UNIVERSITY OF MANITOBA

Design of Windrower Transport Stand for MacDon Industries

PHASE III DETAILED DESIGN REPORT

Sponsoring Company: MacDon Industries Ltd.

Professor: Dr. Paul E. Labossiere
Advisor: Dr. Juan Abello

Date: [7-Dec-2015]

Team 12 MaxDesign

Adam Friesen

George Odwar

Yi Wang

Lu Mi

Executive Summary

MacDon Industries, a Manitoban manufacturer of agricultural harvesting equipment, has identified that the current assembly and shipping process for their windrower tractors could be improved. The following report outlines our work with MacDon to develop and design a stand that can support the current windrower models. The stand will allow the tractor to be manufactured and transported without the drive wheels and casters installed, saving time and improving their operations.

The customers identified three key needs for the final design. It needed to improve the operational efficiency, be safe to use and meet a number of functional requirements. The team then developed conceptual designs which could best meet all of the customer's needs. With the consultation of the customers, two final concepts were selected and developed. A final design was then chosen that provided the best overall performance for 5000 tractors over a 5 year design period.

The final design consists of a disposable tractor stand, a set of reusable caster wheels and a reusable forklift attachment. The stand was designed to support 6000 kg with a minimum safety factor of 1.37. It weighs 44.9 kg and has an expected cost of $68.12 each. Three forklift attachments and four sets of caster assemblies will be used in combination with the stands, each weighing 322 kg and 19 kg respectively. These reusable designs will add an additional $0.60 to the stand cost when used for the 5 year period. The total cost of the design is $68.72 per tractor which is less than the $100 budget.

If the proposed design gets implemented, the tractors will not require the wheels to be installed with the tractor on the assembly line. It reduces the time required to load the tractors for shipping and will make the tire inventory easier to track and manage. The design improves the safety of the loading process with the use of the forklift attachment and the caster assemblies allow the tractor to be moved easily without a forklift. Having met these needs and staying within the budget, this design will improve MacDon's overall assembly and shipping processes.

Table of Contents

Lists of Figures

Lists of Tables

1. Introduction

MacDon Industries is a Winnipeg based company that specializes in the design and manufacturing of agricultural harvesting equipment. Founded in 1949, the company's range of products includes rotary disk, auger, draper and pickup type headers and self-propelled windrowers. These products are produced to provide high quality and high performance machines to the customers, whose input directly contributes to improving the designs.

Windrowers are specialized tractors which are used along with headers to cut down some crops before they are harvested. There are currently four windrower models that MacDon sells which differ in engine horsepower and emission control systems [1]. These windrowers are all based on the same basic frame design, but each model has its own unique features, including options chosen by the customer. The windrower models can have different masses accordingly, ranging from 4000 kg for the M105 model to 4559 kg for the M155 E4 model. Figure 1 shows a M155 E4 model being used for harvesting.

Figure 1: The MacDon M155 E4 SP windrower with header. Used with permission [2].

MacDon has set company objectives which help them to meet the high quality standards they strive to deliver. These objectives are summarized in Table I. The desire to meet these objectives has led to the investigation of current operational procedures to determine whether improvements can be made to increase efficiency and reduce costs.

TABLE I MACDON'S QUALITY OBJECTIVES [3].

"To be a customer focused organization through listening to our customers and translating their needs into market-leading products that exceed their expectations"
"To continually improve our operations, systems and products"
"To be prudently cost aware and cost effective in all aspects of our organization in order to provide a strong value proposition for ourselves, our dealers and our customers"
"To maintain a safe, fair, respectful and creative work environment that promotes innovation"
"To develop and sustain a world-class distribution network that delivers professional, reliable and timely products and services"

An area of operation where MacDon has recognized the opportunity for improvement involves the production and shipping of MacDon's self-propelled windrowers. Currently, the windrowers leave the production line with a set of front drive wheels and rear casters which allow the windrowers to be driven to various locations on the facility grounds as needed. Three problems have been identified with this current practice. Firstly, the on-site tractor inventory can grow to be in excess of 200 units, which causes the number of tires tied up in the inventory to also grow accordingly. The growth of the inventory increases the difficulty of tracking tire inventory and also leads to increased tire degradation as the tires can be exposed to harsh weather conditions for extended periods of time before the tires are sold. The second problem results when tractors are sold after they are manufactured. Customers have the option to choose from a selection of tire and caster options, so different tires and casters than what were installed during production often need to be packaged with the sold tractor. Finally, windrowers are shipped to the dealers and customers on flatbed trailers which require that the drive wheels, and sometimes casters, be removed to meet dimensional requirements for shipping. This configuration and the general dimensions of the tractor are shown in Figure 2.

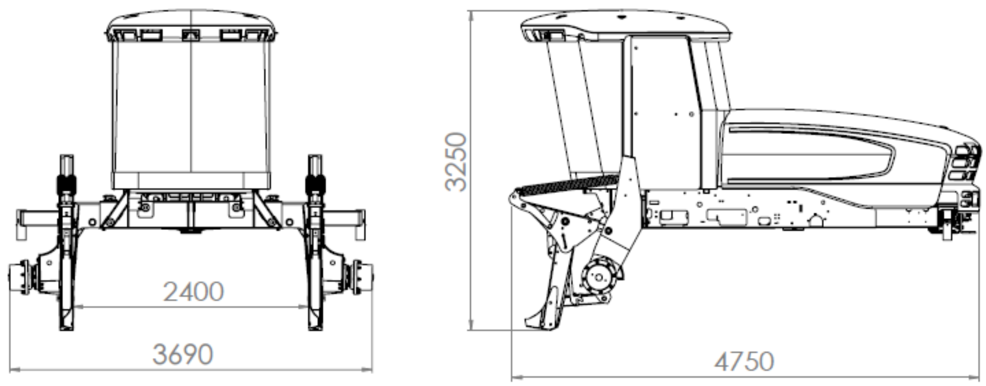


Figure 2: General dimensions of M Series windrower (in mm), redrawn from [4].

Our design team has been tasked with designing a stand for the tractors which will allow for them to be moved around the facility by forklift without the need for drive wheels or casters. If implemented, our design should help reduce production assembly times, shipping disassembly times, protect tire inventory from weathering and make inventory easier to track. These benefits will help MacDon meet their company objectives, making this a justifiable project.

Our work will be the first of its kind for the company as they have only identified the need for the project. Our team's research found no competitor products which can be directly compared or used in benchmarking, as this project will be very specifically tailored to MacDon's needs. Instead, design inspiration will come from various related sources, such as agricultural equipment transporters and dedicated forklift stands for equipment.

1.1 Project Objective

The purpose of the project is to design a stand that will support the current MacDon tractor model without the drive wheels and casters installed. The stand will be designed to support a minimum tractor weight of 6000 kg. If a reusable stand is chosen, the budget is $2400 per stand and if a disposable stand is chosen the budget is $100 per stand, all based on a 5 year design life. The team will also provide technical drawings, CAD models and FEA analysis of the stand to the customer. Furthermore, a detailed process for installation and transportation will be provided by the team upon completion of the design, and three project reports will be provided to the University of Manitoba and the client before December 7, 2015.

1.2 Scope of Work

The project is to design a stand which will support the current MacDon Tractor models without the drive wheels installed that can be moved by a forklift, and can be removed before or after shipping.

The project is composed of seven deliverables. The deliverables include a product user guide, CAD models, FEA analysis, and technical drawings along with the two progress reports and one final report required for the University of Manitoba. The client received the Phase I report on October 5th, Phase II report on October 30th, and the final report on December 7th, 2015.

Resources that were required for this project include a current windrower CAD model, forklift dimensions and details, CAD software such as SolidWorks or AutoCAD, FEA software, team meetings (at least 3-5 hours every week), MacDon personnel (manager, supervisors, design engineer, operators), University personnel (Instructor, Project Advisors, Technical Communication Advisors), and two site visits.

The identified project risks included client and team availability, employee buy-in, and the information gathering process. The team assumed that we wuld get all necessary information from the client in a timely manner.

The client will only accept this project if the design meets the cost and functionality requirements. The scope of work did not include the production of a prototype or analysis for current loading and unloading process improvements.

1.3 Target Specifications

The needs of the customer and target specifications have been established in Phase I of the project, and are shown in Table II.

The customer needs focused on operational efficiency are based around MacDon’s desire to improve operations and processes. During the first on-site visit, our team was told that implementing the design should not introduce a bottleneck into MacDon’s current production and shipping processes. This specific need will require our team to minimize the time added to the client’s daily operational activities when using the stand. In order for the stand to perform as the client wishes, certain functional needs have to be met. Finally, providing a safe workplace is one of MacDon's primary objectives, so the design needs to be deemed safe for use in their industrial setting. Customer needs that reflect this safety objective will benefit the people, equipment and tools that come in contact with the design.

The established customer needs have been related to quantifiable metrics. These metrics were chosen so that they could be, as much as possible, independent of a specific design. Marginal and target values at that point in the project were achieved by estimating the possible design solutions that could be used in the project. To make some of these values applicable over a wider range of designs, certain metrics were normalized with a design property, or represented as a fraction of a currently unknown quantity. Marginal and target values for these metrics were chosen which relate to the functional, operational and safety needs while leaving room for a range of design options, as shown in Table II.

TABLE II: CUSTOMER NEEDS AND TARGET SPECIFICATIONS

		#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		Marginal Value	0.75	4	20	80	6	30	>5000	1	6500	<0.5	2	10	10^2	No	25	Yes	>1.25	30000
		Target Value	<0.5	2	10	100	>12	<10	>6000	2	6200	<0.25	4	5	10^3	Yes	45	Yes	2.5	60000
		Unit	ratio	#	mins	%	months	min	kg	m	kg	m2	#	%	cycles	Yes/No	degrees	Yes/No	#	N
		Needs Metrics	Storage area / Deployed area	Minimum number of people required to install/remove	Time to transfer windrower from wagon to stand	Percentage of BOM items in stock	Maintenance Interval	Time for maintenance, inspection	Stand loading Capacity	Range of fork spacing for lifting stand	Combined windrower and stand weight	Surface Area between stand and windrower frame	Number of sides accessible	Percentage of units requiring rework	Load/Unload cycles until failure	Can be moved without lifting fully off ground	Angle at which stand/windrower is unstable	Removed all sharp edges	Safety Factor in stress analysis	Force required to shift windrower position on stand
#	**Priority**	**Needs**	Needs #: 1-3 Operational Efficiency, 4-11 Functionality, 12-14 Safety												Priority: Scale 1-5, 1 lowest, 5 highest					
1	3	Stand is easy to store when not in use	•																	
2	3	Stand is easily installed and removed from windrower		•	•															
3	2	Stand is easy to maintain				•	•	•												
4	5	Stand is compatible with North American windrower models							•											
5	5	Stand with windrower can be moved around the facility without the wheels/casters									•					•				
6	5	Stand can be lifted with a forklift								•	•									
7	5	Stand keeps windrower frame in original shape										•								
8	4	Stand can be lifted from multiple sides											•							
9	4	Keep the paint in "brand new" condition												•						
10	2	Stand can be used repeatidly													•					
11	2	Stand is maneuverable with multiple forklift sizes								•						•				
12	5	Should be safe to use															•	•		
13	5	Stand frame is structurally reliable							•						•				•	
14	5	Stand mounts to windrower securely																		•

1.4 Constraints and Limitations

There are several different aspects of the project that were analyzed to determine the design constraints and limitations. These include the availability of materials, manufacturing processes, the project budget and the limitations of MacDon's available loading equipment.

The stand must be designed to use parts and materials in MacDon's inventory. Parts should be able to be manufactured using cutting, welding and bending processes, as these are MacDon's primary manufacturing operations.

1.4.1 Cost

The budget for this project was made to minimize the total cost of using the design over a 5 year period, imposing a limit of \$100 per tractor for the duration. If the stand is designed to be disposable, the budget from MacDon is \$100 per stand. If a reusable stand is chosen, this corresponds to \$2400 per stand. The total budget includes the costs for all required materials used for stand manufacturing. Since the labor cost is not considered by the client, the total budget doesn't include the manufacturing cost of the windrower stand.

To determine the budget using engineering economics principles, the inflation rate r (yearly basis) of 1.27% has been used [5]. As shown in Figure 3, the projected annual cost for disposable stands would be \$100 000 over a 5 year span, based on information given by the client. By considering the inflation rate, the annual cost for the 5 years can be converted to present value, which indicates the total budget for the reusable stand design. The cost of a single reusable stand is calculated below,

$$\textbf{Present Value} = \frac{100{,}000}{(1+r)^1} + \frac{100{,}000}{(1+r)^2} + \frac{100{,}000}{(1+r)^3} + \frac{100{,}000}{(1+r)^4} + \frac{100{,}000}{(1+r)^5}$$

$$= 98745.93 + 97507.58 + 96284.76 + 95077.28 + 93884.94$$

$$= \text{CAD\$ } 481500.50$$

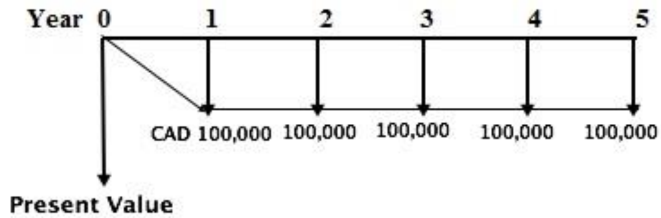


Figure 3: Present value of future cost per stand.

There are about 1000 windrowers being produced each year. Also, the reusable stands are required to be used in five cycles in one year. Thus, the number of tractors in each cycle can be calculated.

$$1000\frac{Tractors}{year} \div 5\frac{Cycles}{year} = 200\frac{Tractors}{Cycle}$$

The cost for each reusable stand is calculated as:

$$Cost\ of\ Reusable = \frac{481500.5}{200} = 2407.5\ /stand$$

1.4.2 Weight

After a windrower is fixed to the stand, the whole assembly will be lifted by a forklift and loaded onto a flatbed trailer. Therefore, the weight of the stand and windrower must be within the lifting capacity of the forklift used during the loading and unloading processes.

Currently, the heaviest windrower is 4500 kg. Our client has requested that we make our design capable of supporting a minimum of 6000 kg, which would allow future models to have weight increases. The two types of forklifts used in MacDon's Winnipeg manufacturing plant are made by Linde and Yale. As shown in Table III, the limiting forklift capacity is 8800 kg. This means that the weight of the stand cannot exceed 2800 kg.

TABLE III: MACDON'S AVAILABLE FORKLIFT MODELS AND CAPACITY [6]

Forklift Model	Capacity
Linde H150D	8800kg
Linde H120	12000kg
Yale GDP280DBEPDV143	12520kg
Minimum Capacity :8800kg	

1.5 Integration with Current Production

MacDon windrowers are assembled on a multi-stage production line. Tractor assembly begins by placing a bare frame on a mobile cart. This allows the frame to travel through all the assembly stations. Currently, the final assembly stage involves installing drive wheels and casters, then removing the cart from the finished tractor. Implementing the transport stand into the current process would replace the current final assembly stage. To keep the assembly process time unaltered, the time to install the tractor on the transport stand should be less than the current 30 minute bottleneck stage [7].

2. Conceptual Designs

Having set a clear project definition, the next stage of the design process was to determine product features and details that could be used to meet the customer's needs.

2.1 General Process

After reviewing the customer's requirements for the project, the next stage of the design process was to determine product features and details that could be used to achieve the target specifications. Our team used a five stage process to come up with concepts and develop them to a useable conceptual design.

The process began with each team member individually creating design concepts based on their experience and research that were then shared with the team. This sharing of ideas allowed the creation of more concepts by combining features from each other's designs. Then concepts were broken into functional categories to allow for more possible design combinations. Next, products with similar functionality were researched to see methods that have been used in building stands for large equipment. The designs in each category were screened and scored to establish the top two concepts for each function. Finally, the top concepts for each function were combined to create the conceptual designs which best meet the customer's requirements. The general design process that was followed is shown in Figure 4.

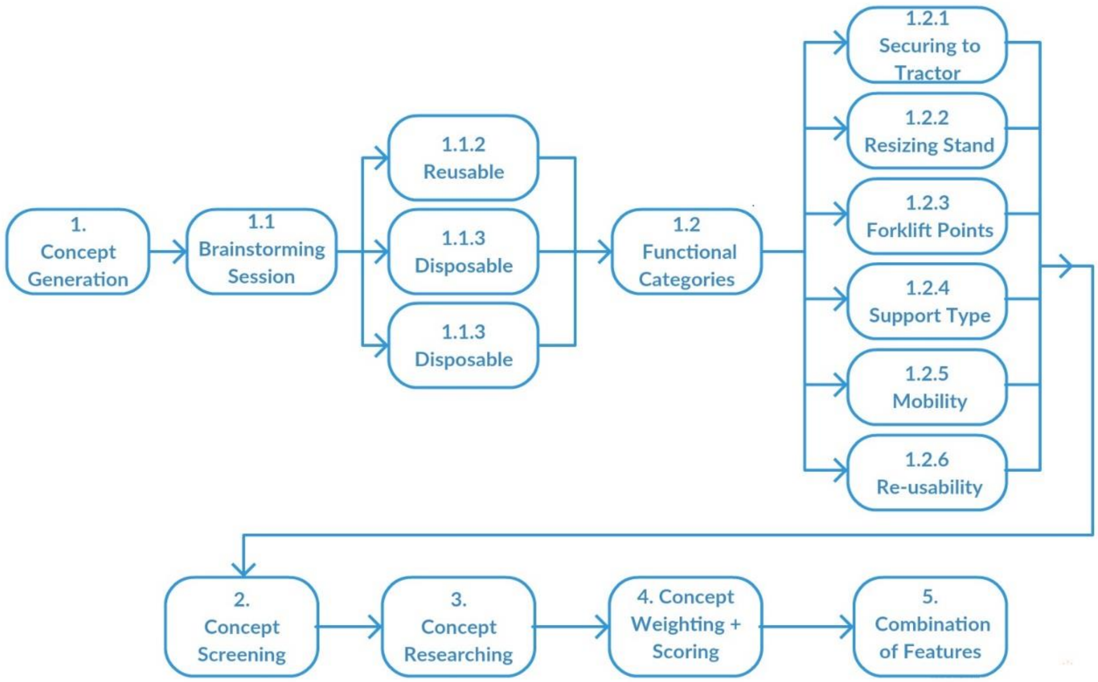


Figure 4: Design Process Flow Chart [A1]

This process led to the creation of nine distinct conceptual designs which could then be evaluated by our customers.

3. Final Design Selections

After the final conceptual designs were created from the highest scoring functions, the detailed sketches were submitted to our contacts at MacDon, as they requested. With their feedback and recommendations, the following concepts were selected for further development in Phase III of the project.

3.1 Final Selection I

One concept selected for further development was a fully reusable tractor stand that had supports which could be collapsabe to save space. The upward support design allowed for a lower frame that may be fitted with wheels so smaller forklifts could move it from place to place. A forklift would be able to lift on the frame securely from the front, the left and right, and possibly the rear by lifting on the lower frame. The tractor supports would include a pocket design which would be made to securely mate with a chosen part of the tractor frame. This design would still require shipping brackets or supports to protect and secure the tractor during shipping. An initial embodyment of this design is shown in Figure 5.

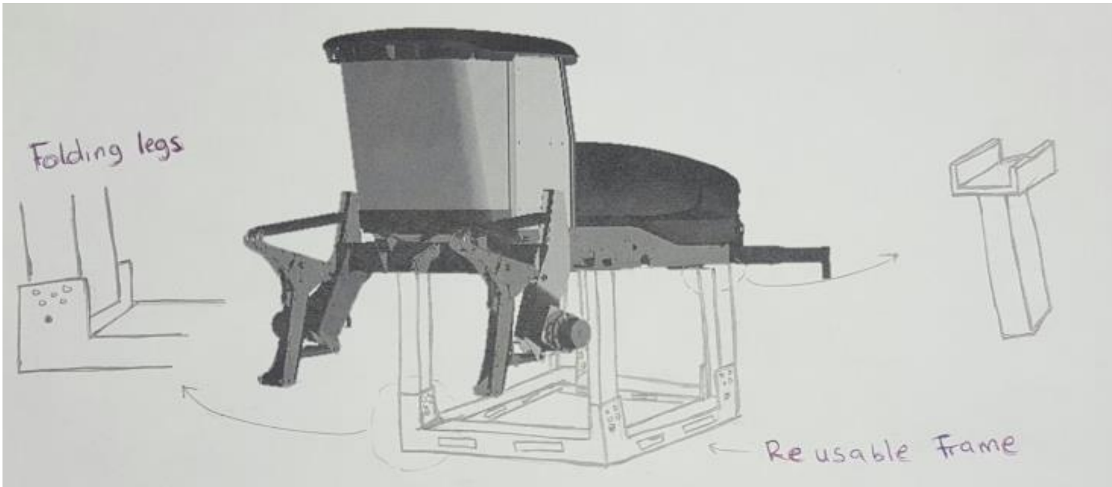


Figure 5: The reusable stand design selected for further development.

3.2 Final Selection II

The other concept chosen for further development included a partly disposable stand with a reusable forklift attachment for lifting. Since the stand would not be reused, the design would be made to reduce the material used as much as possible. The supports at the front of the tractor would likely consist of small shipping bracket positioned underneath both of the front drive wheel hubs. MacDon currently used this design to keep the front of the tractor elevated while in transport position on the flatbed trailers. The rear of the tractor would be supported by a small stand which would be attached in the production line and would only be removed once the tractor had been delivered to the dealer. The benefit of this design was that it did not require additional supports or brackets for shipping. The forklift attachment would be a reusable feature that would allow the forklift to lift the tractors safely while protecting the paint. The benefit with this is that there would be no additional disposable pieces. An initial embodiment of this design is shown in Figure 6.

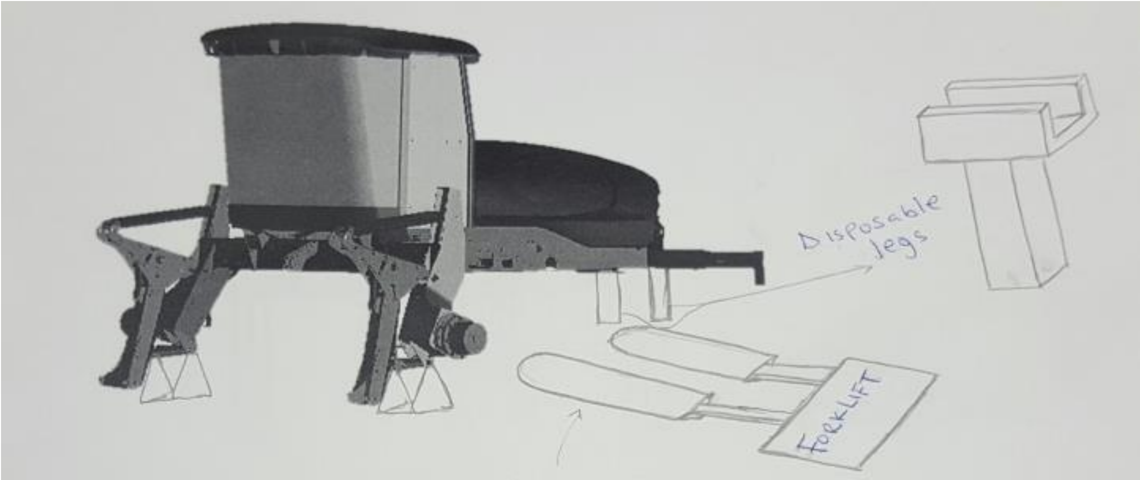


Figure 6: The final selection for a disposable stand, including reusable forklift attachment.

3.3 Considerations for Final Design

In the final phase of the project, the two selected concepts would be further developed and evaluated in order to make a final design selection to present to the customer. A number of aspects would be considered in the development and evaluation based on the request of our customer. These aspects included the detailed cost breakdown, recommendations for storage solutions, predicted installation and removal times and required labor, and the overall functionality of the stand. With these aspects, a single final design would be selected based on the detailed evaluation of both designs.

4. Failure Mode and Effect Analysis

In order to improve the quality and safety of the final design, our team followed a Failure Modes and Effects Analysis (FMEA) procedure to identify possible ways our designs could fail. The decision to perform this analysis was based on the severe effects of potential failure, since the stand will support very heavy equipment and will involve close involvement by human operators. The results of the FMEA procedure helped us to actively make design decisions to mitigate the risks, helping to create a safe and reliable product for our customers.

The FMEA process started with brainstorming the possible stand or forklift attachments that could fail. This included considering the failure of components specific to the reusable stand, disposable stand, and the forklift attachment. There were three main categories of failure which were considered, including structural failures, functionality failures, and failure to protect the tractor from damage. The following table describes the failure with the potential effects and causes.

TABLE IV: PREDICTED FAILURE MODES OF POSSIBLE STAND DESIGNS

Failure Mode #	Component	Failure mode	Potential Effect	Potential Causes
1	Bolts	Shearing	Tractor falls off stand/unbalanced	Overloading, dropped (impact), human error
2	Bolts	Thread Failure	Bolts are Difficult to Remove	Improper tightening, overload, corrosion
3	Bolt holes	Plastic deformation	Bolts Binding or too much Clearance	Overloading, dropped (impact), human error
4	Stand Legs	Buckling	Unstable, Unable to Support Tractor Safely	Overloading, weight not evenly distributed
5	Stand Legs	Bending	Unstable, Unable to Support Tractor Safely	Lateral load applied to legs, uneven loading
6	Steel Components	Rusting/Corrosio n	Decreased Fatigue Life, Increased Friction in moving parts	Environment, chemicals exposure
7	Steel Components	Fatigue	Tractor Falls Off Stand/Unbalanced	Exceeding the design life, overloading
8	Painted Surfaces	Paint chipping/wearin g off	Causes more Scratches on Tractor Frame, Allows Corrosion	Operation,
9	Wheels	Bearing Failure	Wheels Don't Turn (rolling, twisting)	Overloading, poor lubrication, exceeding design life
10	Wheels	Axle/Supports Breaking	Wheels Become Detached	Overloading, fatigue failure, exceeding design life
11	Wheels	Wheels Jamming	Wheels Don't Turn (Rolling, Twisting)	Environment, lubrication, bad bearings, uneven surfaces
12	Forklift Attachment	Fatigue	Tractor Becomes Loose/Unbalanced on Forklift, Requires Fixing	Exceeding the design life, overloading
13	Forklift Attachment	Plastic deformation	Won't Fit with Tractor Properly	Overloading, human error (bumping into things)
14	Contact Surface with tractor	Plastic Deformation	Surface Becomes Uneven, Scratches, Difficult to Fasten Stand	Improper installation, overloading, non-uniform load distribution
15	Entire Frame	Ice/Snow Buildup	Joints Freeze up, Difficult to Remove	Environment, water does not drain, site maintenance

Each failure was then assessed a value from 1 to 10 for severity, frequency of failure, and the ability to detect the failure. A rating of 10 represents the worst performance in the respective area. A final Risk Priority Number (RPN) was then calculated by multiplying each of the three ratings together. Failure modes with the highest RPNs are the ones that require the most attention during designing. The resulting RPNs are shown in Table II.

TABLE V: ASSIGNMENT OF RISK PRIORITY NUMBERS FOR IDENTIFIED FAILURE MODES

Failure Mode #	Component	Failure mode	Severity	Frequency	Detection	RPN
1	Bolts	Shearing	10	3	6	180
2	Bolts	Thread Damage	5	4	4	80
3	Bolt holes	Plastic Deformation	6	3	5	90
4	Stand Legs	Buckling	10	2	3	60
5	Stand Legs	Bending	10	2	3	60
6	Metal components	Rusting/Corrosion	3	4	5	60
7	Metal Components	Fatigue	10	2	9	180
8	Painted Surfaces	Paint chipping/wearing off	2	9.5	2	38
9	Wheels	Bearing Failure	3	4	4	48
10	Wheels	Axle/support breaking	7	4	6	168
11	Wheels	Wheels Jamming	2	4	2	16
12	Forklift Attachment	Fatigue	10	2	9	180
13	Forklift Attachment	Plastic Deformation	6	5	5	150
14	Contact Surface with tractor	Plastic Deformation	3	5	2	30
15	Moving Parts	Seizing/Jamming	2	5	3	30

By conducting FMEA for our selected conceptual designs, we identified that the failure modes with the highest associated risk are those related to the loading and load cycles of the stand. These include fatigue failure, shearing failure and permanent deformation of critical components such as the legs, wheels and forklift attachment. Knowing these allowed us to make design decisions to improve the reliability of the product and make it safer to use.

5. Final Design Selection

The disposable stand design and reusable stand design were compared by being ranked as better than, the same as, or worse than the benchmark. The reusable stand was selected as the benchmark. Scores were assigned to each ranking and a total score was given to each design. The final scores determined which design would be selected as the final design for the client. Our team made the decision to select the criteria based on identified customer needs. This decision resulted in the formation of 6 criteria of customer needs, which were used to further compare the two designs. The full list of criteria used in screening is given in TABLE VI.

TABLE VI: SELECTED CRITERIA FOR DESIGN SELECTION.

Criteria
Easy to store
Easily installed
Easily removed
Expected cost
Movable by small forklifts
Mounts to tractor securely

As shown in Table VII, The results of the weighting matrix show that the top three most important criteria are “Easily installed”, “Expected cost”, and “Mounts to tractor securely”. The weighting matrix should be treated as a preliminary result based on our team’s subjective judgement of several criteria. A further analysis for the criteria weighting matrix should be conducted by the client.

TABLE VII: WEIGHTING MATRIX FOR THE SELECTED CRITERIA

	Criteria	A (Easy to store)	B (Easily installed)	C (Easily removed)	G (Expected cost)	I (Movable by small forklifts)	L (Mounts to tractor securely)
A	Easy to store		B	C	G	A	L
B	Easily installed			B	G	B	L
C	Easily removed				G	I	L
G	Expected cost					G	L
I	Movable by small forklifts						L
L	Mounts to tractor securely						
Total Hits		1	3	1	4	1	5
Weightings		6.667	20.000	6.667	26.667	6.667	33.333
Rank		4	3	4	2	4	1

As the results show, the highest scoring stand design is disposable stand. Ideally, this design would be used. However it may not be practical if there are any other design standards and additional specific requirement provided by customer. The decision making process was made based on limited information about factors that could affect the final decision, such as loading process times.

TABLE VIII: CONCEPT SCREENING FOR THE REUSABLE STAND AND DISPOSABLE STAND

		Concept Variants			
		Reusable Design		Disposable Design	
Selection Criteria	Criteria Weight	Score	Weighted Score	Score	Weighted Score
Easy to store	6.667	4	26.667	4	26.667
Easily installed	20.000	3	60.000	5	100.000
Easily removed	6.667	4	26.667	5	33.333
Expected cost	26.667	4	106.667	3	80.000
Movable by small forklifts	6.667	4	26.667	4	26.667
Mounts to tractor securely	33.333	3	100.000	5	166.667
NET		**346.667**		**433.333**	
RANK		2		1	
CONTINUE?		No		Yes	

The details of the reusable stand that was considered in the selection process are given in Appendix A. The remaining sections of the report discuss the chosen disposable design which also incorporates some reusable features.

6. Material Selection

MacDon Industry currently keeps three different steel alloys in their sheet metal stock, which are listed in Table IX. The range of material thicknesses in inches and gauge number, are also given. The available thicknesses are all converted to millimeters in the table to indicate the range of sizes in the same scale.

TABLE IX: MACDONS MATERIALS IN STOCK [8]

Alloy	
A36/44W and A1011 CQ CS TYPE B	
ASTM A1008 CR CQ	
HSLA Grade 50	
Thickness	**Unit Conversion**
18 GA	1.27 mm
16 GA	1.59 mm
14 GA	1.98 mm
11 GA	3.18 mm
7 GA	4.76 mm
0.250’’	6.35 mm
0.375’’	9.53 mm
0.500’’	12.7 mm

In order to decide the suitable material to our design, it was necessary to conduct research about each alloys properties, including yielding stress, density and modulus of elasticity. The cost for each material should be an important consideration in final selection so the budget can be met. The details about cost and properties for the three alloys are described fully in Appendix B.

The steel alloy that was ultimately selected for use in our designs was ASTM A1011 CS Type B. This alloy is a hot-rolled carbon steel alloy sheet that exhibits high strength and high formability. A1011 sheet is capable of being bent at room temperature in any direction through 180° flat on itself without cracking on the outside of the bent portion. The list of mechanical properties for A1011 is given in Table X.

TABLE X MATERIAL PROPERTY OF ASTM A1011 CQ [9]

A1011 CQ		
Milling Process	Hot-Rolled	
Grade	CS Type B	
Yield Tensile Stress:	250	MPa
Yield Shear Stress	125	MPa
Ultimate Tensile stress	400	MPa
Density	7.872	g/cm^3
Modulus of Elasticity	200	GPa

The results of the material cost analysis also determined that A1011 was the least expensive of the three alloys. This was a large factor in selecting this specific alloy, as the similar properties but lower cost would help us to stay within the budget.

7. Disposable Stand Design

The following section details the design procedure, features and analysis of a disposable stand which can support current MacDon tractor models. The design also includes reusable aspects in a forklift attachment and caster assemblies.

7.1 Goals of the Design

One of the first stages in designing the disposable stand for MacDon's M-Series tractors was to revisit the goals of the design. This design has the many of the same overall goals as have already been discussed, such as working within the cost and manufacturing limitations. In addition to these, we also wanted the stand to be made of few parts while still maintaining the desired functionality to simplify manufacturing. We also wanted the stand to be easy and fast to assemble so it can be integrated into the current production line without creating a bottleneck. This would be important in achieving the greater goal of improving MacDon's operational processes.

7.2 Features of the Design

The chosen design for the disposable tractor stand incorporates three major sections. The first is the rear stand assembly which gets assembled onto the tractor at the end of the assembly line. This stand will remain on the tractor during storage, shipping and will be removed by the dealers after delivery. The entire stand assembly is shown in Figure 7.

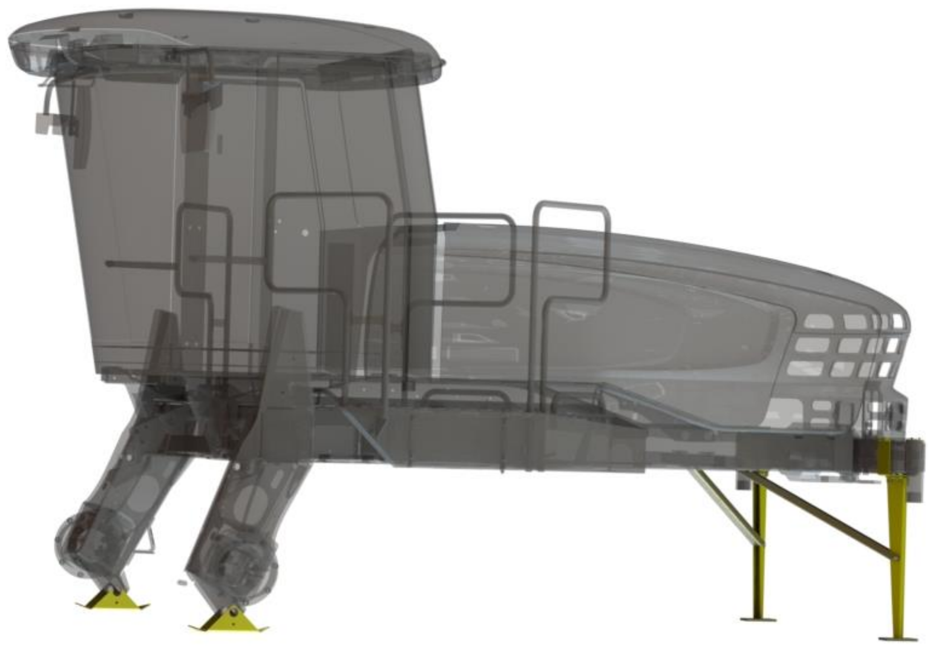


Figure 7: Final stand assembly (yellow components) shown mounted to a tractor.

The second part of the design allows for casters to be fitted to the tractor to allow for easier movement within the tractor assembly plant. These casters can be removed once the tractors leave the assembly plant since they will be then be moved around by forklift. The full reusable caster assembly is shown in Figure 8.

Figure 8: Rendered image of the tractor stand assembly with the optional casters installed.

The third part of the design is a forklift attachment that will be used to safely and quickly pick up and move the forklifts. The forklift attachment assembly is shown in Figure 9.

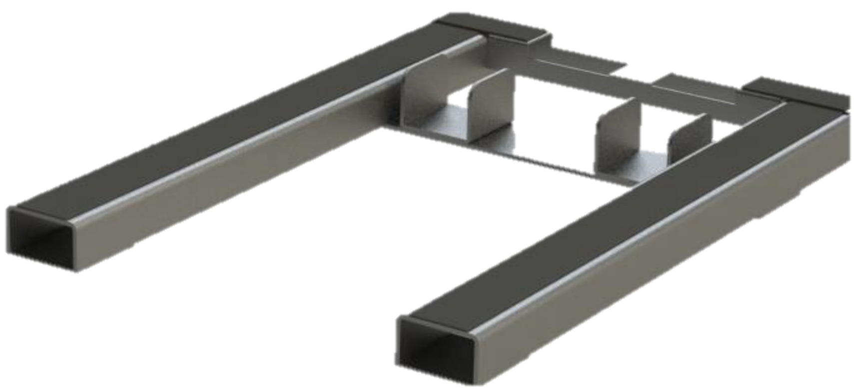


Figure 9: Rendered image of forklift attachment assembly.

7.3 Stand Assembly

The following sections outline the design decisions that were made when designing features of the rear stand as well as the final details and analysis.

7.3.1 Design Decisions

The first thing that was identified during the design process for the rear stand assembly was the types of loading that would be seen. Since the stand is required to support the back end of the tractor to keep it off the ground, the stand will see compressive loading. This immediately requires the consideration of buckling and the ways that it can be suppressed. In the ideal static condition when the tractor is simply sitting in the yard, this is likely to be the only loading seed on the stand. To make the stand safe in all situations our team had to identify other loading situations that the stand could see so that the safety will not be compromised in these situations.

When the stand is being moved around there is the likelihood of lateral and longitudinal loads to be applied to the tractor. These loads could be the result of the forklift moving in to pick it up and put it down or the stand being placed on uneven ground. The stand will also be subject to these types of loads when the tractors are on the road for shipping, caused by bumps, cornering, acceleration and braking. These types of side loads will put the stand in bending. Assuming that the stand is fixed to the tractor securely, the horizontal forces applied at the base of the stand legs will put the legs in bending like the case of a cantilever beam. This would cause the largest bending moment at the fixed connection, or in this case, where the stand is fixed to the tractor.

In anticipation of the previously described loads, several design features were included. The first feature was in the leg of the stand. It was designed to have a tapered profile, having a large cross sectional area at the top and a smaller cross sectional area at the base. This would increase the strength of the leg at the connection to the tractor as well as give more surface area for mounting. Since the stand needed to be made of sheet or plate steel, a C channel design was used to improve bending strength with the same cross sectional area compared to planar geometry alone. Additional strength could have been achieved by closing off the cross section into a tube, however MacDon does not have the manufacturing ability to easily bend metal into closed shapes. Another piece of metal could be used to close of the shape but that has the down side of requiring additional fastening or welding. A cross brace was also used for two purposes. A cross brace would serve to provide another support for horizontal loading, reducing the stresses at the fixed end of the stand. This brace could also be positioned at a place to suppress the first buckling mode which would increase the critical buckling load by a factor of four.

An aspect of safety that needed to be considered was the stability of the tractor on the stand. The greatest stability will be achieved by placing the supports as far from the center of mass as possible. To support the rear of the tractor a stand would need to be placed rearward of the center of gravity. On the M series windrowers the rear axle tube is the most rearward structural part of the tractor. By placing the stand at this location, the longitudinal stability is maximized. Placing the stand here also has the benefit of reducing the load on the legs, as more weight is supported by the front supports. This concept is demonstrated in Figure 10.

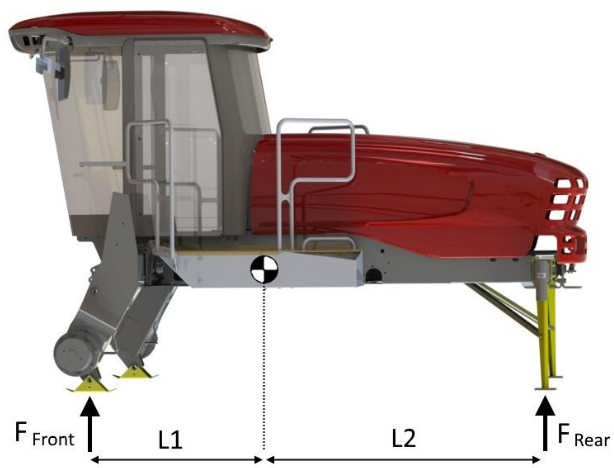


Figure 10: The approximate location of the Center of Gravity for the windrower. Front and Rear weights depend on distances (L1 and L2) from CG.

Placing the rear stand on the axle tube also has the benefit of allowing the legs to be spaced further laterally since the axle tube extends further out to the sides than the rest of the frame. This will increase the lateral stability of the tractor.

Wanting to mount the rear stand to the rear axle tube plays a large factor in how the stand will be mechanically connected to the tractor. One possibility was utilize the mounting location for the caster wheels by using a solid pin that fits within the caster bushing. The caster wheel mounting point is shown in Figure 11.

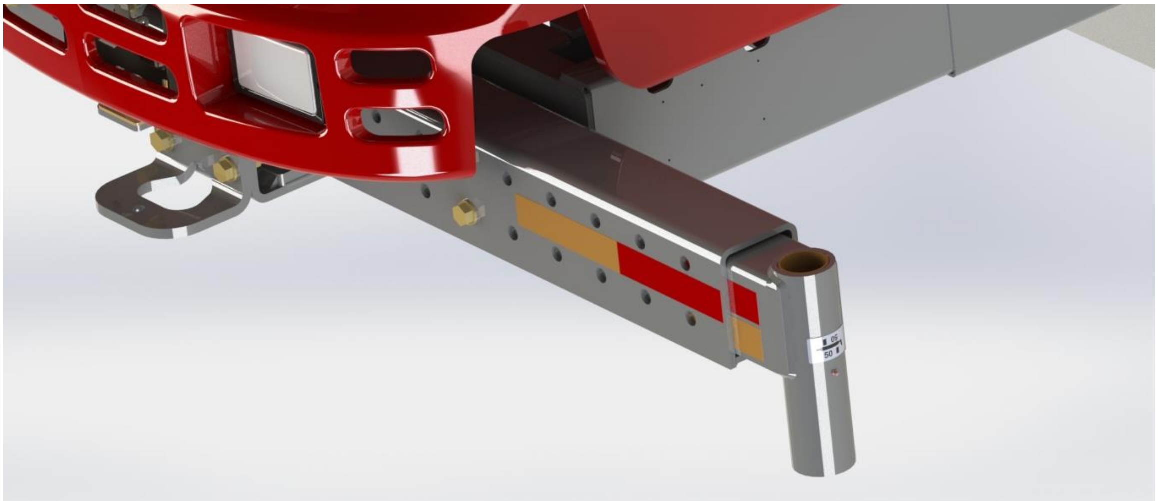


Figure 11: Rendered image of the rear axle tube of M Series windrowers. The caster support is shown in the lower right.

This mounting method was not selected because of the risk of damage to the caster bushing. The current practice of removing and reinstalling the rear casters sometimes results in the bushing being damaged when the caster wheels are put back on the tractor. Removing and installing this part with tight clearances is what can result in damage to the bushing. For a pin mounted stand to be secure, it would have to have similar clearance to the caster pin and would have the same risk.

Another possible location to mount the rear stand is to have it bolted directly to the axle tube using the bolts that fix the adjustable axles in their position. These bolts are shown in Figure 12.

Figure 12: Rendered image of the rear of the tractor, showing the 8 axle bolts.

This possibility would also be secure since the bolts would prevent the stand from moving in any direction. The downside to this mounting method is that the legs of the stand would have to be positioned closer to the centerline of the tractor where the bolts are located. This would reduce the stability of the stand. This method would was also more difficult to design in a way that was easy to assemble, manufacture and distributed the load evenly to the stand.

The final design was chosen to use a pocket design. This had been chosen as the best method of securing the tractor to the stand during Phase II of the project. It also had the flexibility to be positioned almost anywhere laterally along the axle tube.

Another factor that was considered was how certain parts would be connected, either by welding or by fastening with bolts or other hardware. A consideration that had to be made was for when some shipping configurations have three tractors on a drop deck trailer. In this case one of them has to have the rear axle supported over the raised trailer section as shown in Figure 13.This would not allow for the full height legs to be used, so the stand should either be very easy to fully remove or be able to have shorter legs installed for this specific shipping condition.

Figure 13: MacDon tractor in 3 tractor loading configuration on flatbed trailer [15].

7.3.2 Final Design Details

The final design of the disposable windrower stand consists of front shipping shoes, which are currently used by MacDon, and two rear stand legs mounted to the axle tube. The stands have been designed to be the same for both the right and left sides. Each stand leg consists of 7 components, plus hardware, each of which serves a specific purpose.

7.3.3 Leg

The leg of the stand is the largest component and is the primary load bearing part of the assembly. It is made from ¼" steel and is bent into a c channel shape. The leg has been designed so that it sees primarily axial compressive loading by having the leg in a straight vertical position. To provide bending strength when horizontal loads are applied to the bottom of the leg, the stand is 3.75" wide at the top and tapers down at a constant rate to a minimum width of 1.5" at the base. Six holes will be cut into the leg before bending to produce three through holes for bolts which will connect the leg to the angle brace and to the mounting pocket. An image of this design is shown in Figure 14.

Figure 14: Rendered image of the rear stand leg.

The length of the stand was designed to be 31.67". This dimension was chosen so that the body of the tractor would remain horizontal to the ground when the front is being supported by the shipping shoes. This also helps to ensure the load is transferred axially through the leg since the leg will be vertical when the stand is mounted perpendicular to the tractor axle tube. The shape and dimensions of the stand leg are shown in Figure 15.

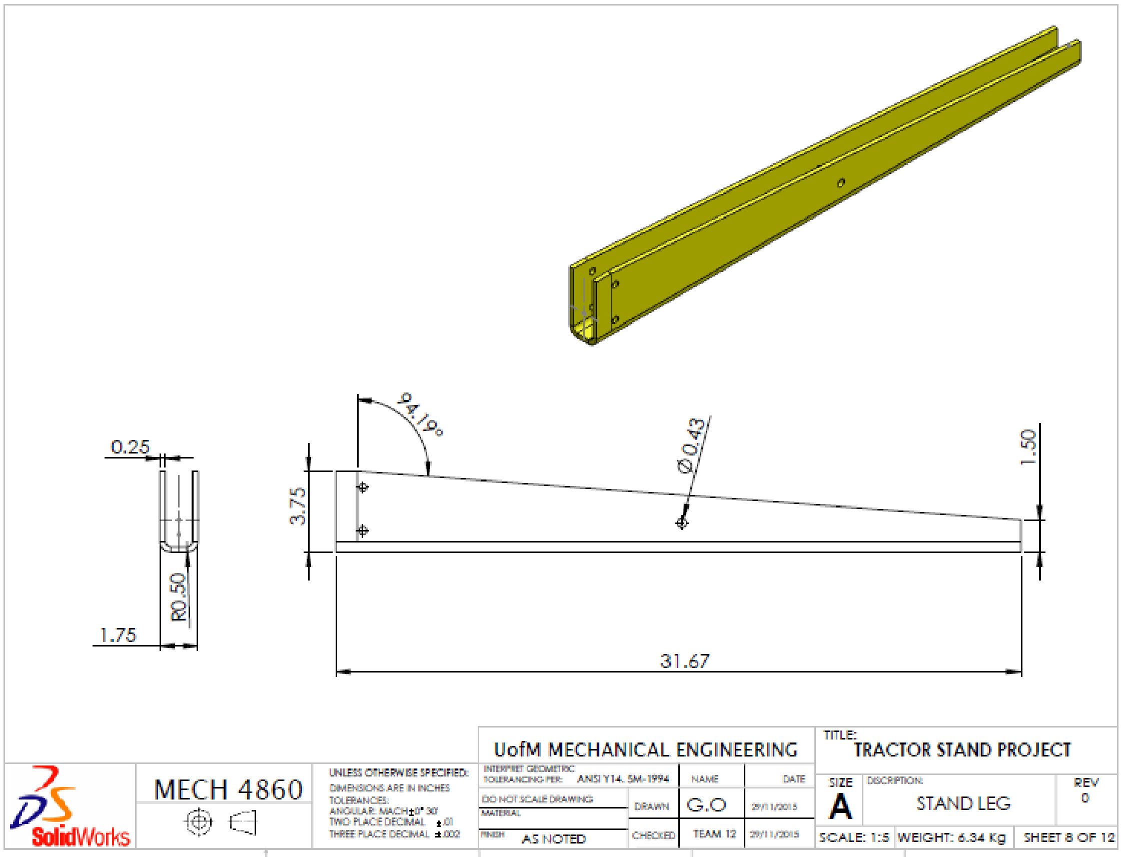


Figure 15: Drawing of final stand leg design, with dimensions in inches.

7.3.4 Mounting Pocket

The mounting pocket serves the stand component that mounts the legs to the tractor. The pocket has been designed to fit tightly to the axle tube and to be mounted from below the tractor. A picture of the mounting pocket is shown in Figure 16.

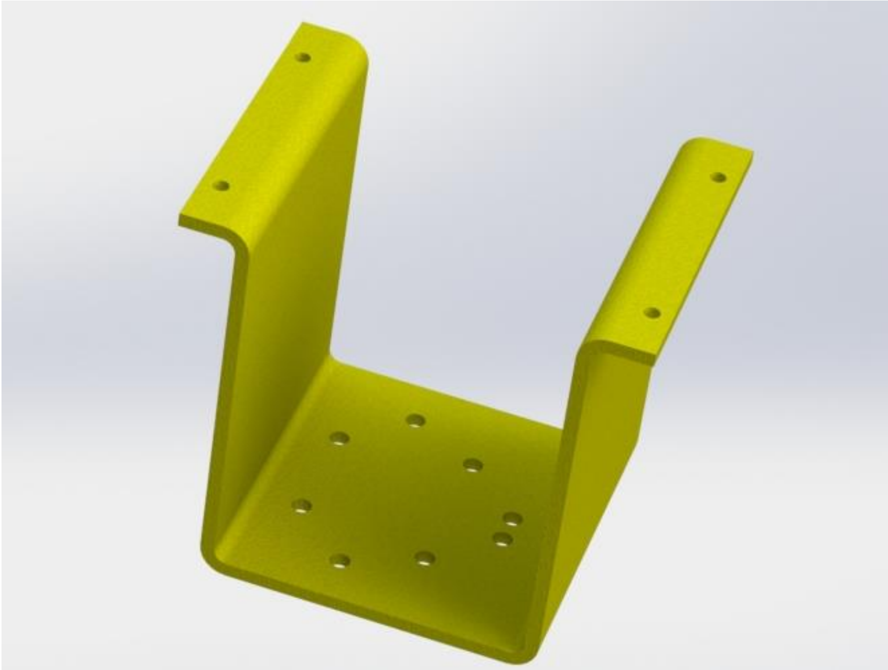


Figure 16: Rendered image of the mounting pocket for the rear stand.

As can be seen in the drawing, there are a number of notable features to this part. First is the overall size. Since it needs to fit on the rear axle tube, the dimensions need to be chosen to give a close fit to the tube. The axle tube on the current tractors measures 5.34" across and is 7.10" in height. Based on these dimensions, the mounting pocket was designed to have an interior width of 5.50", allowing for some clearance for easier assembly and paint thickness. The height of the pocket was designed to be 6.9" from bottom of the base area to the top of the upper flanges. This dimension was made slightly smaller than the total height of the axle tube so that extra clamping force could be achieved when the top plate will be fastened to the mounting pocket and the bolts are tightened. The gap between the mounting pocket and the top plate when the stand is mounted to the axle is shown in Figure 17. The width of the pocket was designed to be 6" to accommodate the dimensions of the stand leg and connecting bracket in both of the 45^{o} angle configurations.

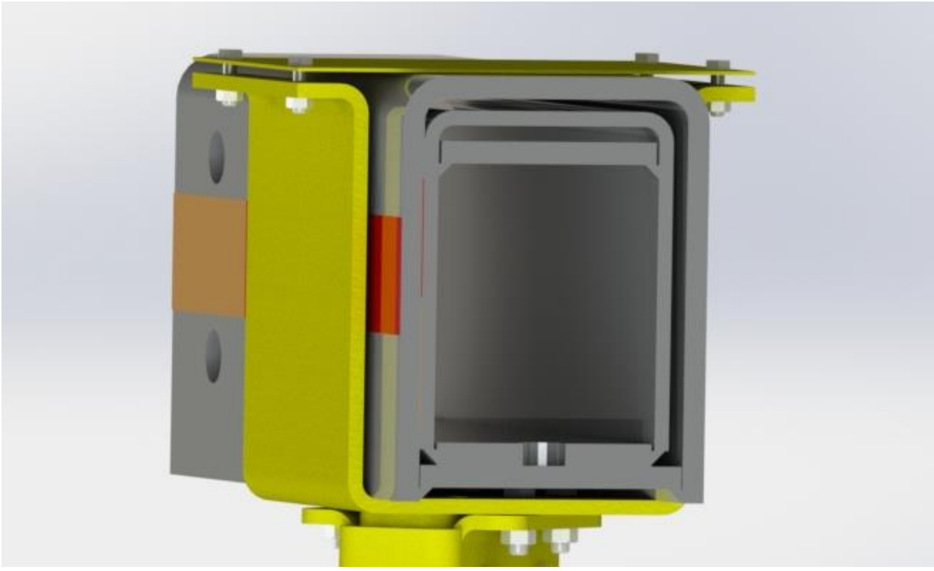


Figure 17: Rendered image of stand mounting pocket installed on axle.

The other notable feature is the hole pattern on the base of the pocket. This series of holes allows for the leg to be mounted to the pocket in two positions. Using one hole set allows the leg to be mounted for use on the left side of the tractor while using the other holes allows the leg to be used on the right side of the tractor. The set of holes is rotated 90^{o} about a central point so that the legs can be positioned at a 45^{o} angle relative to the tractor frame for both the left and right stand legs. The stand leg was chosen to be mounted at a 45^{o} angle to make the angle brace easier to mount, and to increase the lateral stiffness of the stand legs. The hole pattern and the bolt locations for the left and right side stand legs are shown in Figure 18.

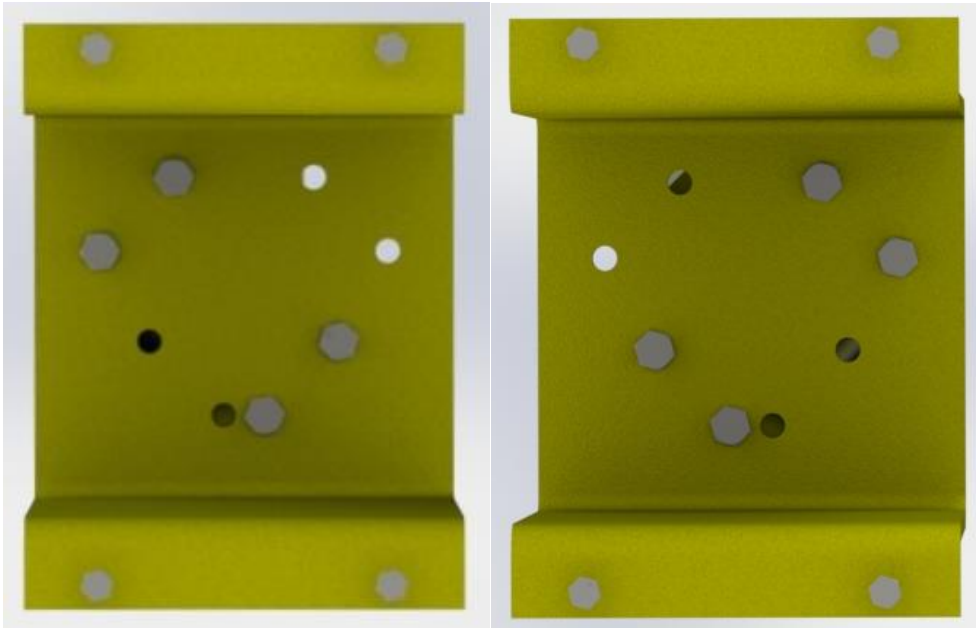


Figure 18: Top views of left and right mounting pockets (left and right image respectively) with bolts for fastening to respective legs shown.

The holes are also located in a specific area so that the bolt heads do not contact the underside of the axle. This was an important consideration because bolts would have a high risk of scratching the paint. The cross section of the axle tube shown in Figure 19 demonstrates how the axle tube has a recessed area which is greater than the height of the bolt heads. The depth of this recess is 0.25” providing a small clearance to bolt heads which have a thickness of 0.21”.

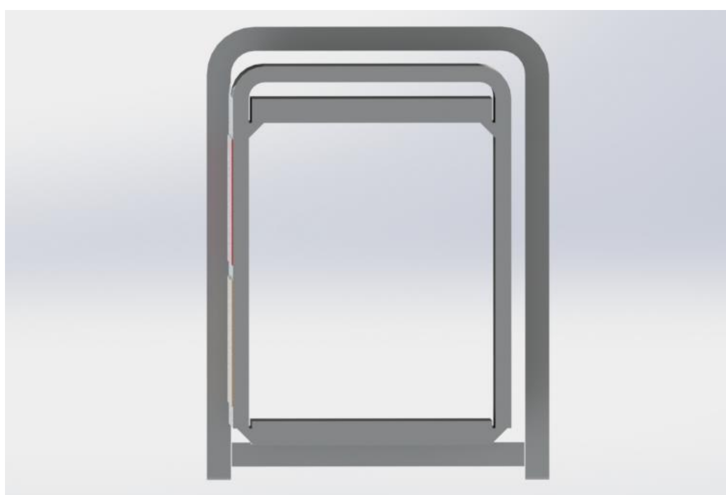


Figure 19: Rendered image showing the cross section of the axle tube and the recessed area on the bottom face.

The final feature of this mounting pocket is the flanged edge on the top of each side of the pocket. These flanges have holes for fastening the top plate to the mounting pocket. Two holes were chosen for each side to make the clamping force more uniformly distributed across the top of the axle tube. The drawing for the final mounting pocket is shown in Figure 20.

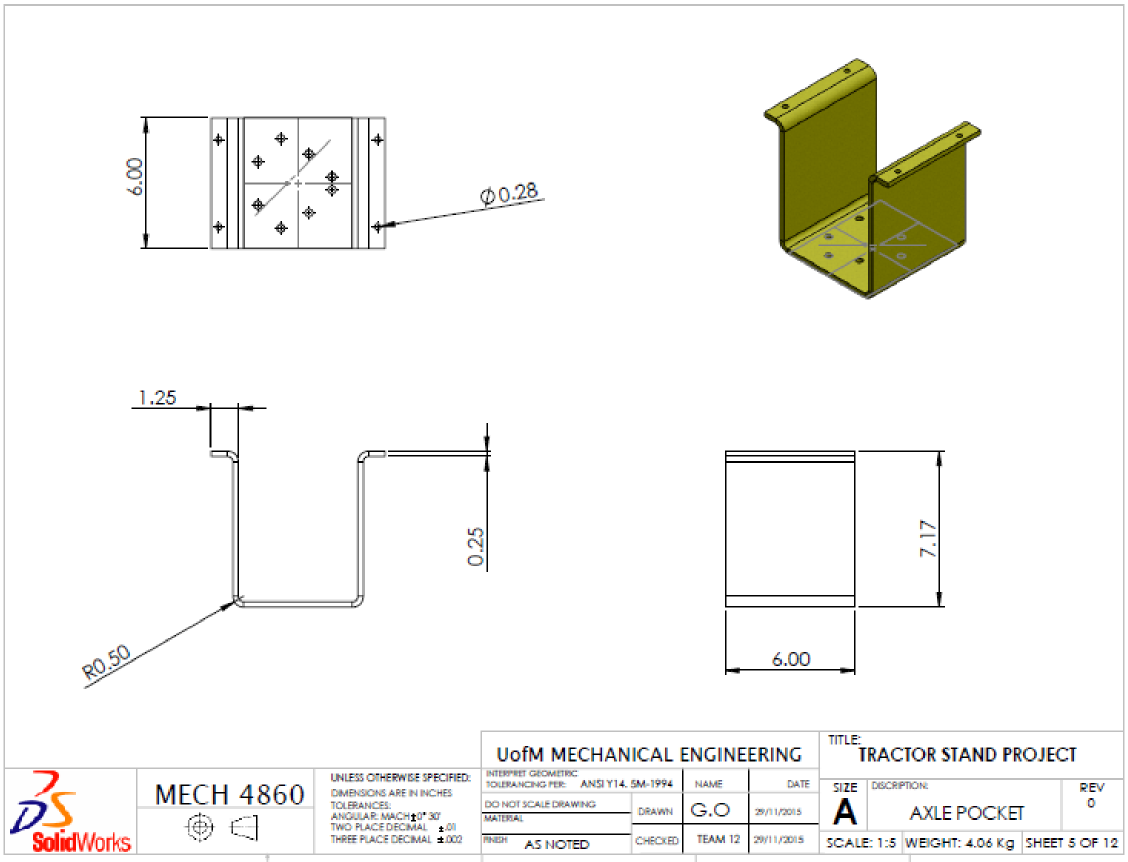


Figure 20: Drawing of final mounting pocket, with dimensions in inches.

7.3.5 Connector Bracket

The purpose of the connector bracket is to connect the stand leg to the mounting pocket. A picture of the bracket is shown in Figure 21.

Figure 21: Rendered image of the connecting bracket for the rear stand.

This bracket is designed to fit around the top edge of the leg and has the holes for bolting to the leg and pocket. One of the design features of this part is that when the bracket is fastened to the stand leg, the top flanges of the bracket are slightly below the level of the top of the leg. The purpose of this is to have the top of the leg be the primary point of contact with the mounting pocket. This contact is where the weight of the tractor will be transferred from the mounting pocket to the leg. If the connector bracket extended above the top of the stand leg most of the weight would be transferred through the bracket and to the leg through the bolted connections. This would put much more stress in the vicinity of the bolt holes. Similarly, less weight will be transferred through the bolts. This is good since bolt failure was identified as having a high risk priority number during the FMEA process.

The bracket was also designed to be a single piece instead of an angle bracket on each side of the leg. This decision was to make it easier for assembly by one person. During assembly the worker will have to line up the leg and connecting bracket holes, place a spacer bushing in line with each hole and insert a bolt through all three pieces. The current design not only reduces the number of individual pieces, but makes the connecter bracket very easy to positon since the holes will automatically be positioned horizontally when the bracket wraps around the stand leg.

The connector bracket is made of ¼” steel and has a height of 1.75” The top flanges are 1.22” wide each giving the part a total width of 4.22”. A detailed drawing of this part is given in Figure 22.

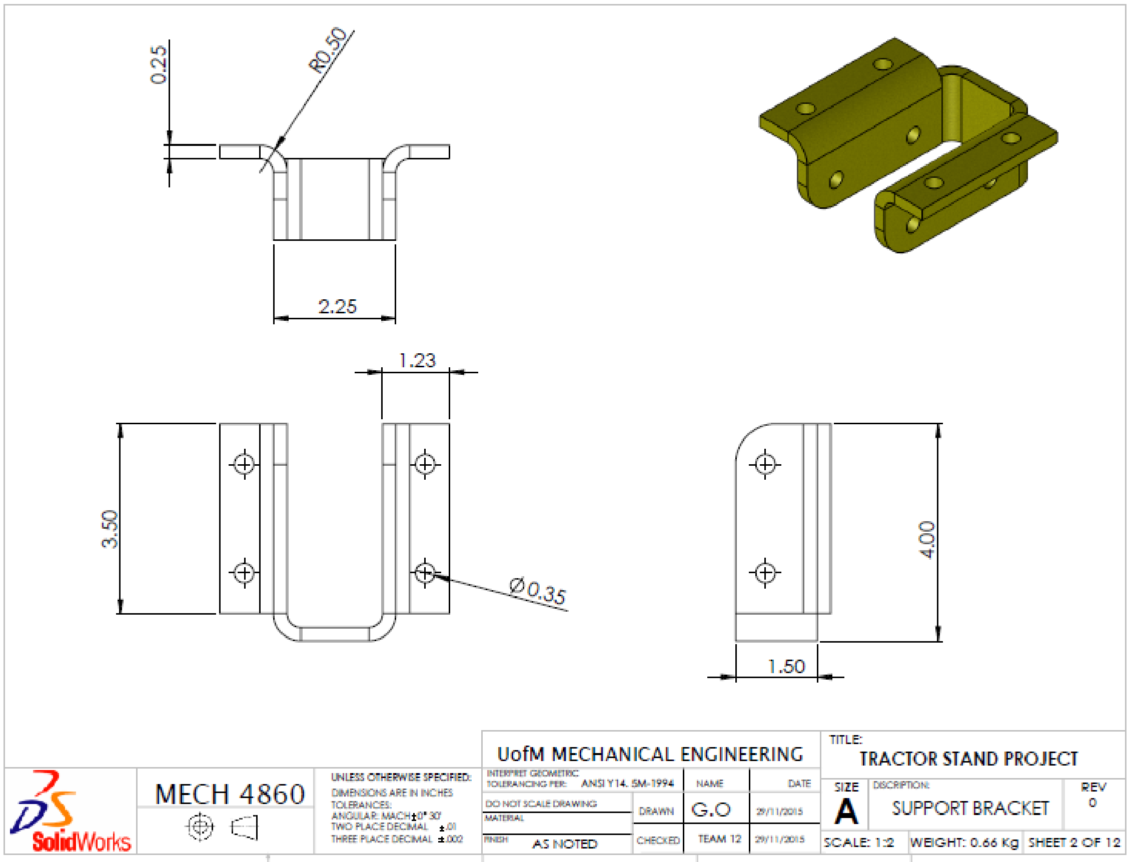


Figure 22: Drawing of Connector Bracket, with dimensions shown in inches

7.3.6 Top plate

The top plate is used for closing off the top of the mounting pocket and producing the clamping force on the axle that will help to keep the stand from moving. An image of the top plate is shown in the following Figure 23.

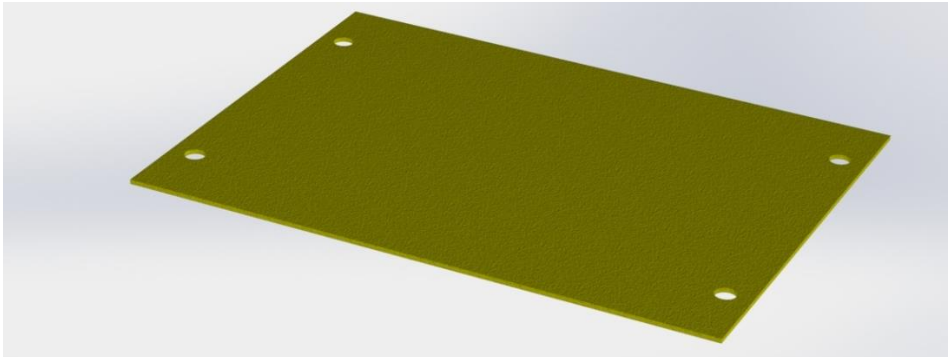


Figure 23: Rendered image of the top plate for the rear stand assembly.

This piece was designed to match the size of the top of the mounting pocket so the holes can line up and so that the force is spread over a large area. Since we do not expect as much force in this piece because of its location and function, a decision was made to make it out of 11 gauge sheet steel. This is to reduce the cost of the part. The final drawing of this part is shown in Figure 24.

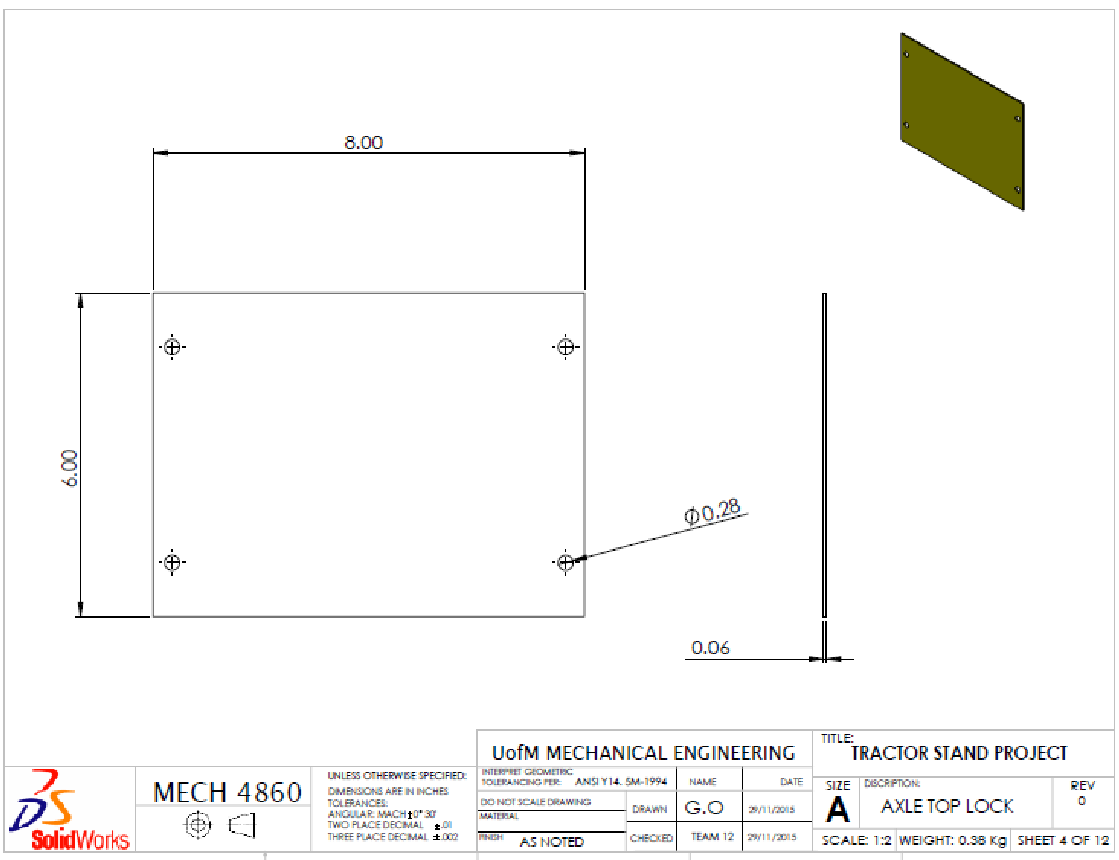


Figure 24: Drawing of final top plate design, with dimensions in inches.

7.3.7 Bottom Plate

The bottom plate is used for two main purposes in this stand design. The first use is to mount the rigid casters so the tractor can be rolled around in the assembly plant. The second is to provide stable ground contact and increase the rigidity of the stand when placed on the ground outside or when loaded on a trailer for shipping. An image of the bottom plate is shown in Figure 25.

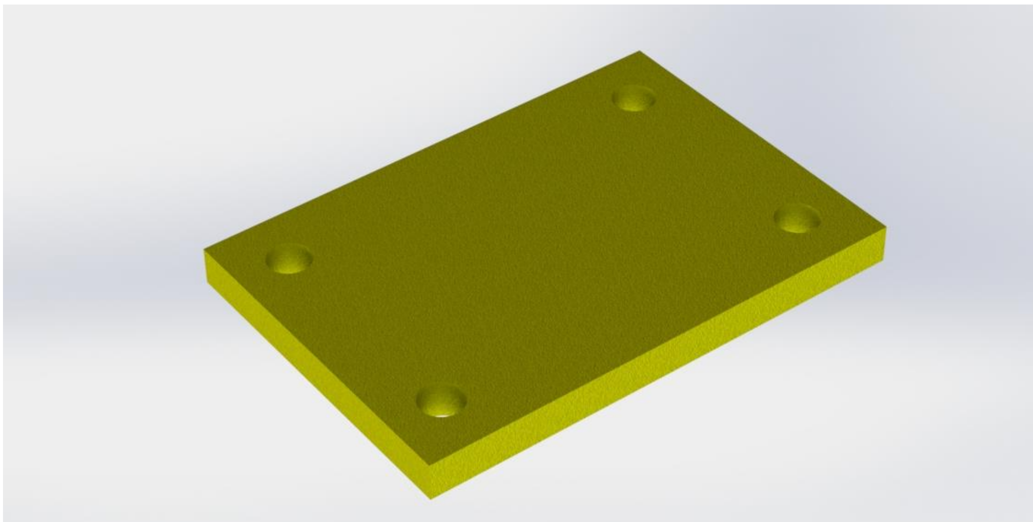


Figure 25: Rendered image of the bottom plate for the rear stand.

Because casters can be installed on the base of the stand, mounting holes need to be available to fasten the caster. The size and spacing of these holes are directly dependent on the specific caster that is specified for stand. Similarly the length and width of the stand were made to match the mounting plate of the caster. This was so there would not be more material than necessary. Overall, due to the specific caster that was chosen for the design, the bottom plate was designed to be 6.5” long by 4.5” wide. The plate also has holes for ½” bolts to mount the caster. This plate was also designed to be made of ½” thick steel to increase the bending strength of the plate when the caster is installed. The plate will not have the risk of bending when the casters of off since the bottom of the plate will be fully supported by the ground. The dimensions for the bottom plate are shown in Figure 26.

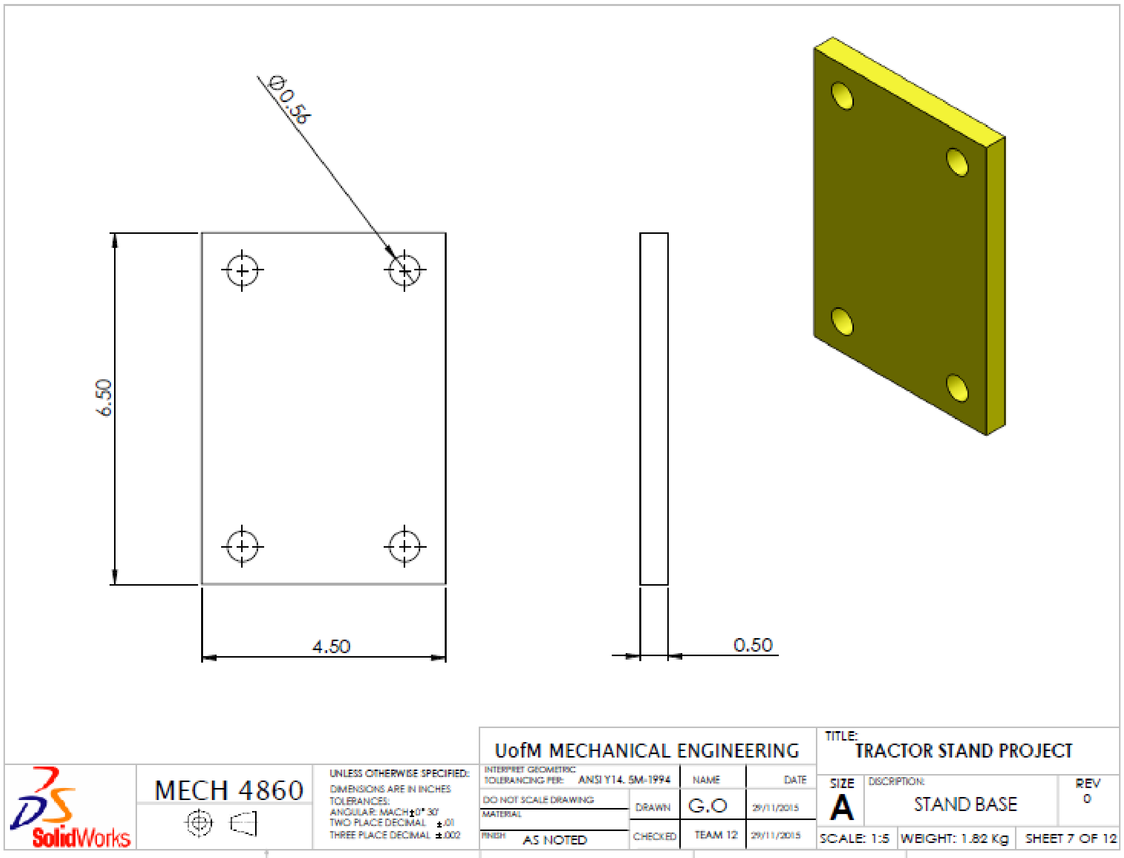


Figure 26: Drawing of final bottom plate design, with dimensions in inches.

7.3.8 Angle Brace

The angle brace is a critical part of the overall stand design. Its purpose is to provide additional strength for when horizontal loads are present by supporting the vertical stand leg. Another reason for the angle brace is to provide an extra support the middle of the stand to increase the probable buckling mode. This was important since the buckling of the stand leg was identified as a failure mode with a high risk priority number during the FMEA process. Figure 27 shows the final design of the angle brace.

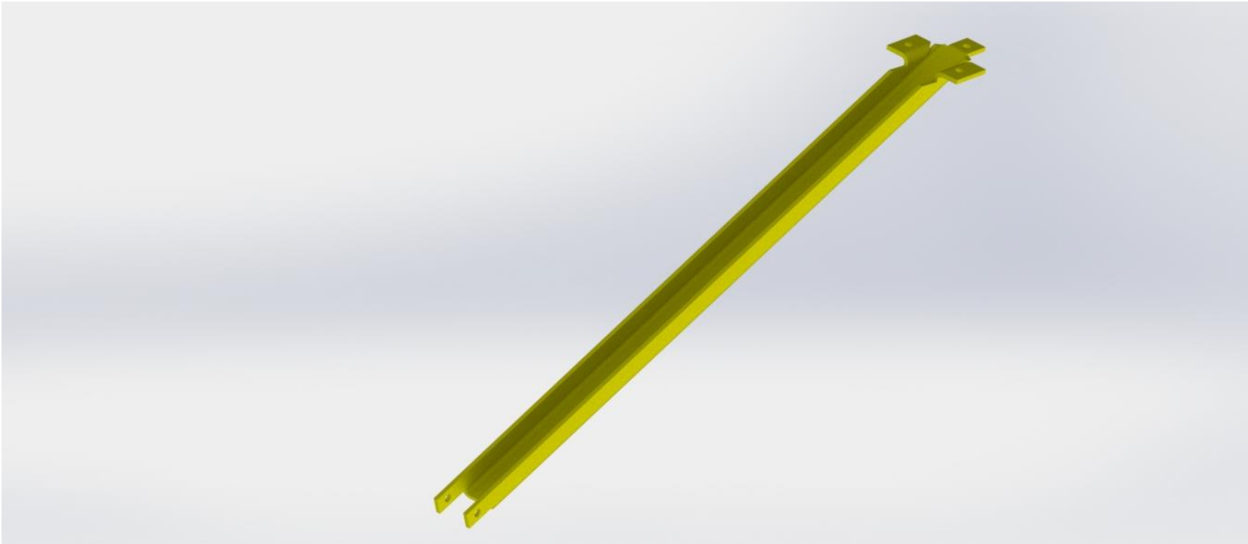


Figure 27: Rendered image of the angle brace for the rear stand.

Similar to the stand leg, the angle brace is made from 0.25 inch steel that is bent into a c-channel. 2 holes will need to be provided in the rear frame cross member to all for bolting the front end of the brace to the frame. The angle brace was designed to be connected by a single bolt to the leg of the stand. This pin type connection is used to make the cross brace a two force member and by putting the brace directly in compression the likelihood of buckling will be reduced as there will be less bending moments in the member. The length of the angle brace was designed to reach from the mounting hole on the stand leg to the underside of the frame, coming from the stand at a 45^o angle with respect to centerline of the tractor. The final design details of the angle brace are shown in Figure 28.

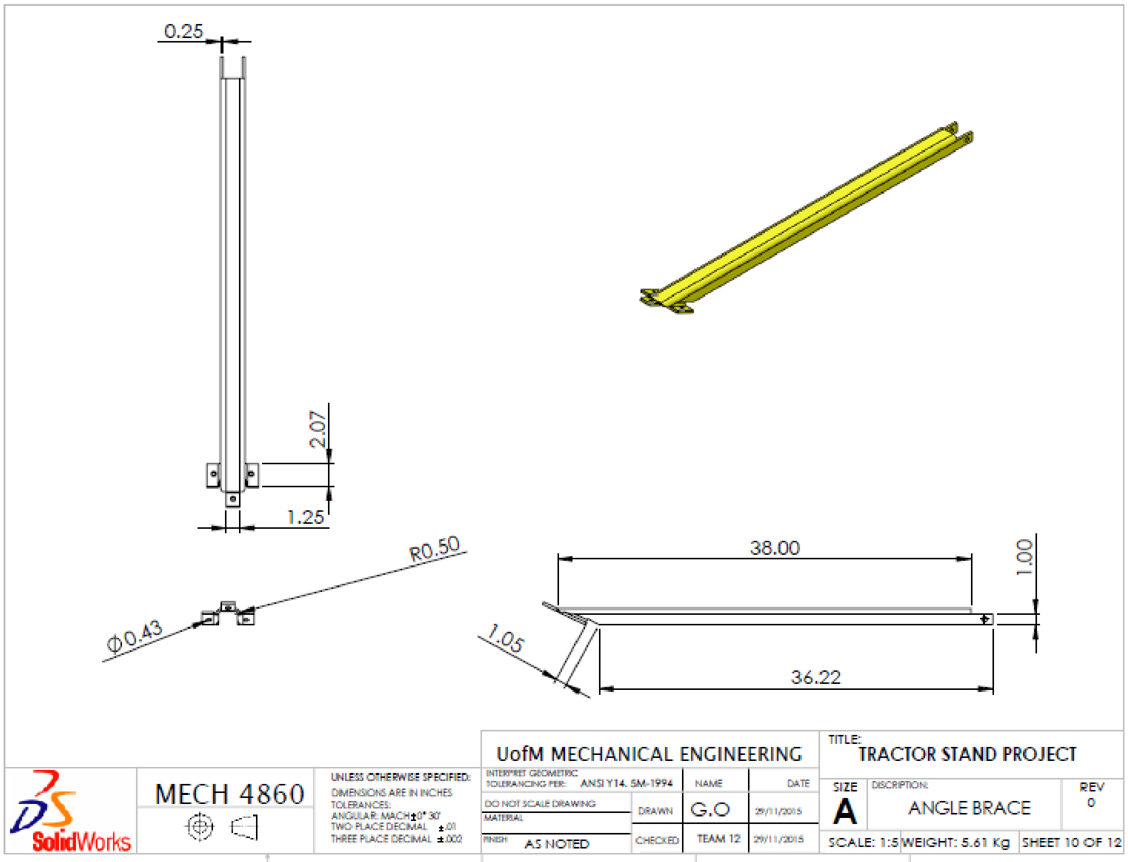


Figure 28: Drawing of final angle brace design, with dimensions in inches.

7.3.9 Shipping Shoe

The final part of the disposable stand is the shipping shoe. This is a part that is currently used by MacDon for shipping their windrowers to support the front end. The shoe is a simple sheet metal piece which can be mounted beneath the front wheel hubs. Our team chose to keep this feature in the design because the processes are already in place to manufacture and install this part. It is simple to implement and has a low cost. Similar to the rest of the stand design, this component is made from 0.25 inch steel. A picture of the existing shipping shoe support is shown in Figure 29.

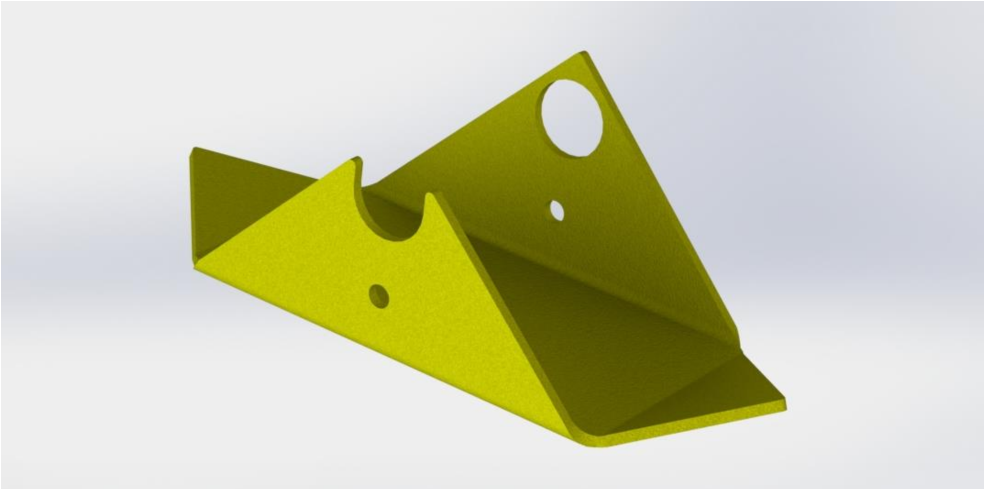


Figure 29: Rendered image of the shipping shoe for the front stand support.

7.4 Analysis of Stand Assembly

For any load bearing structure, adequate analysis must be conducted to ensure that design will meet strength and safety requirements. The following sections detail the buckling and stress analysis that was performed on the stand.

7.4.1 Buckling Analysis

For a slender structural member supporting compressive loads, buckling is immediately a mode of failure which must be considered. The best way to determine whether buckling is likely is to determine the critical buckling load. The critical concentric buckling load for a column in compression is given by the equation,

$$P_{cr} = \frac{\pi^2 n^2 EI}{L_e^2}$$

Where P_{cr} is the critical buckling load, L_e is the effective length of the column and n is the buckling mode. The variables E and I are the Young's modulus and minimum moment of inertia of the cross section respectively. Because the cross section of the stand leg is not uniform and the stand will have different boundary conditions with the casters on and off, the worst case scenario will be evaluated for risk of buckling. The worst case loading scenario was chosen by defining the worst case for each of the variables in the critical buckling load equation.

Columns by default will buckle under the first buckling mode, but additional supports can be added to strategic positions to increase the buckling mode. An angled brace was incorporated into the stand design to suppress the first buckling mode, but the ideal location for buckling mode suppression was not found, as the combination of leg geometry and boundary conditions complicated the analysis. Therefore the worst case assumption, although unlikely, was that this brace does not suppress the first buckling mode.

The bending stiffness of the stand leg is different depending on the bending axis, and also changes as a function of vertical positon due to the changing cross section. To simplify the analysis, the stand was treated as having a uniform cross section. The smallest cross section, at the base of the leg, was chosen as the worst case option. The minimum moment of inertia for this cross section is 21256 mm^4.

The effective length of the leg depends on the actual length and the end conditions of the leg. Knowing that the stand will always be fixed to the tractor on the top end, the bottom is the only end condition that can change. The actual end condition at the bottom of the leg can either be a caster wheel or a flat plate, which can be approximated as a roller and a pin respectively. The two possible end conditions and their equivalent lengths are shown in Figure 30.

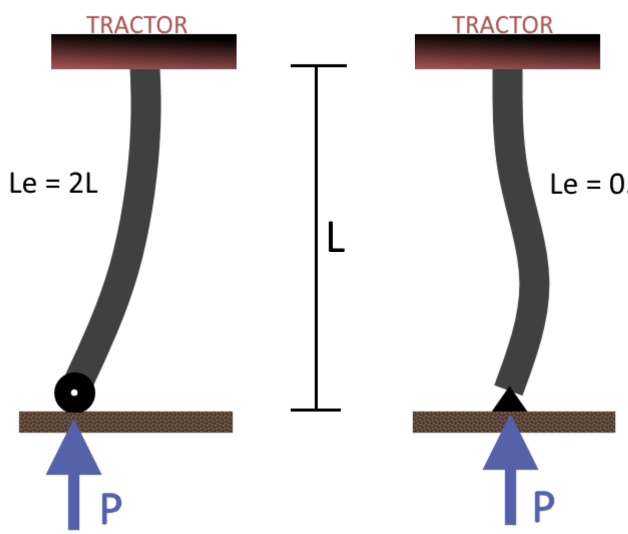


Figure 30: End conditions and corresponding equivalent lengths for the wheel (left) and plate (right) stand leg [12]

From Figure 30, it is shown that a wheel at the bottom end condition produces the largest equivalent length and therefore poses the biggest risk of buckling. Using the previous worst case assumptions and a material stiffness of 200 GPa for steel, the critical buckling load becomes

$$P_{cr} = \frac{\pi^2 * 200Gpa * 21256mm^4}{(1.56m)^2} = 62155\ N$$

This critical buckling load should then be compared to the actual compressive load seen by the legs. The calculations used to find the load supported by each of the rear stands are shown below. The center of gravity of the tractor is located 55 inches rearward of the front drive wheel hub centers and the total distance from the front wheel to the rear axle is 139.5 inches.

$$Weight\ of\ tractor = 6000\ kg * 9.81\frac{m}{s^2} = 58860\ N$$

Taking the moment about the front wheel hub,

$$\sum M_{front} = 0 = (58860\ N * 55\ in) - (F_{rear}\ N\ * 139.5\ inches)$$

$$F_{rear\ total} = \frac{58860\ N * 55\ in}{139.5\ in} = 23206\ N$$

$$F_{rear\ sides} = 23206.5\ N\ \div 2 = \mathbf{11603\ N}$$

By comparing the critical buckling load to the actual compressive load, the critical worst case buckling load is still 5.4 times larger than the force seen by the stand. Therefore the actual stand with casters concentrically loaded on level ground will not buckle. The stand will be even more resistant to buckling when the casters are removed, as the effective length will decrease.

7.4.2 Finite Element Analysis

To determine the safety of the stand when non concentric loads are applied a different loading case will need to be analyzed, where the stand is exposed to compressive and bending loads. The situation most likely for non-concentric loading is expected for when the tractor is outside of the assembly plant without casters. In this setting there is a greater likelihood of the tractor resting on uneven ground and the legs experiencing horizontal loads. This will also include the horizontal loads expected when the tractor is loaded on a trailer for shipping. When the tractor is on casters, large horizontal loads will cause the wheels to roll.

For the following analysis the worst case loading scenario for the tractor during loading was considered. When the tractor is moved around by forklifts, there is a risk that the forklift could apply a horizontal force on the tractor while it is still resting on the ground. The highest horizontal force that could be transmitted to the legs would be the maximum static frictional force. If the horizontal force would exceed the frictional force the stand would simply slide.

The maximum frictional force was found using the known weight on the stand and an expected coefficient of friction. The coefficient of friction is fully dependent on the materials that are in contact. The frictional force used in the analysis was determined from a metal-to-wood contact, replicating the contact of the stand and the deck of a trailer. An average coefficient of friction of 0.4 was used to calculate the frictional force [13]. Knowing that the expected normal force for the rear stand is 11600 N, the maximum expected frictional force was calculated to be 4640 N.

The next stage in the analysis was to determine the maximum deflection at the bottom of the stand when the 4640 N horizontal load is applied. Solidworks Simulation FEA was used to solve this deflection with the force applied in the lateral direction with respect to the tractor. The leg and angle brace were the components of interest in this analysis so they were the only components analyzed. This was also due to the limitations of Solidworks Simulation and the difficulty it has with analyzing full assemblies. The base plate was also included because it is where the horizontal forces would be applied. The top of the stand leg was constrained to replicate the connection between the leg and the mounting pocket, while the angle brace was constrained to replicate the bolted connection to the frame. In addition, shell elements were used for all sheet metal parts. Figure 31 shows the displacement plot that resulted from the analysis.

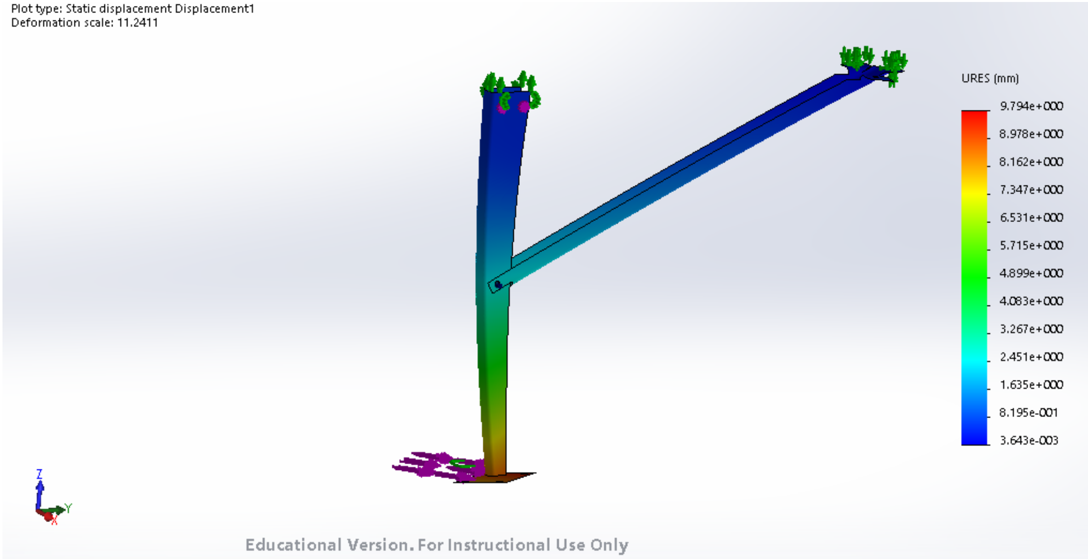


Figure 31: Preliminary displacement plot of the left stand leg with 4640 N lateral load.

With the previous horizontal lateral load, the bottom of the stand is expected to be displaced 9.8 mm. This displacement represents the eccentricity of the compressive load applied by the weight of the tractor. Instead of applying a remote load to the bottom of the stand, an equivalent concentric load will be applied with an additional bending moment to account for the offset. Given that the compressive load is 11600 N and the eccentricity was found to be 9.8 mm, a moment of 113.7 Nm will be added to the base of the stand along with the lateral and compressive load.

The last stage of FEA that was performed consisted of the same boundary conditions as used in the purely lateral loading case. The loads that were applied were the 11600 N compressive load, a 4640 N lateral load to the base of the stand, and a 113.7 Nm moment to account for the eccentricity of the compressive load. Figure 32 shows the results of the stress analysis.

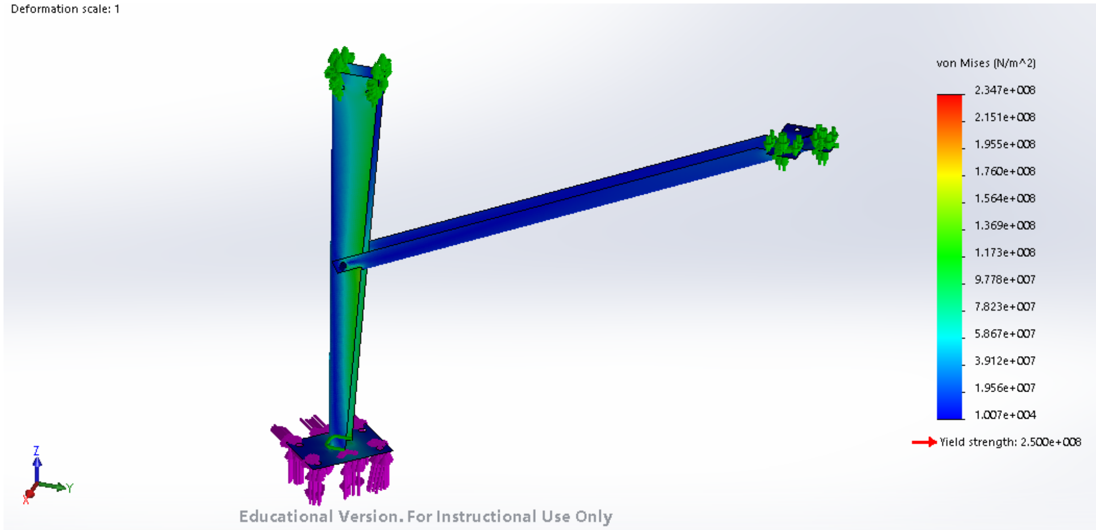


Figure 32: Preliminary FEA Von Mises stress results for rear stand leg with worst case horizontal loading

The results show that the stress is well below the yield strength of the material. There are four specific areas in this stand assembly that should be examined for the stress results. First, the length of the leg shows the most stress along the open end of the c channel. As shown in Figure 33, the stresses are the highest close to the bolted connection where the angle brace is connected.

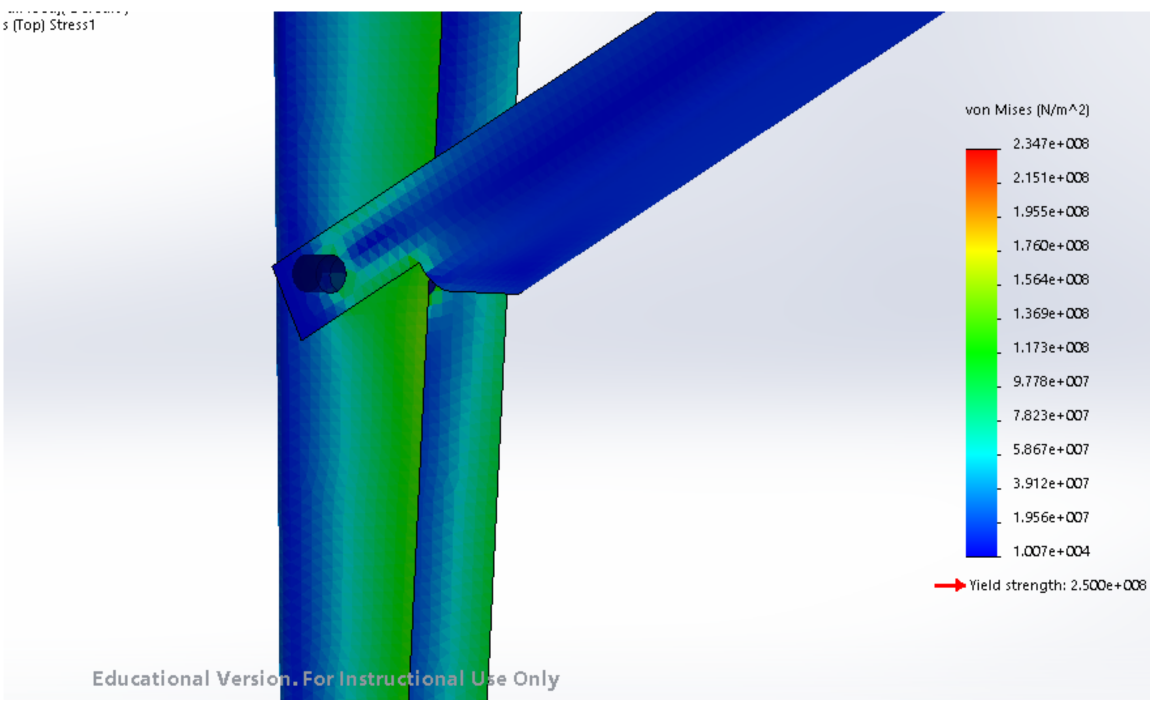


Figure 33: Preliminary FEA Von Mises stress results near the bolted connection of the stand leg and the angle brace.

In this area the highest stress is 147.3 MPa, corresponding to a safety factor of 1.7 relative to the yield strength of the material.

The next place of interest is the welded connection between the leg and the base of the stand. As shown in Figure 34, the maximum stress is located right along the connection.

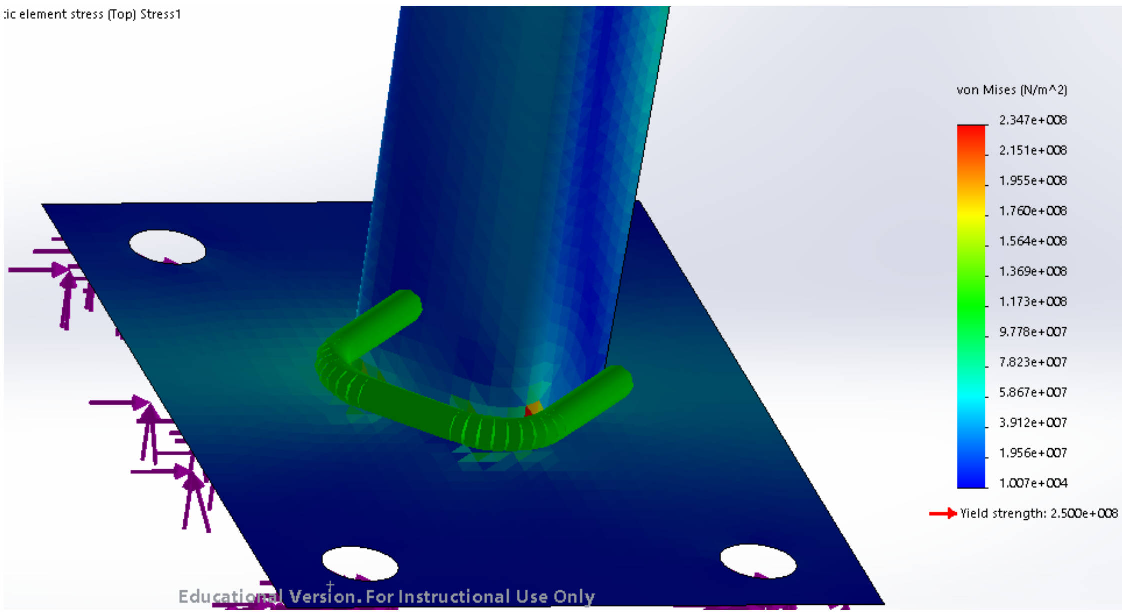


Figure 34: Preliminary FEA Von Mises stress results at the welded connection between the stand leg and bottom plate.

The figure shows one element that has a unusually large stress, compared to the elements in the near vicinity. This could be a spurious stress resulting from element shape or numerical solving. Regardless, the stress is still below the yield stress and all the next lowest stress is 210 MPa, which still has a safety factor of 1.2.

The next location to be examined is the top of the stand. The stress plot at this location is shown in Figure 35.

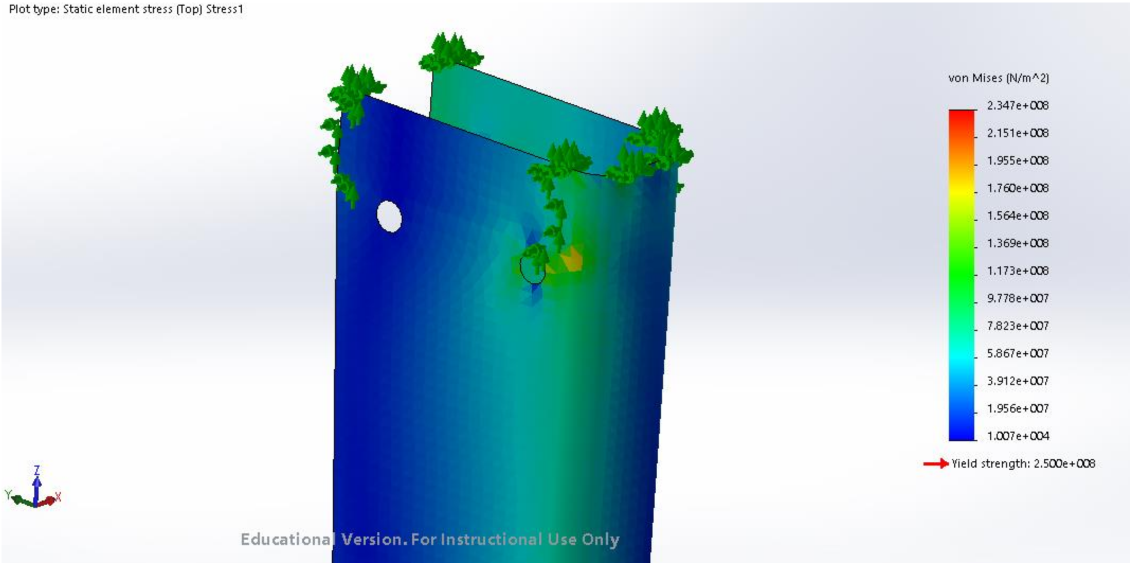


Figure 35: Preliminary FEA Von Mises stress results at near the stand leg bolt holes.

The previous stress plot shows one area of high stress in the vicinity of a bolt mounting hole and a bend in the sheet metal part. The highest stress at this location is 183 MPa which still has a safety factor of 1.37.

The final location of interest is the location where the angle brace mounts to the tractor. This location has the lowest stress of the four examined areas, having a maximum stress of 86.3 MPa. This relates to a safety factor of 2.90. This stress plot is shown in Figure 36.

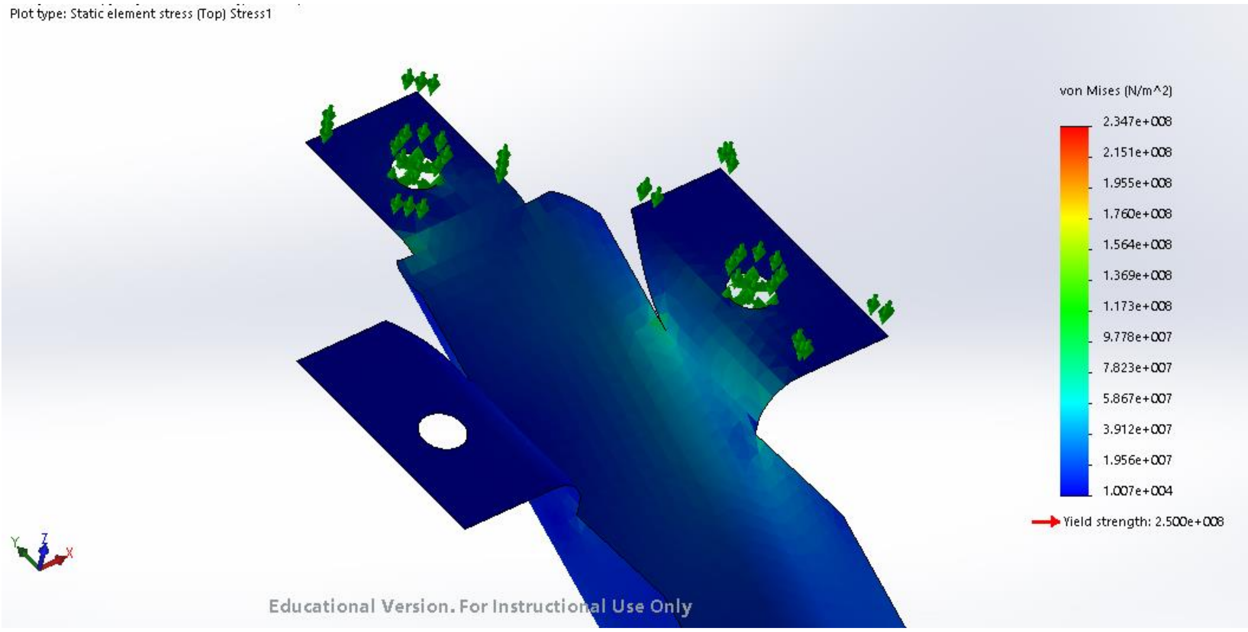


Figure 36: Preliminary FEA Von Mises stress results showing stresses in the angle brace where it mounts to the tractor.

The FEA stress analysis that was conducted on the stand took into account the worst case loading conditions as estimated by the team. The results showed that the minimum safety factor in the lower leg assembly was 1.37 when the outlying element value was not considered. These results fell within the safety factor range of 1.25-2 as requested by the client.

7.5 Caster Assembly

The caster assembly was incorporated to the design to provide extra functionality and flexibility for when the tractors are in the production facility. The casters to be used in the design were chosen based on a few considerations. The most important requirement was that the selected combination of casters had to be rated to support the full weight of the tractor. The second requirement was to have at least one pair of swiveling casters. These were needed to provide easier maneuverability of the tractor on the stand.

The static weight distribution on the rear stands for the tractor has already been found to be 23206 N total. The weight on the front supports of the tractor can be found by finding the difference between the total weight and the weight on the rear.

$$F_{front\ total} = 58860\ N - 23206\ N = 35653\ N$$

$$F_{front\ sides} = 35653\ \div 2 = \mathbf{17826\ N}$$

The weight values can also be converted into pounds since many caster manufacturers provide the rated load for the caster in pounds. Making this conversion, each side of the front supports will bear 4000 lbs, while each side of rear support will bear approximately 2600 lbs. Casters were then chosen with weight ratings equal to or above these values.

The first caster that was specified was for the rear stands. A rigid caster was identified as being the best choice for this location. Swivel casters have a wheel offset which eccentrically loads the part mounted to the caster. Since the rear stand legs are trying to be designed to minimize buckling and bending, a rigid caster was chosen. A rigid caster that is centered properly on the stand leg will concentrically load the leg. Considering the 2600 lbs minimum capacity and that costs should be minimized, a McMaster 2435T63 rigid double wheel rigid caster was selected for each side of the rear stand [10]. This caster is rated for loads up to 2800 pounds. The caster was specified to have a slightly larger capacity than required to further reduce the risk of failure, as wheel failures were identified as potential failure modes where the risk should be minimized. A drawing giving the dimensions of this caster is shown in Figure 37.

Figure 37: Drawing of the rigid caster chosen for the rear stand [11].

With rigid casters chosen for the rear of the stand, swivel casters were chosen for the front. Considering the 4005 pounds minimum capacity and that costs should be minimized, two McMaster 2435T32 compact alliance dual wheel casters were selected for each front wheel axle, as shown in Figure 38. The diameter of each wheel is 6 inches, and the width of each wheel is 2 inches. Each wheel of this caster is rated for loads up to 2400 pounds, and the total capacity of the caster is 4800 pounds. To further reduce the risk failure, the selected caster has a slightly larger capacity than required.

Figure 38: Drawing of the compact alliance dual wheel caster chosen for the front wheel axle [11].

Each of the swivel casters should be able to freely rotate 360 degrees. To maximize the turning angle of each caster, as well as minimize the distance between two casters for each assembly, the casters were positioned in-line in the longitudinal direction of the tractor, as shown in Figure 39.

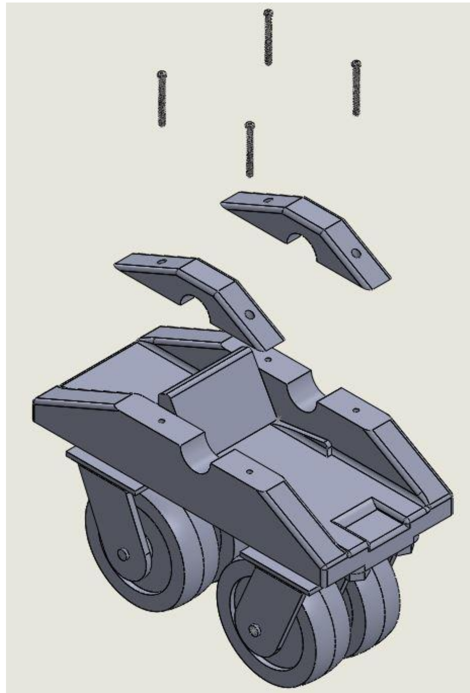


Figure 39: Exploded view of front wheel assembly.

The front caster assembly includes two top fixtures, four screws, and a base which has two casters mounted in-line. Figure 40 and Figure 41 show the dimensions of the top fixture and base of the front caster assembly.

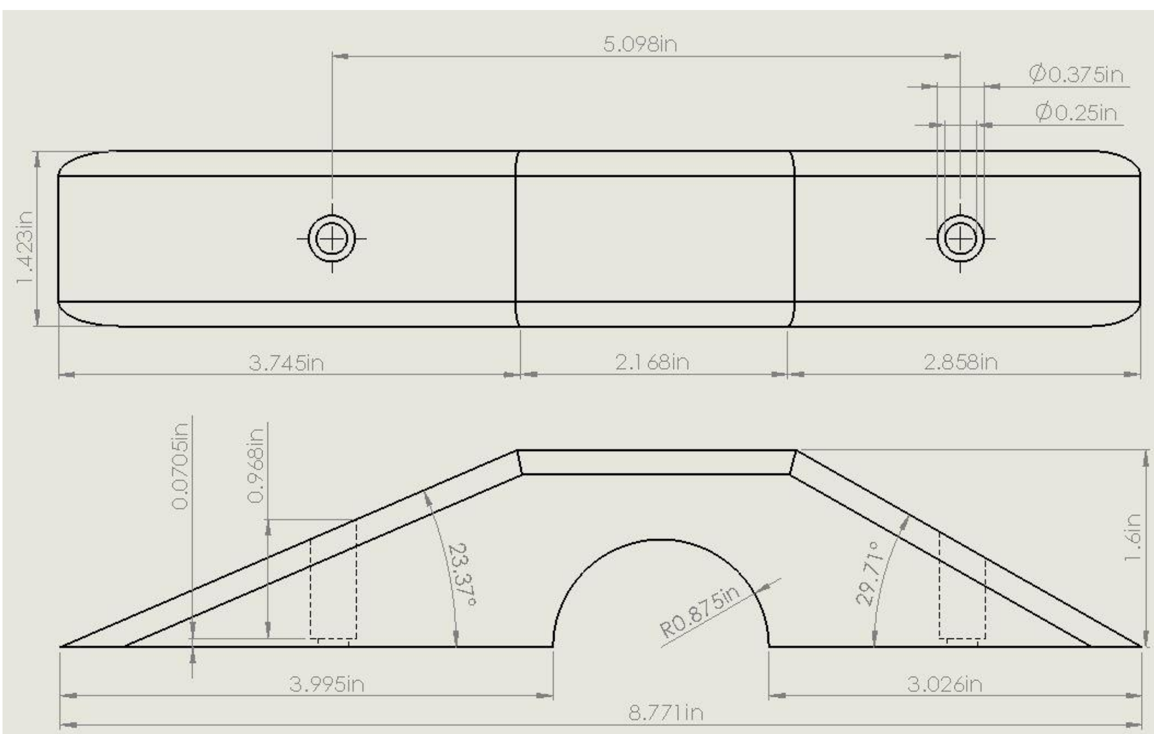


Figure 40: Dimensions of the top fixture of the front caster assembly.

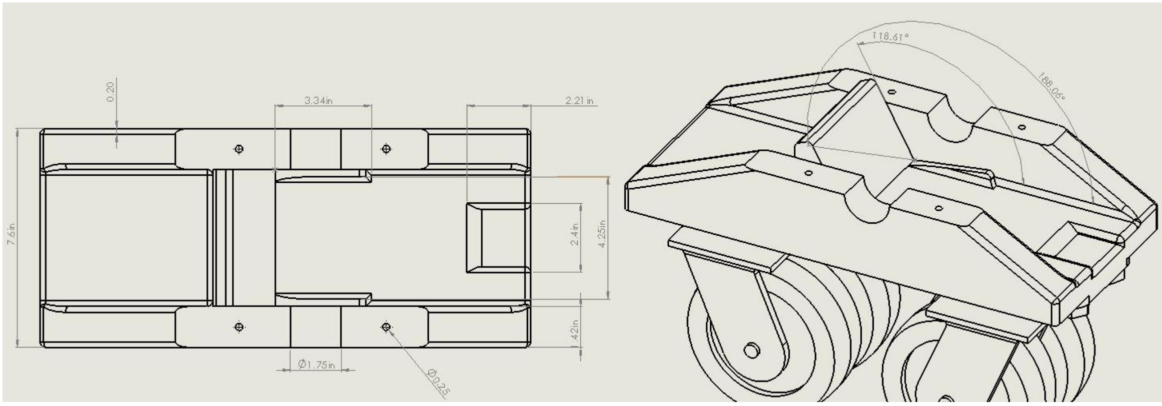


Figure 41: Dimensions of the base of front caster assembly.

As shown in Figure 42, the front caster assembly was designed to be installed on each front wheel axle. The front caster assembly is identical to each other. The base requires to be machined by computer numerical control machine. The fillet of the top fixture and the base is 0.2 inch.

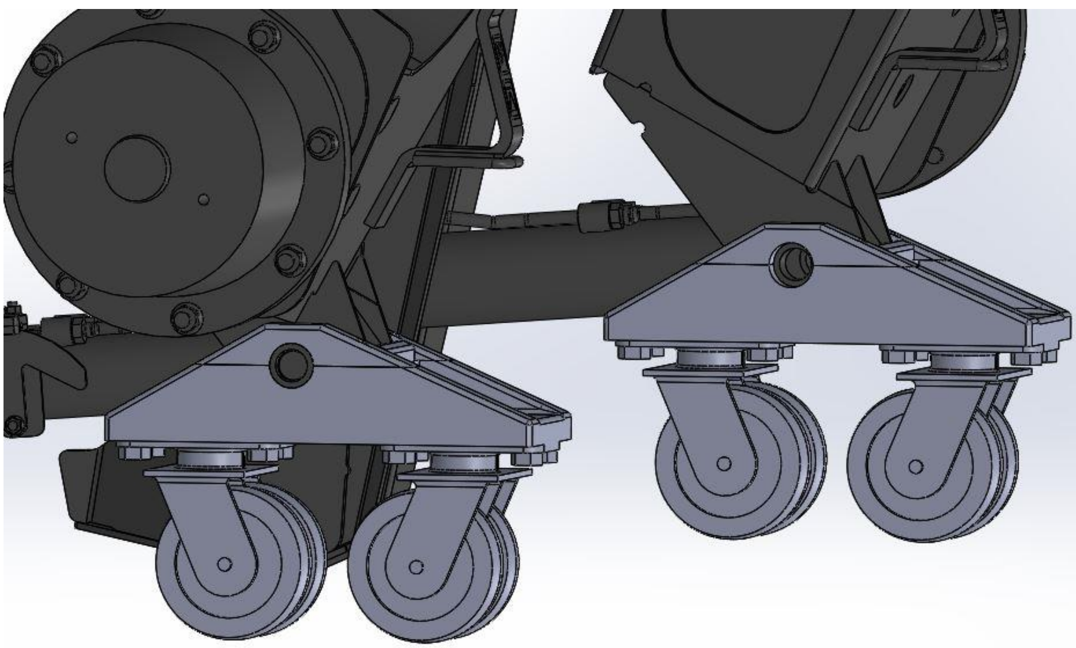


Figure 42: Front wheel assemblies installed on the front wheel axles of the tractor.

To avoid rotating during the operation, the design took an advantage of the two surfaces (angle between the two surfaces are 110.55 degrees) of each front wheel axle. As shown in Figure 43, the two surfaces of the front wheel axle are perfectly sitting on the base to avoid rotating.

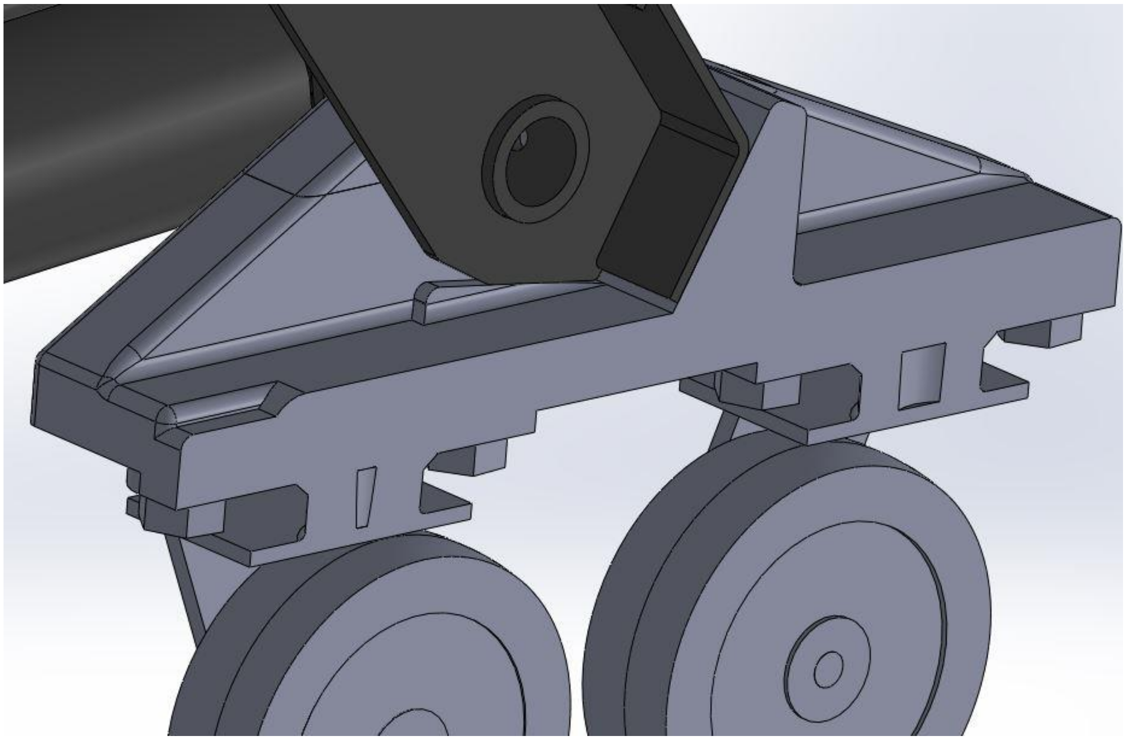
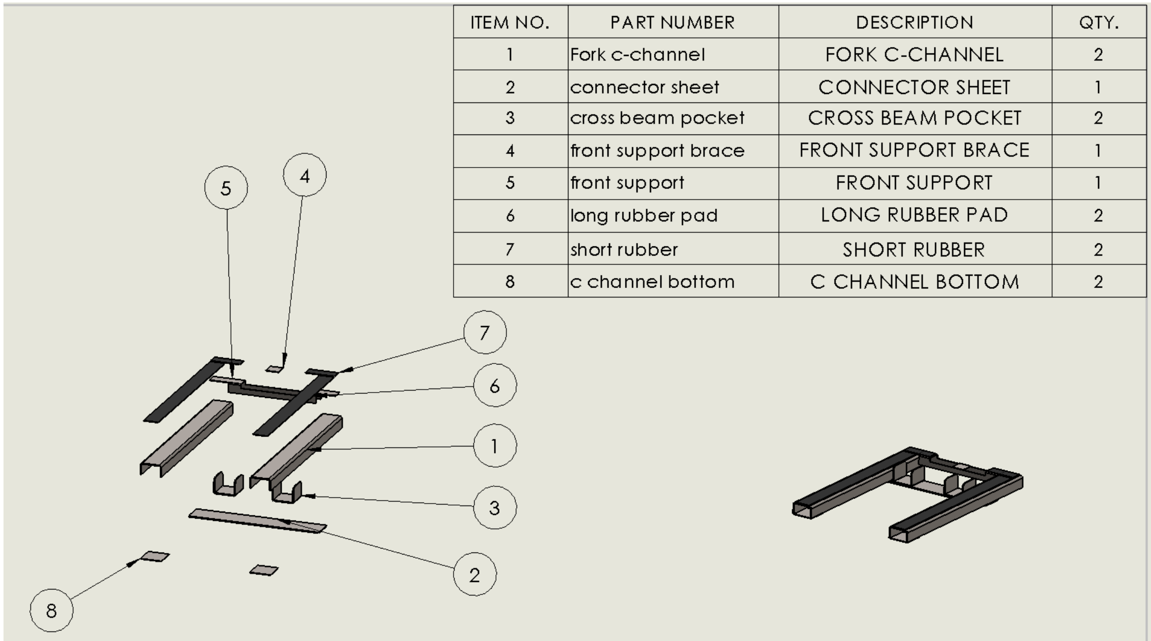


Figure 43: A cross-section view of the design consideration for avoiding rotating during operation.

7.5 Forklift Attachment

The forklift attachment was included as a part of the final design to make the movement of the windrowers by forklift safer and easier. The forklift attachment was designed to fit within the frame of the current windrower models so it could be lifted from the front and both the left and right sides. The attachment was designed so it could be positioned with the tractors center of gravity nearly centered between the forks while lifting. Another goal of the design was for it to accommodate rubber or plastic pads that could add grip and protect the painted surfaces on the tractor. All the parts involved in designing the forklift attachment have uniform thickness and can be made out of sheet metal. The exploded view of the reusable forklift attachment is shown in Figure 44.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Fork c-channel	FORK C-CHANNEL	2
2	connector sheet	CONNECTOR SHEET	1
3	cross beam pocket	CROSS BEAM POCKET	2
4	front support brace	FRONT SUPPORT BRACE	1
5	front support	FRONT SUPPORT	1
6	long rubber pad	LONG RUBBER PAD	2
7	short rubber	SHORT RUBBER	2
8	c channel bottom	C CHANNEL BOTTOM	2

Figure 44: Exploded view of the Forklift Attachment.

By carefully observing the bottom frame of the tractor and taking correct measurements from the supplied CAD model, the forklift attachment was designed symmetrically so it could be lifted from the three desired sides. This design eliminates the need to build two different forklift attachments each specialised for either the front or the side. The detailed drawings of all the parts used in making the forklift attachment are discussed in the following paragraphs.

The design is based around the two c-channels that the forks slide into for lifting. This design allows for the tractor to be fully supported on the two c channels when lifting the tractor with a forklift. The length of these pieces had to be long enough to reach the far end of the frame when lifting from the left and right sides. This included the extra distance to clear the ladder platform on the forklift side. Furthermore, the length was designed to be long enough to support the tractor when lifting from the front. In this case it had to extend far enough to reach past the center of gravity. The two fork c-channels are designed to fit the forks of all the large forklifts currently being used at MacDon Industries. A drawing of this component is given in Figure 45.

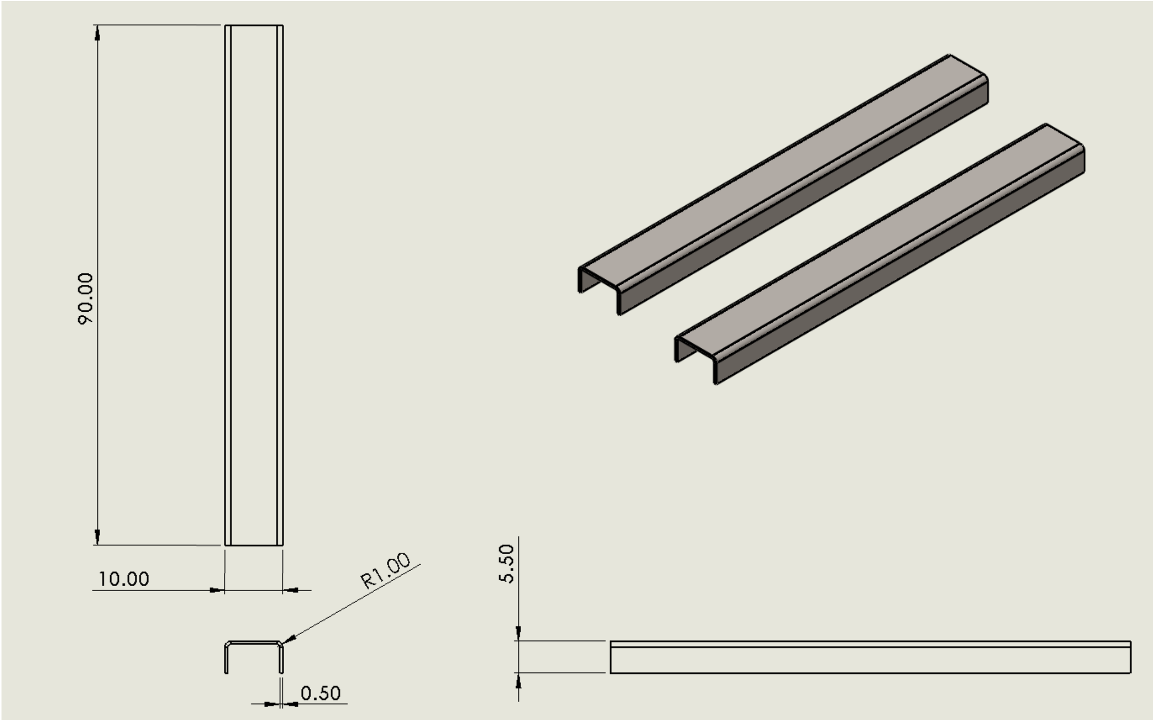


Figure 45: Drawing of Fork C channel, with units in inches.

Figure 46 shows a drawing of the front support component, which is used to hold the two fork c-channels together and create more lifting area. Careful consideration had to be taken when designing the front support. The main focus was to create a shape that would not interfere with the frame of the tractor when lifting from the side and to extend the supporting area between the forks for lifting from the front. A uniform c channel beam was first considered to connect the two fork c channels together which worked for lifting the tractor from the front but not from the side. This was due to the fact that the uniform c channel was interfering with the bottom frame of the tractor when lifting the tractor from the side. The frame cross member that dips below the plane of the rest of the frame is shown in Figure 47.

Figure 46: Cross sectional view of the tractor frame showing the cross member (bottom of image) that is not in the level plane as the rest of the frame.

To solve the interference problem, measured cut outs had to be made in between the front support structure to make it be compatible with the bottom frame of the tractor when lifting the tractor from the side.

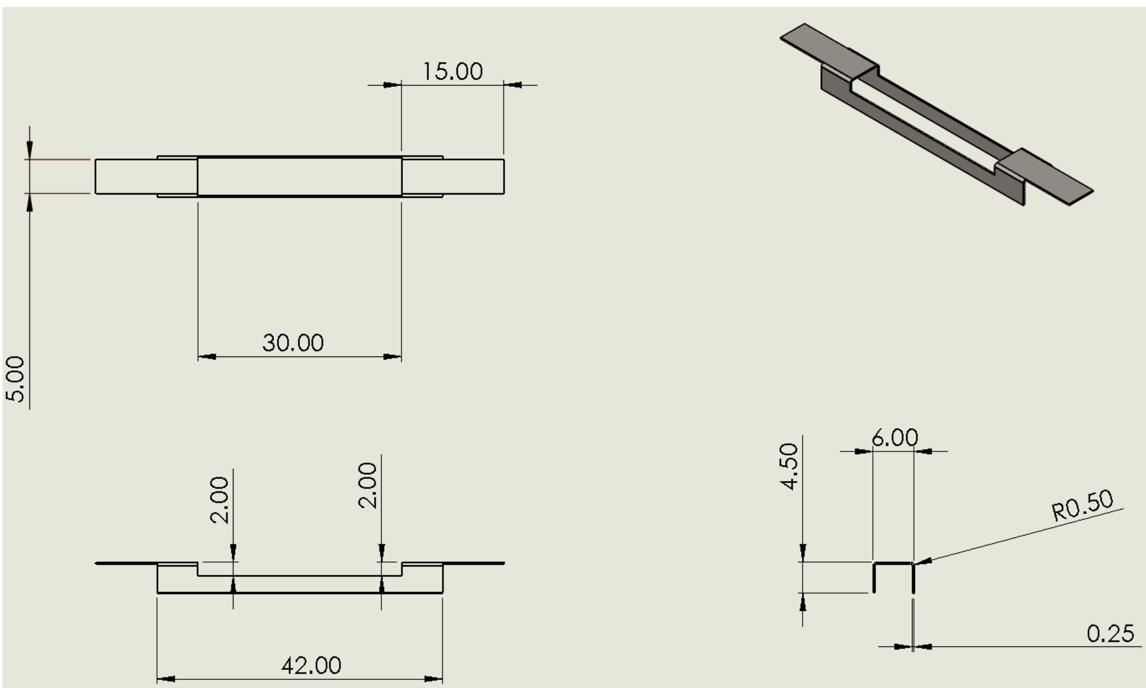


Figure 47: Drawing of the Front support piece, with dimensions in inches.

Due to the cut-out in the front support piece, the two parallel sheet metal edges have a long span without and support structure. An additional piece was designed to connect these two sections by being welded between them. This was done to improve the rigidity of the frame. A drawing of this connecting piece is shown in Figure 48.

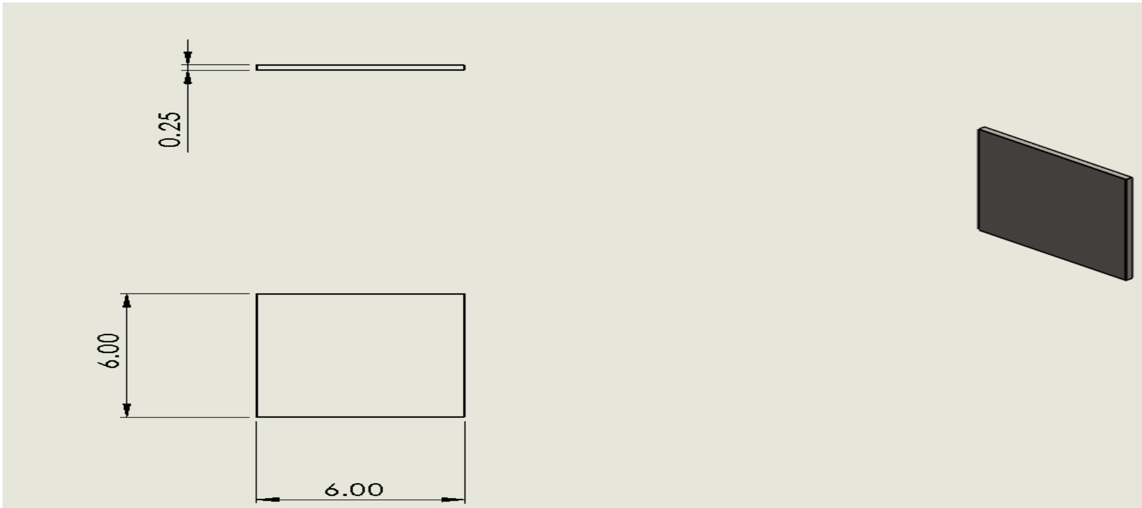


Figure 48: Drawing of the Front support brace, with units in inches.

The next component of the attachment assembly is the connector sheet. The connector sheet, shown in Figure 49, is a flat sheet metal part that performs two functions. The first function is to provide an extra connection between the two fork c channels and the second functions is to act as a mounting location for the two u shaped cross beam pockets that will be discussed in the next paragraph.

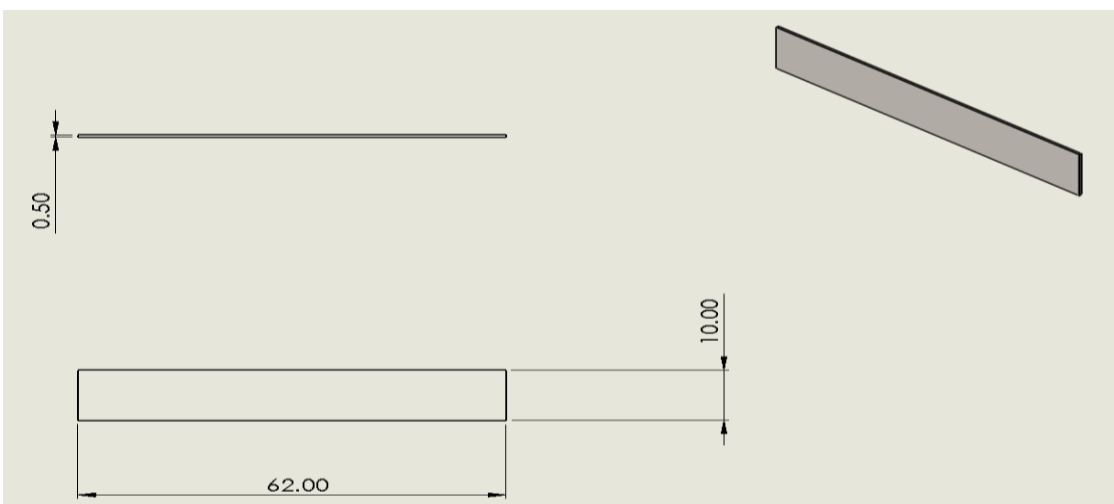


Figure 49: Part drawing of the Connector sheet, with units in inches.

One of the goals of the forklift attachment was to prevent the tractor from shifting while being moved by the forklift. The cross beam pocket is the part of the forklift attachment that securely mounts to the frame of the tractor from the bottom and keeps the forklift attachment in position relative to the frame. The cross beam pocket is a unique part of the forklift attachment that fits the frame of the tractor when lifting from both sides and the front. A large radius was put on the edges of the pocket to make a smoother edge. This will help to reduce the risk of paint scratching. A drawing of this part is shown in Figure 50.

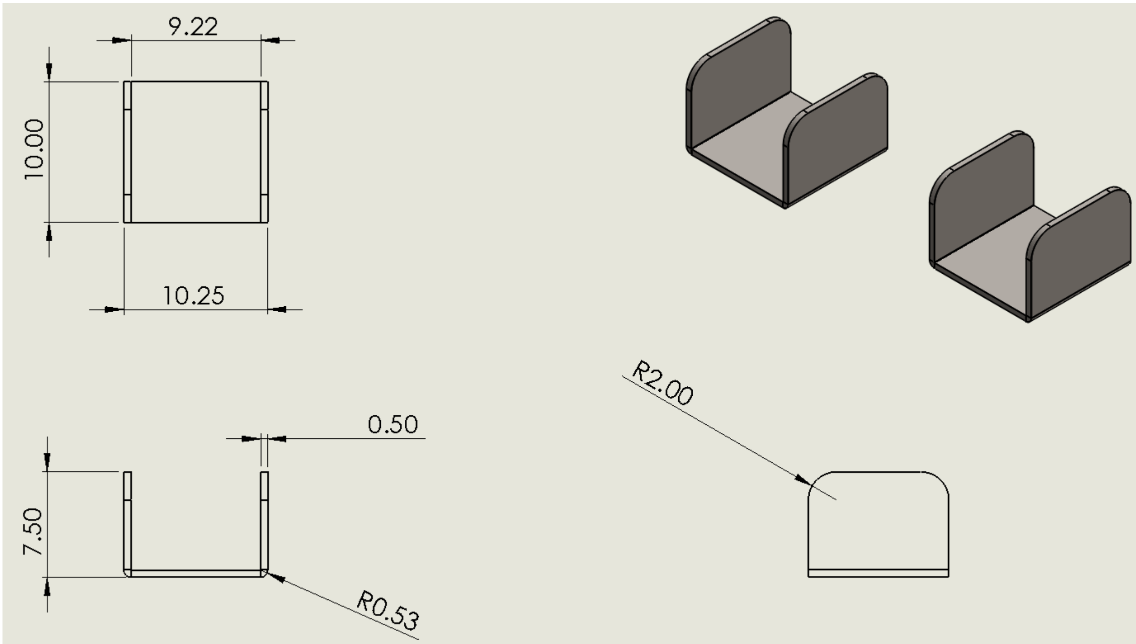


Figure 50: Drawing of the Crossbeam Pocket, with dimensions in inches.

The C-Channel Bottoms are used to close off the fork c channels at the front end of the attachment. This will allow for a forklift equipment to go through the fork c channel loops when lifting the tractor. This piece is also useful in preventing the attachment from lifting off the forks. The team considered designing a c channel bottom that could cover the whole frame of the fork c channel but decided that the additional material was not necessary. The drawing for this piece is given in Figure 51.

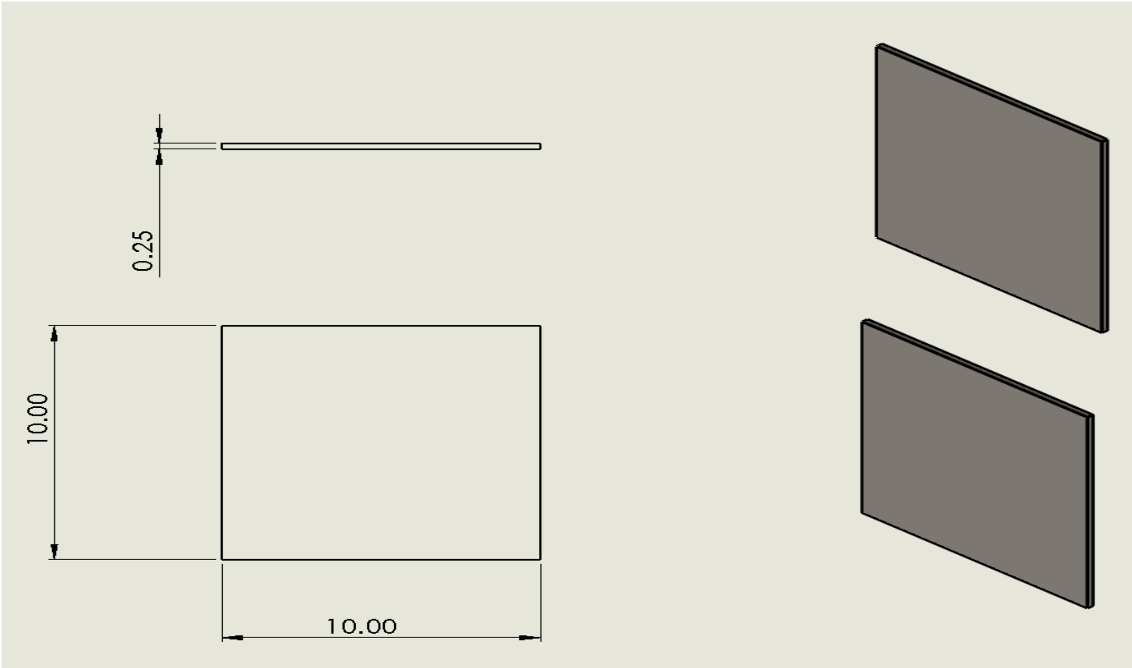


Figure 51: Drawing of the C-channel Bottom component, with dimensions given in inches.

The final design component of the forklift attachment is the rubber or plastic pads which can be put on the top surface of the attachment. The rubber pads are designed to fully cover the surfaces of the parts that will be in contact with the frame of the tractor to add additional grip and paint protection. Two lengths of pad will be required for the design; a long piece to cover the length of the fork, and a short section to cover the front support piece. The specific material for these pads can be varied depending on what is available to MacDon. Figures 52 and 53 show the dimensions suggested for the long and short rubber pads respectively.

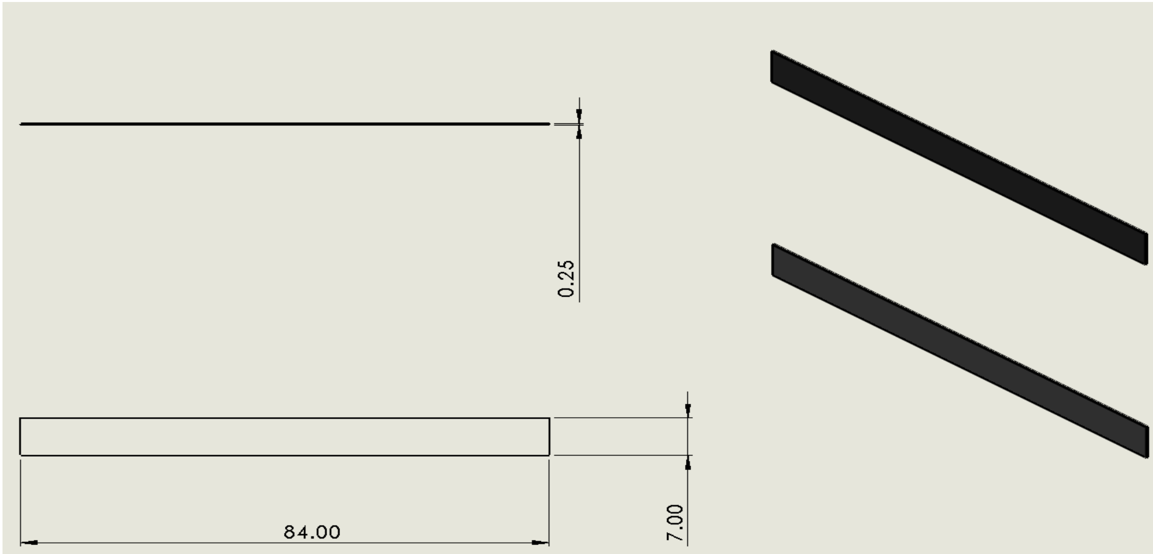


Figure 52: Drawing of the Long rubber pad, with dimensions in inches.

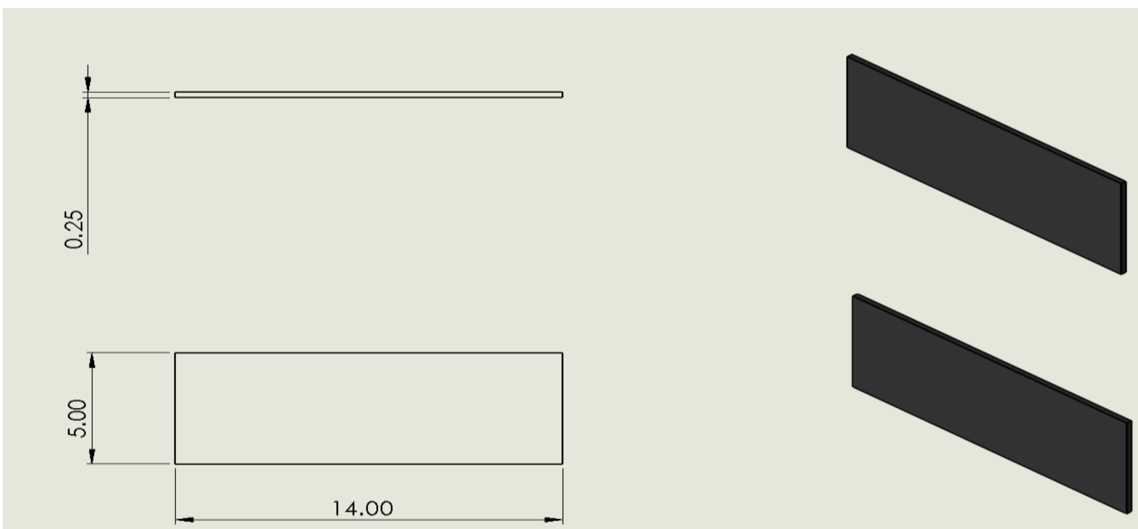


Figure 53: Drawing of the Short rubber pad component, with dimensions given in inches.

7.5.1 Mounting Forklift Attachment to the Forklift

The forklift attachment must be securely mounted to the forks before lifting the tractor. Proper mounting is achieved when the forklift attachment is lying flat on the ground and the forklift operator drives the forklift through the two main c-channels as seen in Figure 54. From here the attachment can be raised to lift the tractor.

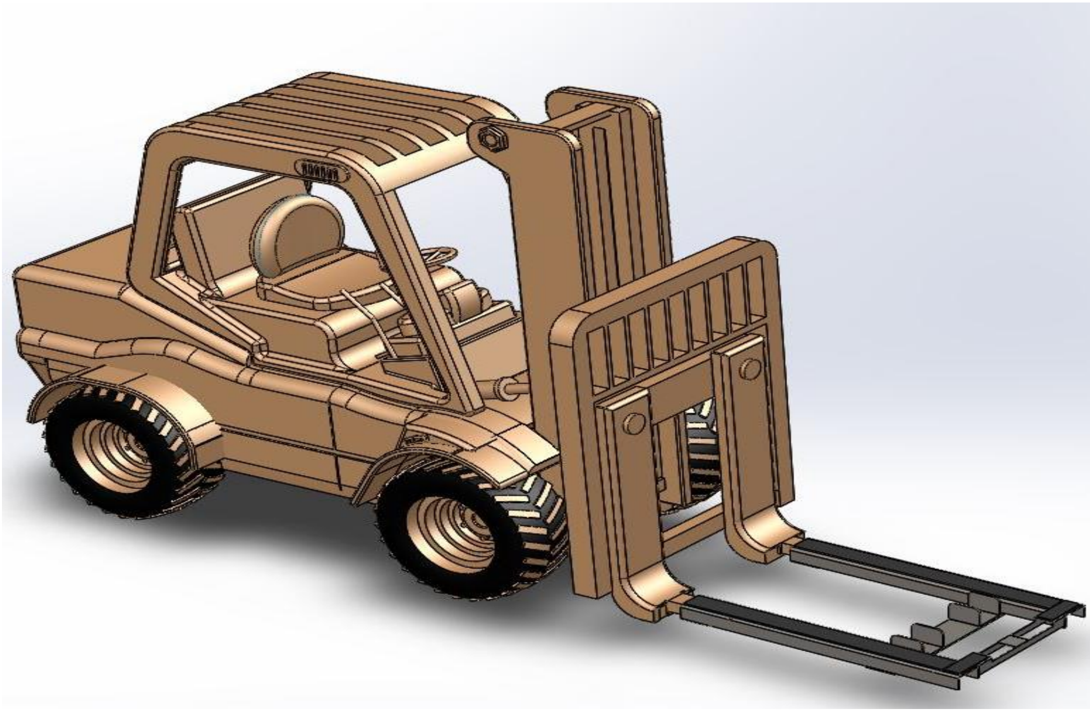


Figure 54: Example of forklift attachment mounted to a representative forklift, not to scale [14]

7.5.2 Lifting Tractor From The Side

To lift the tractor from the side after the forklift attachment is securely mounted to the forks, the forklift operator should position the forklift attachment as shown in Figure 55. The inner edge of the right fork c-channel should be roughly in line with the rear edge of the ladder platform in order to properly align the pocket with frame and to prevent the possibility of scratches and dents.

Figure 55: Forklift attachment position for lifting tractor from the side

Figure 56 demonstrates how the pocket fits with the frame at this location to help prevent the tractor from sliding on the forks.

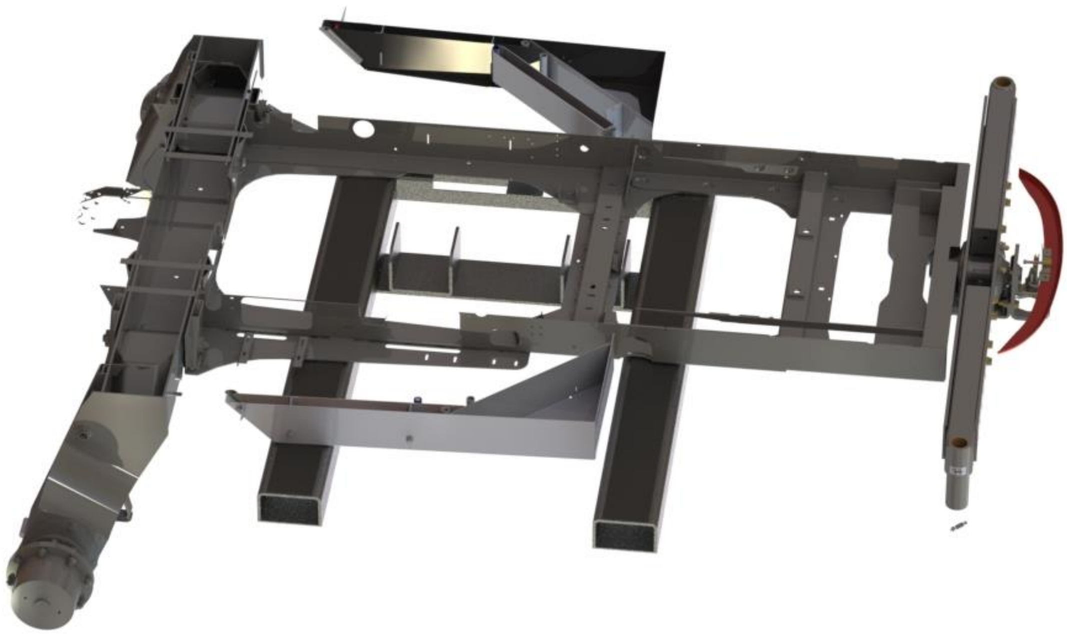


Figure 56: A sectional view of the tractor frame showing how the attachment pocket fits around the frame.

The attachment should be aligned in an equivalent fashion when lifting from the right side of the tractor.

7.5.3 Lifting Tractor From The Front

To lift the tractor from the front after the forklift attachment is securely mounted to the forks, the forklift operator should align the forklift attachment as shown in Figure 57. The forklift attachment should be approximately centered with the cab.

Figure 57: Rendered image of the forklift attachment in position to lift from the front of the tractor.

Figure 58 also shows how the attachment pockets fit within the frame in this lifting configuration to reduce the likelihood of the tractor sliding.

Figure 58: Cross sectional view of the tractor frame showing how the attachment fits with the frame.

7.5.4 Storage

The forklift attachment is very convenient when it comes to storage and the availability of storage space. The rectangular shape makes it easy to store the forklift attachment anywhere in the storage facility. Multiple forklift attachments can be placed on top of each other to minimize storage space. To safely store the attachment, a forklift simply needs to set the attachment down and backs out, leaving the attachment in the given storage location.

7.6 Implementation of Design

Having detailed the design features and details for the disposable stand, forklift attachment and caster assembly, the final aspect to be address is how the workers and operators will interact with the designs. The people responsible for assembling and using the designs must also be aware of the important features and the limitations for the components they will be using. Our teams FMEA results predicted that improper use of the designs would be a significant risk, so having the operators aware of these risks will help them to avoid using the products in a way that they were not designed for.

In an effort to convey the features and proper usage techniques to the workers and operators, an assembly guide and operating manual was produced. This was one of the deliverables required by the client. The resulting document is given in Appendix C.

8. Bill of Materials

Having thoroughly described the three sections of the final design, the final Bill of Materials (BOM) can be compiled for disposable stand, the reusable forklift attachment and the reusable caster assembly.

8.1 Disposable Stand Assembly BOM

The following table outlines the complete list of components needed to make the disposable stand assembly. This includes parts for the rear stand, the front shipping bracket and all mounting hardware.

TABLE XI: BILL OF MATERIALS FOR DISPOSABLE LEG ASSEMBLY

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	STAND LEG	Stand Leg	1
2	AXLE POCKET 45 deg	AXLE POCKET 45 deg	2
3	STAND BASE	Stand Base	1
4	90854A167	Nut	4
5	94223A102	Nut	6
6	95327A589	Bolt	2
7	Bolt Bushing	Bolt Bushing	3
8	AXLE TOP LOCK	Axle Top Lock	1
9	91280A330	Bolt	4
10	94223A101	Nut	4
11	ANGLE BRACE 4	Angle Brace	1
12	91280A557	Bolt	1
13	94223A103	Nut	1
14	SUPPORT BRACKET	Support Bracket	1

8.2 Caster Assembly BOM

The following table outlines the complete list of parts required to make the caster assembly. A total of 48 pieces is needed for the design, including all fastening hardware.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Front Wheel	Compact alliance dual wheel swivel caster	4
2	Top Fixture	Top fixture	2
3	92220A206	Low-profile Alloy steel socket head cap screw	8
4	93810A580	Bolt	24
5	953036A038	Nut	8
6	Rigid Double Rear	Compact alliance double wheel rigid caster	2

8.3 Forklift Attachment Assembly BOM

The following table outlines the complete list of parts required to make the forklift attachment. A total of 13 individual pieces is needed for this design.

TABLE XII: BILL OF MATERIALS FOR THE FORKLIFT ATTACHMENT ASSEMBLY.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Fork c-channel	FORK C-CHANNEL	2
2	connector sheet	CONNECTOR SHEET	1
3	cross beam pocket	CROSS BEAM POCKET	2
4	front support brace	FRONT SUPPORT BRACE	1
5	front support	FRONT SUPPORT	1
6	long rubber pad	LONG RUBBER PAD	2
7	short rubber	SHORT RUBBER	2
8	c channel bottom	C CHANNEL BOTTOM	2

9. Cost of Final Design

With all components for the final design defined, the total cost can be calculated to determine if the design remained within the allotted budget of $100 per stand. Each of the three design sections will contribute to the final cost.

The largest cost for the overall design is the disposable stand itself. Although the individual parts are relatively inexpensive, a disposable stand assembly is required for each of the 5000 tractors that are expected to be built during the five year design life. The unit cost of the disposable stand assembly is given in Table XIII.

TABLE XIII: TOTAL COST OF ONE DISPOSABLE STAND

Final Design (Disposable Parts)			
	Rear Stand	Shipping Shoe	Fasteners
# of Units	2	2	34
Unit price ($)	22.31	1.93	0.58
Total Price ($)	44.26	3.86	20.00
Total Price per Stand	**$68.12**		

The design also includes some reusable features which also need to be included in the unit cost. Our team anticipated that three forklift attachments could be produced, corresponding with the three models of large forklift used at MacDon, allowing all three forklifts to move tractors simultaneously if needed. Our team also anticipated that four sets of caster assemblies would be required for use in the assembly plant. Four full sets would allow there to be three tractors in the rework bays while the final set would be installed on the next tractor off the line. Each set of casters consists of 4 front casters and 2 rear casters.

To include the cost of the reusable components with the cost of the disposable stand assembly, the total cost of all reusable parts was determined. This total price was then divided by the number of tractors that would use these components over the five year cycle (5000) to get a portion of the cost for each tractor. The cost breakdown for the reusable components is shown in Table XIV.

TABLE XIV: COST BREAKDOWN FOR THE REUSABLE PARTS IN THE FINAL DESIGN.

Final Design (Reusable Parts)			
	Attachment	Front Casters	Rear Casters
# of Units	3	16	8
Unit Cost ($)	154.36	116.62	82.85
Total Price ($)	463.08	1865.92	662.80
Total Reusable Price ($)	2991.80		
Total Price per Stand	**$0.598**		

By considering the effect of the disposable and reusable aspects of the final design, the final design was found to cost $68.72 per tractor. This was below the $100 per tractor limit that was set by the customer.

10. Conclusion and Recommendations

Throughout this project our team has been working with MacDon Industries to design and develop a stand design that could support the current windrower tractors without needing the drive wheels or casters installed. This project has taken us through the complete design stage, from the definition of our customer's needs through to detailing the final design. We were able to combine features from several different concepts to produce a design that incorporated the convenience of a disposable design with the cost effectiveness of a reusable design.

The final design consists of three subsections. A disposable stand was designed to support the tractor without the wheels needing to be installed, as this was the main goal of the project. The stand will be mounted to the tractor during assembly and will remain there until the tractor is delivered to the dealers. Structural analysis was performed on this stand to ensure that it would be safe to use, even in the worst case loading situation. To meet the safety requirements, a forklift attachment was designed to make moving the tractors with a forklift easier and more secure. The design also needed to integrate with the current production process, so a caster wheel assembly was designed for use in the assembly plant. These reusable wheels allow the tractor to remain mobile when the large forklifts cannot be used to move them. Sheet metal parts were designed wherever possible with A1011 steel to match with MacDon's manufacturing abilities and material resources.

For this design to be the most beneficial for MacDon, additional analysis should be conducted on design factors that were out of the scope of this project, or where information was not readily available. One such area could be the loading and manufacturing processes. More information would be needed to compare the current process times with the estimated times associated with the new design. Likewise, a more accurate cost analysis could be performed using MacDon's actual material costs and by sourcing hardware and casters from MacDon's suppliers.

Other changes could also be made to simplify the design. The disposable stand was designed to safely support a 6000 kg tractor, while the current tractors are only 4500 kg. With the disposable stands, dimensions could be changed to optimize the stand for the current weight. The stand could then be made stronger as the future tractors get larger in size. This could be a way to reduce the cost further. Another future change that could reduce the cost is for the wagons on the assembly line. If the wagons were designed so they could go into the rework area, the need for a caster assembly would be eliminated.

The final recommendation to improve the designs is to conduct thorough analysis using MacDon's best practice for designs. This would include specifying minimum safety factors for each component as per their standards. Industrial FEA software could also be used to fully analyze the strength of the disposable stand design, going beyond the limitations imposed by the simulation software that was used. This could include performing stress analysis on the entire stand assembly to fully determine the interactions between components. It could also include performing fatigue analysis using the SN curve for the exact alloy being used. The analysts could also re-assess the worst case loading scenarios to consider the impact of vibrations and dynamic loads experienced during transportation.

Overall, our team was able to meet the needs set out by the client in the early stages of the project. Our final design meets the cost requirement with an expected cost of $68.72 per stand, meets the weight limitation with a total weight of 385kg and has the desired functionality for this design to be implemented.

11. References

[1] Products, Self-Propelled Windrowers and Headers [Online]. Available: http://macdon.com/products/category/self-propelled-windrowers-and-headers [September 20, 2015].

[2] "Hero_m-series-4", in M Series SP Windrowers [Online]. Available: http://www.macdon.com/uploads/images/hero_m-series-4.jpg [September 25, 2015].

[3] Quality Policy [Online]. Available: http://www.macdon.com/about [September 20, 2015].

[4] MacDon, "Full Assembly" MacDon Industries, Winnipeg, MB, [September 23, 2015].

[5]Inflation.eu WORLDWIDE INFLATION DATA (2010). "Inflation Canada-current Canada inflation" [Online]. Available: http://www.inflation.eu/inflation-rates/canada/in flation-canada.aspx [September 05, 2015].

[6] MacDon Industries, "Forklift Specification Tag" MacDon Industries, Winnipeg, MB, [September 23, 2015].

[7] MacDon Industries, "Bottleneck Stage" MacDon Industries, Winnipeg, MB, [September 29, 2015].

[8] MacDon Industries, "Material Thickness and Alloys," Unpublished. [Dec.05.2015]

[9] AK Steel "HOT ROLLED STEELS" [Jun.22.2012] Available: http://www.aksteel.com/pdf/markets_products/carbon/AK_Hot_Rolled_PDB_201406.pdf

[10] McMaster-Carr. Compact Alliance Dual Wheel Caster [Online]. Available: http://www.mcmaster.com/#2435t63/=101abpk [November 25, 2015].

[11] McMaster-Carr. "2435t630l.gif" [Online]. Available: http://www.mcmaster.com/mva/library/20121029/2435t630l.gif?ver=1351167914 [November 25, 2015].

[12]. F.P. Beer, E. R. Johnston, J. T. DeWolf, D. F. Mazurek (2012). Mechanics of Materials, 6th ed [Print]. [November 20, 2015].

[13] Coefficient for Static Friction of Steel [Online]. Available: https://www.carbidedepot.com/formulas-frictioncoefficient.htm [December 5, 2015].

[14] Kaliraj. (Dec.03.2014) "Forklift" [Online] Available: https://grabcad.com/library /forklift-9 [Dec.05.2015]

[15] Sean Hakansson, “MacDon tractor in 3 tractor loading configuration on flatbed trailer” MacDon Industries, Winnipeg, MB, [September 23, 2015].

Appendix A: Details of Reusable stand design

The reusable stand is not selected as our final design, therefore, all of the numerical and analytical analysis will be stated in the appendix as below.

- **Cost of Reusable Stand**

The material selected for building the reusable stand is the same with the material for usable stand. From the client's target specifications, the safety factor is between 1.25 and 2.5. The team chose 1.5 and applied the following calculation. Finally taking the cost of unit weight into consideration, the team decided to select the Hot-Rolled A1011 CQ, for which the yield tensile stress is 200 MPa and yield shear stress is 100 MPa.
Table XV concludes the total cost for both reusable and disposable stands, containing all of the assembled components.

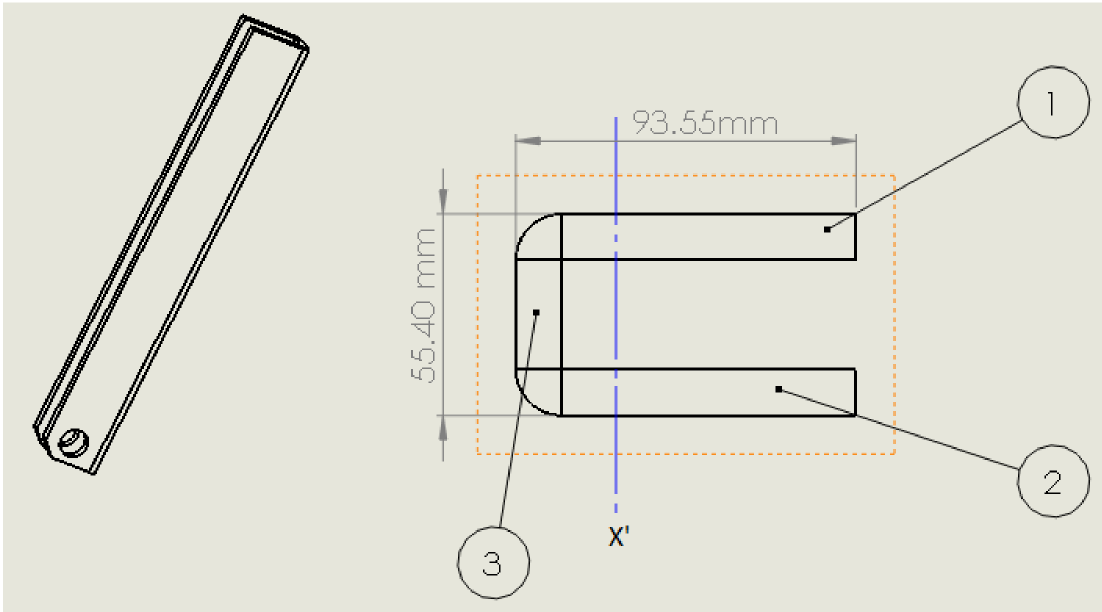
Table XV Total Cost of the One Reusable Stand

Reusable Stand			
	Stand	Bolt+Nuts	Front Casters
Unit	x1	x4	x4
Price ($)	154.56	15	582.32
Sum Price ($)	751.88		

All reusable stands will be produced in the first year for quantity of 200, and can be reusable for next 5 years. Therefore the present value of stands is the sum total price of 200 stands, which can be calculated as the following equation.

$$\textbf{Present Value of Reusable Stand} = 751.88 \times 200 = \$150376$$

- **Analytical Calculations**



	Area (mm^2)	Y_0 (mm)	AY_0 mm^3
(1)	1028.7	46.775	41.7×10^3
(2)	1028.7	46.775	41.7×10^3
(3)	381	6.35	2.4×10^3
	2438.4		85.8×10^3

New center of inertia can be calculated by equation:

$$\overline{Y_0} = \frac{\sum AY_0}{\sum A} = \frac{85.8 \times 10^3}{2438.4} = 35.19\ mm$$

Centroid moment of Inertia: the parallel-axis theorem is used to determine the moment of inertia of each rectangle with respect to the axis X' that pass through the centroid of the composite section. Adding the moments of inertia of the rectangles, we write:

$$I_{X'} = \sum(\bar{I} + Ad^2) = \sum\left(\frac{1}{12}bh^3 + Ad^2\right)$$

$$I_1 = \frac{1}{12} \times 12.7 \times 81^3 + 1028.7 \times 5.31^2 = 591.447 \times 10^3\ mm^4$$

$$I_1 = I_2$$

$$I_3 = \frac{1}{12} \times 30 \times 12.7^3 + 381 \times 28.84^2 = 322.016 \times 10^3\ mm^4$$

$$I_{Tot} = I_1 + I_2 + I_3 = 913.463 \times 10^3\ mm^4 = 913.463 \times 10^{-9}\ m^4$$

The critical force creates the buckling is

$$P_{cr} = \frac{\pi^2 E\ I_{Tot}}{L^2} = \frac{\pi^2 \times 200 \times 10^9 \times 913.463 \times 10^{-9}}{(2 \times 0.67)^2} = 1034839.12\ N$$

The force acting on the individual beam is 14715 N ($\frac{Windrower\ Weight}{4}$), which is much less than P_{cr}. Therefore, the team assured that there will be no buckling created.

Next the material need to be test if the applied stress will excess the allowable stress with safety factor 1.5.

$$\sigma = \frac{F}{A} = \frac{14715}{2.4384 \times 10^{-3}} = 6.03 \times 10^6\ Pa = 6.03\ MPa$$

$$\sigma < \frac{\sigma_{Yield}}{1.5} = 133MPa$$

Because applied stress is less than yield stress of selected material; therefore, the legs can safely support the windrower.

- **Bolt Calculations**

The design uses pin-connection to make four legs able to rotate. The front view and side view of design are shown in the Figure [A1] and Figure [A2].

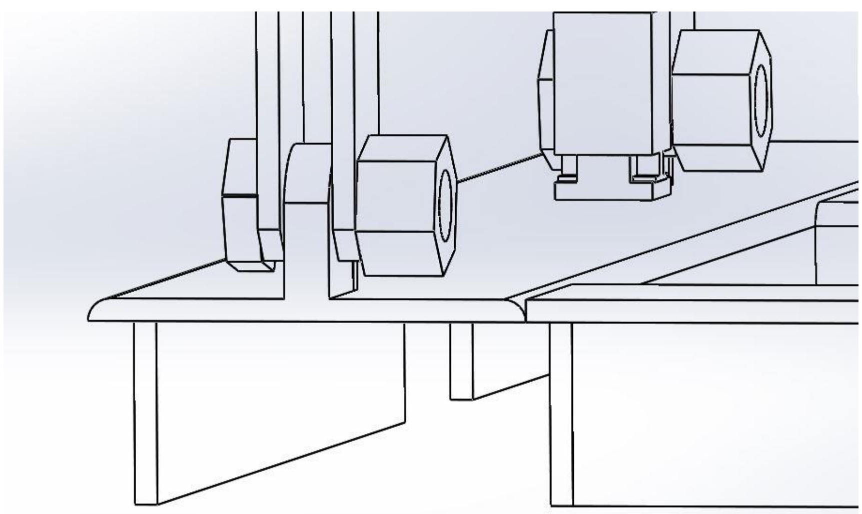


Figure A1: Front view of pin connection

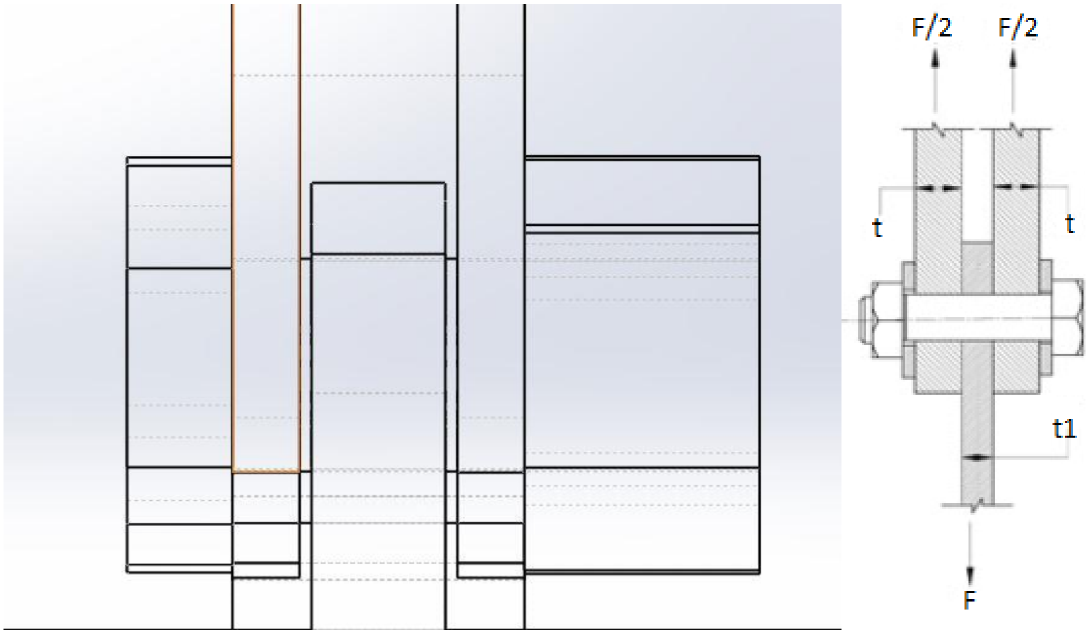


Figure A2: Side view of pin connection

The calculation focus on the yield stress of the bolt, to make sure the pin-connection will not crack.

As can be seen from the Figure [A2], the pin is in double shear. The diameter of the selected pin is 40mm, and the calculation steps and outcomes are shown in the TABLE [A1].

Shear Stress Average = Applied Force / Area

$$Shear\ Stress\ Average = \frac{F}{2\ \pi\ r^2}$$

Bearing Area Stress for t Plate and Bolt/Pin

$$B_t = F/(2\ t\ d)$$

Bearing area stress for plates t1 and Bolt/Pin

$$B_{t1} = F/(t_1\ d)$$

TABLE A1 DIMENSION OF THE PIN-CONNECTION AND OUTCOMES

Bolt or Pin Double Shear Stress	
Applied Force F (N)	14751.00
Pin Diameter d (mm)	40
Plate Thickness t (mm)	12.7
Plate Thickness t1	25.4
Yield Stress of the Material (MPa)	340
Factor of Safety	1.5
Results	
Section Area of Pin (mm^3)	1256.628
Shear Stress Ave Pin (MPa)	5.85
Bearing Area Stress B_t (MPa)	14.48
Bearing Area Stress B_{t1} (MPa)	14.48
Allowable Stress (MPa)	226.67

The highest shear stress applied in the pin is 5.85 MPa, which is much less than allowable shear of the bolt used in the MacDon. Therefore, the pin-connection is absolutely safe to use in the design.

- **Fatigue Analysis**

When the team tested fatigue life, the stress applied on the top can be assumed as repeated fluctuating stress which is shown in the Figure A3.

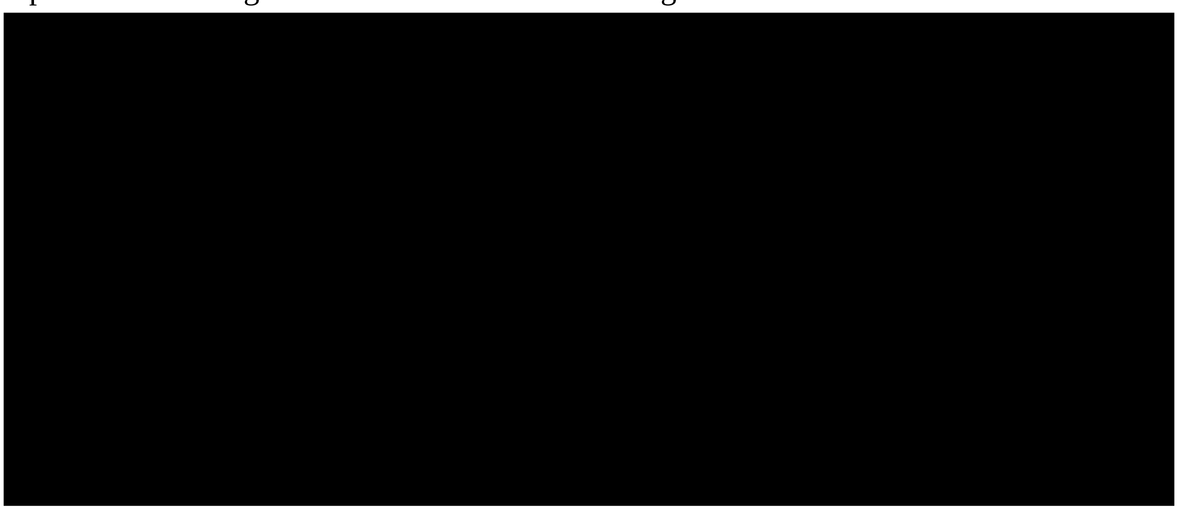


Figure A3: Repeated, one-direction stress [A1]

From Figure A3, all of three stresses can be calculated, the maximum stress applied on beam is

$$\sigma_{max} = 6.03 \times 10^6$$

The mean stress $\sigma_m = \frac{\sigma_{max}}{2} = 3.01 \times 10^6$

The maximum permissible value $\sigma_a = \sigma_m = 3.01 \times 10^6$

Figure A4 the relation of endurance strength Sn and Tensile Strength Su [A1]

The tensile stress of the selected material A1011 CQ is Su = 250MPa, corresponding to the endurance strength S_n=120MPa

The actual endurance strength $S_n{}'$ can be calculated as

$$S_n{}' = S_n(C_m)(C_{st})(C_R)(C_s)$$

$C_m = 0.8$ for cast steel [A1]

$C_R = 0.81$ Desired reliability 99%

$C_{st} = 0.8$ for axial loading

$C_s = 1.0$ for any shape in repeated direct axial tensile stress

$$S_n{}' = 120 \times 0.8 \times 0.8 \times 0.81 \times 1 = 62.208\ MPa$$

By applying the Goodman method, the combinations of mean and alternating stresses that lie under the Goodman line, therefore after 1000 cycles of load, the fatigue life of the structure is considered to be safe.

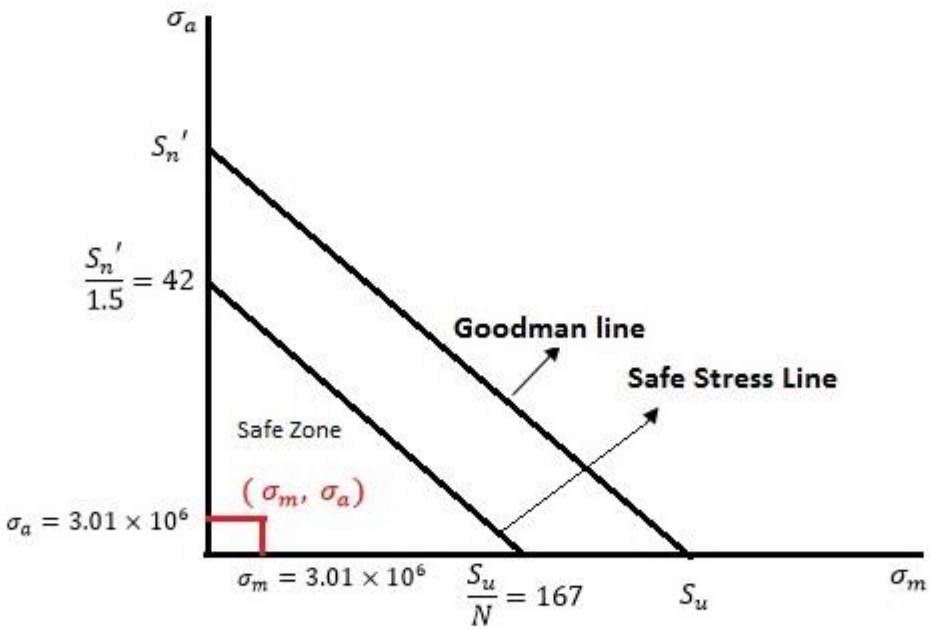


Figure A5 Goodman method for Fluctuating Stresses

- **Numerical Results**

Our team used Solidworks to model and conduct FEA for the reusable stand. Our team chose to analyze individual leg. The total load is 58860 N based on a tractor weight of 6000 Kg. each leg will support ¼ of the load, which is 14715N.

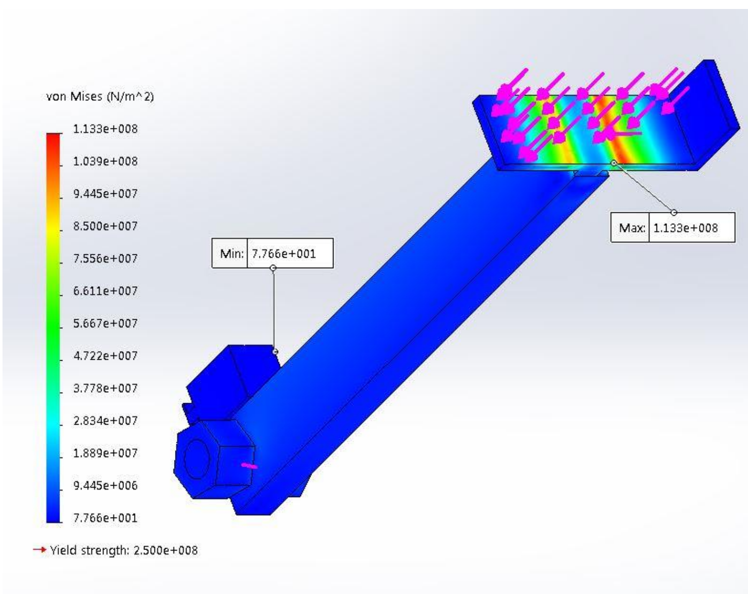


Figure A6 Finite Element Analysis for Rear left leg (von-Mises Stress).

As shown in Figure 1, the maximum von-Mises stress is 1.133 X 10^8 N/m^2, which is much less than the yield strength 2.5 X 10^8 N/m^2. The result meets the design requirement.

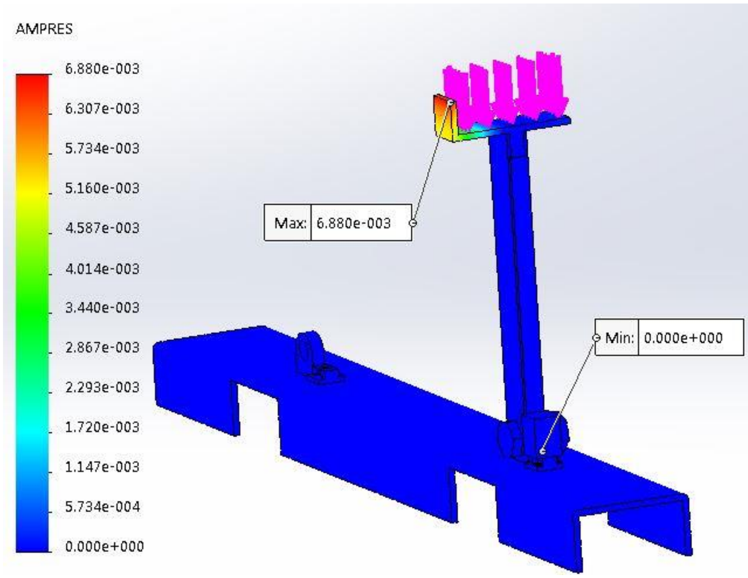


Figure A7: FEA buckling test for Rear left leg.

As shown in Figure 2, the leg does not have bucking failure. The corner tip of the rear left hand has maximum displacement 6.88 X 10^{-3} m, which is very small.

- **Final Reusable Stand Assembly**

Figure A8 shows the final assembly of the reusable stand.

Figure A8: Final assembly of reusable stand.

The reusable stand is able to support the front and side loading, as shown in Figure A9 and Figure A10.

Figure A9: Side loading view of using reusable stand.

Figure A10 Front loading view of using reusable stand.

Figure A11 shows the way of the front legs of supporting the tractor.

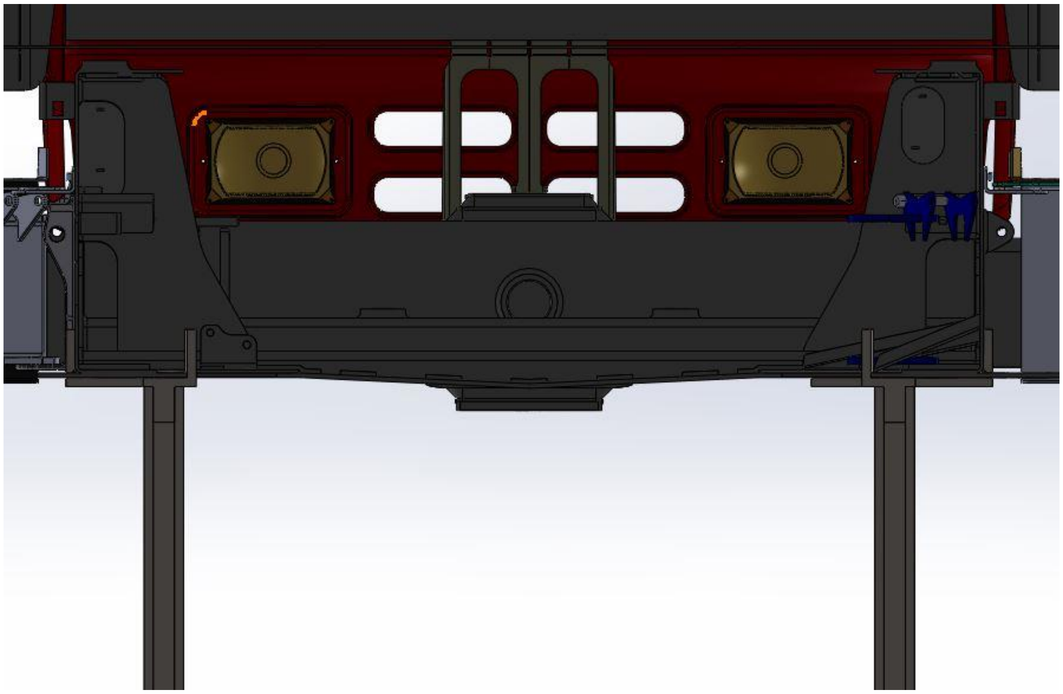


Figure A11 The way of Front legs of supporting the tractor.

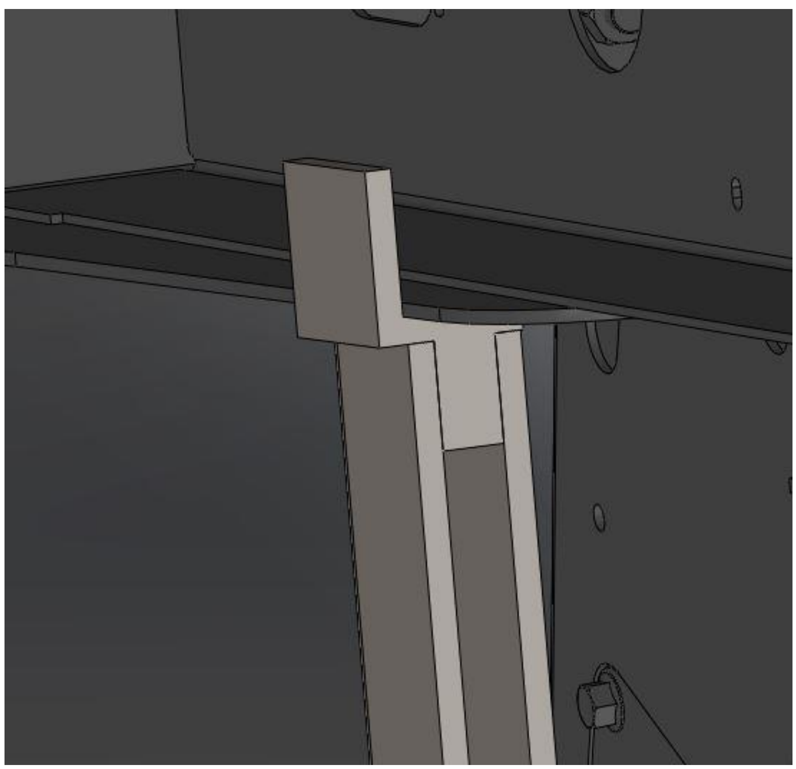


Figure A12: Front left hand side leg.

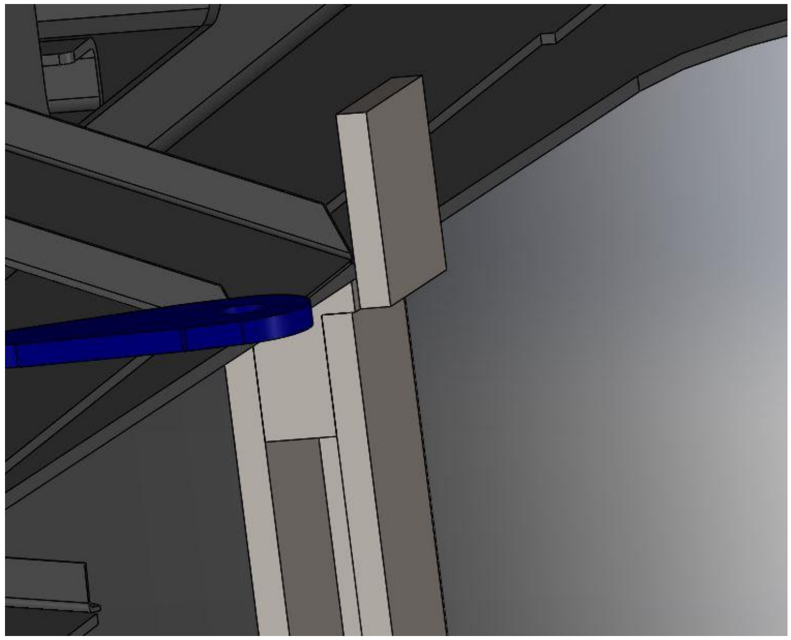


Figure A13: Front right hand side leg.

Figure A14 shows the way of the front legs of supporting the tractor.

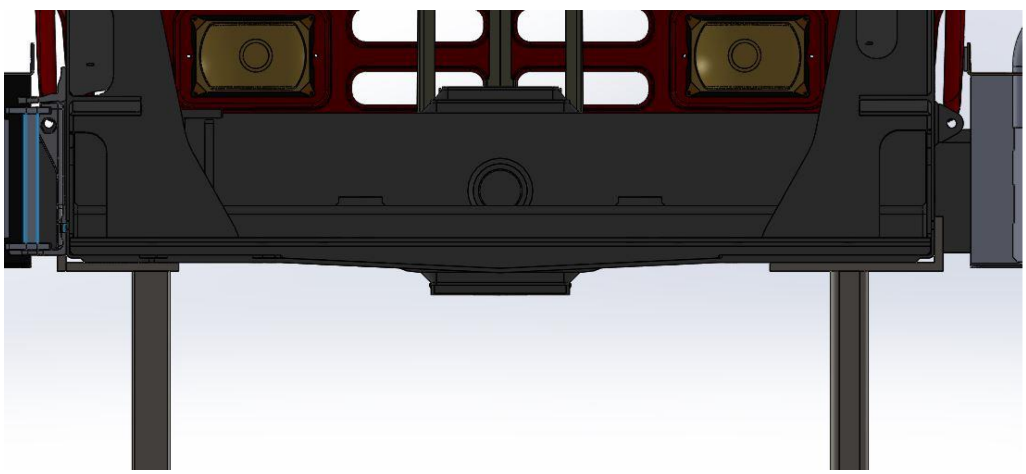


Figure A14: The way of rear legs of supporting the tractor.

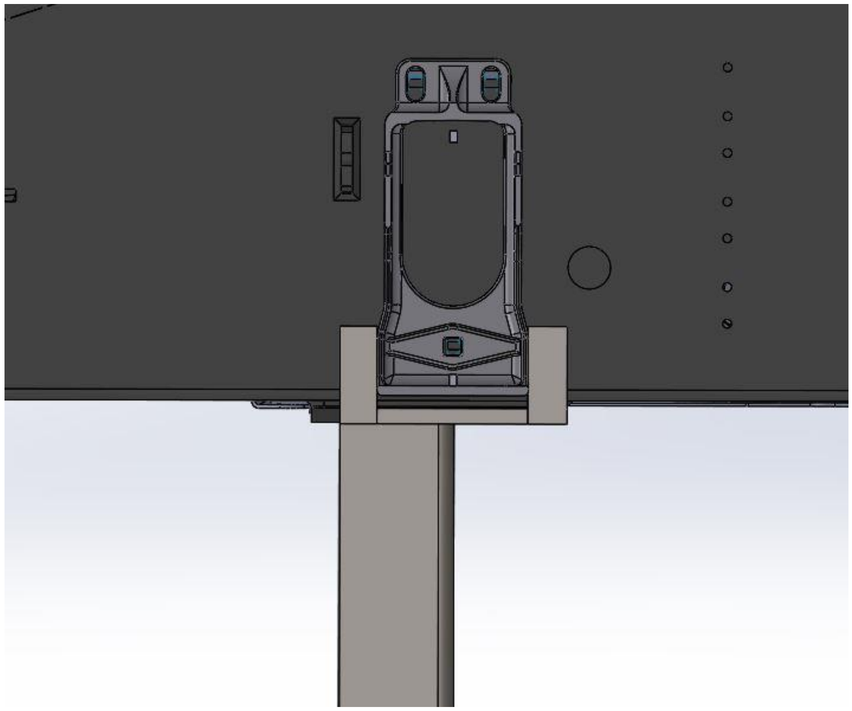


Figure A15: Rear left hand side leg.

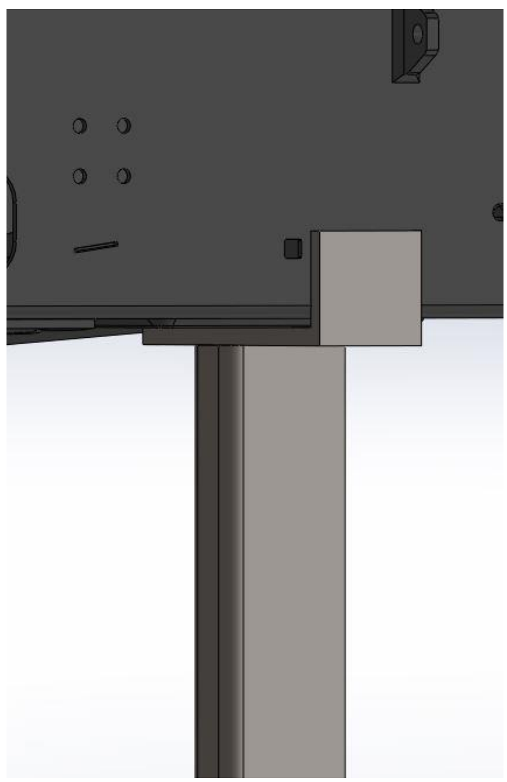


Figure A 16: Rear right hand side leg.

Appendix B: Material Selection

To properly assess the available steel alloys, the mechanical properties and cost information was collected and compared. The following sections give the details for the materials and costs that were used in the final material selection.

Material Properties

The following section gives the material properties for each of the three available steel alloys.

ASTM A1011 CS TYPE B HR P&O

ASTM A1011 CS Type B sheet is a hot-rolled carbon steel alloy sheet that exhibits high strength and high formability. A1011 sheet is capable of being bent at room temperature in any direction through 180° flat on itself without cracking on the outside of the bent portion.

TABLE B1: MATERIAL PROPERTY OF ASTM A1011 CQ [B1]

A1011 CQ		
Milling Process	Hot-Rolled	
Grade	CS Type B	
Yield Tensile Stress:	250	MPa
Yield Shear Stress	125	MPa
Ultimate tensile stress	400	MPa
Density	7.872	g/cm^3
Module Elasticity	200	GPa

ASTM A1011 HSLA Gr.50 P&O

Grade 50 steel is probably the most commonly used material in the dump body industry. Grade 50 is ideal for general use bodies which aren't going to be used to haul highly abrasive and high impact materials such as boulders and demo materials. 50K is ideal for asphalt, sand, dirt, gravel, and other small aggregates

TABLE B 2: MATERIAL PROPERTY OF ASTM A1011 HSLA G50 [B1]

HSLA Grade 50		
Steel Type	ASTM A1011	
Milling Process	Hot Rolled	
Grade	(Class 1) 50	
Yield Tensile Stress	340	MPa
Yield Shear Stress	170	MPa
Ultimate tensile stress	450	MPa
Density	7.872	g/cm^3
Module Elasticity	200	Gpa

ASTM A1008 CS Type B Sheet

ASTM A1008 CS Type B sheet is a cold rolled low carbon, high-strength steel-alloy sheet with improved formability. It is manufactured by annealing and temper rolling hot rolled steel sheets to provide formability, surface texture and flatness. The surface is matte finish and is oiled to prevent rust, allowing for use in exposed applications.

TABLE B 3 MATERIAL PROPERTY OF ASTM A1008 CQ [B1]

A1008 CR CQ		
Milling Process	Cold-Rolled	
Grade	CS Type B	
Yield Tensile Stress:	200	MPa
Yield Shear Stress	100	MPa
Ultimate tensile stress	317	MPa
Density	7.872	g/cm^3
Module Elasticity	200	Gpa

Cost of the Material

All of the materials available for use come from MacDon's current inventory. Considering that the MacDon makes large quantities of purchasing at every time; to make sure the cost estimation will be reasonable and accurate, the team used floating market price based on the U.S steel futures contract that quoted in the Chicago Mercantile Exchange (CME).

To eliminate the effect of fluctuation of price volatility, the team chose the average price during last four to six months, the price trend line about both Hot-Rolled and Cold-Rolled steel are shown in figure [B3] and figure[B4] .

[redacted]

Figure B1: U.S Midwest domestic hot-rolled coil steel (CRU) index future quotes [B2]

[redacted]

Figure B2: Market Price of Cold Rolled Coils USA Steel [B3]

Based on the future contract price line, the team calculated the estimated price and format the outcomes into the Table [B4]

TABLE B4: MATERIAL PRICE PER KILOGRAM

	Hot-Rolled		Cold-Rolled
	A1011 CQ	HSLA G50	A1008 CR CQ
Purchase unit	20 Short Ton (907.18 kg)	20 Short Ton (907.18 kg)	N/A
Price per kg ($)	0.48	0.54	0.63

References:

[A1]: “Machine Design” Machine Elements in Mechanical Design, 5th Edition by Robert L.Mott. University of Dayton. Charter 5, p164-p183.

[B1] *AK Steel “COLD ROLLED STEELS*” [Jun.22.2012] Available: http://www.aksteel.com/pdf/markets_products/carbon/AK_Cold_Rolled_PDB_201406l.pdf

[B2] *CME Group, U.S. Midwest Domestic Hot-Rolled Coil Steel (CRU) Index Futures Quotes*. [Online] Available: http://www.cmegroup.com/trading/metals/ferrous/hrc-steel.html

[B3] METALPRICE.COM, Cold Rolled Coils USA Steel. Available: http://www.metalprices.com/p/SteelBenchmarkerFreeChart?weight=KG&size=M&theme=1011

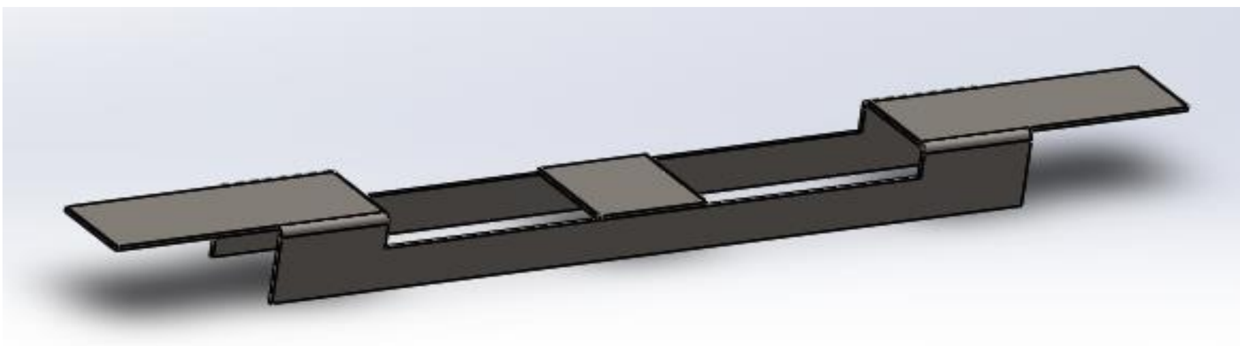
Appendix C: Assembly Guide and Operating Instructions

The following provides the step by step instructions for the assembly of the Forklift attachment and the disposable stand.

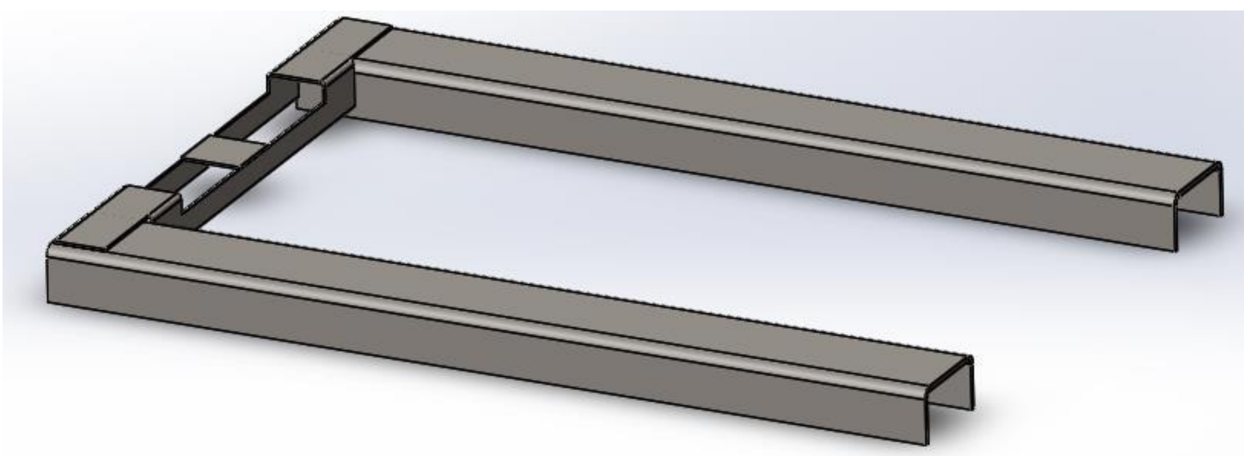
ASSEMBLY INSTRUCTIONS

Forklift Attachment Assembly

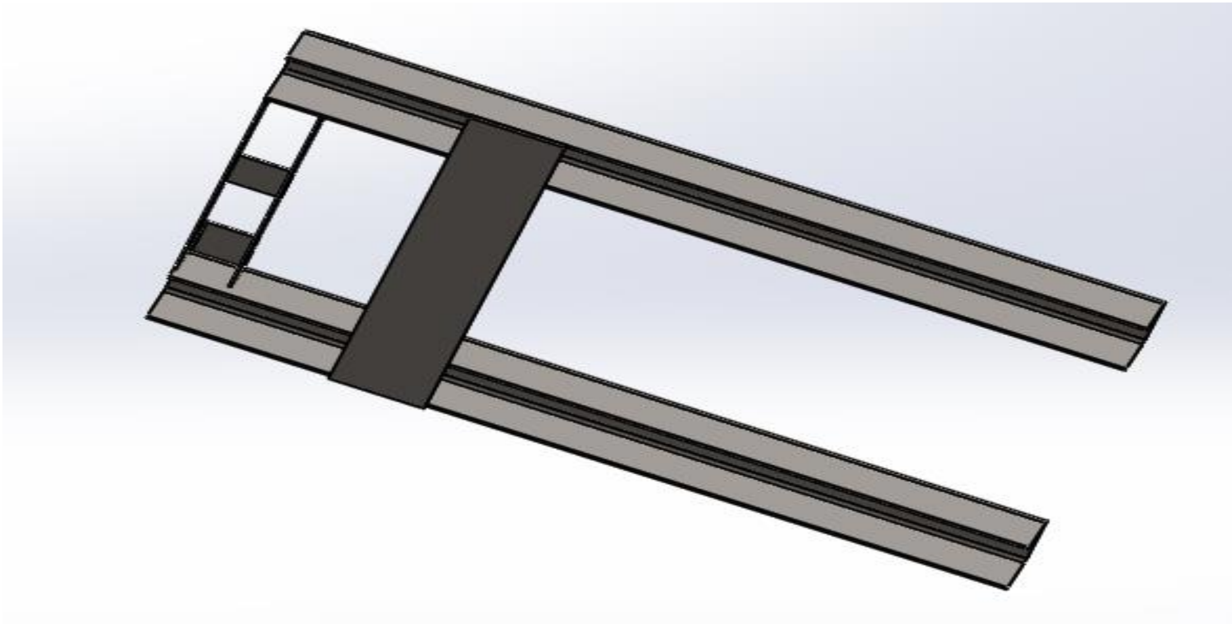
Step 1: Weld the front support brace on the cut out made on the front support as shown. Place the front support brace at 12.13 inches from the beginning of the cut out.



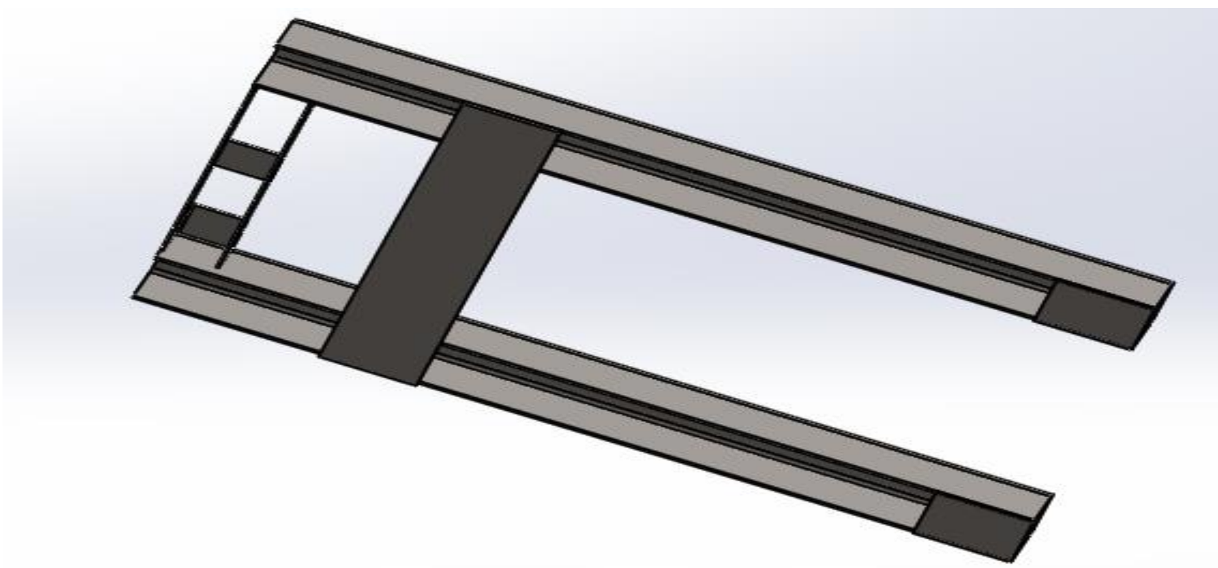
Step 2: Weld the Front support towards the end of the two front c channels as shown below



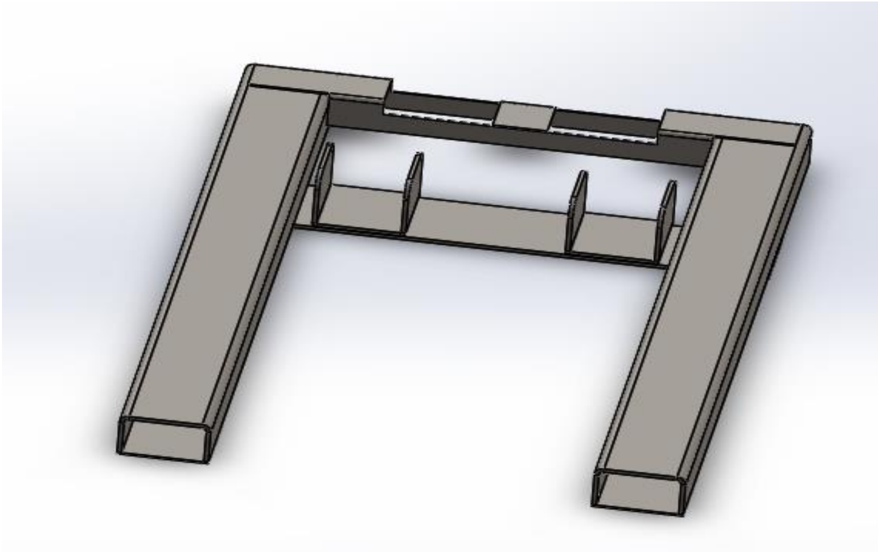
Step 3: Weld the connector sheet at the bottom of the two front c channels as shown. Position the connecter sheet at 19.24 inches starting from the end where the front support is attached.



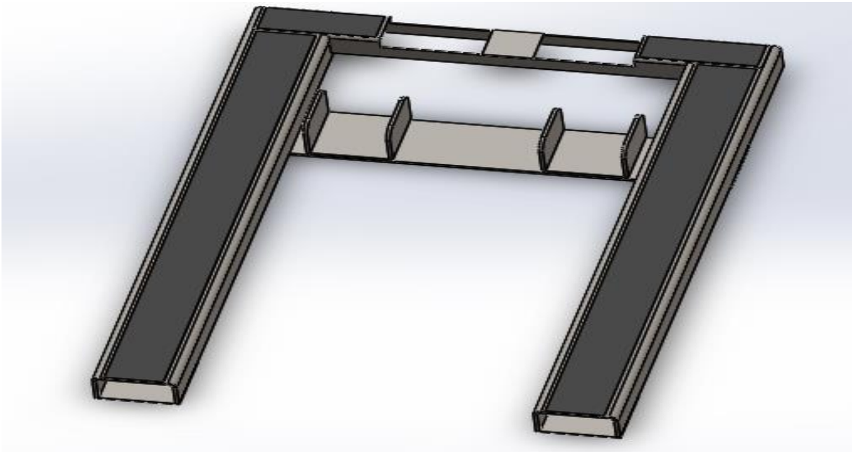
Step 4: Weld the two c channel bottoms to the other end of the two front c channels as shown.



Step 5: Weld the two cross beam pockets on the connector sheet as seen in figure. Position the cross beam pockets at 2 inches from the inner side of the two front c channels. Confirm that the separation between the two cross beam pockets is 17.50 inches.

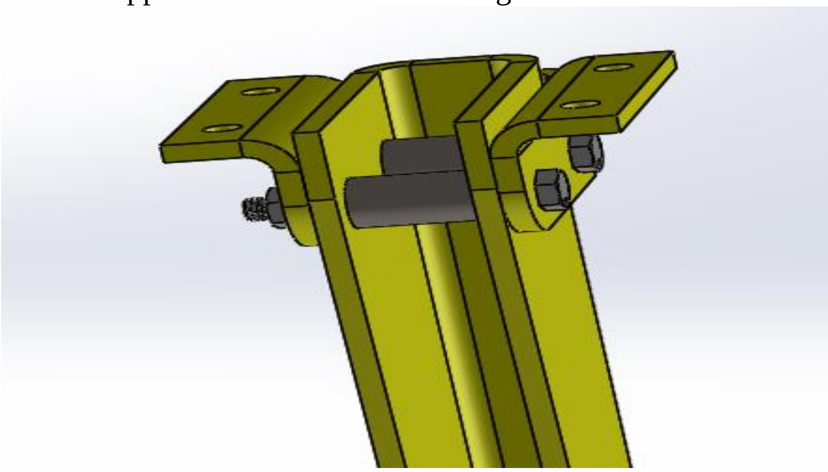


Step 6: Use glue to bond the short and long rubber pads on the two front c channels and the front support as shown

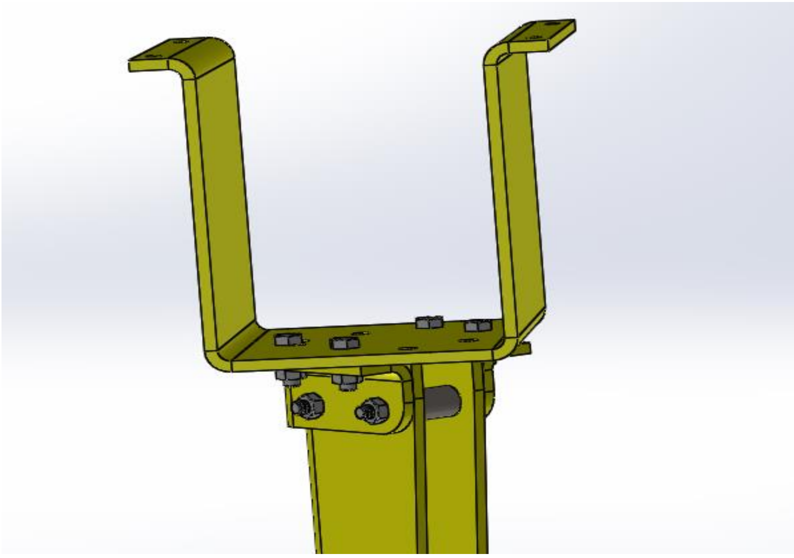


Disposable Stand Assembly

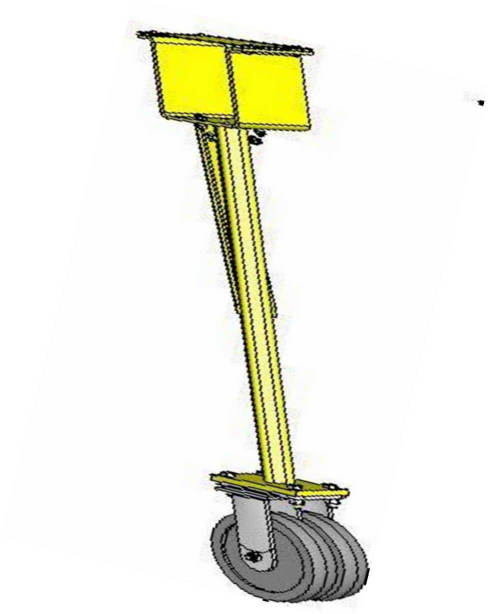
Step 1: Connect the support brackets to the stand legs with the bolts as shown in figure.



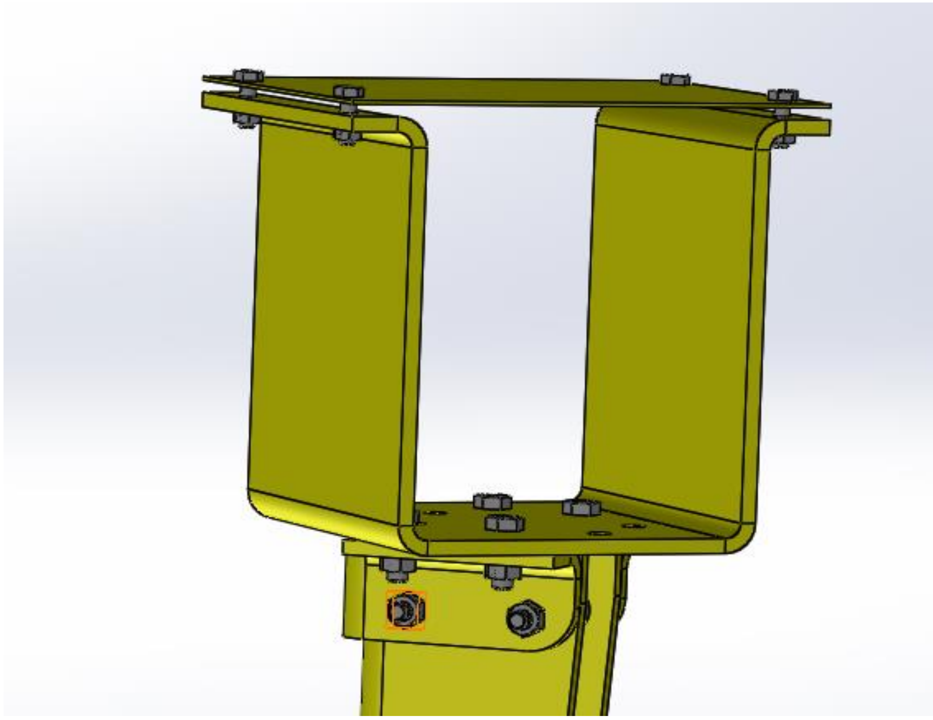
Step 3: Connect the axle pocket to the other end of the support bracket and use bolts to lock them together.



Step 4: Mount the wheels to the bottom of the stand leg as shown in figure.



Step 5: With the tractor frames placed in the pockets, connect the axle top lock to the axle pockets and use bolts to hold them together on the fame of the tractor.



Step 6: Connect the side piece to the stand legs and use bolts.

Appendix D: Detailed Cost Analysis of Final Design

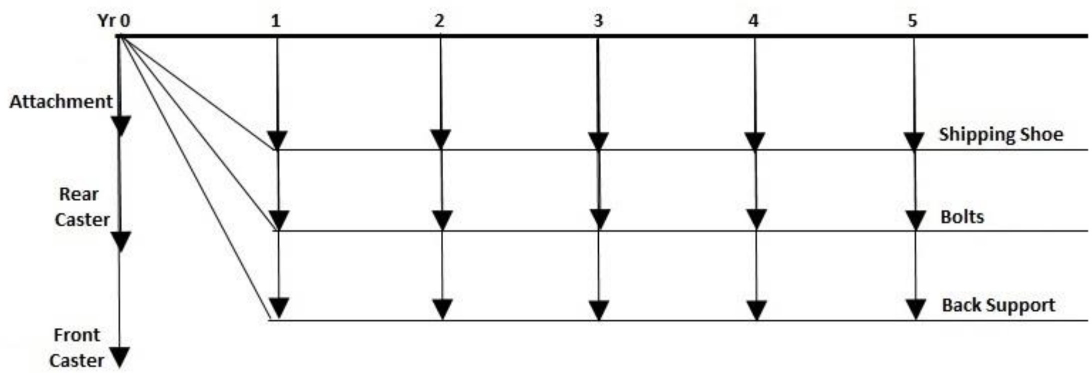


Figure D1: Manufacturing present cost

To determine the budget using engineering economics principles, the inflation rate r (yearly basis) of 1.27% has been used. The Attachment, Rear casters, and front caster will be produced at year-0, and disposable units will sequentially produce in next 5 years. Thus, the total present expenditure at year-0 can be calculated as:

$$\textbf{Present Value of Disposable Parts} = \frac{68.12 * 1000}{(1+r)^1} + \frac{68120}{(1+r)^2} + \frac{68120}{(1+r)^3} + \frac{68120}{(1+r)^4} + \frac{68120}{(1+r)^5} = 3336102.27$$

$$\textbf{Present Value of Reusable Parts} = 929.72 \times 3 = 2789.49$$

Total Present Value of Disposable Stand = 3336102.27+2789.49 = 336102.27

Appendix E: Drawings of Disposable Stand

Appendix F: Drawings of Reusable Stand

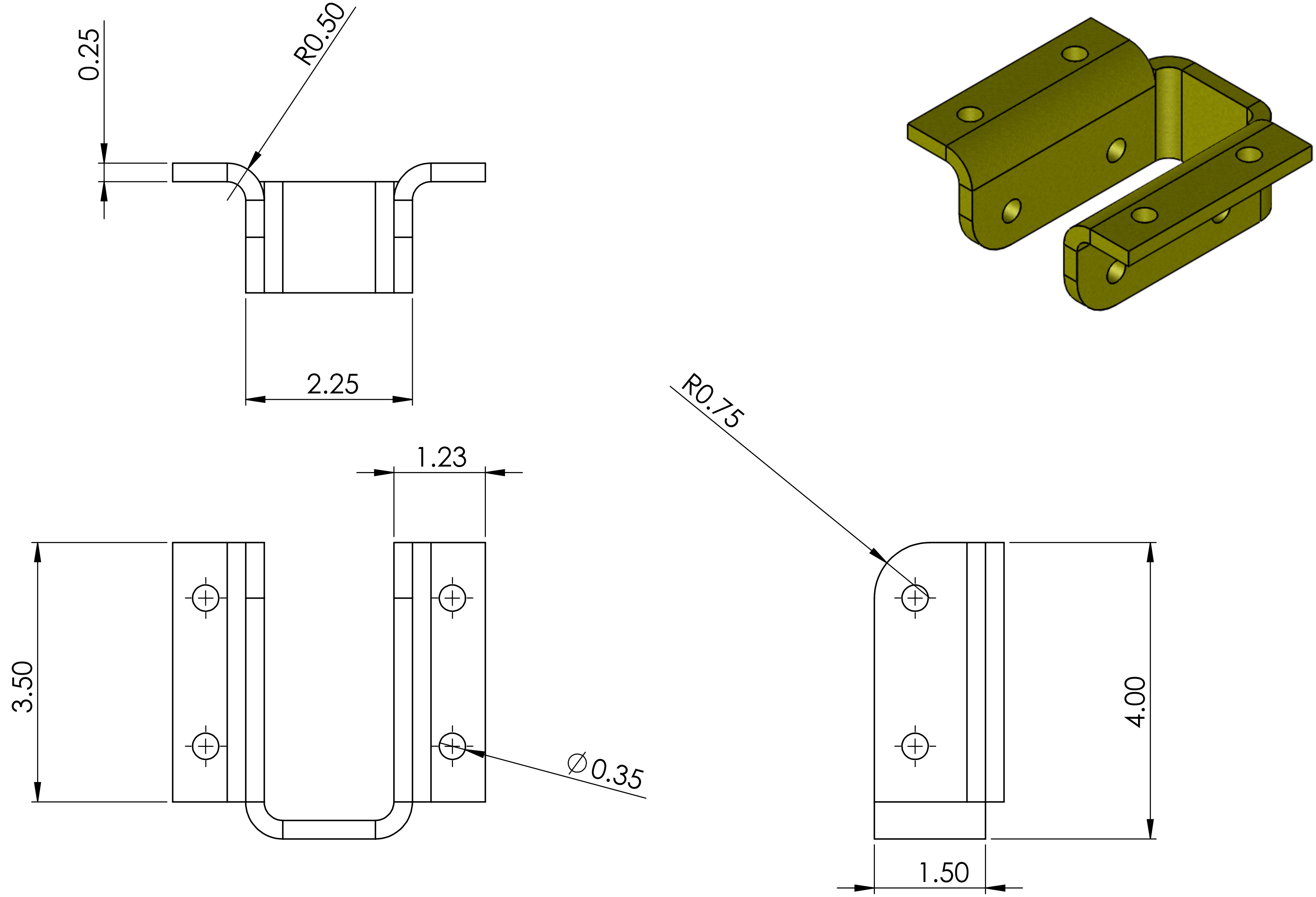
UofM MECHANICAL ENGINEERING				TITLE: **TRACTOR STAND DRAWINGS**	
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE	SIZE **A**	DISCRIPTION:	REV 0
DO NOT SCALE DRAWING	DRAWN	G.O	29/11/2015		
MATERIAL					
FINISH AS NOTED	CHECKED	TEAM 12	05/12/2015	SCALE: 1:1	WEIGHT:	SHEET 1 OF 12

SolidWorks

MECH 4860

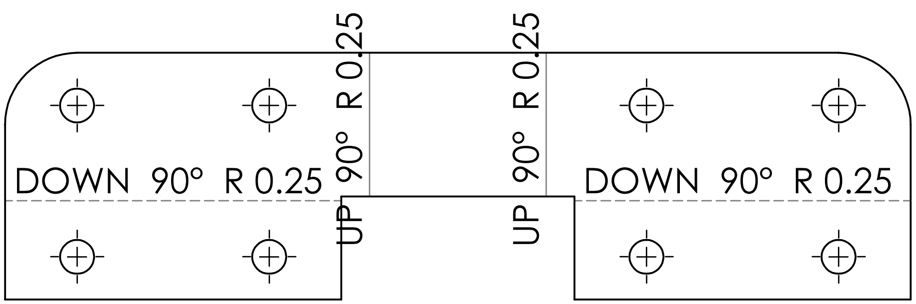
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

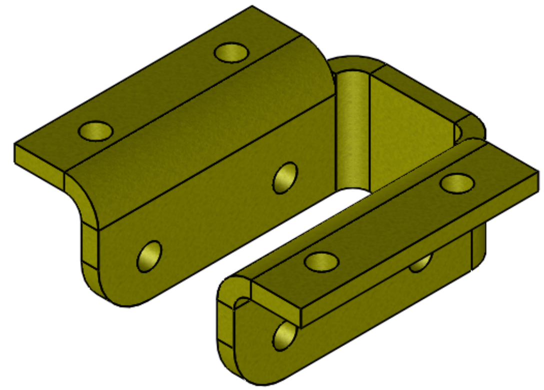
5 4 3 2 1



SolidWorks	MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING			TITLE: TRACTOR STAND PROJECT
			INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE	SIZE A
			DO NOT SCALE DRAWING	DRAWN: G.O	29/11/2015	DISCRIPTION: SUPPORT BRACKET
			MATERIAL: ASTM A36			REV 0
			FINISH: AS NOTED	CHECKED: TEAM 12	05/12/2015	SCALE: 1:2 | WEIGHT: 0.66 Kg | SHEET 2 OF 12

5 4 3 2 1





SolidWorks

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

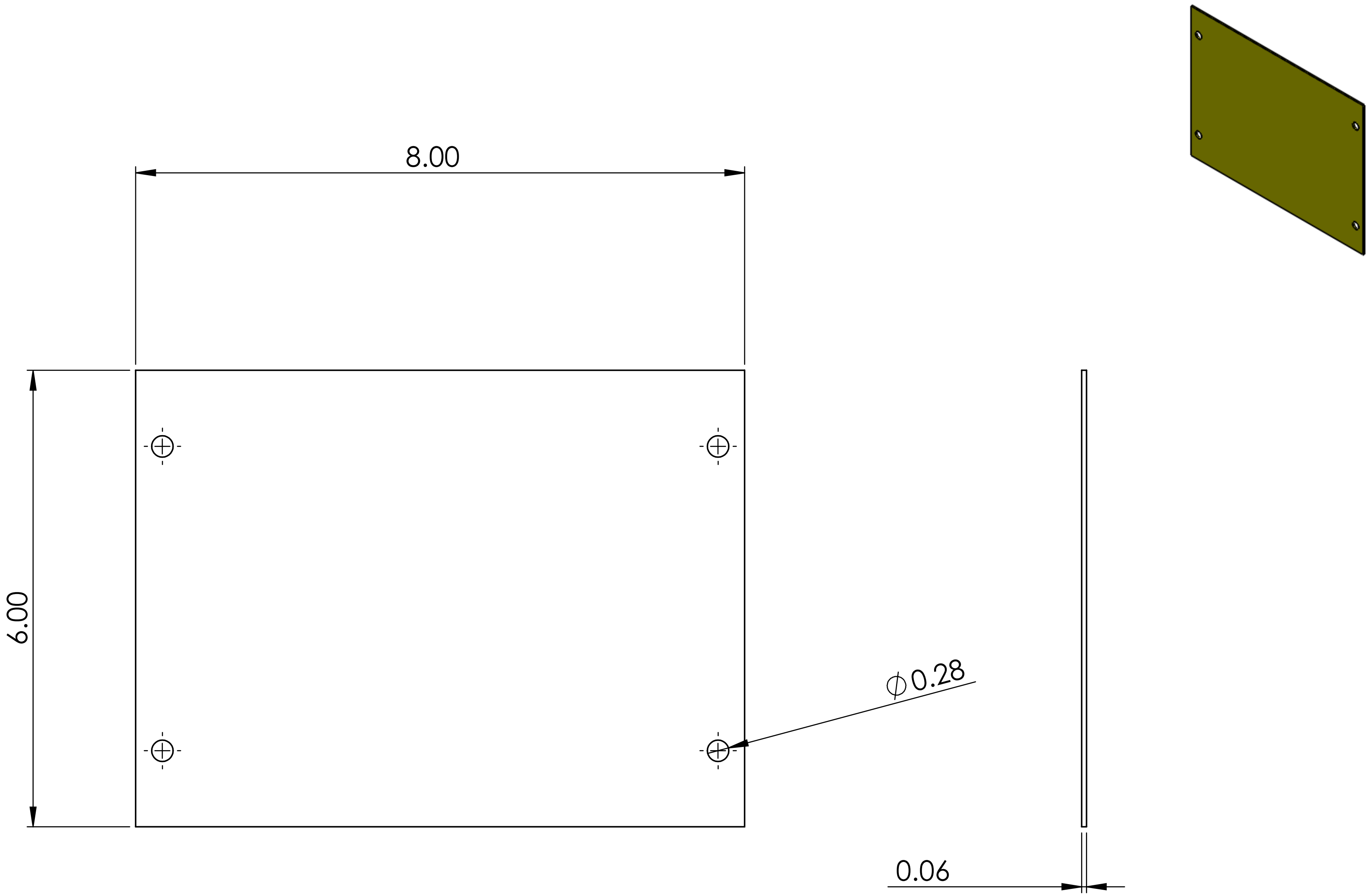
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE
DO NOT SCALE DRAWING / DRAWN	G.O	29/11/2015
MATERIAL ASTM A36		
FINISH AS NOTED / CHECKED	TEAM 12	05/12/2015

TITLE: **TRACTOR STAND PROJECT**

SIZE	DISCRIPTION:	REV
A	SUPPORT BRACKET	0

SCALE: 1:2 WEIGHT: 0.66 Kg SHEET 3 OF 12

5 4 3 2 1



UofM MECHANICAL ENGINEERING

TITLE: **TRACTOR STAND PROJECT**

MECH 4860

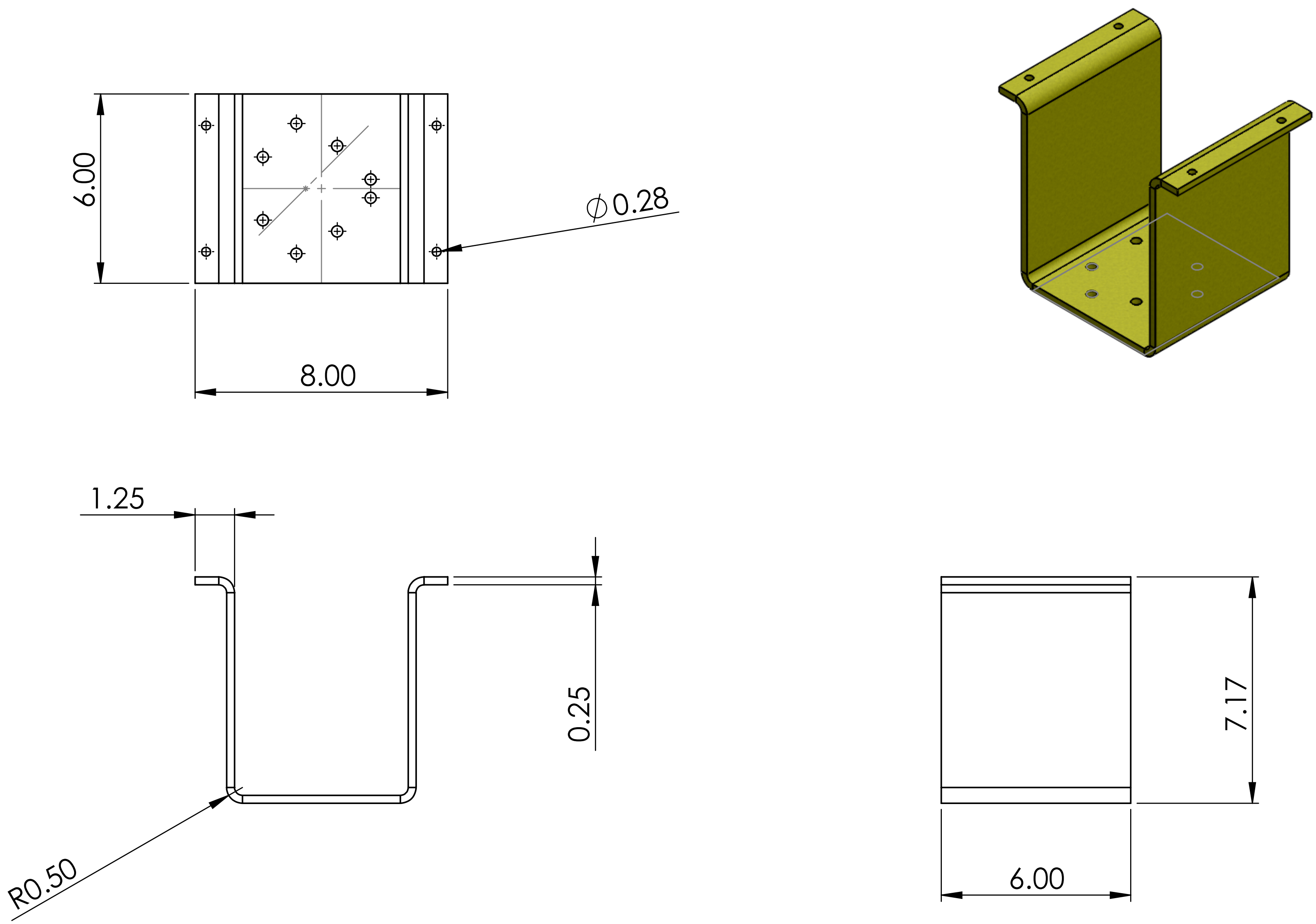
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE
DO NOT SCALE DRAWING	DRAWN G.O	29/11/2015
MATERIAL ASTM A36		
FINISH AS NOTED	CHECKED TEAM 12	05/12/2015

SIZE	DISCRIPTION:	REV
A	AXLE TOP LOCK	0

SCALE: 1:2 WEIGHT: 0.38 Kg SHEET 4 OF 12

5 4 3 2 1



UofM MECHANICAL ENGINEERING

TITLE: **TRACTOR STAND PROJECT**

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

MATERIAL ASTM A36

FINISH AS NOTED

	NAME	DATE
DRAWN	G.O	29/11/2015
CHECKED	TEAM 12	05/12/2015

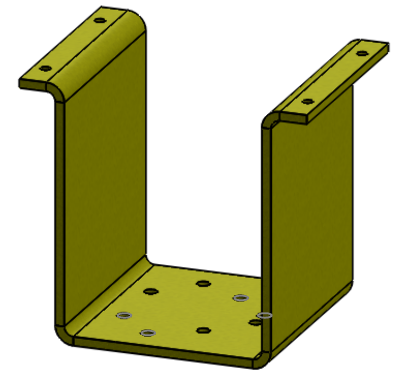
SIZE A

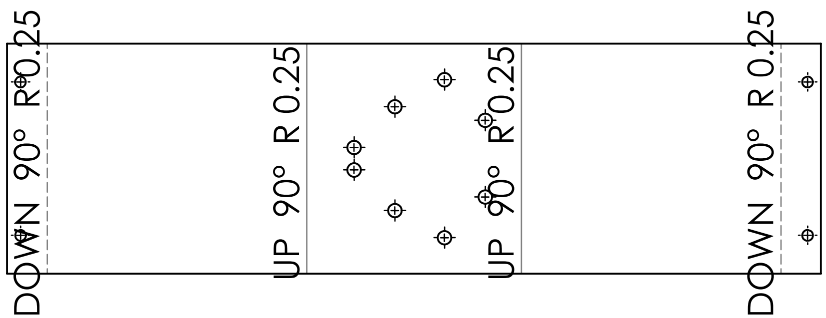
DISCRIPTION: AXLE POCKET

REV 0

SCALE: 1:5 WEIGHT: 4.06 Kg SHEET 5 OF 12

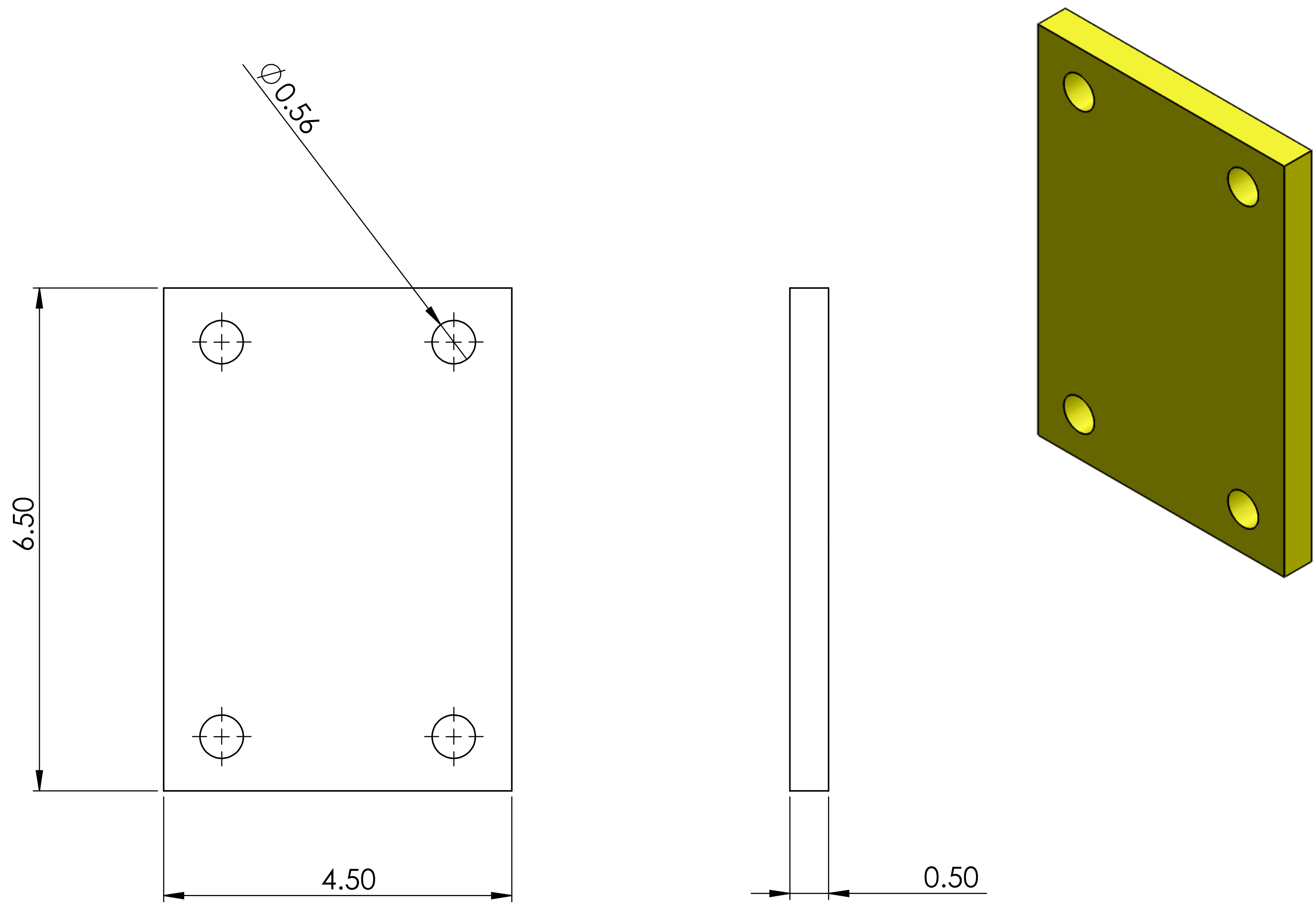
5 4 3 2 1





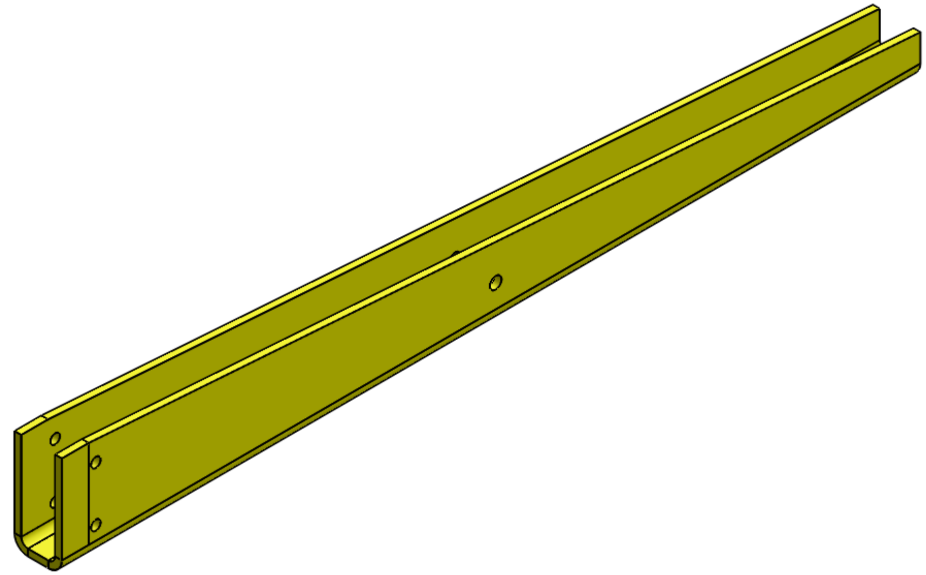
SolidWorks	MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING			TITLE: **TRACTOR STAND PROJECT**
			INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE	SIZE A; DISCRIPTION: AXLE POCKET; REV 0
			DO NOT SCALE DRAWING	DRAWN G.O	29/11/2015	
			MATERIAL ASTM A36			
			FINISH AS NOTED	CHECKED TEAM 12	05/12/2015	SCALE: 1:5 WEIGHT: 4.06 Kg SHEET 6 OF 12

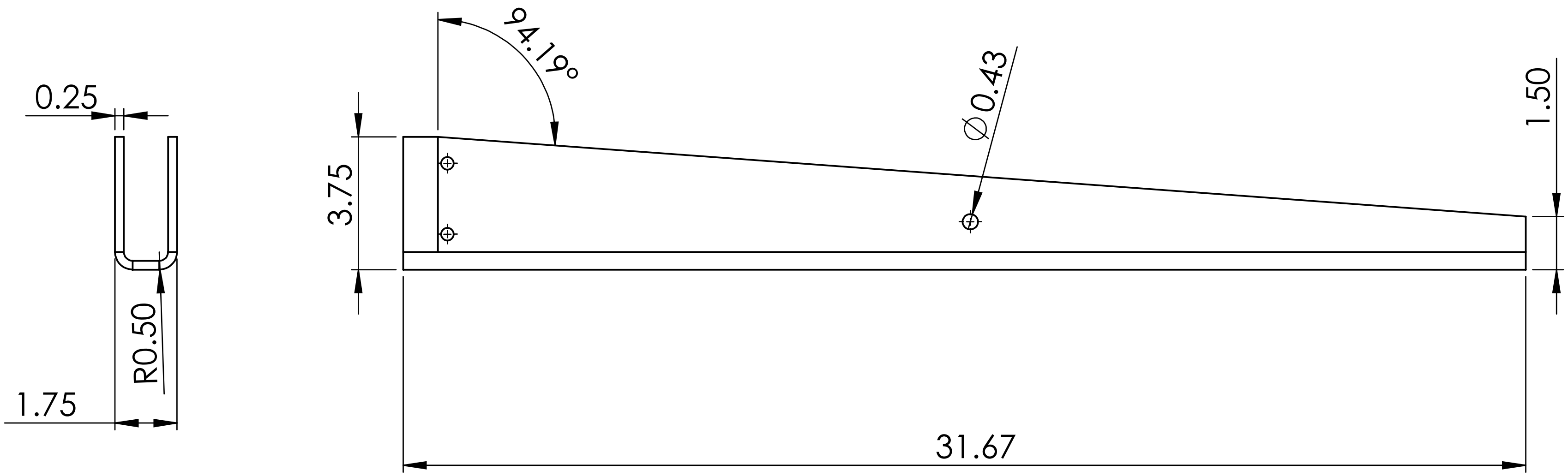
5 4 3 2 1



SolidWorks	MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING			TITLE: **TRACTOR STAND PROJECT**
			INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE	SIZE A / DISCRIPTION: STAND BASE / REV 0
			DO NOT SCALE DRAWING	DRAWN G.O	29/11/2015	
			MATERIAL ASTM A36			
			FINISH AS NOTED	CHECKED TEAM 12	05/12/2015	SCALE: 1:5 / WEIGHT: 1.82 Kg / SHEET 7 OF 12

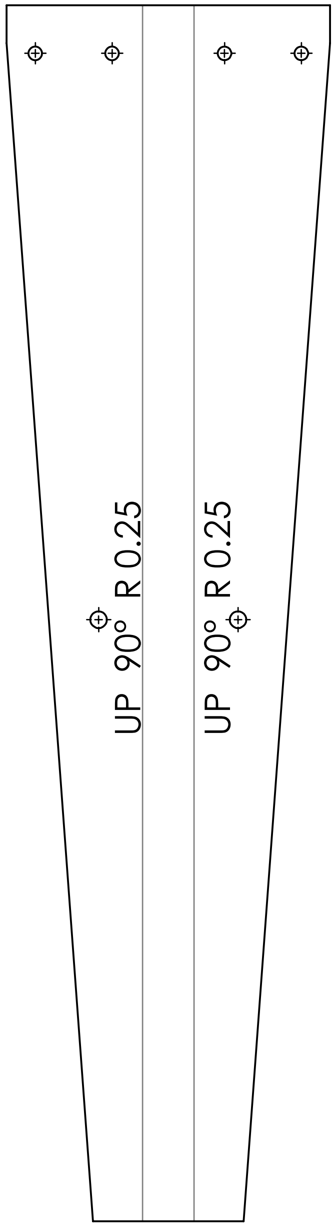
5 4 3 2 1

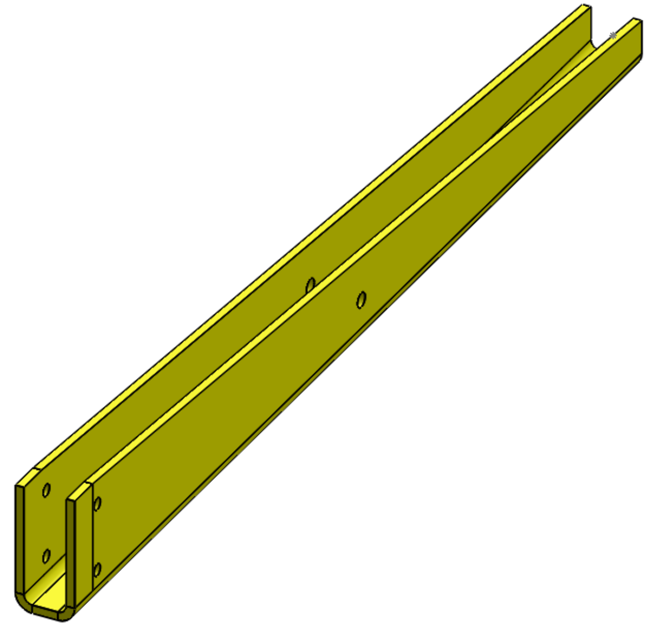




SolidWorks	MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING		TITLE: **TRACTOR STAND PROJECT**
			INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME / DATE	SIZE **A** / DISCRIPTION: STAND LEG / REV 0
			DO NOT SCALE DRAWING	DRAWN G.O 29/11/2015	
			MATERIAL ASTM A36		
			FINISH AS NOTED	CHECKED TEAM 12 05/12/2015	SCALE: 1:5 / WEIGHT: 6.34 Kg / SHEET 8 OF 12

5 4 3 2 1





SolidWorks

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

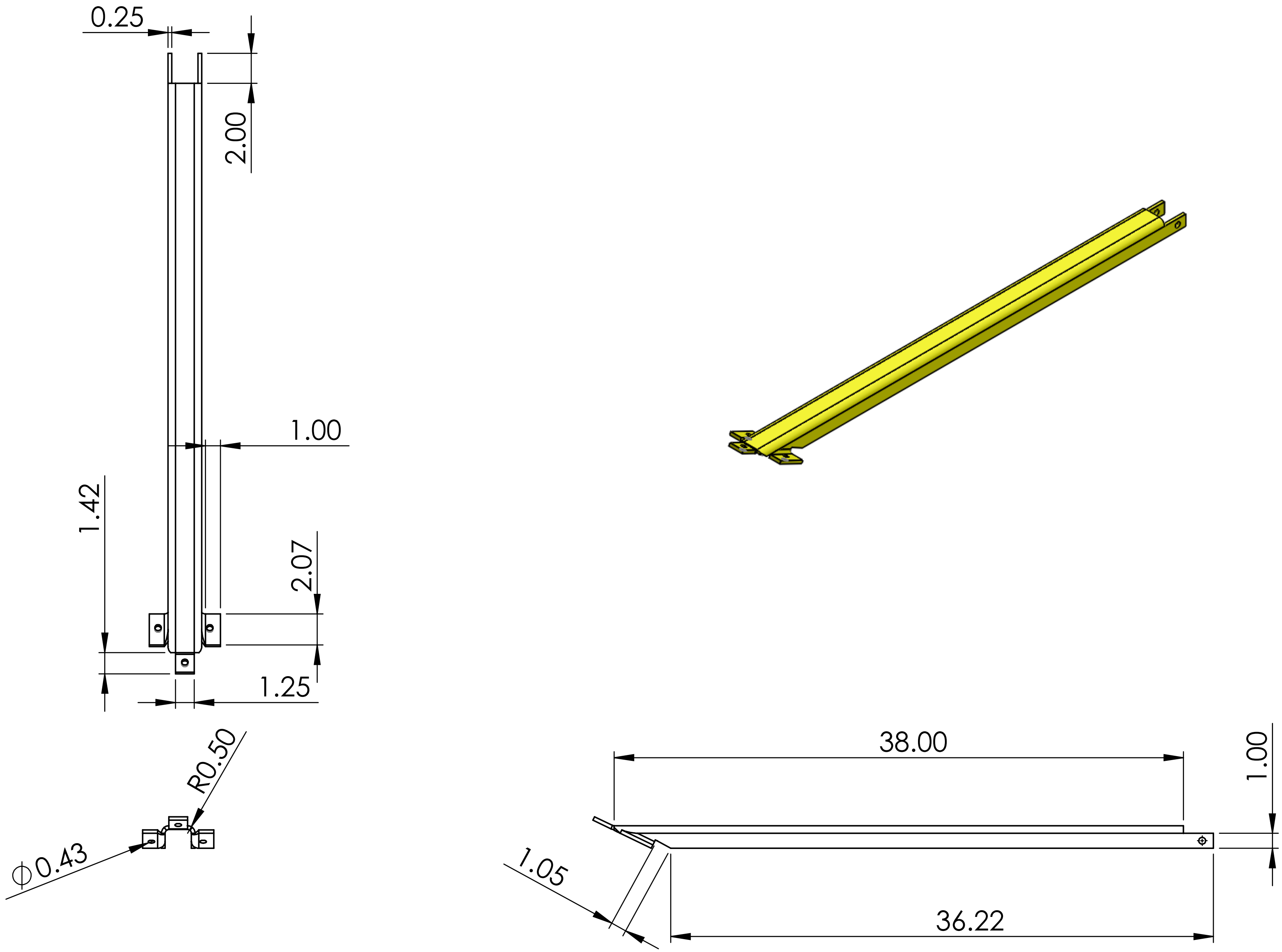
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	G.O	29/11/2015
MATERIAL ASTM A36			
FINISH AS NOTED	CHECKED	TEAM 12	05/12/2015

TITLE: **TRACTOR STAND PROJECT**

SIZE	DISCRIPTION:	REV
A	STAND LEG	0

SCALE: 1:5 WEIGHT: 6.34 Kg SHEET 9 OF 12

5 4 3 2 1



UofM MECHANICAL ENGINEERING

TITLE: **TRACTOR STAND PROJECT**

MECH 4860

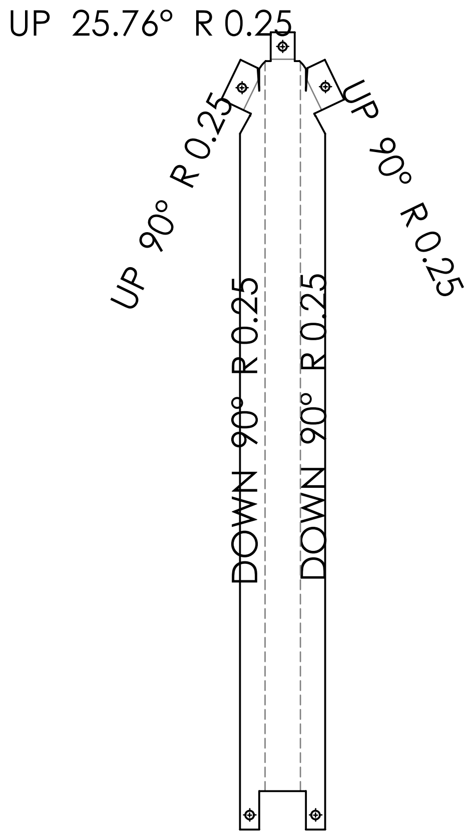
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

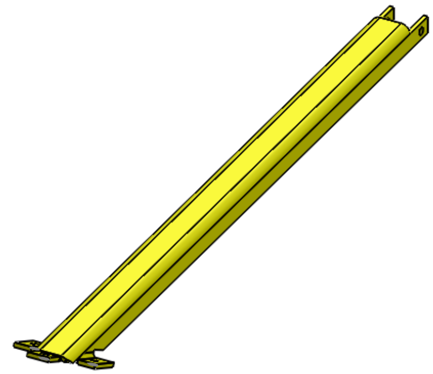
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	G.O	29/11/2015
MATERIAL ASTM A36			
FINISH AS NOTED	CHECKED	TEAM 12	05/12/2015

SIZE	DISCRIPTION:	REV
A	ANGLE BRACE	0

SCALE: 1:5 WEIGHT: 5.61 Kg SHEET 10 OF 12

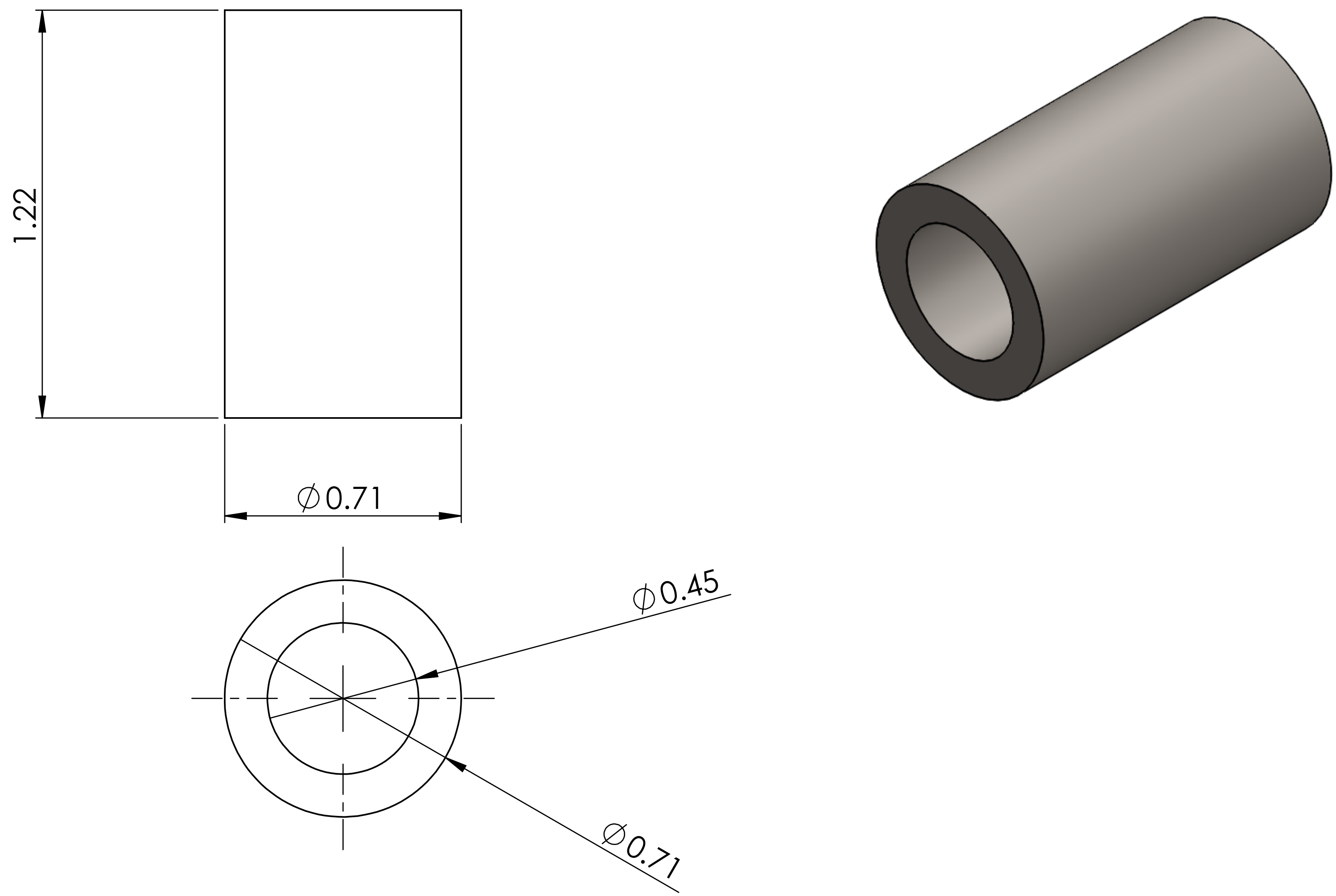
5 4 3 2 1





MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING			TITLE: **TRACTOR STAND PROJECT**
		INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE	SIZE A / DISCRIPTION: ANGLE BRACE / REV 0
		DO NOT SCALE DRAWING			
		MATERIAL ASTM A36	DRAWN G.O	29/11/2015	
		FINISH AS NOTED	CHECKED TEAM 12	05/12/2015	SCALE: 1:10 WEIGHT: 5.61 Kg SHEET 11 OF 12

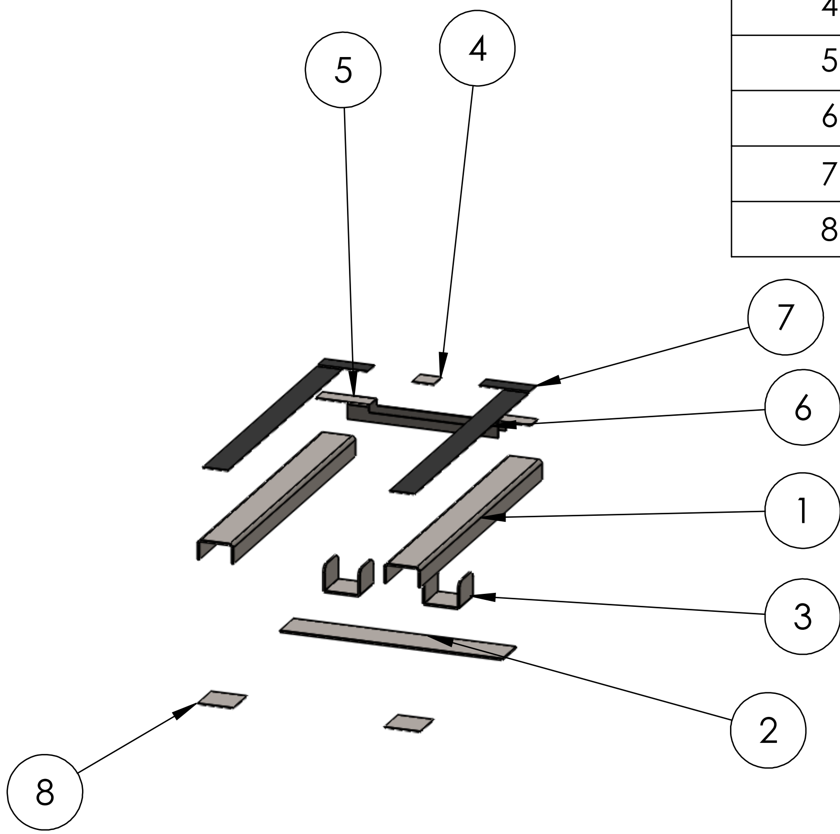
5 4 3 2 1

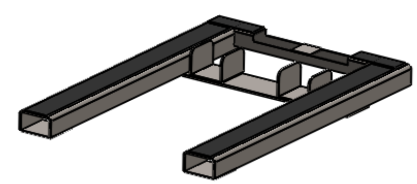


MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING			TITLE:	TRACTOR STAND PROJECT
		INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE	SIZE A	DISCRIPTION: BOLT BRUSHING / REV 0
		DO NOT SCALE DRAWING	DRAWN G.O	29/11/2015		
		MATERIAL ASTM A36				
		FINISH AS NOTED	CHECKED TEAM 12	05/12/2015	SCALE: 2:1	WEIGHT: 0.04 Kg / SHEET 12 OF 12

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Fork c-channel	FORK C-CHANNEL	2
2	connector sheet	CONNECTOR SHEET	1
3	cross beam pocket	CROSS BEAM POCKET	2
4	front support brace	FRONT SUPPORT BRACE	1
5	front support	FRONT SUPPORT	1
6	long rubber pad	LONG RUBBER PAD	2
7	short rubber	SHORT RUBBER	2
8	c channel bottom	C CHANNEL BOTTOM	2





UofM MECHANICAL ENGINEERING

TITLE: TRACTOR STAND PROJECT

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

MATERIAL: ASTM A36

FINISH: AS NOTED

	NAME	DATE
DRAWN	G.O	29/11/2015
CHECKED	TEAM 12	05/12/2015

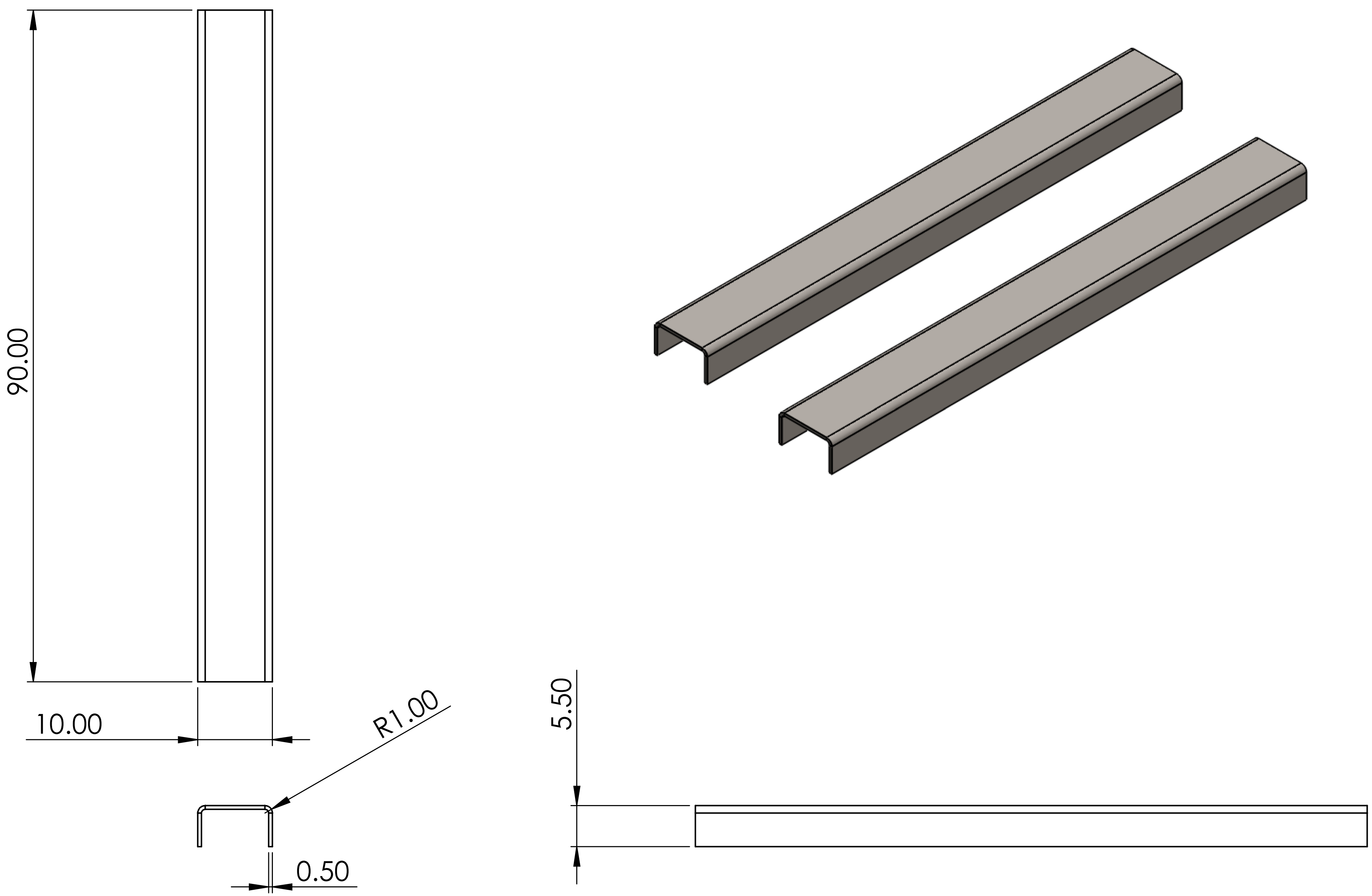
SIZE: A

DISCRIPTION: FORKLIFT ATTACHMENT

REV: 0

SCALE: 1:1 WEIGHT: 321.87Kg SHEET 1 OF 12

5 4 3 2 1



UofM MECHANICAL ENGINEERING

TITLE: **TRACTOR STAND PROJECT**

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

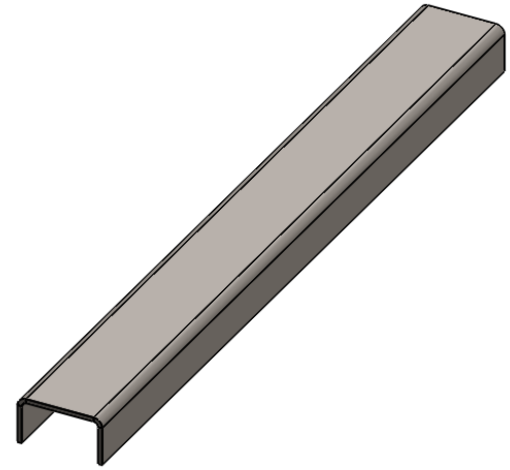
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994
DO NOT SCALE DRAWING
MATERIAL ASTM A36
FINISH AS NOTED

	NAME	DATE
DRAWN	G.O	29/11/2015
CHECKED	TEAM 12	05/12/2015

SIZE A
DISCRIPTION: FORK C CHANNEL
REV 0

SCALE: 1:20 WEIGHT: 112.05 Kg SHEET 2 OF 12

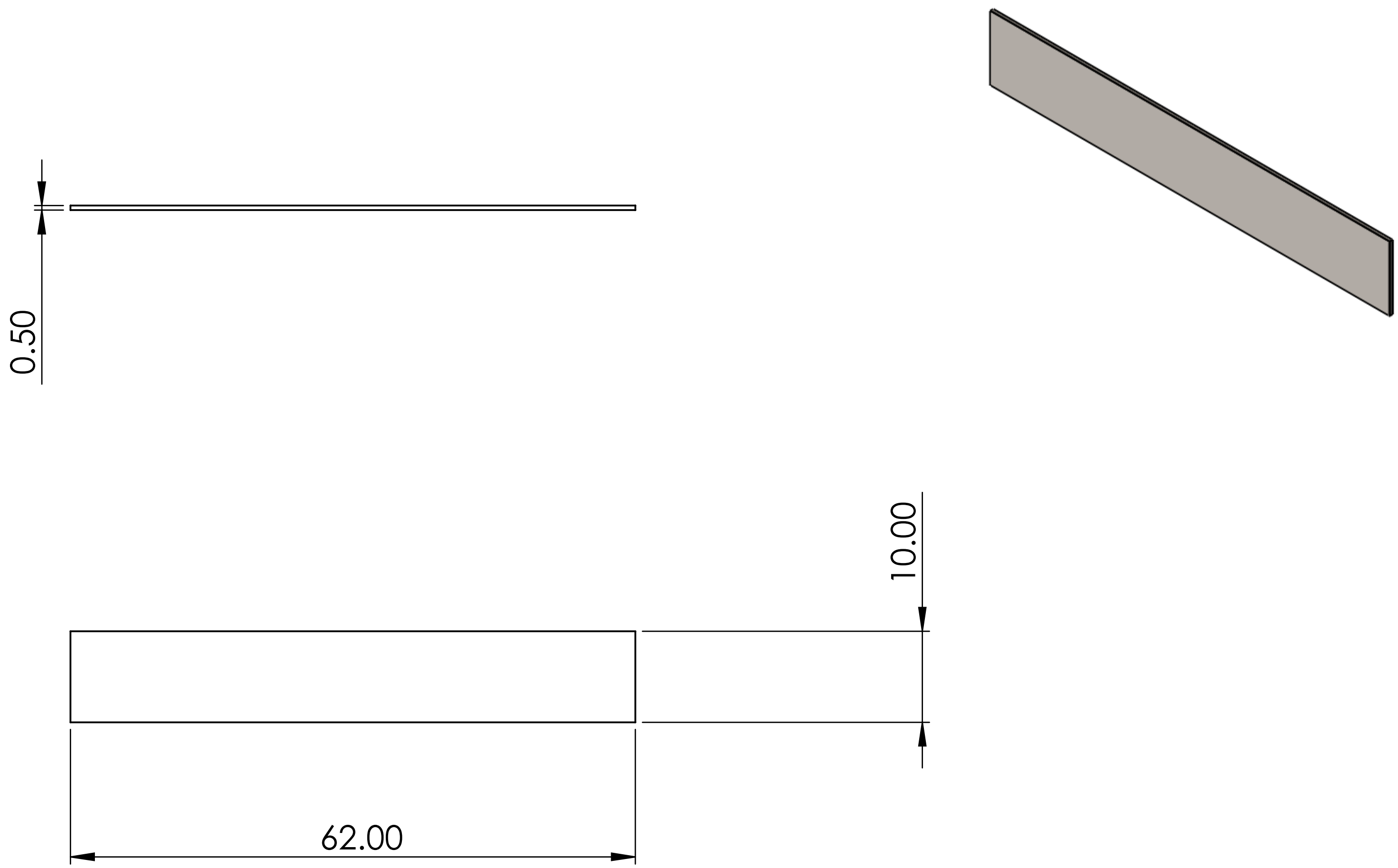
5 4 3 2 1



UP 90° R 0.5
UP 90° R 0.5

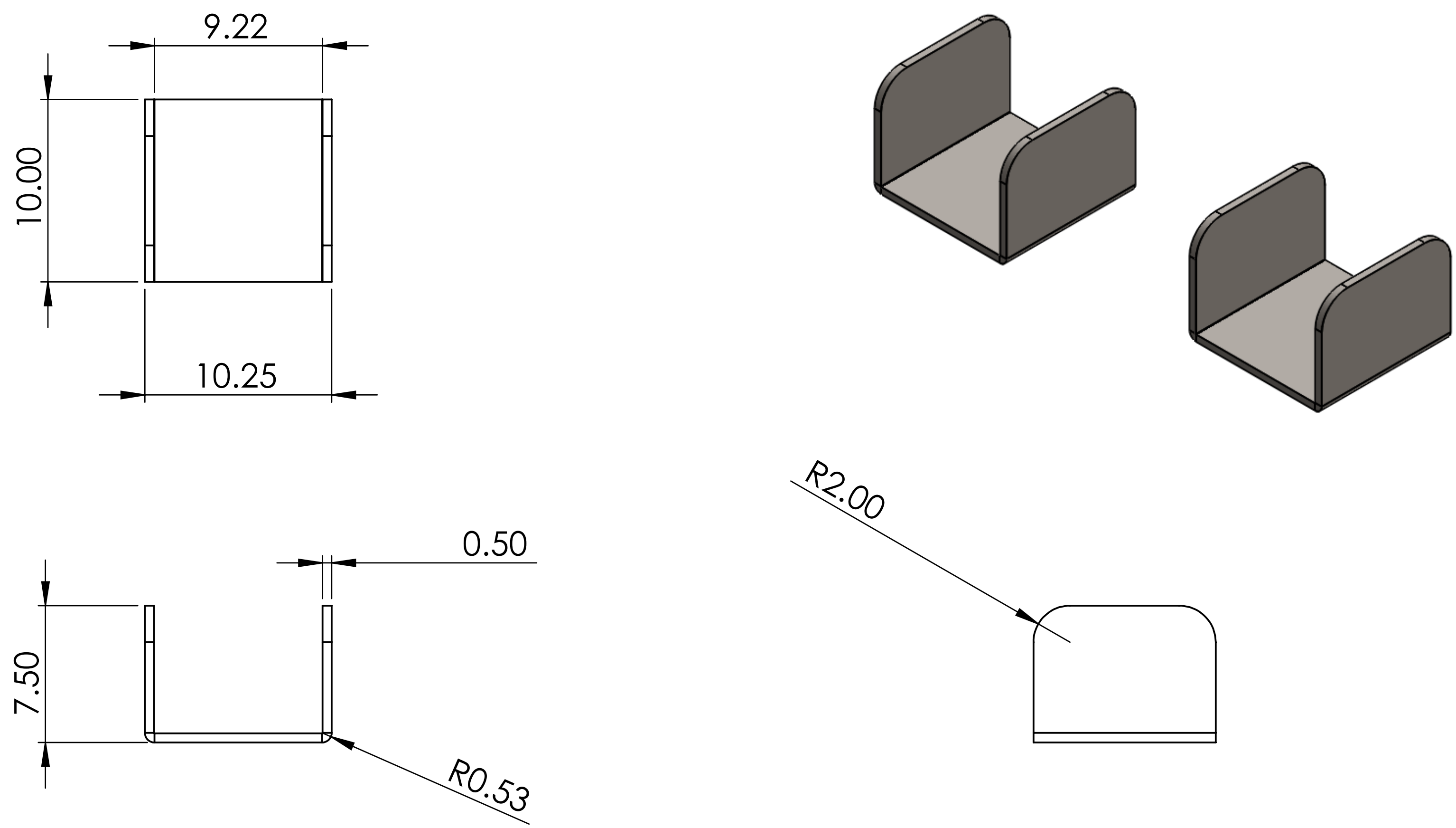
SolidWorks	MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING		TITLE: TRACTOR STAND PROJECT
			INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME / DATE	SIZE A / DISCRIPTION: FORK C CHANNEL / REV 0
			DO NOT SCALE DRAWING	DRAWN G.O 29/11/2015	
			MATERIAL ASTM A36		
			FINISH AS NOTED	CHECKED TEAM 12 05/12/2015	SCALE: 1:20 WEIGHT: 112.05 Kg SHEET 3 OF 12

5 4 3 2 1



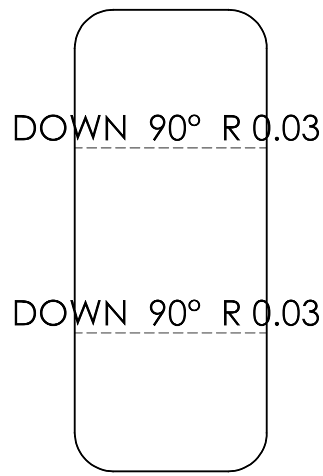
MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING			TITLE: TRACTOR STAND PROJECT	
		INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE	SIZE A	DISCRIPTION: CONNECTOR SHEET
		DO NOT SCALE DRAWING				REV 0
		MATERIAL ASTM A36	DRAWN G.O	29/11/2015		
		FINISH AS NOTED	CHECKED TEAM 12	05/12/2015	SCALE: 1:20	WEIGHT: 39.88 kg
					SHEET 4 OF 12	

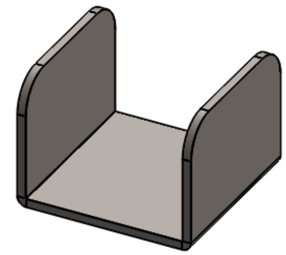
5 4 3 2 1



MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING		TITLE: TRACTOR STAND PROJECT
		INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME / DATE	SIZE A
		DO NOT SCALE DRAWING	DRAWN G.O 29/11/2015	DISCRIPTION: CROSS BEAM POCKET
		MATERIAL ASTM A36		REV 0
		FINISH AS NOTED	CHECKED TEAM 12 05/12/2015	SCALE: 1:10 WEIGHT:15.22 Kg SHEET 5 OF 12

5 4 3 2 1





UofM MECHANICAL ENGINEERING

TITLE: TRACTOR STAND PROJECT

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

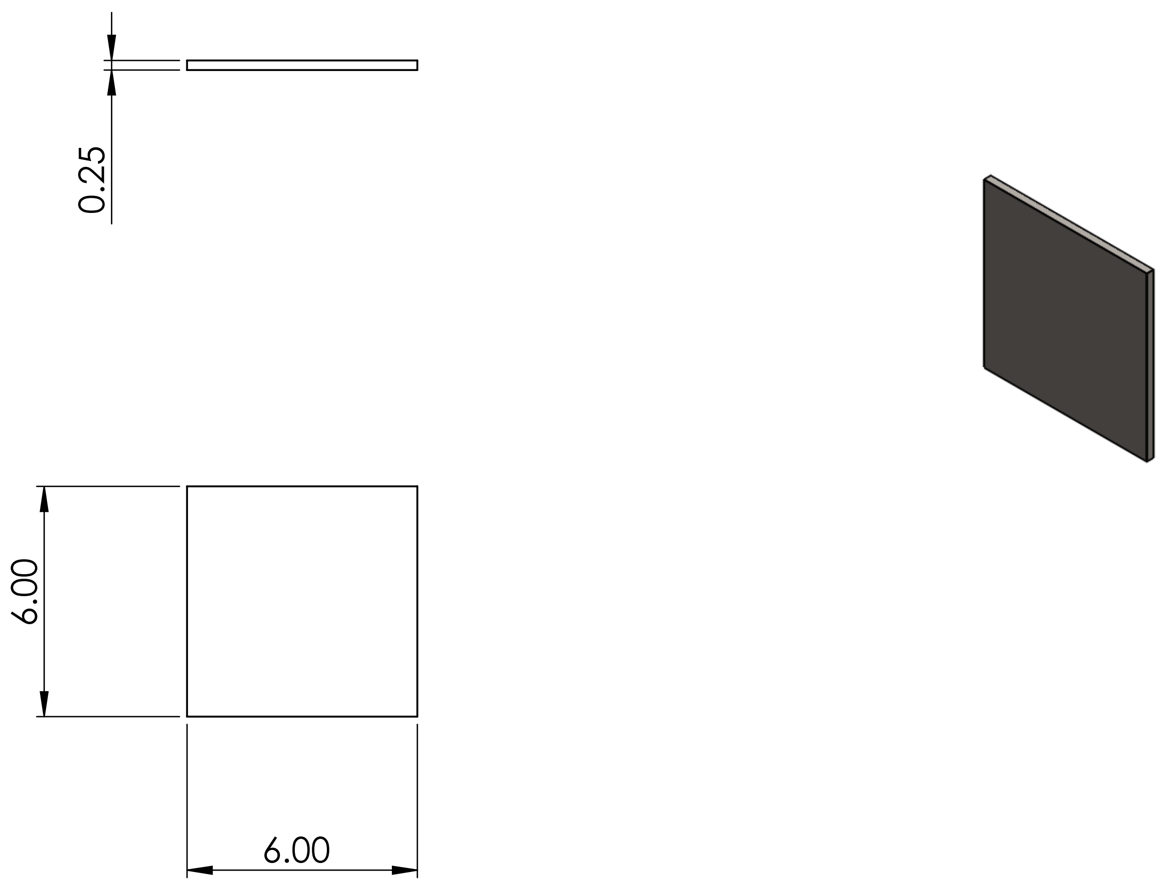
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994
DO NOT SCALE DRAWING
MATERIAL ASTM A36
FINISH AS NOTED

	NAME	DATE
DRAWN	G.O	29/11/2015
CHECKED	TEAM 12	05/12/2015

SIZE A
DISCRIPTION: CROSS BEAM POCKET
REV 0

SCALE: 1:10 WEIGHT: 15.22 Kg SHEET 6 OF 12

5 4 3 2 1



UofM MECHANICAL ENGINEERING

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

MATERIAL ASTM A36

FINISH AS NOTED

	NAME	DATE
DRAWN	G.O	29/11/2015
CHECKED	TEAM 12	05/12/2015

TITLE: TRACTOR STAND PROJECT

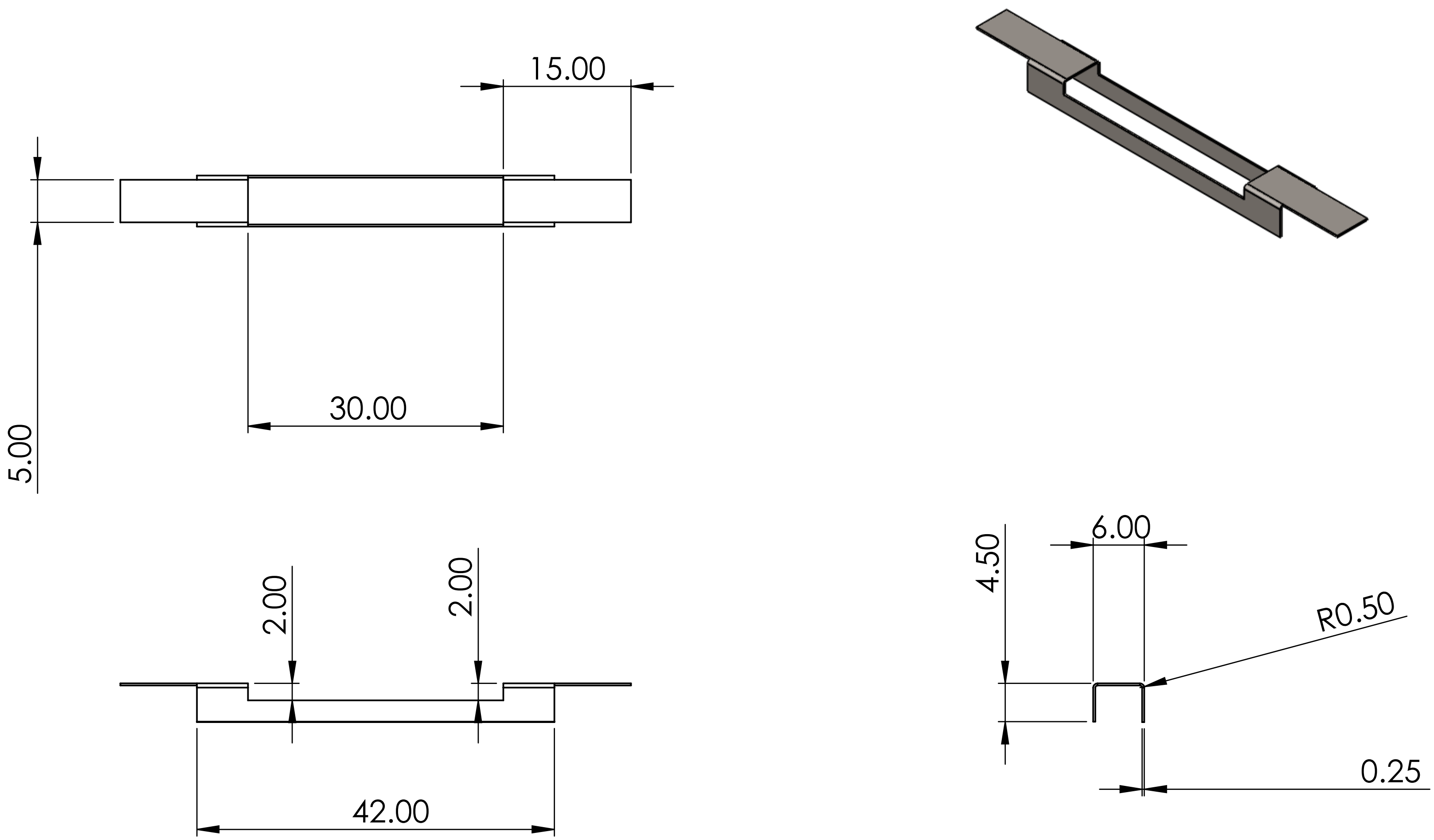
SIZE A

DISCRIPTION: FRONT SUPPORT BRACE

REV 0

SCALE: 1:1 WEIGHT: 1.16 kg SHEET 7 OF 12

5 4 3 2 1



UofM MECHANICAL ENGINEERING

TITLE: TRACTOR STAND PROJECT

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

MATERIAL: ASTM A36

FINISH: AS NOTED

	NAME	DATE
DRAWN	G.O	29/11/2015
CHECKED	TEAM 12	05/12/2015

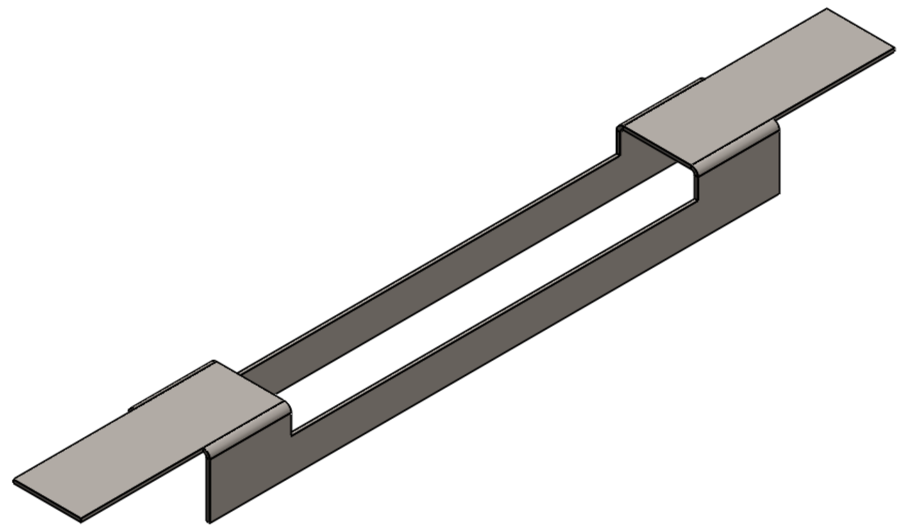
SIZE: A

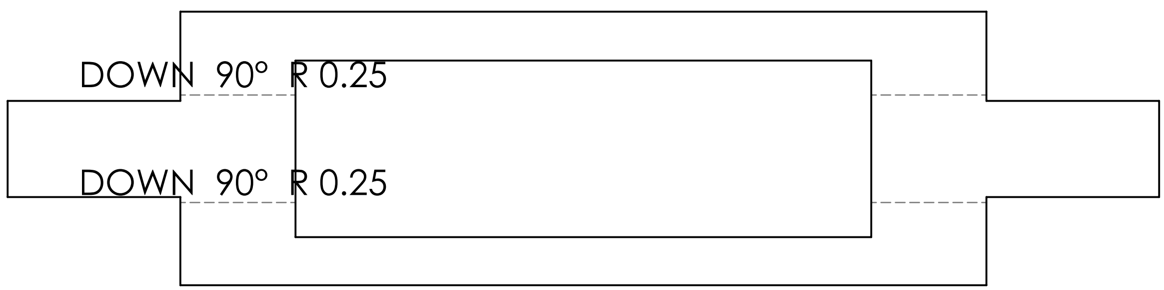
DISCRIPTION: FRONT SUPPORT

REV: 0

SCALE: 1:20 WEIGHT: 13.26 Kg SHEET 8 OF 12

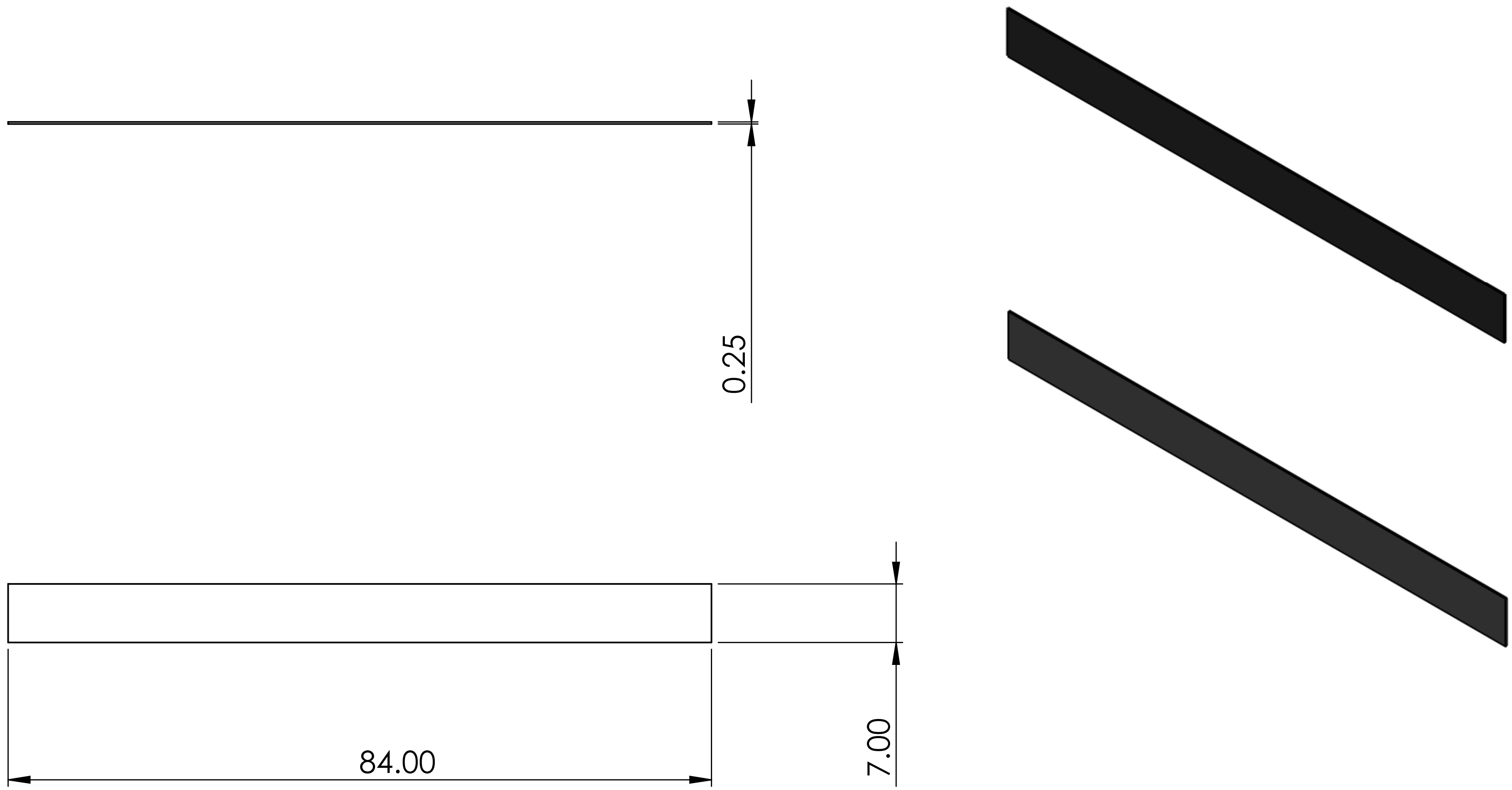
5 4 3 2 1





UofM MECHANICAL ENGINEERING				TITLE: TRACTOR STAND PROJECT	
MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE	SIZE A	DISCRIPTION: FRONT SUPPORT	REV 0
		DO NOT SCALE DRAWING	DRAWN	G.O	29/11/2015		
		MATERIAL ASTM A36					
		FINISH AS NOTED	CHECKED	TEAM 12	05/12/2015	SCALE: 1:10	WEIGHT:13.26 Kg	SHEET 9 OF 12

5 4 3 2 1



UofM MECHANICAL ENGINEERING

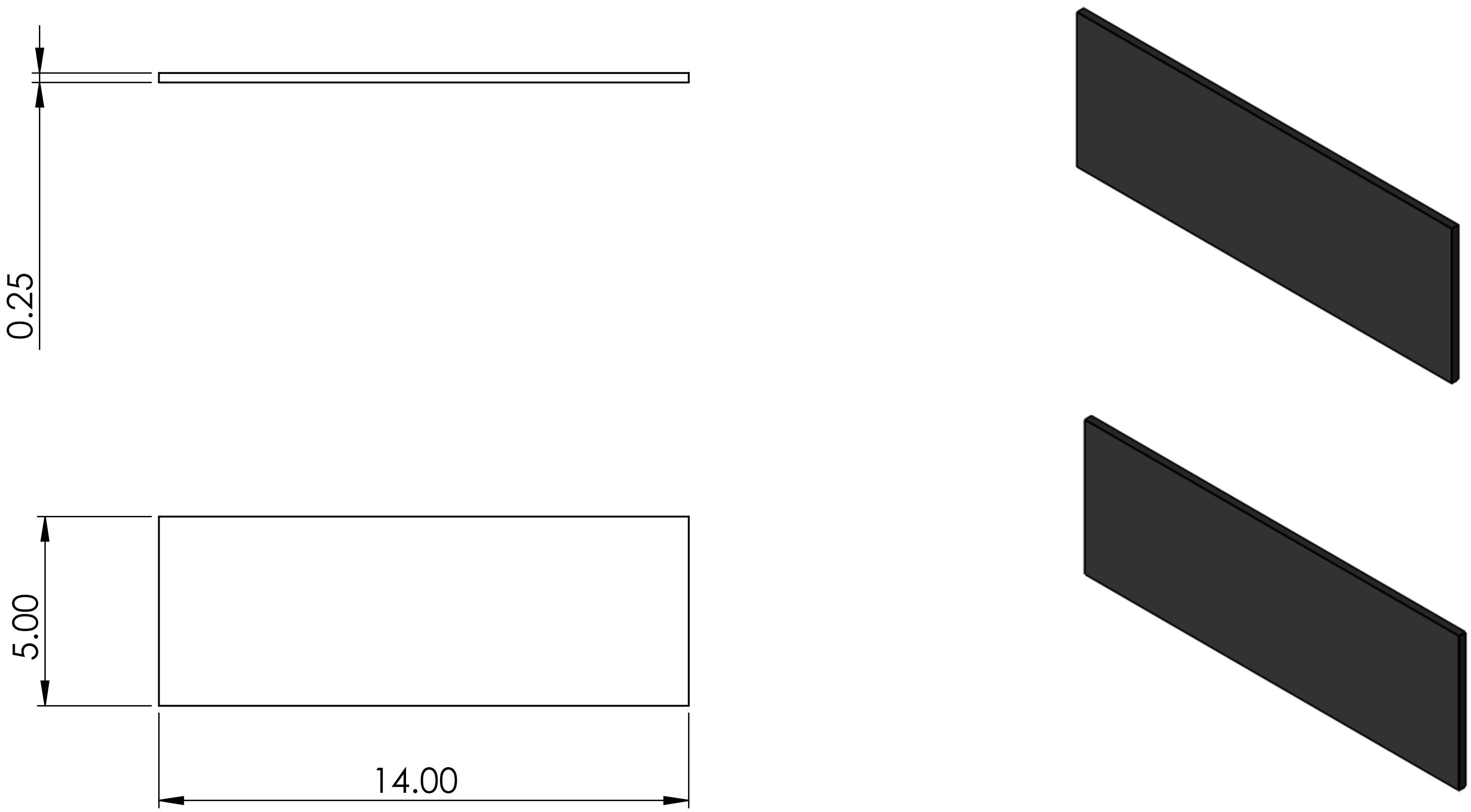
TITLE: TRACTOR STAND PROJECT

MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE
		DO NOT SCALE DRAWING	DRAWN G.O	29/11/2015
		MATERIAL ASTM A36		
		FINISH AS NOTED	CHECKED TEAM 12	05/12/2015

SIZE A | DISCRIPTION: LONG RUBBER PAD | REV 0

SCALE: 1:20 WEIGHT:2.95 Kg SHEET 10 OF 12

5 4 3 2 1



MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

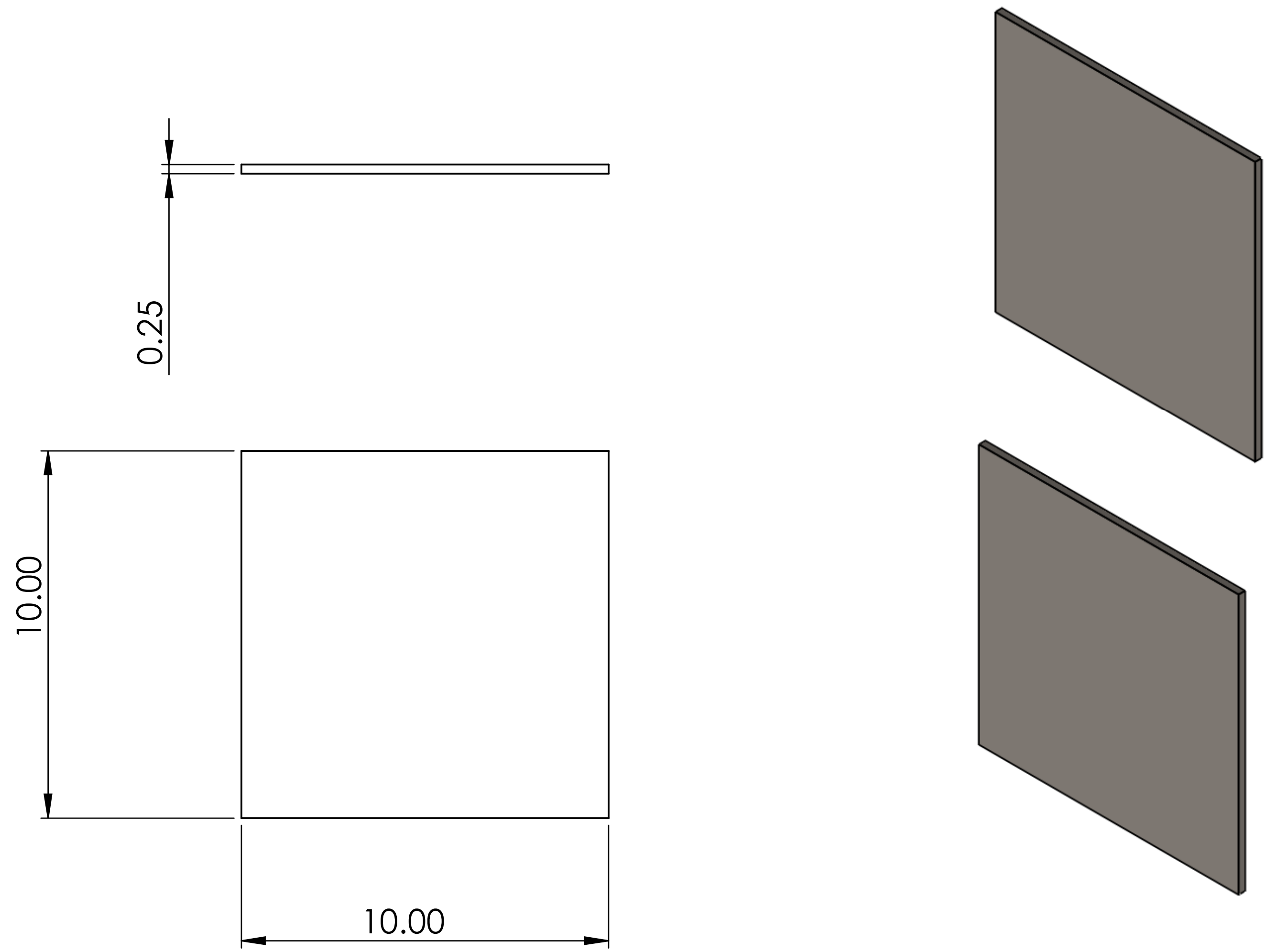
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	G.O	29/11/2015
MATERIAL ASTM A36			
FINISH AS NOTED	CHECKED	TEAM 12	05/12/2015

TITLE: **TRACTOR STAND PROJECT**

SIZE	DISCRIPTION:	REV
A	SHORT RUBBER	0

SCALE: 1:5 WEIGHT: 0.35 Kg SHEET 11 OF 12

5 4 3 2 1



UofM MECHANICAL ENGINEERING

TITLE: **TRACTOR STAND PROJECT**

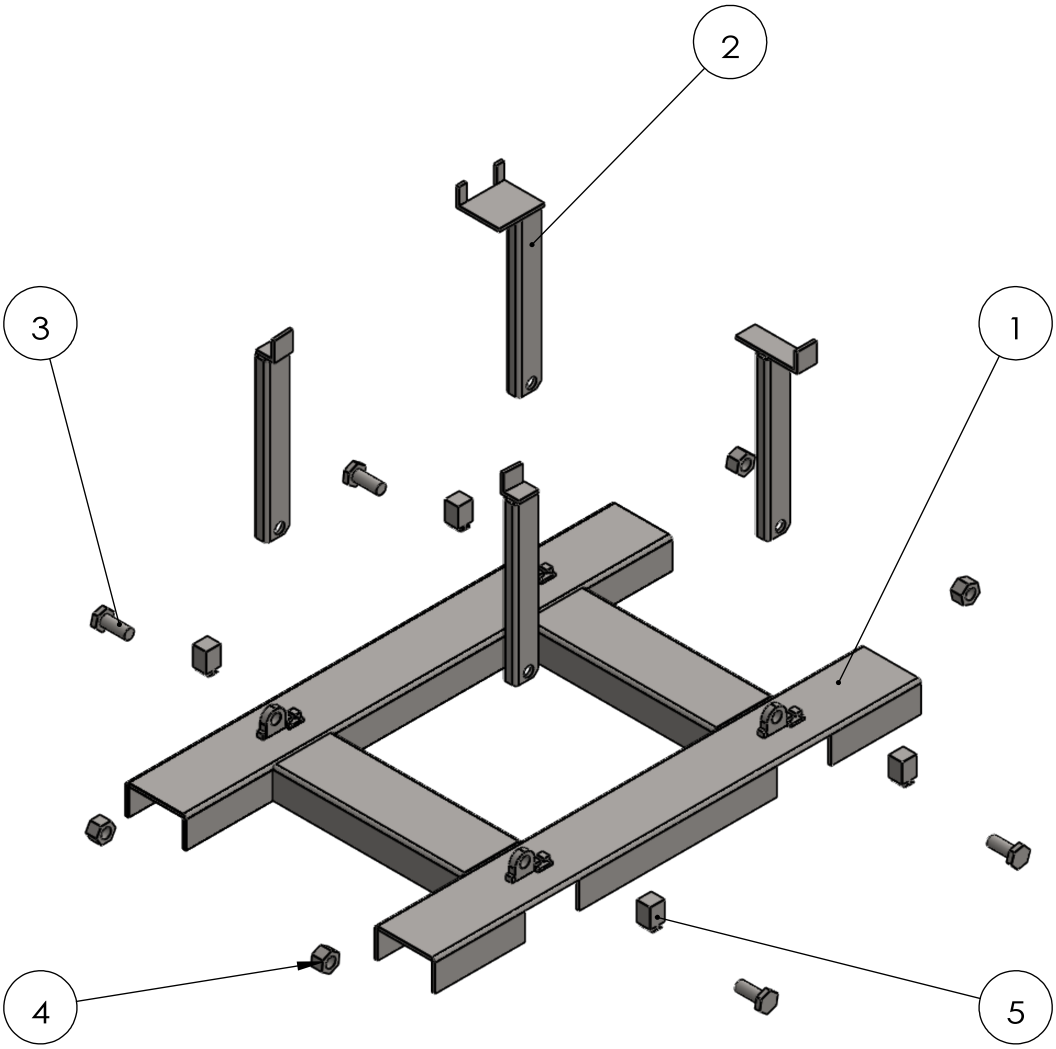
MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE
		DO NOT SCALE DRAWING		
		MATERIAL ASTM A36	DRAWN G.O	29/11/2015
		FINISH AS NOTED	CHECKED TEAM 12	05/12/2015

SIZE	DISCRIPTION:	REV
A	C CHANNEL BOTTOM	0

SCALE: 1: 5 | WEIGHT: 3.22 Kg | SHEET 12 OF 12

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Stand	Reusable Stand Body	1
2	Leg	Tractor Support Legs	4
3	Pin	Pin Bolt	4
4	Nut	Nut for Pin Bolt	4
5	Fixture	Stop Legs Rotating During Operation	4



U of M MECHANICAL ENGINEERING

	NAME	SIGNATURE	DATE
DRAWN	Y. W.		11/16/15
CHK'D	L.M.		11/18/15

DO NOT SCALE DRAWING
REVISION: 0
FINISH
DO NOT SCALE DRAWING

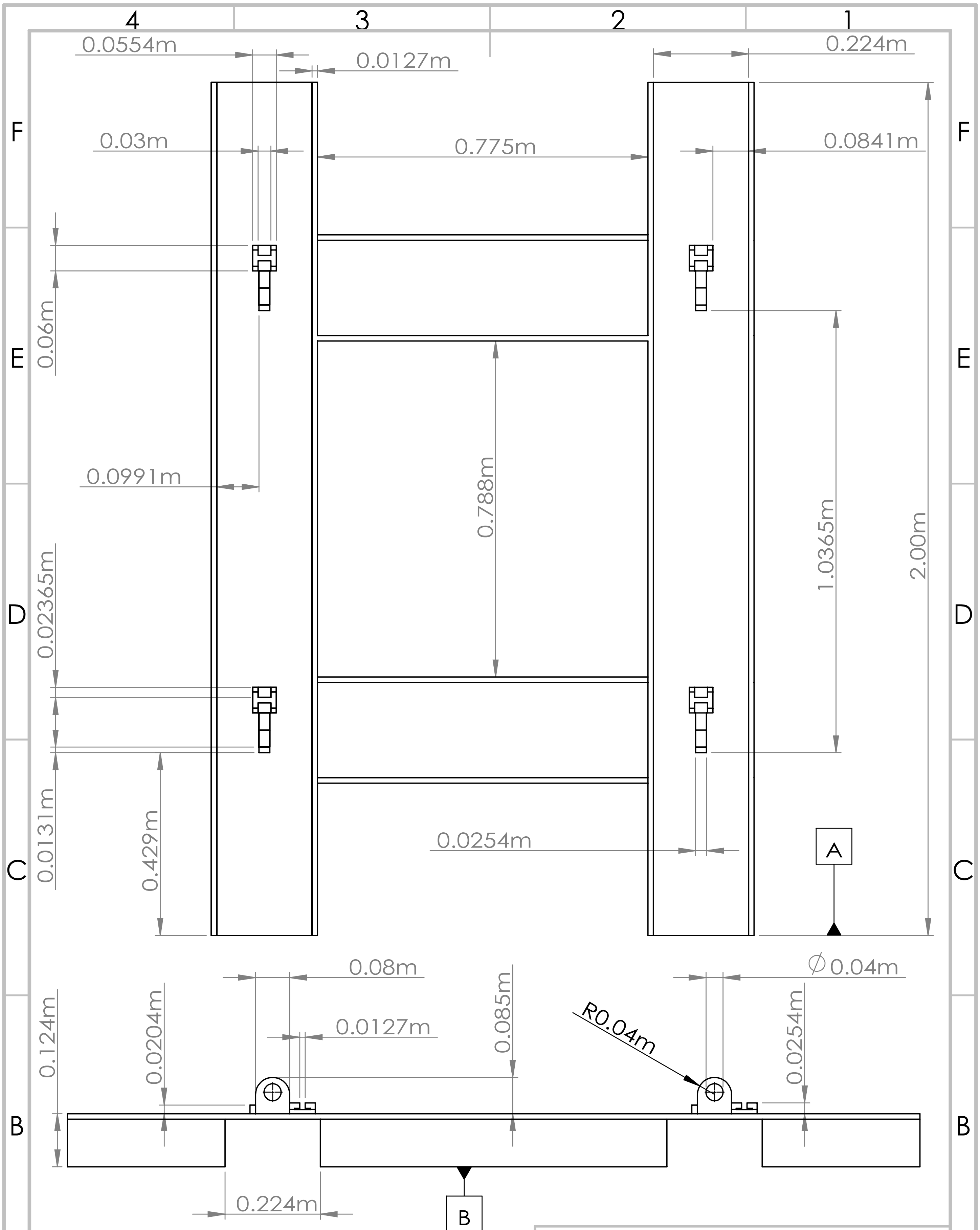
TITLE:
MACDON WINDROWER TRANSPORT STAND DESIGN

MATERIAL:
ASTM A36

DWG NO.
Assem1

A4

WEIGHT: 498.4 Kg
SCALE 1:22
SHEET 1 OF 9



U of M MECHANICAL ENGINEERING

	NAME	SIGNATURE	DATE
DRAWN	Y. W.		11/16/15
CHK'D	L.M.		11/18/15

DO NOT SCALE DRAWING

REVISION: 0

FINISH: DO NOT SCALE DRAWING

DESCRIPTION: STAND

MATERIAL: ASTM A36

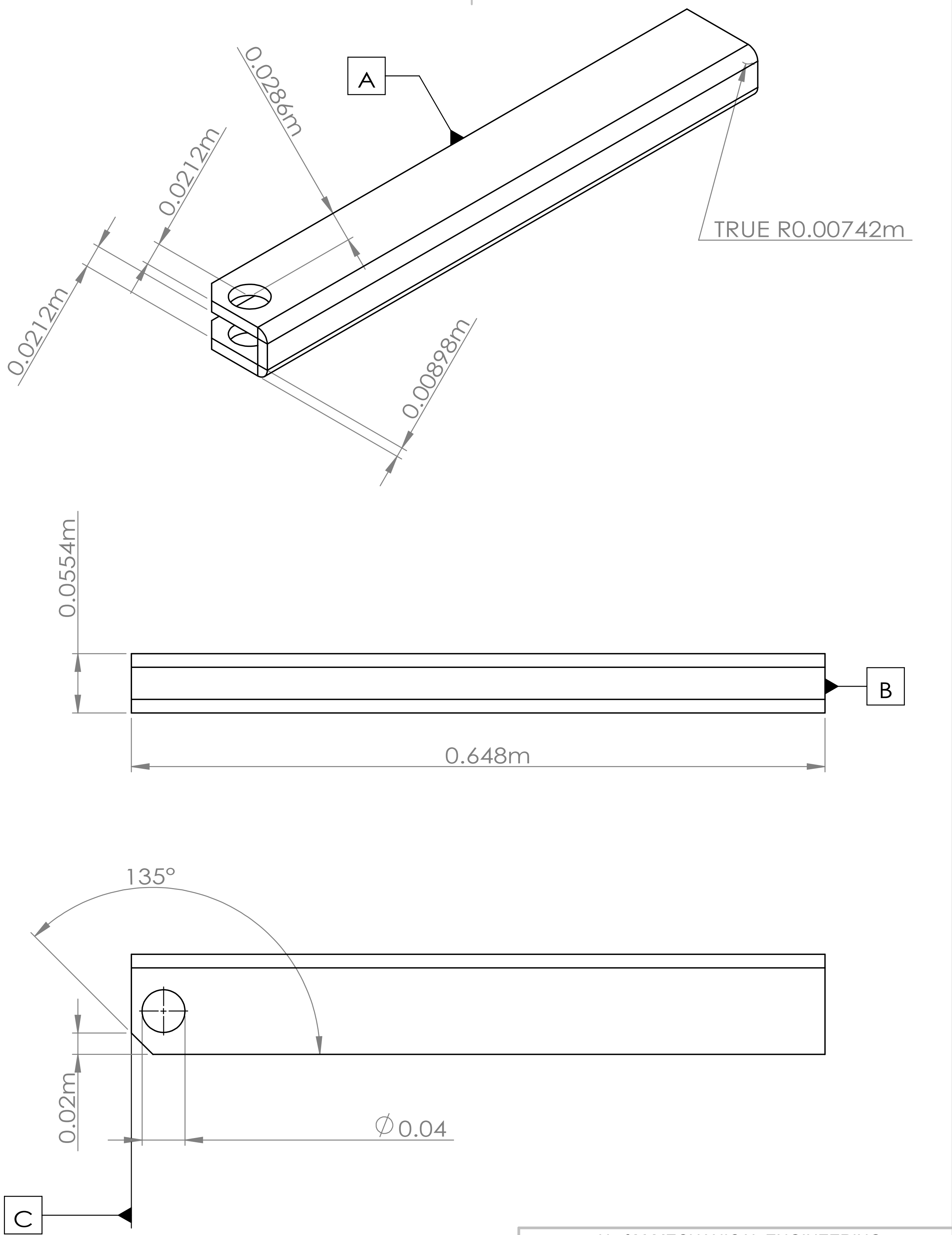
TITLE: MACDON WINDROWER TRANSPORT STAND DESIGN

DWG NO. Assem2

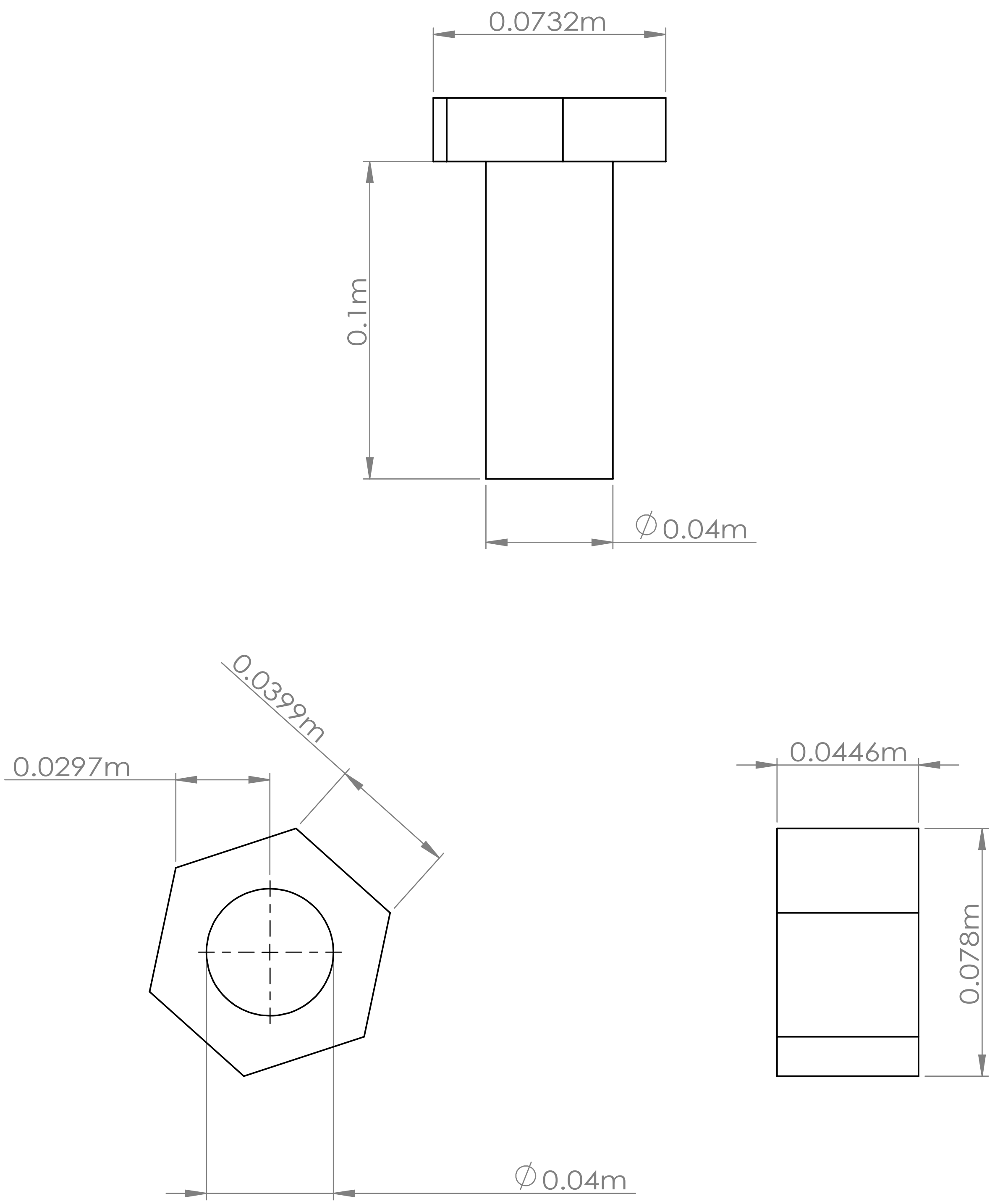
A4

SCALE 1:13

SHEET 2 OF 9



	NAME	SIGNATURE	DATE	DO NOT SCALE DRAWING	REVISION: 0	U of M MECHANICAL ENGINEERING	
DRAWN	Y. W.		11/16/15	FINISH DO NOT SCALE DRAWING		TITLE: MACDON WINDROWER TRANSPORT STAND DESIGN	
CHK'D	L.M.		11/18/15				
				DESCRIPTION: **LEG**			
				MATERIAL: ASTM A36		DWG NO. Assem3	A4
						SCALE 1:13	SHEET 3 OF 9



U of M MECHANICAL ENGINEERING

	NAME	SIGNATURE	DATE
DRAWN	Y. W.		11/16/15
CHK'D	L.M.		11/18/15

DO NOT SCALE DRAWING

REVISION: 0

FINISH: DO NOT SCALE DRAWING

DESCRIPTION: **PIN & NUT**

MATERIAL: ASTM A36

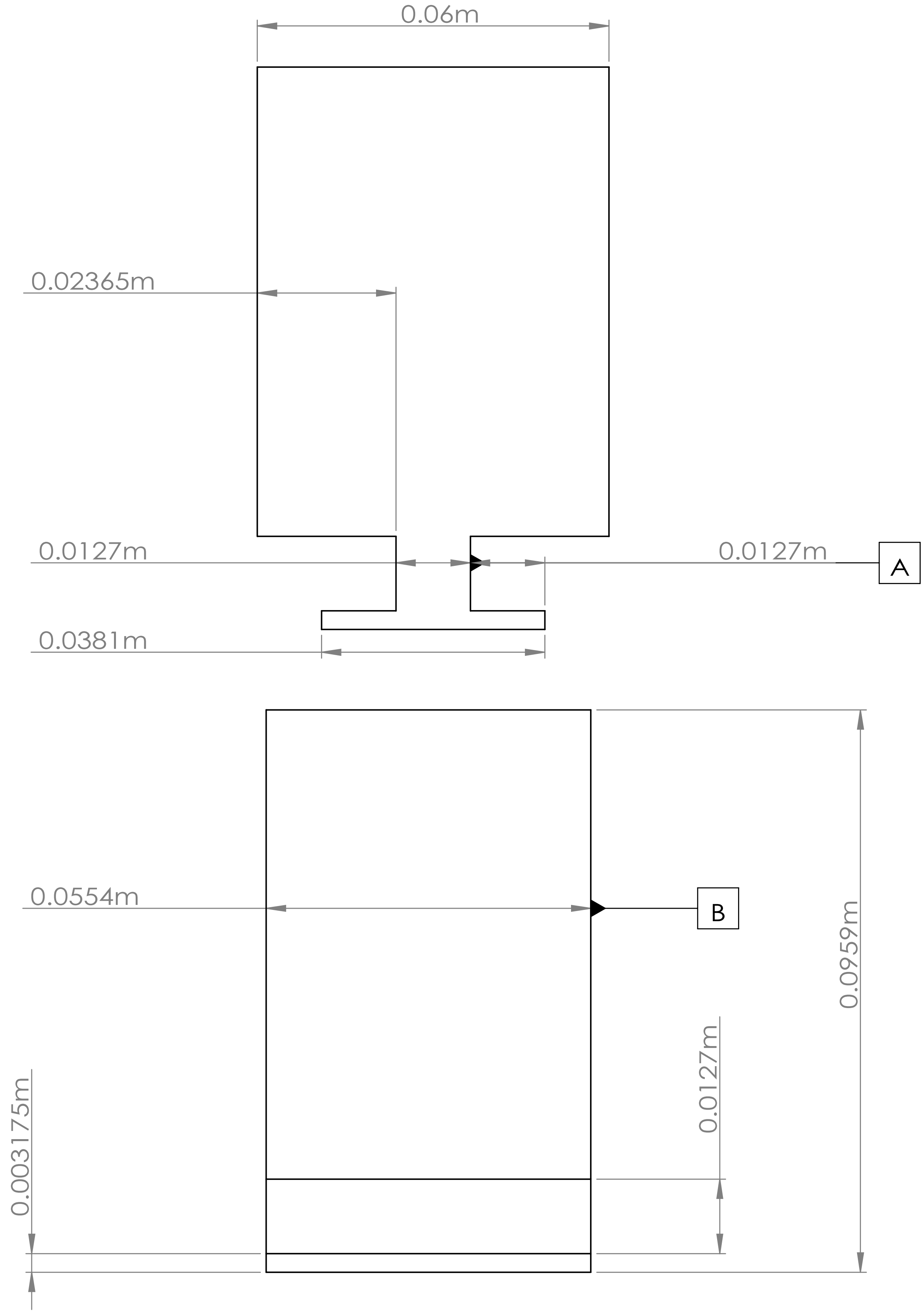
TITLE: MACDON WINDROWER TRANSPORT STAND DESIGN

DWG NO. Assem4

A4

SCALE 1:13

SHEET 4 OF 9



U of M MECHANICAL ENGINEERING

	NAME	SIGNATURE	DATE	DO NOT SCALE DRAWING	REVISION: 0
DRAWN	Y. W.		11/16/15	FINISH DO NOT SCALE DRAWING	
CHK'D	L.M.		11/18/15		
				DESCRIPTION: **FIXTURE**	
				MATERIAL: ASTM A36	

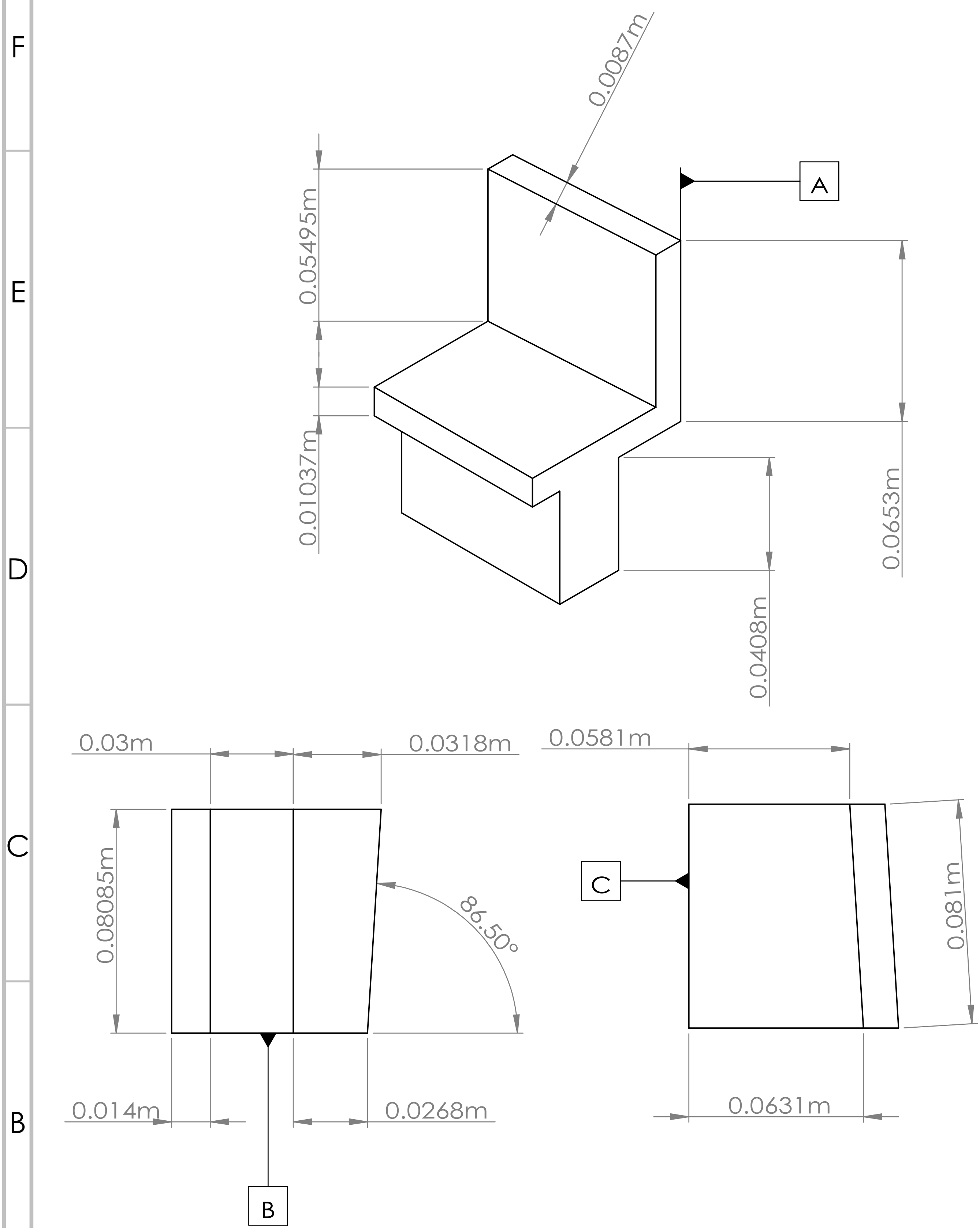
TITLE: MACDON WINDROWER TRANSPORT STAND DESIGN

DWG NO. Assem5

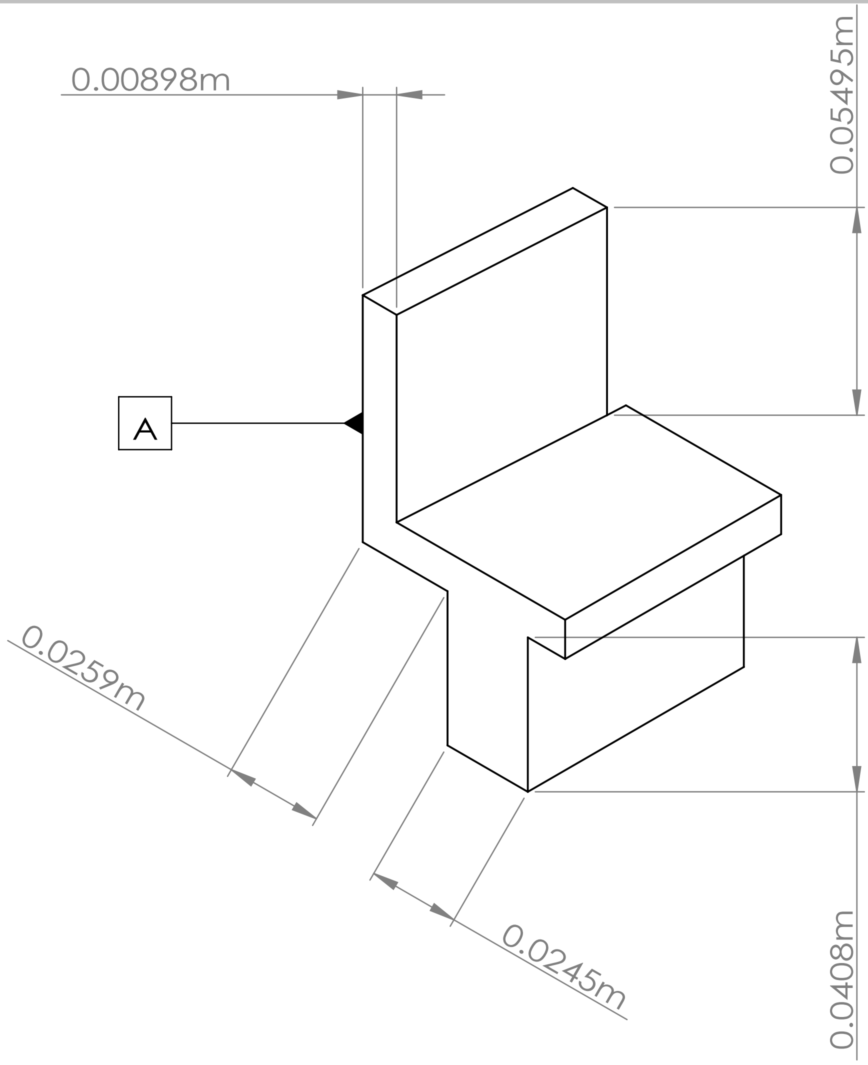
A4

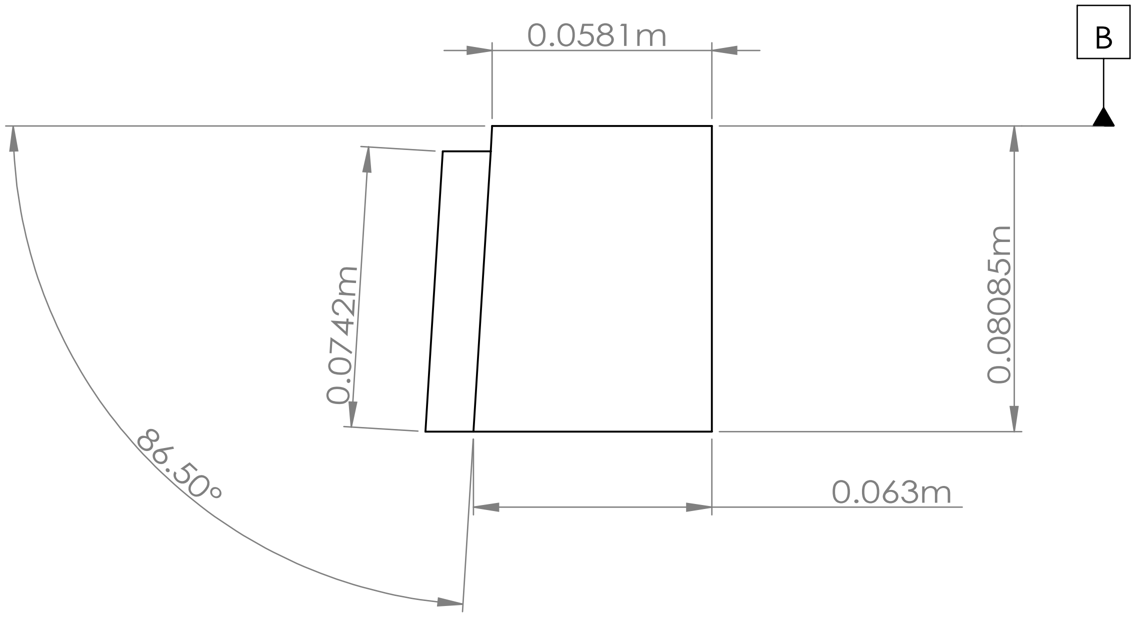
SCALE 1:13

SHEET 5 OF 9



	NAME	SIGNATURE	DATE	DO NOT SCALE DRAWING	REVISION: 0	U of M MECHANICAL ENGINEERING
DRAWN	Y. W.		11/16/15	FINISH: DO NOT SCALE DRAWING		TITLE: MACDON WINDROWER TRANSPORT STAND DESIGN
CHK'D	L.M.		11/18/15	DESCRIPTION: **FRONT LEFT HAND**		
				MATERIAL: ASTM A36		DWG NO. Assem6 — A4
						SCALE 1:2 — SHEET 6 OF 9





U of M MECHANICAL ENGINEERING

	NAME	SIGNATURE	DATE	DO NOT SCALE DRAWING	REVISION: 0
DRAWN	Y. W.		11/16/15	FINISH DO NOT SCALE DRAWING	
CHK'D	L.M.		11/18/15		

DESCRIPTION:
FRONT RIGHT HAND

MATERIAL:
A1011 CQ

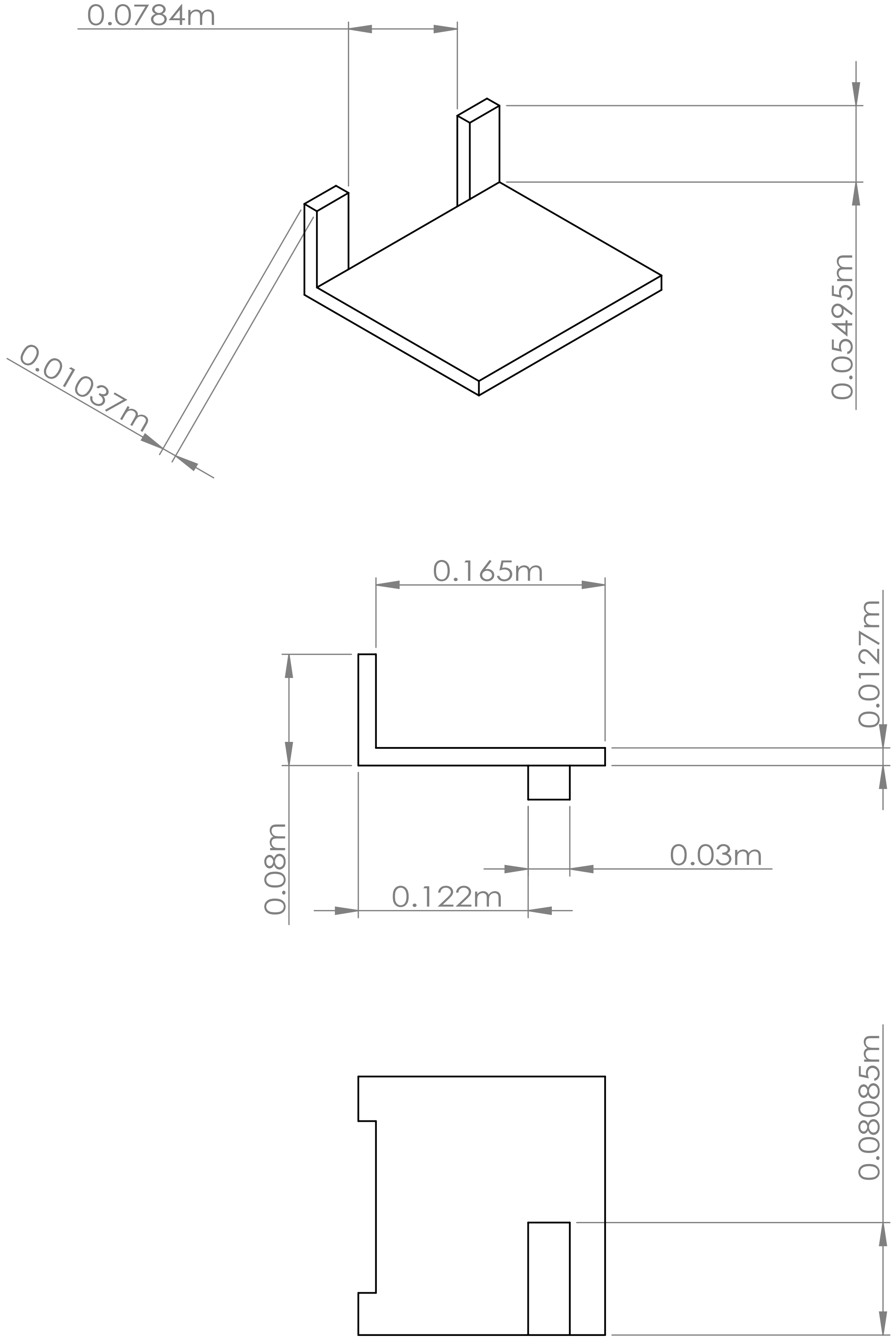
TITLE:
MACDON WINDROWER TRANSPORT STAND DESIGN

DWG NO.
Assem7

A4

SCALE 1:2

SHEET 7 OF 9



U of M MECHANICAL ENGINEERING

	NAME	SIGNATURE	DATE
DRAWN	Y. W.		11/16/15
CHK'D	L.M.		11/18/15

DO NOT SCALE DRAWING

REVISION: 0

FINISH

DO NOT SCALE DRAWING

DESCRIPTION:

REAR LEFT HAND

MATERIAL:

A1011 CQ

TITLE:

MACDON WINDROWER TRANSPORT STAND DESIGN

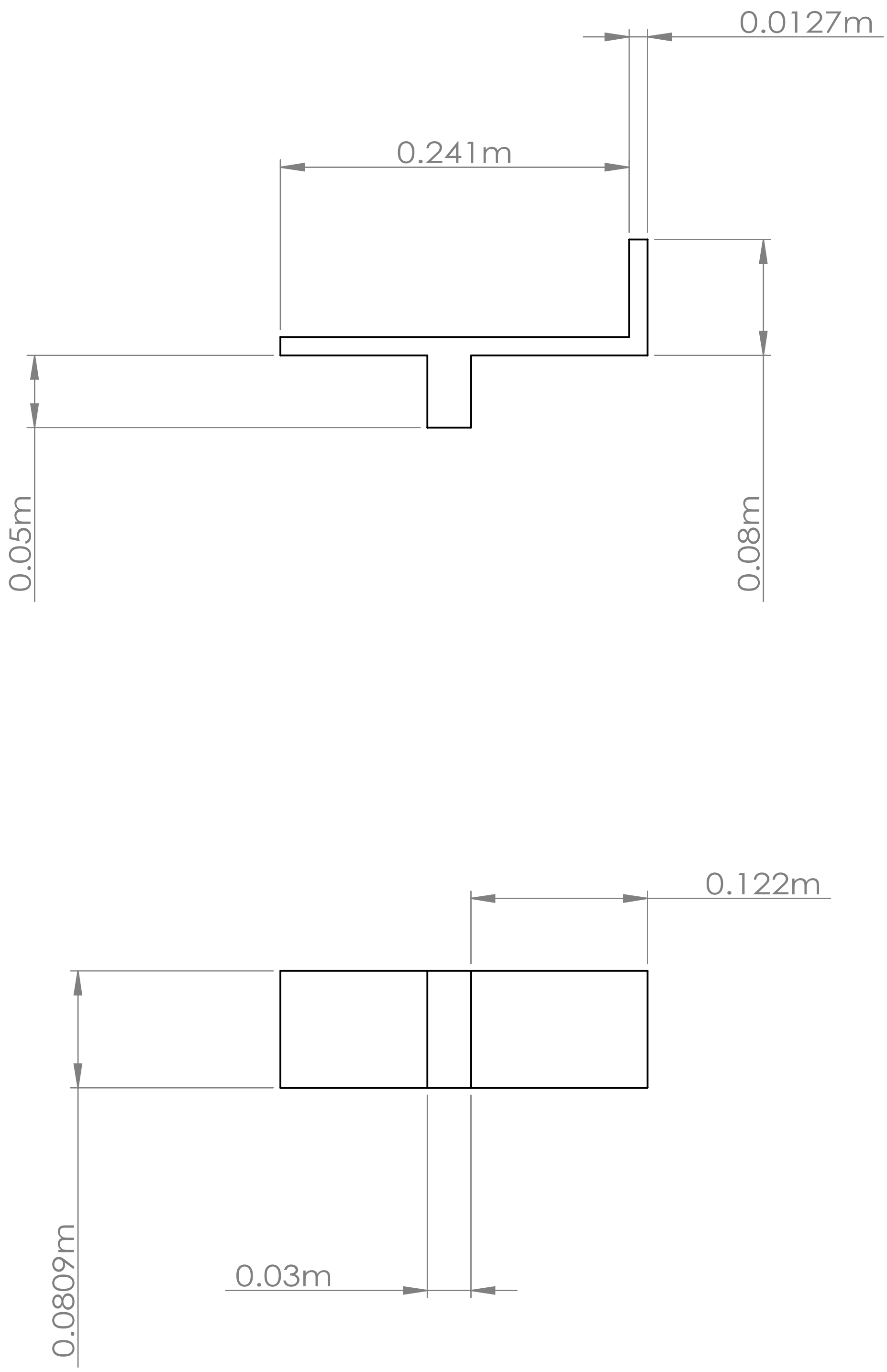
DWG NO.

Assem8

A4

SCALE 1:5

SHEET 8 OF 9



U of M MECHANICAL ENGINEERING

	NAME	SIGNATURE	DATE	DO NOT SCALE DRAWING	REVISION: 0
DRAWN	Y. W.		11/16/15	FINISH: DO NOT SCALE DRAWING	
CHK'D	L.M.		11/18/15		
				DESCRIPTION: REAR RIGHT HAND	
				MATERIAL: A1011 CQ	

TITLE: MACDON WINDROWER TRANSPORT STAND DESIGN

DWG NO. Assem9

A4

SCALE 1:5

SHEET 9 OF 9