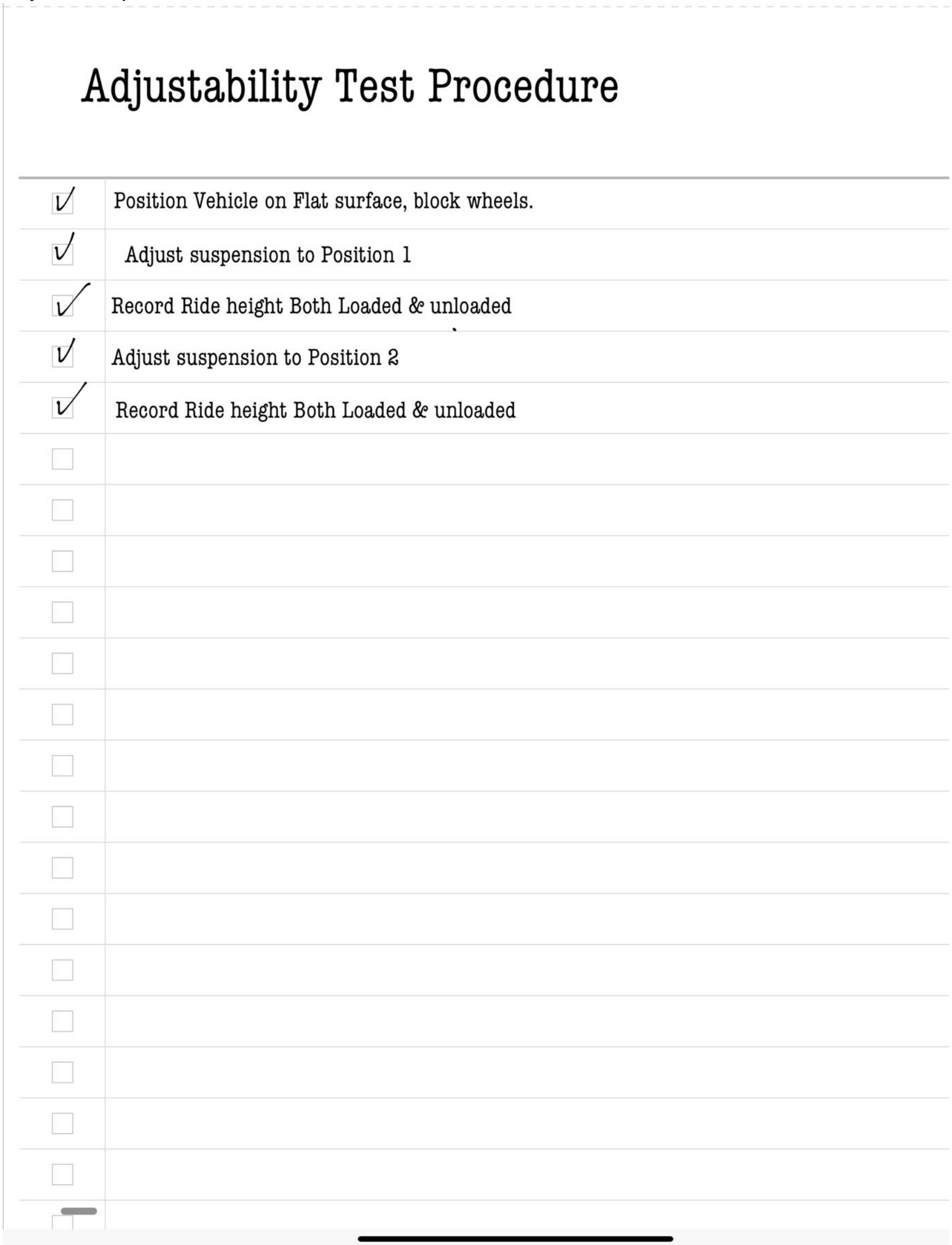


Camber deviation test Procedure

- [x] Position wheels in Forward Position
- [x] Place digital inclinometer on wheel Brake rotor
- [x] Record camber Angle
- [x] Repeat for Lett and right Turning Position

Figure 36-IPAD Camber testing checklist

Adjustability Test Procedure



Adjustability Test Procedure

- [x] Position Vehicle on Flat surface, block wheels.
- [x] Adjust suspension to Position 1
- [x] Record Ride height Both Loaded & unloaded
- [x] Adjust suspension to Position 2
- [x] Record Ride height Both Loaded & unloaded

Figure 37-IPAD Adjustability Procedure

Excel Sheets/Data

Ground Clearance Test

Ground Clearance	Stationary Clearance	Operation Clearance	Requirement	Design Factor
Forward	4.4	4.4	1.5	2.93
Left	4.4	4.2	1.5	2.8
Right	4.4	4.1	1.5	2.73

Camber Deviation Test

Camber Test	Previous Design LF	Updated Design LF	Previous Design RF	Updated Design RF
Forward angle (degrees)	-2.1	-1.6	-1.6	-1.3
Left turn angle (degrees)	1.3	-1.3	-2.1	-1.5
Right turn angle (degrees)	-3.5	-1.9	0.5	-1.7
Max Deflection	3.40	0.6	2.6	0.40

Adjustability Test

Minimum Preload Loaded Height	Minimum Preload Unloaded Height	Max Preload Loaded Height	Max Preload Unloaded Height
4.4	5	5.45	5.75
Min Peload Deviation=	0.6	Max Preload Deviation=	0.3

Gannt

Appendix H- Resume

DAYMON R. FRITZ

FRITZDAYMON@GMAIL.COM

360-441-1538

https://www.linkedin.com/in/daymon-fritz-84420972/

PERSONAL PROJECT:

1977 CELICA RESTO-MOD
https://77celicabeams.wordpress.com

OBJECTIVE

To gain experience related to field of mechanical engineering.

SKILLS

Problem Solving, Resourcefulness, Leadership, Adaptation

EXPERIENCE

UNIVERSITY OF WASHINGTON
PEER INSTRUCTOR
2017-2018
Develop and implement supplemental coursework for current University Mathematics students for Calculus. Assist students in understanding concepts in mathematical concepts relating to calculus.

PIERCE COLLEGE
SUPPLIMENTAL INSTRUCTOR
2016-2017
Develop and implement coursework for current Pierce College students in the fields of Physics, Calculus, and lower mathematics.

UNITED STATES ARMY
42ND MP BDE SYSTEM ADMINISTRATOR
2010-2014
Sole network administrator for the 42nd Military Police Brigade. Managed standard unit computer intranet and data flow. Obtained Secret Security Clearance. Managed access to Secret communications for the BDE in and out of warzone operations.

HYUNDAI MOTOR AMERICA
DIAGNOSTIC TECHNICIAN
2007-2010
Completed automotive technician apprenticeship. Diagnosed and repaired Hyundai, Volvo, and Nissan vehicles. Completed factory training and obtained professional automotive licenses. Helped customers understand concerns and options related to their vehicles.

EDUCATION

CENTRAL WASHINGTON UNIVERSITY
B.S. MECHANICAL ENGINEERING TECHNOLOGY
MINOR IN MATHEMATICS
CURRENT-SENIOR

Study curriculum related to mechanical engineering technology.
Experience in AutoCAD, SolidWorks, and Shap3r modeling programs.

Maintaining a GPA of approximately 3.5, earning both quarterly honor roll and Dean's lists.

PIERCE COLLEGE
ASSOCIATES IN SCIENCE

Obtained general science degree for studies in preparation for engineering degree.

VOLUNTEER EXPERIENCE OR LEADERSHIP

Current ASME (American Society of Mechanical Engineers) president.

Volunteer Coordinator for ASME Efx Conference

Former University of Washington Mathematics Club president.

Volunteered with the city of Steilacoom for park restoration.

Founder/Manager of Seattle Rock music group, DedElectric

Regular volunteer for Family Readiness Group during military service.

Appendix I- Job Hazard Analysis

Engineering Technologies, Safety, and Construction Department

JOB HAZARD ANALYSIS
EV Brake System

Prepared by: Daymon Fritz	Reviewed by: Approved by:

Location of Task:	CWU Hogue Building
Required Equipment / Training for Task:	Machine Shop Equipment, Saftey Training on equipment
Reference Materials as appropriate:	

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
	Milling Machine: **Milling of Brackets will cause metal chips to be projected from the machine. The Machine itself poses a hazard from rotating parts.**	**Chip debris enters eye** **Body part and/or clothing Caught in rotating parts of mill.**	**Eye protection is worn. In case of eye contact, use eye wash station and report the injury.** **Saftey Training is conducted on the machines in use. In case of incident, use emergency stop, report the incident and seek medical assistance as needed.**
	Drill Press: **Drilling of holes requires the use of a drill press. The drill press presents a hazard from rotating parts.**	**Body part and/or clothing Caught in rotating parts of mill.**	**Saftey Training is conducted on the machines in use. In case of incident, use emergency stop, report the incident and seek medical assistance as needed.**