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## Orchard Bin ATV Trailer

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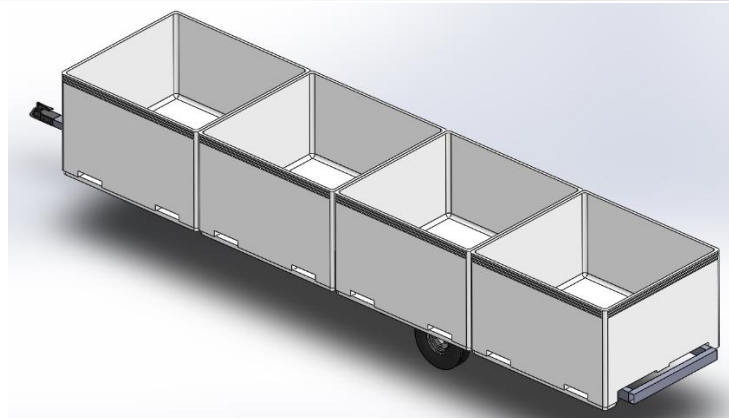
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# Orchard Bin ATV Trailer

By

Neil Leitz



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# Introduction

## Motivation

The motivation behind this project was the need for a method for transferring empty apple picking bins into an orchard that would make use of unutilized equipment. The contracting orchardist in this case needed an alternative method of transporting the empty bins into the orchard to enable the use of their industrial grade, hydraulically driven bin trailer to be used in solely picking up filled bins that would be too heavy to be moved with other equipment, rather than putting empty bins into the field.

## Function Statements

A device is needed that will be able to transport apple picking bins from a staging zone into an orchard.

## Design Requirements

The design requirements for the device are as follows:

- The device must be a trailer.
- The device must be able to carry a total of 4 bins with a total combined length of 16.5 feet.
- The device must be able to interface with a Honda Rancher 350 ATV via a two inch ball hitch.
- The device must be able to carry a total of 12 lbs/ft spread evenly over its surface.
- The device must be able to carry the weight of the bins during a situation where all of the bins bounce 6 inches above the trailer deck.
- All parts and structural materials must cost less than \$750.00.
- The device must be able to accommodate Macrobins of sizes 28-FV and 33-FV and standard wood bins. The range of distances for these bins are 33-41 inches inside rail to rail length.
- The device will be able to travel at 20 mph under full load.
- The ball hitch must support 10-15% of the distributed load (Where to put wheels?, 2010)

## Engineering Merit

This project includes basic structural design, budgeting, stress analysis, and basic dynamics. This includes the use of the static equations of equilibrium, momentum and velocity analysis equations, and stress equations including bending stress and maximum shear stress.

## Scope of Effort

This project will take a large amount of effort, the majority of being in the design phase. Best estimates predict a work time of approximately 50 hours of design time and a work time of about 20 hours for the assembly of the trailer.

## Success Scenario

The success criteria for this project will be based on both the satisfaction of the customer, and on tests of the capabilities of the device, including an obstacle course based utility test, in a fashion consistent with the scenarios imagined during designing.

## Design and Analysis

### Approach

The proposed approach to the problem is a wheeled trailer that will be able to couple to an ATV. In the realm of materials and structure, a good fit for both categories would be a type of steel tubing. The size of the tubing will be 2x3 outside dimensions (being most readily available from the supplier), with the thickness being determined through stress analysis.

The placement of the wheels must also be calculated. According to listed source number 1, a good way to go about this is to place the wheels so that the hitch of the trailer will carry 10-15% of the load. (Where to put wheels?, 2010)

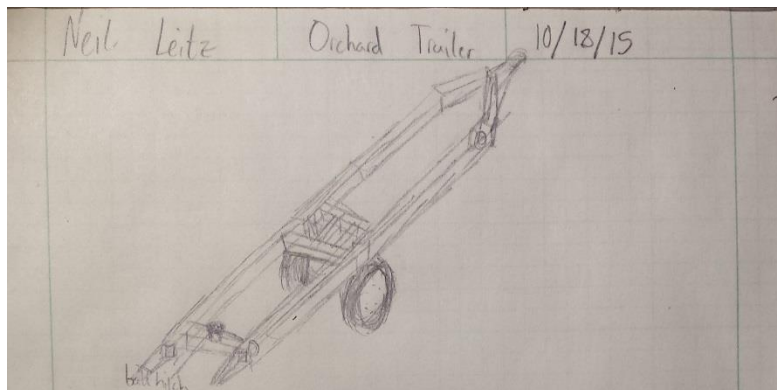
To perform these analyses of the structure of the trailer, the beam will be analyzed via the zero-sum force and moment equations. This will allow the positioning of the tires, which will then progress into energy/momentum analysis to find maximum loading, and finally using this max loading the maximum stress will be found again with the use of statics and strength of materials equations, primarily being bending stress found with both shear and moment diagrams, as well as section cutting. With maximum stress known, a thickness can be chosen for the tubing based off of the required section modulus. This modulus will be optimized through the use of computing software.

### Design Description

The preliminary concept sketch for the trailer design is included in Appendix J and labeled as "Analysis A". Since all that is needed is a trailer that can carry bins that are designed for being lifted by forked machines, the trailer design will contain two long rails, similar to forklift forks. To fit four bins, the length of the rails must be 16.5 feet. This accommodates all of the bins and leaves a small amount of room, in the length range of 4 inches. The rails have structural members that span the rails in the front, back, and middle to maintain rigidity and also to make an area for the later mentioned axles to mount to.

To keep the trailer from bouncing excessively, the design makes use of independent torsion bar axles. These independent axles are connected to the cross members via a steel plate and will absorb some of the energy the trailer will be subject to when traveling over bumps. In doing this, it will help minimize the chance of bins falling off the trailer.

A quick example of an above view is also included in Appendix J and is labeled as "Analysis A" It includes the full trussing of the trailer and the aforementioned parts. However, it excludes the two inch ball hitch coupling that will be located on the protruding tubing at the front. For the most basic draft of the structure of the trailer see Fig. 1 below.



**Fig. 1** – The first sketch of the design. Since the time of this sketch, the trailer has changed a few characteristics, including a differently shaped tongue and rail endings.

There are, in fact, two different iterations of the design. The main differing characteristic between them is the type of torsion bar axle used. The second iteration was chosen as the final design due to its more compact nature.

### **Benchmark**

A benchmark that this device is attempting to reach is to be able to replace the industrial strength, hydraulically powered bin trailer owned by the contracting party in its bin placement duties. Another benchmark this project aspires to is to minimize the cost of the design to 750\$ or lower. These benchmarks are both readily attainable with correct implementation of the designs and materials involved.

### **Performance Predictions**

While the analysis performed to arrive at a final design contained a fair amount of uncertainty (regarding the kinematic analysis primarily), the chosen material provides a very large safety factor of 18. There are no doubts that this design will perform up to the standards of the customer in terms of strength and resilience of the structure of the trailer.

### **Description of Analyses**

The analyses began with the evaluation of where to put the tires in relation to the front of the trailer. Using the basic equations of statics (sum of forces and moments equals zero), and the guidelines of 10-15% of the loading weight should be on the hitch, a distance for the tires of 11.75 feet was arrived at. This analysis method is detailed in Appendix A and is titled "Analysis A".

The next section of analysis involved assuming an impulse being transmitted onto the rails of the trailer by bouncing bins, to find an assumed maximum loading. A max velocity of the bins was found using both potential and kinetic energy. This velocity was then used to calculate the momentum carried by a single bin, and then into the forces this bin would impart onto the deck if it were to collide completely flat. This ended in a maximum distributed load of 20 lbs/foot, compared to the original distributed load of 12 lbs/ft. Details on this analysis can be found in Appendix A - Analysis B.

The final set of analyses involved calculating the maximum stresses occurring in each element of the structure. Each individual element was examined to find the maximum shear and maximum occurring internal moment. When the overall maximum was discovered to occur in the end of the trailer right next to the tubing that provides height to the frame, that moment was used in conjunction with given mill specs (ultimate strength) for the steel being used to find what the minimum required section modulus of the tubing would be. After calculating it, an optimization spreadsheet was used to examine the required dimensions of the tubing. These calculations and the spreadsheet can be found in Appendix A-Analysis C and Appendix A- Analysis D respectively.

## Scope of Testing and Evaluation

The scope of testing and evaluation will depend mostly upon the satisfaction of the customer. There are currently only discussions involving testing mainly of the utility and functionality of the trailer through work in the field and observation.

## Analyses

The analysis procedure followed these steps:

1. General shape sketched for performing calculations
2. General shape used to calculate the required positioning of the tires
3. Maximum possible loading calculated for each of the components, with the overall max being used to find the required section modulus of the structural materials.
4. Section modulus chosen from an optimization chart taking into account the customer's desired material.
5. Final max stress and tire position are calculated based on final design for the trailer. Position of the tires is verified.

What follows is a detailed breakdown of each of these steps:

1. The general shape of the structure was decided primarily from the design requirement of carrying 4 bins. This means the trailer would be required to have a carrying length of 16.5 feet to comfortably fit the entire load. The other structural members were put in to provide a place for axle mounting and to provide rigidity and load sharing between the two rails.
2. The position of the tires was calculated based on the static loading of the design. The details for this analysis can be found in Appendix A – Analysis A.
3. The maximum possible loading was calculated using an energy-momentum collision method. The analysis for this section is detailed in Appendix A – Analysis B
4. A section modulus was chosen from the required stress calculated in the previous step using the ultimate tensile strength of the steel material being used. The material of 3"x2"x.125" was chosen based on this optimization. These portions can be found in Appendix A- Analysis C and D.
5. Wheels, hubs, and axles were chosen and the trailer model was adapted to accommodate these parts.
6. A final stress analysis was performed of all individual components of the trailer. The final position of the tires was verified to fit the design requirements. These analyses can be found in Appendix A- Analysis E and F.
7. A quick analysis of fatigue life of the material was created and inserted into Appendix G

## Device: Parts, Shapes, and Conformation

The majority of the structure of the trailer is 2" x 3" x .125". A few pieces of bracing and the mount for the axle stubs are made of .25" thick plate. The other components of the trailer (the ball hitch coupler, fasteners, and the axle stubs/hubs/tires/rims) are all to be ordered from part suppliers. The steel will be ordered in the proper lengths from Moses Lake Steel Supply.

The structural steel was chosen in part due to its dimensions. With the chosen axle stubs and wheels, a fair amount of height was needed to prevent the tires from penetrating up into the upper plane of the rails. Not only this, but the added safety factor is well warranted in a situation of highly fluctuating loadings.



### **Device Assembly and Attachments**

The assembly of the device will consist of primarily welding. Holes will have to be marked out and drilled on the mounting plate and the through the tongue to make way for the fasteners that will be used to secure the parts. The hole drilling will be the very first step in the assembly process.

Continuing on, the frame will first have all of its component parts laid out in the shape. Then each individual part will have to be prepared for welding, which will involve a few hours of joint grinding. After the frame is fully assembled and welded, the welds will need to be cleaned up and the painting process can begin.

The paint will be applied with a pneumatic paint gun, which will greatly expedite the painting process.

### **Tolerance, Kinematics, Ergonomics**

The most important tolerances on the trailer is the placement of holes drilled for mounting the torsion stub axles, as well as the bolt holes drilled into the tongue for mounting the ball hitch coupler. These holes must be very precise (+/- .005 inches) so as to allow a clean fit for the fasteners all the way through.

### **Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operational Limits**

This trailer will undoubtedly fail in bending stress fatigue. This will take a large amount of repeated loading cycles for this to happen, but will be accelerated by being stored in an outdoor setting and from the welding disrupting the heat treatment of the tubing.

## Methods and Construction

### Description

The construction process will utilize a two person team. With best estimates, the total welding time for the frame will be around 12 hours, and consume approximately thirty dollars of welding rods. The general process for the construction will be to drill all the required holes in the mounting plate and the tongue, grind joints into the tubing and clean it off in preparation for welding, assemble and weld the frame, and finally complete final assembly by bolting on the tire assemblies and the ball hitch coupler. The frame will be welded upside down to assist in holding the work steady and square when welding/fabricating.

### Drawing Tree

The drawing tree for the finished trailer can be found at the beginning of Appendix B. It contains a total of 5 drawings and their accompanying alpha-numeric designation. The reason for this low number of drawings is primarily due to the nature of project, where two of the subassemblies contain parts that are simply mirror images of each other, meaning a drawing was only warranted for one side of the trailer. The only need for the drawing was to demonstrate the assembly of the purchased parts, not to list or demonstrate dimensioning or tolerance of the parts.

### Parts List

A complete parts list and the breakdown of the price of each part is included in Appendix C. There are a total of 71 individual components in the trailer, including individually cut to length tubing, steel plates, bolts, torsion axle stubs, tires, nuts, lugnuts, and a towing coupler.

### Manufacturing Issues

Currently, the only issue with manufacturing so far has been the tolerances on parts produced from the steel supplier cutting the tubing to length. However, all of these parts were cut slightly larger than necessary, so it can be fixed with a small amount of grinding to bring the parts to the proper dimension.

## Testing Method

### Introduction

There were two major documented tests performed to verify the functional characteristics of the orchard bin trailer. One test was a weight recording test, and the other was a filmed field functionality test that included conditions such as turn radius, loading and unloading, as well as observed design issues that would need to be fixed.

The weighing test sought to verify the weight that is distributed from the fully loaded picking bin trailer onto the trailer hitch. According to the analyses performed, and the placement of the tires on the frame, the hitch should be supporting approximately 10%-15% of the total loading. This test was covered by Gantt chart item 5a.

The recorded field functionality testing sought to observe and locate any issues that would occur during operation. It also was used as a benchmark to gauge the general performance of the trailer during normal operation. This particular test was covered under Gantt chart items 5b-5f.

### Methods/Approach

#### Weight Testing

The weight test utilized the following equipment:

- Fully assembled bin trailer
- Spring scale capable of measuring up to 250 pounds of weight
- Four 33-FV type Macrobins to load onto the trailer
- A structural frame to hang the spring scale on during measurements
- Blocks to stop the trailer from rolling

The data was hand recorded onto the attached data sheet, and was later input into Excel for further analysis. However, this test was performed purely to measure deviation from

The precision of measurements in this test rest solely on the precision of the spring scale being used. For this test, having a precision of  $\pm 5$  pounds is adequate. The accuracy of this test depends entirely on the consistent use of all the equipment by the tester. That is, for greater accuracy of the test, the tester is required to make sure to keep all steps of the test as consistent as possible. Care should also be taken to have all measurements taken on level ground to prevent skewed results.

To assist in keeping these measurements consistent, after each weighing, the spring scale should be fully unloaded before having another object placed onto the scale for weighing.

#### Functionality Testing

The functionality testing utilized the completed bin trailer, the ATV it was designed to be pulled by, and a video recording device. The trailer was recorded in a variety of situations, including actual simulated operation in the orchard.

## Test Procedure

### Weight Testing

The weight test takes approximately a half hour. This time does not include setup time. It should be performed on a flat surface that contains the rigid frame for hanging the spring scale. The procedure is as follows:

1. Hang spring scale on frame.
2. Calibrate spring scale using a calibration weight with a known value. Record the error in the spring scale readings from this calibration. Repeat until you have ten weight errors that can be averaged.
3. Use the spring scale to measure the weight of each of the five picking bins and record these weights on the attached data sheet. Adjust the measurements for the spring scale error. Record these values.
4. Use the spring scale to measure the weight of the tongue of the unloaded trailer. **Make sure the trailer has the wheels blocked during any weighing to prevent rolling that could lead to accident or injury.** Repeat until you have five recorded measurements to average. Adjust this measurement for the spring scale error.
5. Place all of the bins onto the rails of the trailer and again weigh the tongue five times, taking an average and adjusting for the scale error. Record these values.

### Functionality Testing

The functionality testing method did not have a formal method, though there were different types of subcategories of tests involved in this larger test. This includes turn radius measuring, loading and unloading time tests, and trailer operation on a hillside. Each of these situations were recorded, and issues that arose during these situations were made careful note of. Afterwards, solutions to these observed problems were proposed and documented as well.

## Deliverables

### Weight Testing

After collecting the data from measurements, it can be used to determine the percent load the trailer coupler is transmitting. The formula for the percent load is as follows:

$$\% \text{ Hitch Load} = \frac{(\text{Full Trailer Hitch Load}) - \text{Empty Trailer Hitch Load}}{\text{Total Weight of Picking Bins}}$$

The value should fall between 10%-15%. A spreadsheet of the data collected from the test is available in Appendix C of this report.

### Functionality Testing

The collected information from the functionality testing is both viewer observations and recorded observations of both normal operation conditions and problems observed during this normal operation. A text narrated copy of the performed functionality testing is available on the following website: <http://leitzneil.wix.com/leitzneil>.

## **Budget/Schedule/Project Management**

### **Schedule**

An in depth Gantt chart describing the scheduling and its breakdown for the introductory phase of this project is provided in Appendix D. It details both the amount of time a task was estimated to take, as well as the amount of time it actually took to complete.

The total estimated amount of time for the first phase of the project was thought to be somewhere in the mid 50 hour range. However, the Gantt chart provided in Appendix D details the fact that it took over a combined 90 hours, from start to finish of the design, documentation, and analysis of the trailer.

### **Cost and Budget**

The main cost of the parts for the trailer design are from the purchasing of the structural steel tubing and wheels/axle stubs. These two categories constitute approximately 90% of the total cost of building the trailer. The contracting party was very forthcoming in their allowable budget, giving a price ceiling of \$750.00 for the materials. With the trailer that was designed, the materials came out to be only about 80% of what the expected cost was. With donated labor, the total cost for construction will not go above the given material ceiling amount. If labor were to be taken into account, with a total amount of man-hours of about 20 for manufacturing, at \$14 an hour that gives roughly an extra \$280 to budget for.

The rest of the cost besides the two categories already discussed are absorbed into fasteners and the towing coupler. The fasteners are all bolts which are strong enough to withstand the shearing forces from the trailer acceleration and the tensile forces from bouncing and rocking.

### **Part Suppliers**

The part suppliers for this project are primarily online sourced part stores. Northern Tool is selling the purchased tires, Southwest Wheel is selling the purchased torsion axle stubs and accompanying hubs. Moses Lake Steel Supply is the company that is supplying all of the required steel tubing, plate, and fasteners.

### **Funding Source**

The funding for this project is being provided by George Jelmsberg. He is the contracting party for this trailer design and is also the owner and manager of Dragonfly Organic Orchards, which is located 15 miles west of Royal City, Washington. He is graciously also donating the use of his facilities, which includes a shop with welding preparation tools, welding machine, and all manner of tools related to this.

## Discussion

This project proceeded at a fairly stable pace. There were a few rocky areas that were run through during the analysis of the structure of the trailer. These involved issues with free body diagrams and how they related to shear and moment diagrams. The problems were eventually solved however, and everything after that point proceeded smoothly in the analysis.

There were a few problems that arose also in the arrangement of the structure of the trailer. In one of the earlier iterations of the design, which contained a torsion bar axle stub that had a longer mounting section, there were numerous problems with collisions between the tires and the frame of the trailer. This was fixed via the selection of a different torsion bar axle stub pair from a different supplier. The shorter length of the mounting section allowed the axles to be moved closer in towards the center of the trailer. This in turn allowed for space between the tires and the inside of the frame. The change to the different axle was also helpful because it allowed the for the use of an accompanying schematic to accurately model the part, which in turn helped create a more accurate overall model.

When looking to do something like this again, it would probably be much more efficient and clean to simply do finite element analysis on the structure, rather than going through and finding each individual components loading and maximum stress. FEA would also allow for predictions of how weld joints would react.

Since the project team is lacking in welding experience, the welding guidelines and information were more or less controlled by the customer, George Jelmsberg. He provided technical knowledge and welding labor to assist in the assembly of the trailer to ensure clean welds that will hold well.

## Conclusion

The design of this trailer was carefully thought through and documented throughout the entire process it went through. From the basic idea all the way through manufacturing, special consideration and care was given. This trailer is of a very simple design while also being comparably cheaper to other very similar trailers. This product fills all the requirements of a bin trailer without sacrificing strength and durability.

The quality of this orchard bin trailer shows from not only the man hours spent meticulously reviewing the scenarios and operating conditions it will be in, but also the time spent choosing proper materials and careful documentation and modeling.

## **Acknowledgements**

A hearty thank you goes out to George Jelmsberg and his family for their support, both mental and material, and their helpful ideas in the design and selection of materials going into this trailer.

A thank you also to Charles Pringle and Craig Johnson for helping along the way to solve any uncertainties that occurred during the analysis of the trailer design.

## References

*Where to put wheels?* (2010, 12 6). Retrieved from Sketchucation:  
<http://sketchucation.com/forums/viewtopic.php?f=15&t=33175>

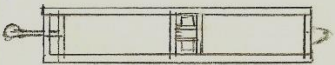


## Appendix A: Analyses

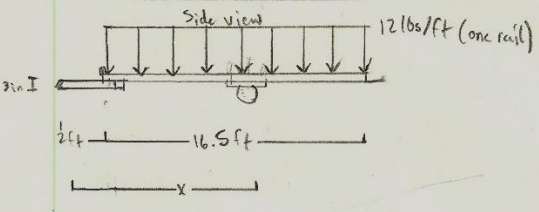
### Analysis A

Neil Leitz Iteration 1

Top View



Side view



12 lbs/ft (one rail)

16.5 ft

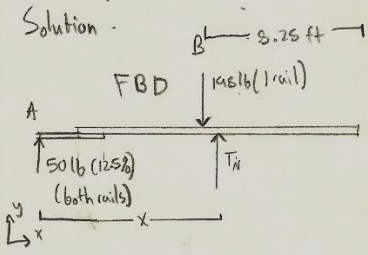
10.25 ft

x

Given: Basic trailer design/Loading

Find: Position of tires on the trailer that give the ball hitch coupling 10-15% of the distributed load

Solution



FBD

8.25 ft

10.25 ft

50 lb (125 lb) (both rails)

396 lb (1 rail)

$T_N$

x

$$\uparrow + \sum F_y = 0 = 50 \text{ lb} - 396 \text{ lb} + T_N$$

$$T_N = 346 \text{ lb (Both tires)}$$

$$\uparrow + \sum M_A = 0 = (-396 \text{ lb} \cdot 10.25 \text{ ft}) + (346 \text{ lb} \cdot x \text{ ft})$$

$$2029.5 \text{ ft} \cdot \text{lb} = 346 \text{ lb} \cdot x \text{ ft}$$

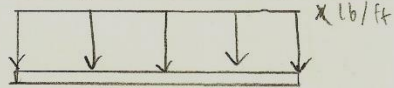
$$x = \frac{4059 \text{ ft} \cdot \text{lb}}{346 \text{ lb}}$$

$x = 11.73 \text{ ft}$

## Analysis B

Neil Leitz

Max Force Analysis



Given: Bins bounce off of trailer binches  
 Bins impact trailer over .5 seconds  
 Bins land flat

Find: Maximum force distribution across rail.

Solution:

$$\frac{1}{2}mv^2 = m \cdot g \cdot h$$

$$v = \sqrt{2gh}$$

$$v = \sqrt{2 \cdot 32.174 \frac{\text{ft}}{\text{s}^2} \cdot \frac{1}{2} \text{ft}}$$

$$v = 5.67 \frac{\text{ft}}{\text{s}}$$

$$p = v \cdot m$$

$$p = 5.67 \frac{\text{ft}}{\text{s}} \cdot 2.891 \text{ slug}$$

$$p = 16.39 \frac{\text{slug} \cdot \text{ft}}{\text{s}}$$

$$p = 16.39 \frac{\text{lb}_f \cdot \text{s}^2}{\text{ft}} \cdot \frac{\text{ft}}{\text{s}}$$

$$p = 1.728 \text{ m/s} \cdot 42.1841 \text{ kg}$$

$$p = 72.89 \frac{\text{kg} \cdot \text{m}}{\text{s}}$$

$$J = 72.89 \frac{\text{kg} \cdot \text{m}}{\text{s}}$$

$$J = F \Delta t$$

$$72.89 \frac{\text{kg} \cdot \text{m}}{\text{s}} = F \cdot .5 \text{ s}$$

$$\frac{72.89}{.1} \text{ N} = F$$

$$F = 728.9 \text{ N}$$

$$F = 164 \text{ lb}$$

$$F = 82 \text{ lbs}$$

one bin  
one rail

$$\frac{82 \text{ lbs} \cdot 4 \text{ bins}}{16.5 \text{ ft}} = 20 \text{ lbs/ft}$$

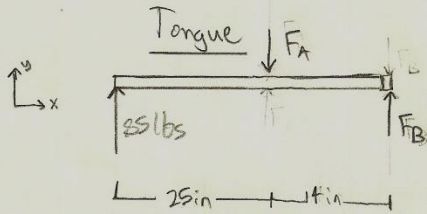
$x = 20 \text{ lbs/ft}$

### Analysis C

Neil Leitz

Stress Analysis

1/4



Max Bending Moment: 2125 lb-in  
Max Shear: -151.79 lbs

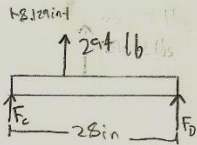
$$\sum + \Sigma M_A = 0 = (85 \cdot 25 \text{ in}) - (F_B \cdot 14 \text{ in})$$

$$F_B = 152 \text{ lbs}$$

$$\uparrow + \Sigma F_y = 0 = 85 - 151 \text{ lbs} + F_A$$

$$F_A = 236.79$$

#### Axle Supports



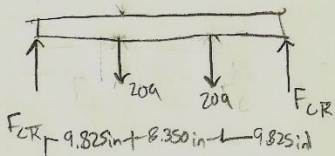
Max Bending Moment: -1694.40 in-lb

Max Shear: -209 lb

$$F_C = 209 \text{ lb}$$

$$F_D = 85 \text{ lb}$$

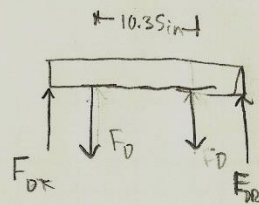
#### Center Cross members



$$F_{CR} = 209 \text{ lb}$$

Max Bending Moment: 2049 lb-in

Max Shear: 209 lbs



$$F_{DR} = 85 \text{ lbs}$$

Max Bending: 833 lb-in

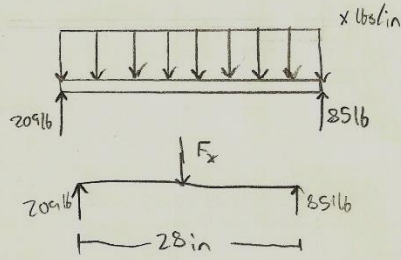
Max Shear: 85 lbs

Analysis C (cont.)

Neil Leitz

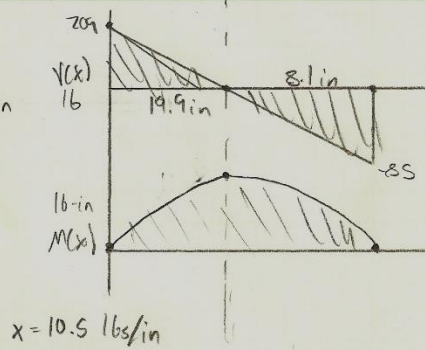
2/4

Height Bar



$$\uparrow + \Sigma F_y = 0 = 209 + 85 - F_x$$

$$F_x = 294 \text{ lb}$$



Max Bending: 2080 lb-in  
Max Shear: 209 lb

$$209 = \frac{10.5}{1}$$

$$- = \frac{10.5}{209}$$

$$209 \text{ lbs} = 10.5 \cdot 1$$

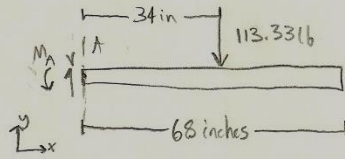
Analysis C (cont.)

Neil Leitz

Stress Analysis

3/4

Rail Overhanging Section



$$\sum M_A = 0 = -M_A - (34 \text{ in} \cdot 113.33 \text{ lb})$$

$$M_A = 3853 \text{ in-lb}$$

Max Moment

$$\text{Max shear} = 209 \text{ lbs}$$

$$\tau_y = .6 \cdot 73,848 \text{ psi}$$

$$\tau_y = 44,309 \text{ psi}$$

$$\tau_{\text{max}} = \frac{2V}{A}$$

$$\tau_{\text{max}} = \frac{2 \cdot 209 \text{ lb}}{1.188 \text{ in}^2}$$

$$\tau_{\text{max}} = 352 \text{ psi} - \text{No problems}$$

Analysis C (cont.)

Neil Leitz

Stress Analysis

4/4

$$\sigma_{max} = \frac{M_{max}}{S_x}$$

$$S_x = \frac{M_{max}}{\sigma_{max}}$$

$$S_x = \frac{3853 \text{ lb-in}}{73848 \text{ psi}}$$

$$S_x = .052 \text{ in}^3$$

$$\sigma_{max} = 73848 \text{ psi (mill specs)}$$

$$M_{max} = 3853 \text{ lb-in (occurs in rail section before height bar)}$$

According to a spreadsheet that was made that gives section properties, the smallest steel tubing commercially available with this section modulus is

1" x 1" x 1/16" with a section modulus of .069 in<sup>3</sup>.

However, with the tires that have been selected for this trailer, there is a need for an amount of height to this design.

Not only this, but tubing as small as that gives the chance for much greater deflection than should be occurring.

The final tubing size will be 3" x 2" x .125".

It has a section modulus of .978 in<sup>3</sup>, effectively giving a safety factor of 18.8. This will be good as the dynamic loadings on the trailer are not well known. The price difference between these two types is also not very excessive, and the 3" x 2" x 1/8" is more readily available.

Final Dimensions for tubing: 3" x 2" x .125"

$$S_y = 73848 \text{ psi}$$

$$S_u = 84418 \text{ psi}$$

### Analysis D

2"x3" Steel tubing section properties						
Height	Base	Thickness	Inner Height	Inner Base	Cross Sectional Area	Section Modulus
3	2	0.0625	2.875	1.875	0.609	0.525
3	2	0.125	2.75	1.75	1.188	0.978
3	2	0.1875	2.625	1.625	1.734	1.367
3	2	0.25	2.5	1.5	2.250	1.698
3	2	0.3125	2.375	1.375	2.734	1.977
3	2	0.375	2.25	1.25	3.188	2.209
3	2	0.4375	2.125	1.125	3.609	2.400
3	2	0.5	2	1	4.000	2.556
3	2	0.5625	1.875	0.875	4.359	2.680

2"x2" Steel tubing section properties						
Height	Base	Thickness	Inner Height	Inner Base	Cross Sectional Area	Section Modulus
2	2	0.0625	1.875	1.875	0.484	0.303
2	2	0.125	1.75	1.75	0.938	0.552
2	2	0.1875	1.625	1.625	1.359	0.752
2	2	0.25	1.5	1.5	1.750	0.911
2	2	0.3125	1.375	1.375	2.109	1.035
2	2	0.375	1.25	1.25	2.438	1.130
2	2	0.4375	1.125	1.125	2.734	1.200
2	2	0.5	1	1	3.000	1.250
2	2	0.5625	0.875	0.875	3.234	1.284

**Analysis D (cont.)**

<b>2"x1" Steel tubing section properties</b>						
<b>Height</b>	<b>Base</b>	<b>Thickness</b>	<b>Inner Height</b>	<b>Inner Base</b>	<b>Cross Sectional Area</b>	<b>Section Modulus</b>
2	1	0.0625	1.875	0.875	0.359	0.186
2	1	0.125	1.75	0.75	0.688	0.332
2	1	0.1875	1.625	0.625	0.984	0.443
2	1	0.25	1.5	0.5	1.250	0.526
2	1	0.3125	1.375	0.375	1.484	0.585
2	1	0.375	1.25	0.25	1.688	0.626
2	1	0.4375	1.125	0.125	1.859	0.652

<b>1"x1" Steel tubing section properties</b>						
<b>Height</b>	<b>Base</b>	<b>Thickness</b>	<b>Inner Height</b>	<b>Inner Base</b>	<b>Cross Sectional Area</b>	<b>Section Modulus</b>
1	1	0.0625	0.875	0.875	0.234	0.069
1	1	0.125	0.75	0.75	0.438	0.114
1	1	0.1875	0.625	0.625	0.609	0.141
1	1	0.25	0.5	0.5	0.750	0.156
1	1	0.3125	0.375	0.375	0.859	0.163
1	1	0.375	0.25	0.25	0.938	0.166
1	1	0.4375	0.125	0.125	0.984	0.167

This optimization showed that the smallest appropriate size of tubing was 1 x 1 x 1/16 inch square tubing. However, this would be close to the calculated required section modulus of .052. The selection of the 3" x 2" x .125" was also partially driven by the need to accommodate selected tires and other hardware. This selection gives the design a safety factor of approximately 18, since the section modulus is approximately 18 times bigger than the minimum requirement. This is a fair approach to take, as many of the loadings the trailer will experience are not easily foreseen.

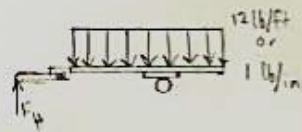


## Analysis E

Neil Leitz

Final Tire Analysis

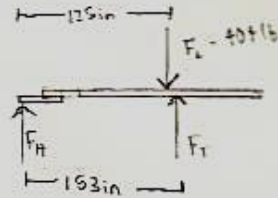
1/1



Given: Final Trailer Design  
Tight Loading

Find: Percentage of load on hitch

Solution -



$$\sum \uparrow ZM_H = 0 = (-404 \text{ lb} \cdot 125 \text{ in}) + (F_T \cdot 153 \text{ in})$$

$$0 = -50500 \text{ lb} \cdot \text{in} + 153 \text{ in} \cdot F_T$$

$$50500 \text{ lb} \cdot \text{in} = 153 \text{ in} \cdot F_T$$

$$F_T = 330 \text{ lbs}$$

$$\uparrow \sum F_y = 0 = 330 \text{ lb} - 404 \text{ lb} + F_H$$

$$F_H = 74 \text{ lb}$$

$$\frac{74 \text{ lb}}{404 \text{ lb}} = 18\% \text{ of load on hitch}$$

I will now resolve for the correct distance:

$$.125 = \frac{F_H}{404 \text{ lb}}$$

$$F_H = 50.5 \text{ lbs}$$

$$\uparrow \sum F_y = 0 = -404 \text{ lb} + 50.5 \text{ lb} + F_T$$

$$F_T = 354 \text{ lb}$$

$$\uparrow \sum M_H = 0 = -(404 \text{ lbs} \cdot 125 \text{ in}) + (354 \cdot x)$$

$$x = 143 \text{ in}$$

The model will be changed to reflect this.

Analysis F

Neil Leitz

Final Stress Analysis

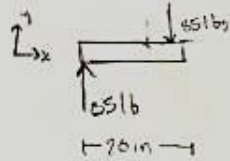
1/4

Given: Known dimensions and loadings of the trailer

Find: Maximum stress point and the maximum stress magnitude

Solution

Coupler Mount

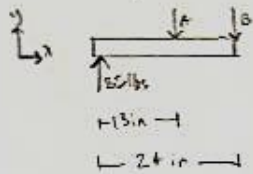


MD Solids:

Max shear: 85 lb

Max moment: 1,700 lb-in

Tongue



$$\sum M_B = 0 = 11 \cdot A - 35 \cdot 24$$

$$A = 185 \text{ lb}$$

$$\sum F_y = 0 = 35 - 185 + A$$

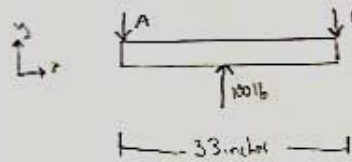
$$B = 100 \text{ lb}$$

MD Solids:

$$V_{max} = 100 \text{ lb}$$

$$M_{max} = 1102 \text{ in lbs}$$

Cross Member (Tongue Connection)



$$A = B = 50 \text{ lb}$$

MD Solids

$$V_{max} = 50 \text{ lbs}$$

$$M_{max} = 1526.25$$

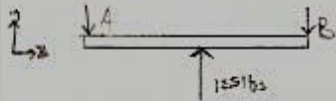
Analysis F (cont.)

Neil Leitz

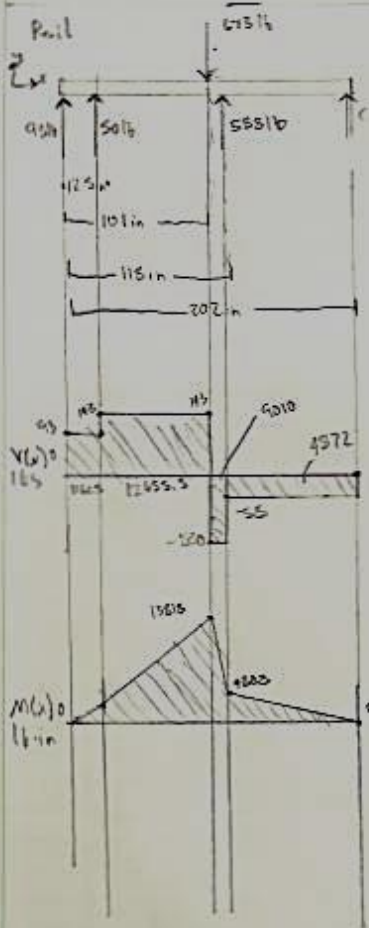
Final Stress Analysis

2/4

Cross Member (Front)



$A = B = 93 \text{ lbs}$   
 MD Solids  
 $V_{max} = 93 \text{ lbs}$   
 $M_{max} = 1926 \text{ lb-in}$



$\sum F_y = 0$

$C = 581 \text{ lbs}$

$V_{max} = \frac{581 \text{ lbs}}{2} = 265 \text{ lb}$

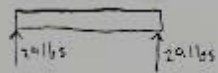
$M_{max} = \frac{13818 \text{ lb-in}}{2} = 6909 \text{ lb-in}$

Analysis F (cont.)

3/4

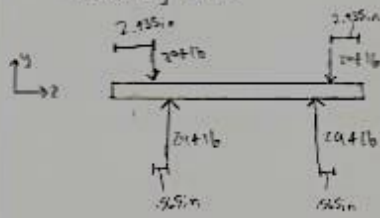
Neil Leitz  
Cross member (Rear)

Final Stress Analysis



Ignorable (max stress occurs in the rail)

Mounting Plate

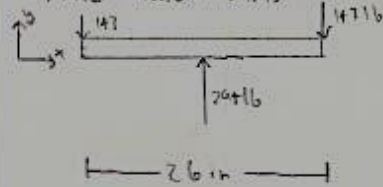


MD Solids

$$V_{max} = 2011 \text{ lb}$$

$$M_{max} = 470.4 \text{ lb-in}$$

Avic Plate Mounts

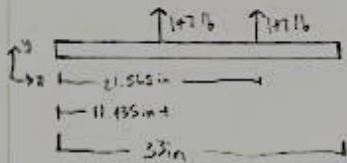


MD Solids

$$V_{max} = 147 \text{ lb}$$

$$M_{max} = 1911 \text{ in-lbs}$$

Middle Cross Members



MD Solids

$$V_{max} = 147 \text{ lb}$$

$$M_{max} = 1676 \text{ lb-in}$$

## Analysis F (cont.)

Neil Leitz

Final Stress Analysis

4/4

$M_{max}$  was found to be 6909 lb-in  
This means for the tubing

$$\sigma_{max} = \frac{M}{S} = \frac{6909 \text{ lb-in}}{.975 \text{ in}^3}$$

$$\sigma_{max} = 7064 \text{ psi}$$

$$\sigma_{tubing} = 74 \text{ psi}$$

$N=10$  (For maximum loading situation)

Now to check the Plate:

$$M_{max} = 470.4 \text{ lbs-in}$$

$$S_{plate} = .10419 \text{ in}^3$$

$$\sigma_{max \text{ plate}} = \frac{470.4 \text{ lb-in}}{.10419 \text{ in}^3} = 4515 \text{ psi}$$

Both of these stresses are well under  $s_u$  and  $s_y$   
for the material

## Analysis G

Neil Leitz

Fatigue Life Analysis

1/1

Given: Cyclical Loading

$$\sigma_{max} = 7064 \text{ psi}$$

$$\sigma_{min} = 0 \text{ psi}$$

Find: Longevity of material

Solution:

Damage Accumulation Method

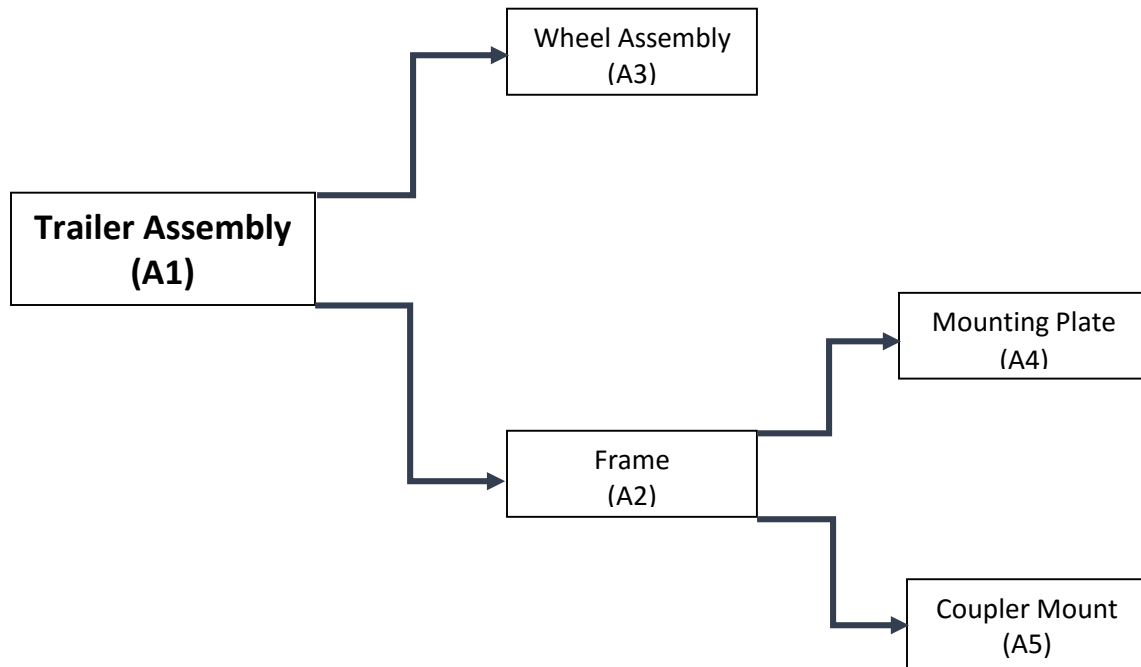
$$D_c = \sum_{i=1}^n \frac{n_i}{N_i} \quad D_i = \frac{n_i}{N_i}$$

$$\sigma_w = 7 \text{ ksi}$$

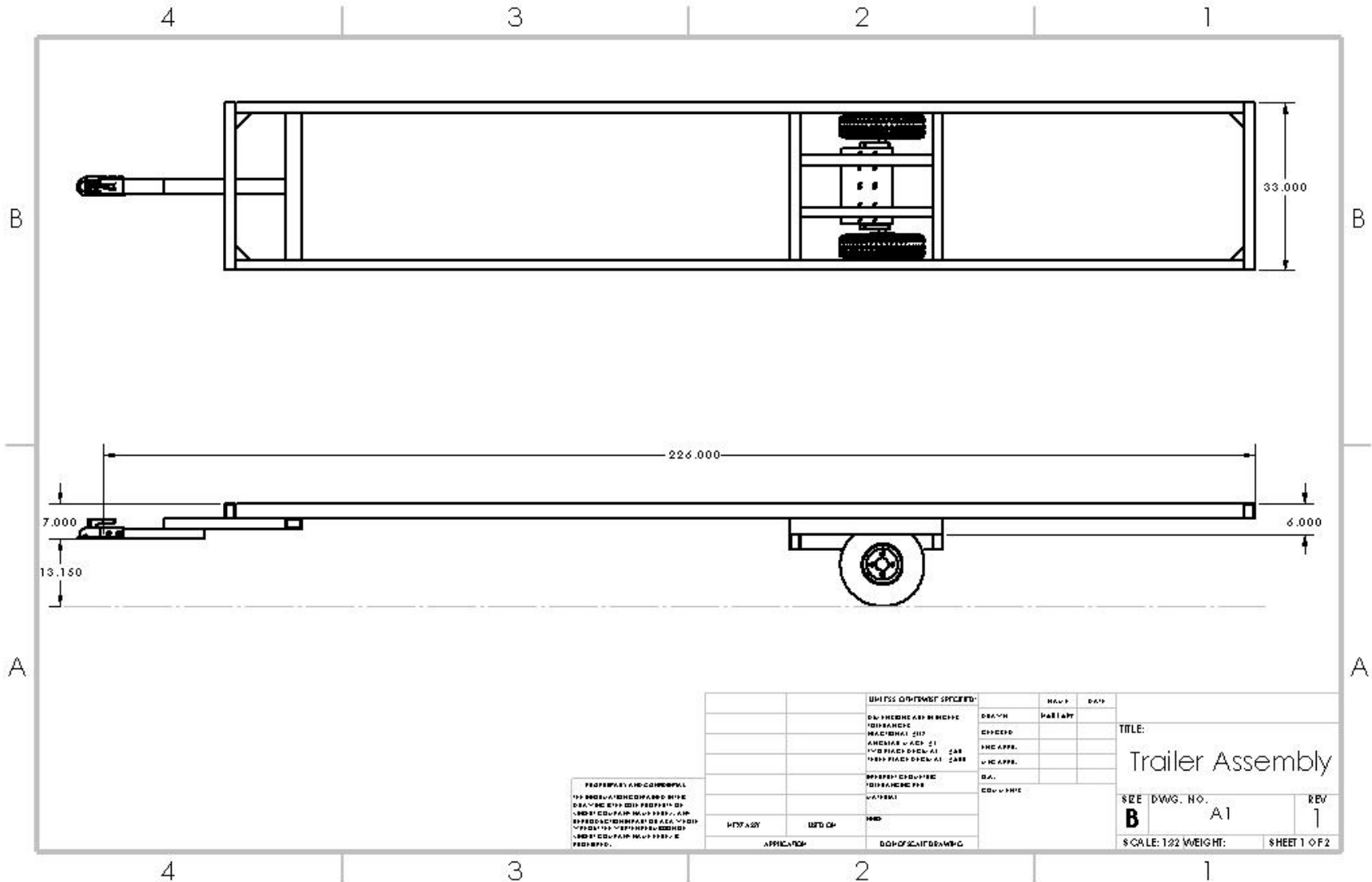
According to Fig 5-7 in Mott, The steel in question is below the stress amplitude fatigue cycle limit. This means that theoretically, barring any structural changes involved from the welding, that the material will never have fatigue failure.

## Appendix B – Sketches, Assembly Drawings, Part Drawings

### Drawing Tree



Drawing A1-1



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DESIGNED	DRAWN		
CHECKED	ISSUED		
APPROVED	IN CHARGE		
DATE	DATE		

TITLE:  
**Trailer Assembly**

SHEET NO. **B** DWG. NO. **A1** REV **1**

SHEET 1 OF 2

SCALE: 1:22 WEIGHT: SHEET 1 OF 2



### Drawing A1-2

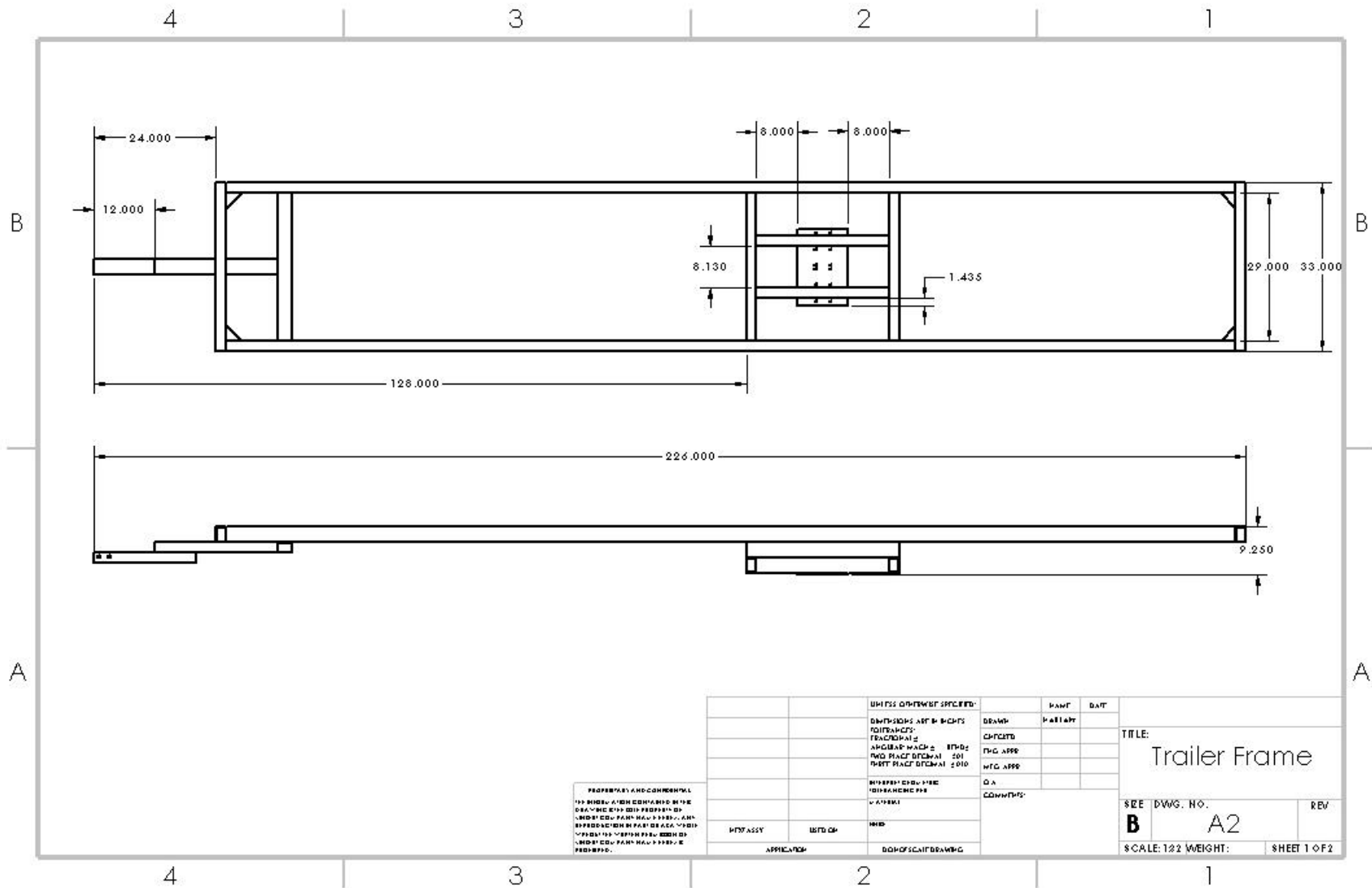
ITEM NO.	PART NUMBER	DESCRIPTION	Exploded View/ QTY.
1	Frame 2	See Drawing A2	1
2	Right Tire Assembly	See Drawing A3	1
3	Left Tire Assembly	See Drawing A3	1
4	Ball Hitch Coupler	1 inch ball with 3 inch wide channel	1
6	P1720A245	5/16 inch x 3/4 inch length bolt	12
7	P0480A013	12-24 thread size nut	12
8	P1247A126	Bolt with 5/16" 24 Thread, 3-1/2" Long	2
9	P5505A612	Nut with 5/16" 24 Thread Size, 1/2" wide	2

DETAIL B  
SCALE 1 : 8

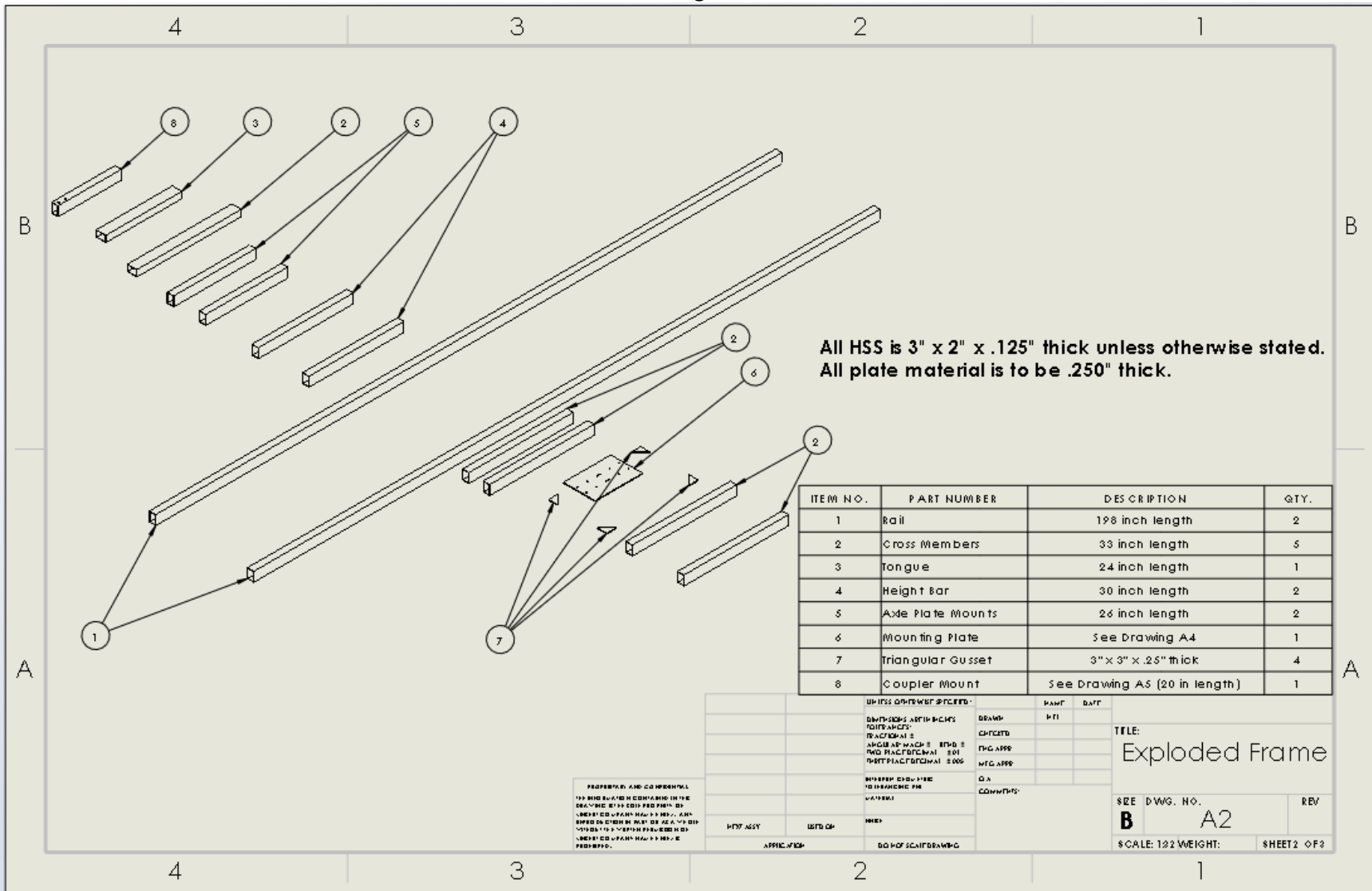
DETAIL C  
SCALE 1 : 8

	<p>UNLESS OTHERWISE SPECIFIED:</p> <p>DRW. DIMENSIONS ARE IN DECIMALS</p> <p>FRACTIONS SHALL BE IN 16ths</p> <p>ANGLES ARE IN DEGREES</p> <p>UNLESS OTHERWISE SPECIFIED</p> <p>FINISHES ARE AS SHOWN</p> <p>ALL DIMENSIONS ARE TO CENTER UNLESS OTHERWISE SPECIFIED</p>	<p>DATE</p> <p>SCALE</p>	<p>DRAWN</p> <p>CHECKED</p> <p>ENG. APPR.</p> <p>INC. APPR.</p> <p>QA</p> <p>CON. APPR.</p>	<p>TITLE:</p> <p style="font-size: 1.2em;">Trailer Assembly</p>
<p>PROFITABILITY AND COMMERCIAL</p> <p>USE OF THIS DRAWING IS LIMITED TO THE PROJECT AND SHALL NOT BE USED FOR ANY OTHER PROJECT WITHOUT THE WRITTEN PERMISSION OF THE ORIGINAL DRAWING AUTHOR.</p>	<p>DATE: 1/1/2024</p> <p>BY: [Signature]</p> <p>APP. [Signature]</p>			<p>SEE DWG. NO. <b>B</b> <span style="margin-left: 20px;">A1</span> <span style="margin-left: 20px;">REV 1</span></p> <p>SCALE: 1:22 WEIGHT: SHEET 2 OF 2</p>

Drawing A2-1



**Drawing A2-2**



All HSS is 3" x 2" x .125" thick unless otherwise stated.  
All plate material is to be .250" thick.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Rail	198 inch length	2
2	Cross Members	33 inch length	5
3	Tongue	24 inch length	1
4	Height Bar	30 inch length	2
5	Axle Plate Mounts	24 inch length	2
6	Mounting Plate	See Drawing A4	1
7	Triangular Gusset	3" x 3" x .25" thick	4
8	Coupler Mount	See Drawing A5 (20 in length)	1

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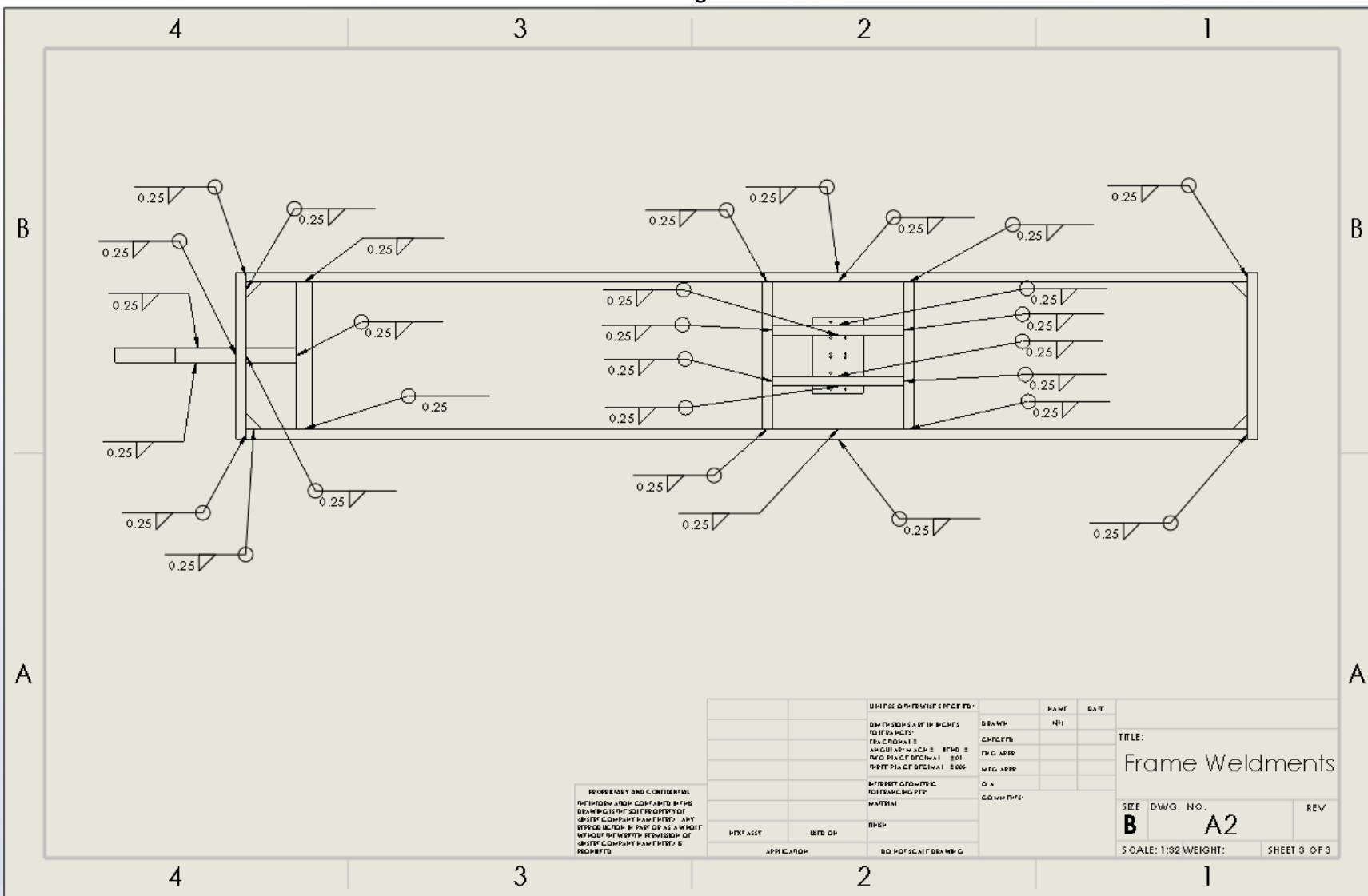
UNLESS OTHERWISE SPECIFIED:	FRAMT	DATE
DESIGNER: [blank]	DATE:	
CHECKED: [blank]	DATE:	
APPROVED: [blank]	DATE:	
PROJECT: [blank]	DATE:	
DATE: [blank]	DATE:	
SCALE: [blank]	DATE:	
BY: [blank]	DATE:	
APP: [blank]	DATE:	

**TITLE:**  
 Exploded Frame

SIZE DWG. NO. REV  
**B** A2

SCALE: 1/2" = 1' WEIGHT: SHEET 2 OF 2

Drawing A2-3



Drawing A3

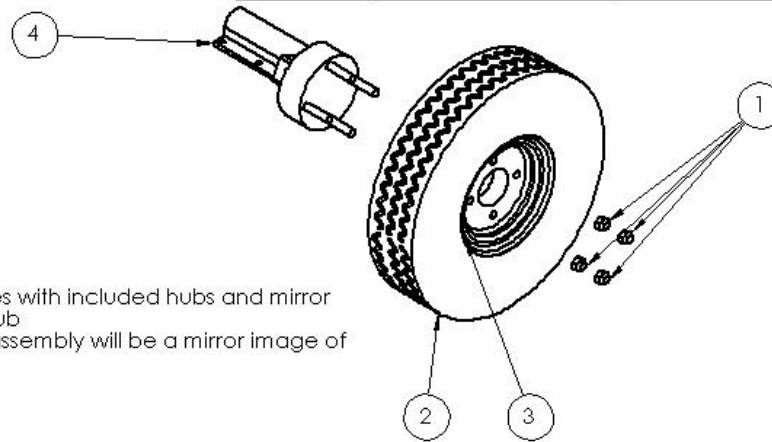
2

1

B

B

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Lugnut		4
2	Tire	4-Hole High Speed Standard Rim Design Trailer Tire Assembly — 480-8 Item# 12110 Northern Tool	1
3	Tire Rim	4-Hole High Speed Standard Rim Design Trailer Tire Assembly — 480-8 Item# 12110 Northern Tool	1
4	Torsion Stub Right	Southwest Wheel Part# FR935SBT121	1



Item No. 4 comes with included hubs and mirror image torsion stub  
Second wheel assembly will be a mirror image of this one.

A

A

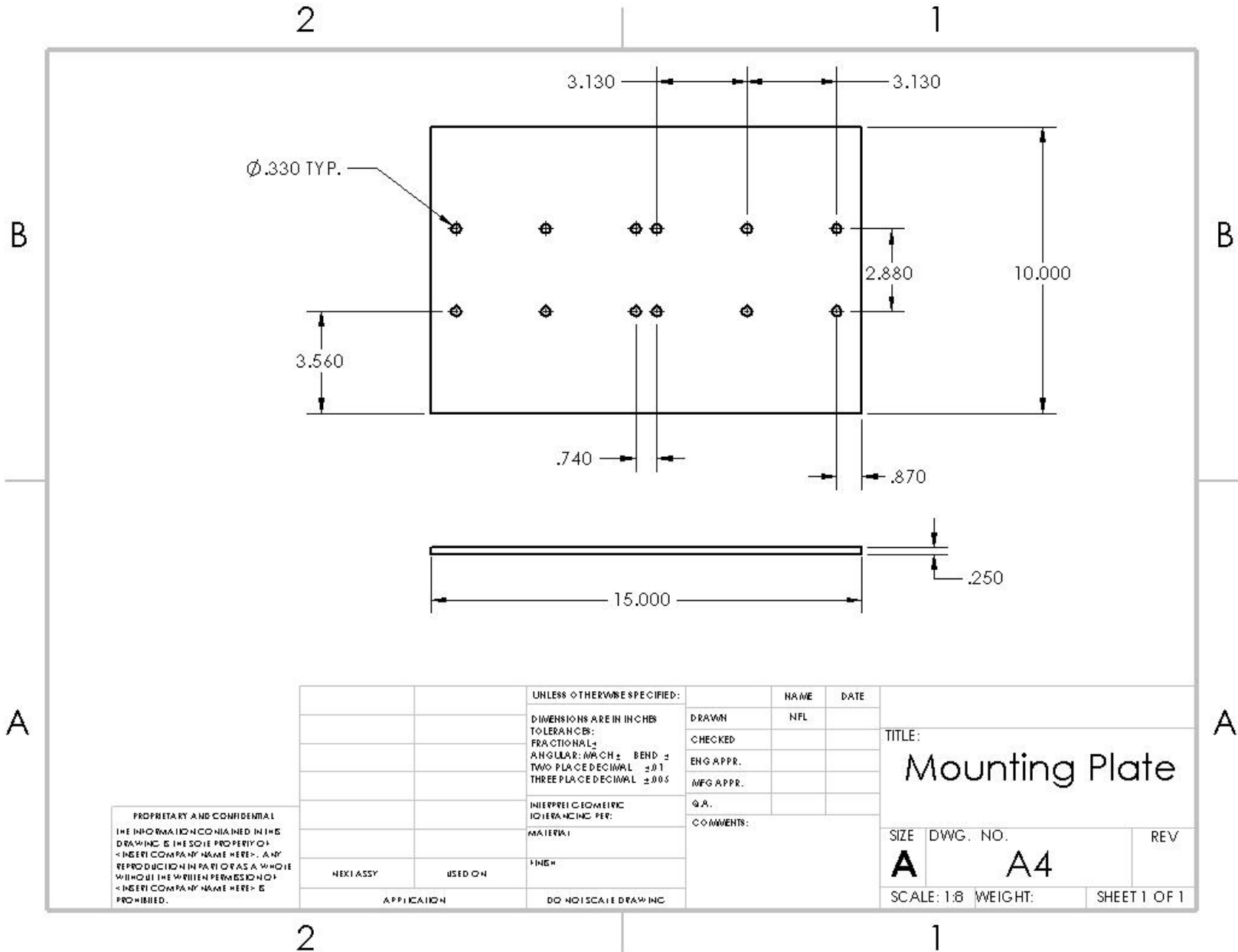
		UNLESS OTHERWISE SPECIFIED:	NAME	DATE	TITLE: <b>Wheel Assembly</b>
		DIMENSIONS ARE IN INCHES	DRAWN		
		TOLERANCES:	CHECKED		SIZE DWG. NO. REV <b>A A3</b>
		FRACTIONAL	ENG APPR.		
		ANGULAR: MACH ±	MTC APPR.		SCALE: 1:8 WEIGHT: SHEET 1 OF 1
		TWO PLACE DECIMAL ±	Q.A.		
		THREE PLACE DECIMAL ±	COMMENTS:		
		INTERPRET GEOMETRIC TOLERANCING PER:			
		MATERIAL:			
		FINISH:			
NEXT ASSY	USED ON	APPLICATION			
		DO NOT SCALE DRAWING			

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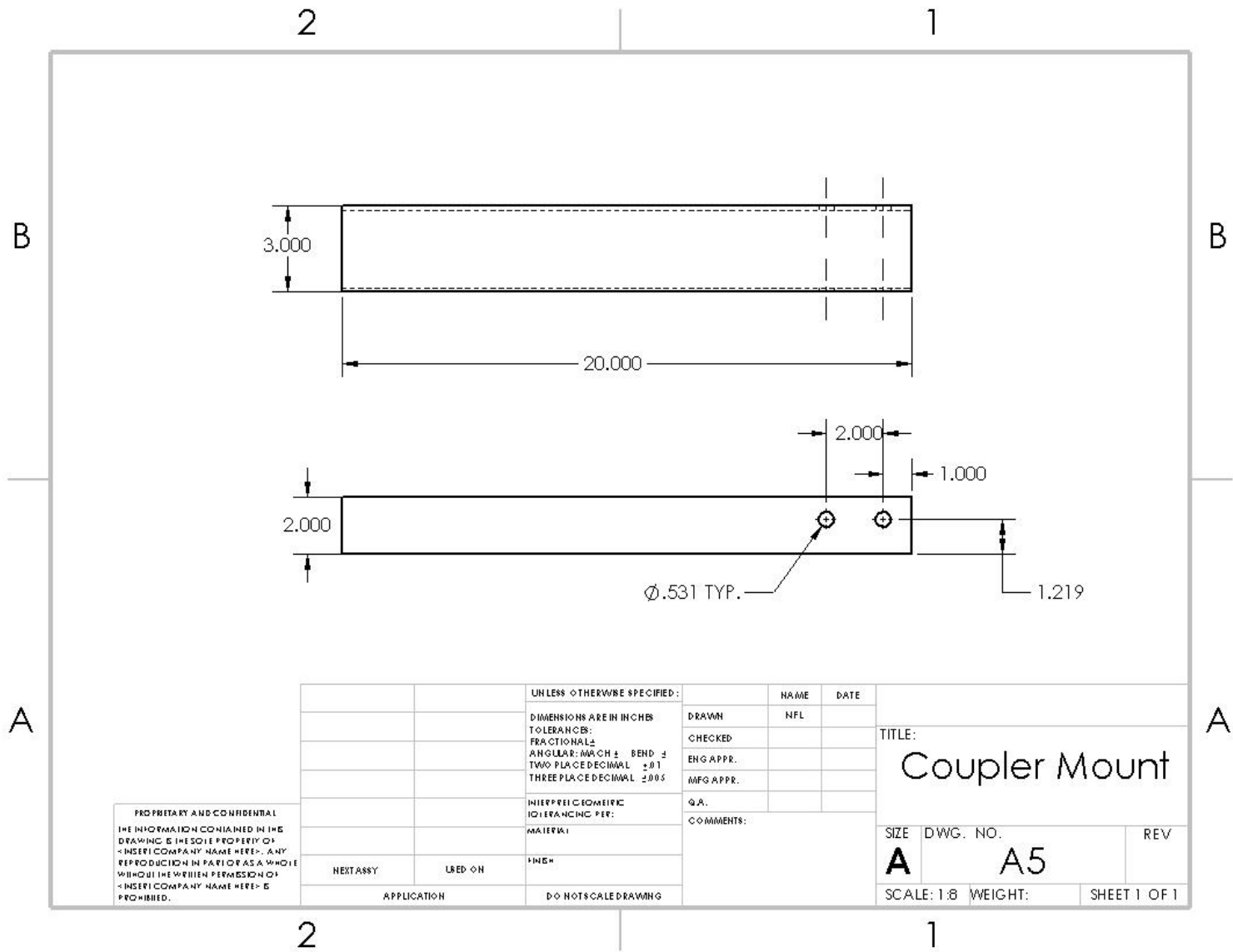
2

1

Drawing A4



Drawing A5



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		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES	DRAWN	NFL	
		TOLERANCES:	CHECKED		
		FRACTIONAL ±	ENG APPR.		
		ANGULAR: MACH ± BEND ±	MFG APPR.		
		TWO PLACE DECIMAL ±0.1			
		THREE PLACE DECIMAL ±0.05	Q.A.		
		INTERPRET GEOMETRIC TOLERANCING PER:	COMMENTS:		
		MATERIAL:			
		FINISH:			
NEXT ASSY	USED ON	DO NOT SCALE DRAWING			
	APPLICATION				

TITLE: <b>Coupler Mount</b>		
SIZE <b>A</b>	DWG. NO. <b>A5</b>	REV
SCALE: 1:8	WEIGHT:	SHEET 1 OF 1

### Appendix C – Testing Results

Spring Scale Calibration (+/- calibration weight value)									
1	2	3	4	5	6	7	8	9	10
±0 lbs	±0 lbs	±0 lbs	±0 lbs	±0 lbs	±0 lbs	±0 lbs	±0 lbs	±0 lbs	±0 lbs
Calibration Weight:	25 lbs							Average:	0 lbs
Picking Bin Weights (Individual Bins) in pounds									
#1	#2	#3	#4						
93	98	98	90						
		Total:	379						
<div style="border: 1px solid black; padding: 10px; display: inline-block;"> <math display="block">\% \text{ Hitch Load} = \frac{(\text{Full Trailer Hitch Load}) - \text{Empty Trailer Hitch Load}}{\text{Total Weight of Picking Bins}}</math> </div>									
(Empty Trailer) Hitch Weights in pounds									
1	2	3	4	5					
53	53	53	53	53					
			Average:	53					
(Loaded Trailer) Hitch Weights in pounds									
1	2	3	4	5					
96	96	96	96	96					
			Average:	96					

Calculated Load percentage on hitch:	11.35%	Within the design specifications!
--------------------------------------	--------	-----------------------------------



## Appendix D – Parts List and Budget

<b>Part</b>	<b>Description</b>	<b>Qty</b>	<b>Cost/Unit</b>
<b>3"x2"x.120" Tubing ASTM A500 Grade B</b>			
198" length	Rails	2	\$2.93/ft
33" length	Cross Members	5	\$2.93/ft
30" length	Height Bar	2	\$2.93/ft
26" length	Axle Plate Mounts	2	\$2.93/ft
24" length	Tongue	1	\$2.93/ft
20" length	Coupler Mount	1	\$2.93/ft
<b>HSS Total Length:</b>	59.75	ft	
		<b>Sub Total:</b>	\$203.32
<b>0.25" Plate</b>			
<b>Description</b>			
15"x10"	Mounting Plate	1	\$.17/in <sup>3</sup>
3"x3" Right Triangle	Triangular Gussets	4	\$.17/in <sup>3</sup>
		<b>Sub Total:</b>	\$6.76
<b>Torsion Axles/Hubs/Tires</b>			
<b>Description</b>			
Torsion axles/hubs	Southwest Wheel Part #FR935SBT121	1	\$319.95
480-8 Tires	Northern Tool Item #12110	2	\$39.99
		<b>Sub Total:</b>	\$399.93
<b>Fasteners</b>			
<b>Description</b>			
5/16 inch x 3/4 inch length bolt	McMasterr-Carr 91720A245	12	\$0.66
12-24 thread size nut	McMasterr-Carr 90480A013	12	\$0.03
Bolt with 5/16"-24 Thread, 3-1/2" Long	McMasterr-Carr 91247A126	2	\$0.53
Nut with 5/16"-24 Thread Size, 1/2" Wide	McMasterr-Carr 95505A612	2	\$0.05
		<b>Sub Total:</b>	\$9.44
<b>Towing Coupler</b>			
<b>Description</b>			
2 in Ball hitch coupler w/3" channel	Northern Tool Item #605666		\$10.00
		<b>Sub Total:</b>	\$10.00
		<b>Grand Total:</b>	<b>\$629.45</b>



## Appendix F – Resume

### Neil Leitz

PO Box 270  
Royal City, WA 99357  
Phone: (509)-855-8398  
Email: leitzneil@gmail.com

### Employment History:

#### **Farmhand 2004-2015**

*Jelmborg Farms, Tonnemaker Hill Farm, Royal City, WA.*

- Fruit stand operation, including cashiering, setup, and tear down
- Heavy equipment operator (tractors, jackhammers, backhoes, excavator)
- Maintenance on irrigation circles and corresponding electrical systems
- Orchard management (planting, mowing, irrigation, chemical mixing and spraying, picking operations)
- Picking/loading produce for market

#### **OIT Network Assistant 2013-2014**

*Seattle University, Seattle, WA.*

- Maintenance of networking connections on switches, patch panels, computers and phones.
- Installation of hardware including, but not limited to, networking switches, jacks, fiber optics and network phones.
- Customer relations/customer troubleshooting
- Documentation and recording of telecommunications network details

#### **Construction assistant 2011**

*Norwest Ingredients Royal City, WA*

- Surveying
- Trenching/pipe laying

### Education:

*Big Bend Community College, Moses Lake, WA.*

- Graduated with Associate in Arts and Sciences in 2012, with honors.

*Royal High School, Royal City, WA*

- Graduated June 2012, with high honors.

*Seattle University, Seattle, WA*

- 2012-2014 pursuing a BA in physics

*Central Washington University*

- 2014-present (pursuing BA in Mechanical Engineering Technology)

#### **Skills and Qualifications:**

- Certified Solidworks Associate (certificate)
- Detail-oriented
- Fast learner and always willing to pick up new tasks and knowledge on the fly

#### **References:**

- Clint Dicus (Seattle University OIT): (206) 296-2643
- Kole Tonnemaker (Tonnemaker Hill Farm): (509)-346-9706
- George Jelmborg (Jelmborg Farms): (509)-346-2807