The Collapsible Trailer: Design and Manufacture

By: Robert Hobson
Executive Summary

This project started out by seeing a need, or rather a potential niche for a trailer that is able to be stored in a small space such as the back of a garage or a small side yard. Almost everybody has had a time where a trailer would have been nice to have to help with a move or remove unwanted furniture from a house. What stands in the way of owning that trailer is money and storage space. This trailer has lessened the storage issue at a reasonable price.

The 7000 pounds capacity model built for this project cost $2945.75 to build, weighs in at 850 pounds and folds from 20' 3" down to 6' 1.5". This model is designed specifically for hauling automobiles and typical road conditions derived from both emergency braking with evasion and a bump with a load at 55 mph. The 4 inch square steel tube frame separates into 4 sections held together by hitch pins and is supported by a pair of 4500 lb axles with hydraulic brakes. The decking is composed of 2 inch thick wood boards screwed down to the frame.

Other, smaller models decrease in both price and weight and can be stored in even smaller spaces. The 2000 lb trailer can be built for approximately $1100 and can be folded and leaned up against a wall in a side yard or a garage because the entire assembly will weigh approximately 200 lbs.

Definition of Terms

Due to the multitude of manufacturers and the number of forums interchanging names for the same part on a trailer, here are pictorial representations explaining the names that shall be given to parts in this report.

Figure 1: The part of the trailer. For this report the separate sections of the trailer shall be called Yoke, Middle Base and Rear sections respectively when moving from the hitch to the ramps (which are raised in this picture). The red lines indicate the hinges which connect the sections of the frame together.
Figure 2: This is a picture of the entire suspension system. The number one is pointing to the hub on the axle. Two is pointing to the leaf spring and three is pointing to the zoomed in hanger assembly portion of the suspension system presented in figure 3.

Figure 3: The middle hanger assembly. One is the doubler, two is the hanger, three is the equalizer and four is a shackle.

Research

There will always need for trailers to be sturdy and functional and collapse to reduce the space they take. This means that the frame of the trailer will need to either fold or telescope so that physical volume of trailer is reduced when stored. There have been multiple potential solutions to this problem, however these solutions have been found to be largely unsuccessful and inefficient. Figure 4 depicts a design for a folding trailer that is hinged right behind the axle and folds up to be placed on its stand. This simple design has a relatively low towing capacity. Prior users also complained that it had a pretty substantial “rattle” when
towed because of loosely the parts where put together and it would flop along the axis when under load.

**Figure 4:** The only collapsible trailer found in either the patent or production stage.

### The Design Process

There have been many design iterations of the collapsible trailer. Different ideas were in various stages of the design process before they ran into their respective insurmountable roadblocks and the ideas were taken back to the drawing board. Everything was originally designed around simplicity to reduce cost and production time. The only thing worse than a broken tool is an expensive broken tool.

The design process always started with specifications so that a product could be designed with a final goal in mind. Before being sponsored, the specifications were set at an arbitrary 2000 pound capacity trailer while collapsing down to one third the trailer's original length. This was a fairly simple idea that got the creative juices flowing and opened up all the doors to the trailer world. Understanding what went into a trailer and how to build a basic trailer out of readily available parts immediately brought a sense of realism to the project. The sponsor dictated the specifications seen in table 1.

Given these requirements, I could see what was required and begin to specify loads and begin engineering. For all of the previous iterations and the final product, the sequence of considerations were the same. The first step involved designing a frame capable of handling the loads determined in a dynamic environment. The second step was to determine a system allowing the trailer to collapse while still maintaining the structural integrity during heavy use. Adding the trailer parts such a wheels, axle(s) and suspension and simultaneously checking for
feasibility and cross checking budgetary concerns concluded the process. Most of the iterations failed the feasibility check when folding.

### Table 1

<table>
<thead>
<tr>
<th>REQUIREMENTS (In order of importance)</th>
<th>DESIRES (In order of importance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Hitch chains</td>
<td>1. Tongue lift can be operated with a hand crank or power wrench</td>
</tr>
<tr>
<td>2. Lights and license hanger</td>
<td>2. Hinge joint bolts work with trailer wheel lug wrench</td>
</tr>
<tr>
<td>3. Electric brakes on one axle</td>
<td>3. Use wheels on trailer that will accept a 1) 5X135mm or 2) 5X114.3mm bolt pattern</td>
</tr>
<tr>
<td>4. Trailer will tow safely if tongue hinge joint is not secured</td>
<td>4. Weight low enough to fold and unfold manually with 2 people</td>
</tr>
<tr>
<td>5. Accommodate 4 inch ground clearance on track day car</td>
<td>5. A linkage that automatically extends the tongue when the trailer is unfolded</td>
</tr>
<tr>
<td>6. Tongue lift is on drivers side</td>
<td>6. Rapidly install and remove the equipment box</td>
</tr>
<tr>
<td>7. Skid bar on tongue</td>
<td>7. Fold the trailer with the equipment box in place</td>
</tr>
<tr>
<td>8. Plan for winch attachment</td>
<td>8. A winch is usable with the equipment box in place</td>
</tr>
<tr>
<td>9. State inspection and license</td>
<td>9. Brackets to add plywood sides and deck</td>
</tr>
<tr>
<td></td>
<td>10. Protect the ability to add fenders</td>
</tr>
<tr>
<td></td>
<td>11. Install dampers to prevent joint damage during folding/unfolding or vehicle loading</td>
</tr>
<tr>
<td></td>
<td>12. Interlock that locks trailer brake if failure to secure any element causes functional risk</td>
</tr>
</tbody>
</table>

The first iteration involved folding the frame width-wise. The frame was simply built out of two five inch I beams and equipped similarly to a standard trailer. The issues with this design were manifold, but the most prominent was the idea of folding the triangular tongue connecting the hitch to the rest of the trailer. The process required to fold it up was long, complicated and detracted from both usability and the final strength of the frame. After the lateral folding idea came the interesting concept of telescoping the trailer. Credit where it is due, my peer, Matt Boncich came up with the original idea of 3 different sized rectangular tube nesting inside each other to decrease folded up length. The concept was sound, easily evaluated and seemed fairly original, but a solution for conveniently rolling, sliding or aligning the tubes while able to support a 6000 pound vehicle continued to elude me.

Finally, a simpler design of folding the trailer using heavy-duty hinges and hitch pins or bolts was adopted. The frame could be folded by two people, hold the requisite loads in emergency situations and passed the feasibility and cost checks. This final design was required to accommodate both a light, low ground clearance race car and a 6000 pound SUV. By having
both of those design criteria, the trailer had to be able to handle a car with 4" of ground clearance while the nose is 20-24" away from the edge of the nose. This gives an angle of 10 degrees with which to load the trailer. This requirement was met by adding in 2' long ramps and tilting the trailer by utilizing the hinges built in. The 6000 pound requirement simply meant adding larger support beams or decreasing the factor of safety of the product.

**The Product**

This trailer has four sections varying in length. The base section attached to the suspension is six feet long to support the combined length of the two leaf springs in series as well as the doublers, equalizer, shackles and connectors (see figure 3). The rear section is three feet long for proper loading of vehicles and the eleven feet of frame in front of the base section was split into two parts. The length of the trailer was based on the size of the SUV with an extra foot on each side to properly chain down the car.

**Structure**

Four inch square tube was used for framing for two reasons. The first reason was dynamic stability: the four inch frame supports loads very well in both shear and torsion, which is optimal for minimizing the number of members in each piece of the frame. This both lowers weight and cost, leaving the customer happier, and lends itself toward better towing characteristics. When originally designing the trailer, a moment diagram was drawn up to prove where the maximum bending moment would be found and what that maximum bending moment would represent. The maximum bending moment was found to be 16992 ft-lbs at the front wheel of the loaded car assuming a deceleration of .8g with a .5g turn. See the Analysis section 11 for full details and calculations. Keeping in mind a bending moment of 16992 ft-lbs produces a bending stress of 87200 psi and the weight of the load producing a shear stress of 4500 psi, a material had to be chosen with sufficient material properties and a shape that lends the inertial properties necessary to bear the stresses from the combined dynamic loading. After some price versus strength research, the best option was clearly ASTM 500 grade B structural steel because it is the only material available either online or in the local metal depots besides stainless steel. There are many reasons not to choose stainless, including difficulty to machine and weld and the exorbitant price.

The second reason the four inch tube was selected was a combination of availability and price. The stress applied on the structure is 89200. The shapes that hold up to this minimum as
well as a safety factor of 3.5 are 4" square tube. The metal depots had limited supplies of 3.5" square tube and 4" x 2" rectangular tube leaving the options of 3", 4" and 5" square tubing. Since there is a certain uncertainty in the unforeseen loads and material inconsistency in the welds due to porosity, the four inch square tube was selected and purchased.

**Tongue shape**

The tongue was built out of three inch square tube for reasons similar to that of the rest of the frame. It was chosen to build the tongue out of three inch tube to further reduce the weight at the front of the trailer which eases both the folding and hitching processes. The tongue is shaped the way it is because of a mistake when ordering materials that actually turned into a success. Originally, the plan was to take three beams from the hitch back the front edge of the first section, two to the outer edge and one to the middle of the front section. A weld able hitch would be welded onto the protruding bit of 3" square steel tube in the front. Since the desired distance from the ball of the truck to the first section was 6 feet, the original approach required 16 feet of 3" tubing cut into three sections of equivalent length.

After purchasing the tubing, I realized that 2 8' sections of tube were bought, rendering the initial plan useless. As shown in the figure below on the right, the crosspiece ended up recessed from the front edge of the outside pieces. After reevaluating the original design, it was discovered that having the middle section reach back to the lateral support in the first section of the frame. The first is the hinges would be out of plane and would not fold properly. Because the hinges are out of plane, the hinges would produce an extra bending moment from any deflection thusly amplifying any stress on the material.

To make the desired distance of four feet, everything was shortened to a minimum distance. The angled supports were reduced from 5'8" to 5'2" while the lateral support and the hitch support are just a measly 34".

![Figure 5: The planned shape (Left) and the actual shape (Right) of the tongue](image-url)
These hinges were designed and built specifically for this trailer. Half inch bar stock was cut into five by five inch pieces attached to two one-inch tubes having three-quarter-inch inner diameter. Agricultural hitch pins were purchased to connect the two plates. Ideally the two hinge parts would be interchangeable, making future trailers modular, so that an owner could add or remove sections both in front and behind the base section. This would allow for a more useful trailer with more applications.

Figure 7: (Left) Picture of the hinge while the trailer is flat without the decking material in place. (Right) Picture of the hinge open with the electric cables running through the hinge.
The hinges do not have to be as large as they are, but were overbuilt because of the failure criteria for the hinge. To start the design of the hinges, machine utility was apprised and the question, "what does the hinge need to accomplish as part of the whole of the project?" was asked. The simple answer to that question is this: the hinge needs to transfer all of the load from one beam to the next, it needs to fold, and it needs to be above the height of the deck to allow for easy access to the pins.

Half inch bar stock was chosen because all of the stress needs to be transferred perfectly from the tube to the pins and out to the other tube while dealing with the added bending moment arm added by the extra 1 3/4" height of the decking. The maximum stress transferred by the beam modified by the safety factor of 3.5 is 89200 ksi, which means the minimum stress requirement for the plate needs to be above that, leading to the half inch plate which allows a stress of 400ksi.

The pins and tube were chosen on fit rather than a strength calculation. The minimum pin diameter to match the loads applied was a .615". The smallest tube found that had an exact inner diameter compatible with any form of hitch pins was of the 3/4 inch inner Diameter/1.04 outer diameter, which blows away any idea of a failure in the tube or the pins. The pins were bought at a tractor supply store and are rated at 80,000 pounds, which is the definition of overbuilt.

**Decking**

The decking on the trailer consists of two parts, the supports and the decking material. The supports concept was taken straight from rafter design on a house. The hanger joist is welded onto the inside of the metal frame so that a 2x4 wood stud spans the structure and will hold up a series of 2x8 boards running the length of the trailer.

*Figure 8:* On the left, the joist is visible as the shiny metal on the rusty backdrop. The 2x4 is in the joist hanger while the 2x8 is on top of it all.
Suspension

The axles are rated at 4500 pounds each, for a total of 9000 pounds. This means that the axles are going to break far after the hinges or the leaf springs. These axles have a 3.5 inch drop from the spindles to the axle proper. The axles are connected to the frame via leaf springs. Each pair of leaf springs are rated to 3500 pounds, which leaves the entire trailer rated at 7000 pounds due to the two pairs of leaf springs.

On the extreme ends of the entire suspension system and in the middle, the trailer has hangers giving the suspension vertical clearance to move. On the two outside hangers, the leaf springs are connected directly to the hangers by bolts, whereas the middle hanger has an equalizer connected to the hanger. In between the springs and the equalizer are shackles, which are in turn connected by bolts. The middle hanger assembly may be viewed in figure 4 and the leaf spring assembly is shown in figure 5.

Due to concerns about piercing the sidewall of the tube while welding the hangers directly onto the 4 inch square tubes, half inch doublers were added to allow for a more aggressive weld on the hangers leading to greater penetration into the doublers. A doubler is a piece of metal welded to the original base metal to add more mass to reduce damage due to overheating in welding. The doublers could be welded onto the tube with a less aggressive weld because there was more weld length reducing the need for thick welds that would potentially overheat and burn through the thinner side wall of the square tube.

Figure 9: A closer view of a suspension for one axle.
Analysis

Assuming a deceleration of .8g with a .5g turn produced the largest moment around the center of mass of the trailer, producing the maximum bending moment. These particular accelerations were chosen because they are approximately the rolling and slipping accelerations. All of the following calculations have been attached as Appendix A and can be found near the end of the document.

Car Analysis

The first part of this process was to evaluate the vehicle loaded onto the trailer, which in this case is a 6000 pound SUV with a 10' wheelbase. To find the four tire loads on the trailer, the car was broken down into two 2D free body diagrams where the front vs rear or the left vs right were compared and by the use of ratios, the reactions of the tires were found to be 1225, 525, 2975, and 1275 as the right front, right rear, left front and left rear respectively and all in pounds.

Trailer Analysis

The next issue was to find the center of gravity of the trailer with the car attached, reactions on the 6 connection points of the suspension of the trailer on each side, and the hitch reactions. To do this, the wheel reactions were first evaluated so that the number of unknowns could be reduced significantly.

To find the center of gravity, found on page A4, the trailer was assumed static with a point load of 6000 pounds in the center of the car and a 1000 pound point load located somewhere between the wheels and the center of the loaded car. The wheels were simplified to a point load directly between the two axles to provide a single point to take a moment. The hitch is assumed to be 700 lbs due to design requirements. After taking the moment about the point simulating the combined reactions of the axles, the center of gravity was found to be roughly 106" from the rear of the trailer.

The hitch reactions, found on pages A5 and A8, used similar simplifications of the wheels to provide a single unknown to allow the resolution of the reactions. After the hitch reaction in the y direction was found, the other four reactions in the y direction can be found by using the same method to find the four tire reactions on the car.
Taking the reactions at the trailer tires found on page A6, the suspension can be resolved by assuming a no deflection condition on the equalizer. Here only the left suspension is evaluated because that side is loaded more than double the right side. The rear leaf spring has been simply divided in half due to the lack of other forces and separated equally onto the front and central hangers. The front suspension is resolved by taking a moment about the pin connection to the equalizer. This gives forces on the equalizer that denote a rotation about the central hanger pin connection. The angular deflection can be ignored due to a conservative estimate because it simply redistributes the load onto the rear hanger, lessening the max moment.

After resolving all of the unknowns on the left side of the trailer, the vertical loads are input into a shear and a moment diagram on page A9. The diagrams output a max moment of 16992 ft-lbs, giving a bending stress of 87200 psi. The axial stress is produced by the trailer hitch reaction in the x direction and the shear stress is given by the forces produced by the turn.

**Hinge Analysis**

The max moment and the max vertical shear are applied to a free body diagram of a hinge that is assumed to be static. From this free body diagram, the resultant forces on the hinges are found to be 34025 lbs. Inputting this information into the shear stress equation with a safety factor of 3.5, we find the minimum diameter of the pin to be 0.615".

**Manufacturing**

To preface the manufacturing portion, everything was designed around weldability, penetration of a weld, and the ability to fit the welder into particular places. When the term weld is used, the portion of the metal being welded is ground clean such that it shines brightly, it is cleaned off with denatured alcohol and usually beveled. These bevels are useful because they allow welds better penetration into thick pieces of metal or give the weld metal a place to flow, generating a smoother finished product. The bevel type will be specified, but 3/8' -1/2" welds are used throughout.

After design analysis and feasibility checks were successfully completed, parts were then selected. Here, the design changed due to lack of readily available parts or fits not meeting specifications. Most of the originally specified parts were swapped for comparable pieces. The electric brakes with a brake box was swapped for the set of hydraulic brakes based on the actuator in the tongue. The only change of any significance was the size of the hinge tube and pin. Originally, both the pin and tube were sized at 5/8", but 5/8" inner diameter tube was not easily found, while it was known that 3/4" pins and tube existed and would create no additional problems. The parts picked up are listed in table 2.
<table>
<thead>
<tr>
<th>Item</th>
<th>QTY</th>
<th>Suspension</th>
<th>QTY</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tires</td>
<td>4</td>
<td>4&quot; Square steel tube</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>93 inch axle w/ 5.5&quot; drop</td>
<td>2</td>
<td>3&quot; Square steel tube</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Hydraulic brakes</td>
<td>1</td>
<td>1/2&quot; flat bar</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Leaf Spring</td>
<td>4</td>
<td>1&quot; tube</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Hanger Kit</td>
<td>1</td>
<td></td>
<td></td>
<td>Pins</td>
</tr>
<tr>
<td>U bolt Kit</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brake hose and kit</td>
<td>1</td>
<td></td>
<td></td>
<td>Trailer Lighting kit</td>
</tr>
<tr>
<td>Hydraulic surge Break and Kit</td>
<td>1</td>
<td></td>
<td></td>
<td>Conductor Wire</td>
</tr>
<tr>
<td>Brake Fluid</td>
<td>1</td>
<td></td>
<td></td>
<td>Wire Cover</td>
</tr>
<tr>
<td>Decking</td>
<td></td>
<td>Angle Iron</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Structural Steel Braces</td>
<td>10</td>
<td></td>
<td></td>
<td>Paint</td>
</tr>
<tr>
<td>2&quot;x8&quot;x8'</td>
<td>8</td>
<td></td>
<td></td>
<td>Trailer Jack</td>
</tr>
<tr>
<td>2.5&quot; Wood Screws</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2&quot;x4&quot;x8'</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The 4" tubes were cut into pieces of the proper size for their respective piece of frame, then welded together. The rectangular frame pieces have the lateral square tubing recessed from the front and rear edges so that the inside seam of the hinge plates were MIG welder accessible when the hinges are added on. The four separate sections were laid aside during the creation of the hinges.

The hinges were the most time consuming portion of the project due to the desired precision of hinges combined with the process of welding, which is the antithesis of precision due to porosity, inclusions and heat deformation of the base metal. The hinges were created as a unit. That is, each hinge was placed into the locations desired, then clamped together so that all 8 pieces of the hinge were stationary, and finally welded together. To achieve maximum penetration, as well as create a place for the bead to exist on the inside of the hinge joint, a fillet was used on the outside edge and a J-groove on the inside edge of the base plate. Twelve of these plates were made which made up six hinges for the four sections.

When the hinges were completed, the hinge plates were taken to the corresponding section of the frame and welded onto the end. This process began with 2 faces onto the front facing side of the base section. After these were attached, then the other half of the hinges were joined by pins to the half already attached to the base section. The middle section was then tacked onto the hinges. Before completely welding the sections to the hinges, the hinges were tested for mobility.
Figure 10: The jig holding the hinges together. It was vital to hold the hinges in the position in which they were supposed to operate to maximize the possibility of a successful hinge.

Figure 11: Holding the two sections together was interesting, but many clamps and supports were used to hold the piece in place.

After the of the sections had their various hinges welded on and assembled, the entire frame was connected to the purchased suspension system. The lights were wired through the frame and the license plate added.
The Folding Process

Figure 12: This is the unfolded position of the trailer. To fold the trailer, the bolts marked are removed from the hinges and set aside. The trailer jack is folded flat and in line with the rest of the tongue.

Figure 13: Here the forward part of the middle section has been lifted, starting the folding of the front and middle sections.
Figure 14: The forward part of the middle section has been lifted so the tongue is folded flat against the middle section.

Figure 15: As the bottom of the middle section is touches the bottom of the tongue, the two sections are laid onto the top of the base section.

Figure 16: The final step is to raise of the rear section to lean on the tongue.
The Loading Process

Figure 17: Step one: Unpin the top part of the forward hinges and use the trailer jack to hoist the first hinge section upward, moving the rear end of the trailer closer to the ground.

Figure 18: Side View of the trailer jack hoisting the front section skyward.
Figure 19: Roll the car being loaded onto the rear section of the trailer. This pushes the rearmost part of the trailer onto the ground. When the truck rolls forward onto the trailer, the rear wheels of the truck will not touch the back edge of the trailer until after the front wheels move forward of the balance point, necessitating the chain on the left to keep the trailer locked into the angular position during loading.

Figure 20: The first loading of the trailer has been complete.
Testing

The testing process for the trailer was a series of test incrementally increasing the weight of the load followed by increasing the speed of travel. The testing started with an unloaded condition driven around town and then on the freeway. The trailer performed admirably throughout, though sections bouncing and rattling were persistent through the drive. The load was increased to around 1500 pounds while removing things from San Luis Obispo. During freeway conditions, the bouncing and rattle were removed. The figure 15 loading was the next test condition. The first real test of the trailer, the subject was driven over 8" speed humps at 35 mph. The truck bounced and we lost some things out of the bed of the truck, but there were no visible signs of the trailer deflecting either at rest or while moving. The final load condition was a 5800 pound Ford Expedition. Under static load, the trailer was deflecting at the hinges, but each of the frame sections were straight. When the expedition was taken over the same speed hump at 35 mph, there was no noticeable deflection from the static loading.

Conclusion

Challenges

The challenge from the designers perspective comes from minimizing the weight and cost of the final product, while not compromising structural integrity of the vehicle. The most taxing aspect of this project was easily the construction side and the number of hours required to build a functional prototype up to specifications, even though most of the specifications were self inflicted. Originally, the estimated time to completion was 15 hours for a skilled crew of machinists and welders. While most of this project did not take skilled welders and machinists, they would have greatly improved the product and reduced production time. The actual time to completion after starting work was about 120 man hours. Most of this time was spent figuring out how to create functioning hinges from a welding process.

Future Additions

Since my family is the proud new owner of the trailer, improvements are both ongoing and planned. Planned improvements cover all of the points in the wish list that were not implemented. These include installing a winch and a four bar mechanism that collapses the trailer without any extra human assistance. Another potential improvement is a system of sidewalls that will allow for greater loading capacity for loose or light material. Additions that don't apply to an automotive trailer that do apply to general trailers may be added to increase utility. These additions may or may not include: sidewalls, roof and an improved deck.
Changes

There are numerous areas that need major improvement if any other model of this trailer is to be produced. The first change would involve producing axles in house. The total cost of the components in each axle is $50, where they were purchased for $200. Originally, I thought they were a complicated piece of equipment, but on visual inspection, they are relatively easy to produce. The second area is acquiring the proper size of tube for the frame and tongue. The entire structure should be built out of 2"x4" tube. This would decrease both weight and cost of the frame by about 25%. The final major improvement would lead to purchasing complete high load hinges instead of fabricating. The fabricated hinges do not hold the frame stiff enough and are time-expensive to make.
In the YZ Plane

\[
\text{EMA} = EMA_{AB} = EMA_{BD}
\]

\[
6000 \text{ lb} \times 30^\circ = 6000 \text{ lb} \times \cos(30^\circ) + (R_{LF} + R_{RF}) = 120^\circ (R_{LF} + R_{RF}) = 504,000 \text{ lb}
\]

\[
R_{LF} + R_{RF} = 4120 \text{ lb}
\]

\[
F_{Y} = 0
\]

\[
0 = -6000 + 4200 + R_{LR} + R_{RR}
\]

\[
R_{LR} + R_{RR} = 1800 \text{ lb}
\]

In the XY Plane

\[
\text{EMA} = -56 \text{ lb} \times (6000 \text{ lb} \times 30^\circ) = -6000 \text{ lb} \times \sin(30^\circ) + (R_{RR} + R_{RF})
\]

\[
-9000 \text{ lb} 
\]

\[
120^\circ (R_{RR} + R_{RF}) = 72^\circ (R_{RR} + R_{RF})
\]

\[
R_{RR} + R_{RF} = 1750 \text{ lb}
\]

\[
F_{x} = 0 = R_{RR} + R_{RF} + R_{LR} + R_{LF} = 6000 \text{ lb}
\]

\[
R_{LR} + R_{LF} = 6000 \text{ lb} - 1750 \text{ lb}
\]

\[
R_{LR} + R_{LF} = 4250 \text{ lb}
\]

Finding Front/Rear weight ratio:

\[
F_{LR} + F_{RF} = 4200 \text{ lb} = 0.70 = F_{LR}/F_{RF}
\]

\[
R_{LR} + R_{RF} = 1800 / 4200 = 0.43 = R_{LR}/R_{RF}
\]

Applying 1 1/2 to left & right sides:

\[
R_{LR} = F_{LR} (R_{RR} + R_{RF})
\]

\[
R_{RF} = 0.70 (1750) = 1225 \text{ lb}
\]

\[
R_{LF} = F_{LF} (R_{RR} + R_{RF})
\]

\[
R_{LF} = 0.70(4250) = 2975 \text{ lb}
\]

\[
R_{LR} = 1.30 (4250) = 525 \text{ lb}
\]

\[
R_{RF} = 1.30 (1750) = 2275 \text{ lb}
\]

\[
R_{RR} = 1.30 (4250) = 525 \text{ lb}
\]

\[
R_{RF} = 12.75 \text{ lb}
\]
Assumptions:
- Constant acceleration
- Hitch transfers no moment
- Breaking force on towing vehicle & car are equivalent

\[ HR_x = FR_x = \frac{1}{2} LR_x \]

Trailer weight 1000 lb

Solve for location of center of mass (approximate)

\[ 600 \text{ lbs} \]

\[ 0 = -6000 \text{ ft lb (ft)} - 1000(x) + 700 \text{ lb (ft ft)} \]

1000 lb \( x = -6000 \text{ ft lb} + 700 \text{ lb ft ft} \)

\[ x = 3.8 \text{ ft} = 55.6\text{"} \]

COG is 105.6" from the back edge
Approximate tongue load

Assume the axles are about the same and can be approximated as one reaction at the central hanger.

\[
\begin{align*}
1800 \text{ lb} & \quad 1000 \text{ lbs} & 4200 \text{ lb} \\
21" & \quad 42" & 39.6" & 28.4" & 96" \\
60" & \quad 174" & \\
\end{align*}
\]

\[\text{Wheels} \quad R_{\text{Hity}}\]

\[\sum \text{Wheels} = R_{\text{Hity}} (174") + 1800 \text{ lb}(42") - 1000 \text{ lbs}(39.6") - 4200 \text{ lb}(78") = 0\]

\[o = R_{\text{Hity}}(75.0"/96" - 39.6"/116") = 327.000"/116"\]

\[R_{\text{Hity}} = 1675\]

Braking - Assume trailer provides half braking power

\[F_{\text{Trailer}} + F_{\text{End}} = N_{\text{Braking}}(o)\]

\[2 F_{\text{Trailer}} = 7000 \text{ lb} + 4000 \text{ lb}, 589\]

\[F_{\text{Trailer}} = 5200 \text{ lb}\]

\[\text{Brake stud} = (2000 \text{ lb})\]

\[\text{Brake arm} = \frac{60}{\text{in}} \times 10^8\]

\[\sum M_{\text{Axle}} = I_{\text{Axle}} - 2000 \text{ lb} (589" + 5200 \text{ lb})\]

\[M_{\text{Axle}} = \frac{(40 \text{ lb})(100 \text{ lb})}{2} \times \frac{3072 \text{ ft}^3}{(37.2 \text{ lb/ft})^2} = 26000 \text{ ft} \cdot \text{lb} + 26000 \text{ ft} \cdot \text{lb} + 26000 \text{ ft} \cdot \text{lb}\]

\[\alpha = \frac{55}{3072} \text{ rad/s}^2\]

\[\alpha = 650 \text{ lb-ft}\]
Axle Reactions

From Y-Z Plane: FBD

\[ F_{\text{rear}} = 0 = 1800 \text{ lb (27 in.)} + (R_{\text{y}} + L_{\text{y}})(30 \text{ in.}) - 1000 \text{ lb (54.6 in.)} - 420 \text{ lb (73 in.)} + 1675 \text{ lb (189 in.)} \]

\[ (R_{\text{y}} + L_{\text{y}}) = 48600 \text{ in lb} - 54600 \text{ in lb} - 34960 \text{ in lb} + 34575 \text{ in lb} \]

\[ R_{\text{y}} + L_{\text{y}} = 26675 \text{ lb} \]

\[ E_{\text{y}} = 0 = R_{\text{y}} + L_{\text{y}} + R_{\text{f}} + L_{\text{f}} + \frac{R_{\text{f}} + R_{\text{y}}}{1000 \text{ lb}} \]

\[ R_{\text{f}} + R_{\text{y}} = (26675) - 1675 \text{ lb} + 7000 \text{ lb} \]

\[ R_{\text{y}} + R_{\text{f}} = 26575 \text{ lb} \]

Name \[ \frac{26575}{26675 + 26675} = 0.999 \text{ in the rear} \]

In front \[ 0.999 \text{ in front} \]

From X-Y Plane: FBD

\[ E_{\text{f}} = 0 = (1675 - 1000) \text{ lb (34 in.)} + (R_{\text{y}} + R_{\text{f}} - 1750 \text{ lb})(6 \text{ ft}) \]

\[ R_{\text{y}} + R_{\text{f}} = 14125 \text{ lb} \]

\[ E_{\text{f}} = 0 = -7000 + 1675 + 14125 + L_{\text{f}} + L_{\text{y}} \]

\[ L_{\text{f}} + L_{\text{y}} = 34125 \text{ lb} \]

\[ L_{\text{f}} = 1960 \text{ lb} \]

\[ L_{\text{y}} = 1942.5 \text{ lb} \]

\[ R_{\text{f}} = 7076 \text{ lb} \]

\[ R_{\text{y}} = 7041.8 \text{ lb} \]
Assuming, static = No Dynamic Deflection/minimal dynamic deflection

\[ R_{Fy} = 976 \text{ lb} \]
\[ E_y = 776 \text{ lb} \]
\[ L_{E_x} = R_{Fy} \]

Since the side of tires on asphalt is only 7 on Dry roads, the max braking force is

\[ F_{max} = M_{\text{reynolds}} \times (N_L) \]
\[ F_{max} = 17 \times (1960) = 33,220 \text{ lb} \]

\[ E_{Fy} = 0 = -1372 \text{ lb} + F_{E_x} + F_{Fy} \]

Since the moment arm from the spindle is only 2\(^\circ\), for the braking force on the hangers, it is set to assume:

\[ R_{E_x} = F_{Fy} = 1372 \text{ lb} = 786 \text{ lb} \]

\[ EM_{Fy} = 0 = F_{Fy} \times 1 \text{ lb} \text{ in} \times F_{Fy, (15\,^\circ)} - R_{E_y, (15\,^\circ)} + 2 \times 786 \text{ lb} \times 2\,^\circ \]
\[ F_{E_{Fy}} = F_{Fy} = 1960 - R_{E_y} \]
\[ F_{Fy} = 615.2 \text{ lb} \]

\[ c_{Hy} = 1344 + 976 \text{ lb} \]
\[ c_{Hy} = 2320 \text{ lb} \]

At this point, the assumption for No/minimal dynamic deflection is proven to be false in that the assembly will rotate around the central hanger, redistributing the 1344 lb reaction forward. This would result in a smaller bending moment. The no/minimal dynamic deflection assumption is a more conservative estimate, and therefore acceptable.
Since the car is skidding, breaking on the right side is:

\[ F_{break} = M_k (RF) \]
\[ F_{break} = 7 (707) = 4911 \text{ lb} \]

From FBD, forces (P2):

\[ EF_z = 18g \left( \frac{7000 \text{ lb}}{6} \right) = F_{break} + F_{break} + RH_t + z \]
\[ -5600 \text{ lb} = -1195 \text{ lb} - 1372 \text{ lb} + RH_t + \text{z} \]
\[ RH_t = -3730 \text{ lb} \]

Making an assumption similar to that on P5 allowing for the resolution of RHx,
we are grouping the 4 sliding forces (on the wheels in the x-direction) into 1 force.

\[ 39.6'' \times \frac{7000 \text{ lb}}{3} \]
\[ \text{wheel } x \]
\[ 174'' \]

\[ \text{M}_{\text{wheels}} = 18g \left( \frac{7000 \text{ lb}}{6} \right) \times 6'' = RH_y (174') \]
\[ RH_y = 2500 \text{ lb} \times 39.6'' \\ 174'' \]
\[ RH_y = 796.5 \text{ lb} \]

\[ \text{M}_{\text{corner}} = 40'' \text{ (Right W)} + 40'' \text{ (Left W)} = 795.5 \text{ lb} \times 134'' \]
\[ \text{Right + Left} = 795.5 \times 134'' \text{ lb} = 2600 \text{ lb} \]

With no other moments Left \approx Right = 1330 \text{ lb}

By same logic
\[ RH_x = RF_x = 665 \text{ lb} \]
\[ LR_x = LF_x = 665 \text{ lb} \]
Hobson

LEFT SIDE

\[ \frac{P}{A} = \frac{R_{1} + z}{A} = \frac{3730 \text{ lb}}{A} = 2002 \text{ psi} \]

\[ \sigma_{\text{bending}} = \frac{M_0}{It} = \frac{16.92 \text{ lb} \cdot \text{in} \cdot 2.12 \text{ in}}{12 \text{ in}} = 87194 \text{ psi} \]

\[ \sigma_{\text{shear}} = \frac{V}{It} = \frac{1350 \text{ lb} \cdot 1.86}{12 \text{ in}} = 4500 \text{ psi} \]

\[ \sigma_{\text{principal}} = \frac{V_{0}}{F_{0}S} = \frac{3.5 \sqrt{(87194 + 2002)^2 + 4500^2}}{312,000} \text{ psi} \]

\[ \sigma_{\text{pin}} = 312,000 \text{ psi} \]
\[ \begin{align*}
\Sigma M_y &= 0 = F_x (\ell) + 16992 + 16 \\
F_x &= 34000 \text{ lb} \\
\Sigma F_y &= 0 = F_x + P_k \\
P_k &= 34000 \text{ lb} \\
\text{Assume } R_y &= F_y = 2(38/2) = 1319 \text{ lb} \\
\text{Resultant } &= \sqrt{(34000^2 + 1319^2)} \text{ lb} \\
&= 34025 \text{ lb} \\
\text{Bolt Sizing } & \text{ using } P_{\text{max}} \\
A &= \frac{P}{F_{\text{ydd}}/2.5} \\
A &= \frac{34025}{400,000/2.5} \text{ in}^2 \\
&= 0.3 \text{ in}^2 \\
A &= \sqrt{0.3/0.7} \text{ in} \\
&= 309 \text{ in} \rightarrow 0.15 \text{ Diameter pin minimum }
\end{align*} \]