# *Harrows Shipping Configuration Design*

# Final Report

**Submitted To:**

Elmer's Manufacturing

c/o Riley Dyck

**Date Submitted:**

December 7, 2016

**Written By:**


Team 4

Rheal Boileau ______________________ Weiran Wang ______________________

Blayne R. Gray ______________________ Hanbin Zhou ______________________

Team 4
University of Manitoba
Winnipeg, Manitoba
R3T 2N2

Dr. Paul Labossiere
University of Manitoba
Winnipeg, Manitoba
R3T 2N2

- FINAL REPORT SUBMISSION -

Dear Dr. Labossiere,

Team 4 is pleased to present to you our report Harrow *Shipping Configuration Design – Final Report* on this Wednesday, the 7th of December.

This report encompasses the project requirements, constraints, concept development and detailed design. Concepts were generated in brainstorming sessions and selected based on their performance in scoring matrices. Research was performed to identify the trailers available through Searcy Trucking and the dimensions of each individual trailer. Additionally the road restrictions as detailed by the individual transit authorities in all regions the proposed shipping method will be used were identified and compiled. Brackets were necessary for the secure and stable mounting of the harrows, therefore brackets were designed and analyzed. Additionally, a final layout of the trailer, loading procedure, list of removed harrow components and cost analysis are included.

If there are any inquiries regarding this report do not hesitate to contact any members of the team via their University of Manitoba emails.

Sincerely,

Rheal Boileau
Team 4 Secretary

Document Enclosed: *Harrow Shipping Configuration Design – Final Report*

# Executive Summary

Elmer's Manufacturing currently has two shipping methods to transport the Super 7 harrow to its dealer network in Western Canada and North Dakota. The first method tows the harrow behind a truck and the second loads the harrow onto a flat deck trailer. Elmer's increasing sales require the shipping of an increasing amount of harrows, leading to large shipping expenses. To lower the shipping expenses a method was developed that packages two 90' Super 7 Harrows onto a single truckload. Before developing concepts the client's major needs were identified, with the most important being cost and safety.

In addition to the client needs the constraints were identified prior to the concept development phase. The major constraints identified were the size dimensions of the trailer and load as specified by the transportation regulation bodies in the individual regions. Size dimension constraints were determined to be 3.8 m for width, 4.7 m for height, 27.5 m for length, and 4 m for overhang.

The final concept utilizes a B-Train trailer and packages the harrow wings on the rear trailer and the hitches on the forward trailer. The wings are secured by six metal brackets designed from stock steel material. The hitches are supported by wood stack brackets and the assemblies are secured to the trailer using tie-downs. The brackets have factors of safety well above the requirement and it was decided not to optimize the design because the reduction in cost was not equal to the decrease in safety of the design. The added load capacity of the brackets may be important during the dynamic loading seen during loading and transportation. In addition to the supporting brackets two pallets and two part boxes were included for all parts omitted from the initial assembly.

A cost analysis of all three methods determined that the cheapest method for destinations outside of Manitoba was the proposed method, with the exact savings dependant on the destination. It was assumed the brackets would be reused and therefore analysis was performed assuming five reuses of each bracket. For example, approximate cost savings for shipping to Lloydminster is $1044.39 per harrow. The cost of an individual metal wing bracket was determined to be $338.78 and the wooden stack brackets were $9.00 each, not including labour.

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# 1 Introduction

Elmer's Manufacturing is a rapidly growing company located in Altona, MB that produces agricultural equipment. The two major products produced by Elmer's are the Super 7 Harrow, shown in Figure 1, and the HaulMaster grain carts, both of which are sold through Western Canada and the Northern United States – with new markets emerging in Europe and Australia. Elmer's grew to fill a market of providing high quality farm implements, primarily row crop harvesters, and expanded to other implements where advancements were needed. With the growing number of equipment being shipped, high shipping costs have become a concern for Elmer's.

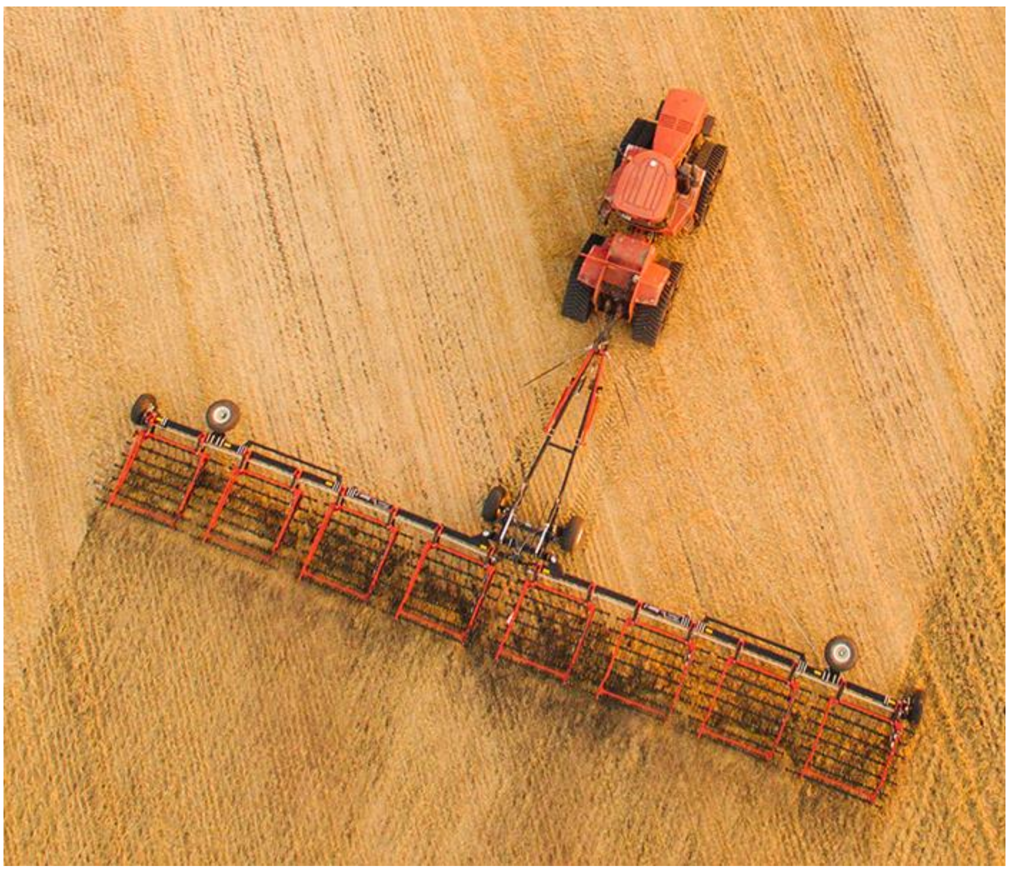


Figure 1: Super 7 Harrow [1].

Elmer's Manufacturing currently utilizes two different shipping methods for shipping the Super 7 Harrow within North America – both shipping the harrow as a fully assembled unit using a truck. Elmer's requested the design of a new shipping method that packages two Super 7 Harrows in on one truck load. Any designed shipping method must conform to road regulations as set by the individual transportation authorities of the regions being traversed and satisfy the needs of the client.

This report produces a detailed trailer layout of the proposed shipping method, along with the design and analysis of required brackets. Additionally a cost analysis comparing the current shipping methods to the proposed method is presented. Finally a loading procedure, included in Appendix B, was developed and documented.

## 1.1 Background

As specified by the client, the designed shipping method will be created for the largest Super 7 Harrow model, which is the 90’ option. All following references to ‘the harrow’ or ‘the Super 7 Harrow’ will refer specifically to the 90’ model.

### 1.1.1 Super 7 Harrow Nomenclature and Dimensions

The Super 7 Harrow consists of two major sections: the hitch and the wings. Attaching the hitch to the wings is the center frame, which can be rotated in relation to the hitch by hydraulic cylinders. The rotation of the center frame is necessary to articulate the harrow between transport and field modes. Attached to each wing are four harrow sections which in turn each have seven tine bars. Attached to each tine bar are the tines that interact with the field. The ninth harrow section is attached to center frame, providing a continuously tined 90’ harrow width. The previously mentioned sections of the harrow along with the relevant dimensions are shown in Figure 2.

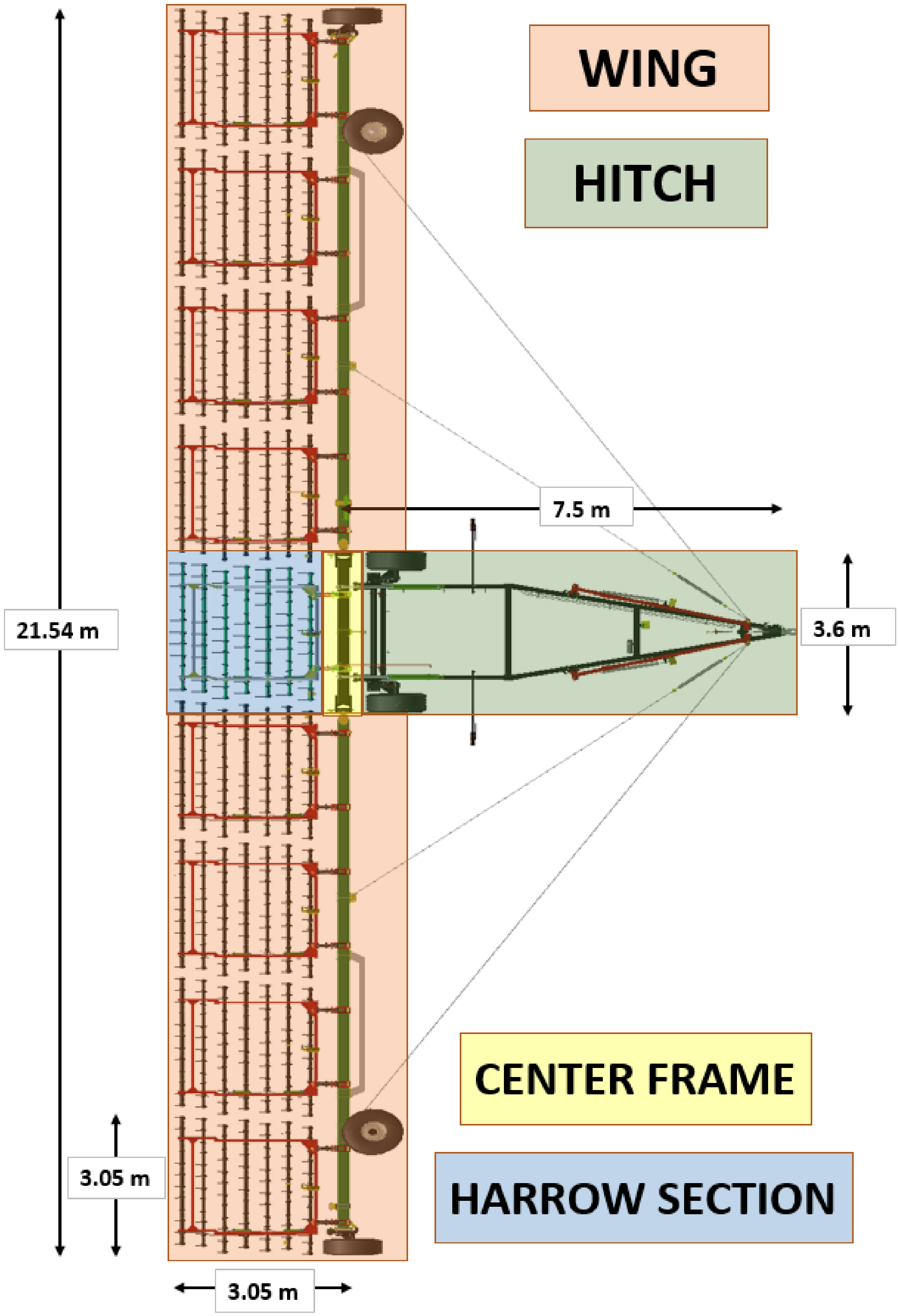



Figure 2: Harrow nomenclature and dimensions.

### 1.1.2 Transport and Field Modes

The Super 7 Harrow can be hydraulically articulated between two modes: one for field operation and other for transportation. Field mode, shown in Figure 1, is used during the intended operation of the machine to condition the surface of a field. While in field mode, the wings are fully extended with the tines interacting with the ground. Transport mode, shown in Figure 3, is used during the transportation of the harrow between fields or to a storage location. While in transportation mode, the wings and center frame are rotated so that the harrow sections are vertical and the tines are not engaging the ground. Additionally, the wings are rotated to be parallel to reduce the overall width of the harrow during transportation.

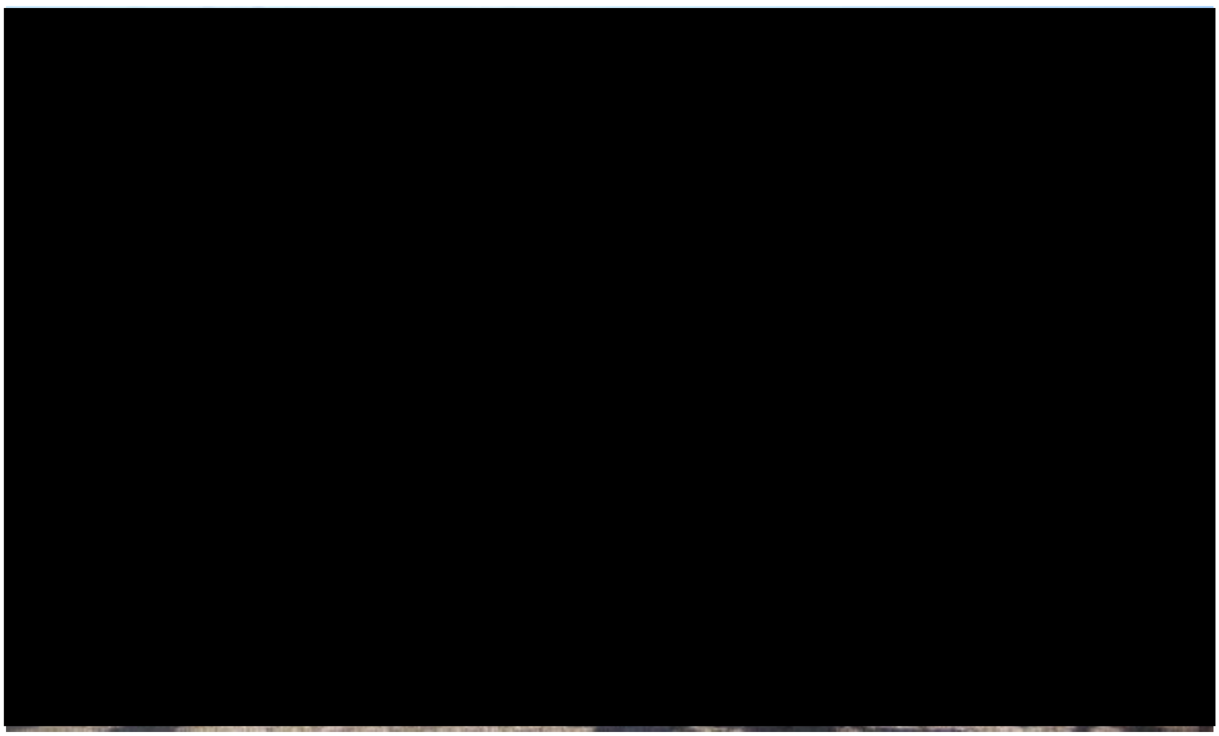


Figure 3: Super 7 Harrow in transport mode [2].

### 1.1.3 Current Shipping Methods

Elmer's currently utilizes two different methods for shipping the Super 7 Harrow within North America. Both methods include shipping a fully assembled harrow using a truck, but differ in the method of preparing the harrow for transport and are used for shipping different distances.

#### *1.1.3.1 Towing Shipping Method*

For short shipping distances, the harrow is converted into transportation mode and towed directly behind a truck, as shown in Figure 4. To prevent damage to the harrow's field tires, the rear harrow tires are replaced with tires designed for highway transportation. While transporting a harrow using the towing method, the speed of the truck is limited to approximately 60 kph. The speed limitation is because of the large size of the harrow making it unstable at high speeds and to reduce potential damage to the harrow from thrown rocks and road inconsistencies such as bumps or potholes.

Figure 4: Towing an 80’ Super 7 Harrow [3].

#### *1.1.3.2 Flatbed Shipping Method*

For longer shipping distances, the harrow is converted into transportation mode and loaded onto a flatbed, as shown in Figure 5. The harrow is loaded onto the trailer by Searcy Trucking with an overhead crane and secured to the trailer using ratchet straps. Additionally, the wings are secured to each other to prevent sway. The harrow’s wheel and tire assemblies are removed and the harrow secured to the flatbed separately. This method leaves a significant amount of empty space on the trailer and requires wide load signage. Depending on the model, the harrow will sit on different harrow components when on the trailer. For the 90’ Super 7 Harrow the harrow sits on the wing support bars.

Figure 5: 90' Super 7 Harrow on trailer [4].

## 1.2 Problem Statement

Team 4 has been tasked with reducing the overall shipping cost per harrow for Elmer's Manufacturing by loading two pieces of equipment on one truckload. A certain level of disassembly may be required to efficiently load the harrows on the truck while minimizing the work required by the dealer. Designed brackets and jigs may be used however they must be manufacturable by Elmer's supplier and integrated into the harrow assembly process. The proposed shipping method will be utilized beyond a determined transition point where it is more efficient than flat-towing the harrow.

## 1.3 Project Objectives

The overall objective of this project is to minimize the 90' Super 7 Harrows shipping cost by increasing the number of units being shipped per truckload. A detailed cost analysis of the new shipping method will be created, locating the cost transition point of using a trailer in comparison to towing behind a truck. The cost analysis will take into consideration all expenditures, including labour involved to install proposed brackets on the equipment, trailer cost, and loading costs.

The proposed shipping method must adhere to all local road regulations, specifically in regards to axle load and load width, height, and length. The client requested the following deliverables:

- CAD Models of the layout of the harrows on the trailer
- CAD Models of all required brackets
- Basic stress analysis of all required brackets
- Detailed cost analysis of proposed method
- Cost comparison to current methods
- Wordless assembly instructions

Wordless assembly instructions were requested to reduce the number of mistakes made during the assembly process, specifically mistakes made because of confusing language or lack of English skills.

## 1.4 Project Scope

This project will include the design of a new shipping method to package two harrows on one truck load and a cost analysis of the new shipping method. The proposed shipping method may require designed brackets to stabilize the load on the trailer. Basic stress analysis of components will be performed, but a detailed FEA analysis is not required as per the client's request. Additionally, the client specifically requested a designed shipping method for 90' Super 7 Harrow – all other Super 7 Harrow models will not be considered. The scope of this project includes a cost analysis of current shipping methods and a comparison between the current shipping methods and the proposed shipping method. While securement methods will be addressed, individual trailers have different securement points and specific details of attaching straps or chains to the trailer will not be covered and are the responsibility of the shipping company.

## 1.5 Target Specifications and Client Needs

To properly determine the target specifications of this project the client's needs must first be identified. The client's needs show the requirements of the project and ultimately allow specific targets for each objective to be established. Table I outlines the needs with regards to this project, as determined by a client questionnaire (included in Appendix A) and a meeting with the client. Each individual need is rated from one to five based on its priority (five being the most important). The first two needs demonstrate the duty to the public, the design must be safe during loading, unloading and transportation. Needs three to eight outline the functional needs as detailed by the client. The remaining client needs represent less important issues but are still considered in this project.

TABLE I: CUSTOMER NEEDS

| # | Need | Importance |
|---|---|---|
| **1** | The shipping, loading, and unloading methods are safe | 5 |
| **2** | The harrow packaging on the trailer needs to be road legal | 5 |
| **3** | The shipping method is low cost | 4 |
| **4** | The cost transition point between different shipping methods identified | 4 |
| **5** | Universally understandable harrow assembly and shipping instructions | 4 |
| **6** | The designed brackets are manufacturable by Elmer's suppliers | 4 |
| **7** | Documentation and analysis for designed components | 3 |
| **8** | The end receiver unloading and assembly are quick and easy | 3 |
| **9** | The harrow shipment packaging and loading procedures are quick and easy | 2 |
| **10** | The shipping brackets can be reused | 1 |

Once the client's needs were identified and the above list was confirmed by the client the target specifications and constraints of the project were determined. For each identified target specification, an associated measurable unit and target value, where applicable, were identified. The main target specification unit for this project is cost. However, the cost of many of the processes are measured in time with the associated cost calculated by multiplying the time spent by the hourly wage of the worker. The target shipping cost per harrow could not be stated because the cost varies greatly based on the method used and shipping destination.

Table II contains the target specifications identified by the team with regards to the pre-determined client needs. Due to the multi-stepped process of assembly, loading, and shipping of a harrow, the individual costs of each process can be quantified but the important metric is the total cost of the entire shipping process. Therefore, target values for certain processes were not established.

TABLE II: TARGET SPECIFICATIONS

| Need # | Specification | Unit | Target |
|---|---|---|---|
| **1** | Processes adheres to safe working laws | binary | Yes |
| **1,5** | Universally understandable instruction set | binary | Yes |
| **2** | Shipping method adheres to local regulations | binary | Yes |
| **3** | Shipping cost per harrow | $ | Less than Current |
| **3,9** | Loading time | hours | n/a |
| **3,8** | Unloading time | hours | n/a |
| **3,8** | Final assembly time | hours | n/a |
| **3,9** | Shipping preparation time | hours | n/a |
| **3,6** | Brackets are low cost | $ | n/a |
| **6** | Manufacturability | binary | Yes |
| **7** | Brackets designed Factor of Safety | numerical | > 3 |
| **8** | Ease of final assembly | subjective | Easy to assemble |
| **8** | Ease of unloading procedure | subjective | Easy to unload |
| **9** | Ease of shipping preparation | subjective | Easy to prepare |
| **9** | Ease of loading procedure | subjective | Easy to load |
| **10** | Reusable shipping bracket | binary | Yes |

Table II shows that few quantifiable targets could be established for this project thus far. The lack of quantifiable targets can be attributed to the nature of the project which deals with meeting mostly binary criteria. For example, the processes within the proposed shipping method may either conform to safe work laws or not and cannot be quantified.

## 1.6 Constraints and Limitations

A number of constraints and limitations must be considered over the course of this project. The first constraint was found to be the lift capacity for loading and unloading the trailer, which is heavily dependent on the method used for the loading and the location for where the loading and unloading processes are performed. The following constraints for this project relate to road restrictions, which are discussed in detail in the following sections:

### 1.6.1 Road Restrictions

The majority of Super 7 Harrows will be shipped to Manitoba, Saskatchewan, Alberta, and British Columbia (i.e. Western Canada). However, some may also be shipped to North Dakota, USA. In order to maintain the customer need that the method must adhere to all local road regulations, there are several road regulations in each province or state that must be met. The goal of this project is to adhere to all regulations in the aforementioned provinces/states with a single shipping solution therefore, the lowest common denominator for regulations will be used. Specific constraint values were identified for the size of the loads. There are increased restrictions on specific highways and roads through Western Canada and North Dakota and these routes either have to be avoided or the more stringent constraints met.

#### *1.6.1.1 Weight Restrictions*

Weight restrictions for road transportation vary across different provinces/states as per their respective transportation authorities. In addition to the varying restrictions based on location, there are seasonal weight restrictions during spring. The weight restriction varied from approximately 7700 – 9100 kg per axle depending on the location, which far exceeds the weight of the combined harrows (approximately 8200 kg). The weight restriction was determined to be a non-factor in the design process due to the relatively light weight of the harrows.

#### *1.6.1.2 Width Restrictions*

Width restrictions for road transportation vary across provinces/states according to the different transportation authorities. In addition to the varying restrictions based on location, there are varying levels of restriction, including no permits required, permits required, wide load signage required, and pilot vehicles required. With the increasing restriction levels there are corresponding additional increases in cost for transportation. The width restrictions for the provinces/states that will be shipped within are shown in Table III. Additionally, a visual to assist in understanding the width regulations, specifically with regard to Manitoba's restrictions is shown in Figure 6.

TABLE III: WIDTH RESTRICITONS

| Location/Requirement | Unit | Limit |
|---|---|---|
| Western Canada (no requirements) **[5] [6] [7] [8]** | m | 2.6 |
| Western Canada (w/ permit) **[5] [6] [7] [8]** | m | 3.05 |
| Western Canada (w/ Pilot Vehicle) **[5] [6] [7] [8]** | | Depends on route |
| MB (w/ Wide Load Signage) **[5]** | m | 4.6 |
| SK (w/ Wide Load Signage) **[6]** | m | 3.85 |
| AB (w/ Wide Load Signage) **[7]** | m | 3.85 |
| BC (w/ Wide Load Signage) **[8]** | m | 3.8 |
| ND (no requirements) **[9]** | ft. | 8.5 |
| ND (over width) **[9]** | ft. | 15.5 |


Figure 6: Manitoba road transportation width restrictions.

As requested by the client to reduce cost, the designed shipping method will attempt to avoid the requirement of pilot vehicles. Therefore largest width allowed for the shipping method is 3.8 m.

#### *1.6.1.3 Height Restrictions*

Similar to the width restrictions, height restrictions for road transportation vary across different provinces/states as per the different transportation authorities. In addition to the varying restrictions based on location there are varying levels of restriction, including no permits required, single permit required, and multiple permits required. In addition to the purchase of the permits, special routing may be required for larger heights. The height restrictions for the provinces/states that will be shipped within are shown in Table IV. Additionally, a visual to assist in understanding the height regulations, specifically regarding Manitoba's restrictions, is shown in Figure 7.

TABLE IV: HEIGHT RESTRICTIONS

| **Location/Requirement** | **Unit** | **Limit** |
|---|---|---|
| Western Canada (no requirements) **[6] [7] [8] [10]** | m | 4.15 |
| MB (w/ MTS Permission) **[10]** | m | 4.8 |
| MB (w/ Hydro Permission) **[10]** | | Depends on route |
| SK, AB (w/ permit) **[6] [7]** | m | 5.2 |
| BC (w/ permit) **[8]** | m | 4.7 |
| ND (no requirements) **[9]** | ft. | 14.5 |
| ND (over height) **[9]** | ft. | 15.5 |

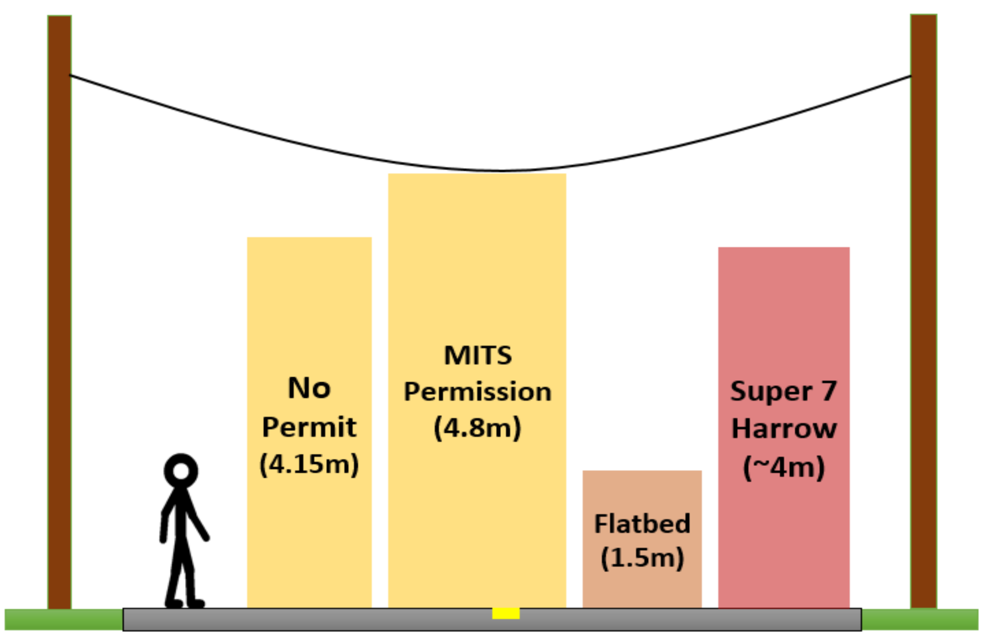



Figure 7: Manitoba road transportation height restrictions.

As requested by the client to reduce cost, the designed shipping method will attempt to avoid as much as possible the requirement of special routing. Therefore, the largest height allowed for the shipping method is 4.7 m.

#### *1.6.1.4 Length Restrictions*

Similar to the width and height restrictions, length restrictions for road transportation vary across different provinces/states according to the different transportation authorities. In addition to the varying restrictions based on location there are varying levels of restriction, including no permits required, single permit required, and multiple permits required. In addition to the purchase of the permits, special routing may be required for larger heights. The height restrictions for the provinces/states that will be shipped within are shown in Table V.

TABLE V: LENGTH RESTRICTIONS

| **Location/Requirement** | **Unit** | **Limit** |
|---|---|---|
| SK (no requirements) **[6]** | m | 23 |
| SK (w/ flagging) **[6]** | m | 27.5 |
| SK (w/ long load signage) **[6]** | m | 34 |
| BC (w/ long load signage) **[8]** | m | 27.5 |
| MB (w/ flagging) **[11]** | m | 30 |
| AB (no requirements) **[7]** | m | 23 |
| AB (w/ wide load signage) **[7]** | m | 34 |
| AB (w/ pilot vehicles) **[7]** | m | 52 |
| ND (no requirements) **[9]** | ft | 50 |
| ND (over length) **[9]** | ft | 100 |

As requested by the client to reduce cost, the designed shipping method will attempt to avoid the requirement of pilot vehicles. Therefore, the longest length allowed for the shipping method is 27.5 m.

#### *1.6.1.5 Overhang Restrictions*

Similar to the width, height restrictions and length restrictions, overhang restrictions for road transportation vary across different provinces/states according to the different transportation authorities. Overhang refers to the length from the turn centre of the full trailer, pony trailer, semi-trailer, to the rearmost point of the vehicle including the load. The overhang restrictions for the provinces/states that will be shipped within are shown in Table VI.

TABLE VI: OVERHANG RESTRICTIONS

| **Location/Requirement** | **Unit** | **Limit** |
|---|---|---|
| SK ( w/ flagging) **[6]** | m | 4 |
| SK (B-Train Lead Trailer w/flagging) **[6]** | | 35% of Wheelbase |
| BC (w/ flagging) **[8]** | m | 4 |
| BC (B-Train Lead Trailer w/ flagging) **[8]** | m | 35% of Wheelbase |
| MB (w/ flagging) **[11]** | m | 4 |
| MB (B-Train Lead Trailer w/ flagging) **[11]** | m | 35% of Wheelbase |
| AB (w/ flagging) **[7]** | m | 4 |
| AB (B-Train Lead Trailer w/ flagging) **[7]** | m | 35% of Wheelbase |
| ND **[9]** | | Dependant on overall length |

The overhang must not protrude past the maximum constraints of 4 m for a regular trailer or rear trailer of a B-Train, or 35% of the wheelbase for the lead trailer of a B-Train trailer.

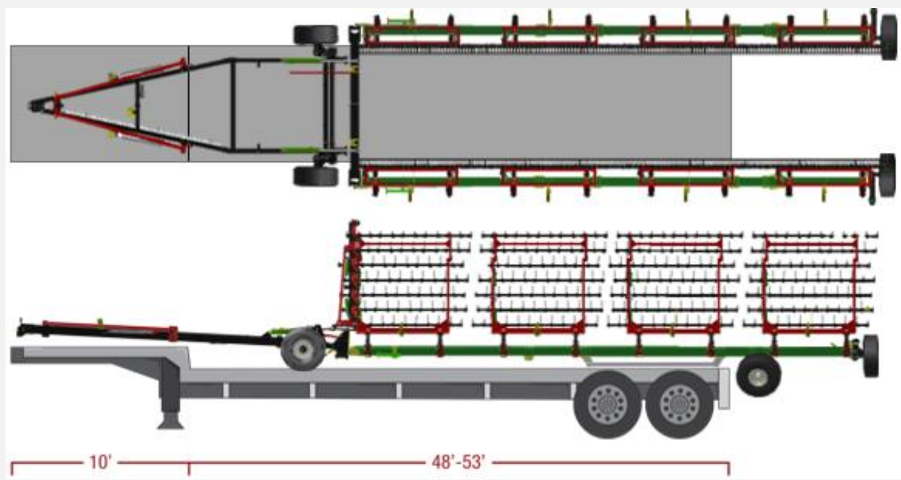
## 2 Concept Development

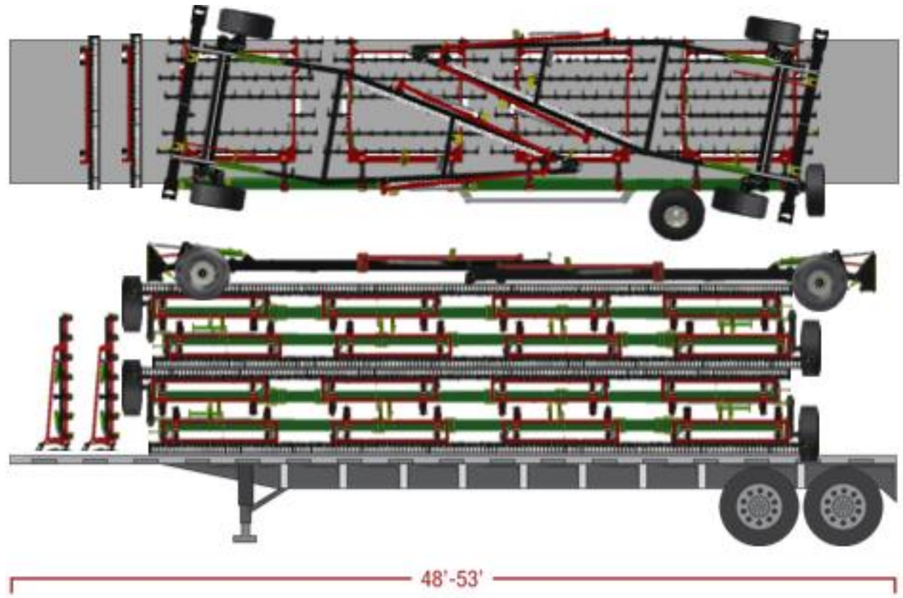
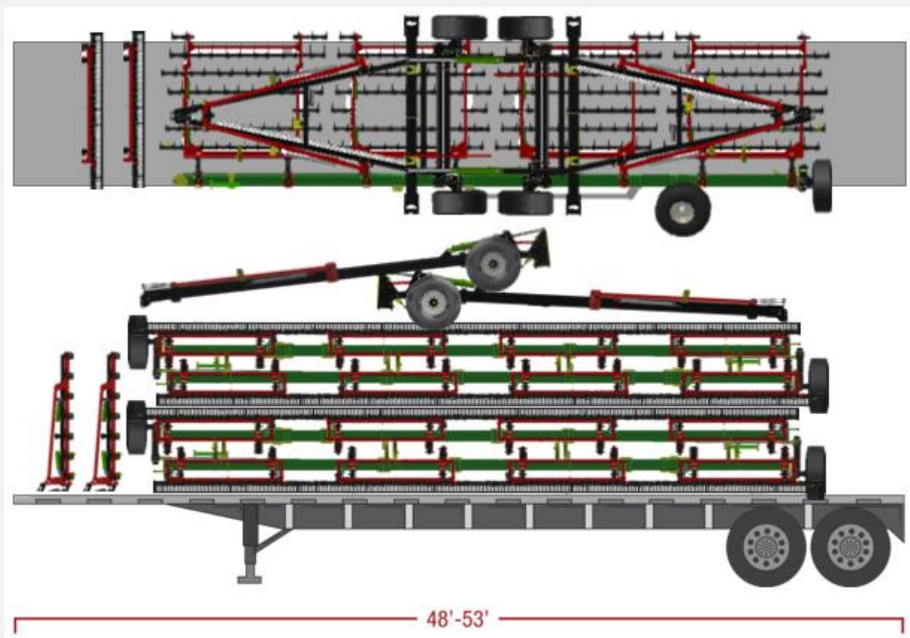
To develop a final concept for the trailer layout and bracketing, a brainstorming method was used to generate a lists of concepts. The concepts were screened and scored against each other as detailed in the following sections.

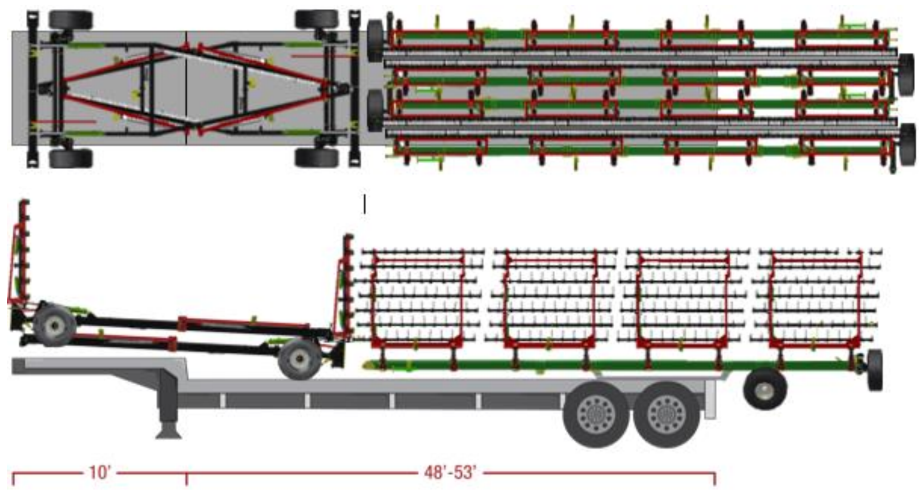
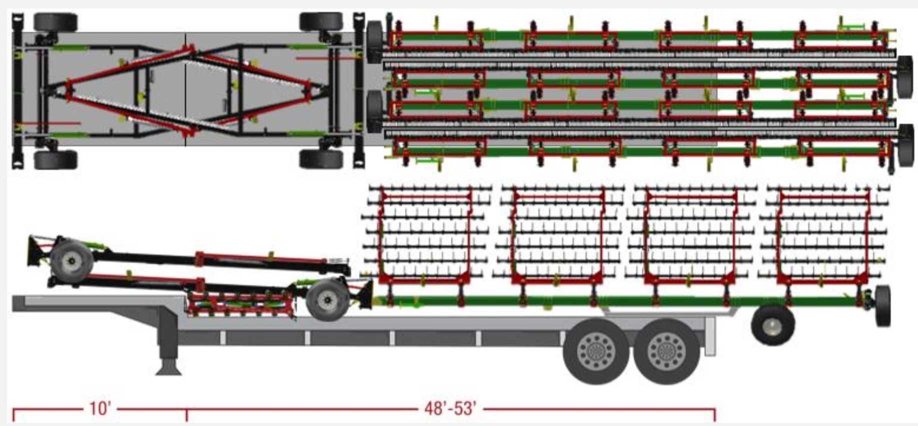
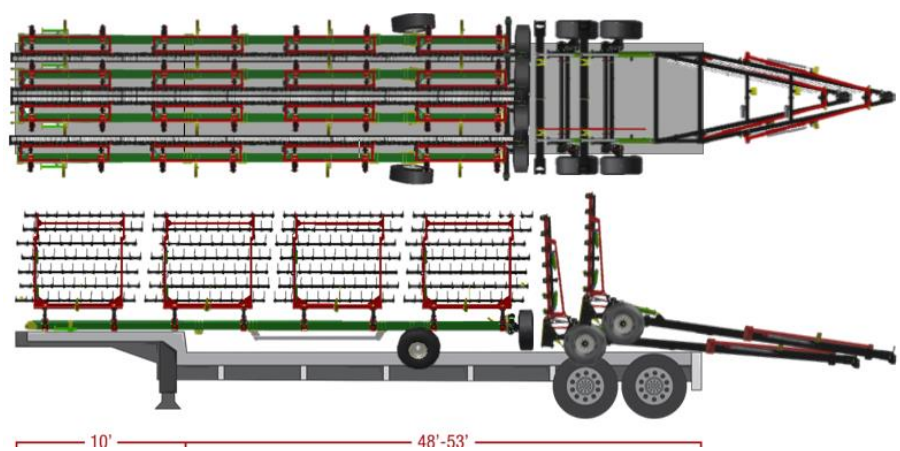
### 2.1 Trailer Layout Concept Generation

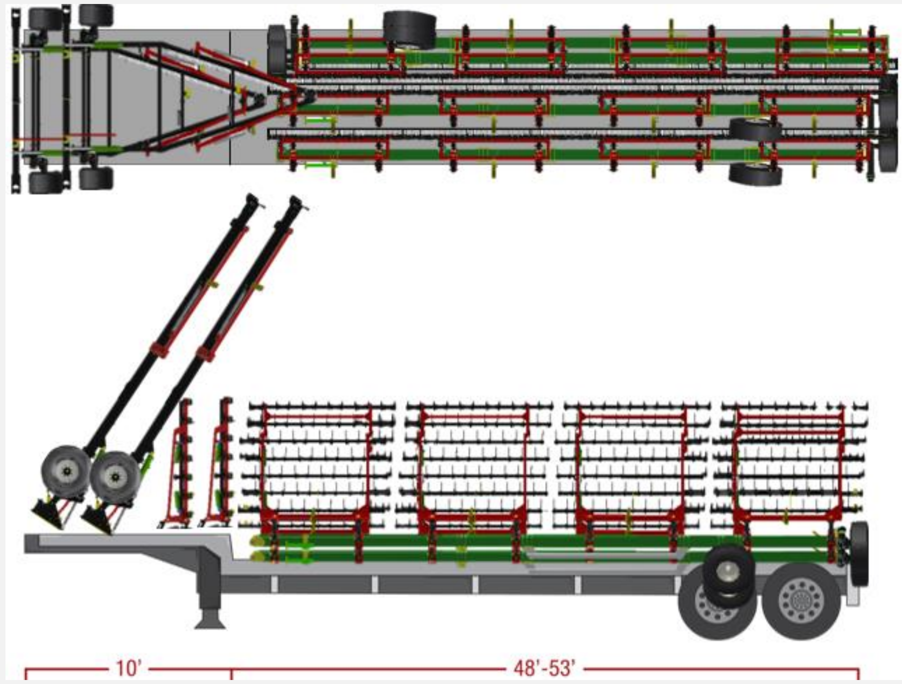
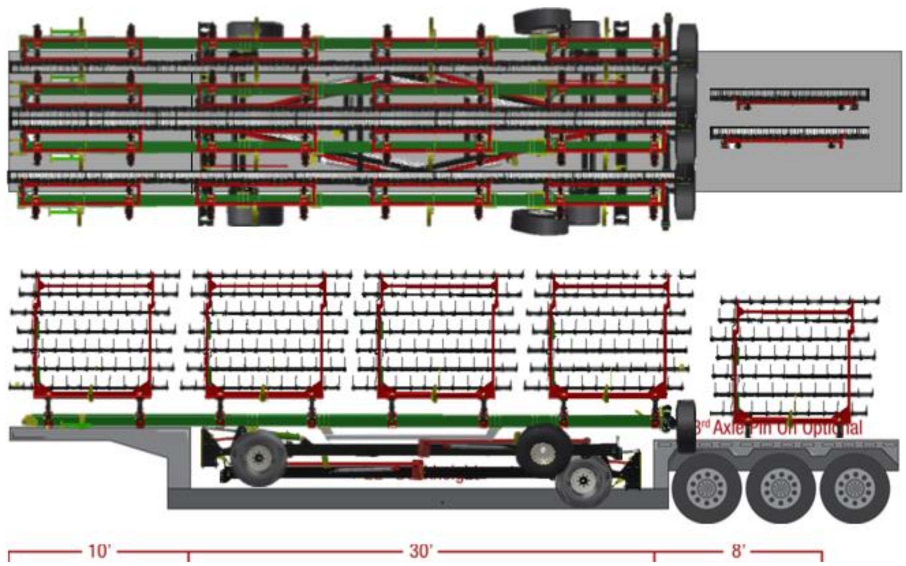
Concepts were generated using scale diagrams of side and top views of the available trailers and of various sections of the harrow. Trailers used to develop concepts included a 53’ flatbed, 53’ step deck, 48’ drop deck, B-Train drop deck and an 81’ Extendable flatbed. The scaled sections of the harrow were arranged on the trailers to produce varied concepts and compiled into Table VII.

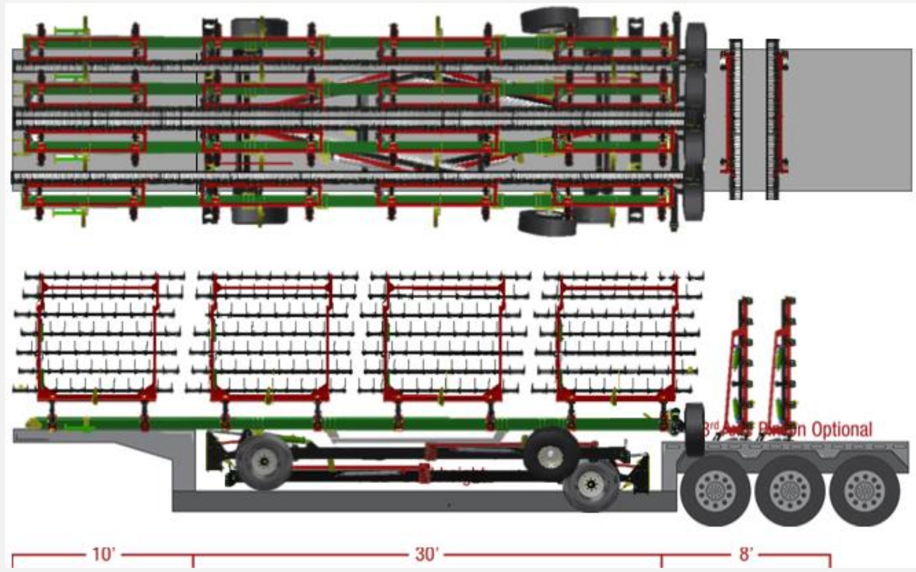
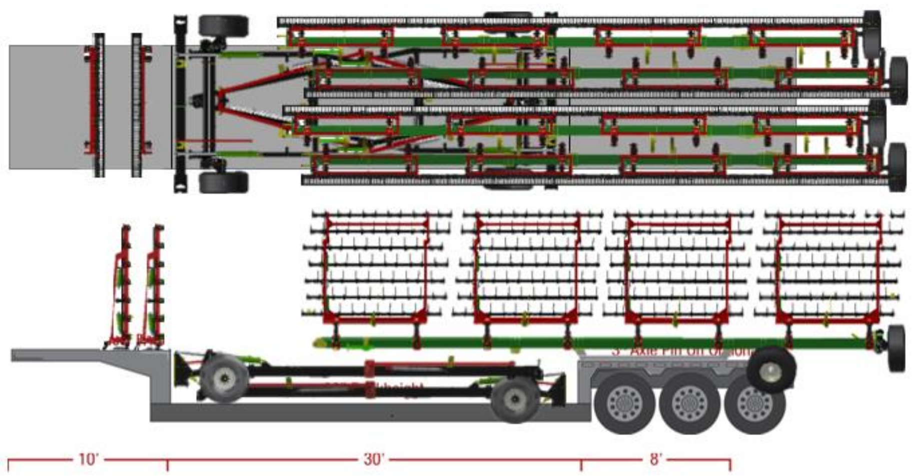
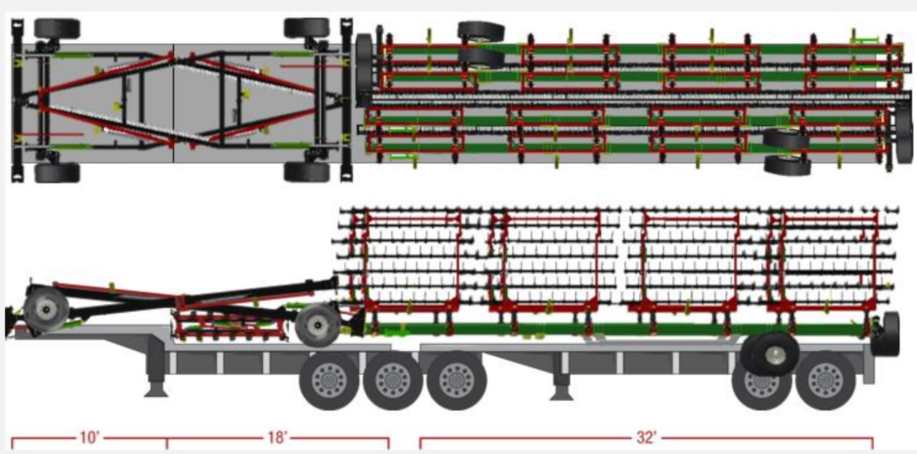
TABLE VII: LIST OF GENERATED CONCEPTS

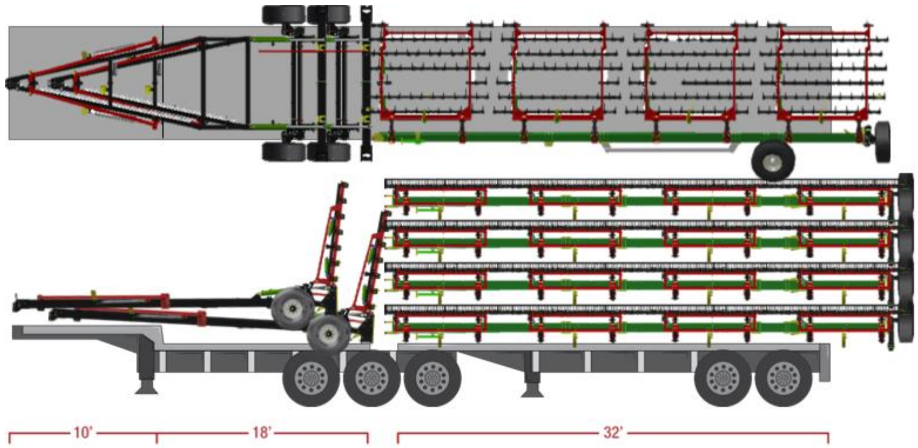
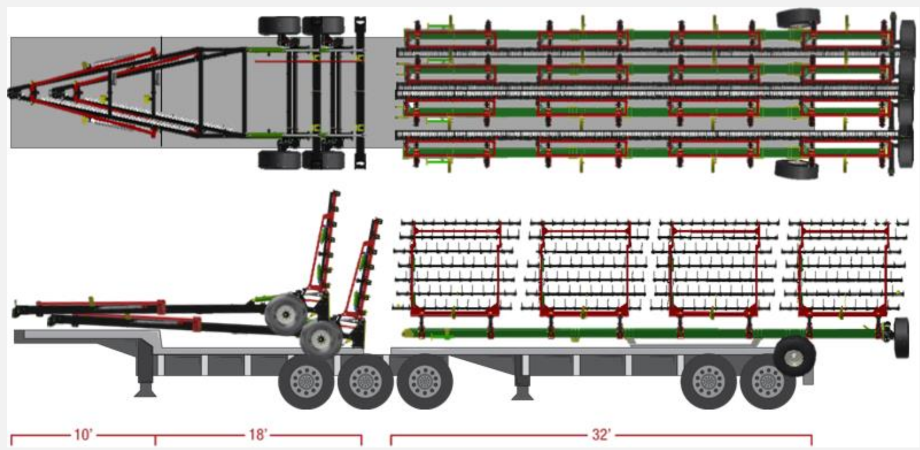
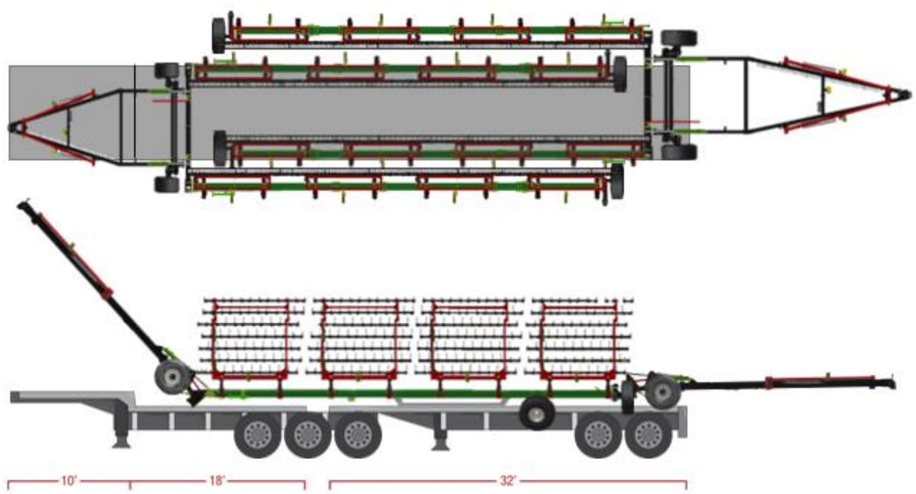
| Label | Description | Diagram |
|---|---|---|
| **A** | 53’ Step deck, Current Method |   |

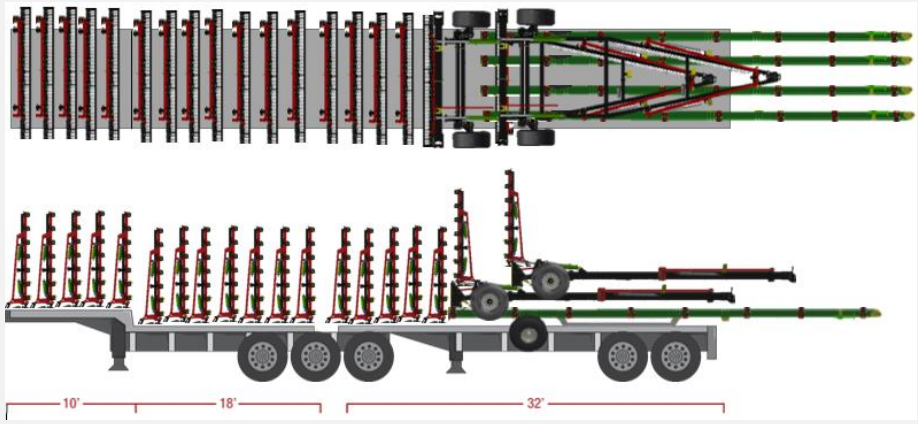
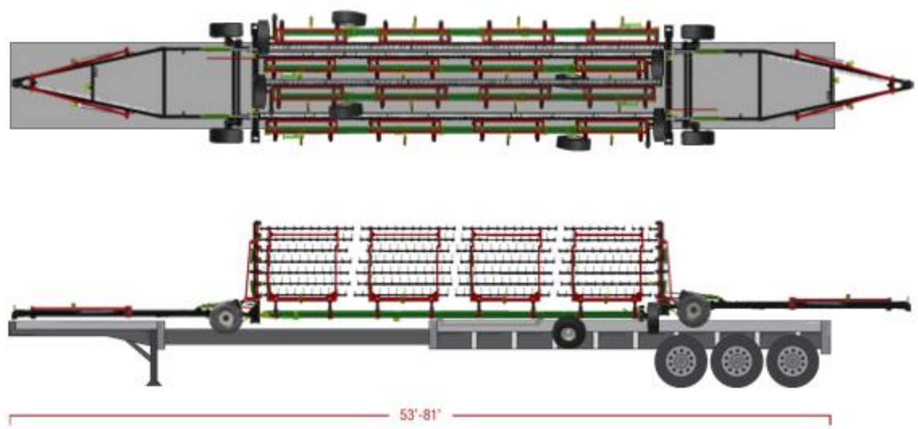
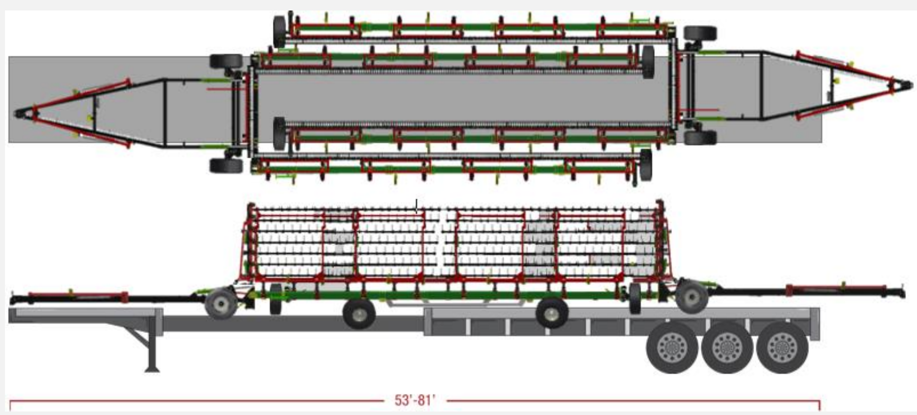
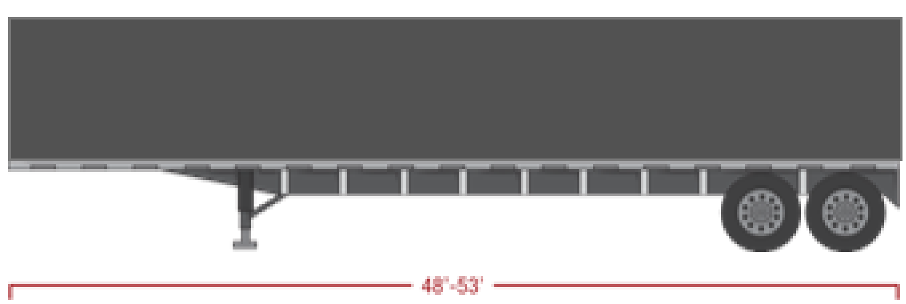
| | | |
|---|---|---|
| **B** | 53’ Flatbed |   |
| **C** | 53’ Flatbed |   |

| | | |
|---|---|---|
| **D** | 53’ Flatbed |  |
| **E** | 53’ Flatbed |  |
| **F** | 53’ Flatbed |  |

| | | |
|---|---|---|
| **G** | 53’ Flatbed |  |
| **H** | 53’ Dropdeck |  |

| | | |
|---|---|---|
| **I** | 53’ Dropdeck |  |
| **J** | 53’ Dropdeck |  |
| **K** | B-Train Stepdeck |  |

| | | |
|---|---|---|
| **L** | B-Train Stepdeck |   |
| **M** | B-Train Stepdeck |   |
| **N** | B-Train Stepdeck |   |

| | | |
|---|---|---|
| **O** | B-Train Stepdeck |  |
| **P** | Extendable Flatbed |  |
| **Q** | Extendable Flatbed |  |
| **R** | 53' Box Trailer, Fully Disassembled |  |

Once the concept generation phase was complete and several concepts were developed the next step of the concept development process was to screen and rank the concepts using screening and scoring matrices. The concepts were compiled into one document where they could be compared to one another side by side. To rank the concepts fairly, a list of selection criteria was compiled based on individual characteristics that could be compared to one another. The selection criteria were then weighted using a criteria weighting matrix to ensure that more important characteristics of the concepts promoted a better overall ranking of the design. All eighteen concepts were then subjected to screening in a Concept Screening Matrix where each design was compared to an arbitrarily chosen reference concept based on the determined selection criteria. Following the concept screening the top seven concepts were carried through to the Concept Scoring Matrix where the weighted selection criteria were applied to each concept and the designs with the highest scores were selected to move forward.

## 2.2 Trailer Layout Selection Criteria

The selection criteria used for the concept development process were chosen based on individual characteristics of the concepts. Each characteristic is based on the client needs, target specifications, and design constraints of the project. These selection criteria are used to help rank the concepts against one another and decide which concept designs to move forward with. Each criterion was ranked on a scale of one to five, where one was the worst and five was the best. The selection criteria chosen for this process were complexity, level of assembly, ease of loading, ease of unloading, weight distribution, and size.

### 2.2.1 Complexity

The overall complexity of each design was evaluated based on a variety of factors, namely: the overall cost, bracketry required, and individual trailer style. This criterion was the most subjective of the six used and required further analysis of the concepts. To fairly evaluate each concept, the complexity was determined last during the concept scoring processes, which allowed the group to use it as a "tie breaker." The least complex concepts were awarded a score of five while the most complex designs were given a one. As such, the subjective criteria were broken down into cost, bracketry and trailer selection.

#### *2.2.1.1 Cost*

The total cost of each concept design is an important requirement as per the client's request. The main purpose of this project is to reduce the total cost of shipping (per harrow) compared to Elmer's current method. During the development stage, it is difficult to determine the exact cost of each concept however, due to the individual characteristics of each design, our team could compare the concepts to one another and form a score for each concept. Some examples of factors that were considered during the cost analysis were:

- Cost of permits/pilot vehicle
- Cost of bracketry
- Cost of trailer

During the brief cost analysis for each concept it became apparent that several other selection criteria also played a part in the overall cost of each design. For the purposes of this concept analysis our team decided to limit the scope to the factors mentioned above as part of the deliverables later in the project include a detailed cost analysis of the proposed shipping method compared to Elmer's current methods.

#### 2.2.1.2 Bracketry

The required bracketry for each concept plays an important role in the overall cost and complexity of the design. While for this project the cost for the client is not directly proportional to the complexity of the bracketry, the subjective analysis included both the complexity and cost of the bracketry as a negative attribute. The overall bracketry required costs the client a variety of resources.

The first cost of complex brackets used in this design is the time required for the design and implementation. As part of the design process it is essential to follow the necessary steps to ensure the customer receives the desired product.

The manufacturing of the bracketry will be outsourced to Elmer's suppliers where most of their cutting and forming of steel is performed. Elmer's may decide to weld and assemble the brackets in house therefore, consideration must be made that they are not overly complex or require special skilled labour for assembly. There is also a consideration that normal production should not have to be interrupted to produce these brackets, unless the cost savings are such that it is acceptable. It can also be noted that the bracketry will be designed to be reusable so the initial cost of manufacturing will ideally be spread throughout several units – decreasing the total cost over time.

The final consideration when designing the bracketry is that it is very likely to be included in the assembly of the harrow at Elmer's Manufacturing. The bracketry must be designed such that it is simple to integrate into the manufacturing process – if installing the bracketry slows production time too much, then increases the overall cost of the concept.

#### *2.2.1.3 Trailer Selection*

The trailer chosen for each designed concept was also considered in the overall complexity of the design. Elmer's currently uses a standard drop flat deck trailer which is very common and readily available by shipping companies. Searcy Trucking offers a variety of trailer configurations and several of their offerings were considered in the concept development. There is an increase in cost with increases in size and complexity of the trailer therefore some trailer types rank lower. During the screening process we did not allow this part of the criterion to solely eliminate any concepts as there was mention that if a long-term solution could be met with our design that Elmer's Manufacturing and Searcy could look into a trailer availability and cost solution for the long term.

### 2.2.2 Level of Assembly

The level of assembly refers to how complete the harrow will be assembled before it is prepared for shipping. The 90' harrow is currently fully assembled at the factory before it towed in transport mode to Searcy's yard where it is loaded onto the truck. The current method of leaving the harrow fully assembled allows it to be hydraulically tested at the factory and retains the ability to move the harrow in transport mode. Unfortunately, leaving the harrow fully assembled limits the ability to package two harrows on one trailer. Some steps of assembly may be omitted during the manufacturing process to allow for easier packaging of two harrows on one trailer. The time associated with each level of assembly was considered in the scoring process and used to help score each concept.

The overall level of assembly of the two harrows highly depends on the configuration of the components on the trailer Table VIII contains the objective scores assigned to each level of assembly. The highest score was awarded to full harrow assembly while the lowest score was given to leaving both harrows fully disassembled.

TABLE VIII: LEVEL OF ASSEMBLY SCORING

| | |
|---|---|
| **1** | Both harrows fully disassembled |
| **2** | Both harrows wing detached, hitches disassembled |
| **3** | Both harrows with wings detached, hitches intact |
| **4** | One harrow fully assembled, on harrow with wings detached |
| **5** | Both harrows fully assembled |

### 2.2.3 Ease of Loading

The current shipping method has the harrows road transported to Searcy Trucking where they are loaded on the flatbed by a crane. The scope of this project includes examining the ease of loading the proposed method onto the truck to be shipped by Searcy. The client is not too concerned with the specific loading method(s) of the proposed design however, the ability to efficiently load the harrows on to the truck is an important consideration when comparing concepts.

The two main criteria when considering the ease of loading are the time and resources required. The time required to load the harrows on the truck is going to be highly variable until a valid loading method is established. As such, it is difficult to quantify the exact time required to load each concept as there are many variables to take into consideration. An easier variable to quantify at this point is the number of resources that will be required to load each design concept. Resources can be broken down further into the equipment and estimated number of workers needed. Table IX contains the determined scores for the loading process:

TABLE IX: EASE OF LOADING SCORING

| | |
|---|---|
| **1** | Long loading time, high number of resources |
| **2** | Short loading time, high number of resources |
| **3** | Average loading time, intermediate number of resources |
| **4** | Long loading time, low number of resources |
| **5** | Short loading time, low number of resources |

Overall, the ease of loading the harrows onto the truck is not the main priority for the design of the harrow shipping packaging. Elmer’s Manufacturing is prepared to make the arrangements for a loading dock or system where they can load the harrows on-site or transport them to Searcy to be loaded by crane. The overall costs in time and resources incurred must not exceed the benefit of being able to ship two harrows in one truckload. The ease of loading is not considered as important as the ease of unloading in this analysis as once the method is standardized and all the required equipment is in place, there will be little variation in the ease of loading. On the other hand, the ease of unloading must be scrutinized further as the number of available resources will vary greatly between dealers.

### 2.2.4 Ease of Unloading

Unloading the harrows from the truck is more difficult to standardize when compared the loading process. Elmer's Manufacturing has a vast dealer network throughout North America all of which possess different resources for unloading shipments. As a result of differences in unloading capabilities between dealers, unloading the harrows must be carefully examined to ensure that the method will be accepted by the majority of customers. Some dealers may sell less than one harrow per year therefore they may not be as willing to accommodate any extra equipment or other resources required for the proposed method. Table X demonstrates the scoring for the ease of unloading criteria.

TABLE X: EASE OF UNLOADING SCORING

| | |
|---|---|
| **1** | Long unloading time, high number of resources |
| **2** | Short unloading time, high number of resources |
| **3** | Average unloading time, intermediate number of resources |
| **4** | Long unloading time, low number of resources |
| **5** | Short unloading time, low number of resources |

To improve in the unloading process one of the project deliverables is to include a set of wordless instructions to assist the customer with removing and assembling the harrows from the truck. The wordless aspect of the instructions will ensure universal understanding of the process and allow the customer to prepare for the shipment beforehand. Another consideration with the unloading is considering the ability to unload one harrow off the truck while leaving the remaining harrow in the shipping configuration. This would allow Elmer's to reap the full benefit of shipping two harrows on one truck (by reducing the overall cost per harrow) while maintaining the flexibility to deliver to two different customers in one truckload.

### 2.2.5 Weight Distribution

The weight distribution of each concept is considered less important in the scope of the project. With the current known flat deck trailer capabilities, there is little concern that the weight distribution on the trailer will have a major effect on the shipping equipment. The main concern with weight distribution in the concept screening and scoring is related to the centre of gravity of the shipment. A high centre of gravity poses issues with safely securing the load to the trailer. It also requires more robust bracketry which in turn increases the complexity of the design. The scores for the weight distribution are included in Table XI, with a low C.O.G. being awarded the highest score.

TABLE XI: WEIGHT DISTRIBUTION SCORING

| | |
|---|---|
| **1** | High C.O.G off centre of trailer |
| **2** | High C.O.G centred on trailer |
| **3** | Intermediate C.O.G |
| **4** | Low C.O.G off centre of trailer |
| **5** | Low C.O.G centred on trailer |

It should also be noted that the C.O.G used for this criterion was estimated using the scaled drawings for the various concepts. A more accurate C.O.G measurement will be important later in the design process when designing the bracketry to support the load. It was also noticed that most of the design concepts naturally had the harrows' weight relatively even spread across the width of the trailer.

### 2.2.6 Size

The size of each concept was judged based on the overall height, width, and length and the load overhang. To pass the initial screening process each concept had to fall within the road restrictions outlined in Table XII.

TABLE XII: LOAD SIZE RESTRICTIONS

| Dimension | Restriction |
|---|---|
| Length | 27.5 m |
| Height | 4.7 m |
| Width | 3.8 m |

Due to the variety of provinces and states that the harrows will be travelling through, the size criterion is aimed to reduce the costs associated with additional permits, signage, and pilot vehicles required for travel. Concepts that adhered to lower levels of regulations were awarded the highest score, while those that did not (therefore incurring higher costs) were given the lowest as illustrated in Table XIII.

TABLE XIII: SIZE SCORING

| | |
|---|---|
| **1** | Requires special routing due to height constraint |
| **2** | Requires pilot vehicle |
| **3** | Requires additional signage |
| **4** | Requires permit |
| **5** | No Permits required |

## 2.3 Trailer Layout Concept Selection

A weighted decision matrix, shown in Figure 8, was used to compare the selection criteria to one another. For this step it is important to have each criterion well-defined in order to accurately weigh it against the others. The matrix used for this process labels the criteria from A to F, moving down the matrix each criterion is compared to each other and the more important criterion is marked with a "hit." The number of "hits" each criterion receives is tallied at the bottom of the matrix where each selection criterion is assigned a weighting based on importance.

| | | Complexity | Level of Assembly | Ease of Loading | Ease of Unloading | Weight Distribution | Size |
|---|---|---|---|---|---|---|---|
| Criteria | | A | B | C | D | E | F |
| A | Complexity | | A | A | A | A | A |
| B | Level of Assembly | | | B | B | B | B |
| C | Ease of Loading | | | | D | E | C |
| D | Ease of Unloading | | | | | D | D |
| E | Weight Distribution | | | | | | F |
| F | Size | | | | | | |
| Total Hits | | 5 | 4 | 1 | 3 | 1 | 1 |
| Weightings | | 0.33 | 0.27 | 0.07 | 0.20 | 0.07 | 0.07 |

Figure 8: Weighting Matrix

### 2.3.1 Trailer Layout Concept Screening

The first analysis used to apply the selection criteria to the concept designs was a screening matrix. With the selection criteria well-defined and their weighted scores established, a matrix was constructed with a column for all 17 concepts. With all the concepts entered in the matrix the first step was to establish a "benchmark" concept that the remaining concepts could be compared to.

Concept D, shown in Figure 9, was chosen as the benchmark because it displayed an average adherence to the selection criteria. It required use of a 53' step-down flatbed trailer which is currently used by Elmer's to ship a single harrow. It also had a relatively high level of assembly and ease of loading/unloading. With the benchmark established the remaining concepts were scored "+", "-", or "0" compared to the benchmark in each of the selection criteria. The net score for each concept was tallied and the seven concepts with the highest scores continued to the scoring analysis. The results for the screening matrix are shown in Figure 10.

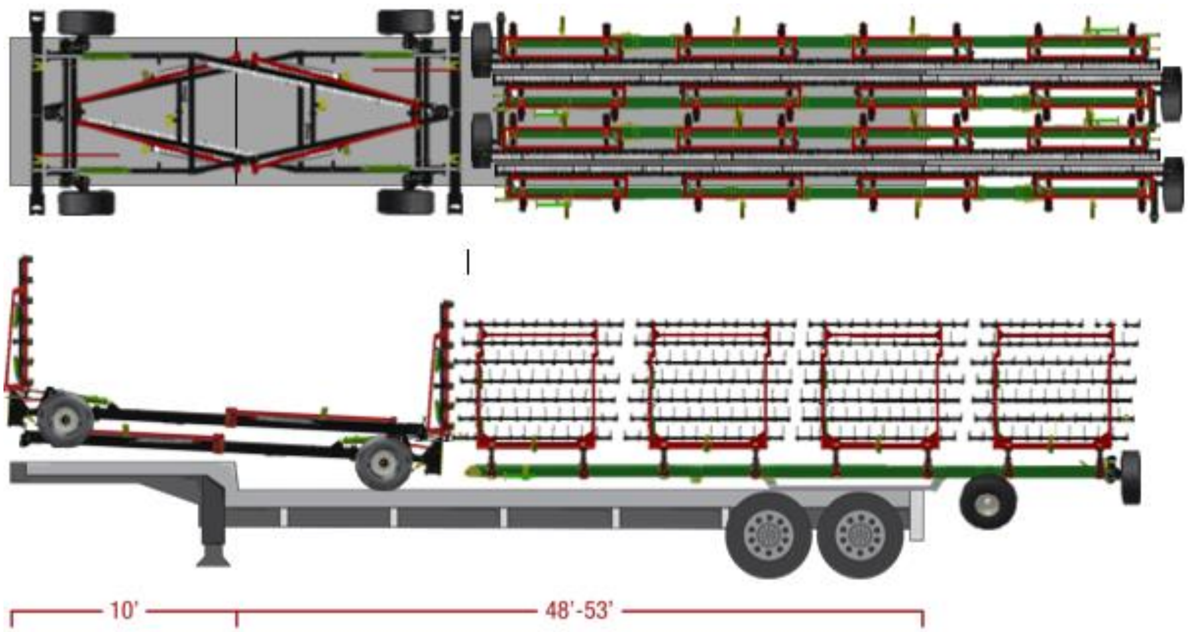



Figure 9: Benchmark - Concept D

| | Flatbed Shipping Methods | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Selection Criteria | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R |
| Complexity | - | - | 0 | - | 0 | - | - | - | - | - | - | - | - | - | - | 0 | - |
| Level of Assembly | - | - | 0 | - | 0 | - | - | - | - | - | 0 | 0 | + | - | 0 | + | - |
| Ease of Loading | - | - | 0 | 0 | 0 | - | 0 | 0 | 0 | 0 | - | 0 | - | - | + | - | 0 |
| Ease of Unloading | - | - | 0 | 0 | + | - | 0 | 0 | 0 | - | - | 0 | - | - | + | 0 | - |
| Weight Distribution | + | + | 0 | 0 | 0 | - | + | + | + | 0 | - | 0 | - | 0 | 0 | 0 | 0 |
| Size | + | - | 0 | 0 | 0 | - | + | + | + | + | 0 | + | - | 0 | - | - | + |
| | | | | | | | | | | | | | | | | | |
| Pluses | 2 | 1 | 0 | 0 | 1 | 0 | 2 | 2 | 2 | 1 | 0 | 1 | 1 | 0 | 2 | 1 | 1 |
| Zeros | 0 | 0 | 6 | 4 | 5 | 0 | 2 | 2 | 2 | 2 | 2 | 4 | 0 | 2 | 2 | 3 | 2 |
| Minuses | 4 | 5 | 0 | 2 | 0 | 6 | 2 | 2 | 2 | 3 | 4 | 1 | 5 | 4 | 2 | 2 | 3 |
| Net | -2 | -4 | 0 | -2 | 1 | -6 | 0 | 0 | 0 | -2 | -4 | 0 | -4 | -4 | 0 | -1 | -2 |
| Rank | 4 | 5 | 2 | 4 | 1 | 6 | 2 | 2 | 2 | 4 | 5 | 2 | 5 | 5 | 2 | 3 | 4 |
| Continue? | N | N | Y | N | Y | N | Y | Y | Y | N | N | Y | N | N | Y | N | N |

Figure 10: Screening Matrix

### 2.3.2 Trailer Layout Concept Scoring

The next part of the analysis was used to quantitatively compare the seven concepts to each other based on the selection criteria. With the weight of each selection criterion determined, each individual design concept was ranked from one (1) to five (5) based on each criterion – with five (5) being the highest score. All seven concepts were evaluated for the same criterion sequentially to allow for a fair comparison. It should be noted that the score given to each design is independent of the other designs therefore, several concepts may receive the same score.

The criteria score for each concept was multiplied by the criteria weight to establish an overall score for that category. This allowed the concepts with better scores in the stronger criteria (complexity, level of assembly, and ease of unloading) to achieve a stronger overall score. This was done to ensure that although some concepts may score well in weaker criteria (ease of loading, weight distribution, and size) it did not hide the fact that they did not conform to the stronger weighted criteria. The complexity for each concept was evaluated last because it was considered the most important criterion and required the most analysis by the group to score. The total score for each concept was totaled and the top four scores were chosen to move on to the next phase of concept development, shown in Figure 11.

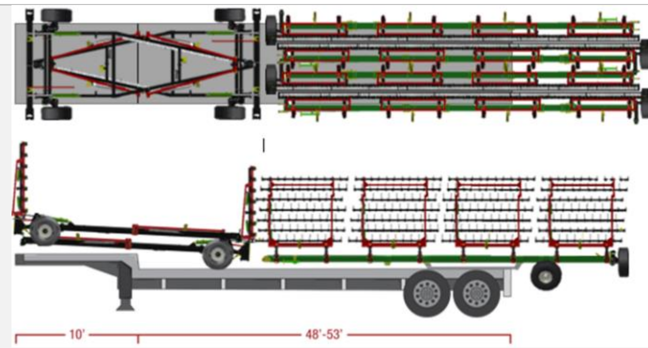
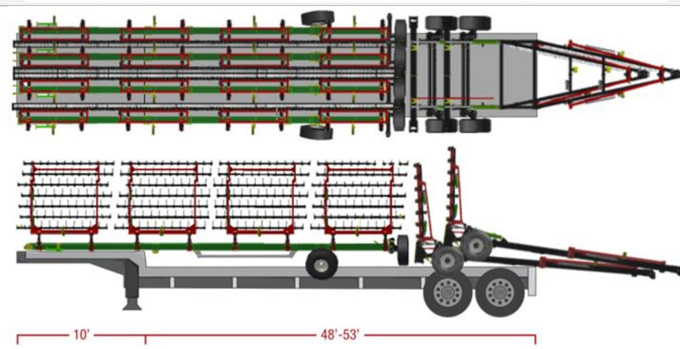
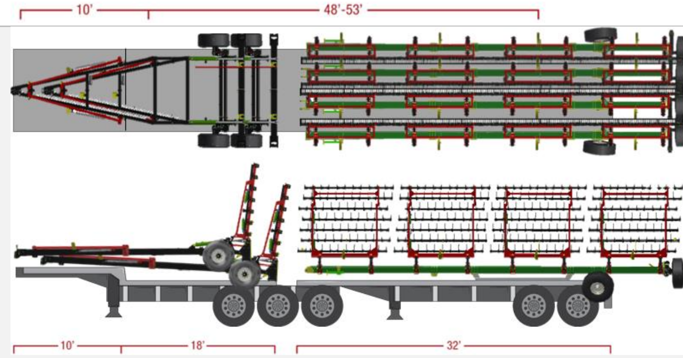
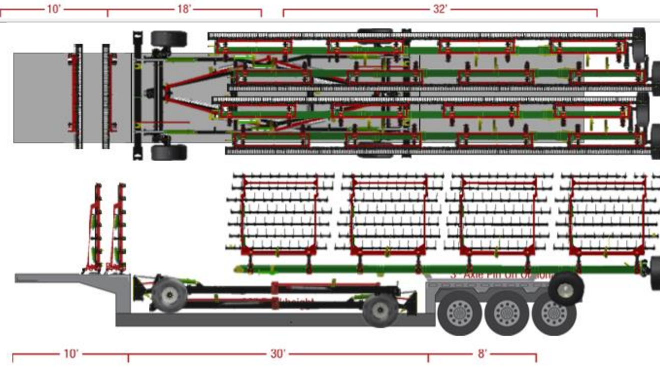
| | | Flatbed Shipping Methods | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | D | | F | | H | | I | | J | | M | | P | |
| Selection Criteria | Weight | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score |
| Complexity | 0.33 | 4.5 | 1.50 | 4.5 | 1.50 | 2.5 | 0.83 | 3 | 1.00 | 4 | 1.33 | 3.5 | 1.17 | 2 | 0.67 |
| Level of Assembly | 0.27 | 3 | 0.80 | 3 | 0.80 | 2 | 0.53 | 2 | 0.53 | 2.5 | 0.67 | 3 | 0.80 | 3 | 0.80 |
| Ease of Loading | 0.07 | 4 | 0.27 | 4 | 0.27 | 4 | 0.27 | 4 | 0.27 | 4 | 0.27 | 5 | 0.33 | 5 | 0.33 |
| Ease of Unloading | 0.20 | 4 | 0.80 | 4 | 0.80 | 4 | 0.80 | 4 | 0.80 | 4 | 0.80 | 5 | 1.00 | 5 | 1.00 |
| Weight Distribution | 0.07 | 5 | 0.33 | 4 | 0.27 | 5 | 0.33 | 5 | 0.33 | 4 | 0.27 | 4 | 0.27 | 5 | 0.33 |
| Size | 0.07 | 4 | 0.27 | 4 | 0.27 | 5 | 0.33 | 5 | 0.33 | 4 | 0.27 | 4 | 0.27 | 3 | 0.20 |
| Total Score | | 3.97 | | 3.90 | | 3.10 | | 3.27 | | 3.60 | | 3.83 | | 3.33 | |
| Rank | | 1 | | 2 | | 7 | | 6 | | 4 | | 3 | | 5 | |
| Continue? | | Y | | Y | | N | | N | | Y | | Y | | N | |

Figure 11: Scoring Matrix

### 2.3.3 Initial Trailer Layout Concept Selection

The top four concepts from the scoring matrix were chosen to move forward to the next phase. These designs demonstrated the highest scores throughout the concept selection process and provided the team with concepts using three different trailer types. The final selected concepts are summarized in Table XIV.

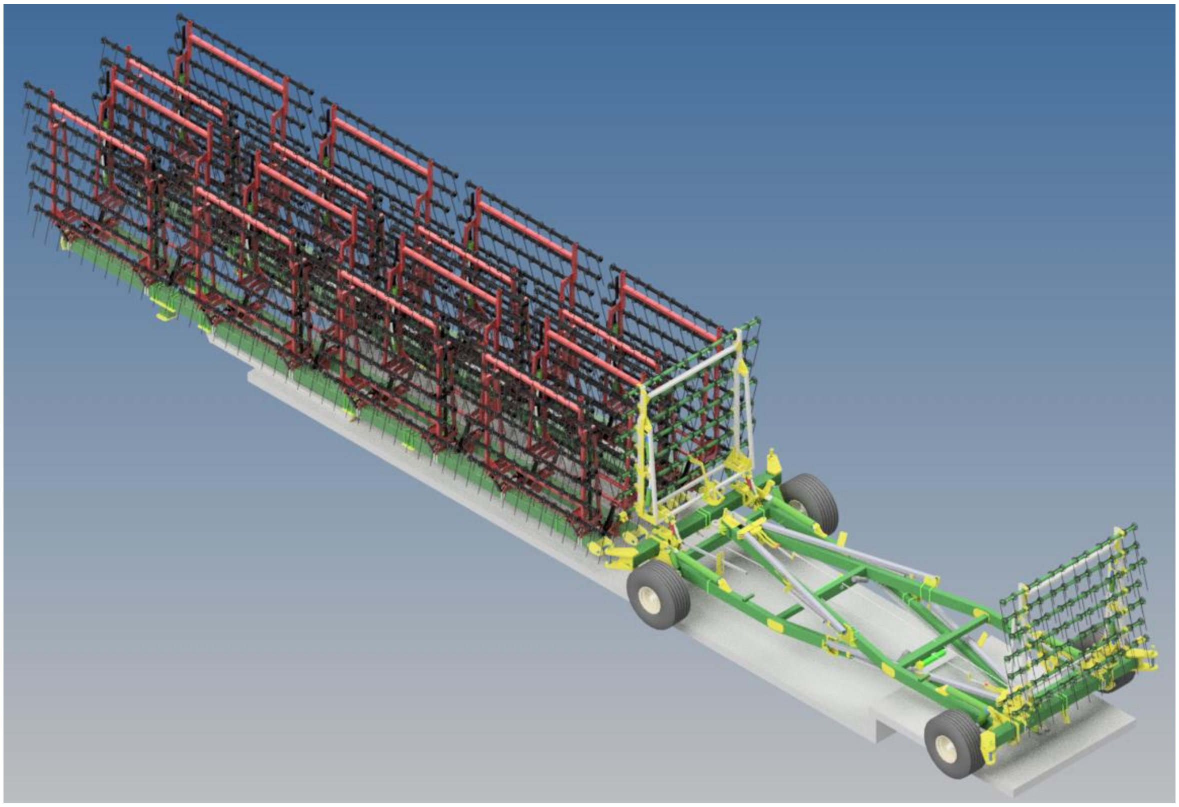
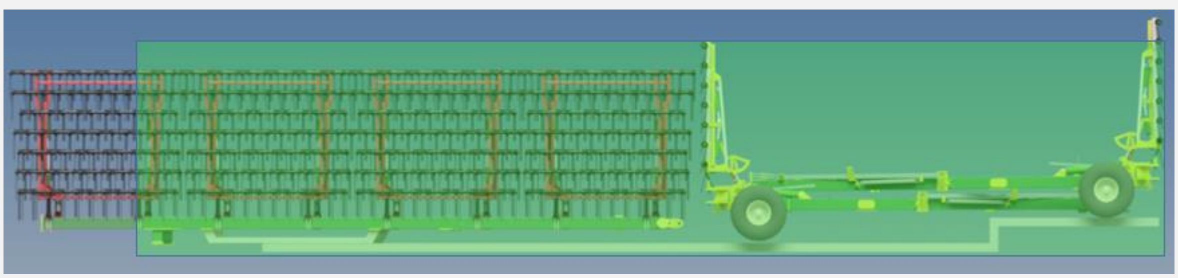
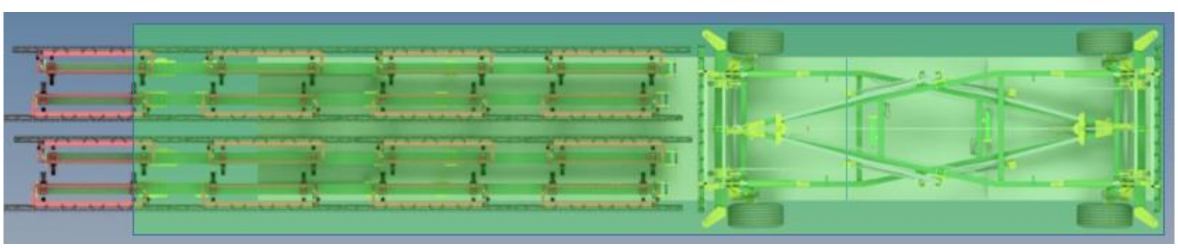
TABLE XIV: TOP FOUR CONCEPTS

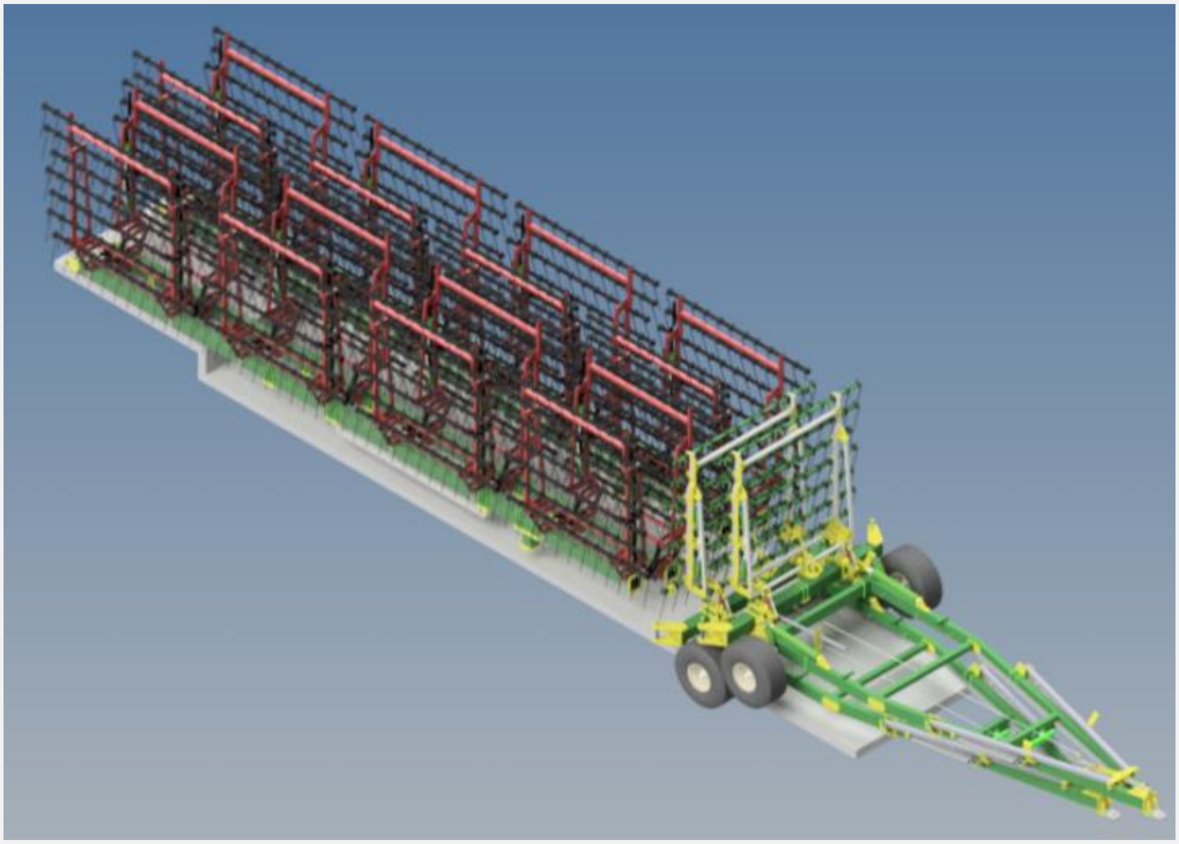
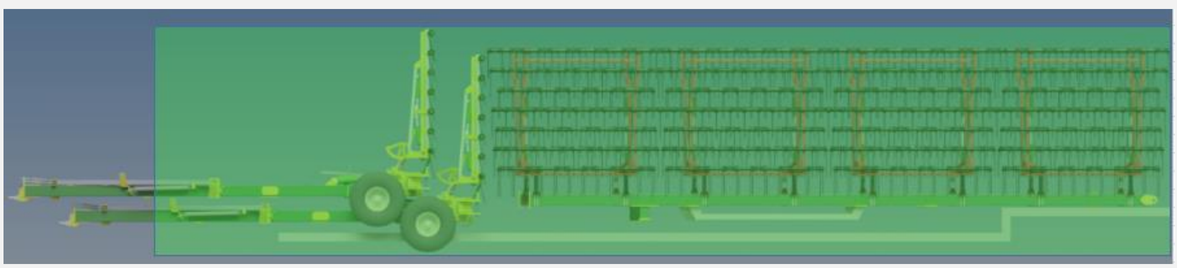
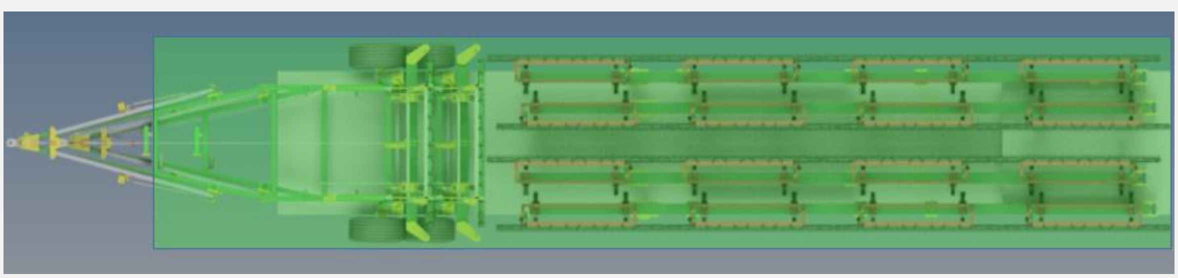
| Rank | Score | Concept | Diagram |
|---|---|---|---|
| **1** | 3.97 | **D** |  |
| **2** | 3.90 | **F** |  |
| **3** | 3.83 | **M** |  |
| **4** | 3.60 | **J** |  |

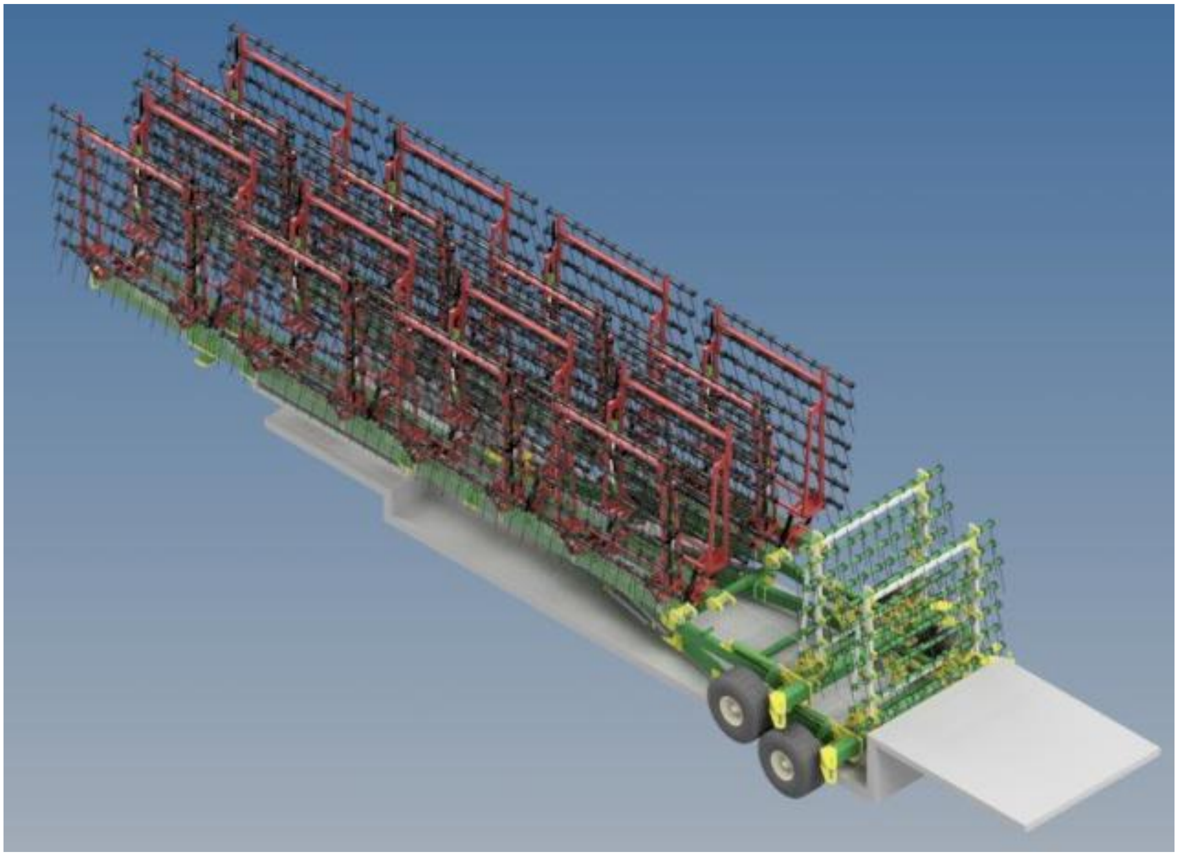
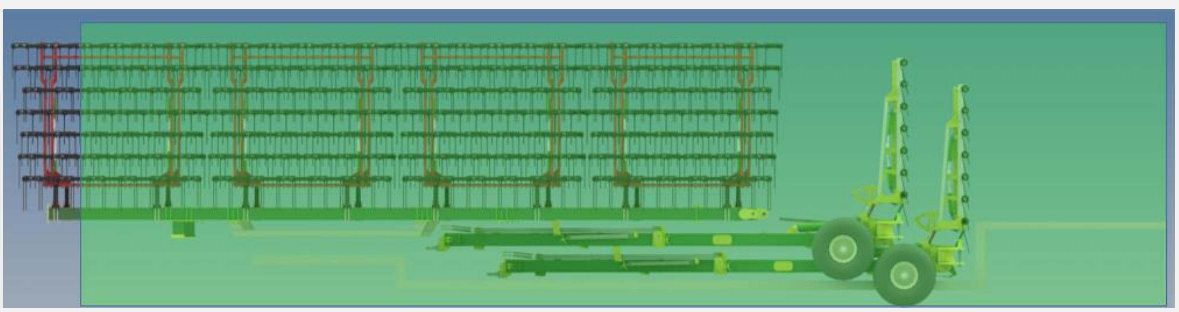
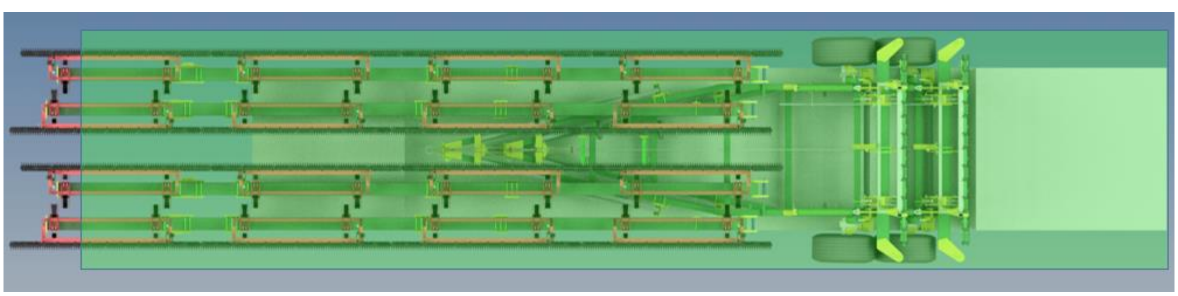
### 2.3.4 Final Trailer Layout Concept Selection

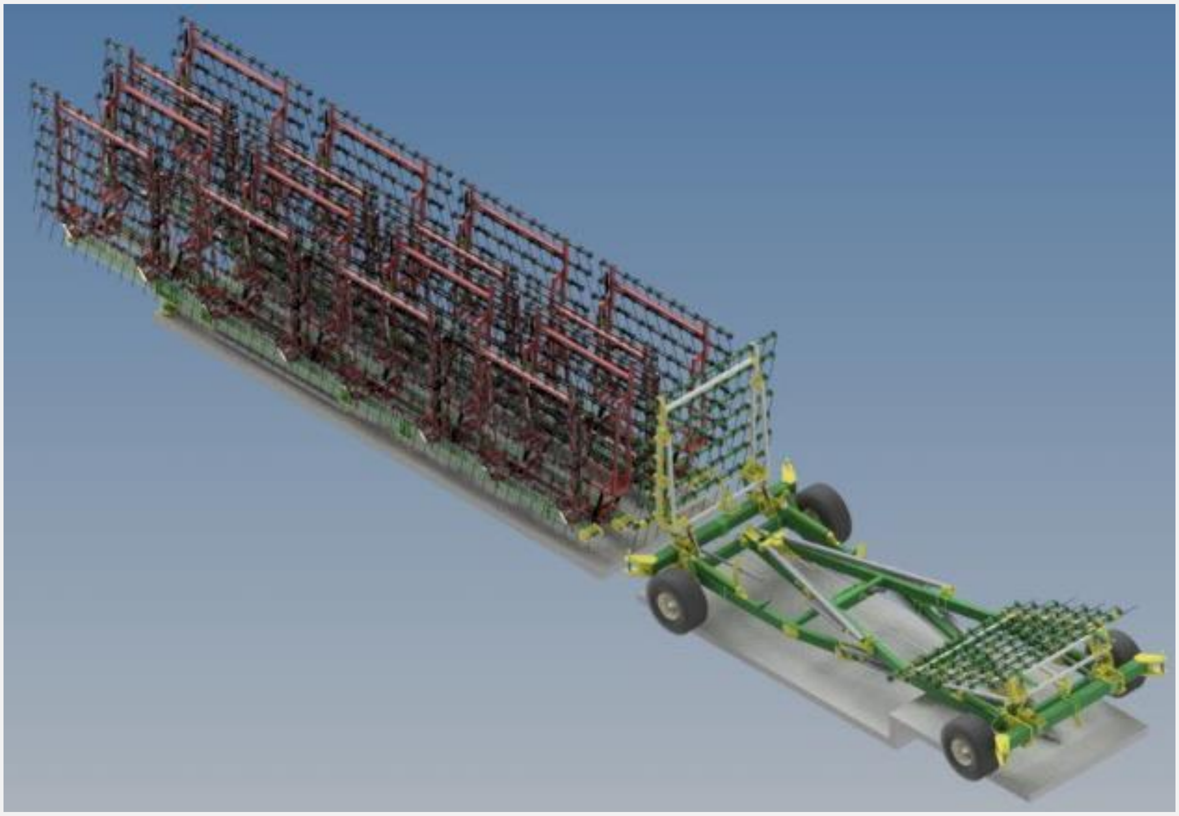
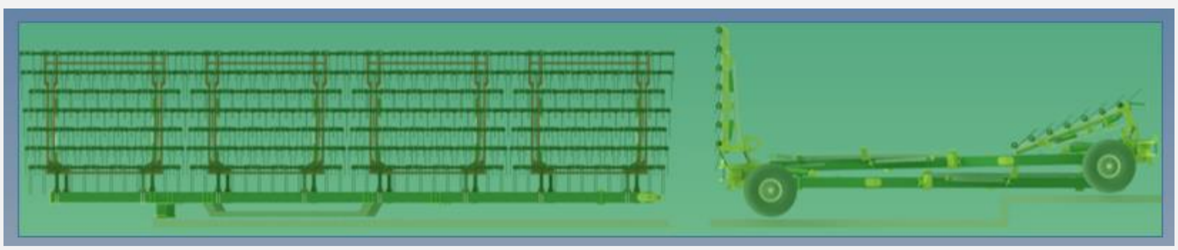
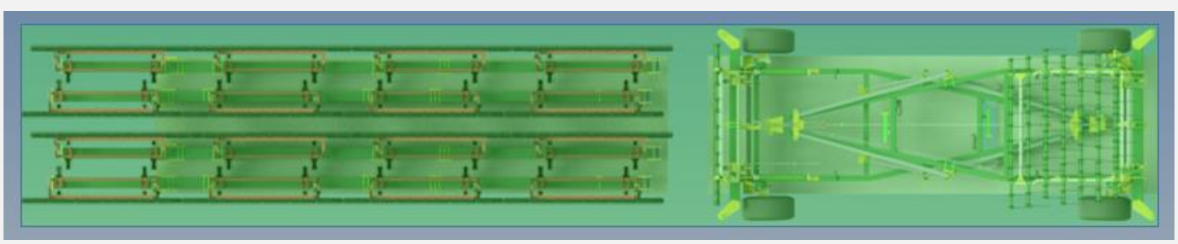
To determine a final concept to be refined, CAD models of the trailers layouts for each of the four concepts shown in Table XIV were created. The trailer layout models, shown in Table XV were created based on trailer dimensions provided by Searcy [12] and the Super 7 Harrow models provided by Elmer's. Optimizations to the individual designs were made and therefore the modeled concepts may vary slightly from the initial designs. Green boxes showing the restriction zones were overlaid on the CAD models to determine if the individual concepts fit within the constraints.

TABLE XV: FINAL CONCEPTS COMPARED TO RESTRICTIONS

| | |
|---|---|
| **D** |  |
| |  |
| |  |

| | |
|---|---|
| **F** |  |
| |  |
| |  |

| | |
|---|---|
| **J** |  |
| |  |
| |  |

| | |
|---|---|
| **M** |  |
| |  |
| |  |

As illustrated in Table XV, concepts D and F violated the maximum allowable overhang and therefore were eliminated as concepts. Although Concept J protruded past the maximum overhang, the harrow wings could have been shifted towards the front of the trailer, but this would increase the difficulty of positioning of the brackets. The design cantilevering of the wing sections over the hitch sections makes locating the supporting brackets difficult. Additionally concept J did not allow for one harrow to be unloaded without requiring the unloading of the second harrow and was therefore eliminated as a concept.

Concept M fits within all the road restrictions as shown in Table XV and as laid out in Section 1.6.1. Additionally, concept M is more spacious then the other final concepts, allowing for more flexibility and higher tolerances on the locations of the harrow pieces on the trailer. Concept M also allows the unloading of one harrow without requiring the unloading of the second harrow. Therefore concept M was chosen to develop as a final design and in the following sections will be referred to as “the proposed method.”

## 2.4 Harrow Wings Bracket Concept Generation

A similar approach to the concept generation method used for the trailer packaging was utilized for the selection of the bracket designs. The following harrow wing bracket concepts were developed based on the locations of the harrow wings in the proposed shipping method. The concepts were hand-sketched and are rough approximations of the brackets appearances.

TABLE XVI: BRACKET CONCEPT 1

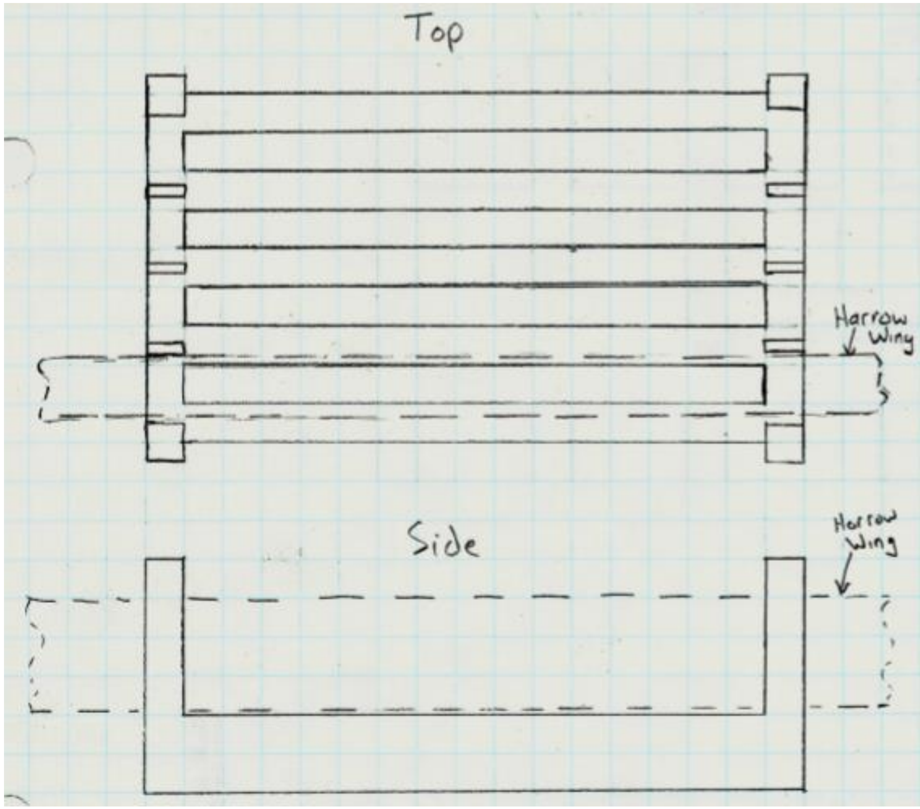



**FIGURE 12: BRACKET CONCEPT 1**

| **Description:** | |
|---|---|
| Concept 1 is a large weldment the width of the trailer that supports all four harrows. The harrow wing sections sit on the bracket separated by vertical members. The wings would then be secured to the brackets by a pin or bar across the top of the wing members. The harrow wings would be built in the brackets, beginning with the centre two and then completing the outer two. | |
| **Advantages:** | **Disadvantages:** |
| • Made from stock material<br>• Simple manufacturing | • Large size<br>• Large amount of stock material required<br>• Does not separate harrow pairs |

TABLE XVII: BRACKET CONCEPT 2

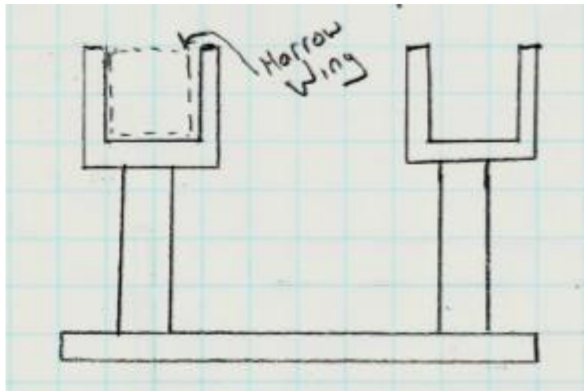



**FIGURE 13: BRACKET CONCEPT 2**

| Description: | |
|---|---|
| Concept 2 is a small weldment that supports two harrows wings. Multiple brackets are required and are placed at different locations along the length of the harrow wings. The harrows would be secured to the bracket using pins or bolts and brackets would be strapped to the trailer. The harrow wings are separated into pairs and would be built in the brackets. | |
| **Advantages:** | **Disadvantages:** |
| • Simple manufacturing<br>• Small size<br>• Separates the four harrow wings into pairs | • Poor horizontal stability |

TABLE XVIII: BRACKET CONCEPT 3

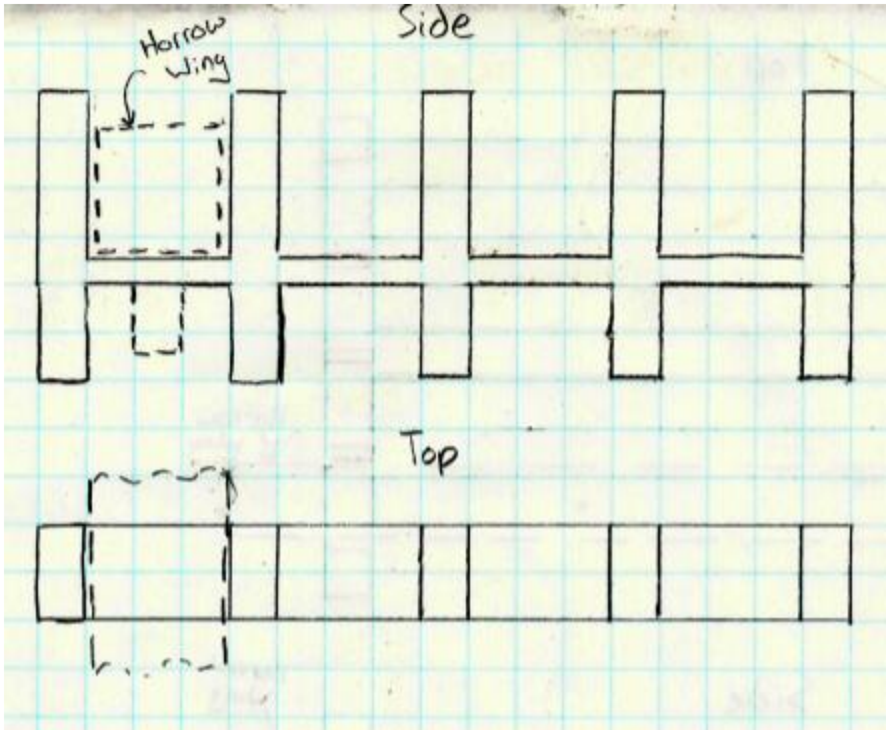



**FIGURE 14: BRACKET CONCEPT 3**

| Description: | |
|---|---|
| Concept 3 utilizes ideas from both concepts 1 and 2. Bracket 3 is a weldment that holds all four harrows. Multiple brackets would be necessary along the length of the harrow wings. The harrow wings would be secured to the brackets by a pin or bar across the top of the wings and attached to the brackets. The harrow wings are separated by vertical members that also provide stability by sitting on the trailer. | |
| **Advantages:** | **Disadvantages:** |
| • Medium Size<br>• Made from stock material | • Does not separate wing pairs |

TABLE XIX: BRACKET CONCEPT 4

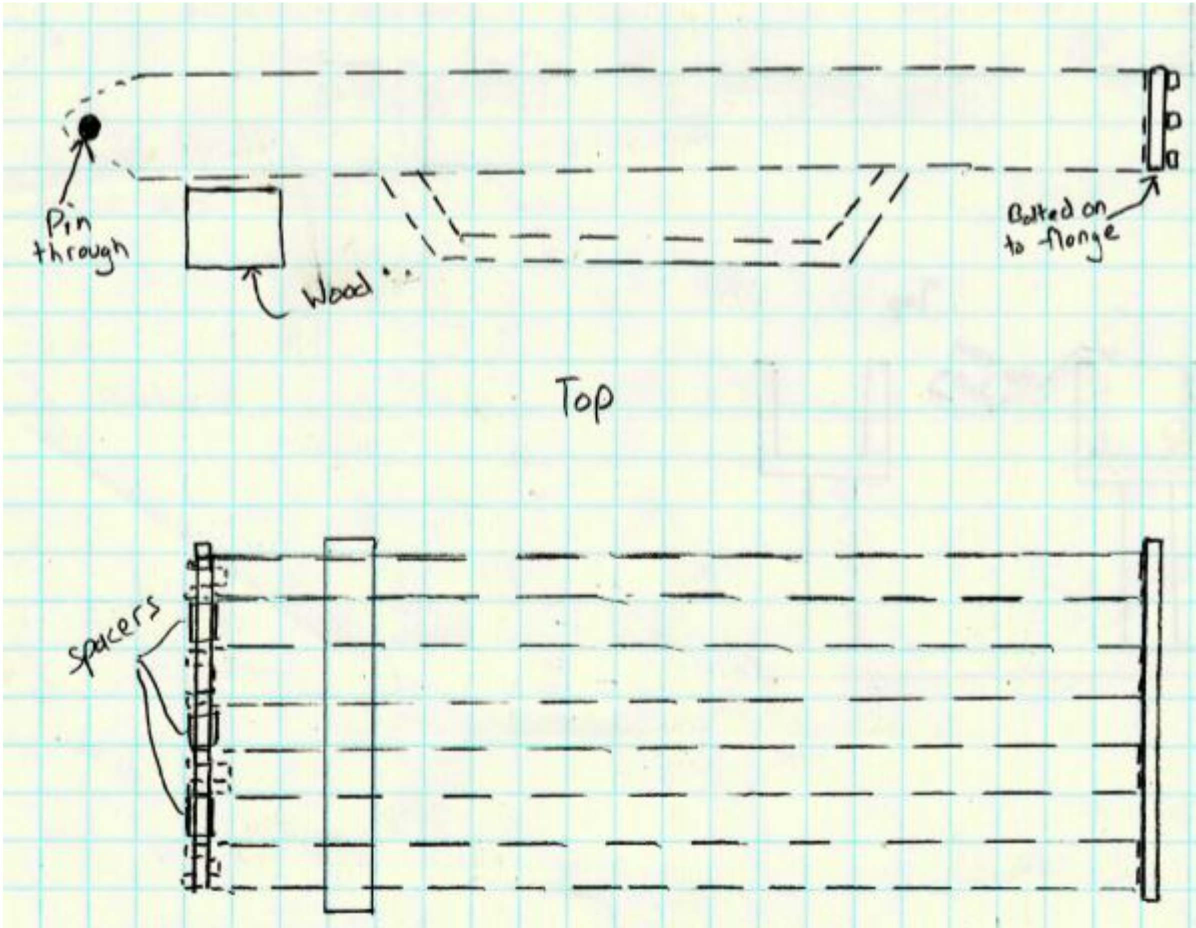



FIGURE 15: BRACKET CONCEPT 4

| **Description:** |
|---|
| Concept 4 supports the wings using wood stacks equal in height to the wing support bar and additionally sits the wing support bar on the trailer. The harrow wings are fixed to each other through a pin inserting through all four wings clevises. The wings are separated with spacers that the pin slides through. Additionally, the harrow wings are fixed to each other by a plate that attached with bolts to the flanges on the rear of the wings. |

| **Advantages:** | **Disadvantages:** |
|---|---|
| • Simple<br>• Low cost<br>• Small size | • Requires the wings be lined up<br>• Lacks the ability to stably sit a single wing on the ground<br>• Allows the wings to twist along the length |

TABLE XX: BRACKET CONCEPT 5

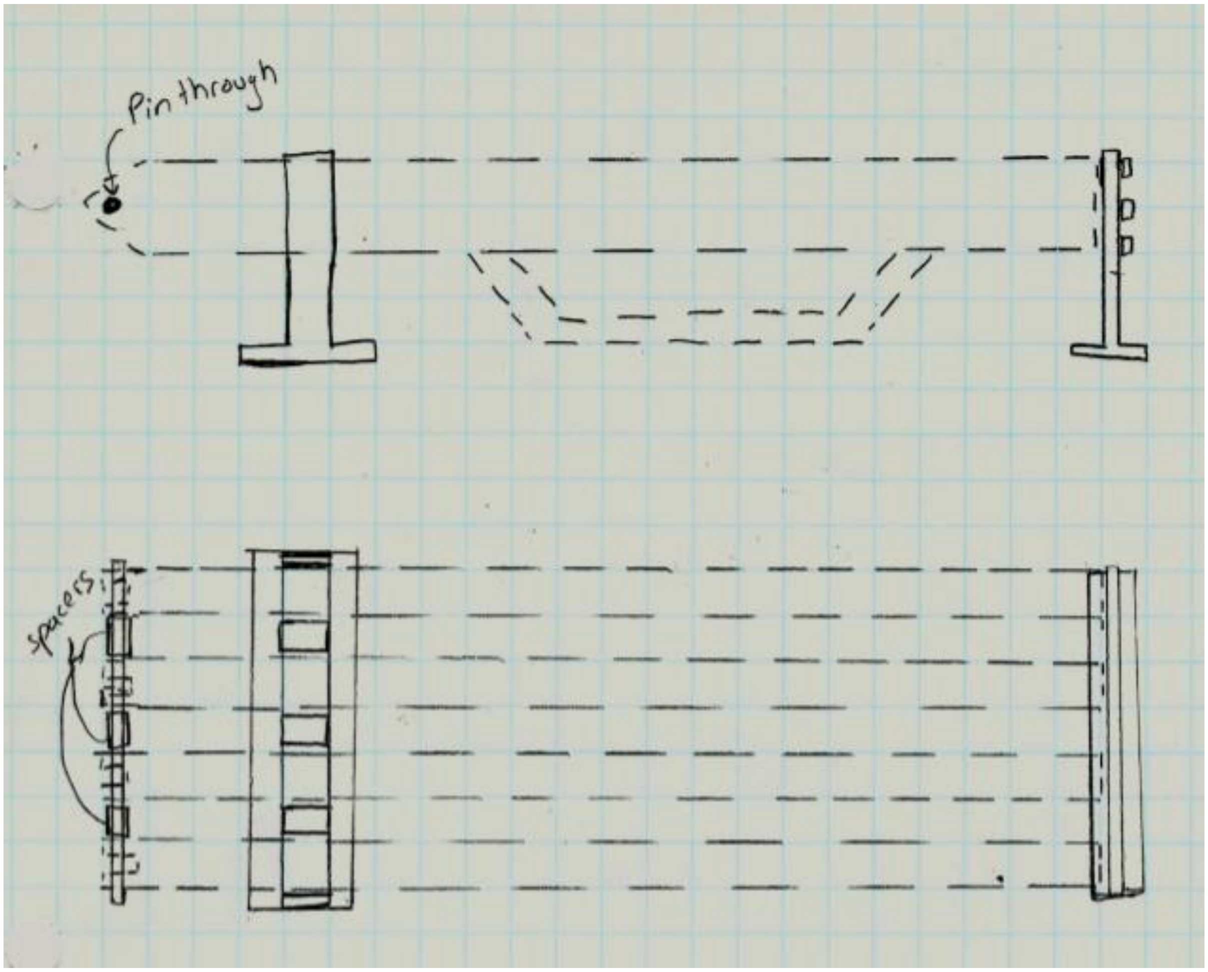



FIGURE 16: BRACKET CONCEPT 5

| Description: |
| --- |
| Concept 5 combines concepts 3 and 4. The harrow wings is lifted off the trailer using a bracket similar to concept 3 at the clevis end of the wing and by a plate similar to concept 4 but with added legs at the rear. Similar to concept 4 a pin and spacers are used to secure and separate the harrow wings at the clevis end. |

| Advantages: | Disadvantages: |
| --- | --- |
| • Simple<br>• Small size | • Required the wings be lined up<br>• Allows the wings to twist along the length |

## 2.5 Harrow Wings Bracket Selection Criteria

To determine the optimum bracket, concept a similar weighting and scoring system that was used to determine the trailer layout was used. First selection criteria were identified including stability, modularity, size, complexity and securement.

Stability refers to the how stable the harrow wings will be when secured to the trailer and when the harrow wings and brackets are sitting on the ground. During final assembly at the dealer there may be occurrences when only one wing remains in the bracket, therefore a situation with a single wing in the bracket is built into the stability criterion.

Modularity refers to the ability to separate the pieces of one harrow from the other so that a single harrow may be unloaded at one location without requiring the second harrow be unloaded.

Size refers to the total size of the brackets. The size of the brackets is important because reuse of the brackets depends on the ability to minimize the cost of return shipping the brackets to the manufacturing facility. If the brackets require a large area of the trailer for return shipping the costs to return the brackets increases.

Complexity refers to the cost and manufacturability of the brackets. Preferably the brackets would be made from readily available stock materials and utilize cheap manufacturing methods. Complexity also refers to the difficulty of using the brackets and whether the wings can be assembled in the brackets.

Securement refers to the ability to secure the harrows to the brackets and the brackets to the trailer.

## 2.6 Harrow Wings Bracket Selection

The harrow wings bracket concept was chosen using a similar method as the trailer layout. The selection criteria weightings are calculated and shown in Figure 17. Concept 2 was chosen for the wing brackets, as determined by the scoring matrix shown in Figure 18.

| | Criteria | Stability | Modularity | Size | Complexity | Securement |
|---|---|---|---|---|---|---|
| | Criteria | A | B | C | D | E |
| A | Stability | | A | A | A | A |
| B | Modularity | | | B | B | B |
| C | Size | | | | C | C |
| D | Complexity | | | | | E |
| E | Securement | | | | | |
| | Total Hits | 4 | 3 | 2 | 0 | 1 |
| | Weightings | 0.40 | 0.30 | 0.20 | 0.00 | 0.10 |

Figure 17: Bracket selection criteria weighting matrix

| | | Flatbed Shipping Methods | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Selection Criteria | Weight | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score |
| Stability | 0.40 | 2 | 0.80 | 2 | 0.80 | 2 | 0.80 | 1 | 0.40 | 1 | 0.40 |
| Modularity | 0.30 | 4 | 1.20 | 5 | 1.50 | 1 | 0.30 | 4 | 1.20 | 2 | 0.60 |
| Size | 0.20 | 1 | 0.20 | 4 | 0.80 | 3 | 0.60 | 5 | 1.00 | 4 | 0.80 |
| Complexity | 0.00 | 3 | 0.00 | 4 | 0.00 | 3 | 0.00 | 5 | 0.00 | 4 | 0.00 |
| Securement | 0.10 | 5 | 0.50 | 3 | 0.30 | 4 | 0.40 | 4 | 0.40 | 4 | 0.40 |
| Total Score | | 2.70 | | 3.40 | | 2.10 | | 3.00 | | 2.20 | |
| Rank | | 3 | | 1 | | 5 | | 2 | | 4 | |
| Continue? | | No | | Yes | | No | | No | | No | |

Figure 18: Bracket concept scoring matrix

## 2.7 Hitch Bracket Concept Selection

A wood stack of rough 2X4" lumber, adjusted to the height necessary for the proper securement of the hitches, was selected. A different approach was used for the selection of the hitch brackets then used for the previous concept selections. The wood stack concept was selected based on experience and common industry practice for shipping large and heavy objects. Advantages to the wood stacks is that they are cheap and easy to manufacture and the soft wood prevents damage to the harrow's structure and paint. In addition to the wood stacks, single pieces of 2X4" lumber will be used between the lower hitch and the trailer and between the two hitches to protect the hitches and trailer from damage. An example render of a wood stack is shown in Figure 19.

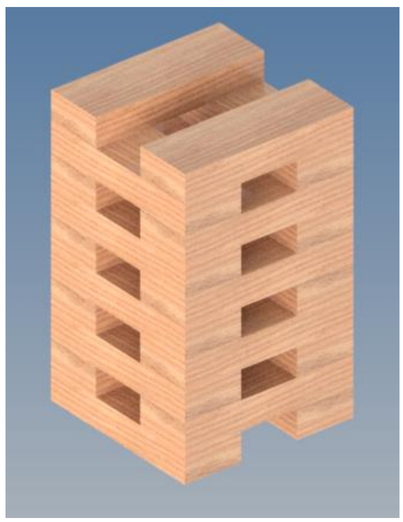


Figure 19: Wood stack bracket.

# 3 Detailed Design

The following sections outline the detailed design performed to develop a completed shipping method to package two Super 7 Harrows on a single trailer.

## 3.1 Bracket Design

The packaging of the harrow requires two main types of brackets. One type of bracket is a metal bracket that supports the harrow wings in pairs, the other brackets are made from stacks of wood to support the hitch.

### 3.1.1 Hitch Brackets Design

The purpose of the hitch brackets is to support the hitch, provide space underneath the hitch for storage, and protect the hitch from damage. The chosen concept was to use stacks rough 2X4” lumber. The height of the stack was determined to be 18” by leveling the lower hitch and measuring the distance between the hitch and the cross tube where the wood stacks will support the hitch from, as shown in Figure 20.

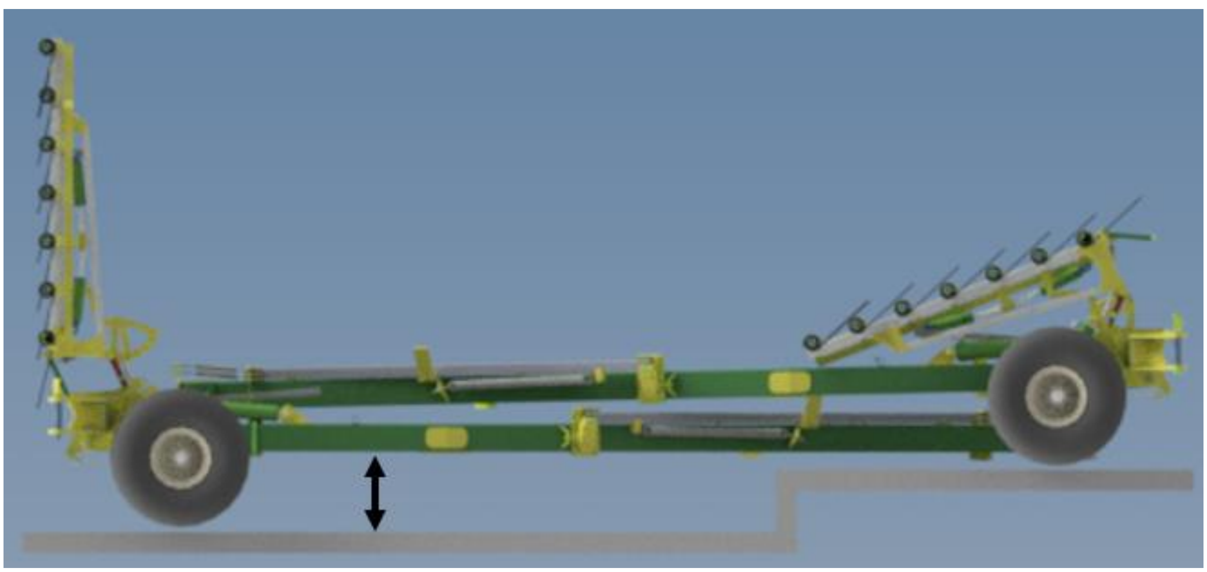


Figure 20: Distance between lower hitch and trailer.

It was also found that the distance required for the top hitch was approximately 18”, determined by raising the top hitch until there was no physical interference between the hitches. Additionally, an extra layer of 2X4” was added to prevent the hitch from sliding off the wood stack. The diameter of the cross tube is 4”, therefore the gap between the wood pieces in each layer must be equal or greater than 4”.

To determine the length of each piece, the width the two 2X4” pieces and the required gap of 4” were summed and the length of each was chosen as 12”. The final design of the wood bracket is shown in Figure 21.

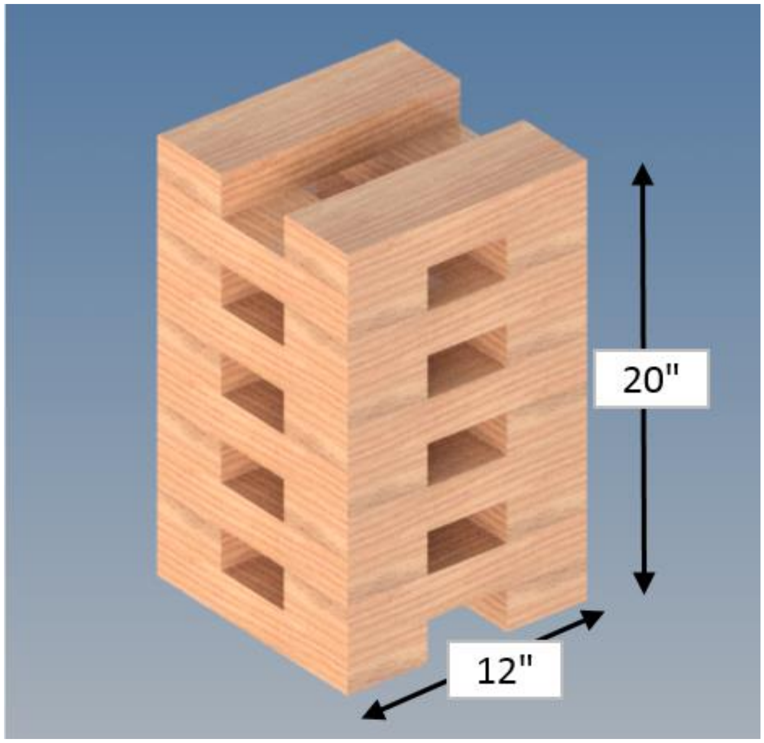



Figure 21: Final design of hitch brackets.

### 3.1.2 Hitch Brackets Stress Analysis

The hitch bracket and support are located the front and rear area of the hitches. The purpose of these supports is to avoiding the two hitches from impacting each other during loading and transport. The bracket will also restrict movement in the horizontal direction. The hitch bracket and wood support point are represented as red dots in Figure 22.

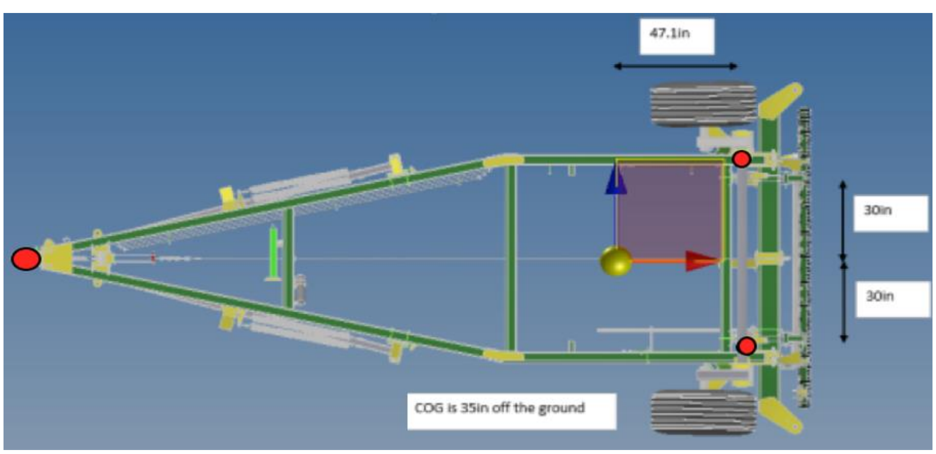



Figure 22: Hitch Bracket Location and Dimensions

To save cost and labour hours, all the hitch bracket and wood support designed to disposable for one-time use. Our team searched various wood properties, listed in Table XXI.

TABLE XXI: MATERIAL PROPERTIES OF VARIOUS WOOD TYPES [13]

| Wood Species | Specific Weight [lb/in$^3$] | Compressive Strength [psi] | Bending Strength [psi] | Stiffness [Mpsi] | Hardness [lb] |
|---|---|---|---|---|---|
| Basswood | 0.37 | 4,730 | 8,700 | 1.46 | 410 |
| Cherry | 0.50 | 7,110 | 12,300 | 1.49 | 950 |
| Maple, soft | 0.54 | 6,540 | 13,400 | 1.64 | 950 |
| Oak, red | 0.63 | 6,760 | 14,300 | 1.82 | 1,290 |

Table XXII shows information about the wings that was used in the hitch bracket stress analysis.

TABLE XXII: RELEVENT HITCH BRACKET INFORMATION

| | |
|---|---|
| **Hitch Weight:** | 2500 lbf |
| **Minimum Safety Factor** | 3 |
| **Hitch Length** | 242.2 in. |
| **Hitch Width** | 60 in. |

Two hitch brackets are located at the rear part of hitch; one long wood cuboid will support the front end of the hitch. Based on the previous study, the center of gravity is located 47.1 inches from the rear end and 35 inches off the ground. The Free-Body Diagram of hitch and all the support are shown in Figure 23.

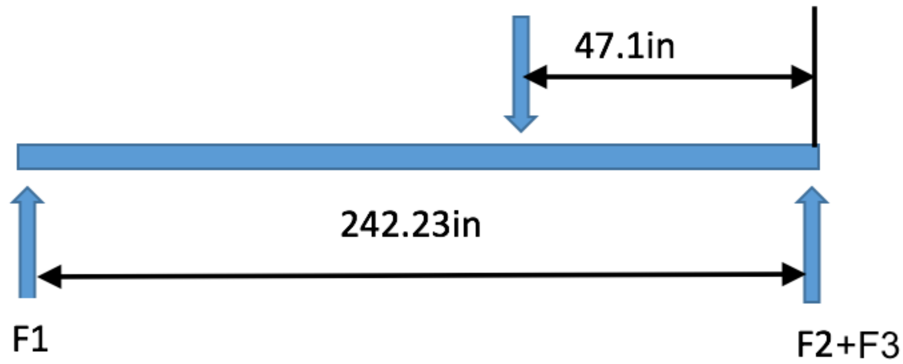



Figure 23: FBD of Hitch

The following calculations were performed on the FBD in Figure 23:

$$F_1 + F_2 + F_3 = 2500\text{lbf}$$

$$F_2 = F_3$$

$$(F_2 + F_3) \times 242.23 = 2500 \times (242.23 - 47.1)$$

$$F_2 + F_3 = \mathbf{2013.89\ lbf}$$

$$F_1 = \mathbf{486.11\ lbf}$$

As a result, the front wood cuboid takes 486.11 lbf and the two hitch brackets take 1006.95 lbf each. The hitch bracket is made up of several units shown in Figure 24 below, achieving the necessary height to support the hitches away each other. Since the hitch bracket connects at the rear axle, the force will present at the centre of the top plank as a point load:

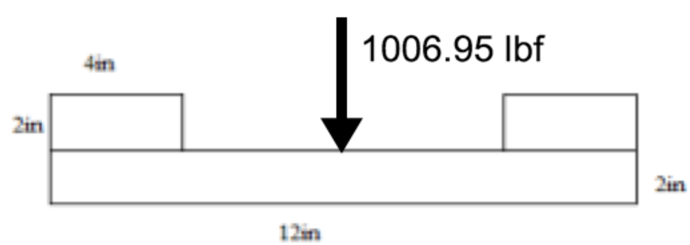



Figure 24: Top unit of hitch bracket

For the top unit of the hitch bracket the beam in bending had to be analyzed. If the top unit can satisfy the minimum safety factor 3, the rest of the unit will support the hitch. The beam bending equations show below and our team chose the weakest wood (basswood) as an example:

$$\mathrm{M_{MAX}} = \frac{\mathrm{I}}{\mathrm{C}}\delta_{\mathrm{wood}}$$

$$\mathrm{M_{MAX}} = \frac{\frac{1}{12} \times 4 \times 2^3}{1} \times 8700 = 23200$$

$$\mathrm{M_{actual}} = \frac{2013.89}{4} \times \frac{12-4}{2} = 2013.89$$

$$\mathrm{M_{MAX}} > \mathrm{M_{actual}} \times \text{ safety factor} = 6041.67$$

The calculated result shows the maximum safety factor achieved is 11. Therefore, the minimum safety factor of 3 is satisfied. As a result the whole hitch bracket structure will hold the hitch and prevent it from moving during transport.

The front support is just a simple piece of lumber, the normal stress study is the only consideration required. The normal stress equation is shown below with the area connecting the hitch and lumber as 2" × 2".

$$\delta = \frac{P}{A}$$

$$\delta = \frac{486.11lbf}{2 \times 2} = 121.53psi$$

$$\delta_y = 8700\text{psi} > \delta \times safety\ factor = 364.58psi$$

Based on the calculation, the maximum safety factor reached is 23. To study the hitch bracket, our team used SolidWorks to run FEA to collect the stress and deflection analysis. Figure 25 shows the stress analysis. The maximum Von Mises is 0.9193 ksi with safety factory 3. The basswood yield strength is 2.901 ksi, therefore the hitch bracket satisfies the design requirement.

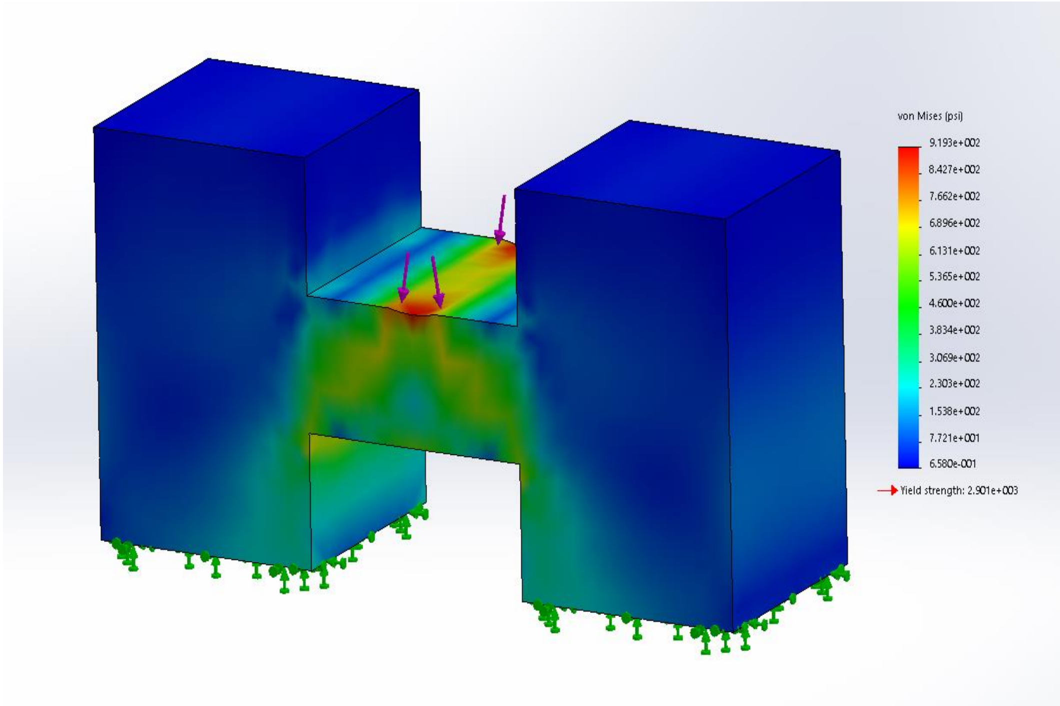



Figure 25: Hitch bracket stress analysis.

Figure 26 shows the deflection analysis about the hitch bracket. The maximum deflection is 0.00763 inch located the center – this minimal deflection is considered insignificant.

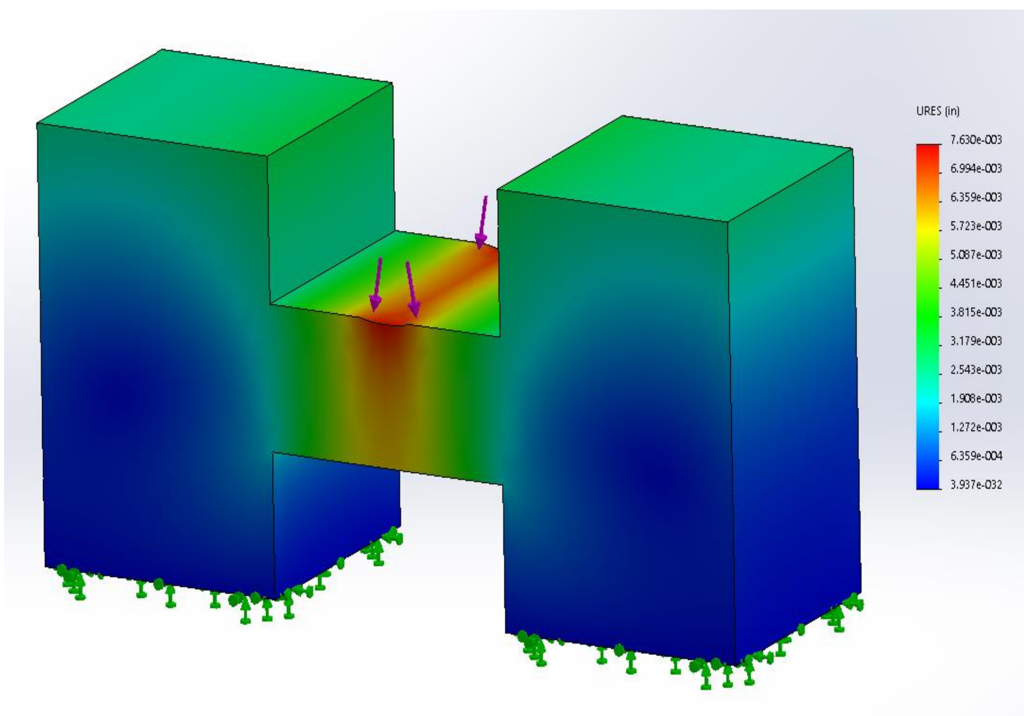



Figure 26: Hitch bracket deflection FEA.

After the bending and normal stress studies were complete, the hitch bracket and lumber support were found to satisfy the required loading scenarios. The brackets were found to successfully be able to load, unload, and transport the harrow hitches with significant safety factors.

### 3.1.3 Harrow Wings Bracket Design

The initial bracket concept dictated a general bracket shape but left areas for refinement. Three sections of the bracket, shown in Figure 27, were identified as areas for refinement. Section 1 dictates how the bracket interacts with the harrow wing and the method of securement between the wing and harrow. Section 2 is the harrow vertical support necessary to support the weight of the wing. Section 3 is the support that interacts with the ground and provides stability for the assembly. Possible refinements were generated and hand-sketched, shown in Figure 28 **-** Figure 30.

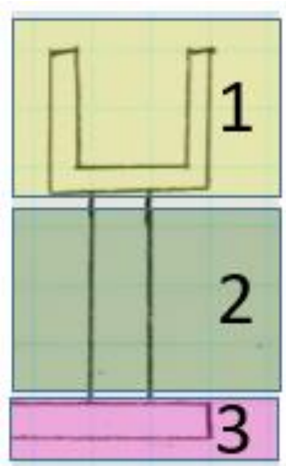



Figure 27: Bracket Concept Refinement Zones

#### *3.1.3.1 Harrow Wings Bracket Concepts*

Concept A, shown in Figure 28, features a U-shape formed ¼” steel cradle to hold the wing in Zone 1. It utilizes U-bolts to secure the wing and adjust the preload when fastening. Zone 2 features an 8” by 8” steel tube to support the wing. A 4”x4” tube is used to tie the two supports together and allow a tie-down strap to be fed through the tube when fastening to the trailer. Zone 3 uses two 2”x6” tubes welded together to support the bracket. Jam bolts are used to fix the support that slides in the bottom tubes to aid in stability during storage.

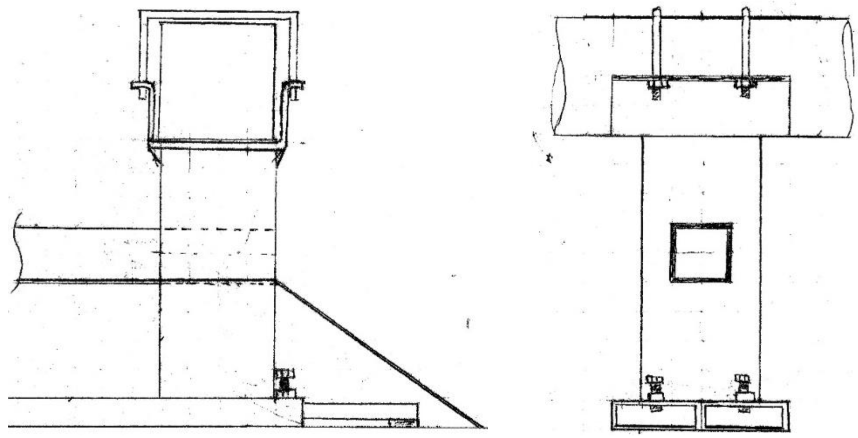


Figure 28: Bracket Refinement Concept A

Concept B, shown in Figure 29, uses a steel plate and longer U-bolts instead of a cradle in Zone 1. The steel plate is welded to a 4”x4” steel tube and supported by gussets at the top. Zone 2 uses a 4”x4” steel tube instead of 8”x8” steel tube shown in Concept A. A diagonal support is used to fasten Zone 2 to 3 to make up for the smaller tube support. The base is constructed of 2”x4” steel tube with a similar sliding support within. However, the support is fastened with a long horizontal pin instead of jam bolts.

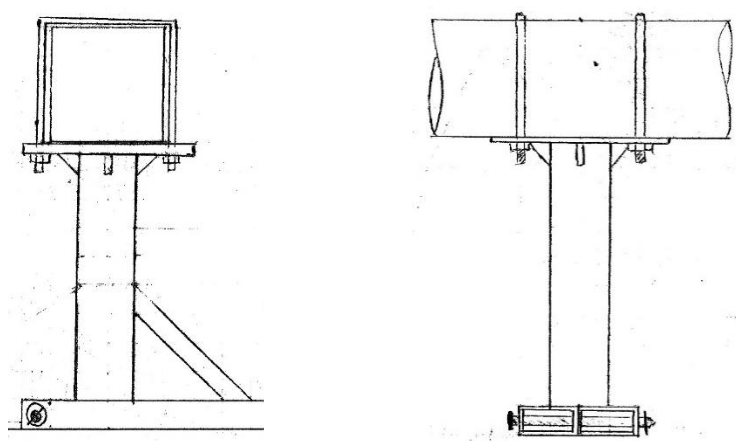


Figure 29: Bracket Refinement Concept B

Concept C, shown in Figure 30, has similar features to Concept A, however, Zone 1 utilizes a full height cradle with horizontal clamp bolts instead of U-bolts to manage the preload on the wing. This allows for the use of friction to hold the wing evenly instead of point-loads introduced by the U-bolts. Zones 2 and 3 are constructed of 8”x8” and 2”x6” steel tube respectively.

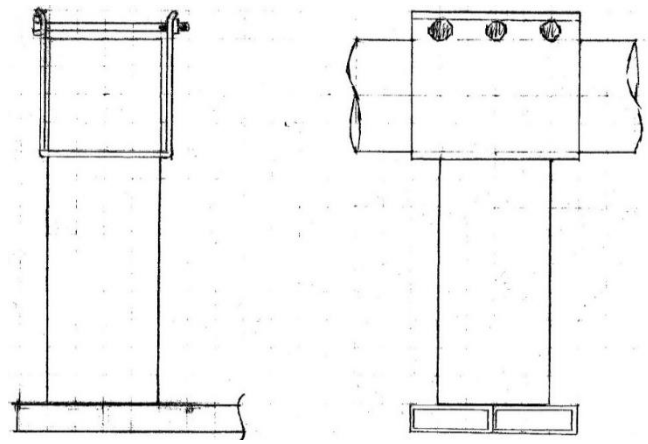


Figure 30: Bracket Refinement Concept C

Concept D, shown in Figure 31, is a combination of Concepts A and C. Zone 1 features the full-cradle formed steel piece with three clamping bolts. Zone 2 utilizes a full 8”x8” with 4”x4” horizontal support that also acts as a securement point. Zone 3 uses two 2”x6” tubes welded together with telescoping ground supports. When compared to the previous three concepts, Concept D contains the features the team deemed the most important. Zone 1 reduces point load stressed on the wing, and allows rubber to be inserted between the wing and cradle to prevent rubbing. The cradle also reduces a point of failure introduced by the U-bolts, as well as possible alignment issues when installing the wings on the brackets. Zone 2 is the most supportive with the large tube support and horizontal member which also can be used for securements. Finally, the base in Zone 3 utilizes wider tubing for improved stability when standing alone (i.e. not transporting a harrow wing). The final refinement will be the design of the telescoping support and how it is secured to the main bracket base.

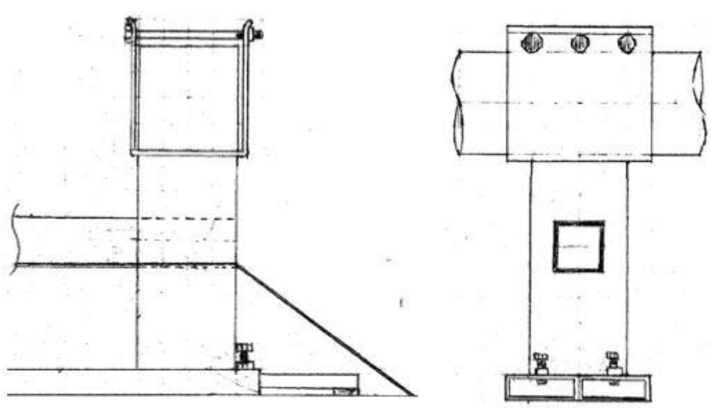


Figure 31: Bracket Refinement Concept D

#### *3.1.3.2 Harrow Wings Bracket Final Design*

The harrow wing brackets were designed to provide a balance of stability, modularity, securement, complexity, and reasonable size. Similar to Concept D in Figure 31, the chosen design incorporates the full cradle constructed of ¼” steel accompanied by three 5/8”-11x10” Grade 8 bolts in Zone 1. The full cradle design was chosen to mitigate any point loads on the wing that could be introduced by U-bolts. The three securement bolts allow the preload on the bracket to be adjusted to control the clamping force on the wings. The brackets were designed such that a piece of rubber shipping sheet could be placed between the wings and the bracket to protect the painted surfaces.

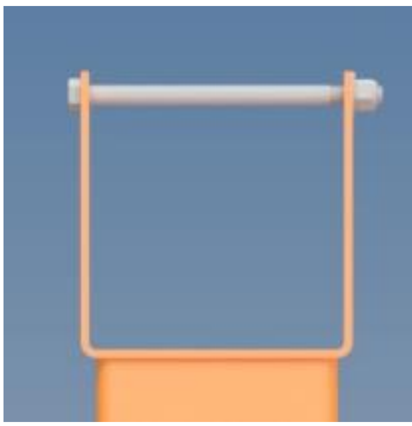


Figure 32: Zone 1 - FRONT

Figure 33: Zone 1 - SIDE

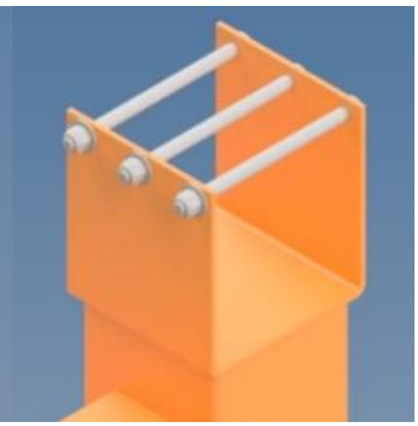


Figure 34: Zone 1 - ISO

For Zone 2, the vertical support members chosen were 8”x8” (¼” wall) square tubing. This was chosen for the added lateral stability it provides combined with increased resistance to buckling compared to 4”x4” or thinner wall stock material. This is the same tubing Elmer’s uses for the main member in the wing so it is readily available at a reasonable price. The horizontal 4”x4” (¼” wall) cross member provides additional stability and a centered location to place a strap when securing the wings to the trailer. Front and side views of the vertical and horizontal members can be seen in Figure 35 and Figure 36.

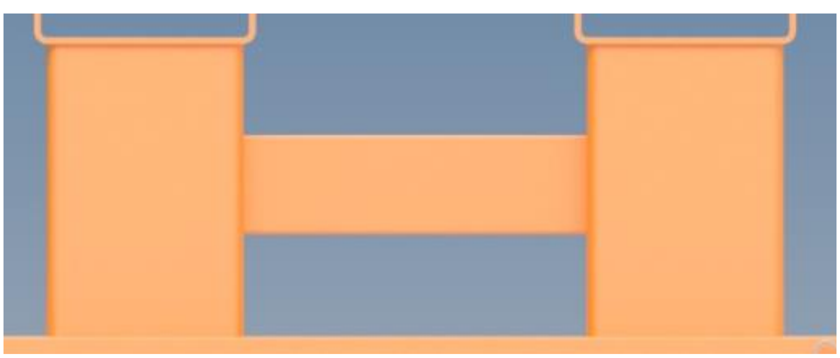


Figure 35: Zone 2 - FRONT

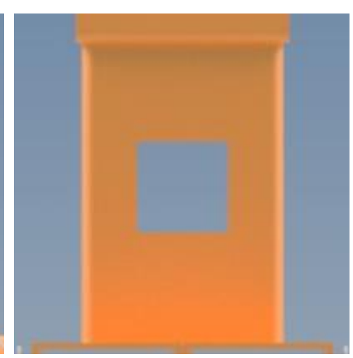


Figure 36: Zone 2 - SIDE

The base of the bracket, Zone 3, was designed to provide support for the wing brackets during assembly, storage, and shipping of the harrows. The brackets were designed such that the harrow wings could be assembled in the factory directly into the brackets to allow for a certain level of disassembly prior to shipping (using the proposed method in this report). To remain stable while standing along (without harrow wings) the bracket base was constructed of 2”x6” stock steel to allow a 38” by 12” footprint. The footprint accompanied by ¼” material provides a relatively low centre of gravity to reduce tipping while the brackets stand alone.

Figure 37: Zone 3 – FRONT

Figure 38: Zone 3 - SIDE

The overall design of the brackets was made so that they are fully welded, painted, and assembled prior to holding the wings. Once the brackets are manufactured they can be sent to the assembly line in preparation of assembly with the harrow wings. Figure 39 and Figure 40 show the final bracket design incorporating Zones 1, 2, and 3.

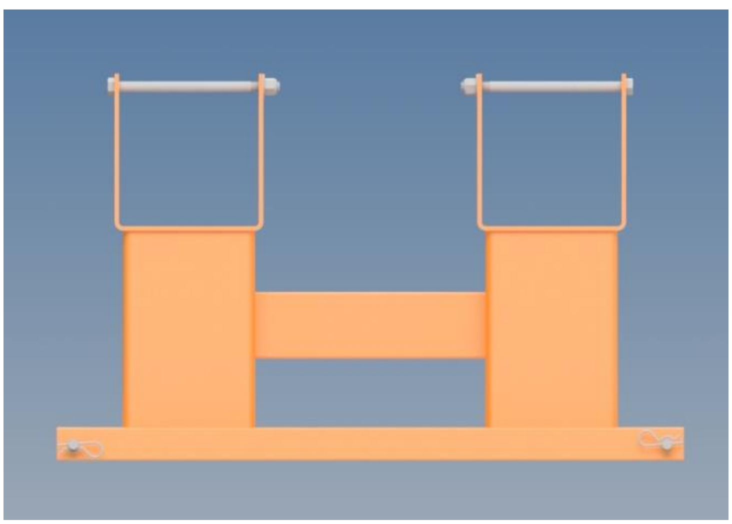


Figure 39: Harrow Wings Bracket – FRONT

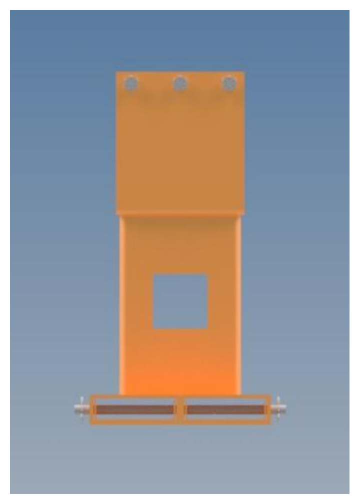


Figure 40: Harrow Wings Bracket – SIDE

To aid in stability while storing pairs of wings in the brackets extendable legs were incorporated into the design. A U-shaped piece of laser cut ¼” steel can be slid into the 2”x6” base members and secured with a 5/8”x14” steel pin. The legs can be extended as deemed necessary by the vendor to aid in stability during storage. Figure 41 and Figure 42 show an isometric view of the final bracket design, with the legs retracted and extended, respectively.

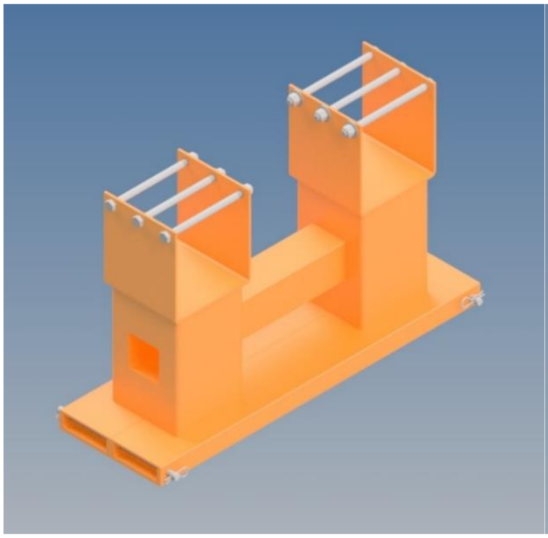


Figure 41: Harrow Wings Bracket ISO View

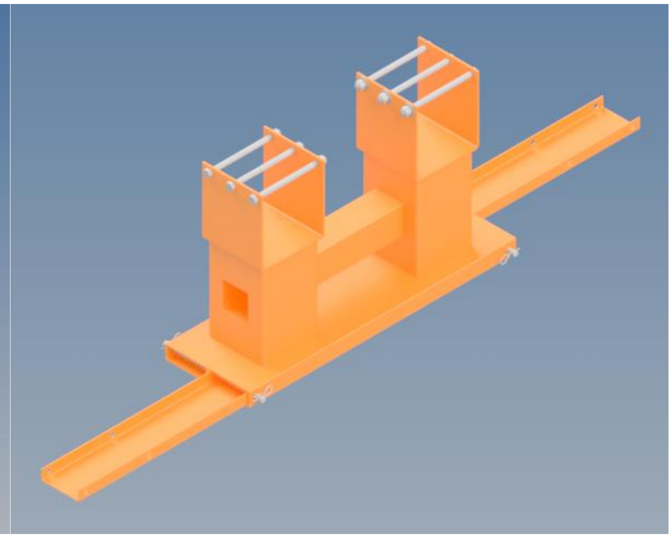


Figure 42: Harrow Wings Bracket Extendable Legs

### 3.1.4 Harrow Wings Bracket Stress Analysis

The weight of a single functioning wing was determined to be 11400 lbf. The wing brackets are designed for prevent the four wings from moving or impacting each other in all directions. The wing brackets also provide easy loading and loading of the wings in pairs. The study of wing bracket design needs to consider the entire weight of wings and the moments produced at each support location. Another design requirement is the wing brackets need to maintain their performance over time through several uses.

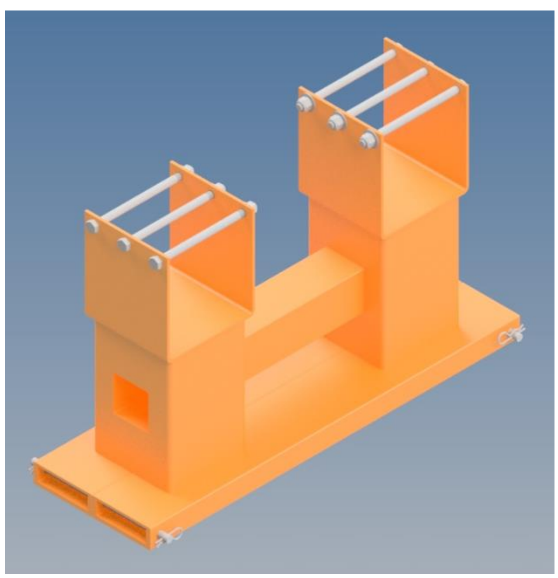


Figure 43: Wings Bracket Overview

The designed shipping method is symmetrical about the centerline. We can just study the left or right wing to know everything we need. The detail information about the wing and wing bracket material are listed in Table XXIII.

TABLE XXIII: MATERIAL PROPERTIES OF STEEL STRUCTURAL (ASTM-A36) [14]

| Material Properties | Specific Weight [lb/in³] | Ultimate Strength (Tension) [ksi] | Yield Strength (Tension) [ksi] | Yield Strength (Shear) [ksi] | Modulus of Elasticity [$10^6$ psi] |
|---|---|---|---|---|---|
| **Steel Structural (ASTM-A36)** | 0.284 | 58 | 36 | 21 | 29 |

The following information about the wings was used in this part of the stress analysis.

TABLE XXIV: RELEVENT INFORMATION FOR WING CALCULATIONS

| | |
|---|---|
| **Wing Weight:** | 5700 lbf |
| **Vertical Support Dimensions:** | 8x8” |
| **Minimum Safety Factor:** | 3 |

As we can see in the FBD shown in Figure 44 below, there are three support points on the wing by the brackets. The loading forces are assuming linear and equate to every inch of wing. Since a single wing is 448.38 inches long and the wing brackets support and area of 8× 8”, our team assumed each wing bracket as a point in the stress analysis.

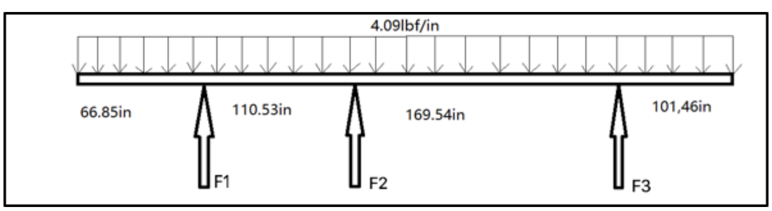



Figure 44: Free body diagram of one wing.

Based on the principle force balance, our team applied the equation on each wing bracket point. The total force of wing is 5700 lbf supported by three points.

$$F_1 + F_2 + F_3 = 5700 \text{ lbf}$$

The wing is roughly symmetrical so that every inch of the wing has the same weight.

$$\frac{5700}{66.85 + 110.53 + 169.54 + 101.46} = 12.71 lbf/in$$

The following calculations determine the load on each bracket as exerted by the weight of the wing.

$$F_1 = 12.71 \times \left(66.85 + \frac{110.53}{2}\right) = 1552.08 \text{ lbf}$$

$$F_2 = 12.71 \times \left(\frac{169.54}{2} + \frac{110.53}{2}\right) = 1779.84 \text{ lbf}$$

$$F_3 = 12.71 \times \left(\frac{169.54}{2} + 101.46\right) = 2366.98 \text{ lbf}$$

As the previous equation shows, each bracket loading force is determined. Our team decided to study the normal stress analysis and shear stress analysis to further study the safety of the wing bracket. If the bracket can hold the largest loading, the rest of wing bracket and support wood will keep the wing fixed during the loading, unloading and transport processes. The cross section to connect the wing are 8”× 8” 1/4” thick steel tube, shown in Figure 45.

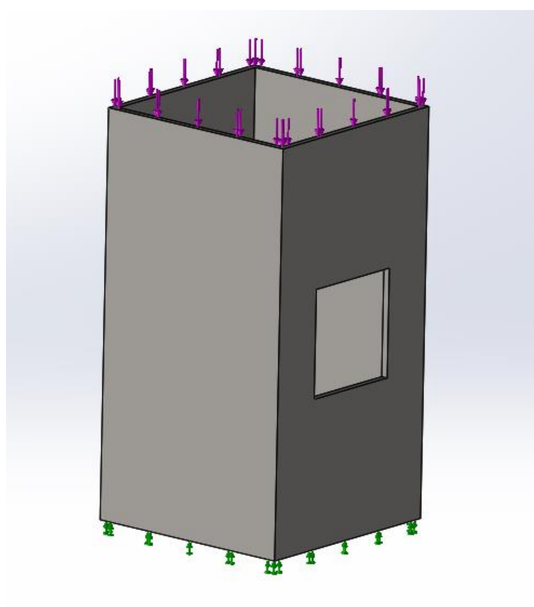


Figure 45: Wing Bracket Vertical Support

The normal stress equation below shows the normal stress loading on one bracket cross sectional area.

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

$$\sigma = \frac{2366.98lbf}{8^2 - 7.5^2} = 305.42psi$$

The yield strength of the ASTM-A36 steel based on the table above is 36000 psi. The minimum safety factor as requested is 3.

$$\sigma \times safety\ factor = 916.25psi$$

$$\sigma_y = 36000 \text{ psi} > 916.25 \text{ psi}$$

The above results show that at the largest loading point the bracket can support the wing successfully with the safety factory 3. In fact, the maximum safety factor the ASTM-A36 steel can take is over 100. Therefore, the normal stress study certified this wing bracket design is satisfied in real life during wing loading, unloading, and transporting.

To prevent the two 8”× 8” (1/4” wall) vertical steel tubes from moving in the horizontal direction, two 2”x6” (1/4” thick) steel tube are welded together with telescoping ground supports. Figure 46 below represents the cross section of two 2”x6” steel tubes and the shear stress location.

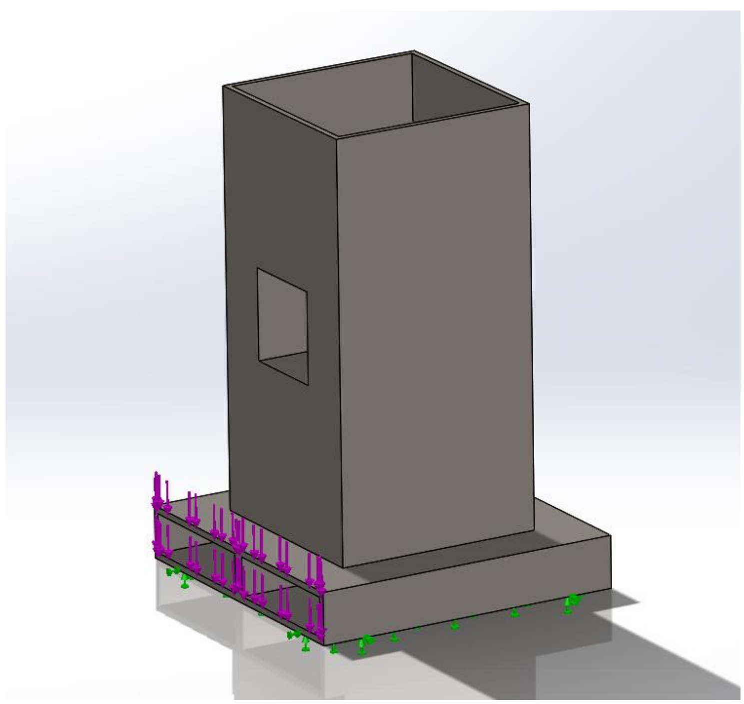


Figure 46: Wing Bracket Shear Stress

The shear stress in the horizontal 2”x6” tubes must satisfy the safety factor.

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

$$\tau = \frac{2366.98}{(2*6 - 1.5*5.5)*2} = 315.60psi$$

$$\tau \times \text{safety factor} = 946.8\text{psi}$$

Since the Shear Yield Strength of ASTM-A36 steel is 25,000 psi, the calculated results are much smaller than the ASTM-A36 steel shear yield strength. The maximum safety factory was calculated to be 26.

Another consideration about the wing brackets is the extended tube on the bottom must prevent the wing from falling on its side. Figure 47 below shows the wing and bracket sitting on the ground.

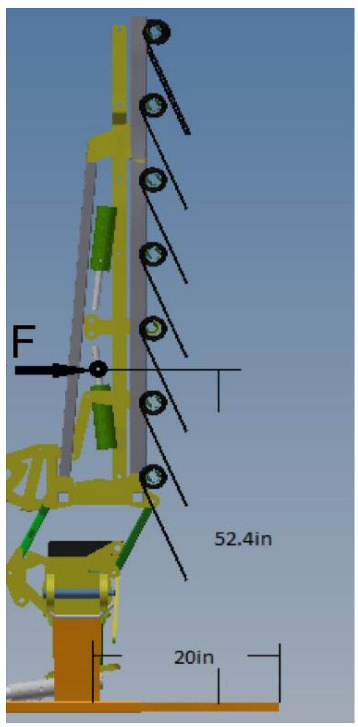



Figure 47: Wing and Bracket on the ground.

The information shown in Table XXV, detailing the relevant information about the wings, was used in this part of the stress analysis.

TABLE XXV: WINGS STABILITY RELEVENT DIMENSIONS

| | |
|---|---|
| **Wing Pair Weight:** | 5700 lbf |
| **Extended Leg Length** | 20 in. |
| **Centre of Mass Location** | 52.4 in. |

The information was used to calculate the force at F.

$$F \times 52.4 \ = 5700 \times 20$$

F = 2175.57 lbf

The result shows that an external force of 2175.57 lbf at the centre of mass is required to tip the wing over. In real life application, 2175.57 lbf is a huge force and unlikely to occur by accident. After performing the basic hand calculations, our team decided to use SolidWorks to run FEA. Figure 48 below shows the maximum Von Mises is 7.684 ksi with the safety factor 3. The maximum stress is concentrated at the joint point between top of 2”x6” steel tube. Even at the maximum stress point, the wing bracket with safety factor 3 is still lower then ASTM-A36 steel yield strength.

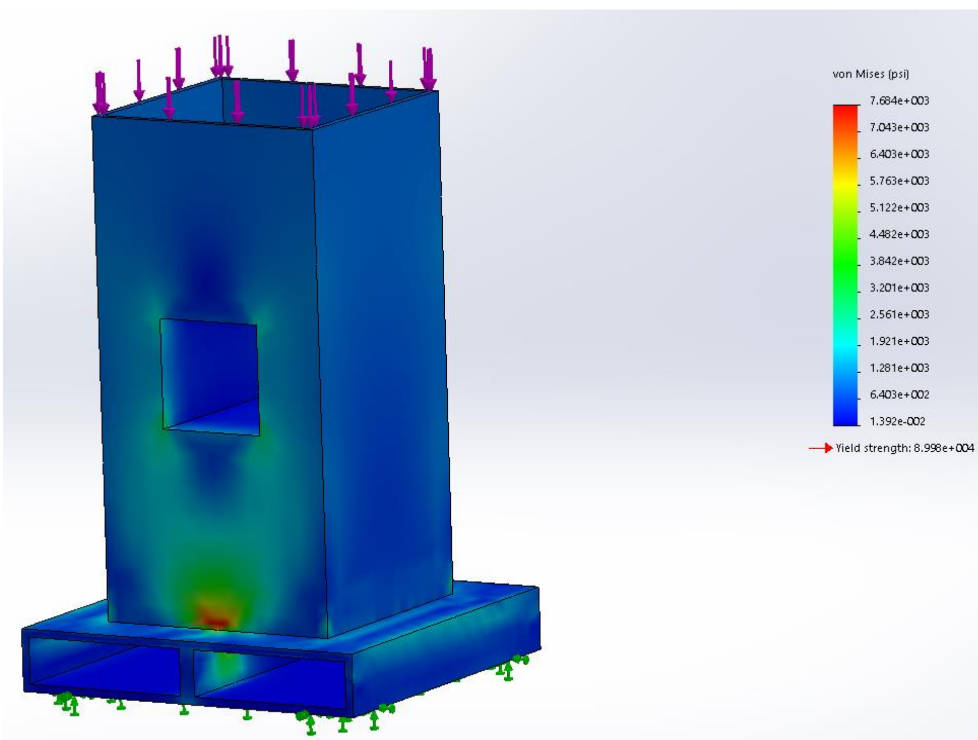



Figure 48: Wing Bracket FEA

Figure 49 shows the deflection occurring on the wing bracket. The result of deflection shows the maximum deflected area occurs at the top of the wing bracket. The maximum deflection is

0.001257 inch which is insignificant. This result shows the wing bracket will satisfy its designed purpose.

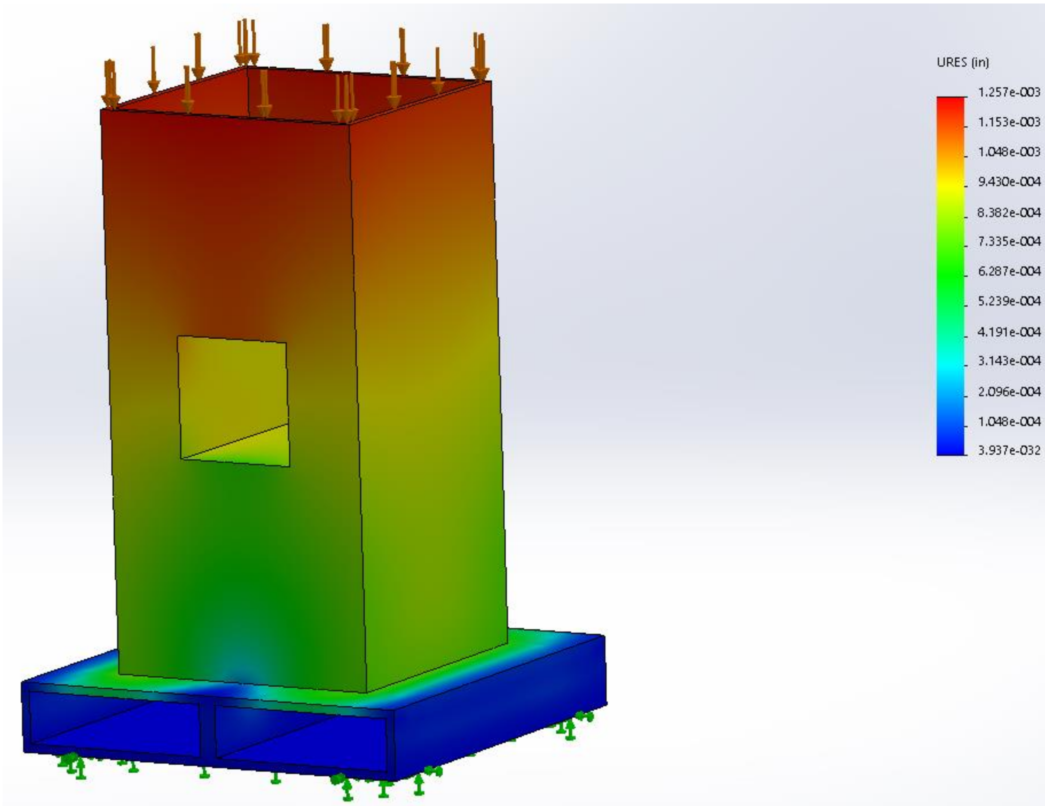



Figure 49: Wing bracket deflection FEA.

Shown in the previous calculations and FEA analysis, the wing brackets satisfy the design requirements and will not fail while loading, unloading and transportation of the harrows.

### 3.1.5 Bracket Design Summary

Overall, the harrow brackets were designed with safety and cost being the top priorities. To reduce cost, stock materials were used whenever possible as they are readily available by the client. Maximum safety was ensured by using ¼" steel tubing throughout the design. The use of wood in the hitch brackets helped reduce cost, weight, and provides support to the hitch without the risk of harming the paint coating. A basic stress analysis was performed on all the brackets to ensure the minimum factor of safety was achieved. As a result of the analysis, it was determined that the design far exceeded the minimum requirements. Due to the minimal cost savings by using thinner stock material, and the added insurance of a high safety factor on public roads, the chosen ¼" stock material was kept in the design. The high safety factors coupled with the minimal cost savings were used to justify the use of stronger material given the various dynamic loading situations possible during public transportation of the harrows. Technical drawings detailing the features of each part included in the metal bracket assembly are included in Appendix D.

## 3.2 Harrow Packaging

The approximate locations of the harrow pieces were developed using the scale models and then the positions were refined in the CAD models based on the clearances between the harrow pieces. To fit the harrows on the trailer it was necessary to omit some components from the initial harrow assembly, these components are stored at other locations on the trailer and will be attached during the final assembly performed by the dealer.

### 3.2.1 Trailer Layout

The layout of the proposed shipping method has the four harrow wings, divided into two sets of two, on the rear trailer of a B-Train and the two hitches stacked on the forward trailer. The hitch stacked on top has the harrow section folded down to lower the height of the load from 5 m to 4.6 m. The layout of the trailer is symmetric about the long axis of the trailer, creating a balanced and visually appealing load. While the aesthetics of the load are unimportant to the functionality, the appearance of a safe load is important to perception of the public. Some parts disassembled from the harrow are stored in two part boxes located beneath the wings, with the rest of the parts stored on two pallets located underneath the hitches.

The exact locations of the components on the trailer is not critical, but the interaction between the harrow pieces and conforming to the road restrictions. Table XXVI reiterates the road restrictions and compares them to the dimensions of the trailer load and the clearance available. Figure 50 and Figure 51 show the approximate locations of the harrow pieces and shipping brackets on the trailer.

TABLE XXVI: TRAILER LOAD CLEARANCES

| | Restriction (m) | Trailer Load (m) | Clearance (cm) |
|---|---|---|---|
| **Width** | 3.8 | 3.7 | 10 |
| **Height** | 4.7 | 4.6 | 20 |
| **Length** | 27.5 | 26.9 | 60 |
| **Overhang** | 4 | 3.65 | 35 |

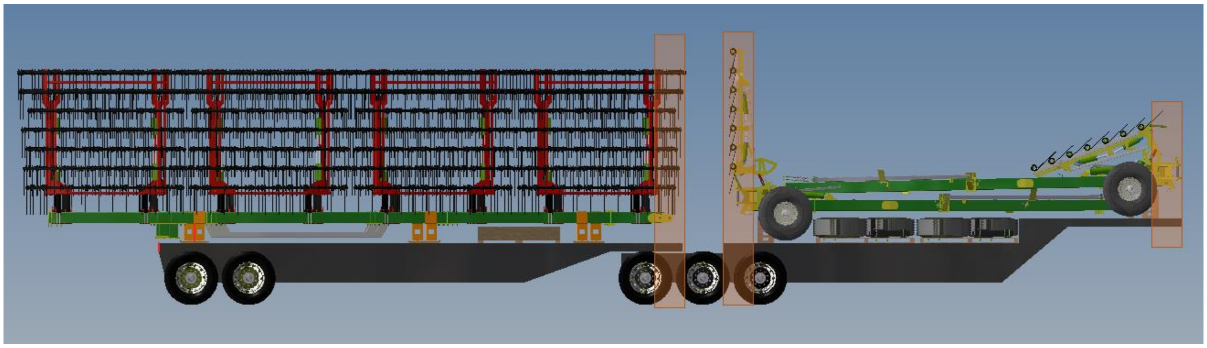


Figure 50: Locations of concern for overhang side view.

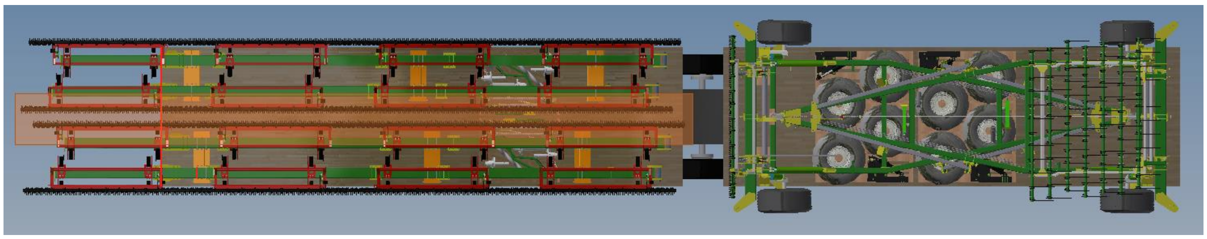


Figure 51: Locations of concern for overhang top view.

Exact dimensions of the harrow pieces are not provided, as the exact dimensions may change slightly from trailer to trailer. Instead approximate locations, based on Figure 50 and Figure 51 are described with the aim to allow the most flexibility in placement while protecting the harrow pieces and remaining within the road restrictions. To prevent interference between the harrows pieces overhang of the individual components highlighted by the orange areas must be avoided. Additionally the trailer should be approximately symmetric about the long axis. Similar to the location of the harrow pieces the location of the pallets and part boxes are approximate and may be located within a zone.

While the exact location of the components is not critical, the locations where the metal brackets are attached to one wing are. The wings located on one set of brackets must be offset from each other between 6” and 8” to prevent interference between the harrow sections. In addition to the offset between the wings in one set, the bracket locations on one set of wings to the other must also be offset to allow the securement straps to pass through to the other side of the trailer. The set of brackets on one wing set must be offset a minimum of 6” from the brackets of the other set, as shown in Figure 52.

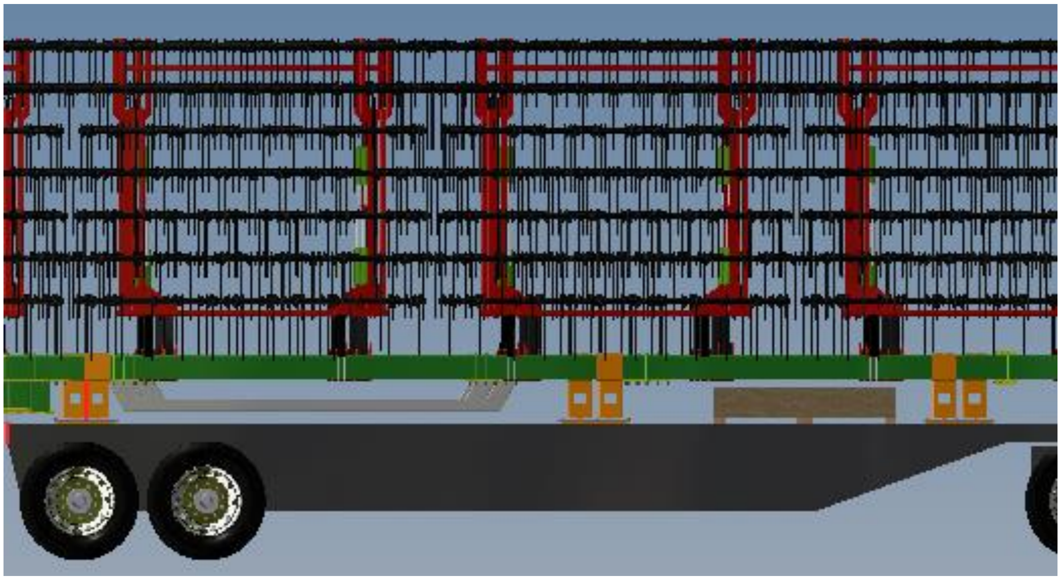


Figure 52: Offset wing brackets.

### 3.2.2 Omitted Assembly Components

To package the harrows successfully on the trailer some components had to be omitted from the assembly process. These parts are stored separately on the trailer for assembly at the dealer. The harrow parts are split between two part boxes and two harrows, shown in Figure 53 and Figure 54. The parts for one harrow are stored in box and one pallet, allowing for the easy unloading of one harrow at one location, and the other harrow at another. The list of parts omitted from the harrow assembly process and their location on the trailer are detailed in Table XXVII.

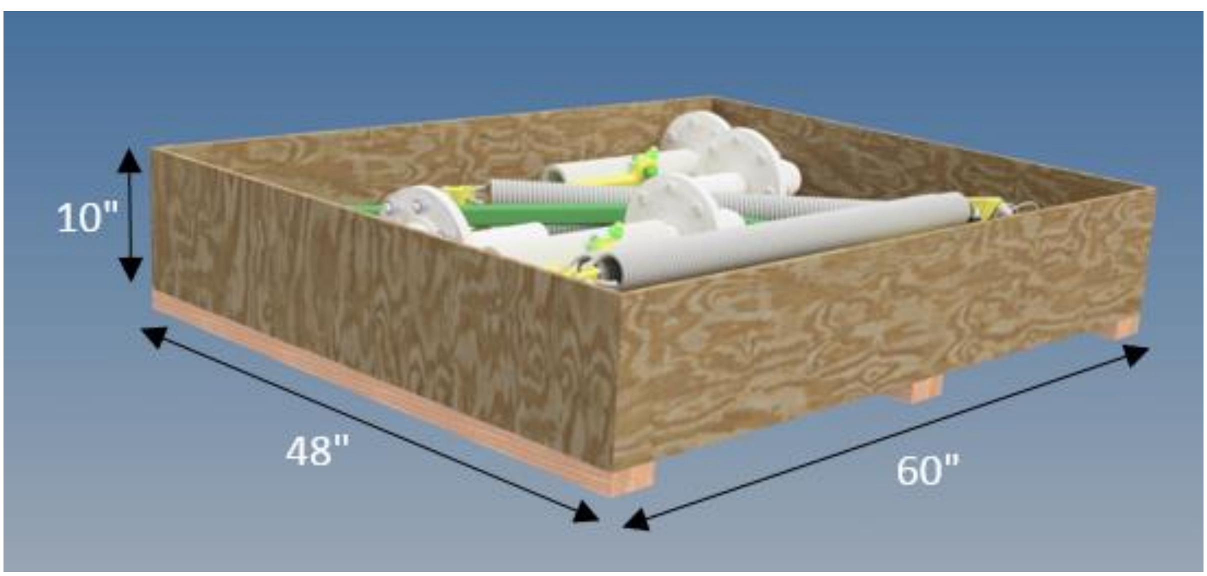



Figure 53: Part box with dimensions.

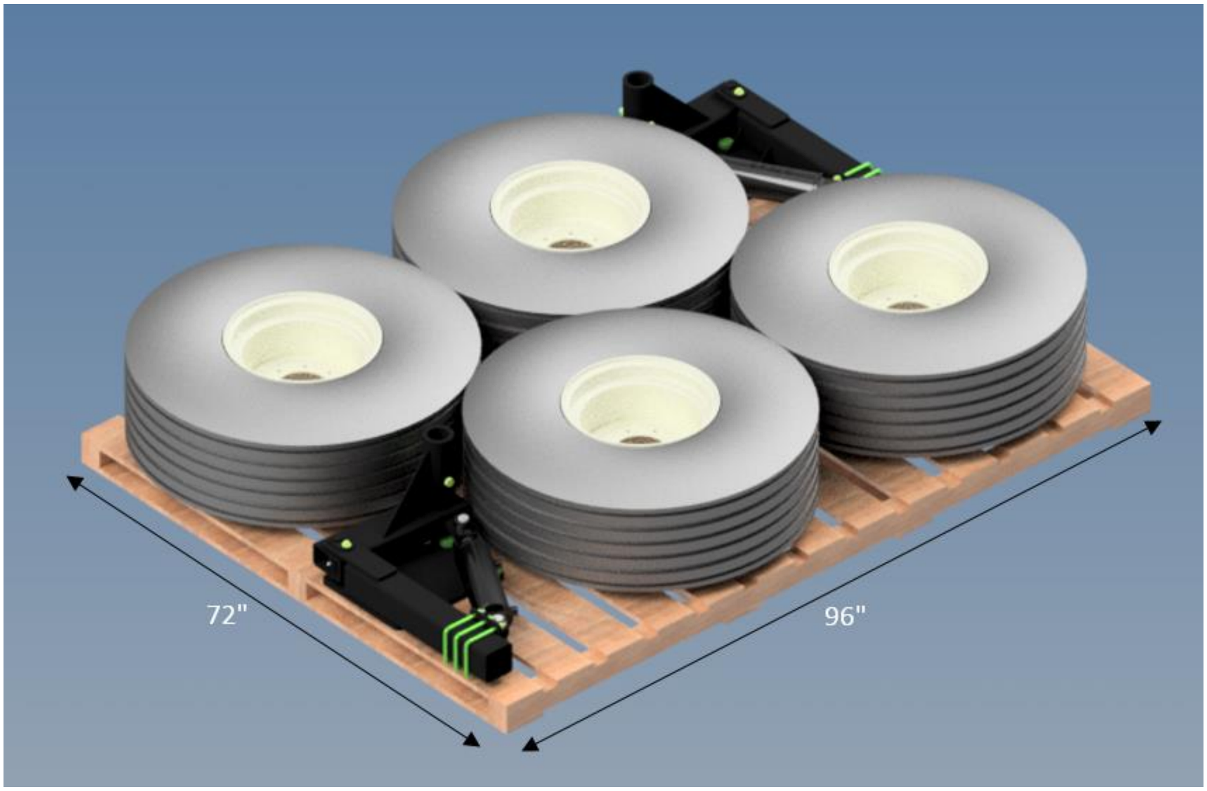



Figure 54: Pallet with parts and dimensions.

TABLE XXVII: PARTS OMITTED FROM HARROW ASSEMBLY

| P/N | Qty. | Description | Disassembled Parts | Includes | Part Box | Pallet |
|---|---|---|---|---|---|---|
| **08098** | 8 | Hub & Spindle Assy. | | | X | |
| **08237** | 2 | Chain Safety | | | X | |
| **18577** | 4 | 90' Inner Harrow Cable | | | X | |
| **18578** | 4 | 90' Outer Harrow Cable | | | X | |
| **18591** | 8 | Wheel, 14x16.1 - 8 Ply Tire | | | | X |
| **21151** | 4 | Transport Wheel Spindle | | | X | |
| **21466** | 4 | Field Tire Mount Assy. | 18591, 08098 | | | X |
| **21467** | 4 | Field Tire Mount Assy. | 18591, 08098 | | | X |
| **21828** | 8 | Cable spring | | | X | |
| **21974** | 2 | Hydraulic Hose Holder | | 18474, (4X) 09088, 07300, 07018, 07364 | X | |
| **127638** | 2 | LH - Light Assembly | | | X | |
| **127639** | 2 | RH - Light Assembly | | | X | |

## 3.3 Loading Procedure

As requested by the client a loading procedure was developed and documented. The document is included in Appendix B. The loading procedure details the order of operations to load the individual pieces of the harrows onto the trailer. Additionally, the loading instructions detail recommendations for the shipper but leave exact locations of securement and the securement methods used up to the shipper. Some details were left to the shipper because securement preferences change from driver to driver along with subtle changes to the trailers, straps and chains available.

## 3.4 Securement

Securement is an important aspect of transporting any goods, both in terms of protection of the public and the goods being shipped. The design of the wing brackets allows for a strap to be passed though the cross tube, creating three strap points per a set of harrow wings. Since the type of chains and straps available change depending on what the shipper has at the time the types of chains and straps are left ambiguous. In addition, although the type of trailer is specified each individual trailer may have subtle differences in securement hook types and locations. Furthermore individual truck drivers have varying preference on securement and therefore the final decision is left to the specific truck driver making the delivery. Enough chains and straps should be used to safely and legally secure the load to the trailer.

# 4 Cost Analysis

An initial cost analysis was performed to compare the cost of the proposed shipping method to the current process used by Elmer's manufacturing. The main objective of the proposed method is to reduce the overall shipping cost by allowing two harrows to be shipped in one truckload, as opposed to the current method of a single harrow per truck. To reduce the overall cost, the *total* cost of all elements of the proposed method must result in a lower overall shipping cost *per harrow*. As such, while the proposed shipping method allows two harrows to be shipped per truck, there are additional costs incurred such as trailer type, bracketry, and loading. The first part of the cost analysis is used to determine the feasibility of the proposed method and whether the overall cost of the proposed method results in a lower (per harrow) shipping cost to critical dealers.

The second part of the cost analysis is to determine a "break-even" point where it is more economical to ship the harrow(s) on a flatbed as opposed to towing it on the highway in transport mode (i.e. flat towing). Elmer's Manufacturing currently utilizes flat towing for shorter distances as it is generally less expensive than loading the harrow on a truck. With the proposed method offering the possibility of decreased shipping cost per harrow, a shipping destination can be determined where it becomes more expensive to flat tow the harrow beyond that point.

## 4.1 Determining Shipping Cost per Harrow

The total cost for the proposed and current shipping methods were determined to evaluate the economic feasibility of the proposed method. The current shipping method utilizes a single 53' flat deck trailer with very minimal incurred costs beyond loading and securing the harrow. The proposed method involves significantly more incurred costs such as trailer type, bracketry, and loading. The benefit for the proposed method being that two harrows can be shipped per truckload, effectively reducing the total shipping cost per harrow.

### 4.1.1 Trailer Cost

Searcy Trucking LTD. offers a variety of trailer styles to their customers in numerous configurations. The Specialized Services Division located in Altona provides services focused toward hauling large equipment. Elmer's Manufacturing currently utilizes a single 53' flat bed/step deck trailer to transport a single harrow. As part of the design process our team investigates several trailer types offered by Searcy, our final concept uses a "B-Train" style trailer to package all the necessary parts for the proposed shipping method. The B-Train trailer allows for an extra 7' of usable deck space compared to the 53' flat deck offered by Searcy. The quote obtained by Searcy to identify the added costs associated with choosing the B-Train trailer over the 53’ flat deck can be found in Table XXVIII.

TABLE XXVIII: SEARCY TRAILER QUOTES

| Trailer Type | Cost ($/mile) |
|---|---|
| 53’ Flat Deck | 4.00 |
| B-Train | 5.00 |

As noted above, the B-Train trailer costs 25% more on average than the standard 53’ flat deck. To compare the shipping cost of the two trailer types, Elmer’s supplied a current list of shipping rates to their dealer network (see Appendix C). The list included over 90 destinations throughout Western Canada and the Norther United States. To avoid analyzing the cost to all 90 dealerships, Elmer’s provided a list of “critical dealers” who are considered the most important in this cost analysis.

TABLE XXIX: CRITICAL DEALER FLAT DECK SHIPPING RATES

| Prov./State | City | Distance (km) | Flat Deck |
|---|---|---|---|
| SK | Saskatoon | 840 | $2,350.00 |
| | N. Battleford | 975 | $2,720.00 |
| AB | Lloydminster | 1130 | $3085.00 |
| | Beaverlodge | 1855 | $4500.00 |
| | Trochu | 1300 | $3375.00 |
| | Vulcan | 1290 | $3230.00 |
| ND | Minot | 385 | $1500.00 |
| | Williston | 575 | $2245.00 |

To determine the additional shipping cost using a B-Train style trailer a 25% increase in cost was anticipated for all the critical dealer locations, see Table XXX. The **Proposed (1 Harrow)** column indicates the B-Train shipping rate for a single harrow and **Proposed (2 Harrows)** represents the lower rate (per harrow) if two harrows are shipped on one truckload. For the purposes of this cost analysis the shipping rates in the **Proposed (2 Harrows)** column will be used when analyzing the proposed shipping method.

TABLE XXX: CRITICAL DEALER PROPOSED METHOD SHIPPING RATES

| Prov./State | City | Distance (km) | Proposed (1 Harrow) | Proposed (2 Harrows) |
|---|---|---|---|---|
| SK | Saskatoon | 840 | $2937.50 | $1468.75 |
| | N. Battleford | 975 | $3400.00 | $1700.00 |
| AB | Lloydminster | 1130 | $3856.25 | $1928.13 |
| | Beaverlodge | 1855 | $5625.00 | $2812.50 |
| | Trochu | 1300 | $4218.75 | $2109.38 |
| | Vulcan | 1290 | $4037.50 | $2018.75 |
| ND | Minot | 385 | $1875.00 | $937.50 |
| | Williston | 575 | $2806.25 | $1403.13 |

### 4.1.2 Bracketry Cost

The cost of the brackets for the final proposed design were a combination of the manufacturing processing, materials, and hardware costs. For the purposes of this analysis the design resource costs (man hours, CAD software, etc.) were not included. The brackets were designed to be reusable to reduce costs of the proposed shipping method over time.

#### *4.1.2.1 Manufacturing*

The costs for basic operations were presented by Elmer's Manufacturing to help estimate the total cost of manufacturing. Laser cutting operation costs are based on the weight of the material used while forming and welding are based on the number of bends and inches welded, respectively. The weights of the members for laser cutting operations were estimated using CAD models, the length of welding was calculated assuming full welding of all members and stitch welding of the two base tubes. Laser cutting rates include the price of base material, Table XXXI contains the *total* values required for each operation:

TABLE XXXI: MANUFACTURING OPERATION COSTS (PER BRACKET)

| Operation | Rate | Unit | Qty. | Cost |
|---|---|---|---|---|
| Laser Cutting | 1.00 | $/lb. | 53 | $53.00 |
| Tube Laser Cutting | 1.00 | $/lb. | 104.5 | $104.50 |
| Sheet Metal Forming | 1.00 | $/bend | 8.0 | $8.00 |
| Welding | 0.30 | $/in. | 217.0 | $65.10 |
| | | | **TOTAL:** | **$230.60** |

### 4.1.2.2 Materials

For the members of the brackets that are not laser cut, stock steel tube will be used to reduce cost. The prices for stock tube were supplied by Elmer's and do not include any of the operations listed in the previous section. Table XXXII contains the costs associated with stock steel tube for the bracketry:

TABLE XXXII: STOCK STEEL TUBE MATERIAL COSTS (PER BRACKET)

| Size | Price | Qty. | Cost |
|---|---|---|---|
| 4"x4"x0.25" | $0.6775/in. | 34 | $23.04 |
| | | **TOTAL:** | **$23.04** |

Many of the supports in the proposed method utilize wood material, therefore the total length of wood required was used determine the cost of the wood bracketry. Table XXXIII contains the costs for wood, determined using local prices from Home Depot (note that prices are subject to change over time).

TABLE XXXIII: WOOD MATERIAL COSTS (HOME DEPOT)

| Component | Wood Size | Rate | Qty. | Total Req'd. | Total (per Harrow) |
|---|---|---|---|---|---|
| Support (4) | 2"x4" | $0.45/ft. | 80 | $36.00 | $18.00 |
| Pallet (2) | 1"x6" (treated) | $0.53/ft. | 120 | $63.60 | $42.60 |
| | 2"x4" | $0.45/ft. | 48 | $21.60 | |
| Box (2) | ½" Plywood | $0.78/ft$^2$ | 105.5 | $82.29 | $47.81 |
| | 2"x4" | $0.45/ft. | 29.6 | $13.32 | |
| | | | **TOTAL:** | **$216.81** | **$108.41** |

#### 4.1.2.3 Hardware

Table XXXIV contains all the necessary hardware used in the proposed method, all hardware prices were sourced from McMaster-Carr and prices were converted using 1.30 CAD per USD (note that prices are subject to change over time). Items offered in a package were priced by taking the package price and dividing the number of units per package, this was done to estimate the bulk hardware prices available to Elmer's.

TABLE XXXIV: HARDWARE COST PER BRACKET (MCMASTER-CARR)

| Hardware | Price | Qty. | Total |
|---|---|---|---|
| Gr. 8 5/8"-11x10" Bolt | $10.42 | 6 | $62.52 |
| Gr. 8 5/8"-11 Ny-Lock | $1.18 | 6 | $7.08 |
| 5/8" Washer | $0.50 | 6 | $3.00 |
| 5/8"x14" Steel Rod | $5.65 | 2 | $11.30 |
| Cotter Pin | $0.31 | 4 | $1.24 |
| | | **TOTAL:** | **$85.14** |

#### 4.1.2.4 Total Bracket Cost

The total cost of the brackets was determined by combining the manufacturing, material, and hardware costs are listed in Table XXXV. The individual cost of each wing bracket (including hardware) was found to be $338.78 – there are three wing brackets required for each harrow. The prices (per harrow) for the wood components were previously determined in the Materials section.

**TABLE XXXV: BRACKET COST (PER HARROW)**

| Component | Cost |
|---|---|
| Wing Bracket (incl. hardware) | $1016.34 |
| Wood Box | $47.81 |
| Wood Pallet | $42.60 |
| Wood Support* | $18.00 |
| TOTAL (per harrow): | **$1124.75** |

** While initial cost of bracketry per harrow is high, re-using the brackets over time will reduce the overall cost per harrow – the wood supports are the only bracket component that are not considered reusable in this analysis.*

#### 4.1.2.5 Bracket Lifespan

The main assumption in the manufacturing costs related to the steel bracketry is the ability to reuse the brackets for an extended period. In many cases the brackets will be secured to the trailer and shipped back to Elmer's once the harrow is assembled, decreasing the total shipping cost over time. The minimum lifespan for the brackets is assumed to be one year (12 months), however, in the event they are reused for a longer period reduces the overall shipping costs even further. The wood supports used to prop the hitches are not considered reusable but further cost savings will be incurred if they are. For this analysis, the wooden boxes and pallets will be considered reusable. While the overall lifespan of the wood material will be much less than the steel, it is safe to assume that an average minimum lifetime of one year is reasonable. Further analysis of the cost savings related to the usage numbers of the bracketry will be further discusses in the Summary section.

#### 4.1.2.6 Labour

The labour costs associated with loading the harrows are currently included in the shipping costs provided by Searcy Trucking. It was understood that for the proposed procedure that if the added labour of loading the harrows using the new method is within reason then the overall loading cost would be the same. In the instance that additional labour is required (beyond what Searcy offers when loading shipments), the assumed labour rate was $100/hour. Folding the tine section of one of the hitches is needed for the height requirement so a cost of $50 (0.5 hours of labour) is incurred.

### 4.1.3 Summary

To simplify the cost analysis for each shipping method Elmer's "critical dealers" were chosen as shipping destinations to examine. The costs for current shipping rates was provided by Elmer's and compared to the proposed method (including trailer and bracketry cost). Table XXXVI compared the proposed shipping total to the current flat deck shipping method for all eight critical dealers. The total shipping cost of the proposed method in Table XXXVI represents the "worse case scenario" where none of the bracketry is reused in the shipping process. **Bolded** cells represent the lower cost between the current method (flat deck) and the proposed method (total).

TABLE XXXVI: PROPOSED TOTAL SHIPPING COST (PER HARROW)

| Prov./State | City | Distance (km) | Shipping | Bracketry | Total | Flat Deck |
|---|---|---|---|---|---|---|
| SK | Saskatoon | 840 | $1468.75 | $1124.75 | $2593.50 | **$2,350.00** |
| | N. Battleford | 975 | $1700.00 | $1124.75 | $2824.75 | **$2,720.00** |
| AB | Lloydminster | 1130 | $1928.13 | $1124.75 | **$3052.88** | $3085.00 |
| | Beaverlodge | 1855 | $2812.50 | $1124.75 | **$3937.25** | $4500.00 |
| | Trochu | 1300 | $2109.38 | $1124.75 | **$3234.13** | $3375.00 |
| | Vulcan | 1290 | $2018.75 | $1124.75 | **$3143.50** | $3230.00 |
| ND | Minot | 385 | $937.50 | $1124.75 | $2062.25 | **$1500.00** |
| | Williston | 575 | $1403.13 | $1124.75 | $2527.88 | **$2245.00** |

As demonstrated in Table XXXVI, even without reusing the proposed bracketry shipping two harrows to Alberta is more economical than the current method. To reiterate the benefit of reusing the wing brackets, boxes, and pallets, a study was performed on each critical dealer to illustrate decrease in shipping (per harrow) experienced as the bracketry is reused. To perform this part of the analysis, it was assumed that Elmer's ships 100 individual harrows per year. Table XXXVII illustrates the cost per harrow relative to the number of times the brackets are used.

TABLE XXXVII: COMPARISON OF TIMES BRACKETS USED VS. OVERALL COST (ONE YEAR PERIOD)

| # Times Used | 1 | 2 | 4 | 5 | 10 |
|---|---|---|---|---|---|
| **# Bracket Sets Req'd.** | 100 | 50 | 25 | 20 | 10 |
| **Overhead Cost** | $112,475.00 | $56,237.50 | $28,118.75 | $22,495.00 | $11,247.50 |
| **Cost (per harrow)** | $1124.75 | $562.38 | $281.19 | $224.95 | $112.48 |

A graph was constructed to demonstrate the reduced cost (per harrow) as the brackets are reused over time. Th equation of the line produced from the above data was used to project the further reduction in cost up to fifteen (15) times. Figure 55 shows the projected decrease in bracket cost past ten uses, the negative exponential nature of the trend demonstrates that beyond 10 uses the further reduction in cost is less significant.

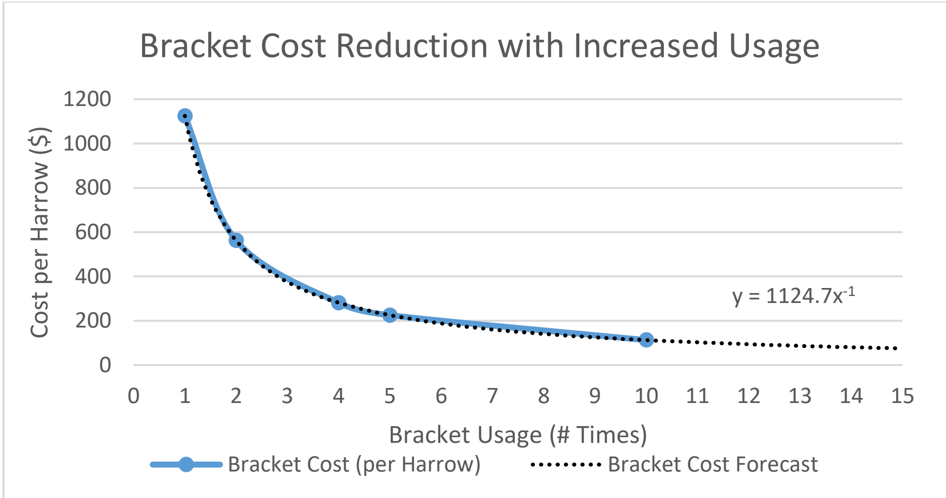



Figure 55: Bracket cost reduction with increased usage.

The data obtained in Figure 55 was used to construct a table to determine the point of bracket usage which makes the proposed method more feasible than the current shipping method used by Elmer's. It was previously known from Table XXXVI that the proposed method was more economical when shipping to the critical dealers in Alberta (without reusing the bracketry). The same method was applied to all critical dealers to determine the required number of uses to achieve a lower cost than the current shipping method. Table XXXVIII shows that for all critical dealers reusing the brackets just once provides an economical advantage for the proposed method – cells highlighted in green represent which shipping destinations are more economical for a given number of bracket uses.

TABLE XXXVIII: BREAK-EVEN POINT OF PROPOSED METHOD BASED ON BRACKET USAGE

| # Bracket Usage | | 0 | 1 | 2 | 4 | 5 |
|---|---|---|---|---|---|---|
| **Prov./State** | **City** | **Current** | **Proposed** | **Proposed** | **Proposed** | **Proposed** |
| **SK** | Saskatoon | **$2,350.00** | $2593.50 | **$2031.13** | **$1749.94** | **$1581.23** |
| | N. Battleford | **$2,720.00** | $2824.75 | **$2262.38** | **$1981.19** | **$1812.48** |
| **AB** | Lloydminster | **$3085.00** | **$3052.88** | **$2490.51** | **$2209.32** | **$2040.61** |
| | Beaverlodge | **$4500.00** | **$3937.25** | **$3374.88** | **$3093.69** | **$2924.98** |
| | Trochu | **$3375.00** | **$3234.13** | **$2671.76** | **$2390.57** | **$2221.86** |
| | Vulcan | **$3230.00** | **$3143.50** | **$2671.13** | **$2299.94** | **$2131.23** |
| **ND** | Minot | **$1500.00** | $2062.25 | **$1499.88** | **$1218.69** | **$1049.98** |
| | Williston | **$2245.00** | $2527.88 | **$1965.51** | **$1684.32** | **$1515.61** |

### 4.1.4 Assumptions

Determining the total shipping cost per harrow for the proposed and current shipping methods involved several assumptions. As part of the cost analysis these assumptions were made to reasonably simplify the analysis while maintaining accurate estimates:

- Quotes for flat towing from 2014 were considered relevant to recent shipping quotes
- 25% cost increase for B-Train trailer used to reduce error of different quote periods
- Labour costs for building wood pallets and boxes were not considered
- Realistically *every* bracket may not be returned to Elmer's for re-use
- Savings in assembly costs before shipping will be later incurred by vendor

## 4.2 Determining Break-Even Point for Flat Towing

The second part of the cost analysis is to determine a destination point where it is more feasible to ship the harrow on a truck as opposed to flat towing. Elmer's supplied a list of flat towing locations and their respective prices, along with their current quotes for shipping on a flat bed. A spreadsheet was constructed (see Appendix C) to compare the shipping costs of all the common locations between the two methods. This initial comparison was used as a preliminary judgement of locations currently more economical to flat tow the harrow. Table XXXIX shows that using current methods it is more cost effective to flat tow the harrows within Manitoba and North Dakota:

TABLE XXXIX: FLAT TOW VS. FLAT DECK COMPARISON

| Prov./State | City | Distance (km) | Flat Tow | Flat Deck | Flat Tow? |
|---|---|---|---|---|---|
| MB | Winnipeg | 112 | **$425.00** | $1500.00 | **Yes** |
| | Portage | 150 | **$500.00** | $1500.00 | **Yes** |
| | Neepawa | 250 | **$770.00** | $1500.00 | **Yes** |
| | Dauphin | 375 | **$1155.00** | $1500.00 | **Yes** |
| SK | Saskatoon | 840 | $2,625.00 | **$2,350.00** | No |
| | N. Battleford | 975 | $3,075.00 | **$2,720.00** | No |
| AB | Lloydminster | 1130 | $3500.00 | **$3085.00** | No |
| | Beaverlodge | 1855 | $5850.00 | **$4500.00** | No |
| | Trochu | 1300 | $4425.00 | **$3375.00** | No |
| | Vulcan | 1290 | $4150.00 | **$3230.00** | No |
| ND | Minot | 385 | **$1325.00** | $1500.00 | **Yes** |
| | Williston | 575 | **$1955.00** | $2245.00 | **Yes** |

The flat deck shipping costs in Table XXXVIII for Manitoba were estimated using the minimum shipping charge from Searcy, therefore, it is more economical to flat tow when the cost is below the minimum charge of $1500. The next step in determining the transition point is to compare the proposed to the current shipping methods, as noted in Table XL. **Bolded** cells indicate the lowest cost values for a given destination between flat towing, current, and proposed shipping methods.

TABLE XL: FLAT TOW VS. PROPOSED METHOD COMPARISON

| Prov./State | City | Flat Tow | Flat Deck | Proposed | # Bracket Uses | Cheapest? |
|---|---|---|---|---|---|---|
| MB | Winnipeg | **$425.00** | $1500.00 | $1162.45 | 5 | Flat Tow |
| | Portage | **$500.00** | $1500.00 | $1162.45 | 5 | Flat Tow |
| | Neepawa | **$770.00** | $1500.00 | $1162.45 | 5 | Flat Tow |
| | Dauphin | **$1155.00** | $1500.00 | $1162.45 | 5 | Flat Tow |
| SK | Saskatoon | $2,625.00 | $2,350.00 | **$2031.13** | 2 | Proposed |
| | N. Battleford | $3,075.00 | $2,720.00 | **$2262.38** | 2 | Proposed |
| AB | Lloydminster | $3500.00 | $3085.00 | **$3052.88** | 1 | Proposed |
| | Beaverlodge | $5850.00 | $4500.00 | **$3937.25** | 1 | Proposed |
| | Trochu | $4425.00 | $3375.00 | **$3234.13** | 1 | Proposed |
| | Vulcan | $4150.00 | $3230.00 | **$3143.50** | 1 | Proposed |
| ND | Minot | $1325.00 | $1500.00 | **$1218.69** | 4 | Proposed |
| | Williston | $1955.00 | $2245.00 | **$1684.32** | 4 | Proposed |

When comparing the proposed method to flat towing the harrows, Table XL shows that it is more cost effective to flat tow the harrows within Manitoba. This was expected due to the proximity of the destinations to Elmer's in Altona, MB. Upon further analysis, flat towing within Manitoba remains less expensive even when the brackets are reused more than five times. In North Dakota, the brackets must be reused at least four times before the proposed shipping method is more economical than flat towing. The proposed shipping method to Alberta and Saskatchewan is more economical with just one and two bracket uses, respectively.

## 4.3 Cost Analysis Conclusion

In conclusion, the cost analysis confirmed the feasibility of the proposed compared to the current shipping method. The increased cost if using the “B-Train” style trailer imposed a base increase of 25% compared to the current trailer cost. The ability to ship two harrows on one truck allowed for the overall shipping cost per harrow to be reduced by half, however, the ability to ship two harrows on one truck resulted in added costs due to necessary bracketry. The total cost of bracketry (per harrow) was found to be $1124.75. This incurred cost coupled with the increased cost due to trailer style only allowed shipping to Alberta to be more cost effective with one-time use bracketry. Fortunately, an analysis on the bracket usage over time showed that with only one re-use (2 total uses) of the brackets yielded enough cost savings to expand the cost effectiveness to the critical dealers in Saskatchewan. Even with the cost savings of the proposed method, flat towing still proved to be a viable option at the closer dealer locations.

The second part of the cost analysis involved determining a “break-even point” where it was more cost effective to flat tow the harrows as opposed to shipping them on a trailer. First, a spreadsheet was constructed to compare the flat towing rates to the current shipping method used by Elmer’s. The result of this part of the analysis yielded it currently being more cost effective to flat tow the harrows to vendors within Manitoba and North Dakota when using the brackets less than four times. The complete cost analysis showed that the proposed method is overall less expensive than the current shipping method to all critical dealer locations, however, it remains more economical to flat tow the harrows within Manitoba. Due to the close proximity of Elmer’s and the ability to ship the harrows complete, flat towing to North Dakota also remains a viable option. The cost is very similar between the proposed method and flat towing to North Dakota, therefore case-by-case discretion should be used to ensure the most appropriate method is used.

# 5 Summary and Recommendations

The team was successfully able to develop a method to reduce the overall shipping cost of the 90’ Super 7 Harrow by loading two harrows on one truckload, as shown in Figure 56. A high level of harrow assembly was achieved to reduce post-shipping assembly required by the dealer. Six metal brackets, four wooden brackets, two boxes, and two pallets were designed to aid in the packaging of the two harrows. A stress analysis was performed on each bracket to ensure the minimum required safety factor was met. The overall result of the bracket design achieved safety factors well above the minimum requirement, this accounted for unpredictable loading scenarios the brackets may be exposed to on public roadways. It was also determined that the minimal cost savings by reducing the bracket material thickness was not worth the added security offered by the bracketry. The overall cost of the bracketry including manufacturing and materials was $1124.75. The cost of using a B-Train trailer was found to cost 25% more than the current method using a single 53’ flat deck, however, it allows for two harrow to be shipped on one truckload.

Figure 56: Final Design

The cost analysis performed on the proposed shipping method determined that the increased overhead cost of using the B-Train trailer and additional bracketry would be mitigated over time. The ability to ship two harrows on one truckload using the B-Train coupled with the reusability of the shipping brackets leads to a lower shipping cost (per harrow). Through the cost analysis it was determined that with just a single bracket use, shipping to Alberta was already more cost effective than the current method. Shipping to Saskatchewan and North Dakota became more cost effective after two and four uses, respectively.

The second part of the cost analysis involved determining the point where the proposed shipping method became more cost effective than flat towing a single harrow. With the shipping information provided by Elmer's it was found that with only four uses of the proposed brackets it was more cost effective to use the proposed method than flat tow the harrows. Shipping within Manitoba remained less expensive to flat tow than ship on a truck, however, discretion should be used when shipping to North Dakota as the cost difference is minimal and could change over time. The costs of each shipping method for the critical dealers are shown in Figure 57.

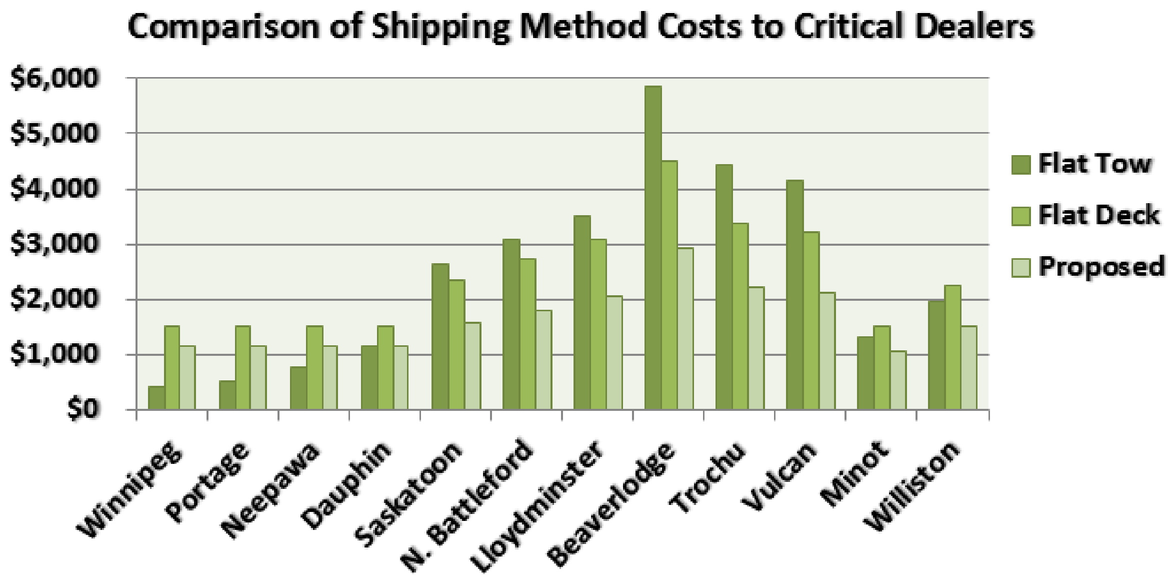



Figure 57: Cost comparison of each shipping method.

It is recommended by the team that all the designs and technical drawings be reviewed by a Professional Engineer before implementation. The design and analysis of all brackets was performed by students and should be considered a preliminary analysis. The manufacturing processes using the wing brackets should be analyzed to ensure the change in production procedure is beneficial to the company. Finally, the design should be discussed with Searcy Trucking to ensure its feasibility and their willingness to adapt from the current shipping process.

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# APPENDIX A

## Client Questionnaire

For the project of designing a new shipping method that packages two Elmer's Manufacturing Super 7 Harrows on one truckload, the client's need first had to be identified. A questionnaire was developed by the project team and forwarded to Elmer's Manufacturing. The following list is a copy of the returned questionnaire received by our team from Elmer's Manufacturing.

1. **What are the dimensions of the flatbed trailers to be used for shipping?**
    - Part of the project will be finding the optimal size flatbed.

2. **What are the loading capabilities at Elmer's (forklift limitations, shipping dock limitations, etc.)?**
    - 2-3 forklifts.

3. **What are the unloading capabilities of the receiver?**
    - 2 forklifts.

4. **At what stage in the assembly process is the receiver capable of completing the assembly process?**
    - The dealers are capable of any assembly necessary.
    - A low level of dealer assembly is preferable.
    - This should be integrated into the cost analysis.

5. **Will designed shipping fixtures/brackets be reused?**
    - Yes, if feasible.

6. **What CAD program is used by Elmer's Manufacturing?**
    a. **Are CAD models developed in Solidworks acceptable?**
        - Elmer's uses Autodesk Inventor. It is a free download for students.
        - CAD models developed in Solidworks are acceptable, but must be saved as STEP files.

7. **Will both of the packaged Super 7 Harrows be unloaded at the same location?**
   - Yes.

8. **Will both Super 7 Harrows be the same model (length)?**
   a. **If not will the designed packaging/process have to accommodate all combinations?**
   - The scope of this project will be the packaging of two 90' Super 7 harrows.

9. **What is the most difficult portion of the current unloading method for the receiver?**
   - Flatbed: Getting the harrow off of the flatbed.
   - Pulled by truck: No difficulty.

10. **What is the most expensive portion of the current loading method?**
    - The cost of transportation.

11. **What is the most difficult portion of the current loading method?**
    - Flatbed: Lifting the harrow from the ground to the flatbed. Currently done by the shipping company Searcy.
    - Pulled by truck: no loading difficulties.

12. **Is there a process in the current loading method that the loading workers would like removed/modified?**
    - Minimum lifting by hand.
    - Small number of packages to take off of the flatbed.
    - Minimum assembly.

13. **Is there a process in the current shipping method the truck operator would like removed/modified?**
    - The truck driver's focus is to transport their cargo from A to B with no damage.

14. **Is there a process in the current unloading method the receiver would like removed/modified?**
    - Similar to the loading workers.
    - Minimum lifting by hand.
    - Small number of packages to take off of the flatbed.
    - Minimum assembly.

15. **Is there any current development for the requested project?**
    - No.

**Target Metrics:**

1. **Cost (Target, Acceptable)**
    - Flatbed shipping:
        - Target = 25% less than current (varies depending on destination)
        - Acceptable = Equal to current
    - Find the distance at which using a flatbed is more cost effective.
2. **Loading procedure cycle time**
    - Based on cost efficiency.
3. **Unloading procedure cycle time**
    - Based on cost efficiency.

**Requested Documentation:**

1. **Super 7 Harrow CAD Models**
    - See shared folder.

2. **Super 7 Harrow Owner's Manual**
    - See shared folder.

3. **Current Super 7 Harrow shipping procedure**
   - Flatbed through Searcy:
     - Tow the Super 7 from Elmer’s to Searcy’s location in Altona.
     - Lift the harrow onto a flatbed using a crane. Finer positioning is done with a forklift. The harrow rests on wood blocks to avoid damage to the harrow.
     - Secure the harrow to the flatbed using straps.
     - A semi-truck tows the flatbed to the destination.
   - Pulled by truck:
     - Replace the harrow’s field tires with road tires.
     - Hitch a fully assembled harrow to a contracted semi-truck.
     - The semi-truck tows the flatbed to the destination.

4. **Current shipping procedure cost breakdown/analysis**
   - Flatbed through Searcy:
     - TBD
     - Elmer’s doesn’t have the costs of shipping through Searcy because Searcy invoices the receiver directly.
     - If you select locations from the provided list of shipping quotes, Elmer’s can contact Searcy for the costs.
   - Pulled by truck:
     - See provided quote sheet.

5. **Complete Super 7 Harrow assembly procedure**
   - See videos on shared folder.

# APPENDIX B

## Loading Procedure

As requested by Elmer's Manufacturing a loading procedure was developed for the proposed shipping method. The loading procedure was created with an effort to provide clear, wordless instructions. The loading procedure was developed to be a separate standalone document, and thus has separate page numbering and styles from the main report.

# 90’ Super 7 Harrow – B-Train Loading Procedure

# LOADING PROCEDURE

The following procedure details the order of operations to load a 90’ Super 7 Harrow onto a B-Train truck and trailer combination. Although the procedure and layout may be adapted for use with additional Super 7 Harrow models, this procedure should not be used for any model but the 90’ Super 7 Harrow. The unloading procedure may be performed as a reverse operation of the loading procedure.

The following equipment is necessary for the loading procedure:

- (2) 90’ Super 7 Harrow(s)
- (1) B-Train Trailer
- Ratchet chains/straps
- Plastic shipping strap (or equivalent as available)
- (6) Metal Wing Bracket(s) [PN: 101000[
- (4) 20” Wood Stack Bracket(s) [PN: 102000[
- (2) 96x72x4” Pallet(s) [PN: 104000]
- (2) 60x48x10 ½” Part Box(es) [PN: 103000]
- (2) 2x4” Wood Piece(s)
- Forklift(s) (or equivalent) Lift Capability of 11,000 lbs

**DISCLAIMER:**

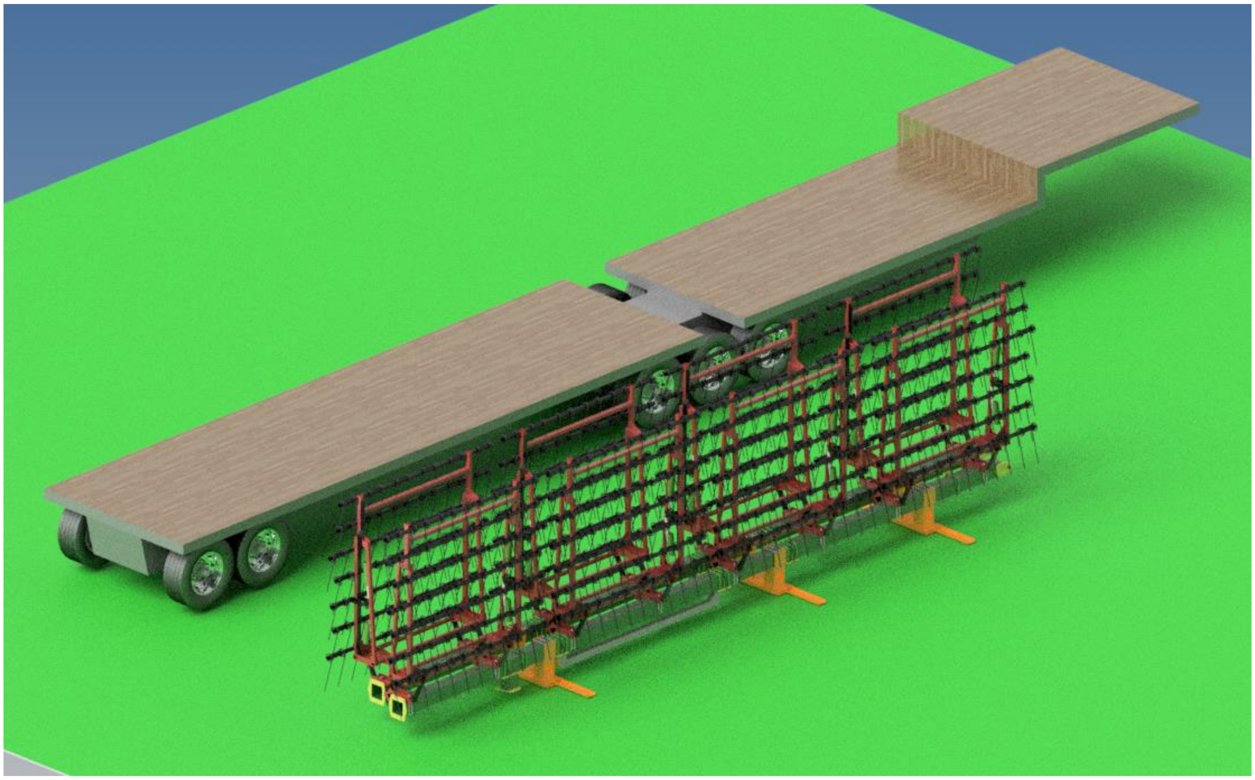
**THIS PROCEDURE WAS DEVELOPED BY STUDENTS AND SHOULD NOT BE USED UNTIL ANALYZED AND APPROVED BY A QUALIFIED PROFESSIONAL**

NOTES:

- Lift operations are not shown as they may vary depending on the available equipment, industry standard safe operating and lift procedures should be conformed too at all times.
- Protective shipping sheet should be placed between the Super 7 Harrow pieces and the brackets where protection of the paint is desired.
- Securement of the hitches to the trailer is unspecified and to be addressed as desired by the shipper.
- Additional straps should be used to secure the Super 7 Harrows wings to the trailer in the case of the bracket bolts failure.
- Parts included in the part box may be placed as necessary for fit.
- Securement of the parts on the pallet should be done with shipping straps as desired by the shipper.

## LOADING PROCEDURE

STEP ONE



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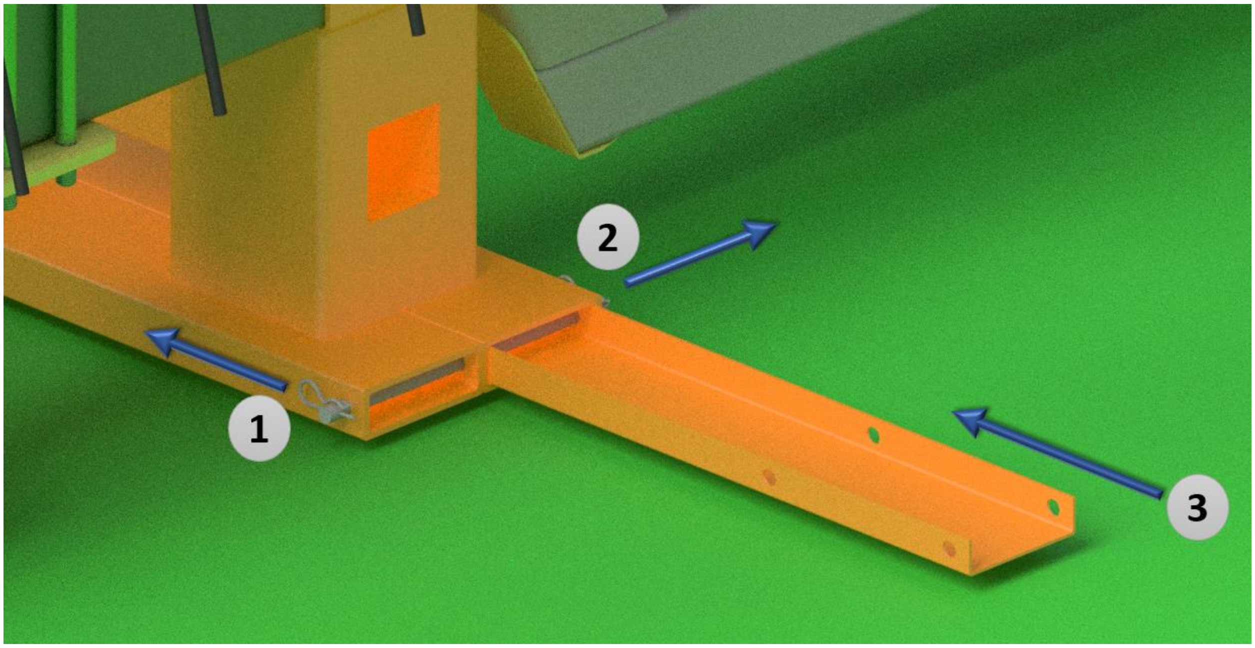

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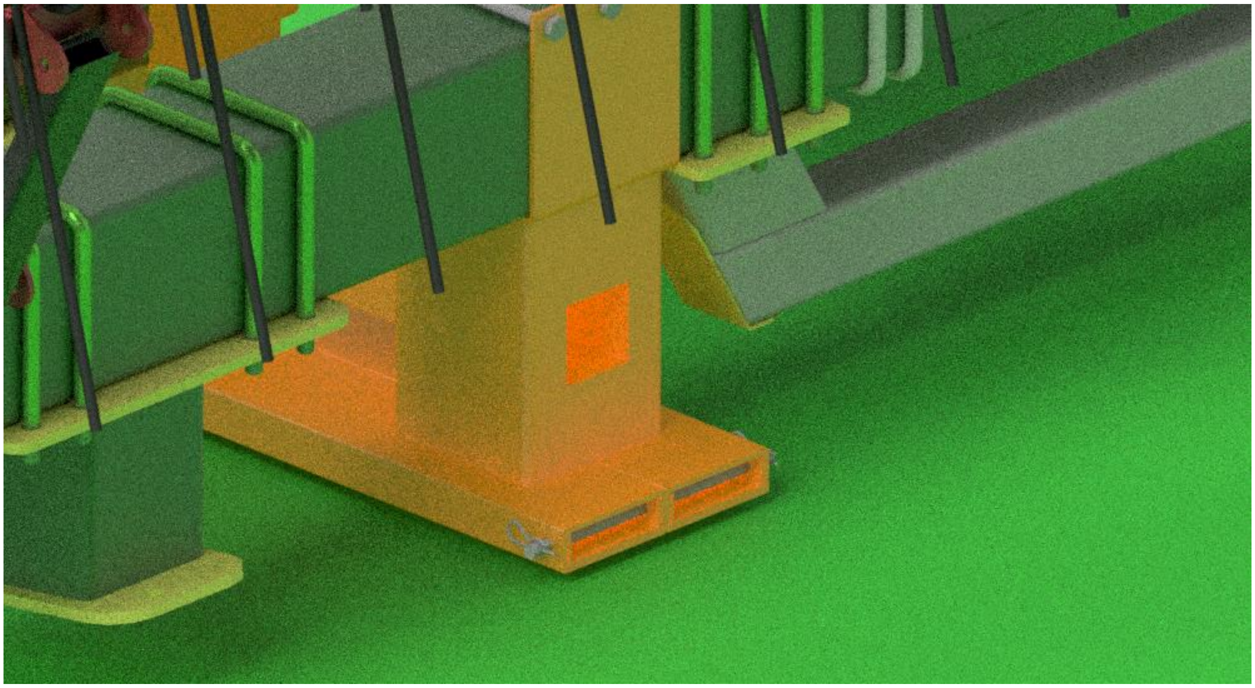

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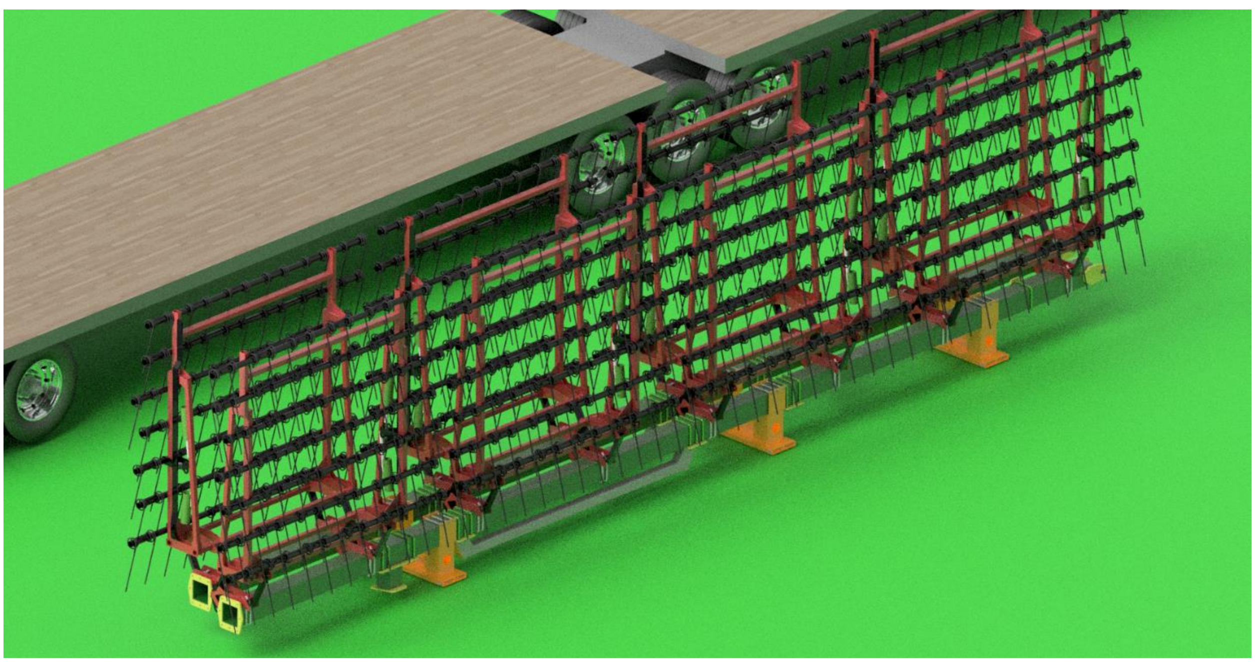
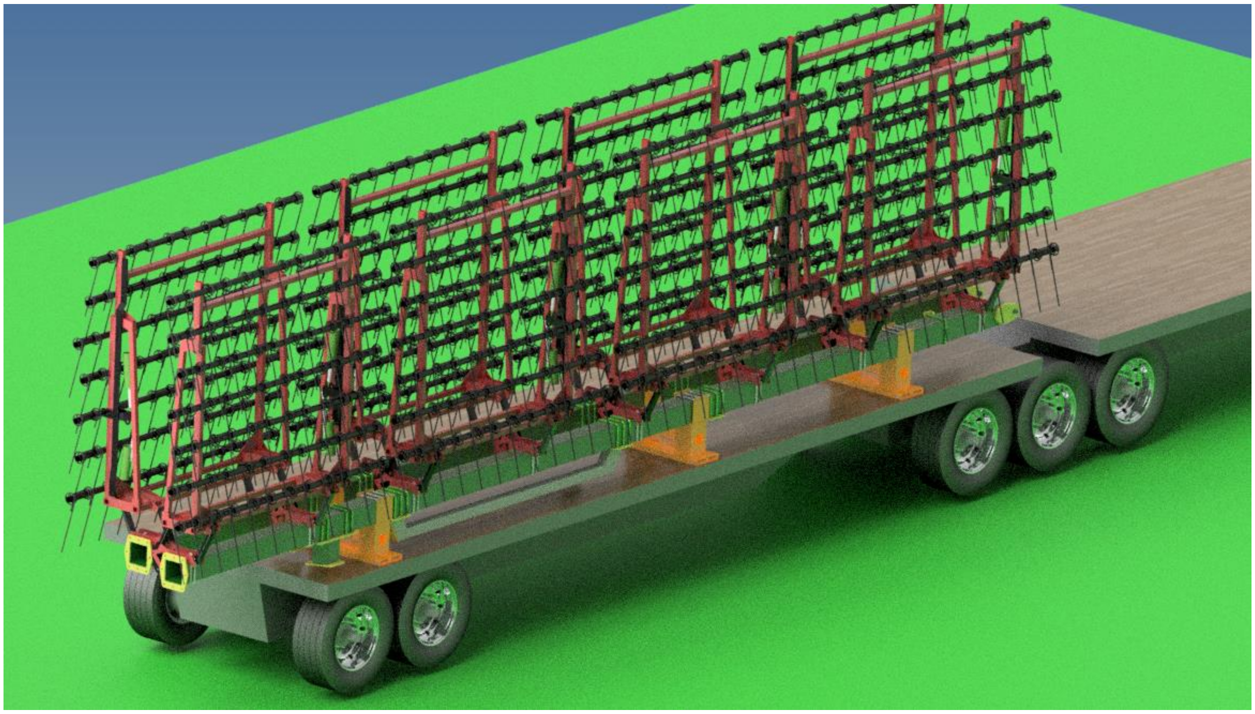


# LOADING PROCEDURE

STEP FIVE



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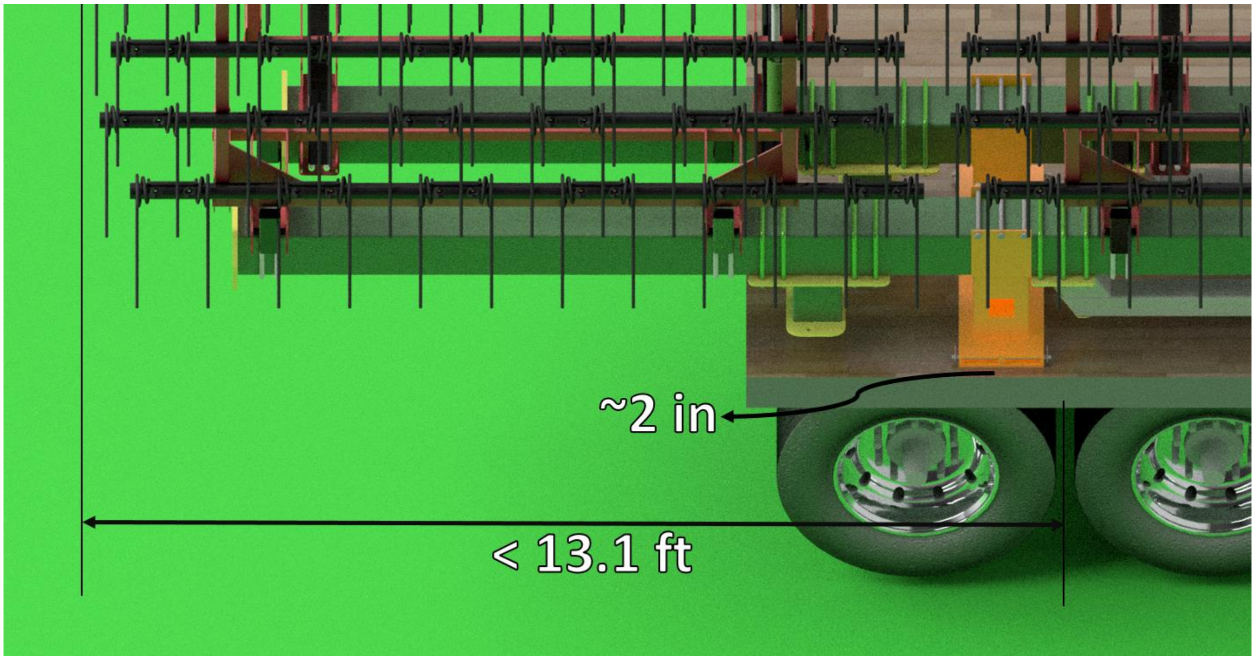

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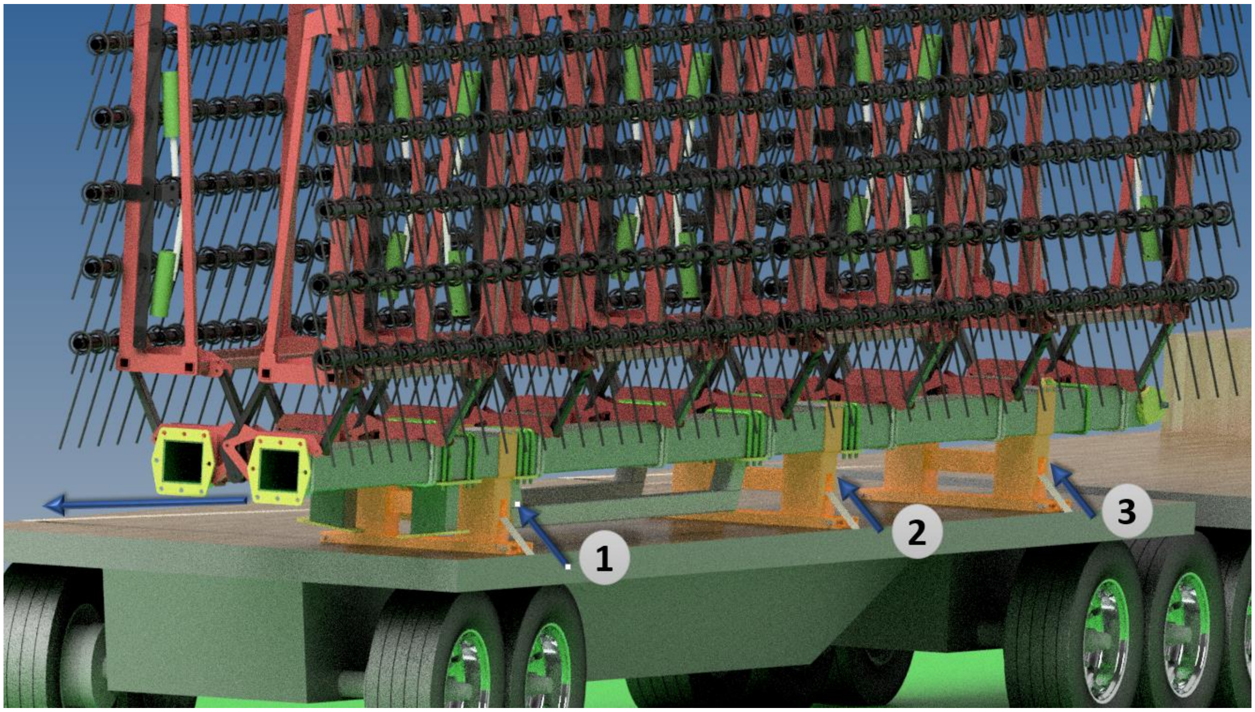


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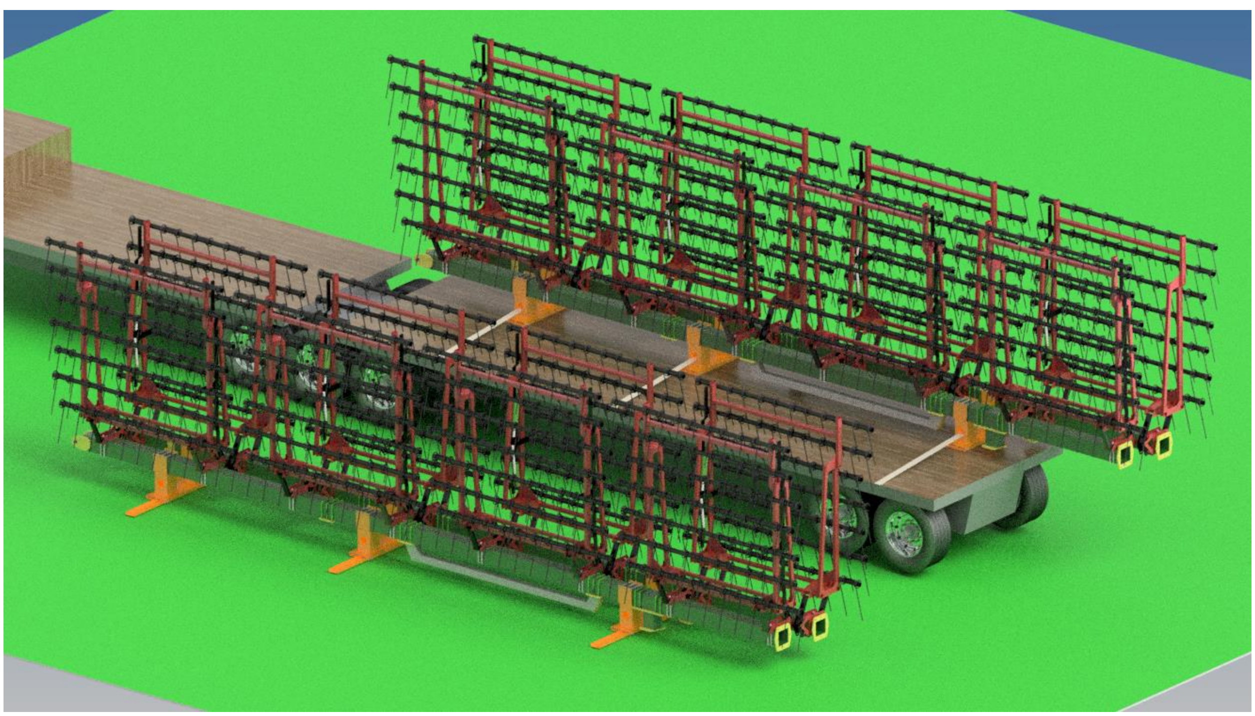

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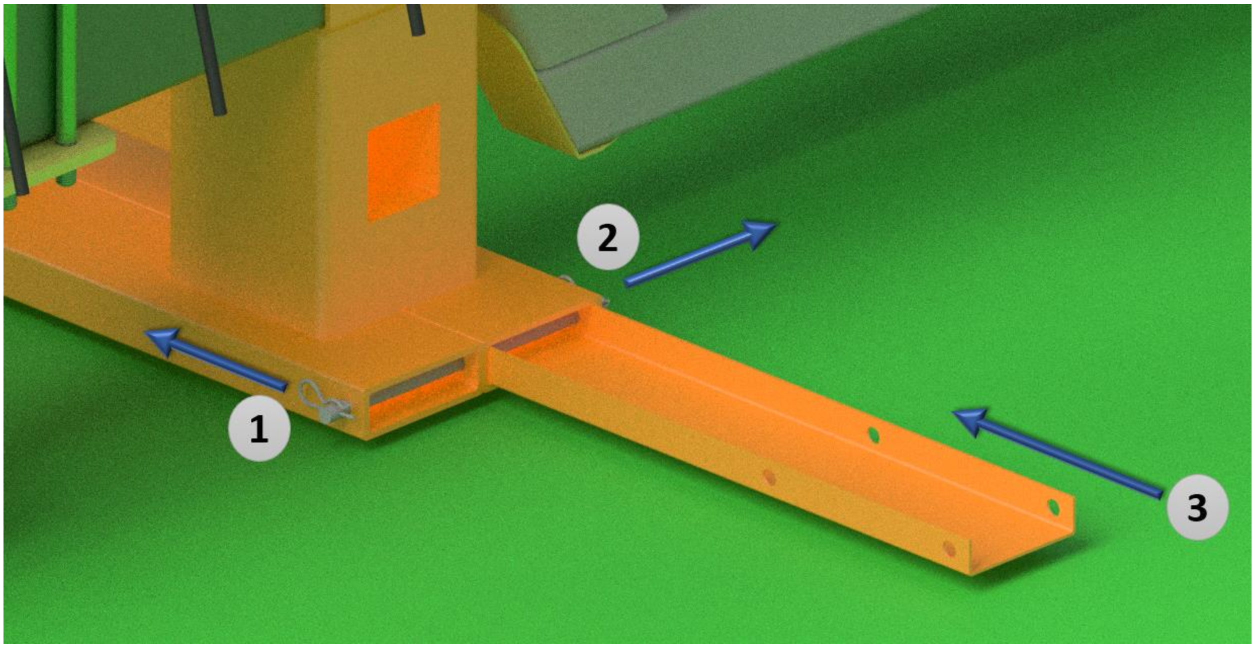


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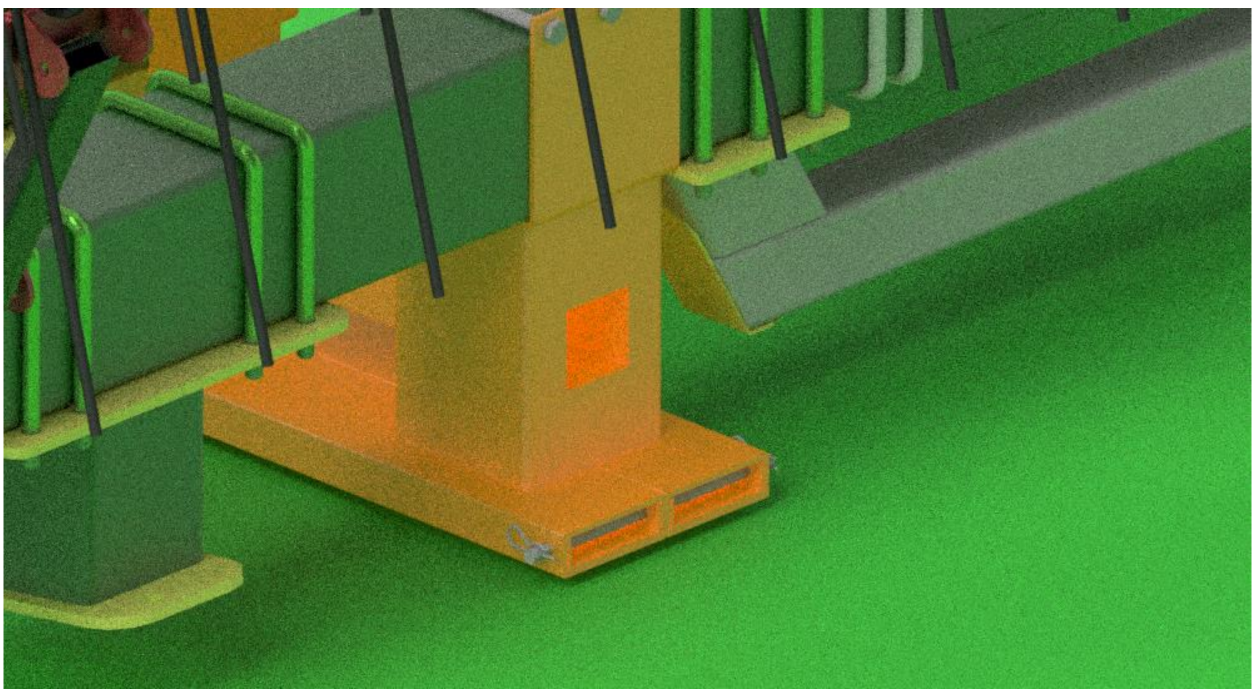

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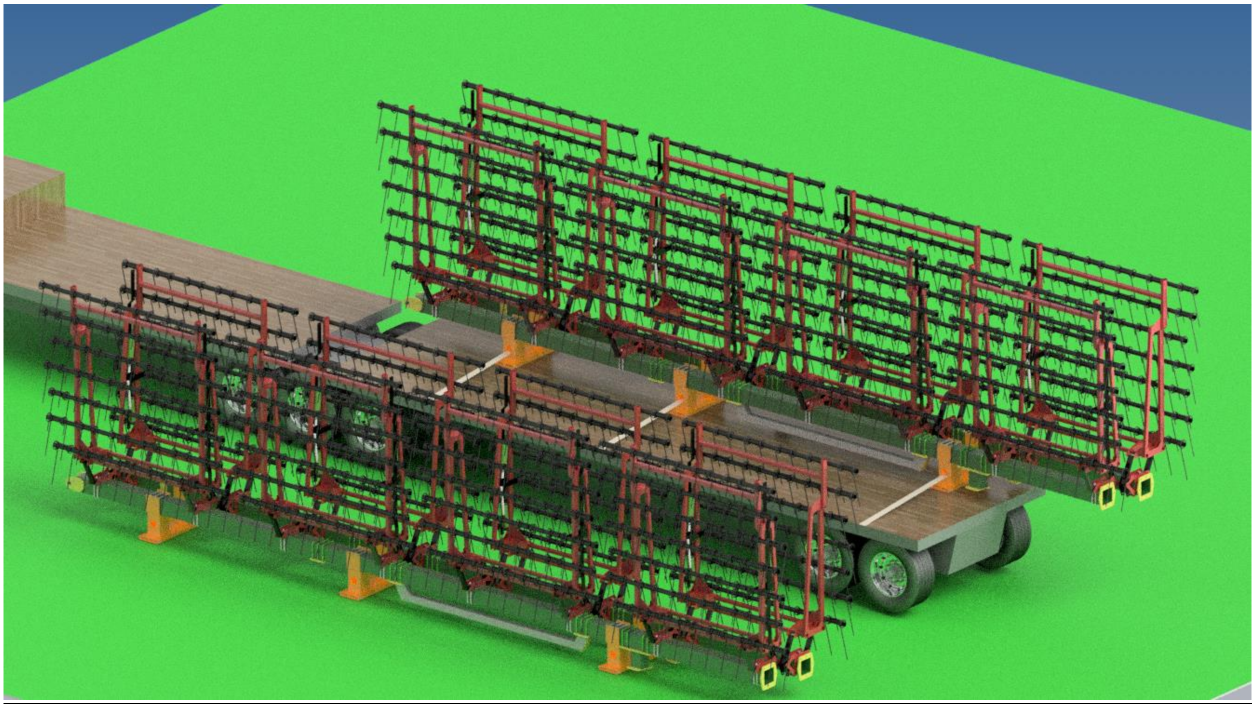

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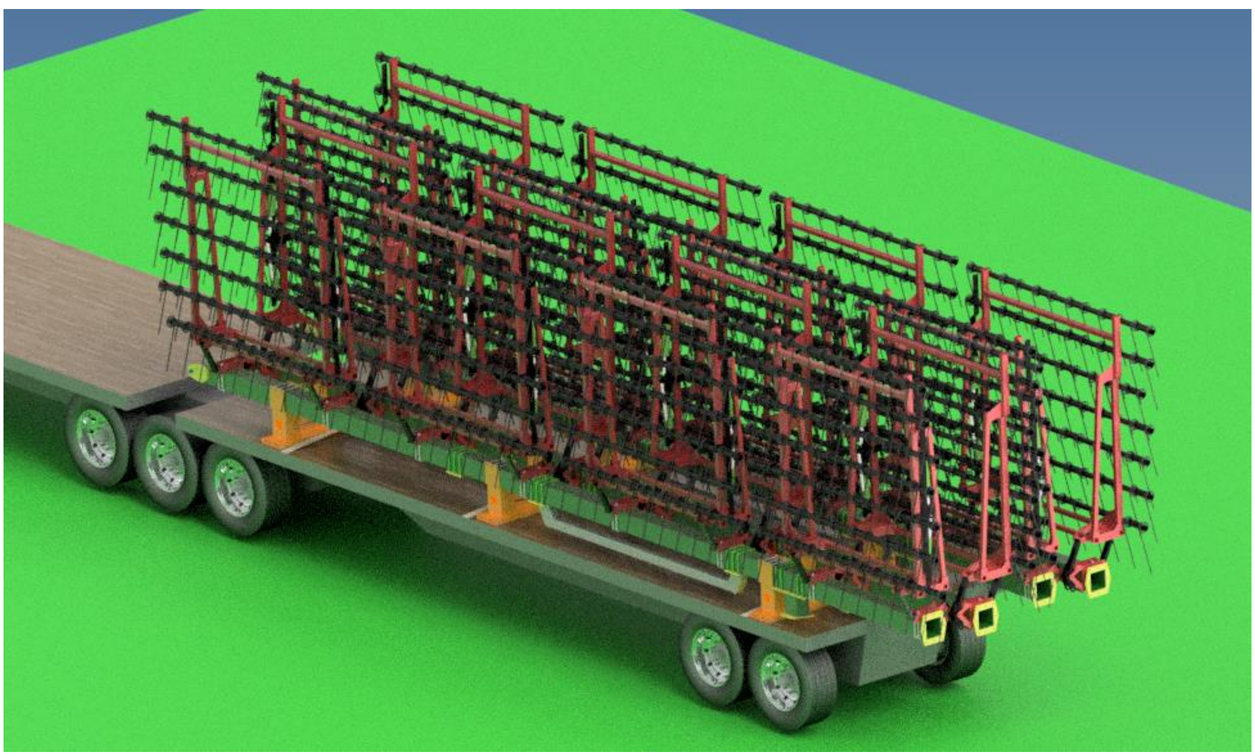

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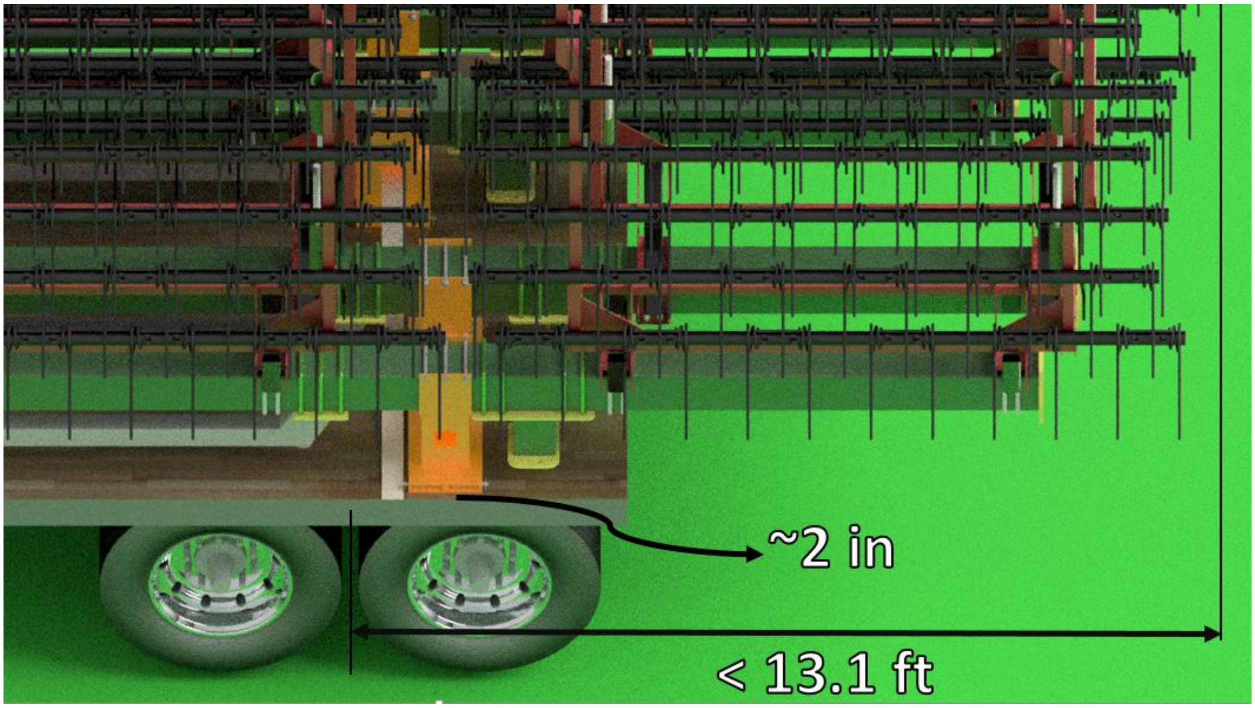


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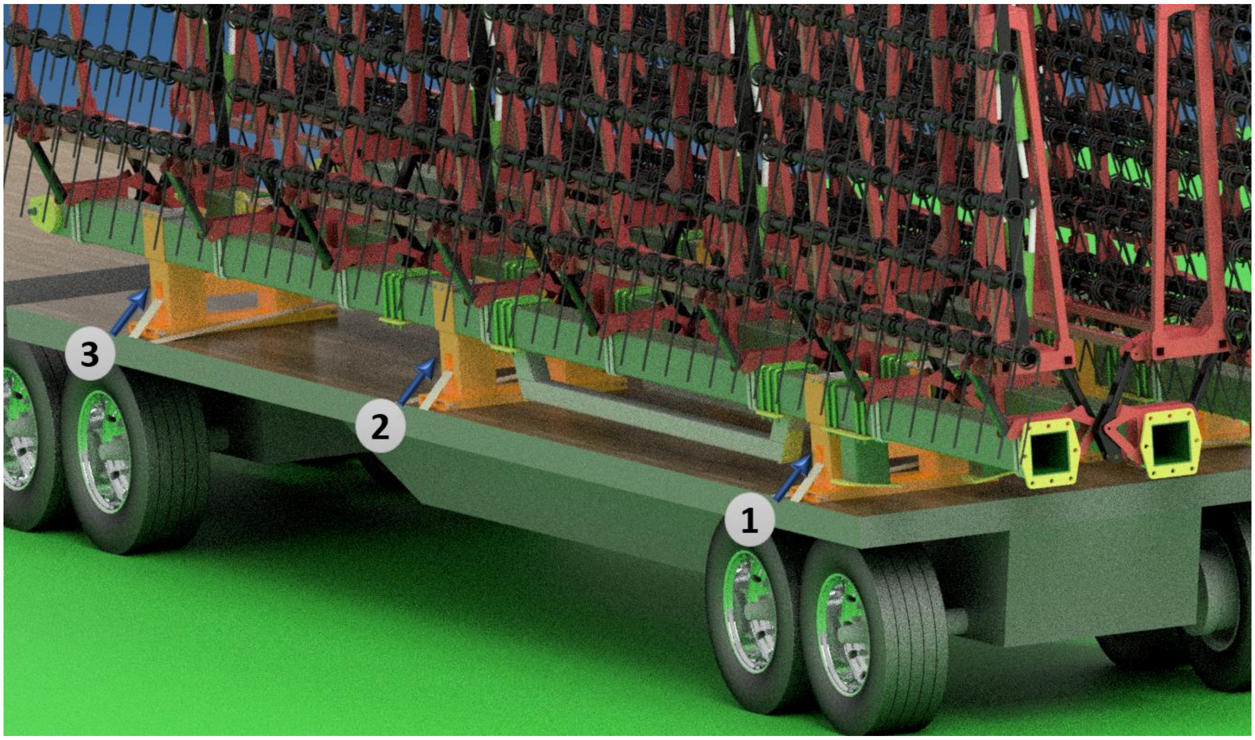

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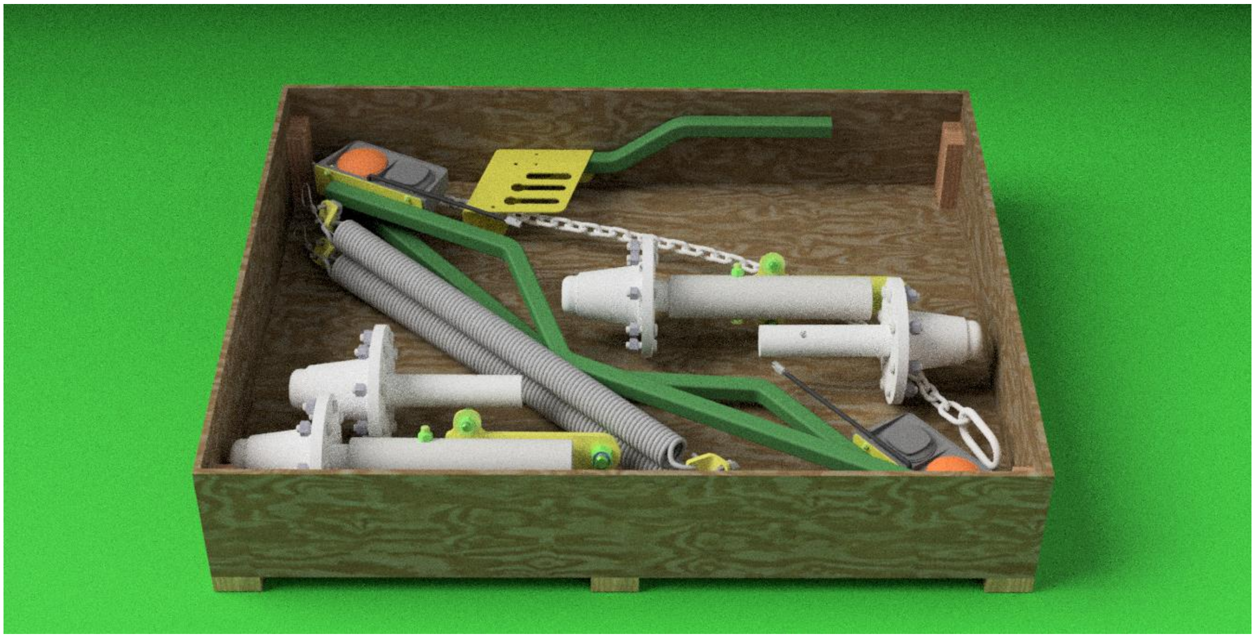

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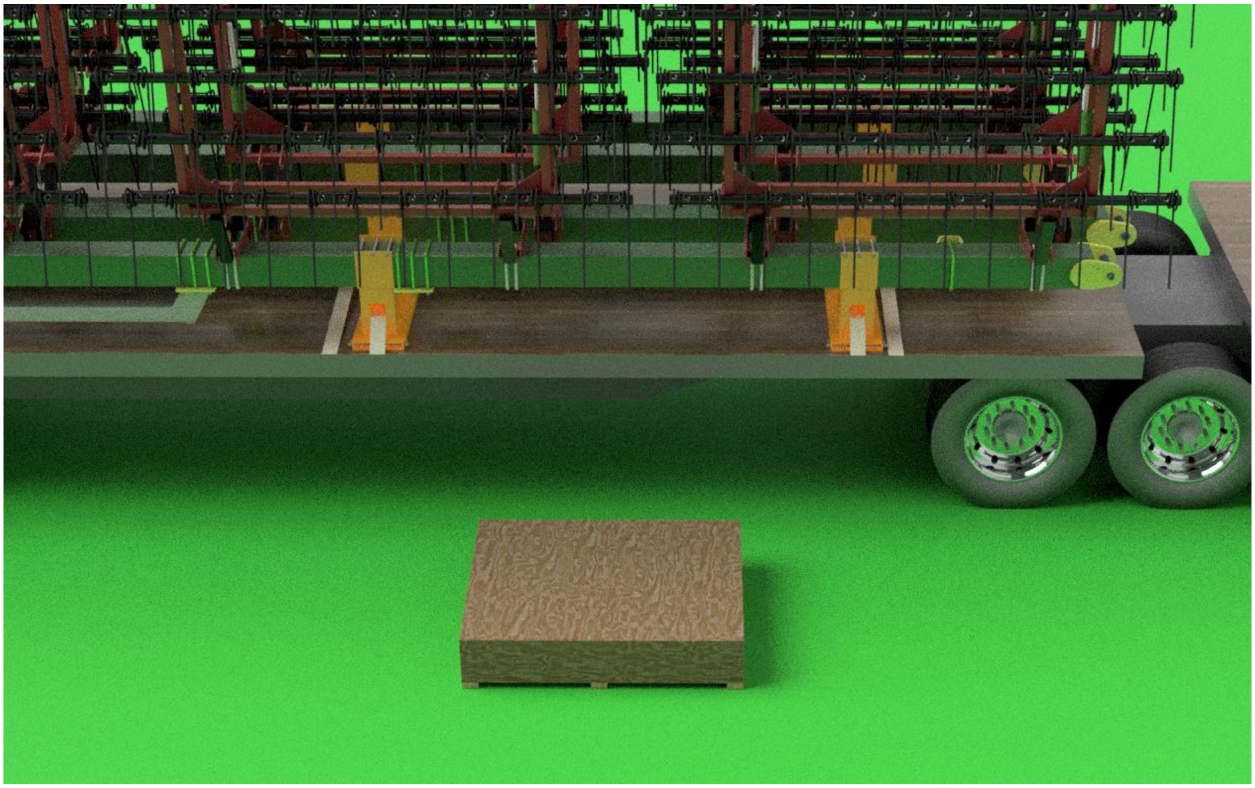

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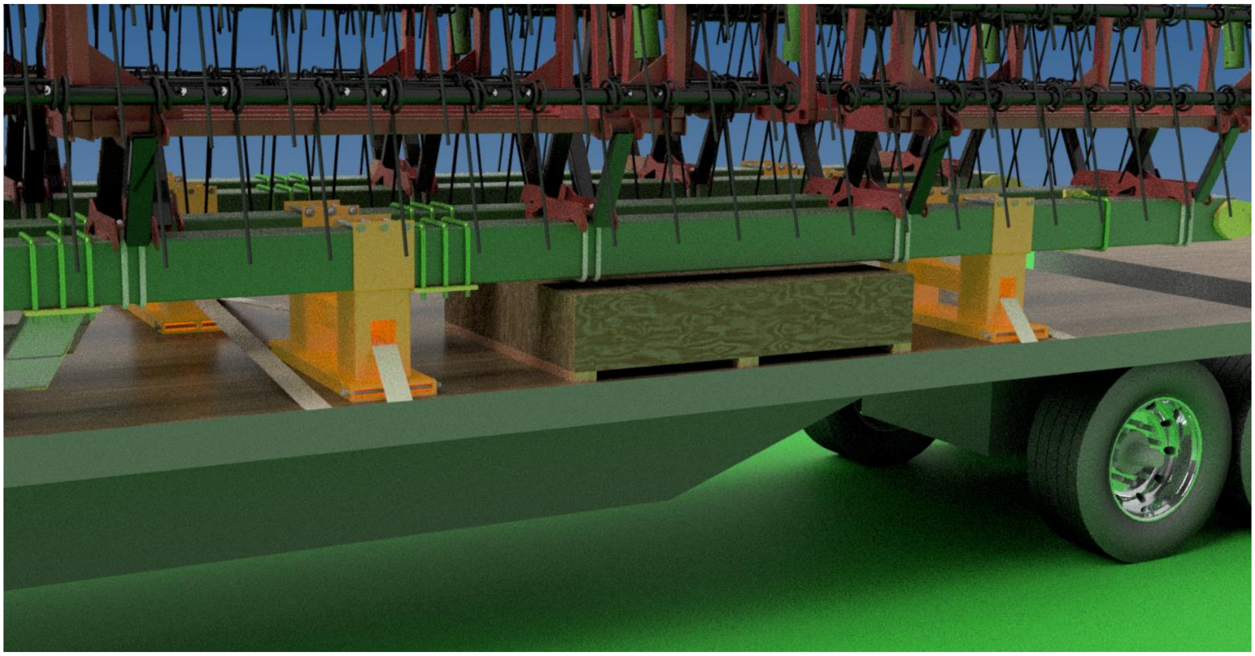

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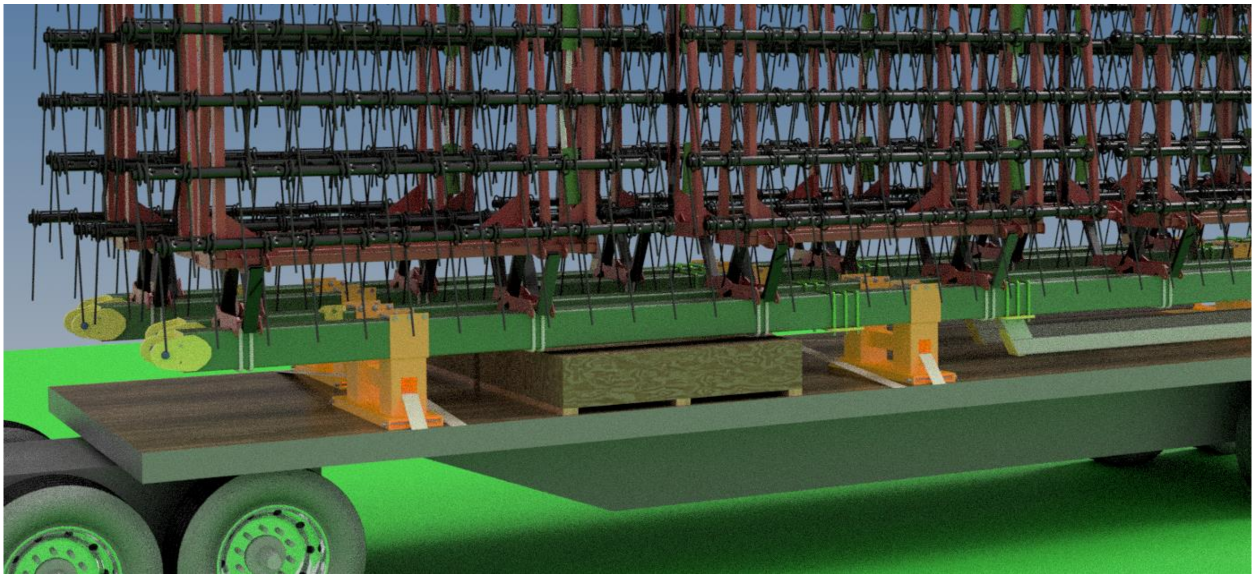

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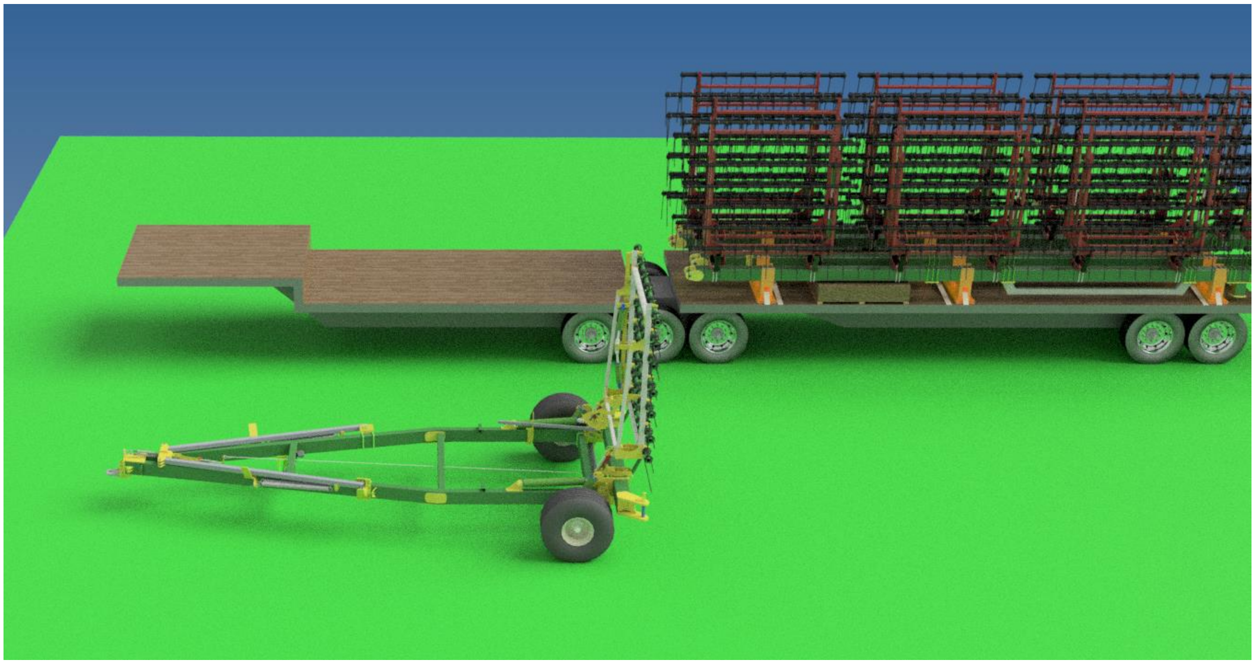

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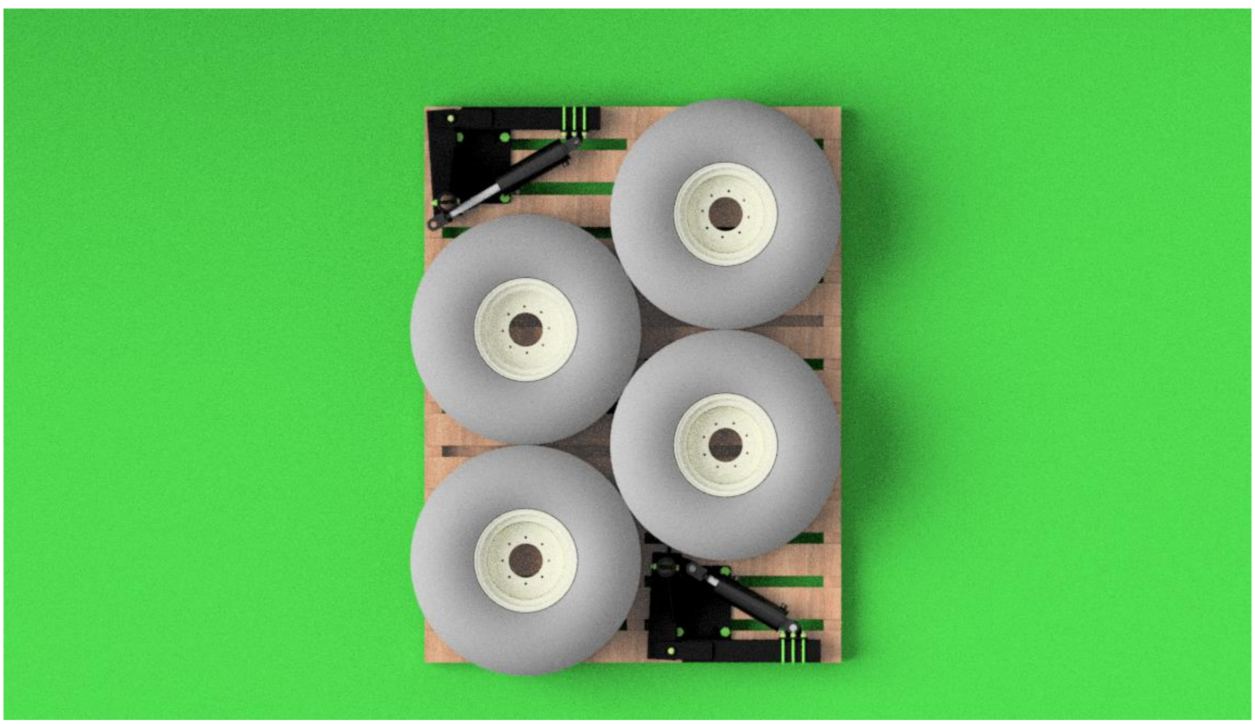

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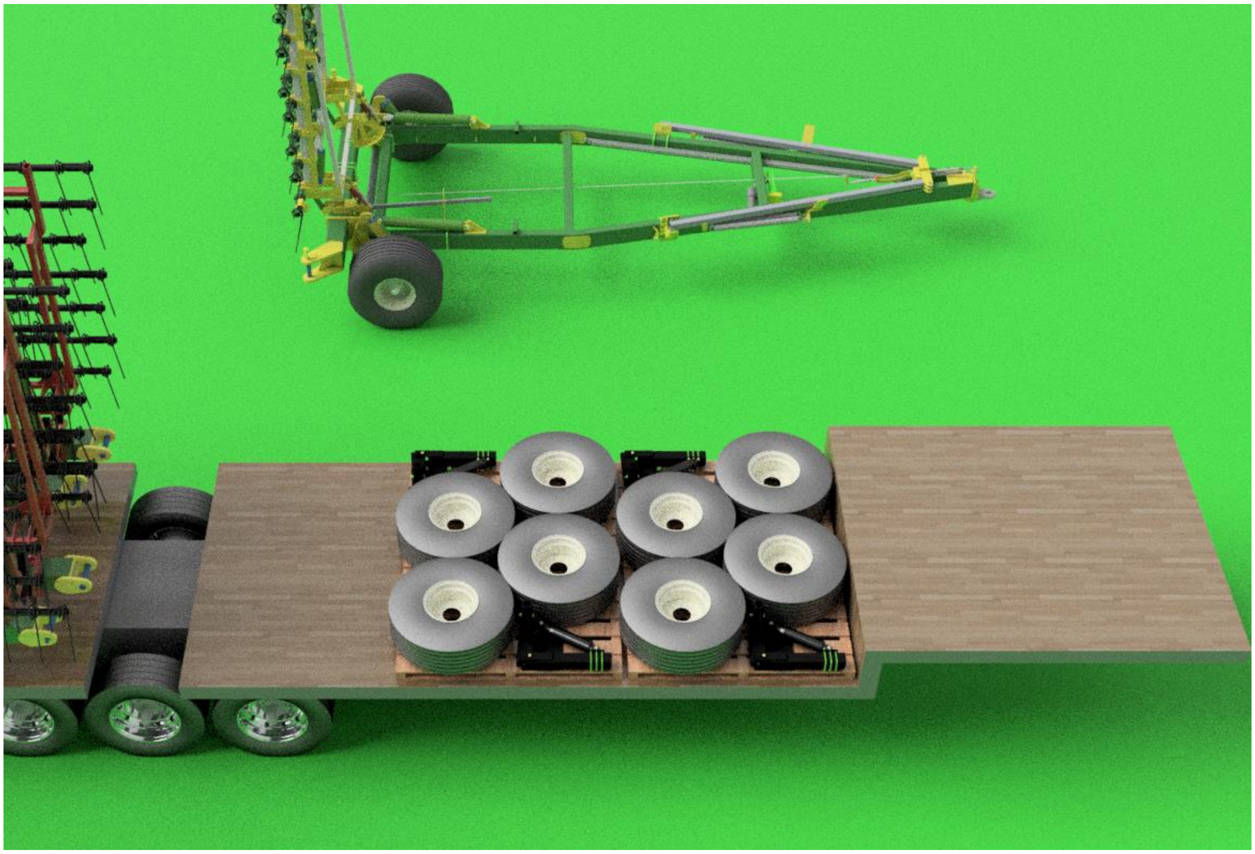

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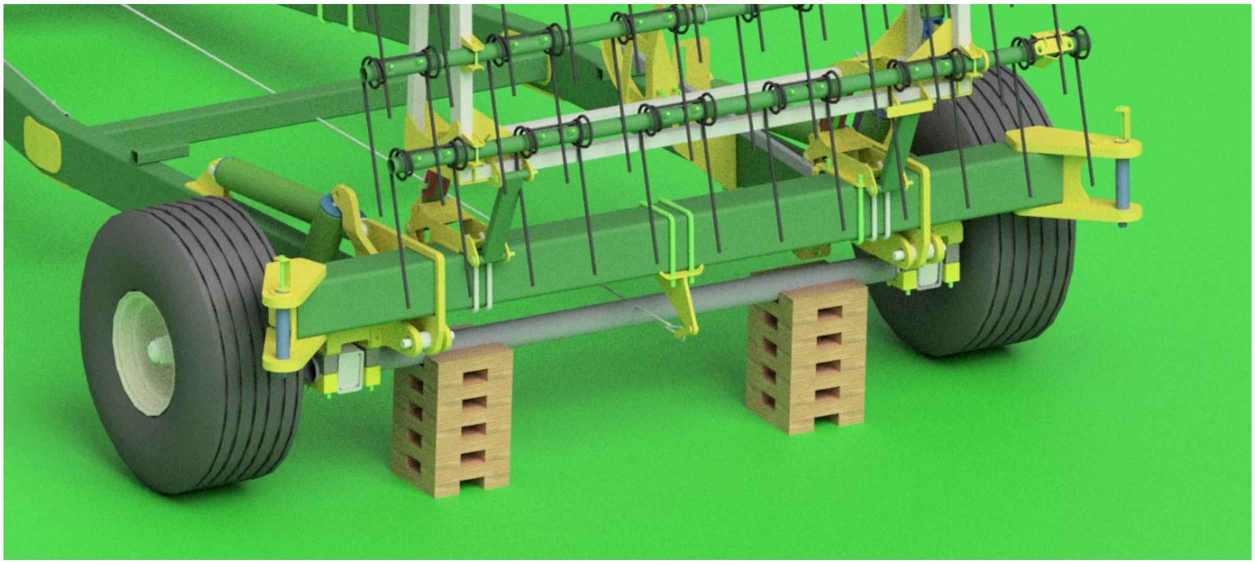

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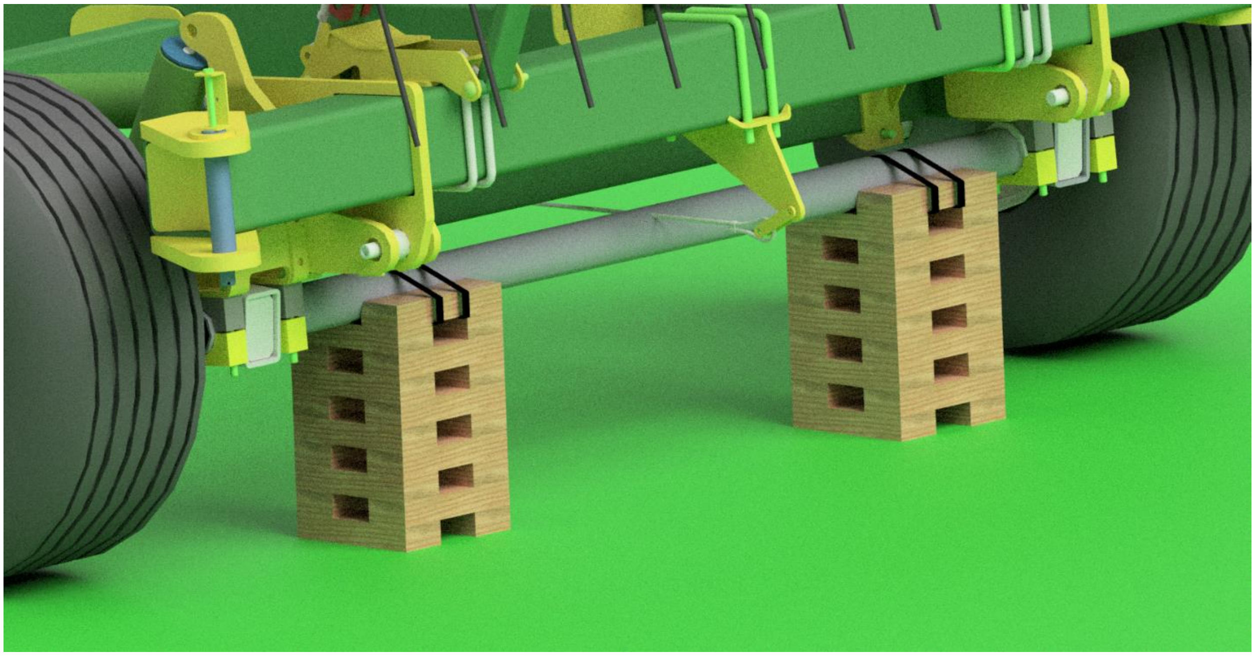

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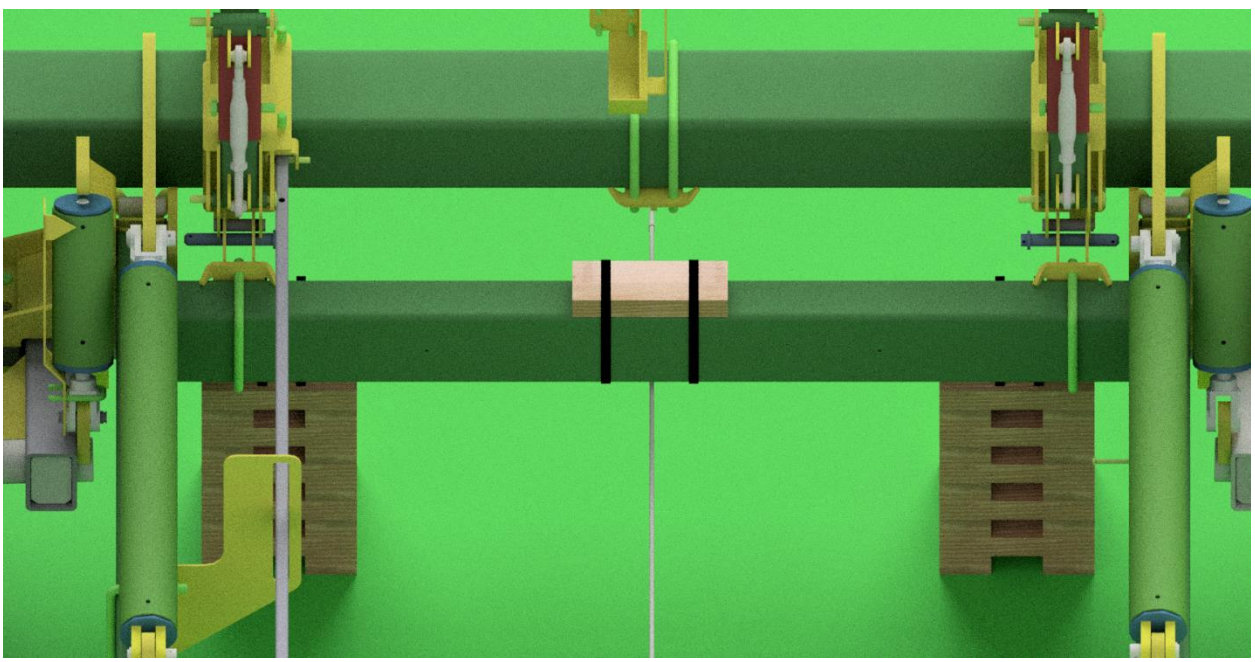

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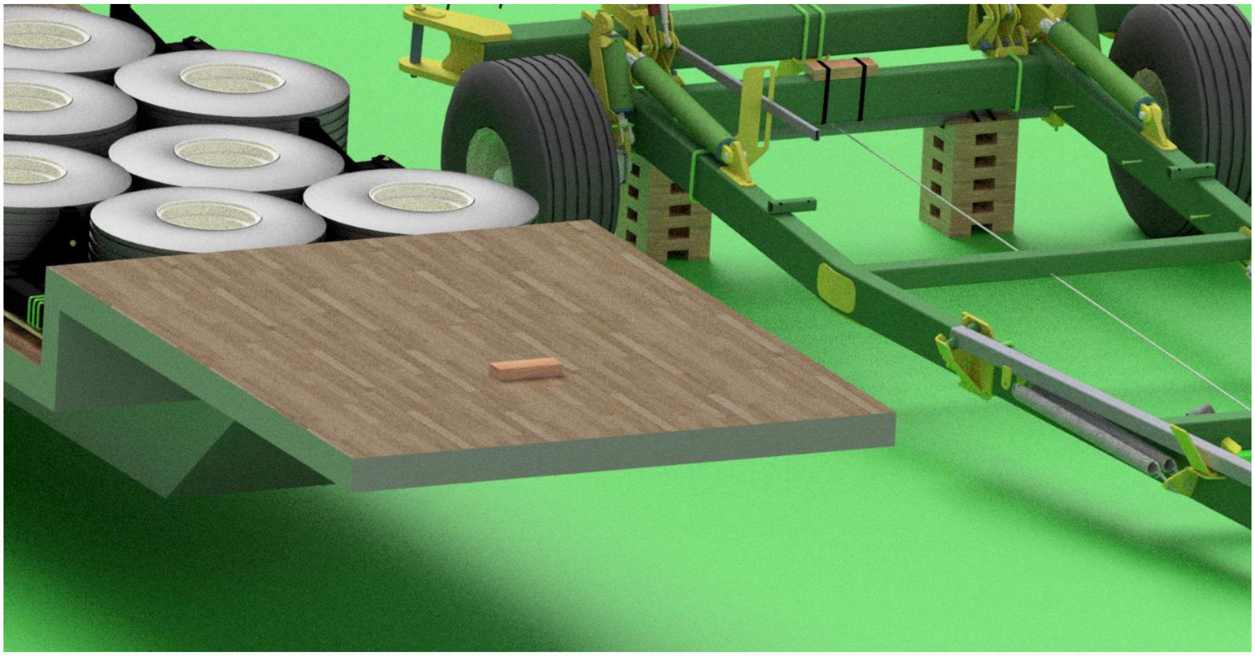

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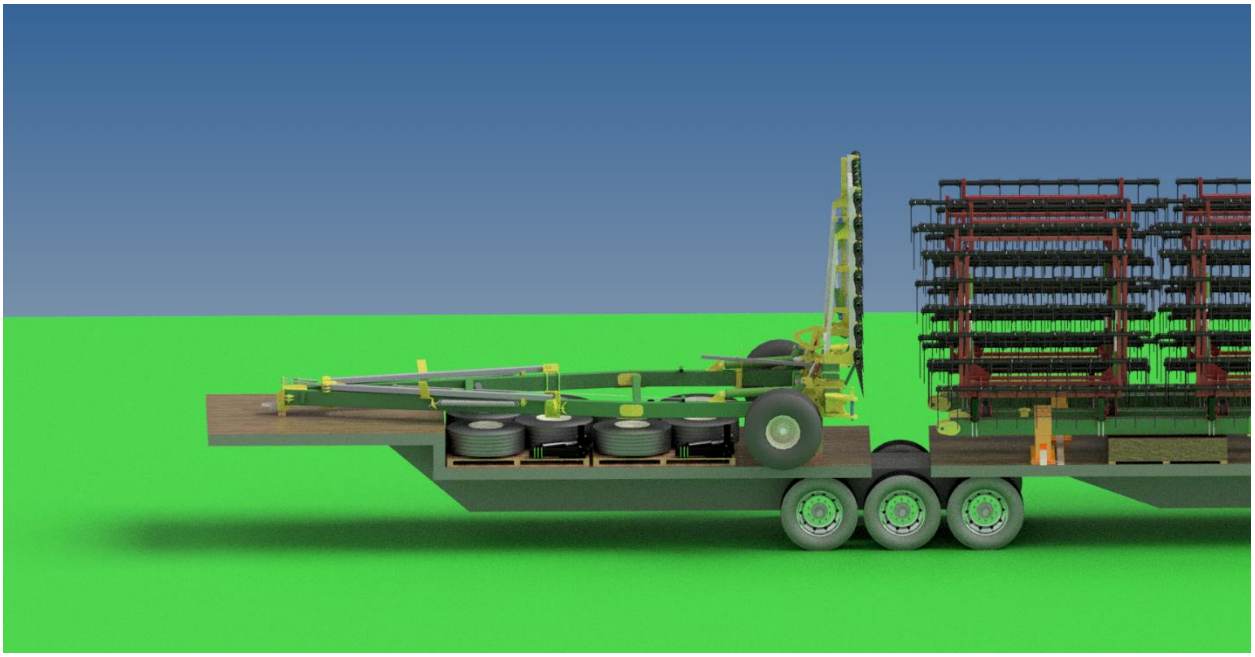

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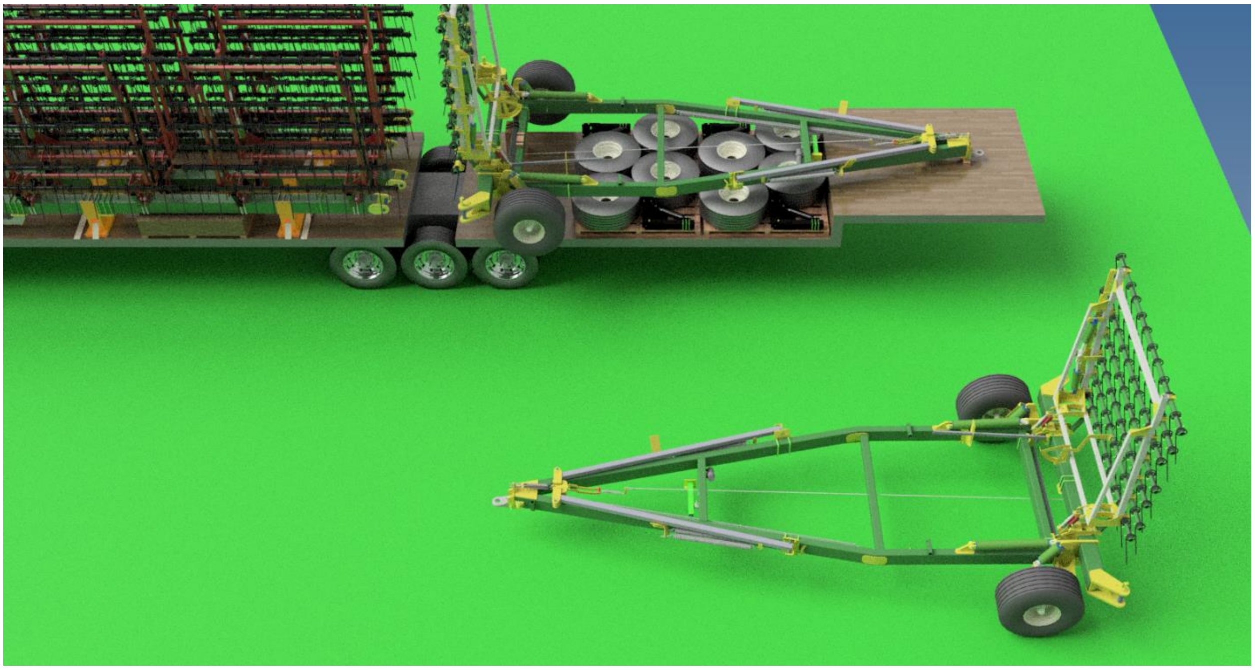

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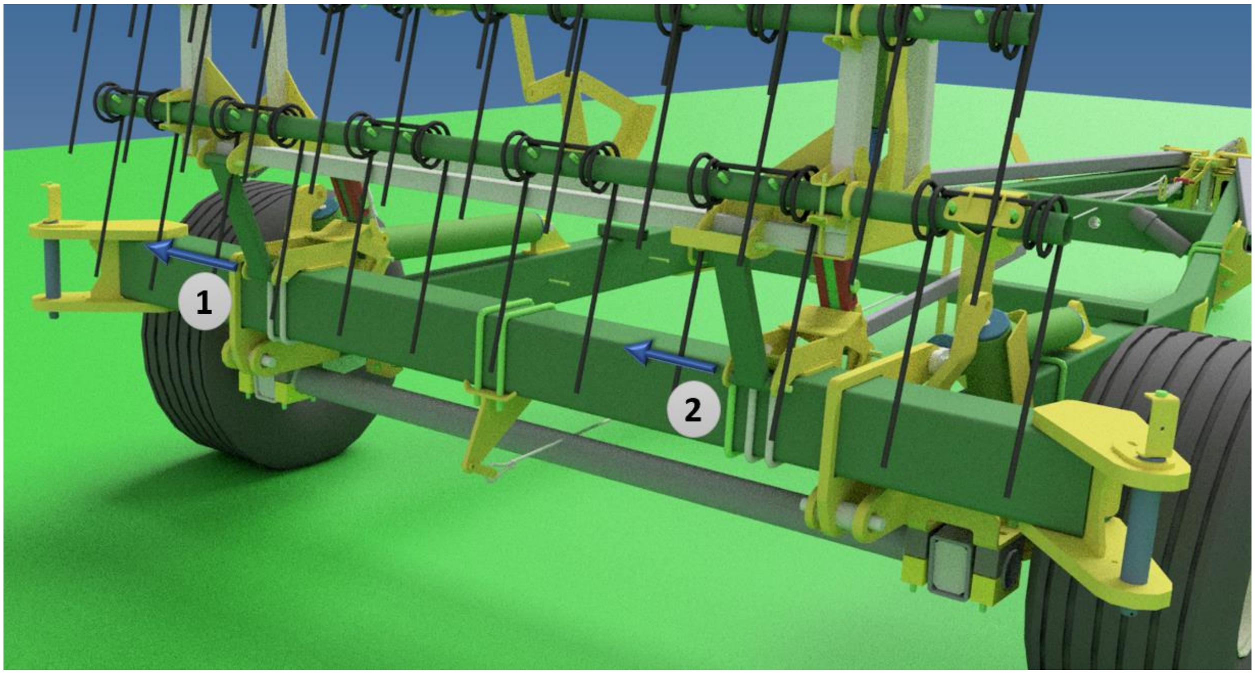

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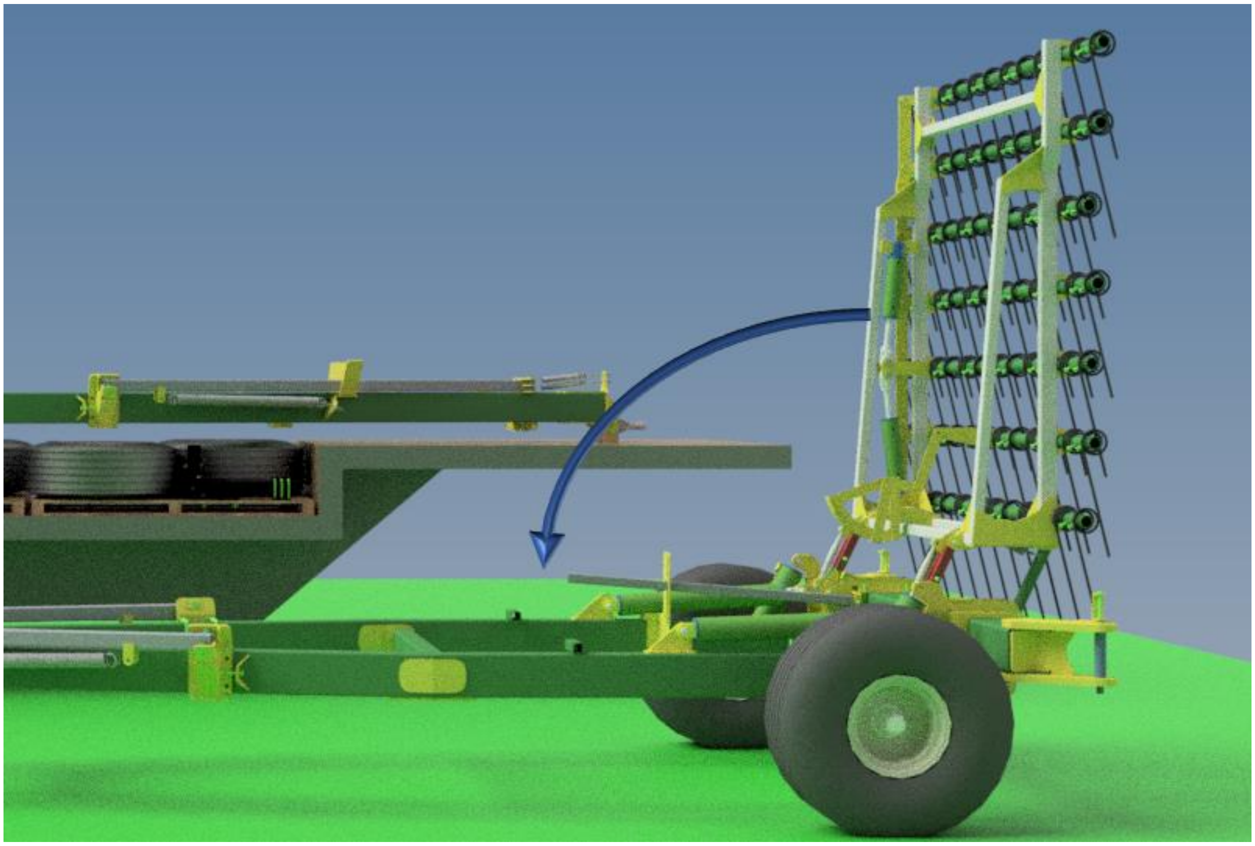

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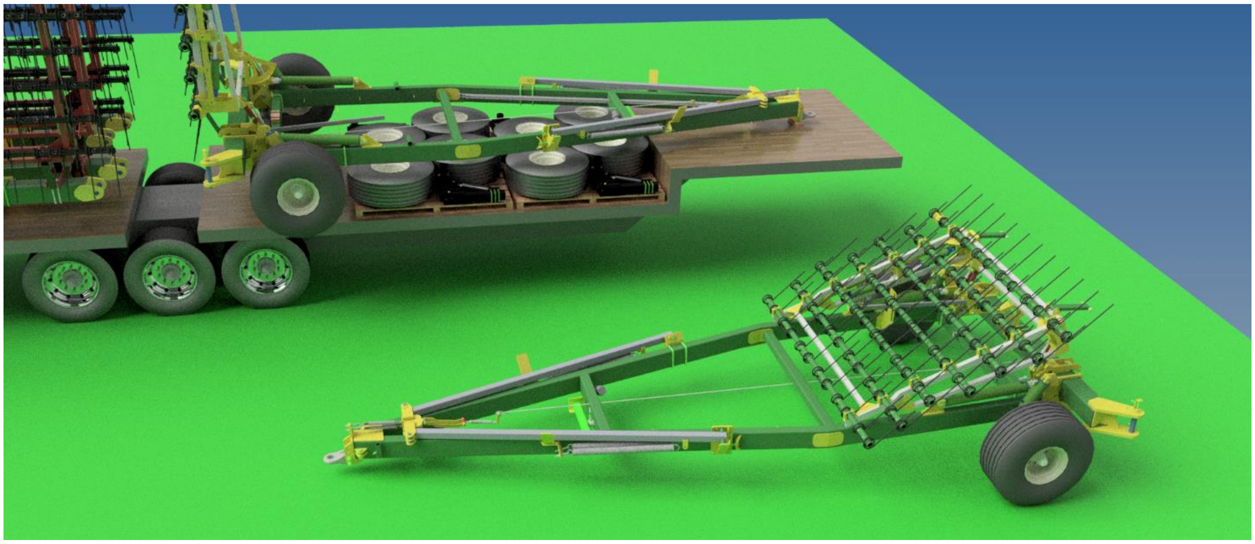

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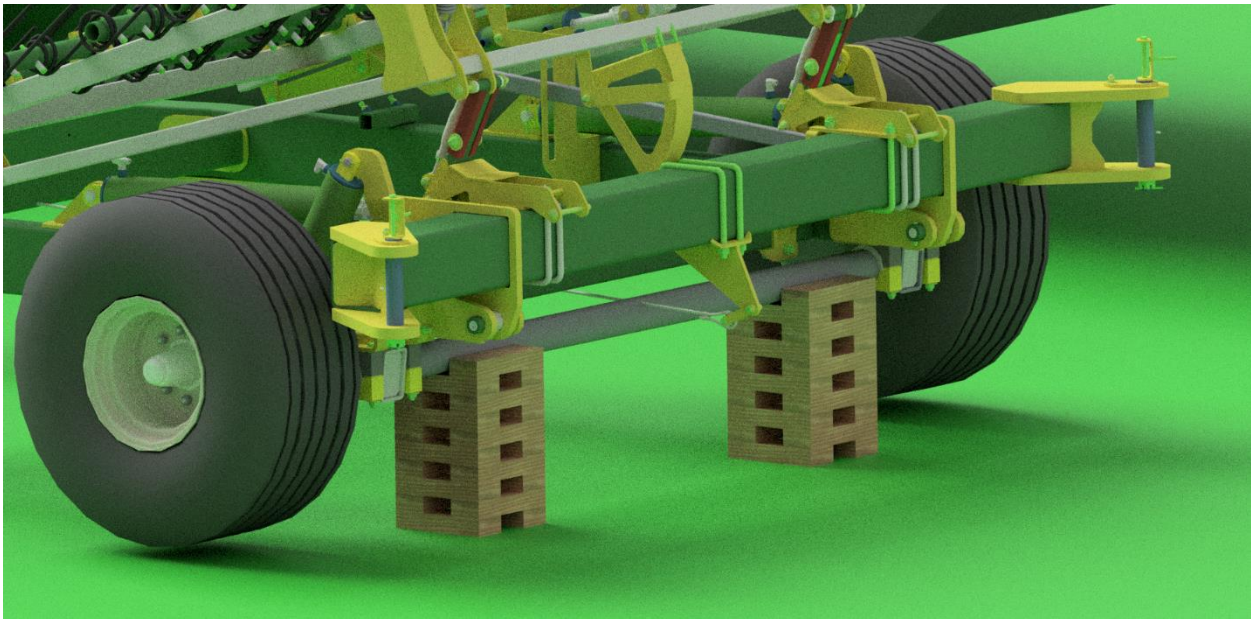

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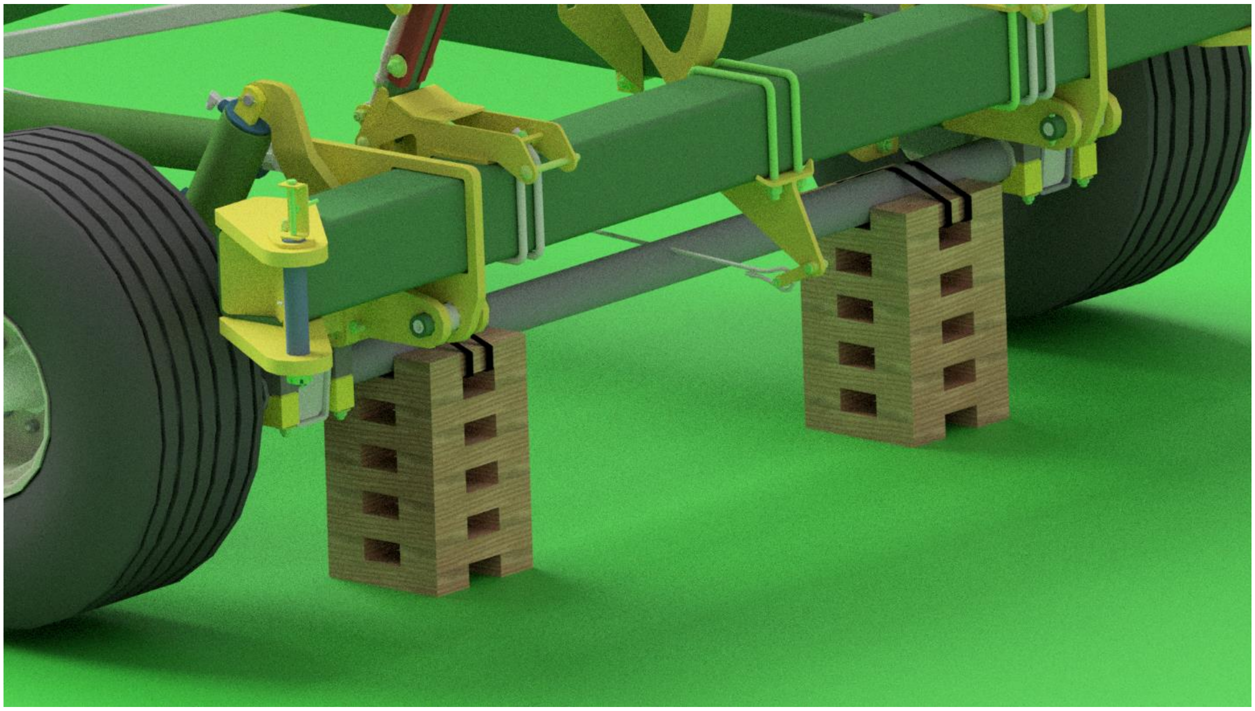

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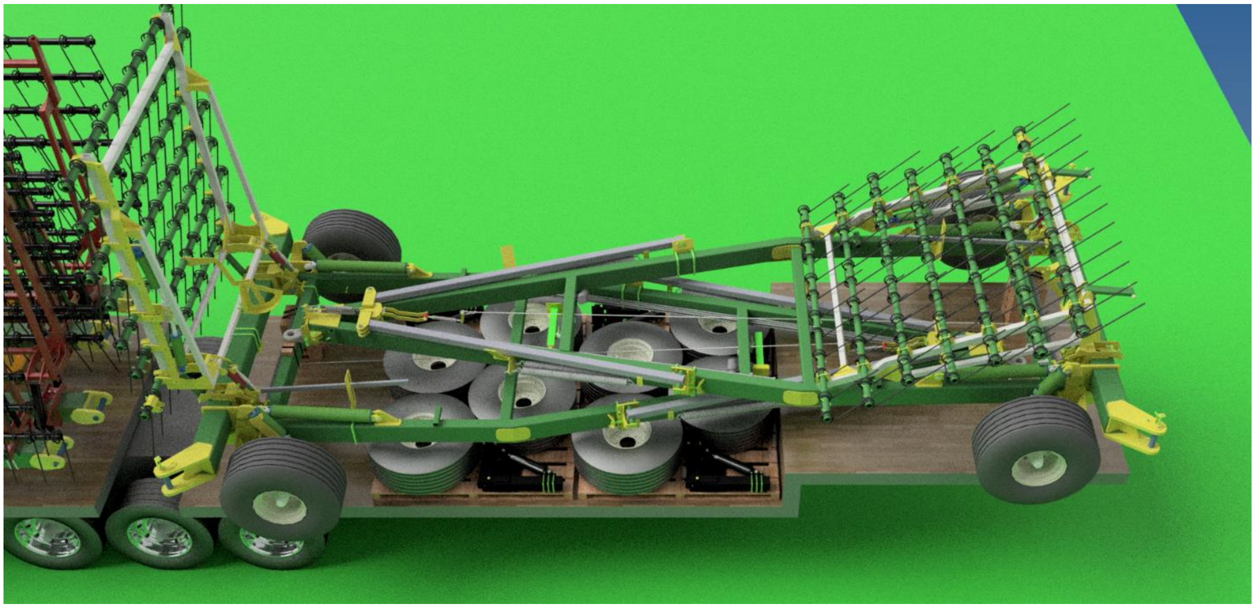
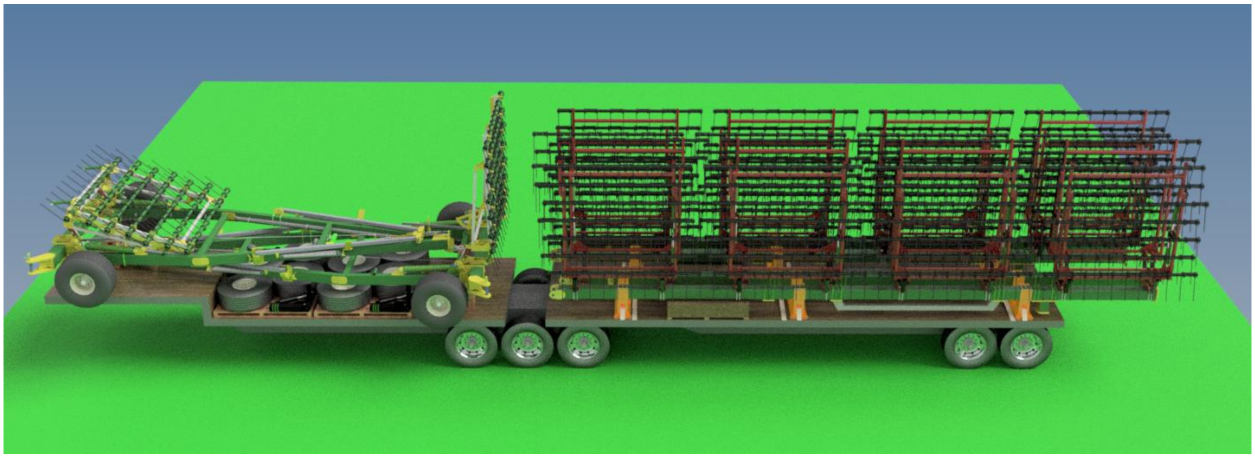


FINAL LOADING LAYOUT



**REMINDER:**

**ADD ADDITIONAL STRAPS/CHAINS AS NECESSARY FOR SECUREMENT**

# APPENDIX C

## Cost Analysis Additional Information

The shipping information used for the Cost Analysis was provided my Elmer's Manufacturing, the flat towing rates are contained in the Table I.

TABLE I: FLAT TOWING RATES

| Flat Towing Rate Quotes (Oct. 2014) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Prov.** | **City/Town** | **kms** | **Quote** | **$/km** | **Prov.** | **City/Town** | **Distance (km** | **Quote** | **$/km** | **State** | **City/Town** | **kms** | **Quote** | **$/km** |
| **MB** | Steinbach | 110 | $400.00 | $3.64 | **AB** | Lloydminster | 1130 | $3,500.00 | $3.10 | **ND** | Grand Forks | 160 | $625.00 | $3.91 |
| | Elie | 105 | $450.00 | $4.29 | | High River | 1350 | $4,325.00 | $3.20 | | Minot | 385 | $1,325.00 | $3.44 |
| | Carroll | 240 | $780.00 | $3.25 | | Wetaskiwin | 1335 | $4,500.00 | $3.37 | | Leeds | 235 | $1,130.00 | $4.81 |
| | Portage | 150 | $500.00 | $3.33 | | Edmonton | 1365 | $4,270.00 | $3.13 | | Rugby | 310 | $1,000.00 | $3.23 |
| | Neepawa | 250 | $770.00 | $3.08 | | Fairview | 1905 | $6,050.00 | $3.18 | | Fargo | 285 | $1,000.00 | $3.51 |
| | Dauphin | 375 | $1,155.00 | $3.08 | | Fahler | 1785 | $5,650.00 | $3.17 | | Langdon | 105 | $625.00 | $5.95 |
| **SK** | Tisdale | 760 | $2,400.00 | $3.16 | | Beaverlodge | 1855 | $5,850.00 | $3.15 | | Devils Lake | 250 | $1,045.00 | $4.18 |
| | Regina | 600 | $2,800.00 | $4.67 | | Claresholm | 1300 | $4,180.00 | $3.22 | | Grafton | 120 | $500.00 | $4.17 |
| | Saskatoon | 840 | $2,625.00 | $3.13 | | Lethbridge | 1275 | $3,925.00 | $3.08 | | Williston | | | |
| | Yorkton | 515 | $1,600.00 | $3.11 | | Trochu | 1300 | $4,425.00 | $3.40 | | | | | |
| | Elrose | 935 | $3,075.00 | $3.29 | | Red Deer | 1375 | $4,750.00 | $3.45 | | | | | |
| | Meadow Lake | 1135 | $3,575.00 | $3.15 | | Vulcan | 1290 | $4,150.00 | $3.22 | | | | | |
| | Humboldt | 750 | $2,385.00 | $3.18 | | Grande Prairie | 1815 | $5,720.00 | $3.15 | | | | | |
| | Swift Current | 840 | $2,750.00 | $3.27 | | Ponoka | 1400 | $4,600.00 | $3.29 | | | | | |
| | Davidson | 745 | $2,450.00 | $3.29 | | Grimshaw | 1870 | $5,890.00 | $3.15 | | | | | |
| | North Battleford | 975 | $3,075.00 | $3.15 | | Taber | 1180 | $3,775.00 | $3.20 | | | | | |
| | Kindersley | 990 | $3,250.00 | $3.28 | | | | | | | | | | |
| | Wadena | 650 | $2,050.00 | $3.15 | | | | | | | | | | |

The flat deck towing rates from Searcy (provided by Elmer's) and the comparison to the flat towing rates can be found in Table II on the following page.

## TABLE II: SEARCY SHIPPING RATES

| Searcy Towing Rate Comparison | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Flat Tow | | Flat Deck Quote | | Flat Deck Difference | | Flat Tow? |
| Province | City/Town | Freq. (/year) | Distance (km) | Quote | Rate ($/km) | Quote | Rate ($/km) | Quote | Rate ($/km) | |
| MB | Steinbach | | 110 | $400.00 | $3.64 | $1,500.00 | $13.64 | -$1,100.00 | $10.00 | YES |
| | Winnipeg | | 112 | $425.00 | $3.79 | $1,500.00 | $13.39 | -$1,075.00 | $9.60 | YES |
| | Elie | | 105 | $450.00 | $4.29 | $1,500.00 | $14.29 | -$1,050.00 | $10.00 | YES |
| | Carroll | | 240 | $780.00 | $3.25 | $1,500.00 | $6.25 | -$720.00 | $3.00 | YES |
| | Portage | | 150 | $500.00 | $3.33 | $1,500.00 | $10.00 | -$1,000.00 | $6.67 | YES |
| | Neepawa | | 250 | $770.00 | $3.08 | $1,500.00 | $6.00 | -$730.00 | $2.92 | YES |
| | Dauphin | | 375 | $1,155.00 | $3.08 | $1,500.00 | $4.00 | -$345.00 | $0.92 | YES |
| SK | Tisdale | | 760 | $2,400.00 | $3.16 | $2,240.00 | $2.95 | $160.00 | -$0.21 | NO |
| | Regina | | 600 | $2,800.00 | $4.67 | $1,802.00 | $3.00 | $998.00 | -$1.66 | NO |
| | Saskatoon | | 840 | $2,625.00 | $3.13 | $2,350.00 | $2.80 | $275.00 | -$0.33 | NO |
| | Yorkton | | 515 | $1,600.00 | $3.11 | $1,950.00 | $3.79 | -$350.00 | $0.68 | YES |
| | Elrose | | 935 | $3,075.00 | $3.29 | | $0.00 | $3,075.00 | -$3.29 | NO |
| | Meadow Lake | | 1135 | $3,575.00 | $3.15 | | $0.00 | $3,575.00 | -$3.15 | NO |
| | Humboldt | | 750 | $2,385.00 | $3.18 | $2,422.00 | $3.23 | -$37.00 | $0.05 | YES |
| | Swift Current | | 840 | $2,750.00 | $3.27 | $2,560.00 | $3.05 | $190.00 | -$0.23 | NO |
| | Davidson | | 745 | $2,450.00 | $3.29 | $2,450.00 | $3.29 | $0.00 | $0.00 | NO |
| | North Battleford | | 975 | $3,075.00 | $3.15 | $2,720.00 | $2.79 | $355.00 | -$0.36 | NO |
| | Kindersley | | 990 | $3,250.00 | $3.28 | $2,700.00 | $2.73 | $550.00 | -$0.56 | NO |
| | Wadena | | 650 | $2,050.00 | $3.15 | $2,250.00 | $3.46 | -$200.00 | $0.31 | YES |
| AB | Lloydminster | | 1130 | $3,500.00 | $3.10 | $3,085.00 | $2.73 | $415.00 | -$0.37 | NO |
| | High River | | 1350 | $4,325.00 | $3.20 | | $0.00 | $4,325.00 | -$3.20 | NO |
| | Wetaskiwin | | 1335 | $4,500.00 | $3.37 | | $0.00 | $4,500.00 | -$3.37 | NO |
| | Edmonton | | 1365 | $4,270.00 | $3.13 | | $0.00 | $4,270.00 | -$3.13 | NO |
| | Fairview | | 1905 | $6,050.00 | $3.18 | | $0.00 | $6,050.00 | -$3.18 | NO |
| | Fahler | | 1785 | $5,650.00 | $3.17 | | $0.00 | $5,650.00 | -$3.17 | NO |
| | Beaverlodge | | 1855 | $5,850.00 | $3.15 | $4,500.00 | $2.43 | $1,350.00 | -$0.73 | NO |
| | Claresholm | | 1300 | $4,180.00 | $3.22 | | $0.00 | $4,180.00 | -$3.22 | NO |
| | Lethbridge | | 1275 | $3,925.00 | $3.08 | | $0.00 | $3,925.00 | -$3.08 | NO |
| | Trochu | | 1300 | $4,425.00 | $3.40 | $3,375.00 | $2.60 | $1,050.00 | -$0.81 | NO |
| | Red Deer | | 1375 | $4,750.00 | $3.45 | | $0.00 | $4,750.00 | -$3.45 | NO |
| | Vulcan | | 1290 | $4,150.00 | $3.22 | $3,230.00 | $2.50 | $920.00 | -$0.71 | NO |
| | Grande Prairie | | 1815 | $5,720.00 | $3.15 | | $0.00 | $5,720.00 | -$3.15 | NO |
| | Ponoka | | 1400 | $4,600.00 | $3.29 | $3,605.00 | $2.58 | $995.00 | -$0.71 | NO |
| | Grimshaw | | 1870 | $5,890.00 | $3.15 | | $0.00 | $5,890.00 | -$3.15 | NO |
| | Taber | | 1180 | $3,775.00 | $3.20 | $2,975.00 | $2.52 | $800.00 | -$0.68 | NO |
| ND | Grand Forks | | 160 | $625.00 | $3.91 | $1,500.00 | $9.38 | -$875.00 | $5.47 | YES |
| | Minot | | 385 | $1,325.00 | $3.44 | $1,500.00 | $3.90 | -$175.00 | $0.45 | YES |
| | Leeds | | 235 | $1,130.00 | $4.81 | $1,500.00 | $6.38 | -$370.00 | $1.57 | YES |
| | Rugby | | 310 | $1,000.00 | $3.23 | $1,500.00 | $4.84 | -$500.00 | $1.61 | YES |
| | Fargo | | 285 | $1,000.00 | $3.51 | $1,500.00 | $5.26 | -$500.00 | $1.75 | YES |
| | Langdon | | 105 | $625.00 | $5.95 | $1,500.00 | $14.29 | -$875.00 | $8.33 | YES |
| | Devils Lake | | 250 | $1,045.00 | $4.18 | $1,500.00 | $6.00 | -$455.00 | $1.82 | YES |
| | Grafton | | 120 | $500.00 | $4.17 | $1,500.00 | $12.50 | -$1,000.00 | $8.33 | YES |
| | Williston | | 575 | $1,955.00 | $3.40 | $2,245.00 | $3.90 | -$290.00 | $0.50 | YES |
| | | | | Avg: | $3.46 | Avg: | $4.10 | Avg: | $0.64 | |

# APPENDIX D

## Additional Information for Designed Parts

The following pages detail the technical drawings provided for the designed bracket parts. The drawings were developed in accordance with the ASME Y14.5-2009 Standard. Furthermore it is important to note the drawings were created by students and should be revised by an experienced engineer prior to manufacturing and use. Additionally the drawings were created as B size, and were scaled for the inclusion in this report. Also provided are Tables III and IV, which detail the part numbers (the same as the file name) and descriptions of the part. The part numbers scheme was developed where the first digit refers to the project, the following two digits refer to an assembly within that project and the final three digits identify the part or sub-assembly.

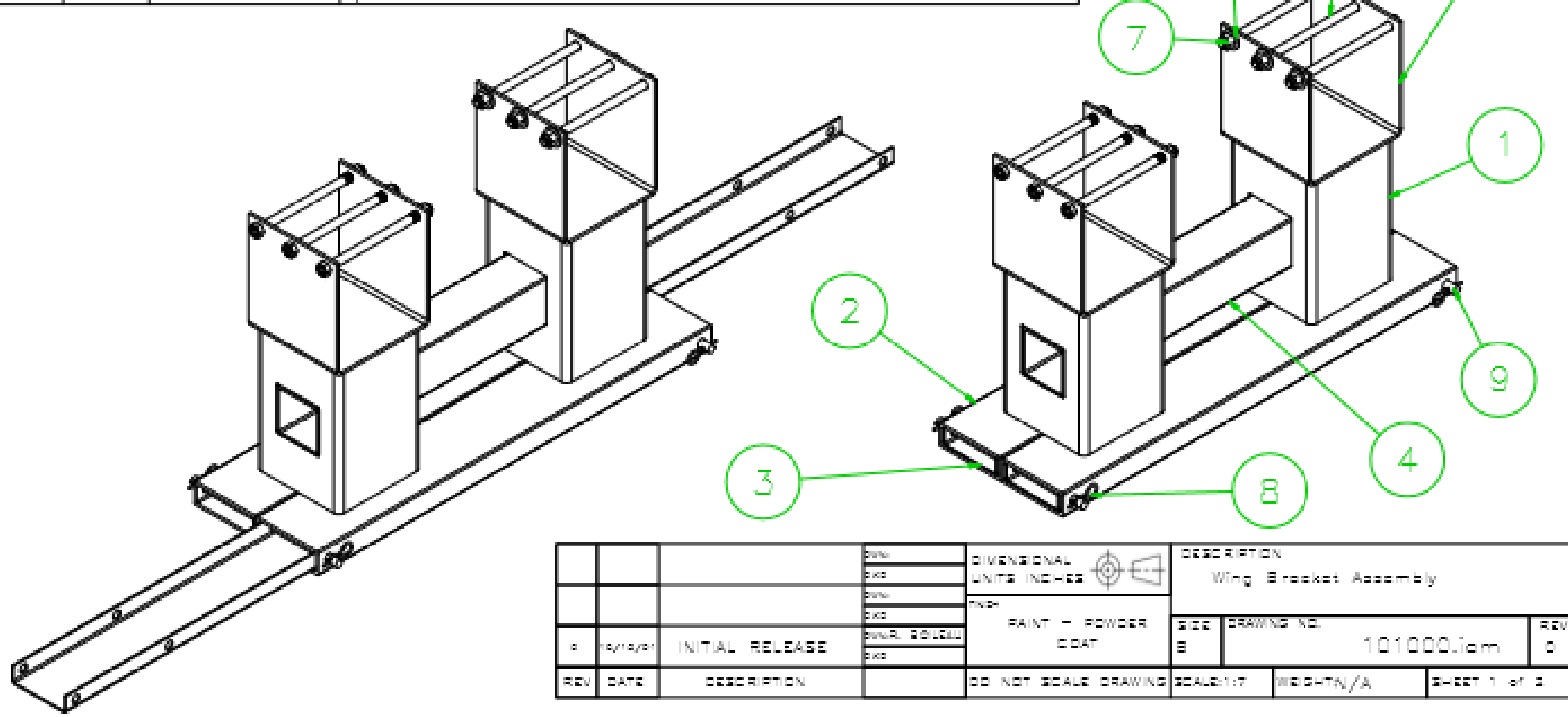
TABLE III: METAL BRACKET PARTS

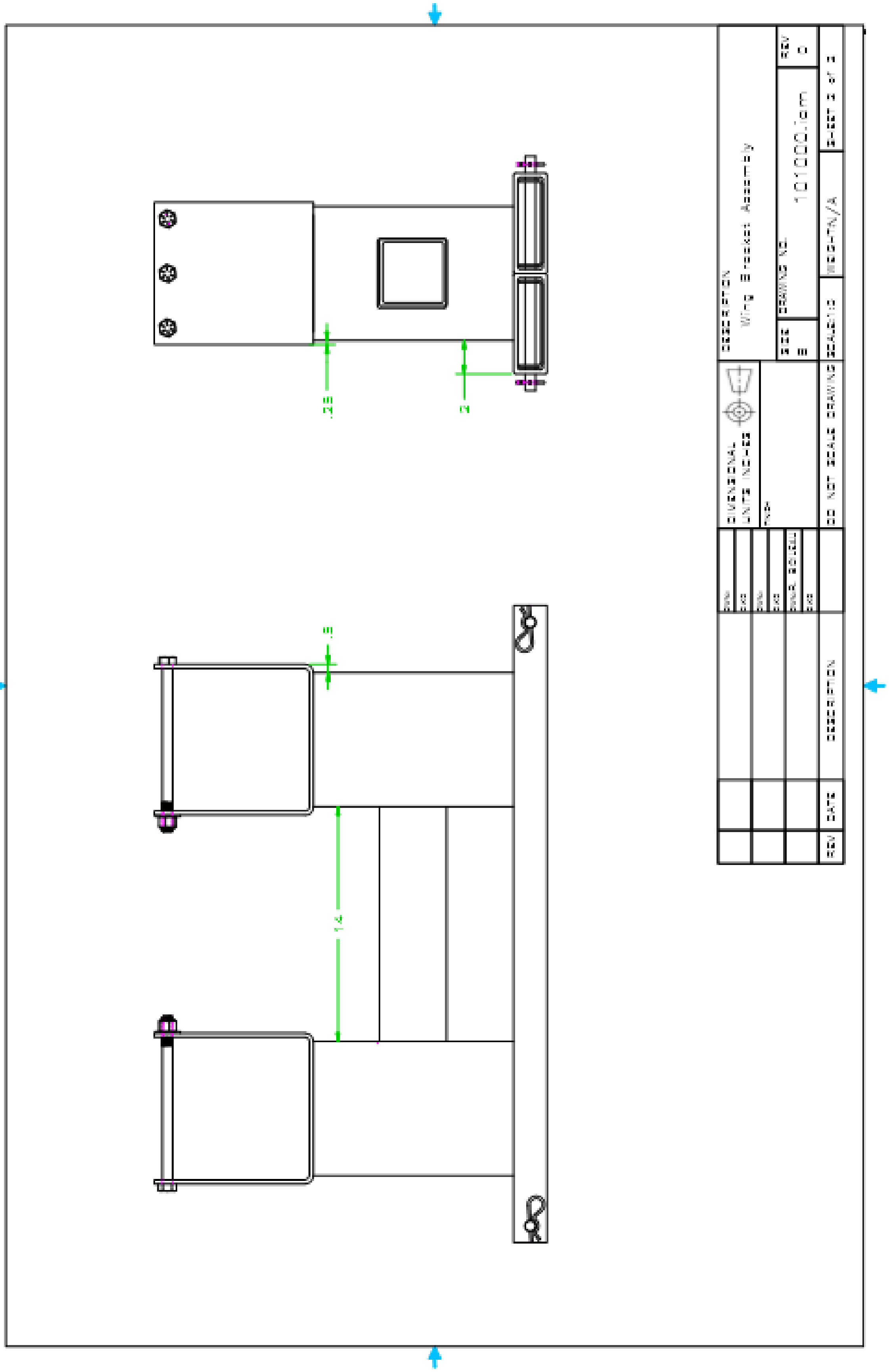
| PN | Description | Quantity |
|---|---|---|
| 101000 | Metal Bracket Assembly | |
| 101001 | Square Tube; 8X8X1/4, Length: 11.95" | 2 |
| 101002 | Rectangular Tube; 2X6X1/4, Length: 48" | 2 |
| 101003 | Formed C Channel 5 3/8 X 1 7/16 X 38" | 2 |
| 101005 | Square Tube; 4X4X1/4, Length: 34" | 1 |
| 101006 | Plate; 18X7.5X1/4 | 2 |
| 101007 | 5/8-11 X 10 Hex Head Bolt | 6 |
| 101008 | 5/8-11 NyLock Nut | 6 |
| 101009 | 5/8 Flat Washer | 6 |
| 101010 | 5/8X14 Steel Pin | 2 |
| 101011 | Cotter Pin | 4 |

TABLE IV: WOOD BRACKET, PART BOX AND PALLET PARTS

| PN | Description | Quantity |
|---|---|---|
| 102000 | 18" Stack | |
| 102001 | Rough 2X4X12" | 20 |
| 103000 | Part Box Empty | |
| 103001 | Part Box w/Parts | |
| 103002 | Part Box Body (Plywood Construction) | 1 |
| 103003 | Part Box Lid (60X48X1/2) | 1 |
| 103004 | Part Box Support (2X4X8.5") | 4 |
| 103005 | Part Box Legs (2X4X48") | 3 |
| 104000 | Pallet (72X96") | |
| 104001 | Pallet w/ Parts | |

| Parts List | | | |
|---|---|---|---|
| ITEM | QTY | PART NUMBER | DESCRIPTION |
| 1 | 2 | 101004 | 8X8X1/4" SQUARE TUBE W/ CUTOUT |
| 2 | 2 | 101002 | 2X8X1/4" RECTANGULAR TUBE W/ PIN HOLES |
| 3 | 2 | 101001 | C-CHANNEL EXTENDABLE LEG W/ PIN HOLES |
| 4 | 1 | 101003 | 4X4X1/4" SQAURE TUBING |
| 5 | 2 | 101006 | WING CRADLE |
| 6 | 8 | 101009 | 5/8" FLAT WASHER |
| 7 | 8 | 101008 | 5/8" NYLOCK NUT |
| 8 | 4 | 101011 | REUSABLE COTTER PIN (5/8" ROD) |
| 9 | 2 | 101010 | 5/8" ROD WITH COTTERPIN HOLES |
| 10 | 8 | 101007 | 5/8-11X10" HEX HEAD BOLT |

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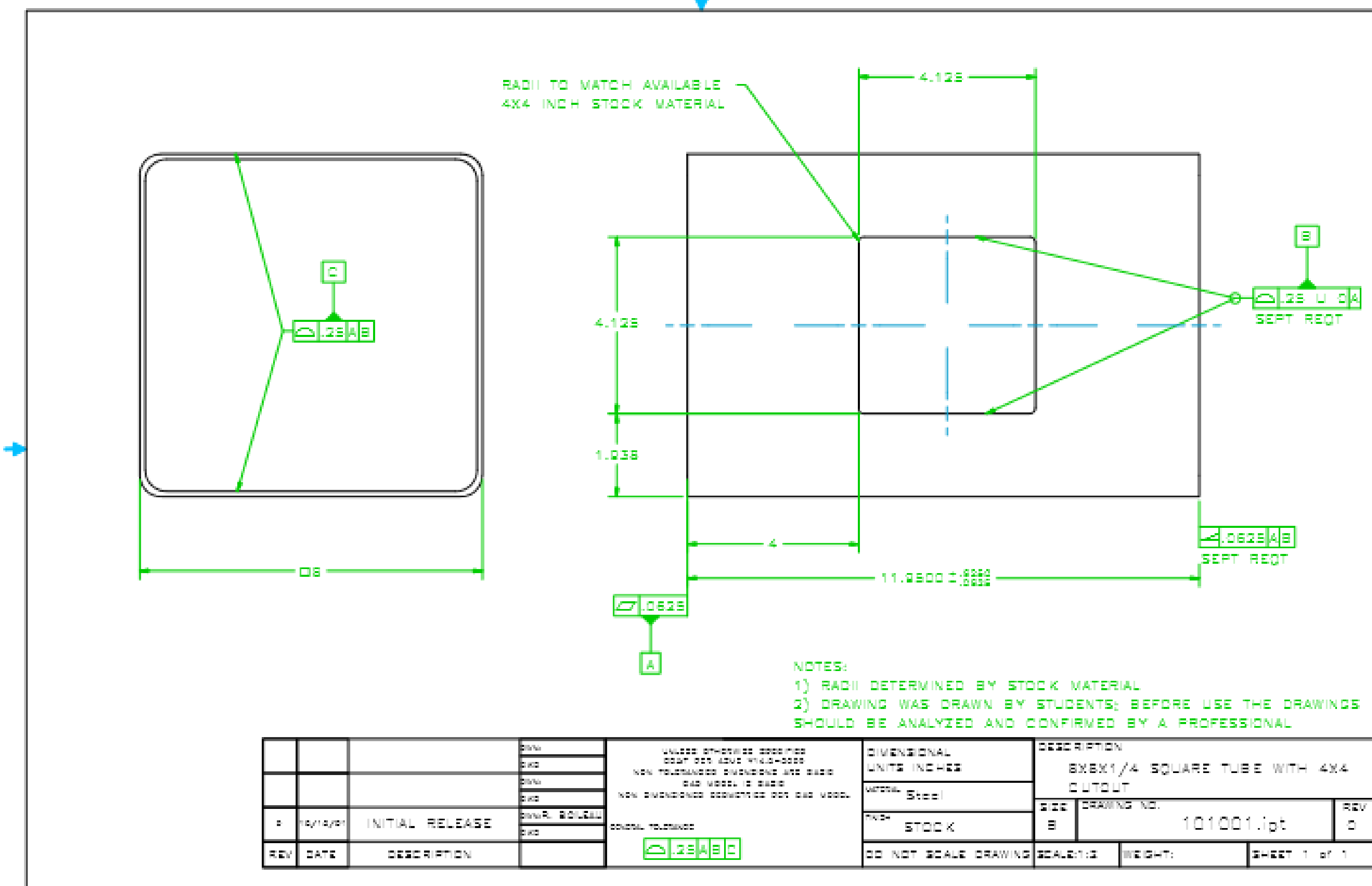
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1) RADII DETERMINED BY STOCK MATERIAL
2) DRAWING WAS DRAWN BY STUDENTS; BEFORE USE THE DRAWINGS
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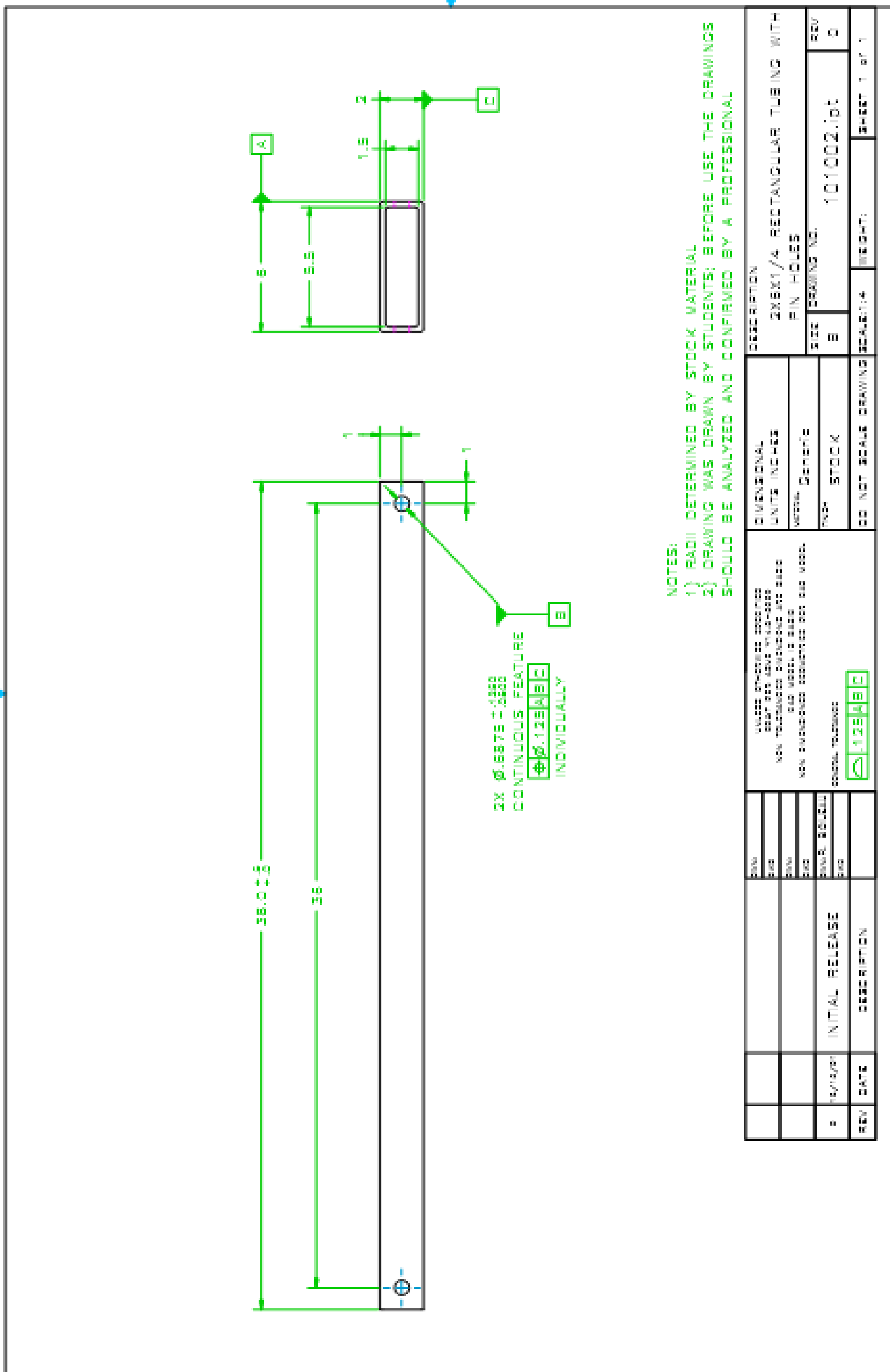

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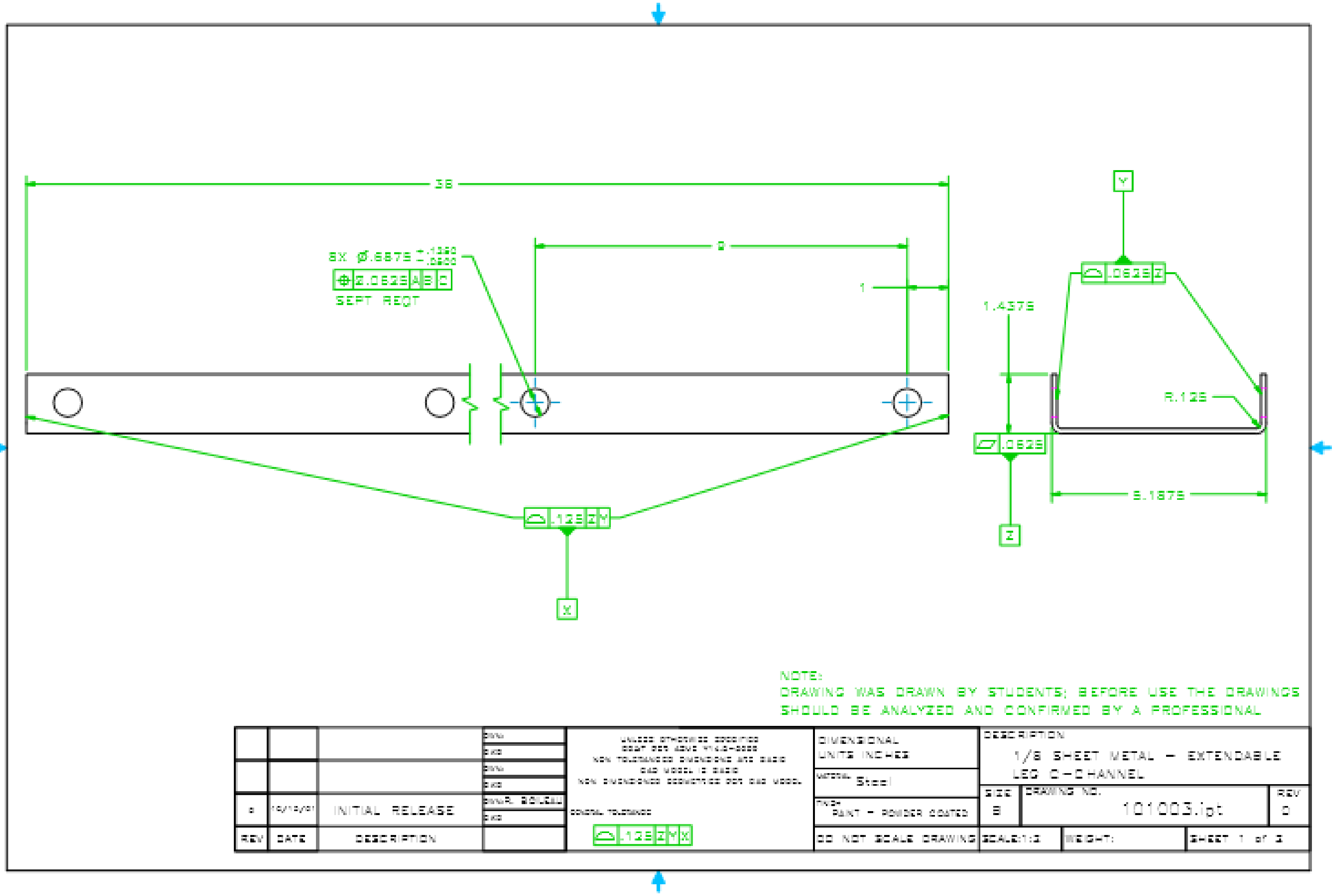

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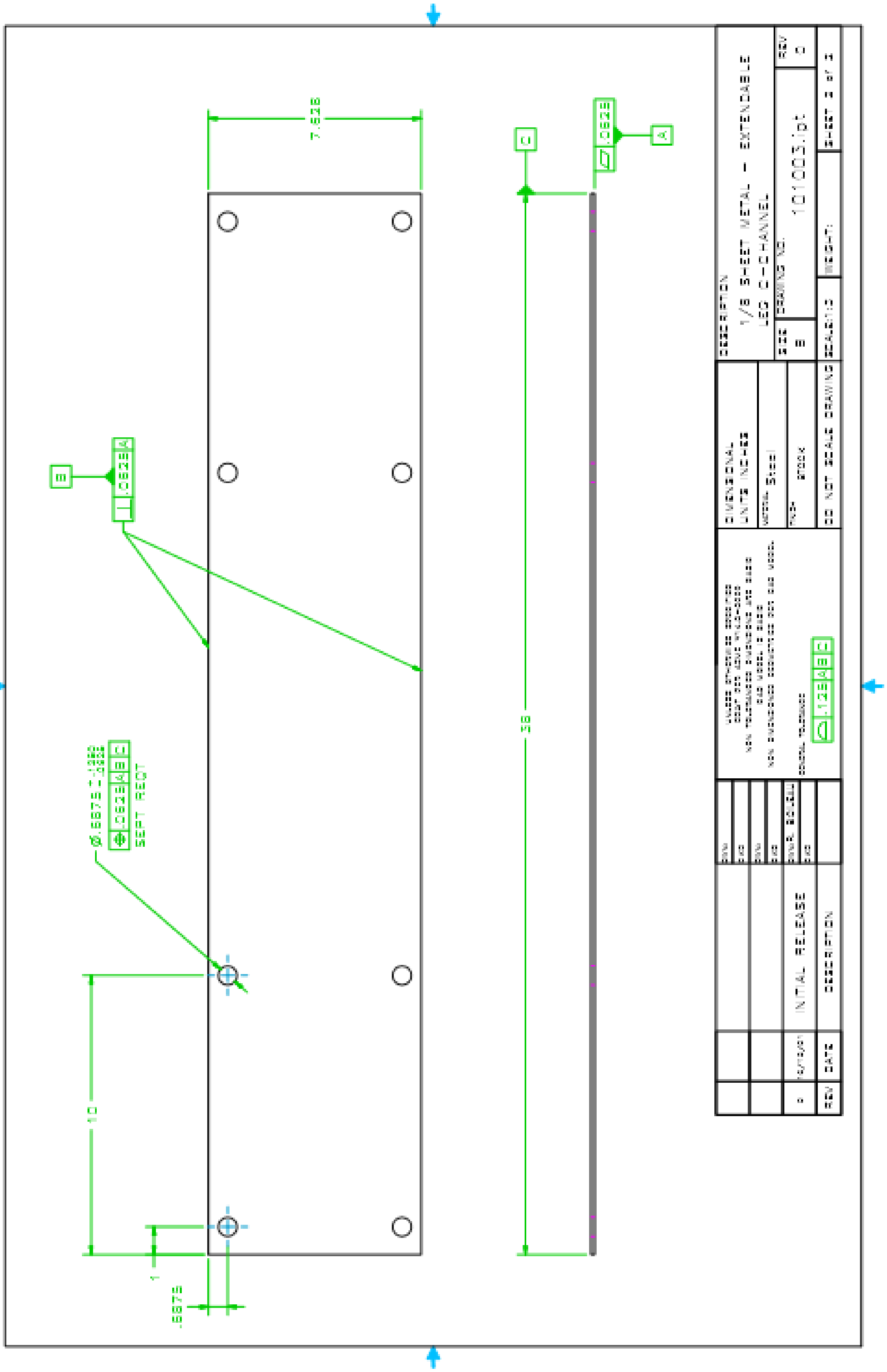

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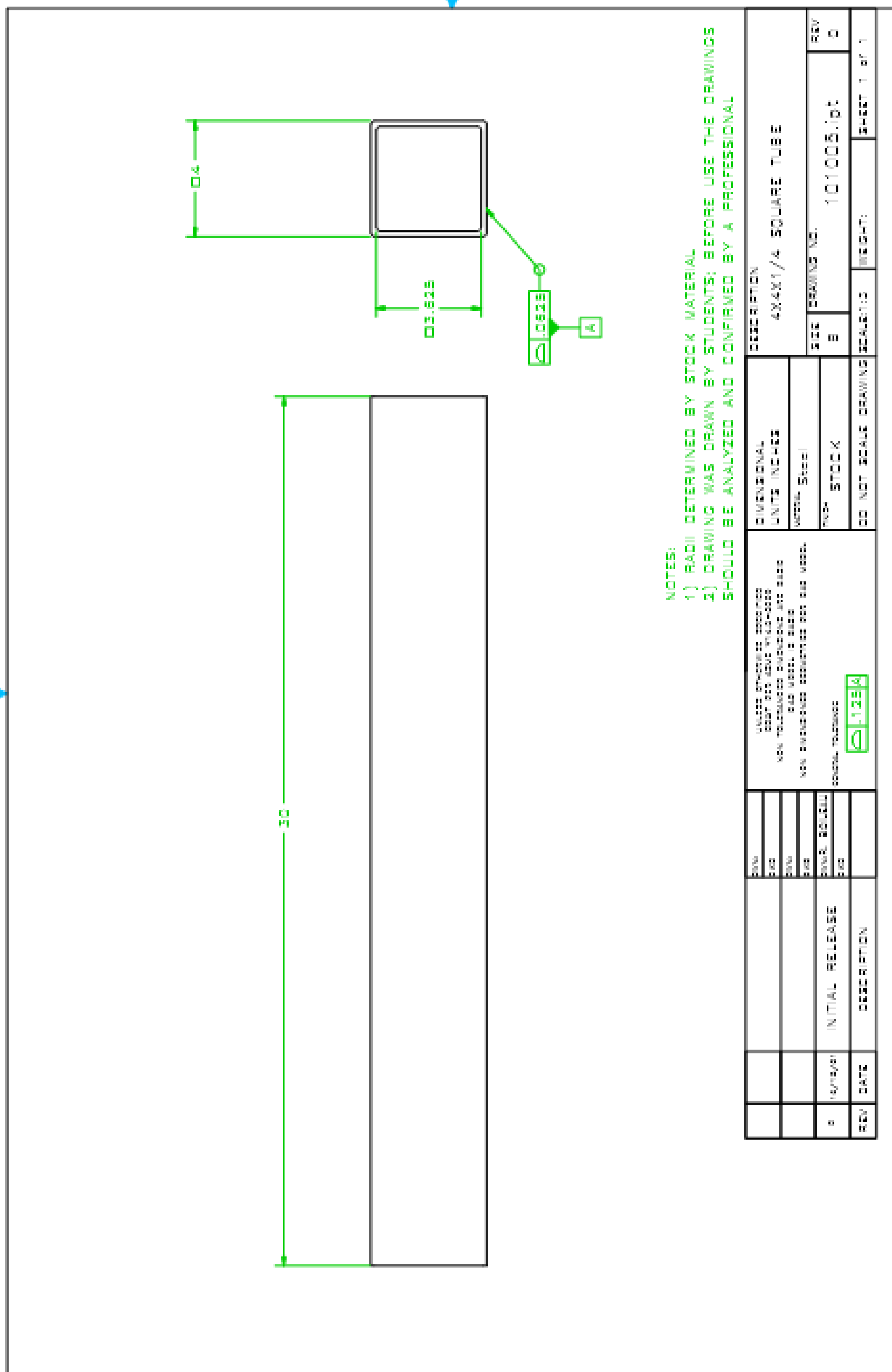
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Steel
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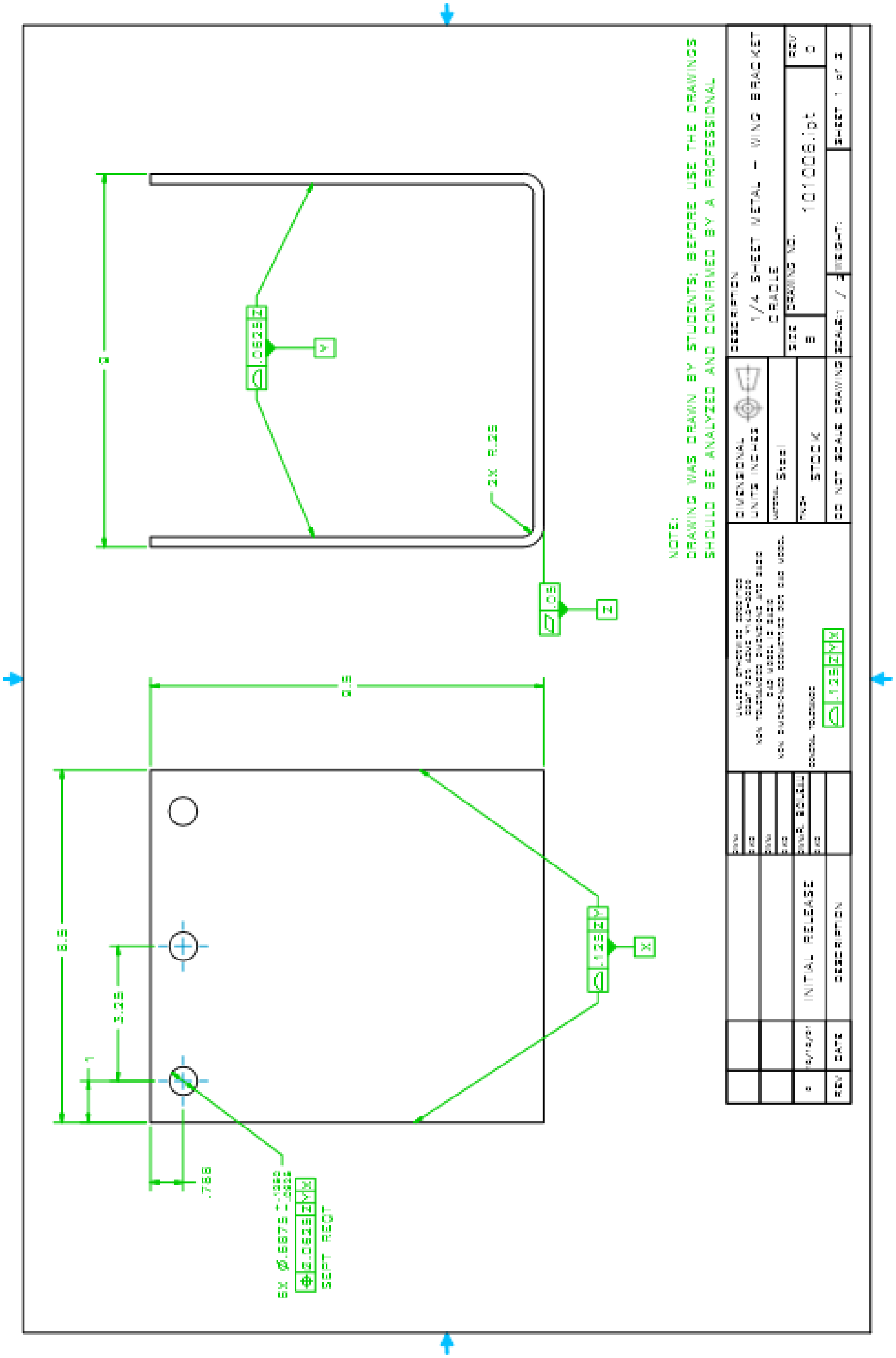
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