Automotive Hub Stand Design

By

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Introduction

Motivation:

This project was motivated by a need for a device that would securely support the weight of late model vehicles without the use of traditional jack stands. Unlike vehicles of the past, the underbodies of modern vehicles are covered in various plastic covers and skid plates. These plastic covers and skid plates are in place to protect the chassis as well as every major component under the vehicle from debris and corrosion. The downside to the integration of these protective covers on modern vehicles is that it creates a problem for the average DIY’er. The covers obstruct the access to traditional points where a floor jack would be used to lift the vehicle. These lift points are control arms, frame or rear differential. Modern vehicles have specific jack points that usually run along the sides of the vehicle, directly behind the front wheels and in front of the rear wheels. The problem with these jack points is that they are too small of an area. There is not enough room on the jack point to use a jack to lift the vehicle and also place a jack stand to securely support the weight of the vehicle when servicing. Modern vehicles inhibit the DIY weekend mechanic the ability to utilize traditional jack stands. This poses a serious safety risk as one should never work under or around a vehicle that is not securely supported.

A hub stand would eliminate the need for traditional jack stands to support the vehicle as well as the risk of servicing a vehicle only supported by a hydraulic jack. The vehicle needing service would be raised up using a normal floor jack at the factory designated jack points as intended. The hub stand would then attach directly to the hub of the vehicle (with the wheels off) using the factory lug bolts or nuts, depending on application. The floor jack could then be lowered and removed and the hub stand would securely support the weight of the vehicle. Other applications of hub stands include long-term storage and more precise wheel alignments. During long-term vehicle storage, the vehicle is raised off the ground so that the tires will not form a flat spot. However, raising the vehicle and letting the suspension components suspend freely for an extended time creates wear and tear. Hub stands would solve these issues. As for more precise wheel alignments, the absence of tires on the vehicle inevitably creates a better setting for alignments due to the elimination of tire deflection. Camber, caster, toe, corner weight balancing and ride height adjustability can all be completed more efficiently and effectively using hub stands. The hub stand solves the problem of not being able to use traditional jack stands on modern vehicles and provides improved long-term vehicle storage and suspension adjustment solutions.

Function Statement:

A device is needed that will support the weight of a vehicle and safely suspend it off the ground.
Requirements:

The hub stand will meet the following requirements.

• The hub stand must weigh less than 21 lbs.
• The hub stand must support 1.5 tons (3000 lbs.)
• The hub stand must accept 5x112 and 5x100 bolt patterns.
• The hub stand must have a center bore size of 77 mm.
• The hub stand must have a minimum height of 18 in.
• The hub stand must have a maximum height of 22 in.
• The hub stand must have a maximum width of 11 in.
• The hub stand must be height adjustable at increments of 1 in.
• The hub stand must pivot up to 3 degrees in all axes for suspension alignment adjustments (caster, camber and toe).
• The hub stand must cost less than $150.
• The hub stand must be made of non-corrosive material.
• The hub stand must be able to perform at a minimum temperature of 20 degrees F.
• The hub stand must meet all government and industry safety standards.

Engineering Merit:

In order to design a hub stand that will safely support the weight of a vehicle the appropriate material and manufacturing process must be used. Static forces will be calculated to select a suitable material as well as meet safety standards. Design features of the hub stand must allow for height adjustment and pivoting capabilities in all axes to allow for suspension adjustments.

The engineering optimization aspect of the Hub Stand Design will result from material selection, geometry and manufacturing ability. The goal will be to manufacture the hub stand efficiently in respects to both time and cost using a material that provides the safety required.

Scope of Effort:

The goal of this project will be due to design and manufacture a set of four hub stands. The hub stand will be designed using SolidWorks, programmed using HSMWorks and manufactured using the Milltronics CNC machines available at Central Washington University’s machine shop.

Success Criteria:

The success of the device will be determined by meeting the design requirements. The hub stand will be considered successful if it performs as intended and safely supports the weight of a vehicle and allows for suspension adjustments.
Design and Analysis

Approach:

The foremost priority of the design of the automotive hub stand will be to insure the safety of the device. The most important factor of design safety is the level of stress the components can withstand and not fail. Using the principles of statics, the forces exerted on the hub stand will be calculated. The kinds of stresses that each member of the device is subjected to by the forces will be identified. From the stress analysis, a suitable material and geometry of the design will be proposed that meets or exceeds the design requirements of weight and cost.

The stress analysis that will be done will include stresses from compressive loads, shear and bending. Fatigue will also play a part in the design safety due to the repeated loads that the hub stand will undergo. A design requirement of the hub stand is the ability to pivot in all axes up to 3 degrees for suspension adjustments. The proper material for this ability will have to be selected. Additional design requirement is the ability to be height adjustable. Traditionally, a pin would be used to lock the desired height in position on a load-carrying device such as jack stand. Stress analysis must be done for the pin to choose the correct diameter and material.

As for manufacturing concerns, the goal will be to maximize efficiency and minimize cost. The strength of the material and its machinability will have to be taken into consideration. The manufacturing process will also have to be chosen for different aspects of the design. For example, welding two members together may be a more cost effective option than machining.

Description:

The Hub Stand must attach to 5x112 and 5x100 bolt patterns. That is a 5-lug pattern on a 112 and 100 millimeter diameter circle. The member that attaches to the vehicle hub itself (hub plate) will be separate from the frame of the hub stand. A benefit of this design is that the detachable member provides the capability of more bolt patterns than just 5x112 and 5x100. It provides a future market for interchangeable bolt specific hub plates for a truly universal fit.

The height adjustability function will come from the assembly of the hub plate to the hub stand frame. The hub plate will slide into the hub stand frame and an appropriate pin will be used to hold the hub stand at the desired height.

An essential function of the hub stand is the pivoting capability. This will be accomplished by using an appropriate polymer base that allows for the 3 degrees of motion that is a design requirement. The polymer base must not hinder the safety of the device and must conform to all safety standards. Figure 1 in the appendix shows an initial sketch of the hub stand design.
Benchmark:

The benchmark to the hub stand design is the BBXracing HUBStands. The specific part number is HS02CTS, which is for the Audi S models with a bolt pattern of 5x112. The cost of a set of four BBXracing HUBStands is $1,149. The goal is to beat the price of this benchmark and still provide a quality product that meets all the design requirements.

![Figure 1: BBXracing HUBStands on a Porsche Cayman](Image)

Performance Predictions:

The performance of the hub stand is predicted to be able to support 1.5 tons (3000 lbs.). The hub stand will weigh less than 21 lbs. and be within the spatial requirements. It will also be capable of 4 inches of height adjustment and be able to pivot in all axes up to three degrees. The hub stand will cost less than $100 to manufacture.

Description of Analyses:

First, the material of which the hub stand will be made of must be selected. The two choices are carbon steel and aluminum. The allowable load of each material at a given length and shape will be calculated using a column analysis. The shape that is being considered is square tubing. The removable hub plate will be machined or welded so that square tubing member of a certain size can be attached to it. This square tubing will be able to slide into the hub stand frame much like a receiver hitch.

The height adjustability will come from the depth of the hub plate member into the frame. The desired height will be locked in place by either a steel or aluminum pin. A shear stress analysis will be done on this pin to calculate the correct diameter.
A material is needed that will allow the hub stand to pivot 3 degrees in all axes. This material must be flexible but still be rigid enough to support 3000 lbs. The pivot motion will create a moment, which will be calculated and considered in the design safety of the device. The mounting method of the material to the hub stand base plate will have to be optimized.

Scope of Testing and Evaluation:

The testing and evaluation of the hub stand will consist of actually using the hub stand to support a vehicle. The size, weight and cost of the hub stand will be evaluated on if it meets the design requirements. Another aspect that will be considered will be “ease of use.” This will be evaluated by the amount of effort it takes to install and adjust the height of the hub stand. The 3 degrees of pivot motion that is required of the hub stand will be tested by using a T-square layout tool. The hub stand frame and base plate should be perpendicular at rest but when installed on the vehicle, the natural camber of the vehicle should pivot the hub stand.

Analyses:

The design analysis for the hub stand device is presented below.

Design Issue:

The hub stand central frame must be able to support a load of 3000 lbs. A column buckling analysis was conducted on an aluminum square tube to insure that frame will withstand the required force.

A stress analysis was conducted on the hub plate. The hub plate consists of holes for the lug bolts and will be under compressive load. A stress concentration factor for a plate with a hole was calculated to insure that the local maximum stress did not exceed the ultimate compressive stress. Also, the hub plate will be welded to the hub plate member. The weld strength was evaluated.

The hub stand central frame will be welded on to the hub stand base plate. The strengths of those welds must be evaluated. Support gussets will be used for extra support. The moments created by the 3 degrees of pivot motion was calculated and stresses considered.

The pin that holds the desired height of the hub stand must have the proper diameter to withstand the shear stresses. The diameter and material of the pin was calculated and chosen.

A polyurethane material must be able to flex at least 3 degrees in order to meet the design requirement of the hub stand. The polyurethane bushing will be mounted on to the base plate of the hub stand via bolts and washers.
Calculated Parameters:

Appendix A3 shows the material properties of 6061-T6 Aluminum. This material was chosen because of its high yield strength of 40 ksi and a suitable ductility of 17%. 6061-T6 Aluminum is known for its excellent joining characteristics and good acceptance of coatings. It possesses high strength, good workability and high resistance to corrosion. Most importantly, it is widely available.

As referenced in Appendix A1, the allowable load of a 6061-T6 aluminum square tube was calculated. A column analysis was done using the J.B. Johnson Formula [1]. The dimension of the square tubing in question was 2.5” x 0.25” and length of 8”. The slenderness ratio was calculated as 5.63 and column constant was 70.3. Because the slenderness ratio was less than the column constant, the short column analysis was completed. The critical load was calculated as 89,711 lbs. and with a safety factor of 1.5; the allowable load was 59,807 lbs. This calculation demonstrates that the above dimensioned aluminum square tubing will support the 3,000 lb. design requirement.

Appendix A2 shows the calculation for critical stress that the hub stand central frame can withstand. The formula for critical stress is: \(\sigma_{cr} = P_{cr}/Area\). The critical stress was calculated to be 39,872 psi. This figure was below the yield stress of 6061-T6 Aluminum (40 ksi) so the material was deemed suitable.

Appendix A4 shows the calculation for the maximum vertical shearing stress on the hub stand central frame. Again, the hub stand central frame is made up of a square tube that is 8” in length and width of 2.5”. The formula for maximum vertical shear stress is: \(\tau = VQ/It\), where \(I\) is the moment of inertia, \(t\) is the width, \(V\) is the load and \(Q\) is the first moment. The maximum vertical shearing stress was calculated as 12.5 ksi. Dividing the maximum vertical shearing stress by the design factor of 1.5, the allowable vertical shearing stress was calculated as 8.3 ksi. 8.3 ksi is less than the yield strength of 6061-T6 Aluminum (40 ksi) and thus is appropriate.

Appendix A5 shows the calculation for choosing the appropriate pin diameter to hold the 3000 lb. load. The formula used was \(\tau_{allow} = \frac{F}{A}\), where \(A = \frac{\pi}{4}d^2\). Solving for \(d\), the minimum diameter to withstand 3000 lbs. of force and 8.3 ksi shear stress was 0.678 in. The pin diameter was rounded up to \(\frac{3}{4}\)” because they are commercially available.

Appendix A6 shows the calculation for the maximum compressive stress on the hub plate. The hub plate is 6” in diameter and 1” thick. It possesses 5 bolt holes, evenly spaced on a 112 mm diameter circle. The diameter of each bolt hole is 5/8”. The center bore diameter is 77 mm. Using stress concentration factor curves [1] (Figure 3-26 Pg. 115 Mott, 2014) the maximum stress of the hub plate was calculated as 6,985 psi.

As seen in appendix A7, the maximum bending stress on the base plate was calculated using the formula \(\sigma_{max} = \frac{Mc}{I}\). The base plate is rectangular with a 10” length and 7” width and 0.75” thickness. The base plate will encounter a bending stress due to
the 3 degrees of pivot that the hub stand will be capable of. The max bending stress of the base plate was calculated as 11.2 ksi, which is less than the yield stress of 6061-T6 (40 ksi).

Appendix A8 shows the calculation of the maximum bending stress on the hub stand frame. The dimensions of the square tube that makes up the hub stand frame is 2.5” x 2.0” x 8”. The load that it will encounter is 3000 lbs. The formula used to calculate the maximum bending stress in the frame was $\sigma_{max} = \frac{MC}{I}$ which came out to be 7,813 psi.

Appendix A9 details the required minimum leg size for the weldments needed to join the hub stand central frame to the base plate and the hub plate to the hub stand member. According to Mott, 2014 [1] a 3/8” fillet weld is necessary for plates greater than 1 1/2” to 2 1/4” inches thick. The weldment will go all the way around.

Best Practices:

According to Mott [1] for ductile materials, a design factor of 1.25 to 2.0 is suitable for design of structures under static loads for which there is a high level of confidence in all design data. This is in line with the industry standard of a design factor or 1.5 for most automotive applications. A correct design factor is important for an automotive support device such as the hub stand because the dangerous nature of working under a 2 ton vehicle.

Device: Parts, Shapes and Conformation:

The goal of the overall device is to be user-friendly, which means weight and size must be taken into consideration. The hub stand device consists of: hub plate, hub plate member, hub stand central frame, base plate and polyurethane feet attached via bolts. The shape of the hub plate must be circular due to the fact that the hub of a vehicle is circular and also because it must not interfere with the brake caliper. The hub plate member and hub stand central frame will be rectangular tubes where the hub plate member will be able to slide into the hub stand central frame. This shape was chosen due to the availability of various sizes and its lower cost. The base plate will be circular so that sharp edges will not be present.

Device Assembly, Attachments:

The hub stand will be manufactured from 6061-T6 Aluminum and consists of the following parts. Reference appendix B for drawings.

Part 1: Hub Plate
Part 2: Hub Plate Member
Part 3: Hub Stand Central Frame
Part 4: Base Plate
Part 5: Hitch Pin/Cotter Pin
Part 6: Spring loaded roller balls
Part 7: Screw Bolts
Part 8: Locknut

Because the hub stand mounts to the hub of a vehicle using the factory lug bolts, the bolt pattern on the vehicle must match the bolt pattern on the hub plate. The tolerance for this bolt pattern position must be accounted for. There is a limited amount of space on the hub of a vehicle for the hub plate to mount onto. The size of the hub plate itself must be considered so that it does not interfere with the brake caliper. As stated before, the hub stand must be user-friendly. The hub stand was designed so that it would be easy to install and transport by being lightweight as well as have rounded edges.

Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operation Limits:

The risks that may be presented over the course of this hub stand design project are financial, scheduling, resources and technical aptitude. The financial risks involved are going over budget and not having enough funds to purchase all the materials needed to manufacture the hub stand. Having a well thought out manufacturing plan and a detailed parts list will mitigate this risk. As for scheduling, the risks involved are not receiving parts and materials when expected as well as under estimating machining times. The scheduling risks will be addressed by incorporating unexpected delays into the schedule and also to over estimate the time needed for machining. The risk of having a lack of resources will be dealt with by ample amounts of research and reaching out to the community as well as seeking out help from peers and advisors. When it comes to
The hub stand will fail if it is overloaded. The hub stand is under a compressive load from the weight of the vehicle. The vehicle must not weigh over two tons for the hub stand to safely operate. Some modes of failure could be buckling and shearing. The pin the holds the hub plate member and the hub stand central frame can shear if overloaded. The hub plate itself can also shear if the local stresses at the bolt-holes exceed the maximum stress. The hub stand central frame and hub plate member can buckle if over compressed. The industry standard safety factor of automotive lifts is 1.5 and is what was used in the design of the hub stand.

The operation limits for the hub stand are as follows: the hub stand must be used on a flat and smooth surface, the weight of the vehicle must not exceed 2 tons (4000 lbs.), only the bolt patterns for which the hub plate is designed for may the hub stand be attached to.

Methods and Construction

Construction:

The construction of the automotive hub stand will be discussed in this section

Description:

The automotive hub stand will be made out of 6061-T6 Aluminum. The hub stand consists of the following parts:

Part 1: Hub Plate
Part 2: Hub Plate Member
Part 3: Hub Stand Central Frame
Part 4: Base Plate
Part 5: Hitch Pin/Cotter pin
Part 6: Spring loaded roller ball
Part 7: Screw Bolt
Part 8: Locknut

The hub plate will be welded onto the hub plate member. The hub plate member slides into the hub stand central frame much like a hitch and receiver. The pin will hold the hub plate member at the desired height. The hub stand central frame will be welded on to the base plate. Lastly, the spring-loaded roller balls will be attached to the base plate via screw bolts and locknuts.
Drawing Tree, Drawing ID’s:

The drawing tree for the automotive hub stand can been seen in appendix C1. The hub plate drawing can be seen in appendix B5. It will be 6” in diameter and 1” in thickness. It will accept 5x112 and 5x100 bolt patterns. The bolt hole diameter will be 5/8”. The center bore will be 77 mm (3.03 in). The hub plate will be welded on to the hub plate member. The hub plate member drawing can be seen in appendix B4. The hub plate member is 6” in height and square stock of 2”. 4 holes of diameter 0.76” will be drilled through the side to allow height adjustability. The hub plate member will be able to slide into the hub stand central frame much like a hitch and receiver. The hub stand central frame drawing can be seen in appendix B3. The hub stand central frame will be a square tube of 8” height and 2.5” width with a wall thickness of 0.25”. It will also have a single 0.76” diameter hole drilled all the way through in order to accept the pin that holds the hub plate member at the desired height. The hub stand central frame will be joined to the base plate via weldment. The baseplate drawing can be seen in appendix B2. The base plate is 10” in length and 7” in width with a thickness of 0.75”. The corners will have a 1.50” radius fillet. The spring-loaded roller balls will be attached to the base plate via screw bolts and locknuts. The final assembly drawing of the hub stand can be seen in appendix B6.

Parts list and labels:

<table>
<thead>
<tr>
<th>Part #</th>
<th>Name</th>
<th>Description</th>
<th>Supplier</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hub Plate</td>
<td>6” Dia. 1” Thick 6061-T6 Extruded Bare Round</td>
<td>OnlineMetals.com</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Hub Plate Member</td>
<td>2”x2”x6” 6061-T6 Extruded Bare Square Bar</td>
<td>OnlineMetals.com</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Hub Stand Frame</td>
<td>2.5” Height 0.25” Thick 8” Length 6061-T6 Square Tube</td>
<td>OnlineMetals.com</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Base Plate</td>
<td>10”x7”x0.75” 6061-T6 Plate</td>
<td>OnlineMetals.com</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Hitch Pin/Cotter Pin</td>
<td>18-8 Stainless Steel Bent-Pull Hitch Pin with Reusable Cotter Pin, 3/4” Diameter, 3-1/2” Usable Length</td>
<td>McMaster-Carr</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 1: Hub Stand Parts List

<table>
<thead>
<tr>
<th>No.</th>
<th>Part Description</th>
<th>Description</th>
<th>Supplier</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Spring Loaded Roller Ball</td>
<td>Flange-Mount Ball Transfer, Standard, 1-1/4&quot; Steel Ball, Steel Housing, 225 lb. Capacity</td>
<td>McMaster-Carr</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>Screw Bolt</td>
<td>Grade 5 Steel Serrated Flange Head Cap Screw 6-32 Thread 1&quot; Long, Fully Threaded</td>
<td>McMaster-Carr</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Locknut</td>
<td>Low-Strength Steel Serrated-Flange Locknut, Zinc-Plated, 6-32 Thread Size, 27/64&quot; Flange Diameter</td>
<td>McMaster-Carr</td>
<td>1</td>
</tr>
</tbody>
</table>

Manufacturing issues:

There will be two welding operations needed in the construction of the hub stand. The hub plate will be welded to the hub plate member and the hub stand frame will be welded on to the base plate. The weldments will be completed using the knowledge and skills gained from MET 357 as well campus resources. All machining operations will be completed on the manual milling machine, drill press and lathe available at CWU using the knowledge and skills gained from MET 423. The fillets on the base plate and the hub plate member will not be machined due to time constraints and lack of proper tools.

Most of the parts received from OnlineMetals.com were not cut to the right dimension. The base plate was too thick for the screw bolts and nuts to work so it needed to be faced on both sides to bring the overall width down to the acceptable dimension. This was done using the manual-milling machine. The hub plate member would not slide into the frame so it had to be faced on two sides on the manual milling machine. Countersinks were added to the holes drilled on the hub plate member and hub stand frame in order to assist the movement of the hitch pin. The hub plate had to be faced on both sides using the lathe machine due to the fact that the saw blade left a very bad finish. 15-degree chamfers were machined onto the top edges of the hub plate member in order to avoid possible fitment issues with the hub of the vehicle. This was done using the manual milling machine and angle dies.
Discussion of assembly, sub-assemblies, parts, drawings:

The raw stock of the base plate will be 10” x 7” x 0.75”. Originally, 1.50” radius fillets were to be machined on each corner of the base plate. However, due to time constraints that machining operation was taken out and instead will be smoothed using a file. Sixteen 0.14” diameter though-holes will be drilled using the drill press to mount the roller balls. The specific locations of these holes can be found on the drawings in appendix B. 4 roller balls will be mounted on to each hub stand using 16 screw bolts and locknuts.

The raw stock of the hub stand frame will be 2.5” square tube with a wall thickness of 0.25” and length of 8”. The only operation needed on the hub stand frame is a single 0.76” diameter through-hole 1” from the top. The hub stand frame will be welded on to the base plate.

The raw stock of the hub plate member will be a 2” square bar with a length of 6”. Four 0.76” diameter through-holes will be drilled on the sides of the hub plate member. The plans for 0.50” radius fillets on the top of the hub plate member was thrown out to save time. The drilling operations will be done using the drill press in the CWU machine shop. The hub plate member will be welded to the hub plate.
The raw stock of the hub plate will be 6” diameter and 1” thick. First the 2.60” center bore of the hub plate will be bored out using a boring bar and lathe. Next, the 5x112 and 5x100 bolt patterns will be drilled into the hub plate using the lathe machine. Lastly, the 2” flat surface on the hub plate will be machined using the manual mill. Once all the machine operations are completed on the hub plate, it will be welded on to the hub plate member.

Note, all aluminum parts in the hub stand will be polished and edges smoothed by hand.

Testing Method

Introduction:

The Automotive Hub Stand will be tested to see if it meets the requirements set forth in the proposal.

The requirements are as follows:
- The hub stand must weigh less than 21 lbs.
- The hub stand must support 1.5 tons (3000 lbs.)
- The hub stand must accept 5x112 and 5x100 bolt patterns.
- The hub stand must have a center bore size of 77 mm.
- The hub stand must have a minimum height of 18 in.
- The hub stand must have a maximum height of 22 in.
- The hub stand must have a maximum width of 11 in.
- The hub stand must be height adjustable at increments of 1 in.
- The hub stand must pivot up to 3 degrees in all axes for suspension alignment adjustments (caster, camber and toe).
- The hub stand must cost less than $150.
- The hub stand must be made of non-corrosive material.
- The hub stand must be able to perform at a minimum temperature of 20 degrees F.
- The hub stand must meet all government and industry safety standards.

Parameters of Interest:

The Automotive Hub Stand will be tested on a pass or fail basis for its dimensional specifications. The device will be tested for fitment and load capacity by installing it on the intended vehicle and making sure it securely mounts to the hub.

Predicted Performance:

The predicted values for the Automotive Hub Stand will meet or exceed the stated requirements. The physical parameters of the device are predicted to be within the required height range of 18 in.-22 in., width of 11 in, weight of less than 21 lbs., and possess a center bore size of 77mm as well as 5x112/100 bolt patterns. The Automotive
Hub Stand is predicted to be able to withstand a load of 3,000 lbs. or greater. The device is predicted to be pivot up to 3 degrees in all axes for suspension adjustments as well as be height adjustable. The Automotive Hub Stand is predicted to fit on an Audi/Volkswagen or Subaru vehicle using the factory lug bolts or nuts.

Data Acquisition:

The data will be collected using basic measurement tools such as a tape measure and scale. The angle of suspension adjustments will be measured using an electronic level. Fitment of the Hub Stand will be dependent on being able to securely mount the device to the vehicle hub.

Schedule:

As shown in the Gantt Chart in appendix A1 and A2, Test Day 1 will be on 4/6/2016. Test Day 2 will be 4/13/2016. Lastly, Test Day 3 will be 4/20/2016. The Test Report will be written the following week of 4/25/2016 and submitted on 5/4/2016.

Method/Approach:

Resources:

My colleague Derek Lamrache provided the test vehicle (2003 Subaru WRX) on Test Day 1. Carson Man provided the test vehicle (2002 Volkswagen Jetta) on Test Day 2. Jose B provided the hydraulic jack needed to lift the vehicle. The electronic level was downloaded from the app store for free and the tape measure and scale were already in my possession.

Data Capture:

An IPhone 6 was used to capture pictures and videos of the test. Data was collected using paper and pen and transferred to a Word Document.

Test Procedure Overview:

The test vehicle was lifted up and the rear wheel was removed. The Automotive Hub Stand was mounted onto the vehicle hub securing it with the factory bolts. The vehicle was lowered so it was resting on the hub stand. Before load and after load angle measurements were taken. The physical specifications were measured.

Operational Limitations:

The camber angle of the Automotive Hub Stand was measured using an electronic scale. However, the caster and toe angles could not be measured because not all four roller balls
on the device contacted the ground. This was due to the roller balls not compensating enough of the camber angle.

Precision and Accuracy:

The precision of the tape measure was 1/16\textsuperscript{th} inch. The precision of the scale was 0.1 lbs. The precision of the electronic level app was 0.1 degrees. The measurements taken were consistent and accurate.

Data Storage:

The data was collected on paper and transferred to a Word document. The data was then compared to the calculated values and requirements.

Data Presentation:

The data was presented in a Word document in a data table.

Test Procedure:

Time/Duration:

1 hour

Place:

Flat level ground - garage or driveway

Actions:

1. Put vehicle in Park and set the Parking Brake (E-brake).
2. Loosen wheel bolts or nuts.
3. Jack up vehicle using an automotive jack with the correct load rating.
4. Remove wheel bolts or nuts completely.
5. Remove wheel.
6. Install the Hub Stand by lining up the bolt holes and using the factory lug bolts or nuts to secure it to the hub of the vehicle.
7. Slowly lower the vehicle so it is solely supported by the hub stand.
8. Leave installed for 30 min.
10. Loosen wheel bolts or nuts.
11. Remove Hub Stand.
12. Install wheel and hand tighten wheel bolts or nuts.
13. Slowly lower the vehicle.
Risk/Safety:

Make sure the test location is flat and level. The jack used to raise and lower the vehicle must have the correct load rating (2.5 tons minimum). When jacking up the vehicle, make sure to place the jack directly under the frame or manufacturer specified jack point. Jacking the vehicle up on any other location can cause serious damage. There is a possibility that the Hub Stand could fail and not be able to support the 3000lb load requirement. To mitigate this risk, the jack will be set so that if the Hub Stand does fail, the jack act as a safety net and catch the vehicle.

Discussion:

The Automotive Hub Stand was designed and manufactured for use on vehicles with a 5x100 and 5x112 bolt patterns, which consist of various Subaru, Audi and Volkswagen models. Also, the Automotive Hub Stand is designed for factory suspension systems and not intended for lowered or raised vehicles.

Deliverables:

Parameter Values:

The physical parameter values that were tested were height, width, weight, center bore diameter and bolt patterns. Other parameters tested were height adjustability.

Calculated Values:

The Automotive Hub Stand was calculated to be support 3000 lbs. and have 3 degrees of motion in all axes for suspension alignments.

Success Criteria Values:

The Automotive Hub Stand is considered to be successful if it mounts up to a 5x112 or 5x100 bolt pattern vehicle and supports it.

Conclusion:

In conclusion, the Automotive Hub Stand Design was a success because it met all the requirements set forth in the proposal.

Budget/Schedule/Project Management

Proposed Budget:
The parts list and material costs are outlined in appendix C1. The total material cost for 4 hub stands is $576.22. There will be no labor costs.

Part suppliers, substantive costs and sequence or buying issues:

The materials and parts necessary for this project will come from OnlineMetals.com and McMASTER-CARR. OnlineMetals.com is located in Seattle, WA. They allow local pick-up of materials. Materials from McMASTER-CARR will have to be ordered online.

Labor or outsourcing rates & estimate costs:

There will be no labor costs associated with manufacturing the hub stand. All machining and welding operations will be done with the resources available at CWU.

Total project cost:

The total project cost is estimated to be $576.22. The final cost of the project was $200.00

Funding source(s):

The sources of funding for this project will come from fundraising and principle engineer’s savings.

Proposed schedule:

The schedule for this project is constrained by the MET 495 course and is shown in appendix E1. This project will be completed by the end of the third quarter. A tentative schedule has been created to help organize and plan for the successful completion of this project. The schedule outlines the time frame for the design, manufacturing and testing of the hub stand.

High-level Gantt Chart:

The Gantt Chart for the hub stand design can be found in appendix E1. Details of task descriptions, duration, timing of duration and milestones can be found on the chart.

Deliverables, milestones:

The deliverable and milestones for this project are: completed design review and completed proposal due at the end of fall quarter, parts and materials arrived by the second week of winter quarter, manufacturing design review and completed construction of the hub stand by the end of winter quarter and lastly testing design review and final report due at the end of the spring quarter.
Total project time:

The total project time is estimated to be 137 hours. The actual total project time was 93 hours.

Project Management:

This project will succeed due to the availability of appropriate technical expertise and resources. Careful planning and budgeting will minimize risks of failure.

Human Resources:

The principle engineer will provide expertise in CNC programming and machining as well as welding.

Physical Resources:

The CAD lab at CWU will provide the necessary software to program machining operations and the CNC machines available in the machine shop will provide the actual parts machining. The foundry at CWU will provide the welding equipment needed.

Conclusion

An automotive hub stand has been conceived, analyzed and designed that satisfies the design requirements stated in the introduction of this proposal. The parts and materials for this device have been specified, sourced and budgeted for acquisition. The Automotive Hub Stand has been constructed and tested. The Automotive Hub Stand Design project was a success because it met all the requirements set forth in the proposal.

This project meets all the requirements for a successful senior project, which include the following:
1. Having substantial engineering merit in structural and material analysis.
2. Size and cost of the project is within the means of successful completion.
3. Being of great interest to the principle investigator.
Acknowledgements

Dr. Craig Johnson, Professor Charles Pringle, Professor Ted Bramble and Mathew Burvee have mentored the principle engineer in completing this project proposal. Special thanks to CWU and the machine shop it provides. Without the CNC machines and resources available at CWU, the construction of the hub stand would not be possible.
References:


Appendix A – Analyses

A1: Allowable Load Calculation for 6061-T6 Aluminum Square Tube

Given: Hub stand must support 3000 lbs. Center structure made from 6061-T6 Aluminum Square Tube 2.5" x 0.25", L = 24 in, E = 10,000 ksi.

K = 0.65

N = 1.5

Sy = 40 ksi

Find: The allowable load of the aluminum square tube to see if it will support the required 3000 lbs.

Solution:

KL = (0.65 in) (24 in) = 5.2 in (effect length)

Radius of gyration = \( \sqrt{\frac{a^2 + b^2}{12}} \) = \( \sqrt{\frac{2.5^2 + 0.25^2}{12}} \) = 0.92 in

Slenderness ratio: \( \frac{KL}{r} = \frac{5.2}{0.92} = 5.63 \)

Column constant: \( c = \frac{2\pi^2 E}{5Sy} = \frac{2\pi^2 (10,000) \text{ksi}}{40 \text{ksi}} \)

\( = 70.3 \)

\( \frac{KL}{r} < c \), use "J.0. Johnson Formula"

\[ Pcr = \frac{A \cdot Sy \left[ 1 - \frac{Sy (KL/r)^2}{4\pi^2} \right]}{B} = \frac{(2.25 \text{ in}^2) (40 \text{ ksi}) \left[ 1 - \frac{(40 \text{ ksi})(5.63)^2}{4 \pi^2 (10,000 \text{ ksi})} \right]}{1.5} \]

\[ Pcr = 89,711 \text{ lbs} \]

\[ P_a = \frac{Pcr}{N} = \frac{89,711 \text{ lbs}}{1.5} \]

\[ P_a = 59,141 \text{ lbs} \]
A2: Critical Stress Calculation of Hub Stand

Given:
- Critical load = 89,711.66 psi
- 6061-T6 Aluminum Square Tube
- 2.5" x 0.25" Length = 2"

Find:
- Critical Stress, \( \sigma_{cr} \)

Solution:
- \( A = bh - Bh \)
- \( A = (2.5\text{"})(2.5\text{"}) - (2\text{"})(2\text{")} \)
- \( A = 6.25\text{in}^2 - 4.0\text{in}^2 \)
- \( A = 2.25\text{in}^2 \)

\( \sigma_{cr} = \frac{89,711.66}{2.25}\text{psi} \)

\( \sigma_{cr} = 39,472\text{psi} \)

\( \sigma_{cr} = 39,472\text{psi} \leq \sigma_y = 40,000\text{ksi} \)
A3: Material Properties of 6061-T6 Aluminum

- Ultimate tensile strength, $S_u = 45$ ksi.
- Yield strength, $S_y = 40$ ksi.
- Ductility, $17\%$
- Modulus of Elasticity, $E = 10,000$ ksi.
- Excellent joining characteristics, good acceptance of applied coatings.
- High strength, good workability, high resistance to corrosion.
- Widely available.
A4: Maximum Vertical Shearing Stress Calculation

Given: Load of 3000 lbs

Maximum Shearing Force, \( V = 3000 \) lbs

\( h = 8'' \)

\( t = 2.5'' \)

Find: Maximum Vertical Shearing Stress, \( T \)

Solve: \( T = \frac{VA}{It} \)

\( I = \text{Area moment of inertia} \)

\( = \frac{a^4 - b^4}{12} \)

\( = \frac{(2.5\text{in})^4 - (2.0\text{in})^4}{12} \)

\( I = 1.92 \text{in}^4 \)

\( t = 2.5 \text{in} \)

\( V = 3000 \) lbs

\( A = Ap \cdot \gamma \)

\( A_p = \frac{t(4h/2)}{2} = \frac{(2.5\text{in})(8\text{in})}{2} \)

\( A = 20 \text{in}^2 \)

\( \gamma = \frac{h}{4} = \frac{8\text{in}}{4} = 2\text{in} \)

\( T = \frac{(3000\text{lbs})(20\text{in}^2)}{(1.92\text{in}^4)(2.5\text{in})} \)

\( T_{\text{max}} = 12.5 \) kpsi

Tall enough = \( 12.5 \) kpsi

\( \frac{12.5 \text{kpsi}}{15} = 0.833 \) kpsi

Tall enough < Yield Strength, \( s_y \)

\( 0.833 \text{kpsi} < 40 \text{kpsi} \)
A5: Pin Diameter Calculation

Given: Load of 3000 lbs
Hub plate member will be pin connected to the hub stand frame to set the desired height, very much like a trailer hitch pin. $P_{allow} = 3.3$ kips.

Find: An appropriate diameter pin to hold the 3000 lb (4486 N) load.

Solve:

$$T_{allow} = \frac{F}{A} \quad A = \frac{1}{4} \pi d^2$$

$$2.3 \text{ kips} = \frac{3000 \text{ lbs}}{\frac{1}{4} \pi (d)^2}$$

$$d = 0.678 \text{ in}$$

So, the minimum diameter of the pin must be 0.678 in.

A $\frac{7}{16}$" diameter pin will be used.
Given: Hub plate 6 in diameter
1 in thickness
Hole diameter = \( \frac{5}{16} \) in
Width = \( \frac{6\text{ in} - \frac{3.075\text{ in}}{2}}{1.444\text{ in}} = 1.484\text{ in} \)
Center bar = 77 mm = 3.0315 in

Find: Maximum stress of the hub plate with a hole when subjected to a compressive force of 3000 lbs.

Sol'n.

\[ \sigma_{max} = K_c \sigma_{nom} \]
\[ \sigma_{nom} = \frac{F}{(W-d) t} \]
\[ \frac{d}{w} = \frac{\frac{5}{16}\text{ in}}{1.444\text{ in}} = 0.421 \]
\[ K_c = 2.0 \]
(Figure 3-26 P.115 W=1.444 in
Mott, 2014)

\[ \sigma_{nom} = \frac{3000 \text{ lbs}}{(1.444\text{ in} - 5/16\text{ in})1\text{ in}} = \geq 492.43 \text{ psi} \]

\[ \sigma_{max} = (2.0) (\geq 492.43 \text{ psi}) \]

\[ \sigma_{max} = 6,970 \text{ psi} \]

\[ \sigma_{max} \leq \text{ yield strength, } S_y \]

6,970 psi \ \leq \ 40 \text{ ksi} \]
A7: Maximum Bending Stress on Base Plate Calculation

Given: 0.75" thick base plate
12" Length 7" width
Load of 3000 lbs

Base plate will encounter a bending stress due to the 3° of pivot that the hub stand will be capable of.

Find: Maximum bending stress on the base plate, \( \sigma_{\text{max}} \), in psi

Solution:

\[ \sigma_{\text{max}} = \frac{M.E}{I} \]

\[ M_{\text{max}} = F \left( \frac{L}{2} \right) \]
\[ = (3000 \text{ lbs})(7\frac{"}{2}) \]
\[ M_{\text{max}} = 10,500 \text{ lb \cdot in} \]

\[ a = 0.75\frac{"}{2} = 0.375" \]
\[ I = \frac{bh^3}{12} \]
\[ = (10\text{ in})(0.75\text{ in})^3 \frac{\text{in}^4}{12} \]
\[ I = 0.352 \text{ in}^4 \]

\[ \sigma_{\text{max}} = \frac{(10,500 \text{ lb \cdot in})(0.375 \text{ in})}{0.352 \text{ in}^4} \]

\[ \sigma_{\text{max}} = 11.2 \text{ ksi} \]

\[ \sigma_{\text{max}} \text{ bending base plate} = 11.2 \text{ ksi} \]

\[ S_y \text{ of 6061-T6} = 40 \text{ ksi} \]
A8: Maximum Bending Stress on Hub Stand Frame Calculation

Given: 2.5" x 2.0" x 2" square tube

Load = 3000 lbs

Hub stand frame will encounter a bending stress due to the moment caused by the 3° point motion of the hub stand.

Find: Maximum bending stress on the Hub Stand frame \( \sigma_{\text{max, bending, frame}} \)

\[ \sigma_{\text{max, bending, frame}} = \frac{M \cdot C}{I} \]

\[ M_{\text{max, frame}} = (3000 \text{ lbs})(2.5/2) \]
\[ = 3750 \text{ lbs} \cdot \text{in} \]

\[ C = 2\cdot 2 = 4 \]

\[ I = 1.92 \text{ in}^4 \]

\[ \sigma_{\text{max, bending, frame}} = \frac{(3750 \text{ lbs})(4)}{1.92 \text{ in}^4} \]

\[ \sigma_{\text{max, bending, frame}} = 7813 \text{ psi} \]

\( \sigma_{\text{max, bending, frame}} \leq S_y \) of 6061-T6

\( 110 \text{ ksi} \)
A9: Required Minimum Leg Size for Welding

Given: Hub stand frame will be welded "all the way around" to the base plate.

Material is 6061-T6 Aluminum.

Figure 20-1 pg. 653 Mutl 2014

Find: Required minimum size for the weld, W

Sol'n:

Direct compression: \( f_c = \frac{P}{A_w} \)

\( A_w = 2b + 2d \)

\( b = 2.5\)"

\( d = 2.5\)"

\( A_w = 2(2.5\text{''}) + 2(2.5\text{''}) \)

\( A_w = 10\text{in} \)

\( f_c = \frac{3000\text{lb}}{10\text{in}} \)

\( f_c = 300\text{ lb/in} \)

\( W = f_c/\text{allowable force on a 1.0-inch weld} \)

\( W = (300\text{ lb/in})/3200\text{ lb/in} \)

\( W = 0.094 \text{ in} \)

3/8" fillet weld will be used for thick plates 7 1/2 - 2 3/4 inches

Table 20-4 pg. 652 Mutl 2014
A10: Dimensions and Cost of Raw Stock for the Base Plate

Given: Hub stand base plate
Material: 6061-T6 Aluminum Plate

Find: Dimensions of raw stock needed and cost

Sol'n:

10" x 7" x 0.75"

Cost $39.90 x 4 hub stand

Total cost: $159.60

Online metals.com
A11: Dimensions and Cost of Raw Stock for the Hub Stand Frame

Given: Hub stand frame
Material: 6061-T6 Aluminum Square tube

Find: Dimensions of raw stock needed and cost.

Solution:
- 2.5" height
- 0.25" wall thickness
- 36" length

Cost: $53.01

Total length = 8" x 4 hub stands = 32" total length needed
- Commercially available length is 36".
A12: Dimensions and Cost of Raw Stock for the Hub Plate Member

Given: Hub plate member.

Material: 6061-T6 aluminum square bar

Find: Dimensions of raw stock needed and cost.

Solution:

Extended Aluminum Barre Square 6061-T6

2" x 2" x 24"

Cost: $42.25

Online Metals.com

Total length = 6" length x 4 Hub bolts
= 24" total length needed

Commercially available size is 24" length.
A13: Dimensions and Cost of Raw Stock for the Hub Plate

Given: Hub plate
Material 6061-T6 Aluminum Extended

Find: Raw stock dimensions needed and total cost.

Solve:

\[ \phi 6'' \]

Diameter = 6''
Thickness = 1''

Cost per 4: $14.11
\times 4 = 56.44

Total cost: $ 56.44

Online metals.com
Appendix B – Drawings

B1: Initial Sketch of Hub Stand Design
Hub Plate

Central Washington University

5.83 - 6.00

2.00 - 2.60

5 Hole Pattern

6.93 x 5

6.93 x 5

2.00

1.00

0.93 x 5

5 Hole Pattern

0.93 x 5
B6: Roller Ball (Transfer Ball) Drawing
### Hub Stand Assembly Exploded + BOM Drawing

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<td>3</td>
<td>9233A388</td>
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<td>6061-16</td>
<td>6061-16 Square Bar</td>
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<td>6</td>
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**Title:** Hub Stand Assembly

**Central Washington University**

**Scale:** 1:10

**Sheet:** 1 of 1
Appendix C – Parts List

C1: Hub Stand Drawing Tree

- **Hub Stand**
  - **Hub Plate**
    - Hub Plate Member
  - **Hitch Pin**
  - **Cotter Pin**
- **Hub Stand Central Frame**
- **Base Plate**
  - Spring Loaded Roller Balls
  - Bolts/washers
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**D1: Materials Cost**

- Total Cost: $57.22
Appendix E – Schedule

E1: Gantt Chart 1/2
Appendix F – Testing Results

F1: Test Procedure Check List

Automotive Hub Stand Design
Test Procedure Check List

1. Put vehicle in Park and set the Parking Brake (P-brake).
2. Loosen wheel bolts or nuts.
3. Jack up vehicle using an automotive jack with the correct load rating.
4. Remove wheel bolts or nuts completely.
5. Remove wheel.
6. Install the Hub Stand by lining up the bolt holes and using the factory lug bolts or nuts to secure it to the hub of the vehicle.
7. Slowly lower the vehicle so it is solely supported by the hub stand.
8. Leave installed for 30 min.
10. Loosen wheel bolts or nuts.
11. Remove Hub Stand.
12. Install wheel and hand tighten wheel bolts or nuts.
13. Slowly lower the vehicle.
14. Tighten lug bolts or nuts in a star pattern and torque to factory specs.
Device: Automotive Hub Stand
Operator: Peter Noh
Date: 04/10/2016
Test Vehicle: 2003 Subaru WRX (5x100 Hub Pattern)
Test Location: Flat level ground – The Grove parking lot

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<tr>
<td>Height Dimensions</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Camber Compensation</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
Device: Automotive Hub Stand  
Operator: Peter Noh  
Date: 04/24/2016  
Test Vehicle: 2002 Volkswagen Jetta (5x112 Hub Pattern)  
Test Location: Flat level ground – Parking Lot

<table>
<thead>
<tr>
<th>Data Sheet 2</th>
<th>Pass</th>
<th>Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hub Pattern Fitment</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Center Bore Fitment</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Sits flush against rotor</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>3000 lb load</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Height Dimensions</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Camber Compensation</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

Camber Angle Initial (No Load): 7.9 Degrees  
Camber Angle Final (With Load): 5.8 Degrees  
Total Camber Compensation: **2.1 Degrees**  
(Requirement was 3 degrees)  

No deflection observed.
Appendix G – Resume/Vita

Peter Noh
Nohp@cwu.edu • (907) 351-3197 • 701 Sanders Road Unit 2 • Ellensburg, WA 98926

EDUCATION

College of Engineering, University of Alaska, Anchorage, Alaska
Mechanical Engineering Major 2011-2013
Activities: UA Scholars Member and Scholarship Award Recipient, Alaska Tuner Catalog Member

School of Engineering, Central Washington University, Ellensburg, Washington
Bachelor of Science Degree in Mechanical Engineering Technology June 2016
Concentration in Manufacturing Engineering
Activities: VEX Robotics Competition Volunteer, Basic/Advanced Machining, CAD/CAM, Solidworks

WORK EXPERIENCE

CJ Contractors and Painting, Anchorage, Alaska: Administrative Assistant
June 2014 - September 2014
- Assisted project manager with scheduling estimates, providing estimates and creating job proposals;
- Responsible for employee timekeeping and payroll duties using QuickBooks PRO;
- Managed inventory levels and purchased paint and supplies for job sites.

FedEx Express, Anchorage, Alaska: Materials Handler
January 2014 - June 2014
- Certified to operate loaders, tugs, and various heavy machinery to move 10,000+ lb. containers;
- Accurately loaded containers onto specific points on aircraft adhering to load sheets for proper balance making sure all locks are in place;
- Certified to work in and around Boeing 777, McDonnell Douglas MD-11/MD-10, ATR 72 and Cessna 208 aircrafts.

Grant Aviation, Anchorage, Alaska: Operations Agent
July 2012 – May 2013
- Assisted pilots for takeoff and arrival by installing/removing tail stand, wheel chocks and checking all exterior doors on Cessna Grand Caravan and Beech King Air 200s aircrafts;
- Created passenger/cargo manifests for outbound flights with weight and fuel considerations;
- Conducted customer service duties including ticket counter operations, resolving customer complaints and planning accommodations for disabled passengers.

SPECIAL SKILLS

- Fluent in Korean
- Extensive customer service and administrative experience
- Proficient in Solidworks, Microsoft Word, Excel, Presentation and QuickBooks
- Comfortable in a machine shop setting and knowledge of all tools and measurement devices
- Experience using lathe and milling machines, drill press, saw blade, grinder and plasma cutter
- Experience in basic programming for 3D parts including holes, curves, slots etc.
- Familiar with Milltronics CNC Machine
- YWAM Tijuana Mission Participant
- Lead Percussionist – All Nations Church Praise Team