MacDon P1:
M Series Attachment for Towing Farm Implements

MECH 4860 Engineering Design

Final Design Report

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Date Submitted: December 7, 2015

LETTER OF TRANSMITAL

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December 7, 2015

Dr. Paul Labossiere
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Dear Dr. Labossiere:

Enclosed is our Final Design Report entitled "M Series Attachment for Towing Farm Implements". This report was written by team 10 and was submitted on December 7th, 2015. The purpose of this report is to present our proposed design for MacDon M Series Windrower attachment device. This report contains information on how the attachment device, built for the M155 windrower, will meet the objective of towing farm implements while running auxiliary functions and facilitating the transmission of rotational power from the tractor to the implement, all while complying with relevant industry codes and standards.

This report explains how the hydraulic and electrical systems on the tractor were modified, to provide the functionality required. This included the addition of a hydraulic motor and gearbox and two intermediate bypass circuits. This report also contains an analysis of the tractor dynamics, such as the draft load and hitching weight, which the attachment would be subjected to while hitching an implement. This analysis was used to design all the components incorporated in the attachment frame including includes built-in-boots, a steel tube kickstand, a drawbar towing system and a turnbuckle running from the tractor to the frame of the attachment.

The group members of Team 10 and the roles they were responsible for are defined below.

- **Bryan Yakimishen, Team Leader:** Executive Summary, Introduction, Conclusion, Hydraulics, Electronics, Instruction/owner's manual
- **Jeff Baylis, CAD Coordinator:** Superstructure CAD, Assembly/part drawings
- **Riley Dyck, FEA Coordinator:** Concept Selection Analysis, Structural FEA, Structural analysis and vehicle dynamics, Hand Calculations
- **Timothy Kyalo, Secretary/Scheduling Manager:** FMEA, Codes and Standards

For further information or clarification, please do not hesitate to contact our team representative, Bryan Yakimishen.

Bryan Yakimishen
MacDon Windrower Design Team

Executive Summary

MacDon M Series windrowers have a limited range of use and can be seen as an unjustifiable expense. As a solution, our team designed an attachment for the tractor that allows it to operate tow-behind farm implements. Our team first analyzed the needs, target specifications and constraints for the project based on interviews conducted and research on industry codes and standards. An extensive concept development procedure was then followed to produce a superior design. Screening and scoring matrices were used to select optimal concepts based on weighted selection criteria. At the end of this process a concepts was chosen for each of the five subsections of the design including frame and packaging, lift linkage connection, drawbar connection, attachment hydraulics, and tractor hydraulics and electronics.

This hitch attachment is constructed from steel sheet and tubing. The main frame member is a 5” x 5” x .25” ASTM A500 grade B steel tube and has been analyzed using finite element analysis and hand calculation to confirm the size and shape of features using a factor of safety of 1.5. The frame includes built-in-boots, a steel tube kickstand, a drawbar towing system and a turnbuckle running from the tractor to the frame of the attachment. The attachment is powered by a Comer 2.5:1 reduction gearbox, and an Eaton 75cc hydraulic motor, both from MacDon’s inventory. An adapter has been specified for the gearbox to convert from a 6-spline to a 21-spline shaft and transfer the 100 HP available to the implement. Hydraulic oil is combined from two separate flows at 4200 psi and a combined flow rate of 58 gpm to spin the motor. A valve block provides a second dual acting circuit for the attachment to go with the primary circuit and a third single acting circuit connected to the implement with pioneer quick couplers. Two wiring harnesses are used to bypass lockouts on the M Series. The first allows the operator to switch between cab-forward and engine-forward manually and the second is used to manually select the traction drive range which dictates the speed and torque achievable at the drive tires. The design for this system works with the current M Series and can be adapted to future models with relative ease.

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1.0 Introduction

MacDon Industries is a Manitoba based company specializing in the manufacturing of harvesting equipment. Four main products are designed, tested, and manufactured by the company. These include a combine pick-up header, a combine draper header, a pull-type rotary header, and a self-propelled windrower which can be equipped with a variety of different headers specific to the customer's needs. Although the company does not produce a wide range of products, each product line is highly regarded by many in the industry as top of the line. In order to earn and maintain such a reputation, MacDon is constantly working to improve its products and by investing in technology and innovation. Research and development is carried out by a large team of experienced engineers and experimental mechanics who design, build, and test prototype equipment before it ever reaches the production line. It is this attitude of constant and tireless improvement and innovation that has helped the company become what it is today.

In an effort to continue to innovate, MacDon has tasked our team with a project aimed to significantly add to the capabilities of its M Series self-propelled windrower. The M Series windrower, as shown in Figure 1, is a very useful tool for farmers working with both grain and livestock. Figure 1 shows the M Series with a draper header attached. However, rotary and auger headers can also be used in the draper header's place by removing the header from the windrower's lift linkages.

Figure 1: MacDon M Series tractor with draper header attached in front of the cab [1].

Our team will design an attachment to take the place of these headers, thereby allowing the M Series to not only function as a windrower, but to also tow various other farming implements that would normally require a different type of tractor. The creation of this attachment will involve working with the current windrower to design a structure that will fit to the current lift linkages, and a hydraulically driven system with electrical control which will provide the power required to operate the additional farm implements.

1.1 Background Information

Designing a hitch attachment for the MacDon M Series will require knowledge of how the windrower is normally used and how it could be used with the attachment. Our team will also need to know how the M Series functions. This includes understanding how the headers for the windrower are hydraulically powered, where the hydraulic power is produced, and how it is directed to the header. The electronic controls should also be understood since these will be used to control the hydraulic system and allow for the safe operation of the M Series.

MacDon windrowers allow farmers to quickly cut down large sections of various crops and lay them into neat rows of cut crop, also known as windrows. Secondary processing, which varies from crop to crop, can then be performed on the windrows. For grain crops, the windrows can be processed by a combine harvester to separate the grain from the other crop material. With hay and forage crops, the windrows can either be baled and stored for later use in livestock production, or chopped and piled to be used as silage feed for livestock production.

Although the M Series windrowers are excellent at cutting crops and laying windrows, they do require a substantial monetary investment on the farmer’s behalf. This can often be seen as an unjustifiable expense for a small to medium sized farming operation, given the windrower’s limited range of use. This limited range of use stems from the fact that the M Series tractors cannot currently operate any tow-behind agricultural implements. Therefore, in order for a farmer to run his operation he must also own an additional tractor to run implements such as hay rakes, balers, stone pickers, and grain augers. This ultimately affects sales of the M Series windrower, and limits the market which MacDon can target.

To address this problem, an attachment must be designed for the windrower which will allow it to tow and operate implements that would normally require an additional tractor. Although this may not completely eliminate the need for another tractor, it would lessen the burden on one and allow a farmer to get more use of his windrower. Implements that could be operated may include the previously stated tow-behind machinery, along with other non-tillage agricultural implements.

The attachment to be designed must be a structure which will span the distance between the two M Series lift linkages. These lift linkages, as shown in Figure 2 and more closely in Figure 3, are the main method used to connect headers to the windrower. A similar system to that used by the headers should be used to connect the attachment being designed.

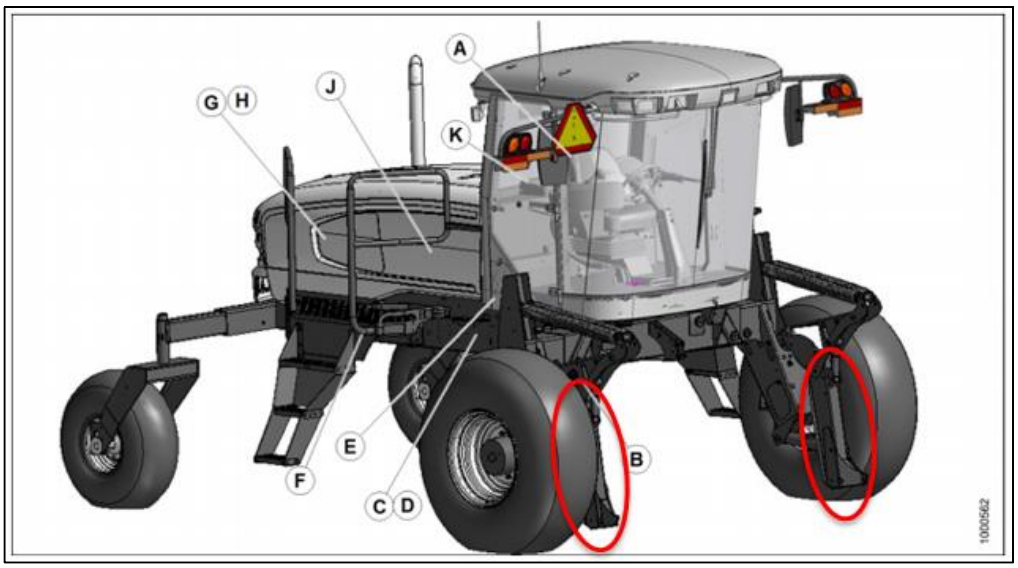

Figure 2: MacDon M Series tractor with lift linkages circled in red. Adapted from [2].

Figure 3: M Series lift linkage close up with hydraulic lift cylinder circled in red. [Photo Credit: Tim Kyalo]

To install a header on the M Series, a “boot” is first installed on the lift linkage. There are currently two versions of this boot, as shown in Figure **4** and Figure **5**. These boots act similar to the forks on a fork lift when the header is being attached. They allow the M Series to lift the header from underneath by sliding into specially designed slots on the frame. The boots are then locked into place using J pins. Although reproducing the boot design exactly is not required, it is recommended that a method be used that incorporates the same mating surfaces between the lift linkages and the boots along with the same load transferring geometries.

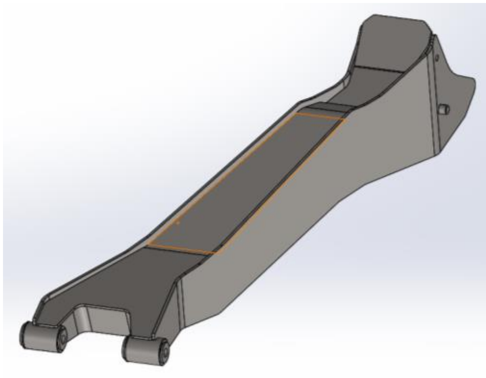

Figure 4: Rotary header boot.

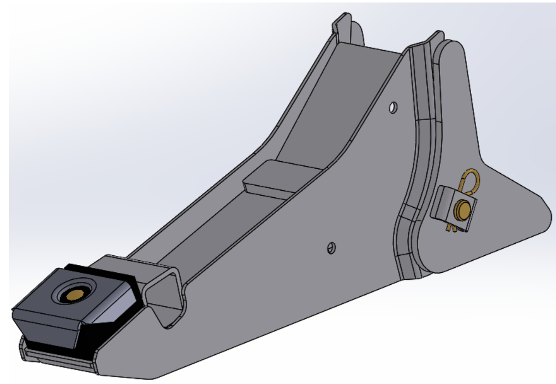

Figure 5: Draper header boot.

The draper and rotary boots are designed to be easy to install onto the lift linkages and to transfer the weight of the header through the lift linkages to the frame. As shown in Figure 6, only the rear lip of the boot and the pin for the boot make contact with the lift linkage. This is what make the boots easy to install. However, it also allows the boots to pivot about the pin running through the lift linkages. This means that if a vertical force is applied to the end of the boot, the boot will move vertically until the upper rear section of the boot contacts the front of the lift linkage. A tilt cylinder is located centrally on the frame under the cab. It is used to further constrain the attached implements, predominantly in fore-aft rocking motions. This cylinder is shown in Figure 7. Normally it is used to adjust the angle of the header on the M Series.

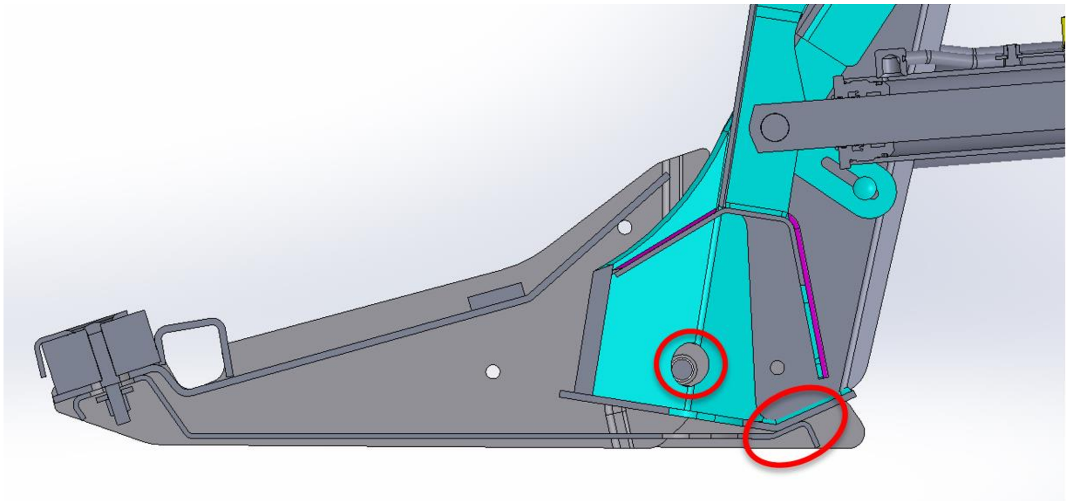

Figure 6: Section view of a MacDon draper boot installed on an M Series lift linkage. Circled in red are the mating surfaces at the back of the draper boot and the pin installed through the hole in the lift linkage.

Figure 7: Extended M Series tilt cylinder pointed downward. [Photo Credit: Tim Kyalo]

The lift linkages on the M Series are controlled by two hydraulic cylinders, which allow the tractor to raise and lower the header while it is being operated. These cylinders and lift linkages make it easy to switch from one header to another. However, they are limited in the fact that the lift linkages cannot be lowered all the way to the ground. This implies that a stand or blocks would be required to remove anything that attaches to the M Series lift linkages. Also, the lift cylinders are positioned in such a way that they do not lift straight up and down. Instead the lift linkage pivots about its attachment point to the frame which is located just below the cab. This produces an arc-like range of motion for anything attached to the lift linkages. The pivot point is well placed to transfer the weight of the attachment directly to the frame and thereby the drive tires. This is important as steering for the windrower is accomplished by varying hydraulic flow between the two hydraulic motors on the drive tires. The added weight provides the traction required to make steering and driving the windrower easy and predictable.

Most implements require a power take-off (PTO) connection in order to run properly. On the tractor side, this consists of either a 6-spline or 21-spline shaft, which could be coupled to a quick-detach PTO drive shaft. By ISO 500 industry standard, a 6-spline shaft must spin at 540 RPM, and a 21-spline shaft must spin at 1000 RPM [3]. This rotation can be achieved by harnessing the hydraulic power produced by the windrower's header drive pumps. The header drive pumps, as depicted in Figure 8, consist of 3 hydraulic pumps stacked together and driven through a direct drive connection to the engine flywheel. These pumps are accessible from the underside of the M Series. They are normally used to provide the hydraulic pressure required for the header to function. The first pump, pump A (Figure 8), provides the flow required for the header knife drive circuit which powers the knife drive motor and allows the header to cut the crop. The second pump, pump B, provides the flow required for the reel, draper, and auger drive circuits which power the respective drive motors. The third pump, pump C, is used for the additional hydraulic circuits of the header specifically to provide lift and charge pressure for the reel lift and fore/aft circuits. The specifications for each pump can be found in TABLE I. It should also be noted that most implements require auxiliary hydraulic circuits to operate various single and double acting hydraulic cylinders. The pressure for these circuits could also be provided by header drive pump C.

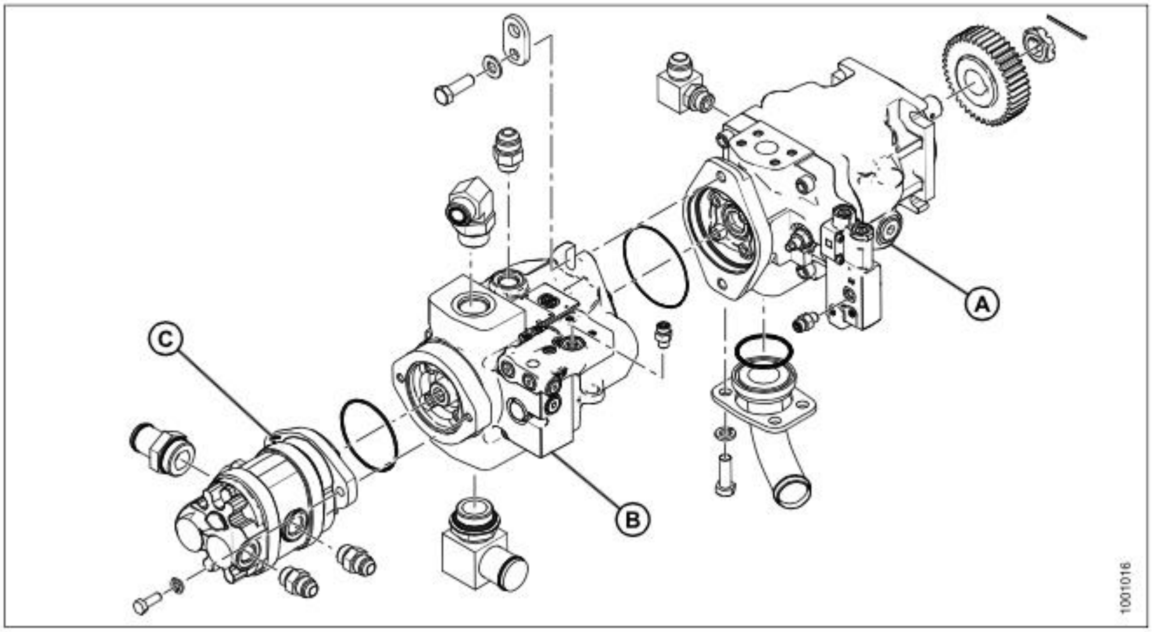

Figure 8: Header drive pumps including the (A) knife drive pump, (B) reel and draper pump, and (C) tandem gearlift pump [2].

TABLE I: HEADER DRIVE PUMP SPECIFICATIONS [2]

Pump	Maximum Displacement	Pressure Margin	Pressure Compensator	Hydraulic Flow
A	45 cc	218 psi (15 bar)	4000-4200 psi (276-290 bar)	26-29 US gpm max.
B	38 cc	260 psi (18 bar)	3200-3400 psi (240 bar)	23-24 US gpm max.
C	38 cc	260 psi (18 bar)	4200 psi (290 bar)	23-24 US gpm max.

As previously stated, the flow from each of these pumps goes to running different motors on the draper headers. However, when a rotary header is installed on the M Series a disc drive block is also installed. This block allows the flows from pump A and pump B to be combined. In order for this to work, the relief pressure on pump B is adjusted to 4200 psi to match that of pump A. The flows from pump A and pump B are also adjusted to be 27-30 gpm and 24-28 gpm respectively. This provides a combined flow of 51-58 gpm at 4200 psi when the pumps are running at peak output. This output can be varied through the Cab Display Module (CDM) to allow for different rotational speeds for the rotary disks.

The implements for which this attachment must be designed are normally attached to the back of a tractor and pulled behind during its operation. This poses a unique problem for the windrower since, unlike most tractors which operate with their engine in front of the cab, or engine-forward, the MacDon windrower is normally operated in cab-forward orientation. One special feature of the MacDon windrower is that it can be operated in engine-forward orientation. However, when the operator switches to the engine-forward orientation, by swiveling the seat to face the engine, the header drive pumps are locked out as a safety precaution. The operator is also limited to the use of high range gearing in regards to the traction drive circuit for the wheel motors. This is controlled through the use of electronic circuitry. Two, two-way switches are located in the cab; one at the front and one at the rear. When the seat is in cab-forward position, the front switch is engaged. To switch to engine-forward orientation, the seat and console are rotated by 180 degrees. In doing this the front switch is deactivated, and the rear switch is activated when the seat locks into place facing the engine. The tractor will only be operational when one of these switches is activated. The signals from these switches run to the Windrower Control Module (WCM). The WCM is programed to use this signal to determine whether the windrower should be operated in engine-forward or cab-forward.

Several components are controlled by the WCM based on the driver orientation. Relevant to this project are the P60 and P61 solenoids on the multifunction block. These are the solenoids responsible for low, medium, and high range for the traction drives. Normally in engine-forward, solenoid P61 is activated limiting the driver to high range. This range is suitable for road transportation, but not for towing an implement.

1.2 Project Objectives and Deliverables

An attachment must be designed for the windrower that will allow it to tow and operate farm implements. In order to limit the scope and narrow the focus of the concept generation phase, our team has outlined a list of objectives that must be achieved. They are as follows:

- The attachment must use a drawbar design to allow the windrower to tow implements.
- The attachment must allow for the towing of implements such as balers, hay rakes, stone pickers, grain augers, and various non-tillage agricultural implements.
- The attachment must be a structure designed in such a way that it could be easily manufactured in the MacDon prototyping shop.
- The attachment must connect to the current M Series lift linkages.
- The attachment must convert hydraulic power from the header drive pumps to rotational energy supplied to the implement through a power take-off (PTO) drive shaft connection.
- The PTO connection must allow for the use of 6-spline and 21-spline output shaft couplings.
- The windrower must function fully in engine-forward position with the attachment installed.
- The attachment must provide auxiliary hydraulic circuits. Two of these circuits must allow for the use of double acting hydraulic cylinders and one must allow for the operation of single acting cylinders.
- All auxiliary circuits must be equipped with pioneer quick couplers.

With these objectives in mind our team can move forward in the design phase and begin to produce the following deliverables which are expected of our team at the completion of the project. Our team must provide:

- Stress analysis and information about the designs capabilities. This includes weight limits for the hitch, strength parameters, and stiffness parameters.
- Engineer drawings and CAD files for all parts of the design.
- DXF files for all laser-cut, sheet metal parts.

- Information about hose and wire size, length and routing.
- A bill of materials with MacDon part numbers and supplier information for all parts not currently in MacDon's inventory.
- An assembly guide for the prototype shop.
- A user manual.

1.3 Customer Needs, Target Specifications, and Constraints

The customer needs for this project were determined from the project summary and a meeting with our MacDon contacts, Jeff Leachman and Donny Putro. The needs highlight the important functions and qualities that the proposed attachment must exhibit. Each need is ranked on a 5-point scale of importance, with 5 being the most important. The needs with a higher importance are the first priority, and the lower importance needs are not always fully achievable without detriment to more important needs. TABLE II summarizes the needs and the importance levels that MacDon has for the proposed attachment.

TABLE II: SUMMARY OF MACDON'S NEEDS FOR THE PROPOSED ATTACHMENT

#	Need	Importance
1	The attachment allows for the use of implements other than those produced by MacDon.	5
2	The attachment allows for the use of 540 and 1000 RPM PTO drive shaft implements.	5
3	The attachment will allow for safe connection of implements.	5
4	The attachment allows implements to be towed behind the windrower.	5
5	The attachment will function with the tractor in engine-forward mode.	5
6	The attachment connects to the lift linkages on a MacDon M Series tractor.	5
7	The attachment will not alter the original operation settings when not attached.	4
8	The attachment converts hydraulic power into rotational energy.	4
9	The attachment is durable.	4
10	The attachment will remain functional and fixed in place when operated over rough terrain.	4
11	The attachment allows for the use of auxiliary hydraulic circuits on implements.	4
12	The attachment will be heavy enough to maintain drive tire traction.	4
13	The attachment can operate in harsh environments on a farm.	3
14	The attachment will allow the operator to be comfortable operating the implement.	3
15	The attachment can be fabricated in the MacDon prototype shop.	3
16	The attachment will be clear of obstructions to the drive shaft of the towed implement	3
17	The attachment will be low cost.	2
18	The attachment can be attached and detached quickly and easily.	2
19	The attachment will be aesthetically pleasing.	1

Each need in TABLE II requires a metric to quantify how well it is met. Each metric has units, a marginally acceptable value, and an ideal value. The goal is the ideal value, but the marginal value is still considered a success. These values are also influenced by the importance of the needs. If a need has a lower importance rating, the marginal value and ideal value are typically lower than they would be for a higher importance need. TABLE III summarizes the metrics used to quantify the level to which each need is met.

TABLE III: A SUMMARY OF THE METRICS USED TO QUANTIFY THE ACHIEVEMENT OF THE NEEDS

Need#	Metric	Units	Marginal Value	Ideal Value
1	Number of usable implements	Number	>5	>10
2	Number of shaft speed outputs	Number	2	2
3	The attachment use is safe	Subj.	-	-
4	Max hitch weight	kg	>5000	>6000
5	Setup time to allow engine-forward operation	Seconds	<120	<30
6	Time to connect attachment	Minutes	<5	<3
7, 14	Ease of use of the implement	Subj.	-	-
8	Output shaft power	HP	90	100
9	Life expectancy	Hours	>5000	>10000
10	Factor of safety on yield stress	-	>1.5	>2
10	Factor of safety on ultimate stress	-	>2	>2.5
11	Number of auxiliary hydraulic circuits	# of Circuits	2	3
12	Weight of the attachment	kilograms	<3000	750
13	Range of environments it can be used in	Subj.	>7/10	>9/10
15	Time to assemble	Hours	50	40
16	Angle of operation of the drive shaft	degrees	>20	>30
17	Manufacturing cost	Dollars	<5000	<4500
18	Time to attach/detach	Minutes	8	3
19	Instills pride	Subj.	-	-

Along with the needs in TABLE II outlined by MacDon, a list of constraints was also produced to guide our team in designing this attachment. These constraints came about for different reasons. Some came about because of the manufacturing limitations of the MacDon prototyping shop. Other constraints are born from the need to abide by industry standards. These constraints, which can be found in TABLE IV, were discussed with MacDon and will be considered throughout the design process in order to produce a design which is feasible and worthwhile for the company.

TABLE IV: CONSTRAINTS AND LIMITATIONS

#	Constraints and Limitations
1	Must fit onto lift linkages of a MacDon M155.
2	M155 must be able to lift the attachment.
3	Must not be more than $5000.
4	Must use as many MacDon parts as possible.
5	Must be manufacturable in the MacDon prototype shop.
6	Must use hydraulic power to create rotational energy.
7	Must rotate at 540 and 1000 RPM.
8	Must provide 2 dual acting auxiliary circuits and 1 single acting circuit.
9	Must be constructed from simple materials such as steel sheet, tubing, and angle iron.
10	Should use 7,11,14,16 gauge or .25", .375", 0.5" sheet metal.
11	No cast parts are to be used in the design.
12	Power to run the attachment can come only from the header drive pumps.
13	All designs must adhere to agriculture/vehicle standards.
14	All dimensions used in modeling should be nominal.
15	The attachment cannot cause the tractor to tilt backwards.

1.4 Expectations of the Design

The production of an attachment, as the one described, would add value to the windrower to the average farmer. Beyond that, this attachment could be adapted to aid the testing department at MacDon in the testing of their prototype windrowers. There are only select times during the year when a farmer requires a windrower, so these attachments can only be tested at such times. Much of the testing conducted on prototype tractors involves clocking high hours on the windrowers. Since this does not necessarily involve running a header, the attachment to be designed would make it substantially easier for the MacDon testing department to carry out their test programs with more opportunities to run the prototype tractors.

The design for the attachment is not expected to be production ready. It need only be well enough designed that it could be produced in MacDon's prototyping shop and run by a test technician. If this attachment were to be mass produced, the company would most likely reprogram the controllers on the windrower with a setting specifically for towing implements. This was kept in mind when screening and rating concepts as the focus was placed more on manufacturability and less on the customer.

1.5 Relevant Codes and Standards

The standards used to generate concepts and the finalized designs were selected based on the equipment which was needed to provide the functional requirements for the design. The two main functional requirements include:

1. Provide a hitch attachment for an agricultural implement using a drawbar.
2. Transmit power from the tractor to the implement through a PTO connection.

Figure 9 illustrates several key dimensions that were relevant to the attachment design. TABLE V and TABLE VI provide values for the dimensions in Figure 9.

Figure 9: Locations of relevant dimensions according to ANSI/ASABE standards. This image is a side view of the hitch of a tractor, including a drive tire, PTO spindle, drawbar, and ground plane. Adapted from [4].

TABLE V: SUMMARY OF RELEVENT DRAWBAR AND PTO STANDARDS [4] [5]

Description	Variable	Minimum [mm]	Maximum [mm]
Distance from Closest Possible Obstruction to Drawbar Pin-Hole	L	25	-
Distance from PTO axis to Top of Drawbar	U	250	320
Distance from Top of Drawbar to Ground	S	330	500

TABLE VI: SUMMARY OF DRAWBAR POSITION DEPENDENT VARIABLES [4]

Description	Variable	Drawbar Position		
		Short	Regular	Extended
Distance from PTO Tip to Drawbar Pin-Hole [mm]	T	250±10	400±10	550±10
Hitch Load Applied at Drawbar Pin-Hole [kN]	R_{hz}	22	15	11

2.0 Details of Design

Over the course of three months, the engineering design process was followed closely in producing a finalized design which could be presented to our client. Meetings with the client yielded carefully laid out lists of needs, target specifications, goals, and constraints. After these lists were defined, research was conducted and concepts were generated for several key requirements of the new hitch attachment. Finalized designs and 3D CAD models were produced after carefully screening, scoring, and finally selecting the individual concepts to proceed with. The final design package included detailed stress analysis, hydraulic and electrical schematics, and a bill of materials for all of the required components along with a basic cost analysis.

2.1 Concept Generation and Selection

Concepts were generated using both prior knowledge of agricultural implements as well as research focused on industry standards for drawbars, PTO shafts, and gearboxes. Ideas were generated internally through brainstorming and externally from onsite visits. Online searches were also conducted for competitors' products or patents that may have been similar in functionality and design. Concepts were then generated for the frame, lift linkage connection, drawbar attachment, attachment-side hydraulics, tractor-side hydraulics, and the tractor electronics.

2.1.1 Competitor Products and Patents

After an extensive search of several agricultural equipment manufactures our team failed to find any equipment on the market with a similar purpose to the equipment we were to design. Searches on patent sites also proved to be frivolous as most patents were centered on tractor hitches specifically for chore type tractors. After some consideration it was decided that most manufactures would not need to produce such an attachment for their windrower as they already produced a chore type tractor that would accomplish the required task. An attachment, such as the one we are designing, would only hurt sales for their chore tractor line.

2.1.2 Concept Generation

Our team examined the windrower tractors and some of their attachments at an initial interview with MacDon. Pictures were taken of many of the components to assist with the design of the new attachment. A John Deere tractor was also inspected, as it is designed to pull all of the implements that the attachment we are designing should be able to pull. The tow behind implements were also researched to understand their requirements. Once our team was familiar with the task at hand, concept generation began.

We broke down the brainstorming sessions into superstructure (frame), lift linkage connection, drawbar connection, attachment hydraulics, and tractor electrical and hydraulics. Concept generation began with each team member coming up with several ideas for each section of the design. During a team meeting, each of the individually generated concepts were discussed. Some new ideas were then generated as a result of some of the individual ideas. The concepts were then evaluated for feasibility and their ability to fulfill the criteria. Some of the concepts were eliminated based on a screening matrix, while others were passed on to a weighted scoring matrix for the final decision making process. All the concepts that were generated can be referenced in Appendix 2, however only the developed concepts will be discussed further in this report.

2.1.3 Concept Selection

The concepts generated for each subsection of our design were put through both a screening and scoring process using a list of weighted criteria. This process was conducted for each subsection of the design. Detailed explanations of the decisions made for each subsection along with the corresponding matrices are contained within Appendix 2. Only the results from this screening and scoring process will be discussed in the following sections.

2.1.3.1 Superstructure and Packaging

The frame is the central focus of the attachment, as it has to incorporate each of the other components required to tow the implements. The frame geometry has the potential to limit the design and packaging of the other components, which is undesirable. The major components it must be able to accommodate are:

- Lift linkage connections
- Tractor/attachment hydraulics
- PTO/ gearbox
- Tilt cylinder
- Drawbar

The frame design must also take into account how the weight from the implement will be transferred to the tractor. If the drawbar is too far in front of the drive wheels, it could affect the tractors center of gravity, creating unbalance while towing implements. The frame must also be able to safely tow the implements without the frame cracking or deforming. The Chariot design, as depicted in Figure 10 received the highest score of 4.15 through a concept scoring matrix. For reference, the second and third highest scores were 3.69 and 3.67. The difference between the first and second scores was decided to be of an acceptable magnitude that a sensitivity analysis was not required.

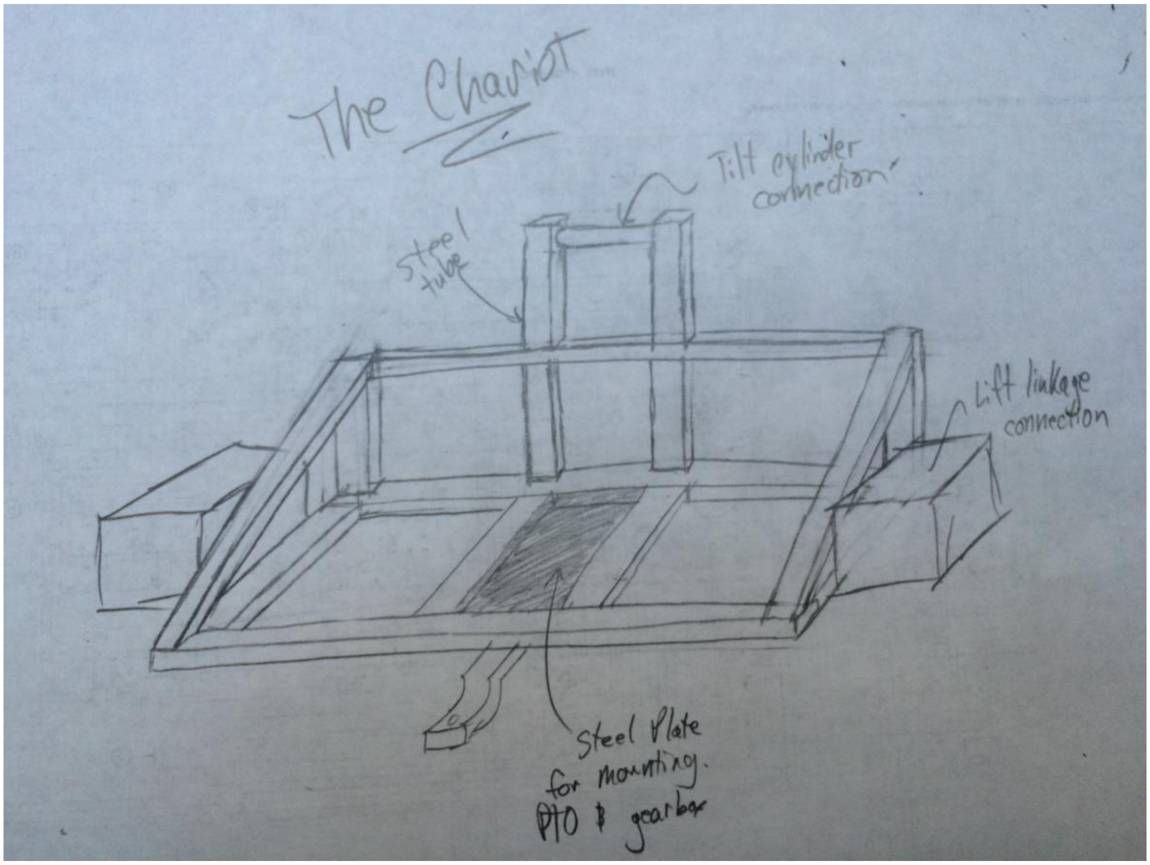

Figure 10: Sketch of the chosen superstructure and packaging concept: "The Chariot".

2.1.3.2 Lift Linkage Connection

The lift linkage connection concepts are ways to connect the frame to the tractor lift linkages. The lift linkages on the windrower currently connect to draper and rotary headers using boots made specifically for each header. The connection method must be accommodated by the frame design so some of the linkage connection concepts require specific frame geometry. Some major considerations when conceptualizing a lift linkage connection are the ease of connection, integration to the frame, and the ease of removal and reinstallation of other header boots.

A weighted concept selection matrix was used to select the Draper Boots concept for the lift linkage geometry. This concepts uses the connection method currently used by MacDon to connect their draper headers to their M Series tractors. The Draper Boots design received the highest score of 4.35 out of 5 through the concept scoring matrix in TABLE VII and TABLE VIII. The second highest scoring concept, with a score of 4.26, was the Rotary Boot concept, which is the connection method MacDon uses to connect their rotary headers to their M Series tractors. The main difference between the rotary and draper boot concepts is that MacDon sells more draper headers, making draper boots more common.

Part of the way through designing the lift linkage connection, several issues became apparent with the chosen concept and thus the decision of which concept to use had to be revisited. The original selection matrices are displayed in TABLE VII and TABLE VIII.

TABLE VII: LIFT LINKAGE CONNECTION, WEIGHTED FINAL SCORES, PART 1 OF 2

	Criteria	**Weight**	**Concepts**							
			Built-In Boots		Hooks		Draper Boots		Rotary Boots	
			Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
A	Manufacturability	0.11	4	0.42	5	0.53	4	0.42	4	0.42
B	Cost	0.17	4	0.67	4	0.67	4	0.67	4	0.67
C	Strength	0.09	4	0.36	3	0.27	5	0.45	5	0.45
D	Ease of Connection	0.12	2	0.24	3	0.36	4	0.48	4	0.48
E	Light Weight	0.00	3	0.00	4	0.00	4	0.00	4	0.00
F	Frame Integration	0.06	3	0.18	5	0.30	3	0.18	3	0.18
G	Rigidity	0.08	4	0.30	2	0.15	5	0.38	5	0.38
H	Serviceability	0.03	3	0.09	5	0.15	4	0.12	4	0.12
I	Center of Gravity	0.12	4	0.48	3	0.36	5	0.61	5	0.61
J	Adaptive Design	0.06	3	0.18	5	0.30	4	0.24	5	0.30
K	Setup Time	0.15	2	0.30	3	0.45	5	0.76	4	0.61
L	Innovative	0.02	3	0.05	2	0.03	2	0.03	2	0.03
		Total Score	3.29		3.59		4.35		4.26	
		Continue?	No		No		Develop		No	

TABLE VIII: LIFT LINKAGE CONNECTION, WEIGHTED FINAL SCORES, PART 2 OF 2

Criteria		Weight	Concepts					
			Dual Boot		Straps		Real Tall Boot	
			Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
A	Manufacturability	0.11	3	0.32	3	0.32	3	0.32
B	Cost	0.17	3	0.50	4	0.67	4	0.67
C	Strength	0.09	4	0.36	2	0.18	3	0.27
D	Ease of Connection	0.12	5	0.61	3	0.36	3	0.36
E	Light Weight	0.00	3	0.00	5	0.00	2	0.00
F	Frame Integration	0.06	2	0.12	3	0.18	4	0.24
G	Rigidity	0.08	4	0.30	3	0.23	3	0.23
H	Serviceability	0.03	3	0.09	3	0.09	2	0.06
I	Center of Gravity	0.12	4	0.48	3	0.36	3	0.36
J	Adaptive Design	0.06	2	0.12	4	0.24	3	0.18
K	Setup Time	0.15	5	0.76	3	0.45	3	0.45
L	Innovative	0.02	5	0.08	3	0.05	3	0.05
		Total Score	3.74		3.14		3.20	
		Continue?	No		No		No	

After internal concept development and meetings with MacDon, it became apparent that the Draper Boot, Rotary Boot, and Dual Boot concepts were not going to be nearly as secure as we thought during the concept selection phase. MacDon's draper and rotary boots are meant to act as forks that pick up the header. They require constant down-force to remain fixed in place. If the tractor bounces, the boots can tilt upward from the momentum. There would be too much slop between the new hitch attachment and the lift linkages for the hitch to be steady.

The runner up to these boot-based concepts was the Hooks concept. However this concept would suffer from the same excess of slop that the boot-based concepts would have.

We decided to develop the Built-In Boots concept. After more detailed discussions, we realized this concept had all of the same advantages that the Draper, Rotary, and Dual Boot concepts had. The major exception being that the Built-In Boots were not as easy to attach, but were more secure when attached to the lift linkages.

2.1.3.3 Drawbar Connection

Drawbars are a hitching method commonly used in agriculture. The implements that the attachment should operate are all compatible with a drawbar hitch. The drawbar can be connected to the frame in many different ways. Strength, mounting location, adjustability, ease of installation, and the difficulty to integrate the concept into the frame were considered when generating drawbar connection concepts.

A weighted concept selection matrix was used to select the Mouth Tongue concept, as depicted in Figure 11, for the drawbar connection geometry. The Mouth Tongue concept received the highest score of 4.44 out of 5 through the concept scoring matrix. The second and third highest scoring concepts had scores of 4.16 and 4.02. The "Mouth Tongue" concept won because it was scored as more serviceable and easier to design within the standards.

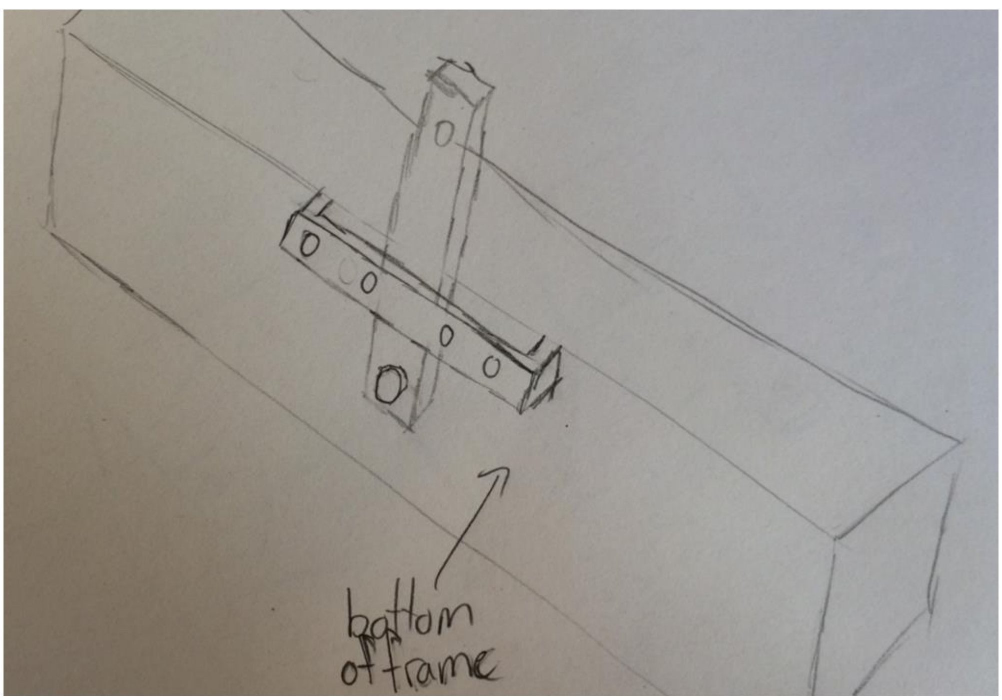

Figure 11: Sketch of the chosen drawbar connection concept: "Mouth Tongue".

2.1.3.4 Attachment-Side Hydraulics

The attachment-side hydraulics refer to the hydraulics contained on the attachment. This includes the hydraulic motor, a gearbox, hydraulic connections, and the auxiliary coupler mounts. Each of these are being treated separately due to the lack of overlap.

2.1.3.4.1 PTO Motor and Gearbox

The 75cc Rotary Motor/Gearbox concept was selected for creating a working PTO spindle for the attachment. Through preliminary flow calculations, it was determined that the adjustability of the hydraulic power from the tractor to a hydraulic motor would not be within the proper range to adjust the speed of the PTO from 540 to 1000 RPM without the use of a gearbox. The gearbox that MacDon stocks in inventory best suited for this application was the gearbox they used for their pull-type rotary mowers. These same mowers housed PTO motors that could also be adapted to our needs. Specification research confirmed that the rotary mower's hitch gearbox and hydraulic motor were the correct components to use to create a PTO spindle for the attachment.

2.1.3.4.2 Hydraulic Connections

After discussions internally and a meeting with our MacDon representative, Jeff Leachman, our team decided to use a threaded ORFS hydraulic connection between the M Series and the hitch attachment. This is the connection type used between the hydraulic hose end and the flat faced quick couplers on the M Series. Several of the quick couplers and hydraulic lines from the tractor can change depending on what style of header was previously on the windrower. This would mean changing a majority of the quick couplers for each connection each time the hitch attachment is installed. Since the hitch attachment would not have to be removed regularly, it was decided that an ORFS connection was the best alternative and the alternative recommended by MacDon.

2.1.3.4.3 Auxiliary Coupler Mounting

A weighted concept selection matrix was used to select the Mounting Brackets concept for mounting the auxiliary hydraulic quick connect couplers. The Mounting Bracket concept received the highest score of 4.29 out of 5 through a concept scoring compared to the next highest score of 3.55. The Mounting Bracket, which uses a formed piece of sheet metal to hold the quick coupler to a second sheet as shown in Figure 12, was also later found to be the method used by MacDon, in a separate design, to attach the same quick couplers.

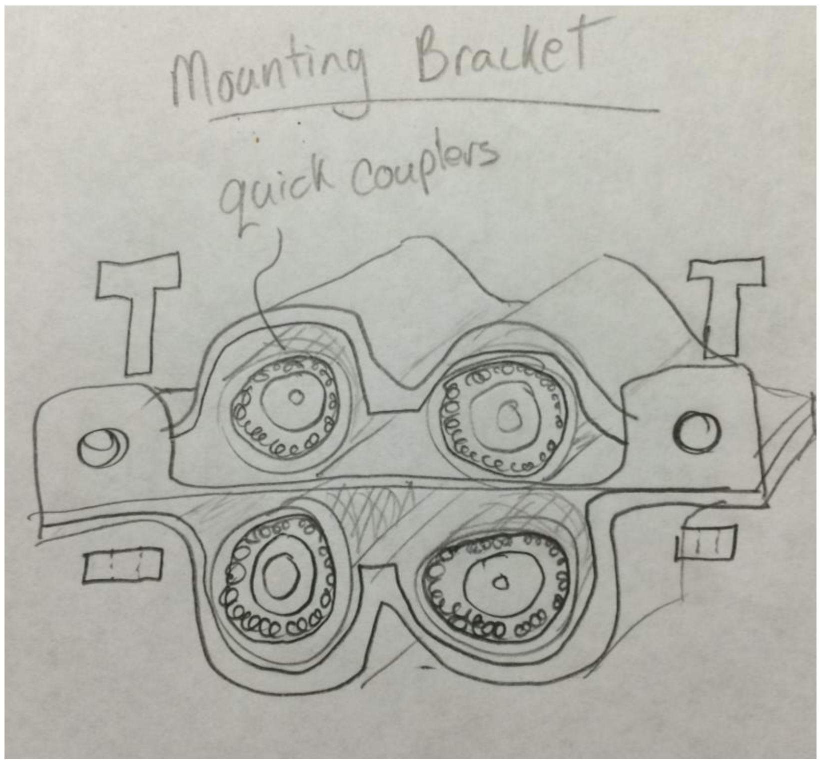

Figure 12: Sketch of the chosen auxiliary coupler mounting concept: “Mounting Bracket”.

2.1.3.5 Tractor-Side Hydraulics and Electronics

A rework for the hydraulic and electrical systems on the M Series must be implemented for the attachment to function as required. The flow from two of the header hydraulic pumps (pump A and pump B) must be combined to run a single hydraulic motor on the attachment. Also, the tractor must be allowed to function fully in engine-forward orientation. This implies that all hydraulics must function in this orientation and all traction drive ranges must be accessible to the operator. The hydraulic concepts and electric concepts were treated separately.

2.1.3.5.1 Hydraulic Flow from the Tractor

The Rotary Disk Block concept was selected to allocate enough hydraulic flow from the tractor. This concept selection came from consulting with Jeff Leachman.

He advised that the simplest and most cost effective solution would be to use the rotary disk block that MacDon creates. He also told us that the rotary disk block can be assumed to be already installed on the tractor, so the cost of the block does not have to be considered in our design.

2.1.3.5.2 Tractor Electronics

The Cab-Forward, Trick Traction Drive Range Selector concept was selected to allow the tractor to function fully while in engine-forward position. For this concept our team would send a false signal to the WCM telling it that the seat is in cab-forward orientation when it is actually in engine-forward. We would trick the traction drive range selector solenoids to allow the tractor to operate in low, medium, and high range. This concept was selected over the Engine-Forward, Trick Hydraulics and Reprogram WCM and CDM concepts after consulting with Jeff Leachman.

He also clarified two very important details. The first detail being that the steering was completely mechanical and did not rely on any electrical manipulation in order to flip the steering left-to-right when switching from engine-forward to cab-forward. The second important detail was that the functionality of the GSL, which controls whether the tractor is being driven forward or backward, also does not change between cab-forward and engine-forward orientation. The only features of the tractor that need to be manipulated are the traction drive speed range selector and the seat position switch. These could be easily manipulated with a few signal wires and switches.

Reprogramming the WCM and CDM would likely have resulted in work lying outside the intended scope of the project and should only be attempted by a qualified electrical or computer engineer. Since the intent of the design is a prototype attachment, reprogramming software would not have been a cost effective solution for testing the overall design of the mechanics and geometry of the attachment.

2.2 Final Design Details

A final design was compiled once several concepts were produced and reviewed through a concept screening and scoring process. The details of this final design are broken down into three categories: the hydraulic system, the electronic system, and the superstructure. The full attachment can be seen attached to the tractor in Figure 13.

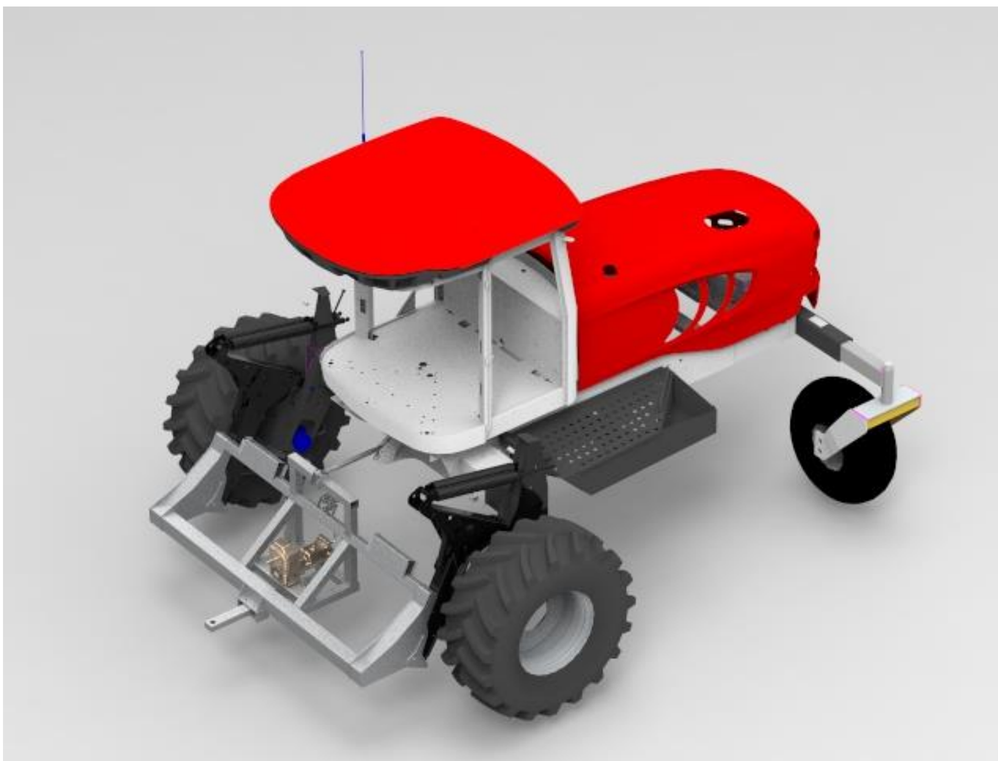

Figure 13: A rendering of the full tractor with the attachment installed

2.2.1 Superstructure

The superstructure for this design consists of the frame and all components which help to package the hydraulic and electrical systems to it. The key features of the design will be reviewed and any detailed analysis will be explained in Section 2.3. To give context to some of the descriptions of the designs, refer to Figure 14.

Figure 14: Finalized hitch attachment CAD model.

The majority of the frame geometry was determined by the geometry of the lift-linkages, built-in boots, gearbox, motor, and standards for PTOs and drawbars. Hand calculations were used to determine preliminary tube sizes to start FEA. FEA of the frame was conducted to determine the final required tube sizes.

The strength demand on the majority of the frame members was relatively low. The highest stress was in the frame member that has the drawbar mounting bracket attached to it (part number P500023). P500023 required a 5” x 5” tube with 1/4 inch walls. The other frame members were 3 inch square tubing with 1/8 inch walls, which is the thinnest wall available for 3 inch tubes from Central Steel and Wire [6].

2.2.1.1 Lift Linkage Connection

One of the most crucial parts of this design is the method in which the attachment will connect to the M Series. It is through this connection that all the loads will be transferred from the implement to the tractor. The design for this connection began with a closer examination of the draper boot, which is the method currently used by MacDon to connect their draper headers to the M Series. Similar mating faces and geometries were then used to connect the lift linkage on the M Series to the built-in boot on our hitch attachment.

The profile on the draper boots was used in the built-in boot to ensure a familiar method to connect the attachment. The profile inside of the draper boot, and now the built-in boot allows the attachment to be hooked into and lifted by the lift linkage without the pins installed. The attachment can be hooked up and lifted without leaving the cab of the tractor until the pins need to be installed. The lift linkage foot can be seen inside the built-in boot in Figure 15 with the side of the built-in boot removed for observation. When the lift linkage is lifted while inside the built-in boot, the attachment cantilevers against the foot and base of the lift linkage.

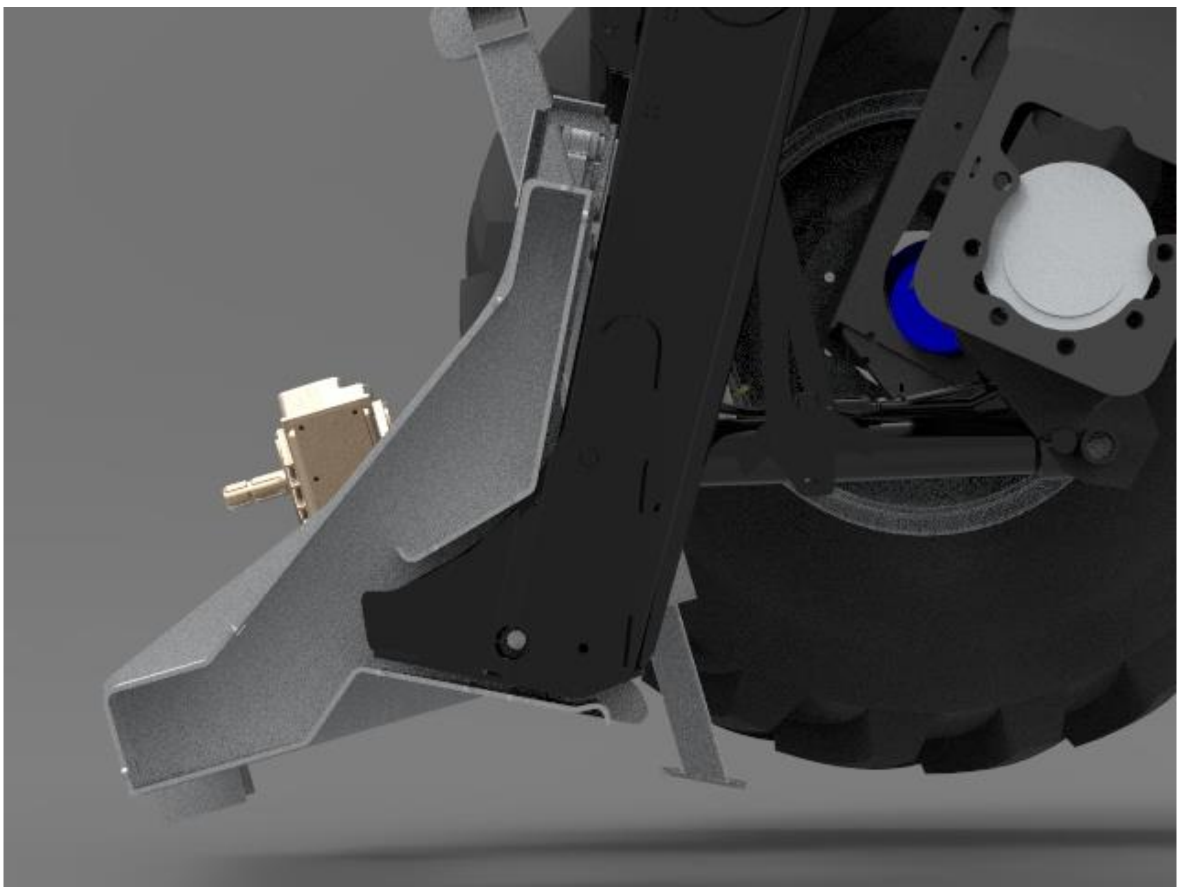

Figure 15: Lift linkage inside the built-in boot with the side panel removed for observation.

Another key concern with the lift linkage connection is the angle at which the attachment will sit while it is in its operating position. Since the lift cylinders on the lift linkages do not apply force vertically, but instead work to rotate the linkage arm about a point on the frame, the angle of the lift linkage in relation to the ground will change as the lift linkage goes through its range of motion.

The built-in boots form an angle of 27 degrees between the bottom and the back sides. This is to allow the draw bar to be parallel to the ground during operation. The lift linkage is at 9 degrees in a fully retracted position. If the frame were operated at this position, the drawbar would only be 263 mm above the ground. The acceptable height for a drawbar is between 330 and 500 mm. To compensate for this, the lift linkage cylinders must be extended to raise the drawbar to an appropriate height. The initial, and target location is illustrated in Figure 16. The green line represents the extendable hydraulic cylinder and the red line indicates the fixed lift linkage.

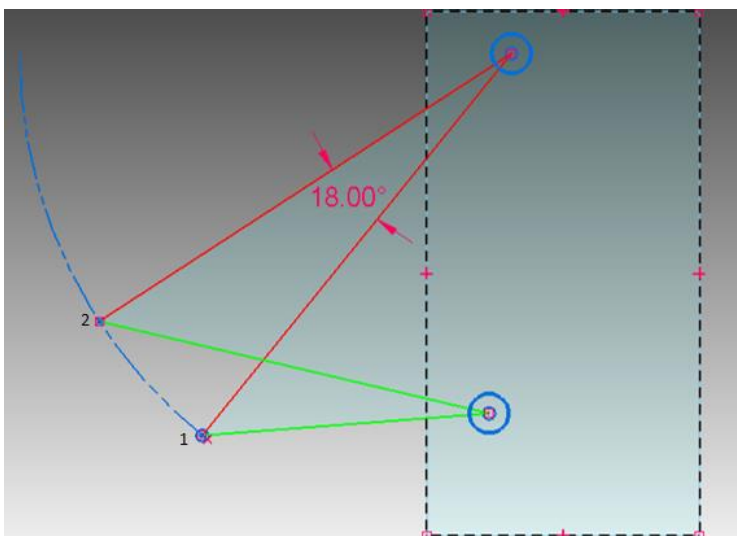

Figure 16: Schematic of the ideal lift linkage position.

It was determined that the lift linkage should be rotated 18 degrees in order to achieve an appropriate draw bar height for operation. This in turn raised the drawbar height 218 mm, to a total operation height of 481 mm. This is towards the upper range of appropriate drawbar height which allows for the tractor to sink into the mud and still be effective. Lift linkage hydraulics would have to extend 216 mm from the fully compressed position. Once extended into position, a mechanical hydraulic block (part # P500013) can be placed over the cylinder to avoid the attachment lowering due to hydraulic relaxation. The combination of the 9 degree lift linkage and 18 degree increase to achieve ideal drawbar height resulted in a built in boot angle of 27 degrees. This allows the back to be parallel to the lift linkage while the bottom of the attachment is parallel to the ground.

2.2.1.2 Drawbar Connection

The drawbar mount illustrated in Figure 17 consists of a 1 inch plate and a 1/2 inch plate that are below and above the drawbar respectively. Both these plates are behind the main frame member, part number P500023. Connecting these top and bottom plates are 1/2 inch side plates that also run partially beneath the main beam of the attachment frame. Gussets made of 1/2 inch plate lie on top of the top plate of the assembly and are in line with the side plates. The sizing and geometry of these components was determined through hand calculations and FEA. The drawbar mount assembly is attached to the underside of the main beam by welding along the edges of the side plates and gussets that make contact with the main beam.

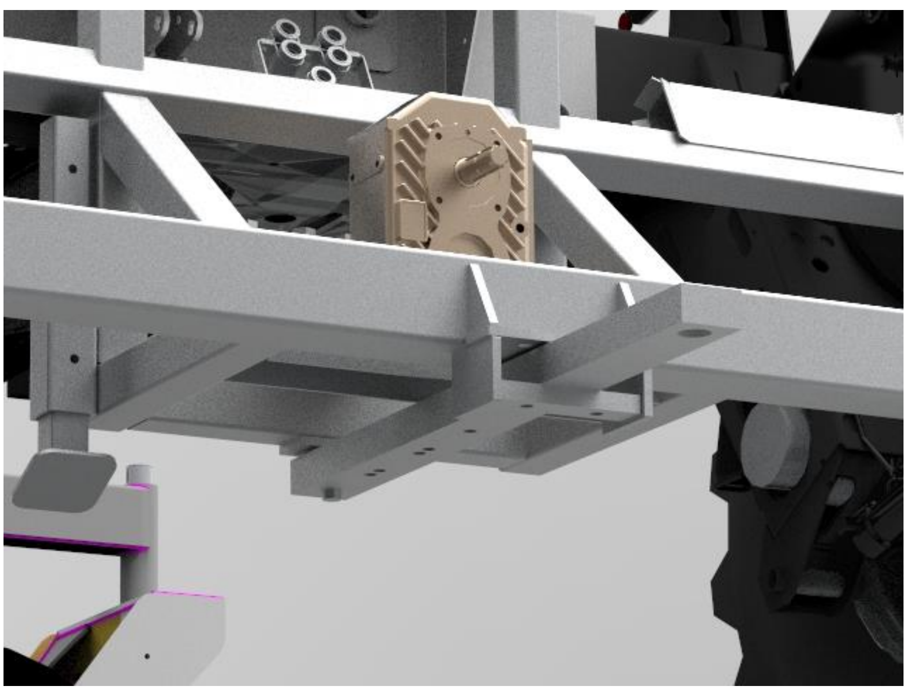

Figure 17: Drawbar mounting bracket.

These two bolts are grade 8.8 M16s on either side of the drawbar. They pass through holes in the upper and lower plates of the drawbar mounting bracket. These bolts serve three purposes; locating the drawbar, adding additional bending strength to the bracket, and allowing for adjustment of drawbar width.

The drawbar is located in the fore/aft position using a single bolt that runs through the drawbar and the rear frame member, part number P500028. The two M16 bolts through the mounting bracket prevent the drawbar from rotating about this pin and keep it aligned along the fore/aft axis of the tractor.

Different size bushings may be added to the bolts for different widths of drawbar. Standards say that the drawbar width has to be a maximum of 90 mm [4]. If the drawbar MacDon uses is narrower than 90 mm, bushings can be added around the bolts to reduce the amount of side-to-side play in the drawbar.

2.2.1.3 Tilt Cylinder Connection

The main connection point for the hitch attachment is at the bottom of the lift linkages. However, to prevent the frame of the attachment from rocking back and forth on the lift linkage pins, a secondary point of contact between the tractor and the attachment was added. This is accomplished through a mechanical turnbuckle, referred to by MacDon as a center link. The center link was originally used on MacDon equipment to allow a farmer to adjust the angle between the header installed on the windrower and the ground in order to improve cutting performance. The same mounting bracket on the tractor will be used to connect one end of the center link to said tractor. The other end will be installed on the mounting bracket at the top of the attachment frame as shown in Figure 18.

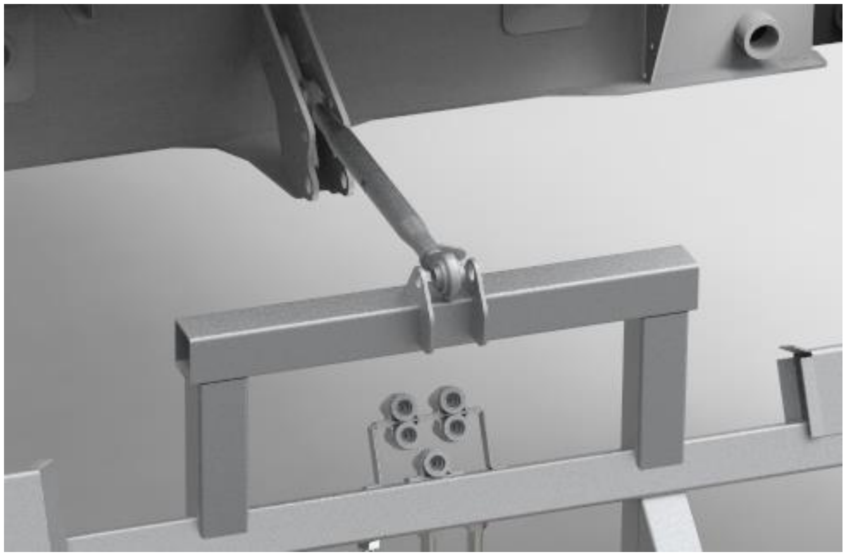

Figure 18: Mechanical center link connection.

The mechanical center link allows for fine adjustment of the angle of the attachment and locks that position in place. With a hydraulic cylinder there is the chance that the ram on the cylinder may relax from the position that is desired. This is not likely to happen with a mechanical turnbuckle. This link is also key in keeping the frame rigidly mounted to the tractor, which allows for smooth towing of an implement.

2.2.1.4 Unhooking Stand

Because of the change in angle created by the motion of the lift linkage, the bottom portion of the attachment will be parallel to the ground when it is at its working height, but it will be at a 27 degree angle when it is lowered all the way down. To help aid in hooking and unhooking the hitch attachment, a kickstand was incorporated into the design and is depicted in Figure 19. When in use a pin is removed from the kickstand to raise it up out of the way. However, when the hitch attachment needs to be removed, the kickstand is lowered down and held in place by a pin. The weight of the attachment is then place on the kickstand and the ground, and once all the weight is removed from the lift linkage pins, they can be slid out, the center link can be removed, and M Series can back away from the attachment. To hook up again, the M Series simply drives up to the attachment and moves until the lift linkages are far enough into the built in boots that the lift linkage pins can be slid in. The hitch attachment can then be raised up and the center link can be installed.

One important note about hooking and unhooking is that the draw bar will have to be removed before the attachment is unhooked. This is because the change in angle will force the drawbar to come in contact with the ground before the rest of the frame. To remove the drawbar only one bolt must be taken off and the bar can be slid out of the frame.

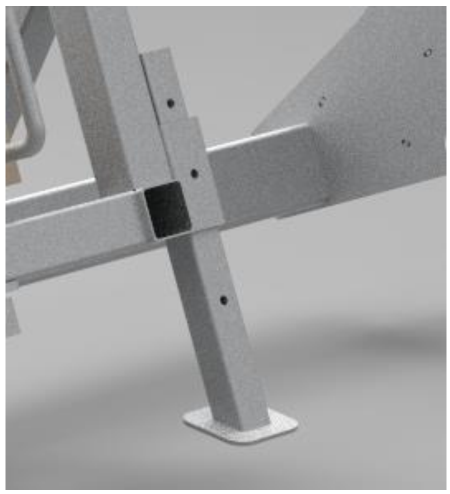

Figure 19: Kickstand for connecting and disconnecting the attachment.

2.2.1.5 Packaging and Frame Components

The packaging and placement of some of the hydraulic components on the frame was considered upon completing the majority of the frame's structural design. One such feature is the mounting brackets used to mount the pioneer quick couplers for the auxiliary hydraulic circuits to the frame. These brackets are composed of a formed steel strap, which wraps the quick coupler and sits in a recess in its outer surface, and a plate to which the strap is mounted. The brackets are first bolted together and then bolted to the frame. The arrangement chosen is depicted in Figure 20.

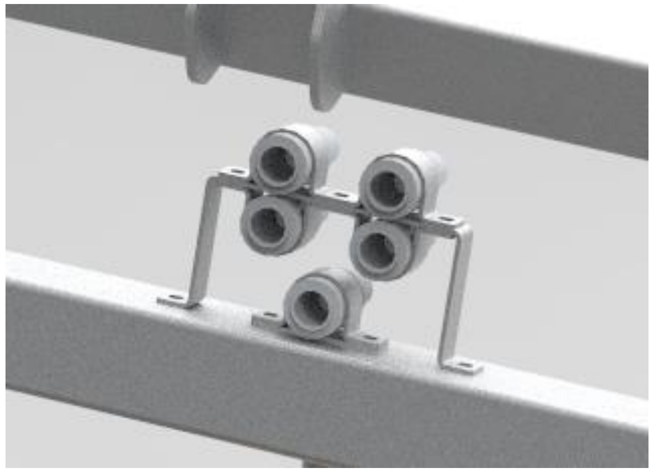

Figure 20: Pioneer quick couplers mounted to the frame.

Another key feature of the design is the hose routing system used for the frame. A C-channel is welded to the top side of the attachment frame for the hoses to be passed through. The ends of this channel are flared outwards to help prevent rubbing and wear on the hoses that pass through. If wear does become a problem our team recommends using grommets to cover the sharp edges.

2.2.2 Hydraulic System

The MacDon M Series windrower uses three hydraulic pumps connected to the engine, as described in Section 1.1, to operate any attachment that may be installed on the tractor. In the case of this design, the main power requirement for our hitch attachment is at the PTO drive shaft. This driveshaft is to be spun using hydraulic power from two of the header hydraulic pumps. The third pump will provide hydraulic pressure for auxiliary circuits required for certain agricultural implements with single or double acting hydraulic cylinders. This system is broken down into the components required for the attachment to function properly.

2.2.2.1 Disc Drive Hydraulic Block

As previously mentioned, when a rotary header is installed on the M Series a disc drive block is also installed. This block allows the flows from pump A and pump B to be combined. In order for this to work, the relief pressure on pump B is adjusted to 4200 psi to match that of pump A. The flows from pump A and pump B are also adjusted to be 27-30 gpm and 24-28 gpm respectively. This provides a combined flow of 51-58 gpm at 4200 psi when the pumps are running at peak output. This output can be varied through the Cab Display Module (CDM) to allow for different rotational speeds for the rotary disks.

Upon consulting with our contacts at MacDon we were directed to make the assumption that the disc drive block would be installed on the M Series. The main advantage to having this hydraulic valve block installed will be that its cost will not be reflected in the overall cost of the system. This is not an unrealistic assumption as many farmers operate rotary headers with their windrower, and thus do have the hydraulic valve block installed.

2.2.2.2 Hydraulic Motor

From the tractor, oil will be pumped to a hydraulic motor on the hitch attachment. The hydraulic motor that was selected is a 75cc heavy duty, hydrostatic, fixed displacement motor made by Eaton. It has a 1.375” diameter 21 tooth spline output shaft with an SAE-C, 4-bolt mounting flange. This motor, as shown in Figure 21, is currently in MacDon’s inventory (MacDon part 150879) and is used on an R85 rotary header with a similar hydraulic feed. This hydraulic feed consists of a pressure and return line connected to the motor with splint flange hydraulic connections and a hydraulic line for the case drain. A pressure relief valve is also installed to help protect the motor. It connects to the case drain circuit and is set for 50 psi.

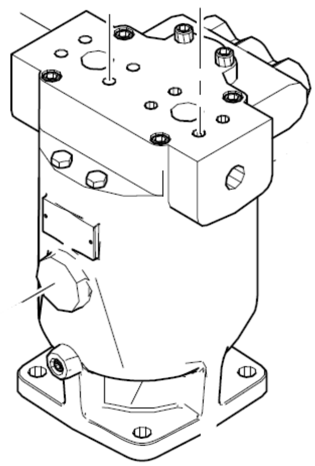

Figure 21: Eaton 75cc hydraulic motor (MD#150487). Adapted from [7].

This motor was selected based on its displacement which dictates the amount of fluid required to force the shaft to make one revolution. This value was used to calculate the range of potential shaft speeds that were achievable. The calculations were conducted using Eq. (2-1) in Section 2.3.1.1. The maximum calculated speed is 2574 RPM which is in agreement with the value of 2500 RPM given in the MacDon technical manual. The technical manual also indicates that the minimum speed at which the motor can be run is 1500 [RPM]. It should be noted that this lower limit is set by the CDM and could be changed by changing the program on the control module to allow less flow from the pumps.

2.2.2.3 Offset Gearbox with Shaft Adapter

The hydraulic motor specified can be made to spin between 1500 – 2500 RPM as specified by the MacDon Technician's Manual [2], but the required rotational speed for a PTO shaft is either 540 RPM or 1000 RPM depending on the design of the shaft. An offset gearbox with a gear reduction ratio of 2.5:1 is specified to reduce the rotational speed. This gearbox is made by Comer Industries and features a lower 1.375" diameter 21 tooth spline female connection and an upper 1.375" diameter 6 tooth spline mate connection with about 3" of protruding spline. It is also currently in MacDon's inventory (Part Number 194039) and is used on an older model R85 rotary header. With the Comer gearbox, the new range of speeds will be between 600 – 1000 RPM. The lower end of the speed range is actually above the required 540 RPM, but it was decided that this was acceptable as the programing on the CDM could be adjusted to accommodate a slightly slower speed. It should also be noted that there is often a certain amount of variation in PTO shaft speed to the standardized 540 RPM with any tractor. An exploded view of the inside of the gearbox is shown in Figure 22.

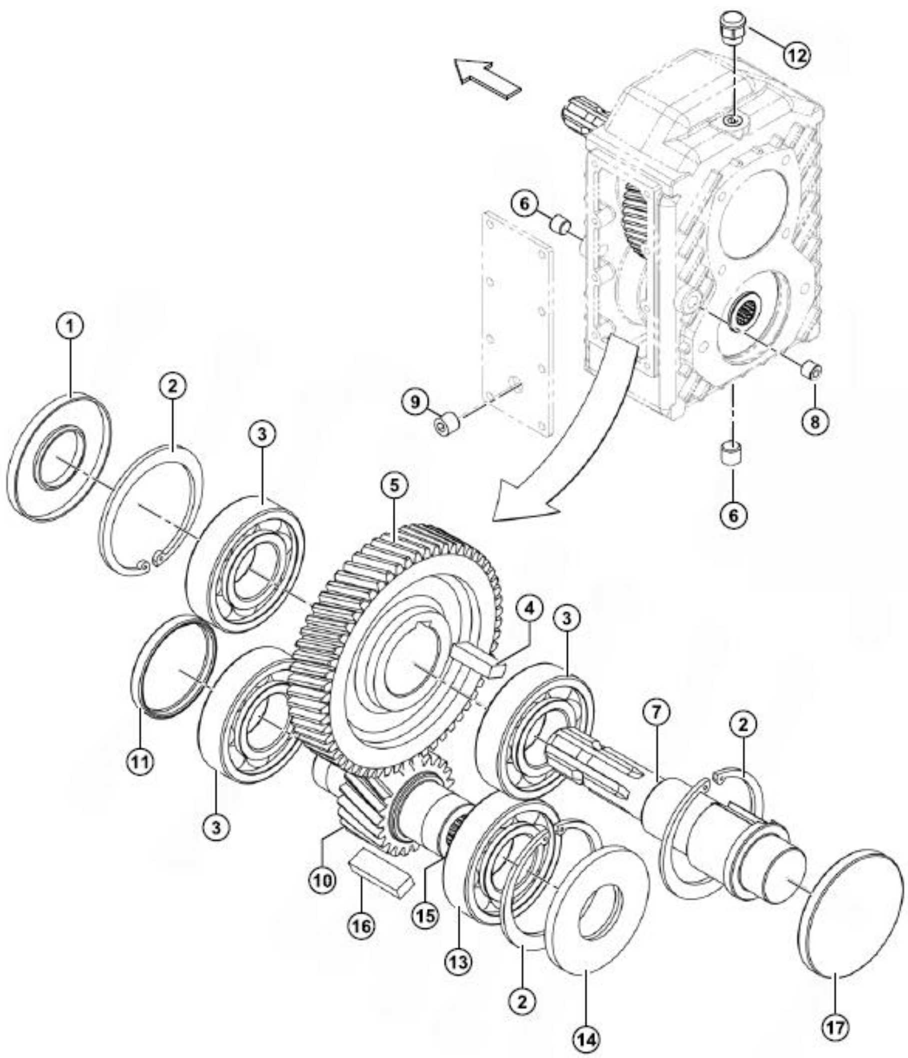

Figure 22: Comer offset gear box (exploded view). Adapted from [7].

It should also be noted that an adapter has been specified to convert from the 1.375” diameter 6 tooth splined shaft to a 1.375” diameter 21 tooth splined shaft. This converter is produced by Hub City (Part Number 0332-00004) and is rated to work with up to 125 HP. It is 6.875” long and when installed it will extend the PTO shaft from the gearbox by 4.813”. This has been accounted for with a variable position drawbar. An example of such an adapter is shown in Figure 23. It should be noted that the actual adapter will have a female end with 6 splines and not the 21 splines as shown.

Figure 23: Hub City 6 spline to 21 spline PTO shaft adapter [8].

2.2.2.4 Auxiliary Valve Block

One of the requirements set out by MacDon is that the hitch attachment will allow for the use of auxiliary hydraulic circuits. For the purposes of producing a cost analysis, it will be assumed that the windrower will be equipped with the necessary hydraulic valves and pathways to provide one single acting circuit and one double acting circuit. This is reasonable as most windrowers use these circuits for the reel lift and reel fore/aft functions respectively. In addition, a second double acting circuit will be installed. MacDon produces an auxiliary valve block package (bundle number B5269), as shown in Figure 24, which is commonly used for this purpose. It is usually used to operate a hydraulic cylinder which either lifts or lowers a swath roller (large concave cylinder used to compress bushy windrows). This block will be installed on the ladder side of the tractor. Two bolts are used to sandwich this additional block up against the valve block used for the first double acting cylinder (the fore/aft block). Two solenoids are installed on the top of the block. These will be used to actuate the circuit. They should be connected to the P72 and P73 connectors.

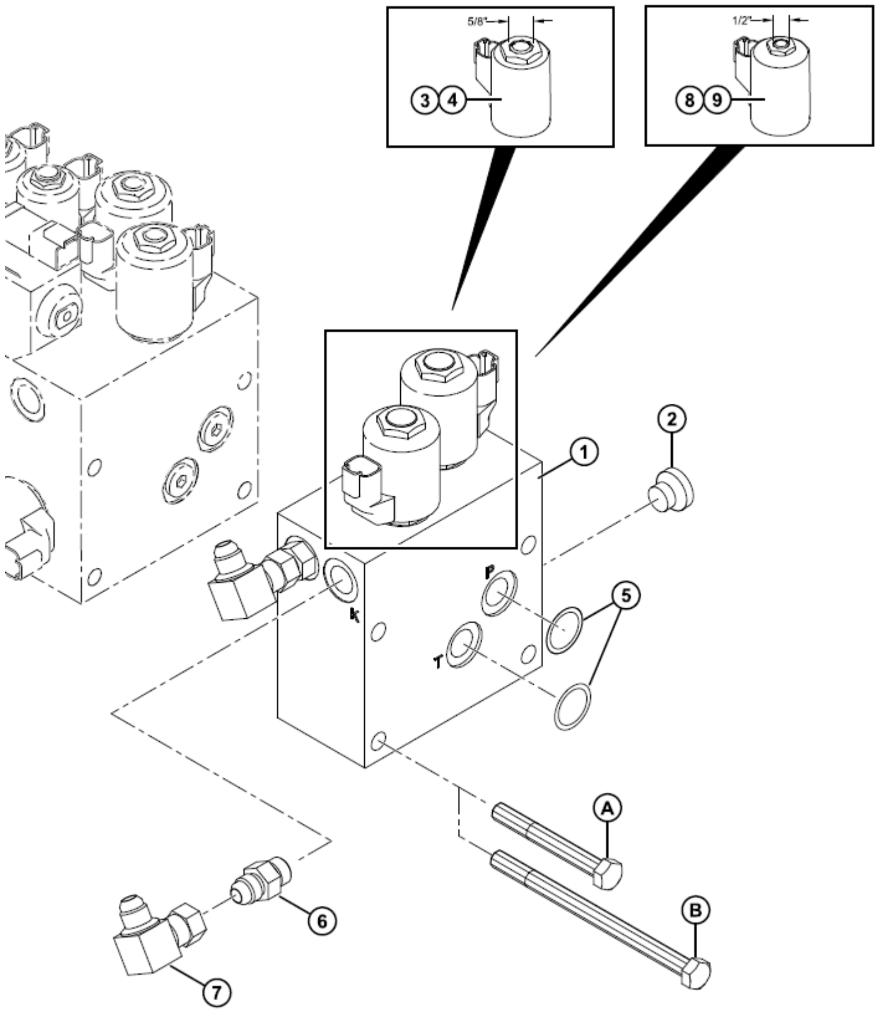

Figure 24: Auxiliary valve block for a double acting hydraulic cylinder. Adapted from [9].

2.2.2.5 Hydraulic Hoses

Two major areas of functionality are accommodated by hydraulic flow on this hitch attachment. One is the transfer of rotational energy to the PTO shaft and the second is the actuation of single and double acting hydraulic circuits on the implement being towed.

The hydraulic motor requires three hydraulic flows to function properly. These are the high pressure flow, the low pressure (return) flow, and the case drain. The circuit starts at the header hydraulic pumps where hydraulic pressure is produced at pump A and pump B. The pressurized oil from pump A is sent to the M1 port and the oil from pump B is sent from the M2 port. At this point the oil leaves the tractor and enters our system through two -16, or 7/8 inch, ID hydraulic hoses made from SAE 100 R15 Type AT reinforced with multiple spinal steel wire hydraulic hose. The oil from M1 and M2 flow through individual hydraulic hoses until they get to a steel line which connects to the hydraulic motor on the attachment. This steel line, made from 1 IN OD X 0.120 IN WALL DOM tube has two input connections which come together to form a "T" before moving to the input of the motor. Each input end of the steel line will accommodate one of the -16 hydraulic hoses coming from either the M1 or M2 port. The combined flow is then directed to the hydraulic motor through a Code 61 split flange connection. High pressure oil is delivered to the motor and the energy carried by the flow is transformed into rotational energy. In doing so, the oil pressure drops. This low pressure flow then exits the motor through a steel line of the same specification as the pressure side, then enters the -16 hydraulic hose and is returned to the tractors hydraulic oil reservoir. The final line coming from the motor is the case drain line. When oil is in the motor it can sometimes seep past some of the internal seals and cause pressure to build within the motor. The case drain allows for this pressure to be alleviated by piping the oil through a -8 or 1/2 inch ID hydraulic hose back to the tractors hydraulic reservoir.

Hydraulic flow is also required for circuits on the implement. This flow is produced by pump C on the tractor. From pump C it is supplied to three interconnected hydraulic blocks where the flow is directed through the use of solenoid valves. These valves can be opened or closed with controls from the cab. Once the oil leaves the valve block it enters our system through -4 or 1/4 inch ID hydraulic hoses and travels to the attachment up until it reaches the Pioneer quick couplers. Hydraulic circuits from an implement can then be connected to these industry standard quick couplers and various cylinders on the implement can then be actuated. Figure 25 and Figure 26 are updated versions of the M155 hydraulic schematic to show the hydraulic routing required for the hitch attachment.

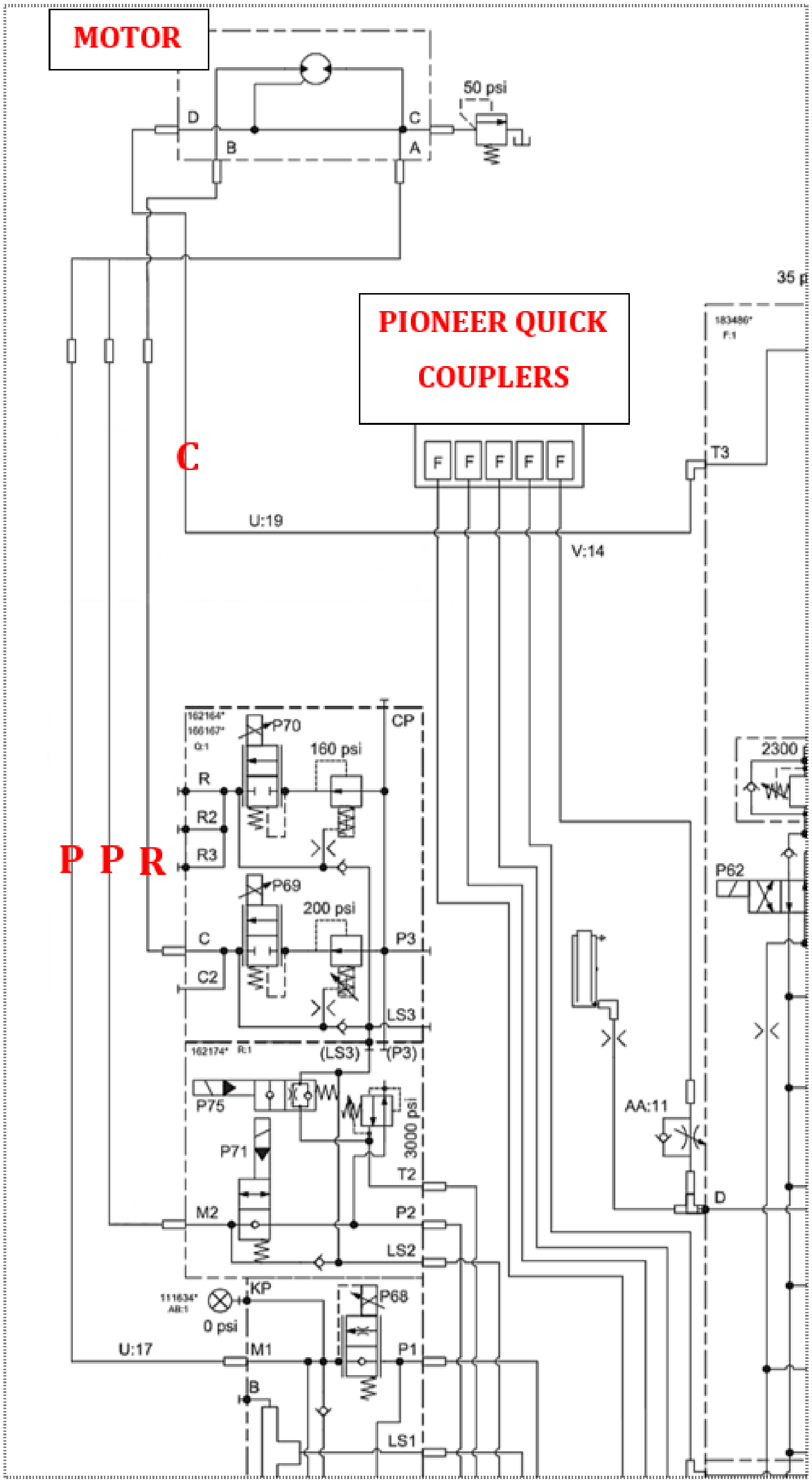

Figure 25: Expanded view of main designed component for attachment hydraulics for the M155 schematic. Important items are in red. P indicates a pressure line, R indicates a return line, and C indicates a case drain line. Adapted from [2].

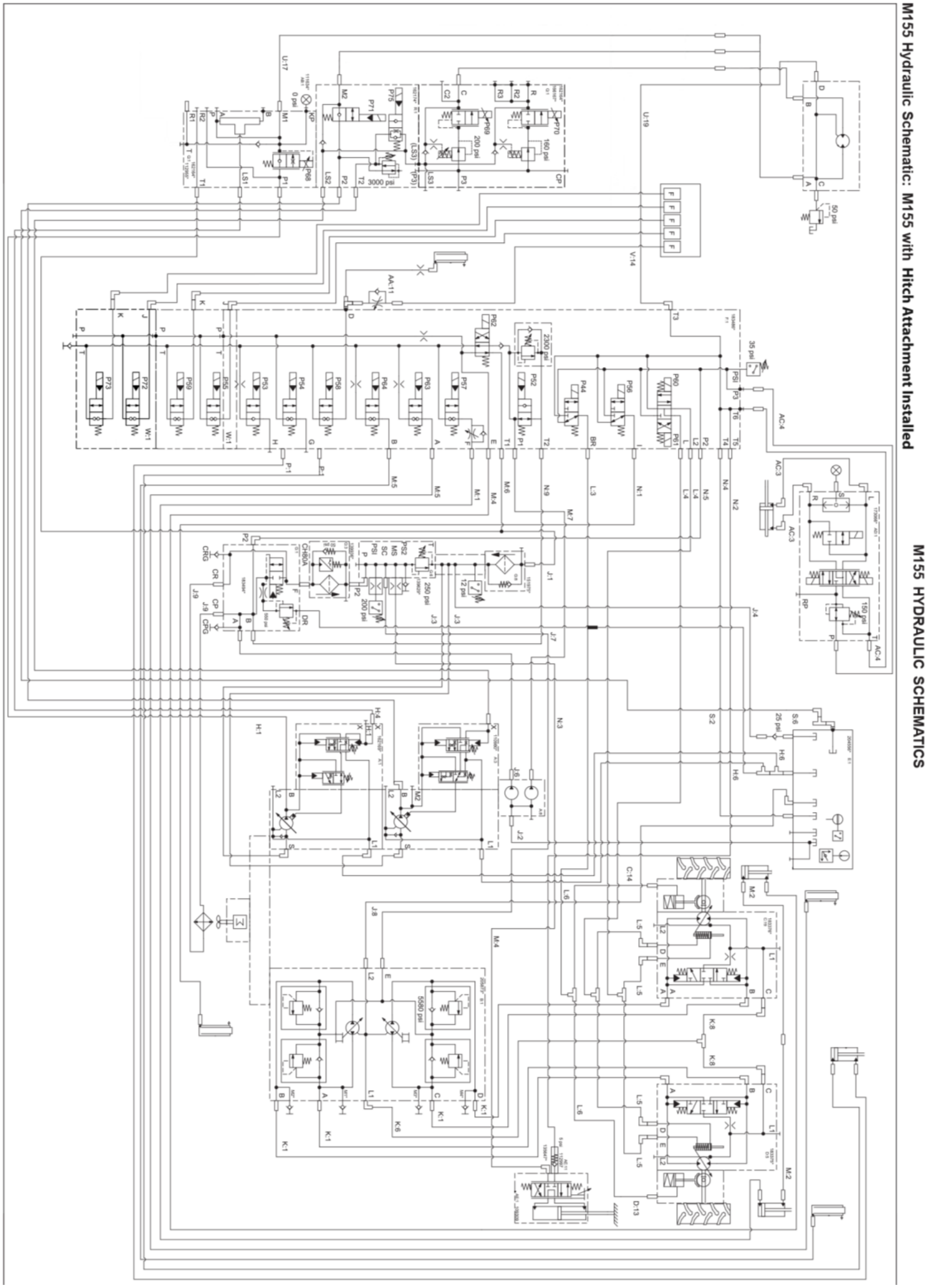

Figure 26: Complete hydraulic schematic for an M155 with the designed hitch attachment installed. Adapted from [2].

2.2.3 Electronic System

When the hitch attachment is installed on the tractor the tractor must function fully in engine forward orientation. However, by default when the tractor is in engine forward orientation the majority of the hydraulic functionality is locked out and the traction drives are locked into high range. Because of this, modifications to the electrical system were required for the design to function properly.

2.2.3.1 Seat Switch Override

To change the tractor from cab forward orientation to engine forward, a mechanical release is activated allowing the seat to swivel 180 degrees to face the engine. There are two switches in the cab which work with the seat position to send a message to the WCM, telling it which position the seat is in. When in cab-forward a switch at the front of the cab is closed, and when in engine-forward the switch at the back of the cab is closed. For the system being designed to work, a false signal will have to be sent to the WCM when the seat is in engine-forward orientation. This signal should be sent from the cab-forward seat switch. To do this a three position switch (on-off-on) will be used. Not all three positions of the switch are required, but the switch will be used since it is readily available and will suit the needs of the system being designed. In one position, the system will act normally and disable hydraulic functionality when in engine-forward. In the other position, the switch will redirect the signal being sent from the engine-forward switch and send it to the WCM through the cab-forward switch. The third, or middle position, will do nothing. This switch will be part of a new wiring harness that will run between the seat switches and the P32 and P33 connectors. The default seat position switch and the CH7 and CH8 wires responsible for sending a signal to the WCM are shown in Figure 27. This was altered as is shown in Figure 28 by adding a switch and corresponding wires to form the intermediate wiring harness between the seat position switches and the connectors to the main wiring harness.

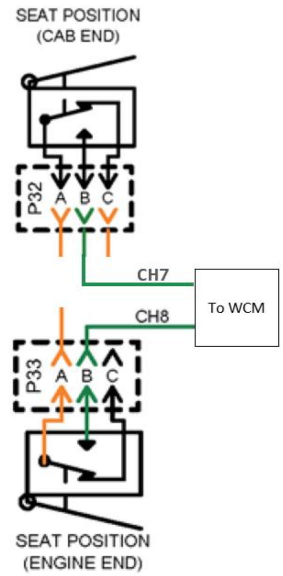

Figure 27: Default seat position switches. Adapted from [2].

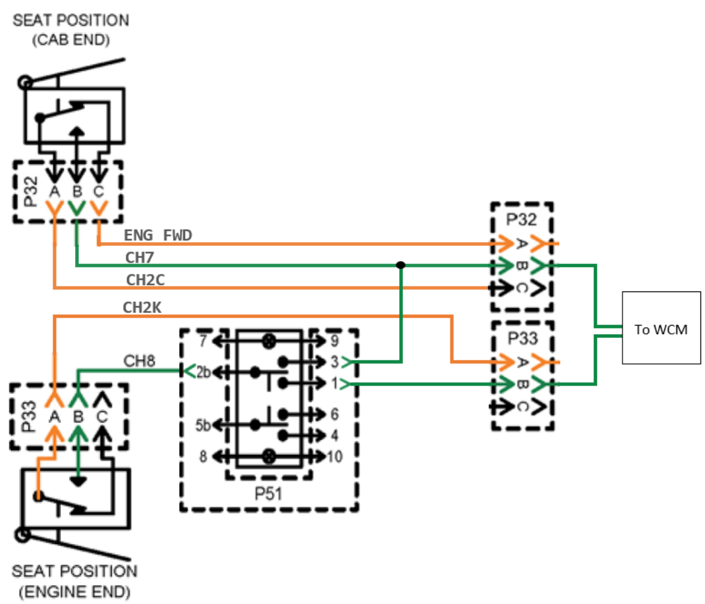

Figure 28: Modified seat position switches with engine-forward redirection switch.

2.2.3.2 Range Selector Override

The traction drive range is selected based on solenoid which is activated on the multifunction control block. Two solenoids are responsible for the three options. When the P61 solenoid is fired, the tractor is in low range and when the P60 solenoid is fired the tractor is in high range. When neither solenoid is fired the tractor is in mid-range. Because of the seat position switch being tricked, the tractor will act as though it is in cab forward orientation. Therefore, only low and mid-range will be accessible with the standard cab controls. For the system being designed to work properly the tractor must first be switched to low range using the standard toggle switch on the consol. A second three position switch (on-none-on) will then be implemented to toggle between the other ranges from the cab. The input to this switch will be from the CH116 wire which carries the firing signal to the P61 solenoid for low range. Since the standard toggle should be switched to low range, this new switch should always be receiving a signal. From the switch the first “on” position will go to the P61 solenoid to activate the low range setting. The second “on” position will go to the P60 solenoid to activate the high range setting. The “none” or mid setting on the switch will prevent a signal from being sent to either solenoid, and thereby place the tractor in mid-range. This switch will be implemented by installing it as an intermediate wiring harness between the P60 and P61 solenoids and their corresponding connectors. The default range selector solenoid are shown in Figure 29 with the corresponding wires running to them through connectors P60 and P61. This was altered as is shown in Figure 30 by adding the switch and corresponding wires to form the intermediate wiring harness between the solenoids and the P60 and P61 connectors.

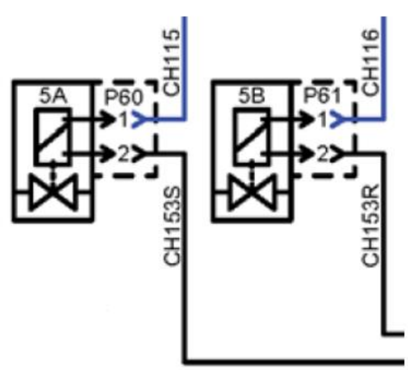

Figure 29: Default range selector solenoids. Adapted from [2].

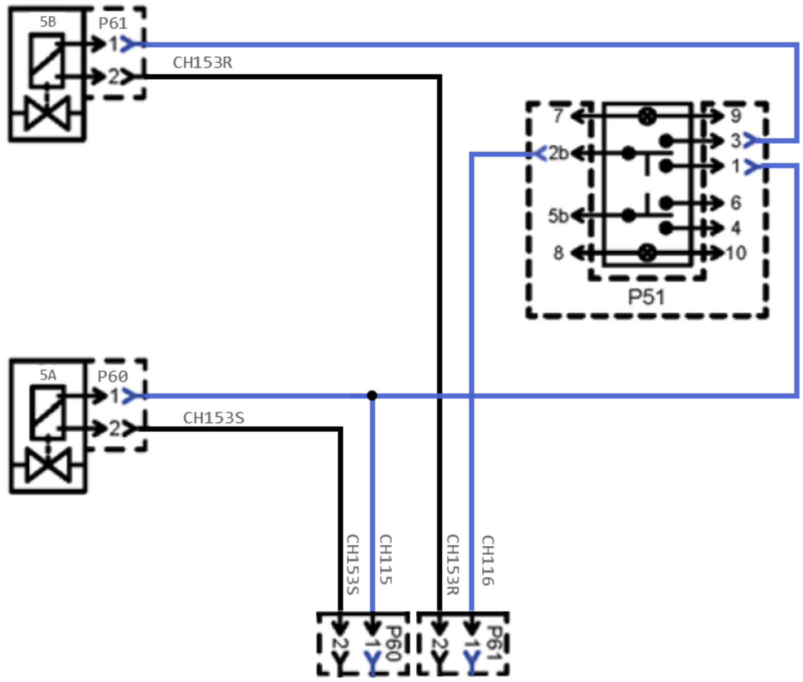

Figure 30: Modified range selector circuit.

2.3 Final Design Analysis

Basic geometric requirements of the frame were established based on the M Series' lift linkages, PTO gearbox, hydraulic motor, tractor drawbar standards [4], and PTO location standards [5]. The relevant dimensions from these standards are summarized using TABLE V, TABLE VI, and Figure 9. Hand calculations were made to determine preliminary tube sizes required for the frame members, required bolt sizes, and the thicknesses of the plates used in the drawbar mounting bracket. They were also performed to determine hydraulic hose sizing and performance parameters for the hydraulic system.

This section references frame members using the number designations outlined in Figure 31.

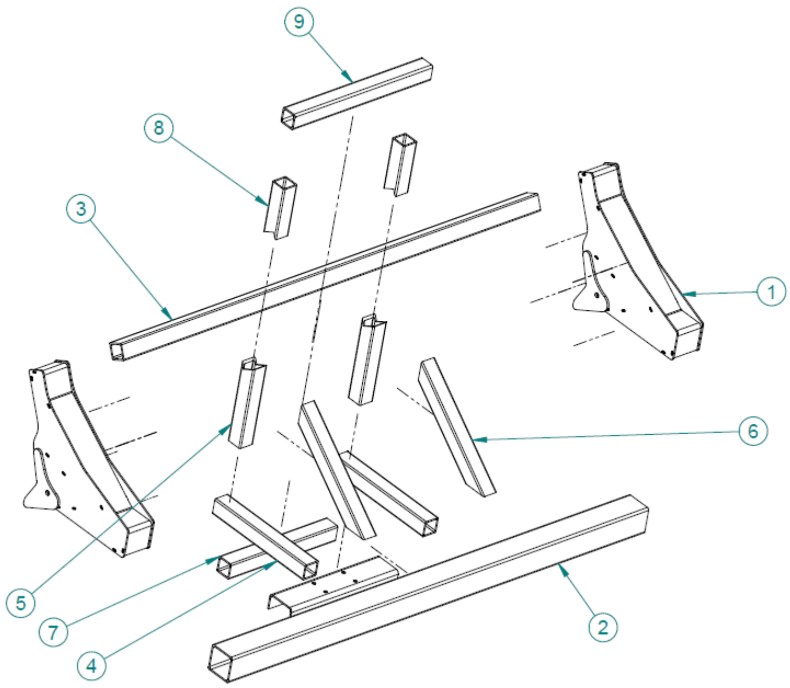

Figure 31: Frame member labelling scheme.

2.3.1 Hand Calculations

Hand calculations were conducted in order to help verify design decisions made and confirm results from FEA. Specifically the hydraulic systems and the superstructure were examined.

2.3.1.1 Hydraulics

To aid in selecting components for the design, some calculations were performed for the hydraulic system. Specifically the rotational speed of the motor, and the required hoses sizes were calculated.

2.3.1.1.1 Motor Rotational Speed

To satisfy standards which govern the PTO shaft rotational speeds, the maximum possible speed of the motor was calculated based on it displacement and the available flow. This calculation is governed by Eq. (2-1). Using a flow rate of 51 gpm (worst case scenario for maximum speed) and a displacement of 75cc, the maximum rotational speed was calculated as 2574 RPM.

$$\boldsymbol{Rotational\ Speed} = \frac{\boldsymbol{Flow\ Rate}}{\boldsymbol{Displacement/Revolution}} \qquad \textbf{Eq. (2-1)}$$

$$Rotational\ Speed = \frac{51\ [gpm]}{75\ [cm^3/rev] \cdot \frac{1\ [gal]}{3785\ [cm^3]}}$$

$$Rotational\ Speed = 2574\ [RPM]$$

2.3.1.1.2 Hydraulic Hose Size

To size the hoses for this design most of the hoses were selected based on the hose sizes of MacDon equipment with similar flow profiles. To check this sizing our team relied on industry standards that provided recommendations based on the application of the equipment being operated and the pressure and the volumetric flow rate of the fluid flows. These calculation determined that the high pressure line did indeed need to be -16 hose size. Detail calculations are contained within Appendix 3.

2.3.1.2 Superstructure

Three different material types were used; structural tubing, plate steel and grade 8.8 bolts.

TABLE IX summarizes the yield and ultimate stresses, as well as the design stresses used. The design stress is based on either the ultimate stress with a factor of safety of 2 or the yield stress with a factor of safety of 1.5, whichever was lower.

TABLE IX: MATERIAL YIELD AND ULTIMATE STRESS VALUES

Stress	Material		
	ASTM A500 Grade B Tube [10]	ASTM A36 Steel Plate [11]	Alloy Steel, Grade 8,8 Bolts [12]
Tensile Yield Stress [MPa/ksi]	290/42.1	250/36.3	660/95.7
Shear Yield Stress [MPa/ksi]	168/24.4	145/21.0	383/55.5
Ultimate Stress [MPa/ksi]	400/58.0	500/72.5	830/120.4
Design Tensile Stress [MPa/ksi]	194/28.1	167/24.2	415/60.2
Design Shear Stress [MPa/ksi]	112/28.1	96.7/14.0	255/37.0

The shear yield stress for these materials was derived using the following equation as a function of tensile shear stress for wrought and alloy steels [13].

$$\tau_{yld} \approx 0.58\ x\ \sigma_{yld} \qquad \textbf{Eq. (2-2)}$$

A hitch load of 22 kN was used for the simplified calculations in this section. This load is based on the largest drawbar load according to ANSI/ASABE standard (see TABLE VI).

The draft load was calculated based on implement weight and desired ground speed. The draft load can be expressed in the following equation:

$$R_{hx} = fr\ W \qquad \textbf{Eq. (2-3) [14]}$$

Where:

R_{hx} = draft load or rolling resistance of the implement [lbf]

fr = rolling resistance coefficient

W = implement weight [lbf]

The rolling resistance coefficient for low velocities can be expressed as:

$$fr = 0.01\left(1 + \frac{V}{100}\right) \qquad \textbf{Eq. (2-4) [14]}$$

Where:

V = velocity of the tractor and implement [mph]

We assumed a maximum implement weight of 45000 lbf based on the approximate weight of a full bale picker, and a desired velocity of 10 mph while towing this weight. The draft load R_{hx} can be solved by combining Eq. (2-3) and Eq. (2-4) :

$$R_{hx} = 0.01\left(1 + \frac{10}{100}\right)45000 = 495\ lbf \approx 500\ lbf = 2224\ N$$

2.3.1.2.1 Main Beam (Frame Member 2)

Calculations for the required size of the main beam, or frame member 2, can be simplified down to a simple cantilever, as seen in Figure 32.

Figure 32: Simplified main beam cantilever.

The following calculations are based on comparing the required section modulus against the section modulus for a particular size of square tube.

$$\boldsymbol{S = \frac{M}{\sigma} = \frac{M_{max}}{\sigma_{A500}}} \qquad \textbf{Eq. (2-5)}$$

Where:

S = section modulus of the component location in question [m³]

M_{max} = the maximum moment in the cantilever beam [Nm]

σ_{A500} = design stress for the A500 tube used [Pa]

$$M_{max} = F\ x\ d = \frac{1}{2} R_{hz} L$$

$$M_{max} = \frac{1}{2}(22000)(1.194) = 13132\ Nm$$

$$S = \frac{M_{max}}{\sigma_{A500}} = \frac{13132\ Nm}{194\ MPa} = 6.769\ x\ 10^{-5} m^3$$

The required tube thickness can be calculated for a given square tube width using the following alternate equation for the section modulus:

$$S = \frac{a^4 - (a - 2t)^4}{6a}$$

$$\boldsymbol{t = \frac{1}{2}\left(a - \left(a^4 - 6aS\right)^{0.25}\right)} \qquad \textbf{Eq. (2-6)}$$

Where:

a = outer width of the square tube [m]

t = wall thickness of the square tube [m]

The following table summarizes the wall thicknesses required for various tube sizes available from Central Steel and Wire [6].

TABLE X: TUBE SIZES FOR THE MAIN BEAM

Tube Size [in]	3.0	3.5	4.0	4.5	5.0	6.0
Minimum Wall Thickness [in]	0.703	0.341	0.231	0.172	0.135	0.090
Minimum Available Wall Thickness [in]	NA	NA	0.250	0.188	0.188	0.188

As TABLE X shows, there are no 3 or 3.5 inch tubes available that can handle the loading. The 4, 4.5 and 5 inch tubes are all available in wall thicknesses relatively close to the minimum required. The 6 inch tube had a wall thickness that was much larger than necessary.

The 5 inch tube with a wall thickness of 0.188 inches was selected as a starting point for modeling and FEA simulations. The 5 inch tube was chosen because it had a reasonable wall thickness and was large enough to have adequate room to mount the drawbar underneath.

The final tube size selected for the main beam was 5 inches with a 1/4 inch wall. See Section 2.3.2.3 for justification.

2.3.1.2.2 Drawbar Fore-Aft Mounting Bolt

The fore-aft mounting bolt is what locates the drawbar in the fore-aft direction of the attachment. All of the draft load stress flows through this bolt when an implement is towed directly behind the tractor.

The goal of this attachment is to allow the M Series tractor to operate like a typical 100 HP utility tractor. John Deere's 105 HP 6105M utility tractor uses a single M16 bolt [15] which we used a starting point. Figure 33 illustrates the loading scenario on the bolt.

Figure 33: Drawbar draft load applied to the fore-aft mounting bolt.

The required bolt diameter was determined with the following equations:

$$\tau = \frac{F}{A} = \frac{4R_{hx}}{\pi D^2}$$

$$D = \sqrt{\frac{4R_{hx}}{\pi \tau_{10.9}}} = \sqrt{\frac{4R_{hx}}{\pi \tau_{8.8}}} = \sqrt{\frac{4(2224\ N)}{\pi(255\ MPa)}} = 3.33\ mm$$

As the above calculation illustrates, a typical M16 bolt that is found on 100 HP utility tractors is large enough to handle the draft load.

2.3.1.2.3 Drawbar Mounting Bracket

The drawbar mounting bracket plate thicknesses were initially set based on industry trends. Figure 34 is an example of the drawbar mounting bracket on a John Deere tractor. The thicknesses for the bottom and side plates were interpreted from this image using known PTO spindle dimensions. The bottom plate is 1 inch thick and the side plates are 1/2 inches thick.

Figure 34: Example of a John Deere drawbar mounting bracket using a 1 inch lower plate and 1/2 inch side plates [16]. Used with permission under the Create Commons Attribution 2.0 Generic license [17].

The hitch load on the drawbar in the extended drawbar position results in a moment applied to the lower plate of the drawbar mounting bracket:

$$M_{max} = R_{hz} L_{max} = (11\ kN)(357.6\ mm) = 3934\ Nm$$

The highest stress point of the bottom plate is where it is welded to the side plates. The moment calculated above is split between either side of the bottom plate resulting in a moment between the end of the bottom plate and the side plate of

1967 Nm. The required section modulus to handle this moment was calculated using Eq. (2-5):

$$S = \frac{M}{\sigma} = \frac{M_{max}/2}{\sigma_{A36}} = \frac{(3934\ Nm)/2}{167\ MPa} = 11777\ mm^3$$

The lower plate of the drawbar mounting bracket is welded to the side plates. Figure 35 illustrates the cross-section of a 1/4 inch weld bead at the surface of the side plate.

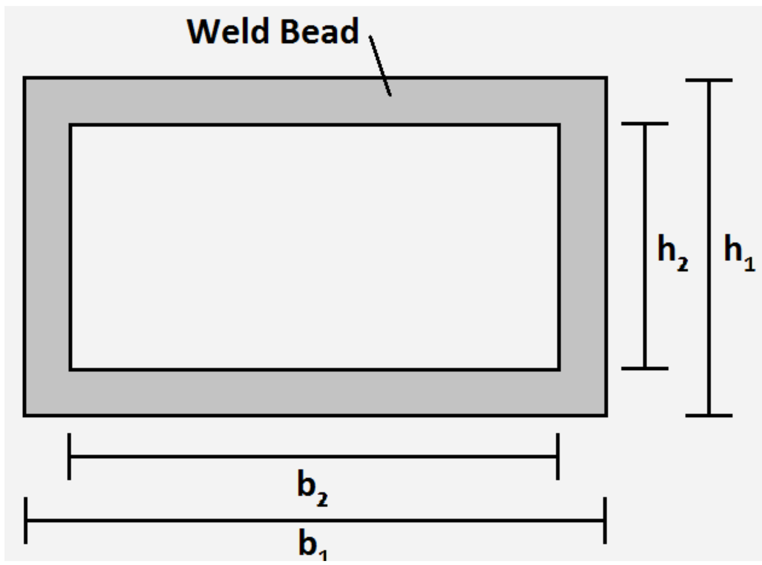

Figure 35: Weld bead around the lower plate connecting it to the side plates.

The section modulus for the weld in Figure 35 can be expressed as:

$$\boldsymbol{S = \frac{b_1 h_1^3 - b_2 h_2^3}{6h_1}} \qquad \textbf{Eq. (7)}$$

$$S = \frac{(2.5)(1.5)^3 - (2)(1)^3}{6(1.5)} = 0.71528\ in^3 = 11721\ mm^3$$

Since the required section modulus is 11777 mm^3 and the section modulus of a continuous 1/4 inch weld around a bottom plate with a 1 inch by 2 inch cross-section is 11721 mm^3

The required section modulus is 11777 mm^3 and the section modulus of a continuous 1/4 inch weld around a bottom plate with a 1 inch by 2 inch cross-section is 11721 mm^3. Given the inexact process of welding where a 1/4 inch bead is approximate, these two values of section modulus are in close enough agreement to say that the 1 inch thick and 2 inch deep bottom plate can withstand the hitch load of the drawbar.

2.3.1.3 Tractor Tipping Scenarios

The tractor tipping point was determined using vehicle dynamics equations. At a maximum load of 11 kN (drawbar extended), or 2472 lb, the M Series can accelerate at 1.2 m/s^2 or climb an incline of 6.72 degrees. With the attachment hooked up with no implement, the M Series can accelerate at 2.5 m/s^2 or climb an incline of 14.12 degrees. The calculations made say that the M Series by itself can either accelerate at 2.5 m/s_2 or drive up an incline of 14.26 degrees. Figure 36 shows the relationship between hitch load, acceleration and incline angle. As the figure shows, the relationships are linear.

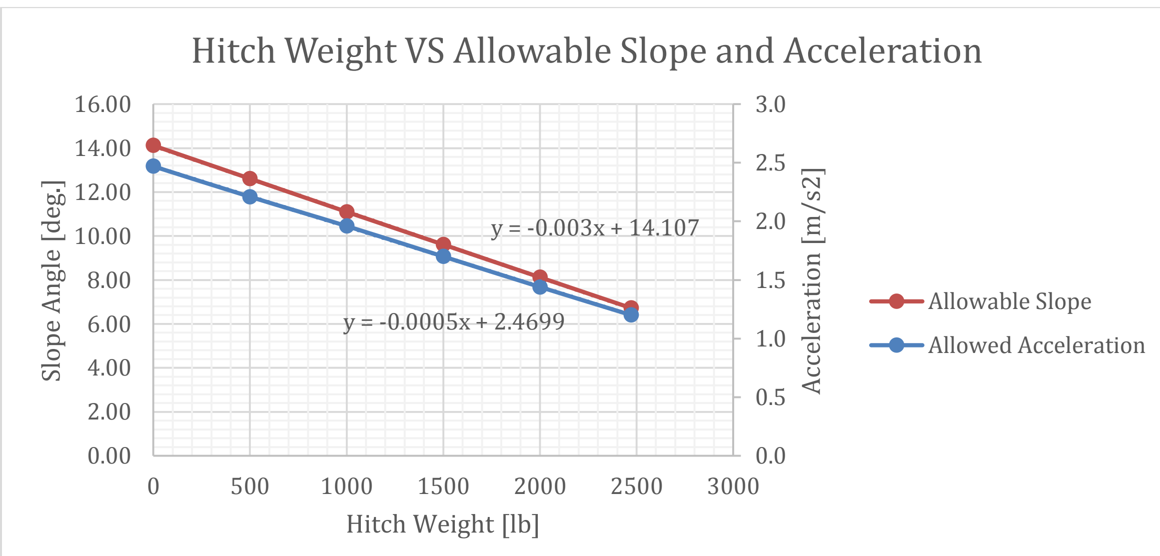

Figure 36: Relationship between hitch weight and allowable incline angle and acceleration to prevent tipping.

Details on the hand calculations for these results are in Appendix 3.

2.3.2 Finite Element Analysis

Finite Element analysis was used to determine the stresses in the superstructure. Autodesk Inventor was used for FEA. To reduce simulation time, three different simulation configurations were used. One focused on the built-in boots that connect to the tractor's lift linkages, the second on the tubes that make up the frame, and the third simulation focused on the drawbar mount. Once the designs were complete, a final master FEA containing all components was conducted to verify the rationalization of the compartmentalized FEAs. The images and constraints outlined in this section are from the master FEA.

Preliminary frame tube sizes were determined through hand calculations (Section 2.3.1). FEA was used to optimize the superstructure geometry according to the design stresses summarized in TABLE IX.

The FEA assemblies are weldments, meaning that all of the components attachment assembly are mated together using weld beads. Stress between two components welded together would flow through the weld and not the mated faces of the components.

Details on the applied forces and constraints of the simulation setup can be found in Appendix 3.

2.3.2.1 Drawbar Mounting Bracket FEA

The maximum stress in the drawbar mounting bracket is 199 MPa (28.9 ksi) located on the lower side plates, seen in Figure 38. The factor of safety of this maximum stress point is 1.25. The maximum stress in the bolts used in the bracket is 201 MPa (29.1 ksi), resulting in a factor of safety of 3.3 from a grade 8.8 bolt.

Figure 37 reiterates the forces applied to the drawbar and the drawbar's relation to the drawbar mounting bracket. There are stress concentrations on the welds, the bolts, and the top-rear edge of the bottom plate of the bracket.

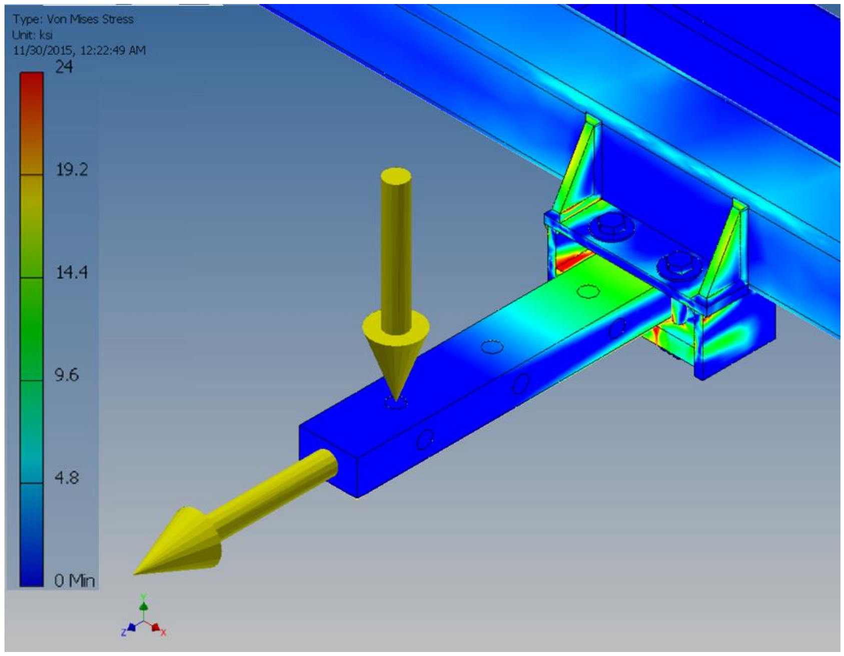

Figure 37: Top-rear-right view. Von Mises stress of drawbar mounting bracket including drawbar and frame.

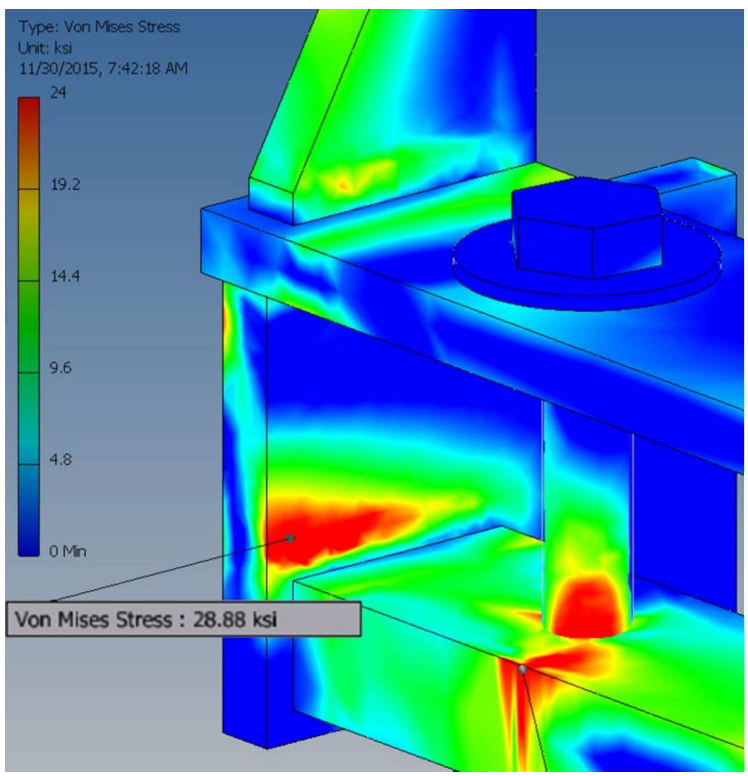

Figure 38: Location of maximum Von Mises stress in the drawbar mounting bracket.

Results of the FEA contained singularities in the welds of the built-in boot assembly. Since the FEA was set to converge on displacement, the singularities in the welds were neglected.

The stress concentration on the top-rear edge of the bottom plate is a result of a sharp edge interacting with the underside of the drawbar. In reality, this stress concentration would result in the edge getting rounded over with use.

The stress concentrations on the bolts appear as a hazard only because the color bar is scaled for the target stress of mild steel. The bolts are grade 8.8 M16 bolts, which have a much higher yield stress of yield stress of 660 MPa (95.7 ksi).

The stress concentrations in the welds are the result of the sharp edges of the welds. The highest stress weld connects the bottom plate to the side plate (Figure 39). This weld has higher stress because of the sharp beveled edge that reaches to the rear face of the bracket, and the sharp edge that runs across the depth of the bottom plate. Without these sharp corners, the stress concentration would likely not be as high as 28 ksi. See Section 2.3.1.2.3 for hand calculations justifying this weld.

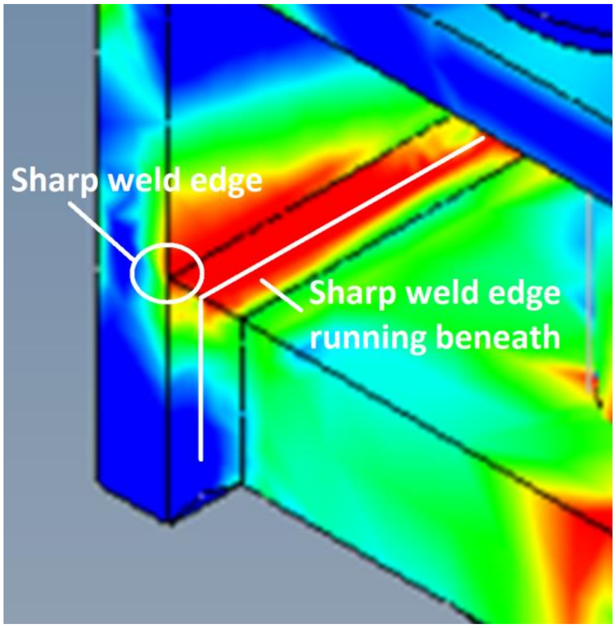

Figure 39: Highlighted stress concentration at the weld connecting the bottom plate to the side plate.

See Appendix 3 for more drawbar mounting bracket FEA images.

2.3.2.2 Built-In Boot FEA

The maximum stress in the built-in boots was 128 MPa (18.6 ksi) located on a weld on the inside of the built-in boot weldments, seen in Figure 41. The factor of safety of this stress point is 1.9. Figure 40 shows an isometric view of the stress distribution in the built-in boot.

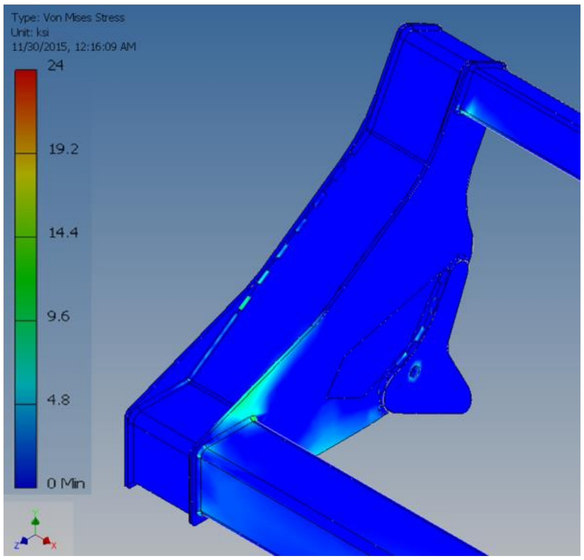

Figure 40: Top-rear-right view. Von Mises stress of built-in boot, including frame members.

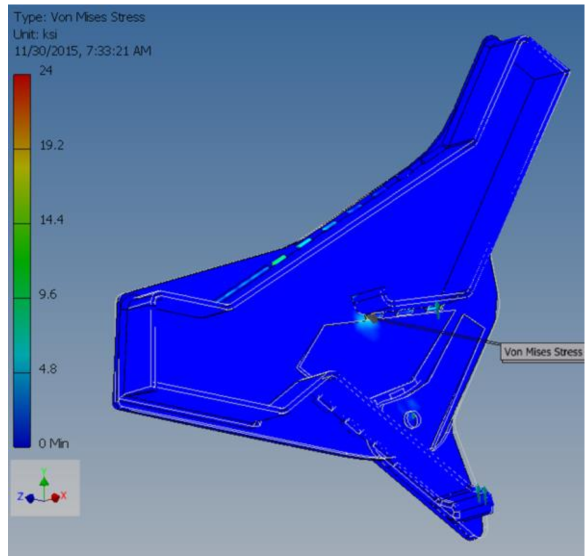

Figure 41: Location of maximum Von Mises stress in the built-in boot weldment.

Results of the FEA contained singularities in the welds of the built-in boot assembly. Since the FEA was set to converge on displacement, the singularities in the welds were neglected. Figure 42 shows the location of the singularity and the location used for the maximum stress.

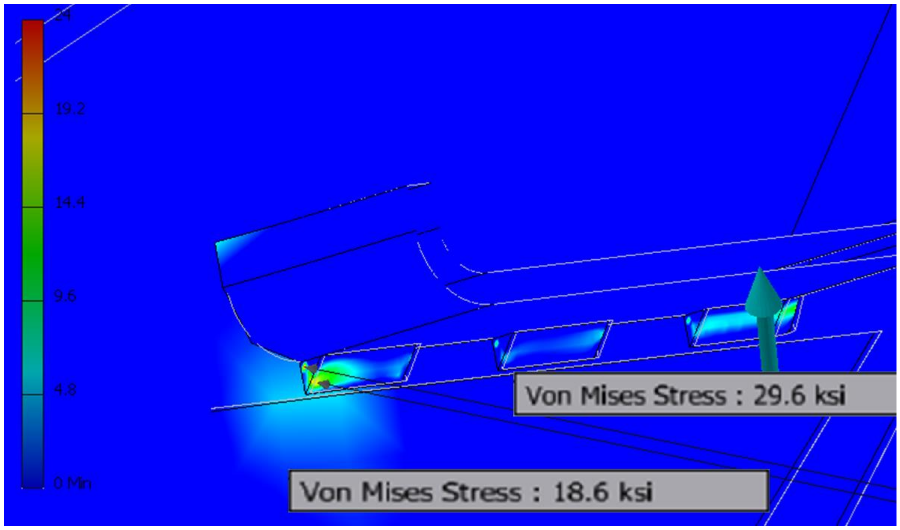

Figure 42: Maximum stress location on the inside of the built-in boot weldment.

2.3.2.3 Frame FEA

The maximum stress in the frame was 137 MPa (19.8 ksi) located on the inside of frame member 2 in the vicinity of the gusset welds, seen in Figure 43 and Figure 38. The factor of safety of this stress point is 1.82. The size of frame member 2 was required to be 5 inches with a 1/4 inch wall in order to have a FOS of above 1.5. The initial size of the main beam was determined through the hand calculations in Section 2.3.1.2.1.

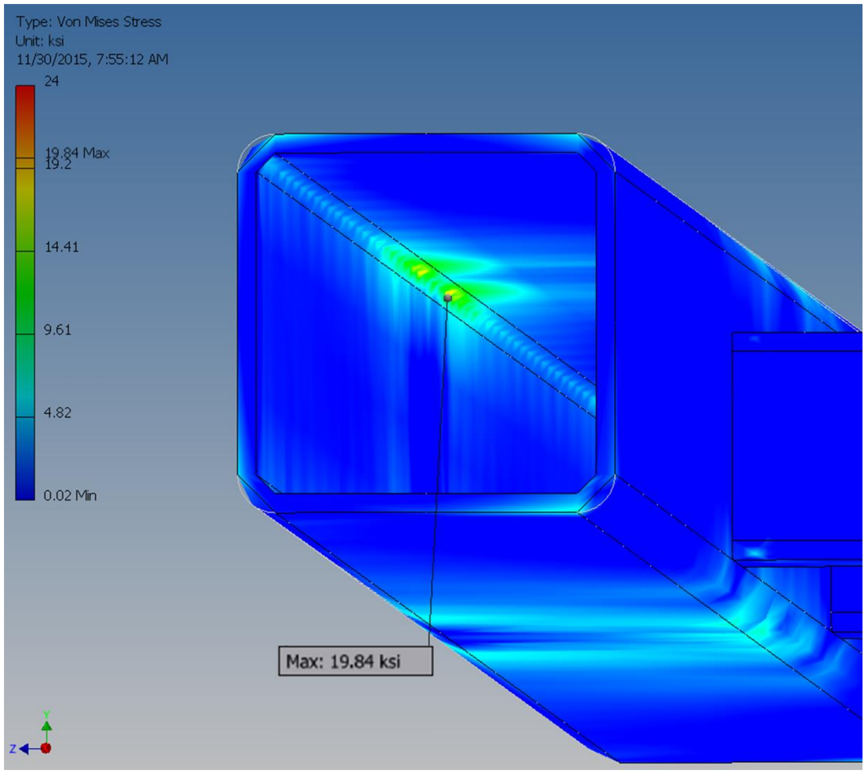

Figure 43: Location of maximum Von Mises stress on the inside of frame member 2 above the drawbar mounting bracket. Note that this image a section view.

Figure 44 shows the stress distribution of the entire frame. The highest stress concentrations in the frame were in member 2 in the vicinity of the welds that attached the drawbar mounting bracket.

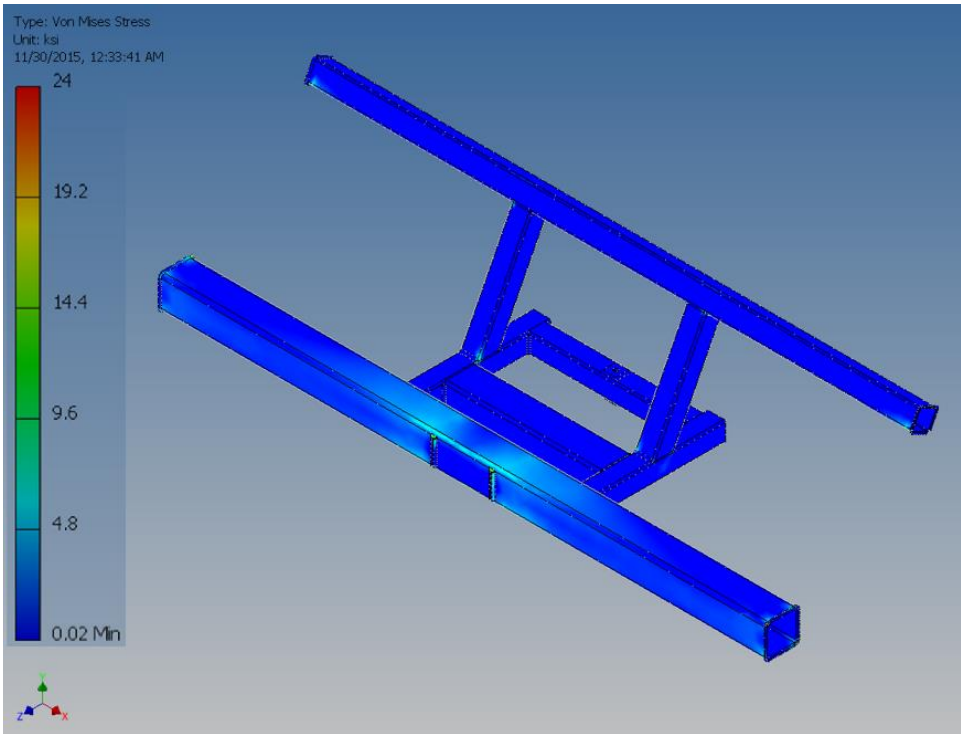

Figure 44: Top-rear-right view. Von Mises stress of attachment frame. Built-in boots and drawbar mounting bracket excluded.

Other stress concentration in the frame tended toward the welded joints, however they were not as high as those in frame member 2.

See Appendix 3 for more frame FEA images.

2.4 FMEA

Failure mode and effect analysis is a structured approach used to problem solve or mitigate risks of a system or design. It is a design tool used to determine the different ways or modes in which a system can fail and assess their risks. It identifies the effects resulting from the potential failures and determines the revisions that need to be made to the system or design to mitigate the associated risk.

The FMEA given in this report is a tool used to identify the potential failures that could occur in development (manufacturing) or in the use of the design (user error), if implemented. Because this design is unique in that no other attachment device such as this is available on the market, it is important to consider the potential failure modes that could stem from the different components of this device despite the fact that the design is based on industry standards. Failures could be introduced to the design during the manufacturing and assembly processes. Examples of these include welding, cutting tolerances and fatigue.

The FMEA approach used for this design considers the potential failure modes that are caused by two aspects of the design. The first cause of potential failure modes considered are the design weaknesses of the proposed attachment device. The components of the designed attachment device are considered a risk due to the inaugural nature of the design concept. This type of FMEA associated with design error is known as Design FMEA. The second potential cause of failure actions considered is the internal (user) or external (manufacturing team) customer. These are known as Process and Service FMEA respectively. Ideally, the Process and Service FMEA should be conducted by including all participants involved in the production or use of the product. However, for now recommended actions are given based on input from the design team.

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TABLE XI: DESIGN FMEA ANALYSIS

Section	Component Process Step/Input	Potential Failure Mode	Potential Effect	SEV	Potential Causes	FREQ	Current Controls	DET	RPN	Action Recommendations	Revised SEV	Revised FREQ	Revised DET	Revised RPN
Superstructure	Auxiliary port	Detachment of quick coupler from frame	Auxiliary hoses detach/disconnect from either the port housing or implement interface	6	Mounting bracket failure due to fatigue	3	Weekly Inspection	5	90	Reinforce mounting brackets with steel sheet	6	2	6	72
	Hose lines	Drive hoses get pulled from connection point on the motor	Hydraulic tank is drained and hoses are destroyed	10	Large debris or ground contact	3	Hose Channel	2	60	Monitor	10	2	2	40
	Drawbar	Mounting bracket bends/ breaks	Pulling force will be transferred to PTO shaft and the hoses causing them to fail	6	Weak attachment of drawbar to frame, not enough connection points	2	Mounting bracket with 1" thick bar stock bottom	6	72	Reinforce with gussets	6	1	6	36
	Drawbar	Drawbar alignment does not fully meet standards	Center of gravity may be offset causing tractor to flip	10	Limited drawbar positioning on frame to the base	2	1 drawbar bolt on the rear beam	5	100	Weight box on engine side to restore balance	10	1	5	50
	Lift linkage attachment	Lift linkage fails due to inadequate support at connections to frame	Frame falls and the tractor tilts counter-clockwise	10	Limited connection points on lift linkage	3	Pins	8	240	Use safety straps around the lift linkages	10	2	5	100
	Lift linkage attachment	Angle of approach during mounting to frame is misaligned	Frame is unable to mount on boots	4	Lack of clear line of sight to frame slots	5	Using center link as perspective/guide	5	100	Funnel/wedge type of guide on boot	4	2	1	8
	Center link	Breaks/detaches due to compression from frame	Loose frame	6	Low grade of turnbuckle or rough terrain causing fatigue	2	Weekly Inspection	5	60	Safety chain, mechanical link/bar	6	1	5	30
	PTO driveline	PTO driveline on implement may be too long	Unable to attach implement	8	Improper approximation of the implement-to-tractor driveline telescoping length clearance	3	Moveable drawbar	4	96	Increase connection points on drawbar	8	1	3	24
Hydraulics	Gearbox PTO spindle	Splines on gearbox spindle could shear off	Gearbox will free spin and implement driveshaft will not	8	Too much torque transmitted through 6 spline connection	3	Use a high grade coupler	5	120	Change the spindle on the gearbox from a 6 spline to a 21 spline	8	1	5	40
	Header drive pumps	Back pressure may cause pump failure	PTO power transmission interrupted	8	Unequal pressure settings on pumps	3	Pressure relief valve setting	8	192	Monitor	8	2	6	96
Electronics	Seat position override switch	Switch may be shorted	Hydraulic functions get locked	8	Wiring harness switch malfunctions sending two signals or none	3	Intermediate wiring harness and safeties within WCM and CDM	10	240	Isolate seat positioning wiring from hydraulic wiring with a relay switch	8	1	2	16

TABLE XII: PROCESS AND SERVICE FMEA ANALYSIS

Section	Component Process Step/Input	Potential Failure Mode	Potential Effect	SEV	Potential Causes	FREQ	Current Controls	DET	RPN	Action Recommendations	Revised SEV	Revised FREQ	Revised DET	Revised RPN
Superstructure	Frame	Kickstand falls out from under frame	Unsafe and unable to connect to the tractor	6	Improper disconnect of frame or uneven ground	6	Wide kickstand base	5	180	Use two kickstands	6	2	4	48
	Lift linkage boots	Boots may be difficult to assemble	Boots would be assemble with poor tolerances and not fit properly on lift linkages	5	Difficult to manufacture bend angles	7	Use tabs to help welders assemble the part more accurately	3	105	Produce a bend template that could be used to check bends during forming	5	2	2	20
	Drawbar	Bends/buckles	Pulling force will be transmitted to PTO shaft and the hoses	7	Overloading from the towed implement	3	Two position support and M16 drawbar bolts	5	105	Use a larger drawbar of stronger steel	7	2	4	56
	Lift linkage attachment	Frame falls off lift linkages either	All force gets transmitted through the center link and the frame will be dragged on the ground	8	Boot aren't properly secured with pins/ pins aren't installed properly	3	Pins with secondary locking pin	5	120	Secondary safety strap to wrap around the back of the lift linkage	8	2	2	32
	Center link	Center link plates on the top beam are welded in the wrong location	Center link cannot be connected easily or not at all	7	Poor manufacturing controls	5	Centered center link plates for easy assembly	8	280	Create a welding jig for this process	7	1	2	14
	Drawbar	Drawbar mounting bracket bends when frame is set on the ground	Structural integrity is compromised reducing maximum load the frame can support	7	Careless disconnect	7	Installation guide to demonstrate proper technique/procedu re	8	392	Use additional kickstands to keep the mounting bracket off the ground.	7	1	4	28
Hydraulics	Gearbox PTO spindle	Spline adapter falls off during operation	Drive shaft to implement will fall off and stop spinning	5	Set screw becomes loose	5	Set screw locking mechanism	7	175	Use a second set screw or a lower hold thread locking compound like Loctite Red	5	2	6	60
	Hydraulic hoses	Hoses begin to leak or burst	Hydraulic pressure is reduced, loss of hydraulic oil, danger due to high pressure hydraulic leaks	1 0	Wearing of rubber/chaffing from vibrations	4	Specified hose path with guides and daily inspections	4	160	Hydraulic hose covers made of non-porous ballistic nylon/use grommets on sharp edges	10	2	4	80
Electronics	Trick Seat Position Circuit	Circuit becomes disconnected	Hydraulics will become locked out instantly possible causing damage to the implement	7	Exposed wires being caught and ripped from their connecters	6	Route wires around high traffic areas and wrap harness in a mesh	5	210	Incorporate circuit in WCM programing	7	1	1	7
	Trick Traction Drive Range Circuit	Circuit becomes disconnected	Tractor may suddenly drop to a lower drive range and rapidly decelerate	1 0	May cause driver injury or loss of control	6	Route wires around high traffic areas and wrap harness in a mesh	5	300	Incorporate circuit in WCM programing	10	1	1	10

The action plans suggested in the FMEA tables above are mainly given as a recommendation and do not need to be implemented in the design phase of the attachment device. This is supported by the fact that the main objective of this project is to deliver a design concept with defined process functionalities that will be used for prototype testing by the MacDon design team in the prototype shop before it reaches the production line. Therefore, the recommended actions provided in this risk analysis process are mainly to highlight that there could be some potential failures in the proposed design that the user needs to be aware of, and to provide information to the design team on the areas of the design that can be improved on or acted on as an early warning approach to preventing failure.

2.5 Bill of Materials and Cost Analysis

A cost analysis was conducted for the proposed design to determine how well the design met the customer need dictating that the attachment should cost no more than $5000. This cost analysis was based on the list of materials which would be needed to build the design. It is important to note that costs of processes such as welding, forming, or laser cutting were not included. These process can be conducted in the MacDon prototyping shop, and if included would make staying within budget impossible. The total calculated cost for the design was found to be $4278.76. A breakdown of the costs is presented in TABLE XIII. A complete bill of materials with descriptions of all parts required and their part numbers with supplier information is contained within Appendix 3.

TABLE XIII: BILL OF MATERIALS

Cost Summary		
Item	**Description**	**Cost**
Steel Tubing	Tubing used to construct the frame	$265.91
Steel Sheet	Sheet steel used built in boot and various frame parts	$643.39
Fasteners	Various pins and bolts for brackets	$25.68
Center Link	Turnbuckle between tractor and frame	$77.85
Hoses and Fittings	Hoses for aux. circuits and the hydraulic motor	$593.21
Hydraulic Motor	75cc Eaton hydrostatic motor	$1,015.84
Gearbox	Comer 2.5:1 reduction gearbox	$912.39

Shaft Adapter	Adapter from 6 spline to 21 spline shaft	$296.47
Aux. Valve Block	Valve block and components for dual acting circuit	$421.17
Electronics	Wires, switches and connectors	$26.85
	Total Cost	**$4,278.76**

2.6 Supplementary Material

Five appendices are included with this report as supplemental information to the reader. Some of this information may be required to build the design, but it isn't required to understand how the design works and what it looks like.

Appendix 1 elaborates on the relevant agricultural standards that are summarized in Section 1.5.

Appendix 2 takes a closer look at the concept generation and selection process. All concepts developed, along with the screen and scoring matrices for these concepts are included in this appendix and explained in detail.

Appendix 3 contains additional analysis performed along with explanations for said analysis. Specifically details of the finite element analysis conducted along with detailed explanations for the failure modes and effects analysis are include.

Part drawings and assembly drawings have been produced to aid in the manufacturing process. These are all contained within Appendix 4.

An installation guide was also produced for the end user of this product. It serves to aid in setting up the M Series to function with our attachment. This set of instructions has been included in Appendix 5 for the sake of completeness of the design.

3.0 Conclusion

MacDon M Series self-propelled windrowers have a limited range of use and can sometimes be seen as an unjustifiable expense for small to medium sized farmers. Also, the M Series can at times be difficult to test for the MacDon testing department due to the short windrowing season. As a solution to this problem our team designed an attachment for the windrower that will allow it to pull and operate tow-behind farm implements, allowing farmers to get more use of their windrowers and MacDon to conduct testing more easily.

To meet all the requirements set out by MacDon, our team collected and analyzed the needs, target specifications and constraints for the project based on information collected from MacDon representatives and research on current applicable industry codes and standards. With this information in mind an extensive concept development procedure aided us in producing what we believe to be a design that exemplifies the customer's vision for the product. Concept screening and scoring matrices were used as an engineering approach to selecting the optimal concept based on criteria which were weighted against one another in terms of importance and used to rank each option. At the conclusion of this process concepts were chosen for each of the five major subsections of the design. The results of the scoring stage are contained within TABLE XIV.

TABLE XIV: RESULTS OF CONCEPT SELECTION

<table>
<tr><th colspan="2">Section</th><th>Concept</th><th>Evaluation</th></tr>
<tr><td colspan="2">Superstructure & Packaging</td><td>Chariot</td><td>4.15/5</td></tr>
<tr><td colspan="2">Lift Linkage Connection</td><td>Draper Boot</td><td>4.35/5</td></tr>
<tr><td colspan="2">Drawbar Connection</td><td>Mouth Tongue</td><td>4.44/5</td></tr>
<tr><td rowspan="3">Attachment-Side Hydraulics</td><td>PTO Motor/Gearbox</td><td>Rotary PT Motor/Gearbox</td><td>Client Aided Decision</td></tr>
<tr><td>Hydraulic Connections</td><td>ORFS Threaded Connection</td><td>Client Aided Decision</td></tr>
<tr><td>Auxiliary Coupler Mounting</td><td>Mounting Bracket</td><td>4.29/5</td></tr>
<tr><td rowspan="2">Tractor-Side Hydraulics & Electronics</td><td>Flow from Tractor</td><td>Rotary Disk Block</td><td>Client Aided Decision</td></tr>
<tr><td>Tractor Electronics</td><td>Cab-Forward, Trick Traction Drive Range Selector</td><td>Client Aided Decision</td></tr>
</table>

It should be noted that after the concept development stage of this project, the draper boot concept was selected as the concept to proceed with into the design phase. This decision was changed to a built in boot design after determining that the draper boot concept would not provide the stiffness and rigidity which the design required.

The design produced at the conclusion of this project embodies the ideas originally put forth by MacDon when the project first commenced. This hitch attachment is constructed from steel sheet and tubing designed to handle a wide range of loading scenarios. The main frame, member 2, is a 5" x 5" x .25" ASTM A500 grade B steel tube. Billions of iterations of finite element analysis were used to replicate and reinforce hand calculation initially conducted to produce a structure which maintained a factor of safety of 1.5 for all loading scenarios. Included in the frame design are built-in boots which quickly couple to the tractors lift linkages using a sliding pin to secure them in place. Also included is a steel tube kickstand with an adjustable height setting to aid in connecting and disconnecting the attachment from the tractor. An adjustable drawbar system is used as the main method of connecting to an implement and is connect at the back of the frame using an M16 bolt.

Also incorporated into the frame is an attachment point for a mechanical turnbuckle running from said attachment point to a bracket at the center of the tractor's front frame member. The attachment is serviced by a Comer offset, 2.5:1 reduction gearbox, powered by an Eaton 75cc heavy duty, hydrostatic, fixed displacement motor, both being products carried in MacDon's parts inventory. The gearbox has a 1.375" diameter 6 tooth splined shaft, and an adapter, manufactured by Hub City, has been specified which can be used to convert from said 6 splined shaft to a 1.375" diameter 21 splined shaft. Also key to the hydraulic system is an additional valve block, which when installed, provides a secondary dual acting circuit for the attachment. This circuit, along with a second dual acting circuit and a third single acting circuit, both of which are standard on the M Series, will provide the attachment with the hydraulic flows needed to power any auxiliary hydraulic cylinders that may be used on the implement being towed. These circuits run to pioneer quick couplers mounted to the frame, which provide a standardized method of coupling between the implement and the tractor.

In terms of electrical design two intermediate wiring harnesses must be installed to trick some of the lockouts on the M Series. The first harness bypasses the signal from the seat position switch and the second harness is used to manually select the traction drive range which dictates the speed and torque achievable at the drive tires.

The total cost of the proposed design is estimated at $4278.76. The attachment will work with the current design of the M Series and can also be adapted to future models with relative ease.

3.1 Recommendations

Although we believe this design to be sound, continuous improvement is a mentality which should be held paramount. A list of recommendations has been provided for the continued development of this product. They are as follows.

- Reprogram the WCM and the CDM to have a 3rd option for seat position so that the tractor can function fully in engine-forward without having to trick either of the controllers.
- Reprogram the CDM to allow for a slightly slower flow to the motor so that the shaft can be set to spin at either 1000 RPM or 540 RPM exactly.
- Have four stands around the corners of the frame so that the drawbar does not have to be removed each time the attachment is removed.
- Incorporate a pocket/tube to hold the PTO spline adapter when not in use. Ensure that there is a spot in this holder for a hex key, which will be needed to install and remove the adapter.
- The high stress welds of the drawbar mounting bracket should be monitored for cracking. Gussets may be added for reinforcement.

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Appendix 1 – Relevant Agricultural Standards

Appendix 2 –Concept Generation and Selection

Appendix 3 – Additional Design Analysis

Appendix 4 – Drawing Package

Appendix 5 – Installation Guide Package

Appendix 1 - Relevant Agricultural Standards

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1.0 An Introduction to Standards

ASABE (the American Society of Agricultural and Biological Engineers) is a professional organization that provides information on the standards, engineering practices and data related to agricultural and biological systems. These standards are developed and used by the ASABE as a form of institutional codes and practices that can be applied mostly in the scope of agricultural field equipment and water resource management.

It is important to note that the standards, engineering practices, and data developed by the ASABE organization are for informational and guideline purposes only. Following these standards does not guarantee conformity with the law, and does not protect the users from infringement of patents. The standards, engineering practices, and data that were initially developed by ASABE before the organization changed its name in July 2005 are referred to as 'ASAE', while the new standards, engineering practices and data implemented after July 2005 are referred to as 'ASABE'.

One of the documents that ASABE develops and adopts are safety standards for the use in designing agricultural machinery. More specifically, ASABE provides safety standards for farmstead equipment, drivelines and PTO connections, implements such as portable augers and rotary mowers, and other agricultural products. The ASABE society currently has 246 standards. However, in this project we only applied and mentioned the standards that fit within the scope of our design.

Some of the documents or standards that are developed by the ASABE are adopted by ANSI (the American National Standard Institute) which is a body that accredits the ASABE. The standards that are adopted by ANSI become American National Standards and are referred to as 'ANSI'. In addition, all ISO adoptions that are included in ASABE publications are also American National Standards.

An example of an ASABE standard that has been approved by ANSI and adopted from ISO standards is the ANSI/ASABE AD6489-3:2004 JUN2009 document.

The ANSI/ASABE AD6489-3:2004 JUN2009 standard is and ASABE publication formerly designated as ASAE S482. This document provides standards for tractor drawbars and contains information regarding the selection of the size and the alignment requirements of the drawbar. This standard outlines the different drawbar designs available for tractors and categorizes the designs based on the power input to the drawbar, meaning the power to the tractor drive wheels, and the power output of the drawbar, meaning the power required to pull the implement at a given speed. This ASABE document is similar to the ISO 6489-3:2004 standard that is of the same name. This document is titled “Agricultural vehicles— Mechanical connections between towed and towing vehicles—Part 3: Tractor drawbar” [1]. This document is an adoption of ISO 6489-3:2004, but contains technical deviations from the international standard where exact specifications could not reach an accordance. For this reason, beside each provision in this document, such as the drawbar power, drawbar dimension and drawbar clearance, there is mention to an ASAE S482 standard as well as an ISO 6489-3:2004 standard.

2.0 Provisions of the drawbar

Throughout the ANSI/ASABE AD6489-3:2004 document, there are certain tables that make reference to or use PTO types as a criterion for comparison to standards. The term “PTO types” refers to the different diameters and number of splines on a PTO spindle. Based on industry standards, there are three types of PTO spindles that are used to transfer power at a given rotational speed. Our design only consider the type 2 PTO which has 21 splines and delivers 1000 RPM. One of our design objectives is to enable our structure to convert hydraulic pressure into rotational power at 1000 RPM to run the implements. The recommendations listed in sections 2.1 through 2.5 were derived from such standards [2].

2.1 Drawbar Provision One

The first standard for the drawbar in ANSI/ASABE AD6489-3:2004 is the dimension *L* (see Figure A1-1), which is the distance of the hitch pinhole to the outer diameter (OD) of the tractor tire. ASAE S482 provides a recommended minimum distance of 25 mm for all drawbar categories for this dimension. This standard is a deviation from the ISO6489-3:2004 standard. This dimension *L* is illustrated in Figure A1-1.

Figure A1-1: Position of dimension *L* [1]

The ANSI/ASABE AD6489-3:2004 document for this standard shows that dimension *L*:

- Appertains to the standard drawbar position when the PTO is in usage.
- Does not refer to a retreated drawbar position when the PTO is not in use.
- Is applicable with the drawbar is centered from side to side.
- To be used with the greatest developed diameter for the largest R1/R1W tires that are identified for a tractor.

The next standard that ANSI/ASABE AD6489-3:2004 provides are the designations of drawbar categories ranked by tractor power ratings. Conventionally the ISO 6489-3:2004 standards rank the drawbar categories by PTO power, while the ASAE S482 uses drawbar power to define the drawbar categories. This document integrates the ISO 6489-3:2004 adoption of drawbar categories based on PTO power, so it is recommended that the tractor is designed based on the PTO power rating provided in the ISO 6489-3:2004 standards. Therefore, this is the standard that will be applied to our design.

TABLE A1-I describes how the drawbar categories are defined based on power ratings. The third row identifies the approximate drawbar power intensity that is related to the PTO power intensity given in the second row.

TABLE A1-I: COMPARISON OF POWER RATINGS FOR DRAWBAR CATEGORIES, ADAPTED FROM [1]

Power Ranges [kW]	**Standard**	**Drawbar Category**					
		0	**1**	**2**	**3**	**4**	**5**
Drawbar Power	Previous ASAE S482	NA	15-35	30-100	60-170	135-300	NA
PTO Power	ISO 6489-3	≤28	≤48	≤115	≤185	≤300	≤500
Estimated Drawbar Power	ISO 6489-3	24	42	100	161	261	435

2.2 Drawbar Provision Two

The next provision given in the ANSI/ASABE AD6489-3:2004 document is the maximum vertical static load rating for the different drawbar categories. This provision is available both in the former ASAE S482 and ISO 6489-3:2004 standards. They are similar for both standards except for a few dissimilarities that are indicated in Table 0.2 of [1]. We will use the maximum vertical load rating based on ISO to conform to the first provision. Therefore, only the ISO 6489-3:2004 standards are shown here. TABLE A1-II gives the relative maximum vertical static load ratings of the different drawbar categories based on ISO 6489-3:2004 standards.

TABLE A1-II: RELATIVE MAXIMUM VERTICAL LOAD RATINGS FOR DRAWBAR CATEGORIES, ADAPTED FROM [1]

Drawbar Category	**Max. Static vertical load, *F***		
	Short Drawbar Position	**Regular Drawbar Position**	**Extended Drawbar Position**
0	7	5	3.5
1	12	8	6
2	22	15	11
3	27	18	13
4	33	22	16
5	45	30	-

2.3 Drawbar Provision Three

Provision number three defines the tractor drawbar and clevis dimensions. This standard is not essential in this phase of our design project which mainly involves developing concepts. The most relevant concept generation needing this standard is the location and mounting style for the drawbar on the frame. The recommended drawbar dimensions based on the ASAE S482 and ISO 6489-3:2004 standards are described below.

In this provision, there are dissimilarities in the measurements that are given in the former ASAE S482 and ISO 6489-3:2004 standards for the tractor drawbar and clevis dimensions. The ANSI/ASABE AD6489-3:2004 standards document recommends that designers should apply ISO standards when performing design work on existing equipment. Therefore, our drawbar dimensions in this project will be based on the ISO document. As previously determined, the drawbar type for this M Series attachment will be a category 2 drawbar, based on 100 HP available from the PTO. TABLE A1-III summarizes the dimension requirements of category 2 drawbars. The dimension variables from this table are illustrated in Figure A1-2.

TABLE A1-III: CATEGORY 2 TRACTOR DRAWBAR AND CLEVIS DIMENSIONS, ADAPTED FROM [1]

Parameter	Standard	Category 2 Drawbar Dimension [mm]
Drawbar width, *A*	Previous ASAE S482	60±3.5
	ISO 6489-3	≤90
Drawbar thickness, *B*	Previous ASAE S482	30 to 40
	ISO 6489-3	≤52
Drawbar pin hole diameter, *C*	Previous ASAE S482	33 +0.8/-2.5
	ISO 6489-3	33 +0.8/-2.5
Nominal drawbar pin diameter, C_1	Previous ASAE S482	30
	ISO 6489-3	≥30
Auxiliary hole diameter, *D*	Previous ASAE S482	21 +0/8-2.5
	ISO 6489-3	NA
Distance, *E*	Previous ASAE S482	102 ±0.8
	ISO 6489-3	NA
Distance, *F*	Previous ASAE S482	≤40
	ISO 6489-3	≤45
Distance, *G*	Previous ASAE S482	≥130
	ISO 6489-3	≥210

Parameter	**Standard**	**Category 2 Drawbar Dimension [mm]**
Height, H	Previous ASAE S482	≥70
	ISO 6489-3	≥70
Throat depth, J	Previous ASAE S482	≥60
	ISO 6489-3	≥80
End radius of drawbar and clevis, K	Previous ASAE S482	≤75
End radius of drawbar and clevis, R	ISO 6489-3	≤55
Longitudinal distance from drawbar pin hole to tire OD, L	Previous ASAE S482	≥25
	ISO 6489-3	NA
Driveline clearance plane, R	Previous ASAE S482	≥200
PTO drive shaft clearance, V	ISO 6489-3	≥100
Height of drawbar, S	Previous ASAE S482	330 to 500
	ISO 6489-3	330 to 500
Drawbar to PTO vertical, U	Previous ASAE S482	200 to 320
	ISO 6489-3	≥250
Chamfer angle around pin hole, W	Previous ASAE S482	NA
	ISO 6489-3	≥20°

Figure A1-2: Dimensions of tractor drawbar and clevis [1].

2.4 Drawbar Provision Four

Provision four gives a recommendation for the specific location and position of the drawbar based on the ISO 6489 standard. This standard shall also be used in our design. The dimensions associated with the location of the drawbar are given in the illustration below.

Figure A1-3: Drawbar location and position relative to the PTO spindle and the ground [1].

The dimensional values for the symbols given in Figure A1-3 above are given in TABLE A1-IV and TABLE A1-V.

TABLE A1-IV: DRAWBAR LOCATION, ADAPTED FROM [1]

Dimension [mm]	**Drawbar Category**					
	0	**1**	**2**	**3**	**4**	**5**
Height difference between ground and drawbar, *S*	220 to 440	330 to 500	330 to 500	380 to 560	380 to 560	400 to 600
Height difference between PTO axis and drawbar, *U*	≥200	≥220	≥250	≥260	≥280	≥310

TABLE A1-V: DRAWBAR POSITION, ADAPTED FROM [1]

PTO Type	Dimension T [mm]		
	Short Drawbar Position	**Regular Drawbar Position**	**Extended Drawbar Position**
1	250±10	400±10	550±10
2	250±10	400±10	550±10
3	350±10	500±10	650±10

2.5 Drawbar Provision Five

The PTO drive shaft clearance from the drawbar clevis is discussed under the fifth provision. This design feature is an important factor in our design and a critical component in the concept selection process of our project. To allow for a proper joint connection between the tractor and the implement, ISO 6489 standards recommend that "the implement end be designed to allow ± 20° of fore-aft pitch and ± 20° of side-to-side roll between the tractor and the implement." [1]. These requirements of the pitch angle and the roll angle do not have to be satisfied at the same time.

The PTO drive shaft clearance being discussed is depicted in Figure A1-4 where *V* represents the PTO drive shaft clearance and *1* represents the clearance plane. The values of the PTO drive shaft clearance *V* are presented in TABLE A1-VI for the different drawbar categories.

b) clevis attached to the drawbar

Figure A1-4: The PTO drive shaft clearance [1].

TABLE A1-VI: PTO SHAFT CLEARANCE, *V*, ADAPTED FROM [1]

Dimension [mm]	**Drawbar Category**					
	0	**1**	**2**	**3**	**4**	**5**
PTO drive shaft clearance, *V*	≥100	≥100	≥100	≥110	≥120	≥130

3.0 Provisions for the PTO Shaft and Gearbox

At this phase in the design, only the mounting location of the PTO spindle is important. This only affects the choice of which frame is chosen based on which can best accommodated and adhere to the standards for the PTO mounting location.

A resource that provides standards for the dimensions of a rear-mounted PTO is the ASABE/ISO 500-3:2004 document. The ASABE/ISO 500-3:2004 is an adoption without deviation of the international standard ISO 500-3:2004 that has the same name. They are titled "Agricultural tractors —Rear-mounted power take-off types 1, 2 and 3 — Part 3: Main PTO dimensions and spline dimensions, location of PTO." This document contains information to do with the manufacturing needs, and the position of the rear mounted PTO with respect to the tractor. This document has also been designated as an American National Standard. The location of the PTO mounted on the tractor is shown in Figure A1-5. Note *1* represents the centerline of the tractor and dimension *2* is the tractor width.

[redacted]

Figure A1-5: PTO alignment, adapted from [3].

In Figure A1-5, the PTO axis is situated within the shaded rectangle and lies parallel to the longitudinal axis of the tractor. The axis should also be parallel to the ground, within ±3°. The distances h_{min} and h_{max}, are given in TABLE A1-VII. These distances apply to conventional agricultural conditions, and not the agricultural applications that require high or low ground clearance. The measurements for dimensions shown in Figure A1-5 are shown in TABLE A1-VII for all categories of PTO.

TABLE A1-VII: PTO LOCATION [3]

PTO Type	**Dimension [mm]**	
	h_{min}	h_{max}
1	480	800
2	530	900
3	600	1000

4.0 Application of Codes and Standards

The standards given in this section were important requirements used to define our design space throughout concept development. Based on the standards given, the position and dimension of the drawbar and PTO could be determined. These dimensions were then used to evaluate the best frame design that would accommodate these standards. For example, it was given that the PTO would need to provide 100 HP to run the non-tillage implements. This criterion of power rating to distinguish the drawbar category would lead us to TABLE A1-I. From this table, it was seen that for a maximum drawbar power of 115 HP, drawbar category 2 would be used. This would also meet our criterion of 100 HP. From this table, it was also seen that the drawbar power associated with this PTO power level is 100 HP.

After selecting our drawbar category we used TABLE A1-II to identify the maximum vertical load that can be applied to the drawbar by the implement. The next step was to determine the size of our drawbar, which is defined in TABLE A1-III. This table has the drawbar and clevis dimensions associated for drawbar category 2. In addition, we also needed to identify the position of our drawbar. This is found from TABLE A1-IV and from studying Figure A1-3 which specifies the height of our drawbar from the ground. Once we have this information from TABLE A1-IV, we used these values to compare our different frame designs and decide which design most easily met the criteria. Figure A1-4 and TABLE A1-VII indicate how far apart the PTO needs to be from the drawbar. This distance can then be incorporated into our design.

In designing the superstructure the position of the PTO relative to the tractor also needed to be considered. This positioning is shown in Figure A1-5 and TABLE A1-VII and is governed using the ISO 500-3:2004 standard given to us in the ASABE/ISO 500-3:2004 document. These dimensions were designed into our frame and helped our team decide which of our designs in the adopted this standard best.

Appendix 2 - Concept Generation and Selection

Table of Contents

List of Figures

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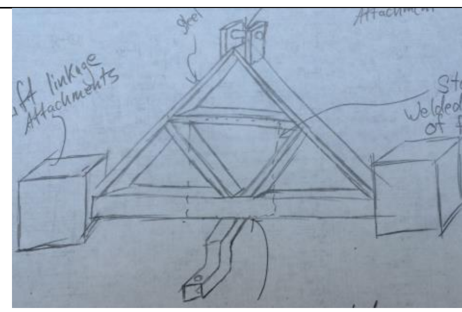
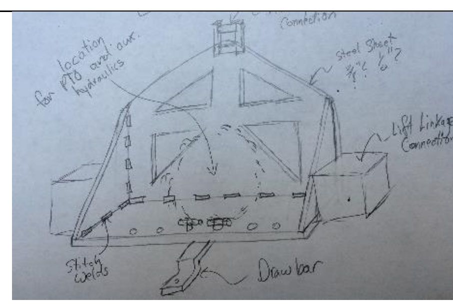
1.0 Concept Generation

Many concepts were generated for each of the sections of the design. Individual and group brainstorming were both heavily utilized in producing all of the concepts. Each team member came up with several of their own concepts before they were discussed as a group to determine the more feasible concepts to be investigated through weighted comparison. All of the concepts discussed are summarized in the following sub sections.

1.1 Superstructure and Packaging Concepts

The following concepts for the superstructure and packaging subsection were generated individually and discussed as a group. They are shown in TABLE A2-I.

TABLE A2-I: A BRIEF DESCRIPTION OF EACH OF THE FRAME CONCEPTS

"Trellis Triangulated" This concept is built entirely of steel tube creating a triangulated truss. The lift linkages are connected on both sides of the truss. The PTO spline is mounted on one of the structural members and the gearbox is located on the cab side of the frame.	 Figure A2-1: Trellis triangulated design.
"L Shaped" This design consists of steel plate bent to form an L shape. The sheet metal is then gusseted on both sides to add strength. The bottom of the L is used to form a platform to mount the motor, drawbar and gearbox to. The lift linkages are connected to both sides of the frame.	 Figure A2-2: L-Shaped design.

“The Chariot”

The chariot is similar to the shape of the L shape concept, but it is constructed out of steel tube instead of sheet metal. The frame is knee braced with steel tube to add strength. This design also offers more strength for the drawbar connection at the front side of the base. The motor and gearbox are mounted similarly to the L shaped design.

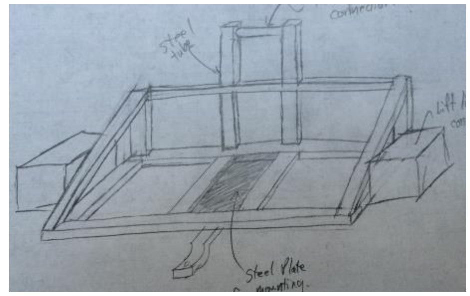


Figure A2-3: The Chariot design.

“Cable Tie”

This concept is constructed using a steel tube rectangular base with the lift linkages connected on the outside of the frame similar to the triangulated trellis, the chariot and the L shape concepts. Instead of having a rigid connection to the tilt cylinder, it has cables that connect to the corners of the rectangular base. The motor and gearbox are mounted on top of the platform. This concept was deemed unrealistic due to its lack of rigidity in a dynamic environment.

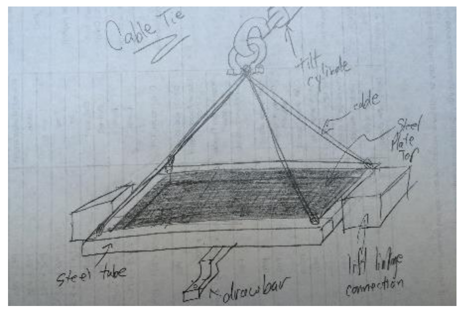


Figure A2-4: The Cable Tie design.

“The Slide”

This concept is constructed using a combination of steel tube and sheet metal. The frame itself is constructed with steel tube, while the implement side is covered in sheet metal to protect the attachment mechanical components. The PTO spline is mounted on the sheet metal face and the gearbox and motor are mounted in the middle of the frame. The lift linkages connect on either side of the frame.

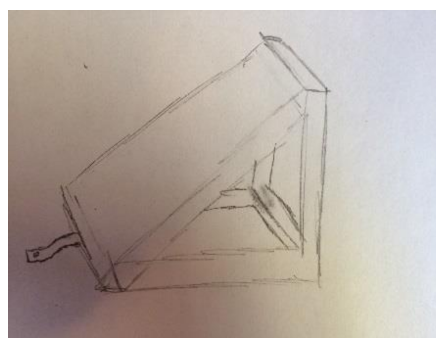


Figure A2-5: The Slide design.

“Box Base”

This concept is constructed using a rectangular base that forms the main structure. The lift linkages are connected on either side of the frame, but can be mounted closer or further from the cab depending on ideal weight distribution. There are two steel tube members triangulated upward to attach to the tilt cylinder. The motor and gearbox are mounted on top of the platform.

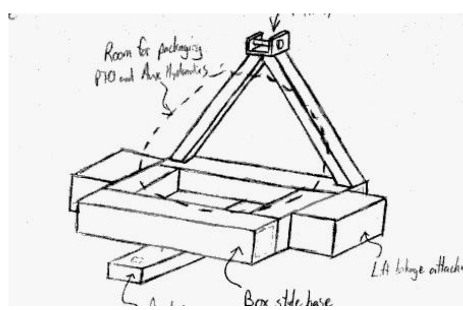


Figure A2-6: The Box Base design.

“Attack Cobra”

This concept is constructed similarly to the box base, but has a triangular base instead of a square one. This reduces the room for the motor and gearbox, but adds rigidity to the drawbar mounting location. The lift linkage connection points also cannot adjust as much as the box base. Two members triangulate up to attach to the tilt cylinder.

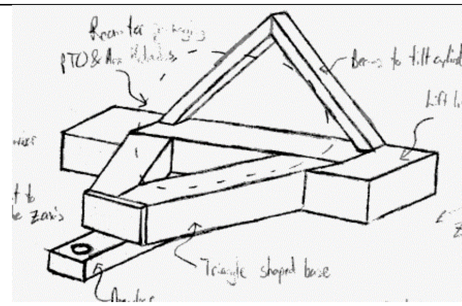


Figure A2-7: The Attach Cobra design.

“Scared Cobra”

Steel tubes frame out a triangular base with connection points for the lift linkages in line with the drawbar connection point. This moves the entire frame toward the center of the drive wheels. This creates more effect weight transfer to the drive wheels. The vertical member is adjustable to allow it to connect to the tilt cylinder at a convenient location.

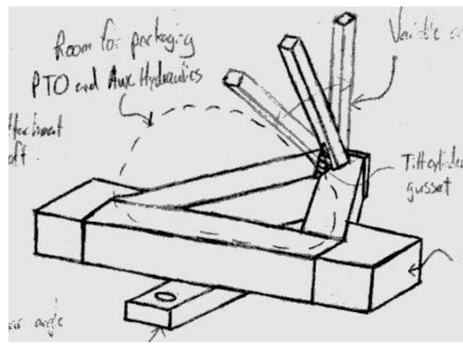


Figure A2-8: The Scared Cobra design.

“The Chick Magnet”

This concept is designed with a welded curved sheet metal frame to allow for connection to the lift linkages, but also moves the drawbar connection point closer to the center of the drive wheels. The motor and gearbox are mounted on the flat top of the frame. There are two steel tube members triangulating up to connect to the tilt cylinder. These members are gusseted for strength.

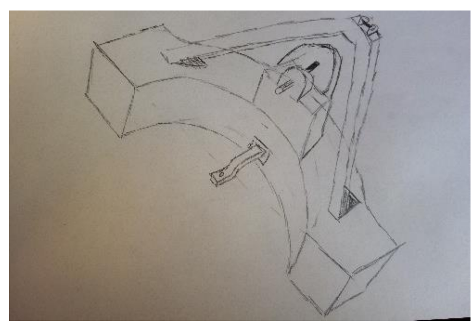


Figure A2-9: The Chick Magnet design.

“The Pylon”

This concept is constructed out of sheet metal in a single plane, similar to the trellis triangulated concept. This creates a very rigid frame which can accommodate the motor inside the frame and the gearbox on the cab side of the frame. The drawbar can be mounted to the bottom of the frame which can be reinforced. The lift linkages connect to the frame from the rear on each side of the frame.

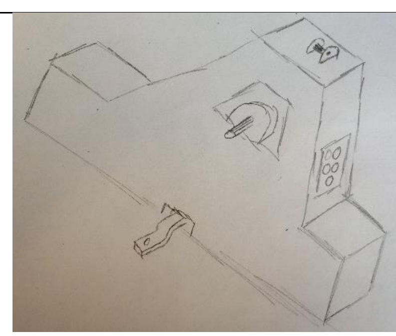
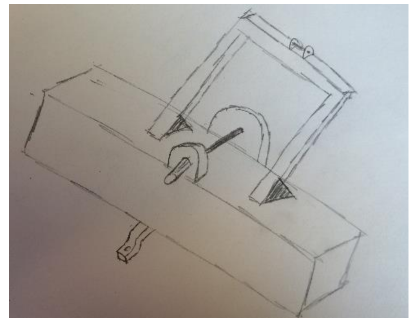


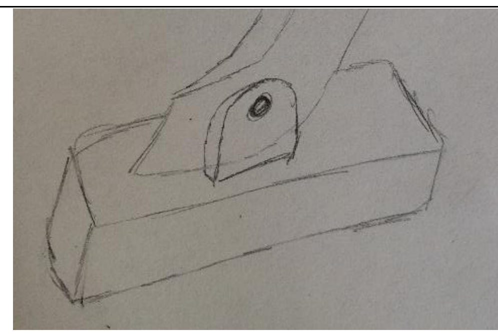
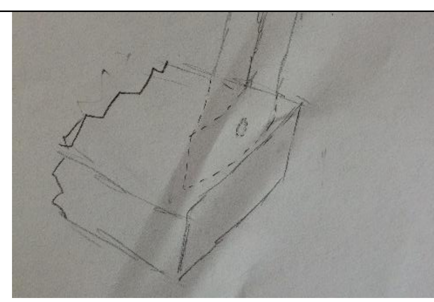
Figure A2-10: The Pylon design.

“The Speed Boat”	
This concept is designed to be as simple as possible while still meeting all of the requirements. It is a rectangular steel sheet metal frame which has 3 steel tube members welded together to attach to the tilt cylinder. The flat top accommodates the motor. The gearbox can be mounted to the back of the frame. The lift linkages can be connected from the rear into both sides of the frame. The drawbar can be connected on the bottom or into the frame.	 Figure A2-11: The Speed Boat design.

1.2 Lift Linkage Connection Concepts

The following concepts for the lift linkage connection subsection were generated individually and discussed as a group. They are shown in TABLE A2-II.

TABLE A2-II: A SUMMARY OF THE LIFT LINKAGE CONNECTION CONCEPTS

“Cinder Block Stilts”	
The lift linkages are mounted to the top of the frame using welded on tabs. The tabs have a hole that lines up with the hole in the lift linkage to allow a clevis pin to hold the two together. The box shape in the picture represents a part of the frame. The frame would be tight to the base of the lift linkages, minimizing the frames ability to tilt independently of the lift linkages.	 Figure A2-12: The Cinder Block Stilts design.
“Built In Boot”	
The lift linkages are inserted into the rear of the frame. The frame has accommodating structure to allow for a tight fit to the base of the lift linkages. The pin must also be able to be installed to mechanically attach the two. This design requires a structure inside the frame similar to a draper boot to ensure the installation is easy.	 Figure A2-13: The Built in Boot design.

“Weld On”

This weld on concept is simple. The frame would be welded directly to the lift linkages. This concept was deemed unrealistic due to the permanent changes to the lift linkages that would interfere with the typical use of the tractor.

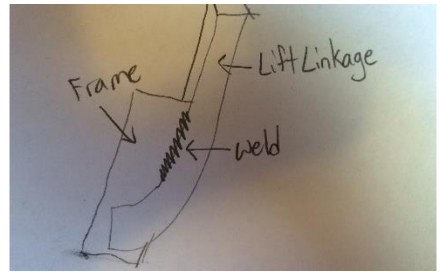


Figure A2-14: The Weld On design.

“Hooks”

This concept consist of a solid hook made of welded together steel plate which would be welded to the lift linkages. The hooks would be mounted above the base of the lift linkages to avoid interfering with the connection of a draper header. This method would hook directly to the attachment frame. The attachment would be held on the hooks by its own weight as well as the applied hitch weight.

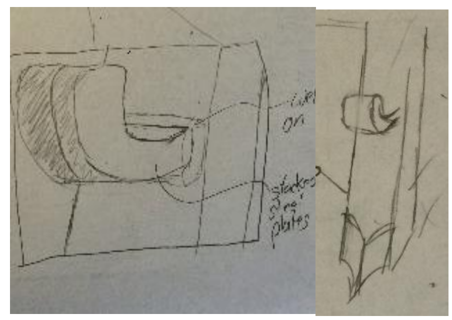


Figure A2-15: The Hooks design.

“Wedge”

This concept is a sheet metal frame with tapered sides. The tapered sides wedge between the two lift linkages. Once wedged in place, the clevis pin could be installed to secure it in place. This design is made to ease the installation of the attachment to the tractor. The wedge shape allows for self-alignment during install.

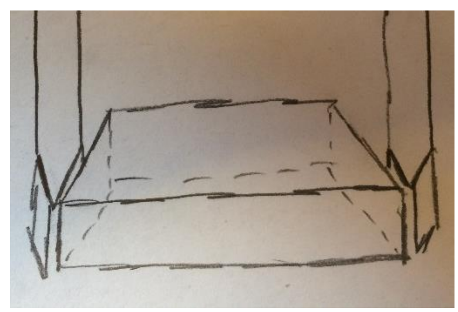


Figure A2-16: The Wedge design.

“Draper Boots”

This concept uses the current production draper boots to connect to the attachment. This would require the frame to have a receiving area similar to the draper headers to connect to the boots. Most farmers that have a windrower tractor already have draper boots which reduces the cost to the farmer.

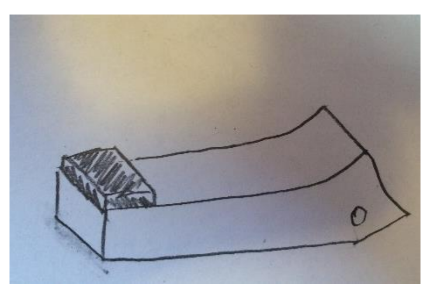


Figure A2-17: The Draper Boot design.

“Rotary Boots”

This concept uses the current production rotary boots to connect to the attachment. Some of the farmers that own a windrower tractor already have the rotary boots. They are shaped in such a way that they allow for a wider attachment frame than the draper boots.

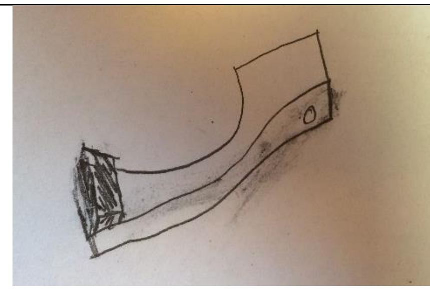


Figure A2-18: The Rotary Boot design.

“Dual Boots”

This design accommodates both draper and rotary boots. The frame would have a receiving area for either type of boot. Farmers that run a windrower tractor either run a rotary or a draper header, meaning that they have at least one of the two types of boot.

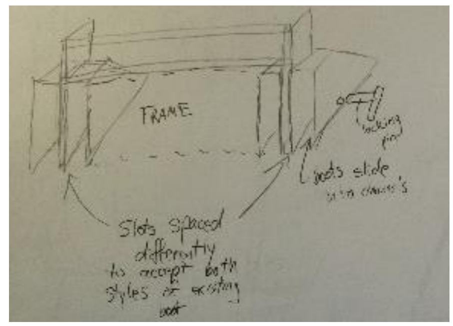


Figure A2-19: The Dual Boot design.

“Straps”

For this concept to work, the frame must have a v shape designed into it to mate with the existing lift linkage base. A strap is then run around the back of the lift linkage to hold the frame to the linkage. This concept uses a simple mating method to make installation quick.

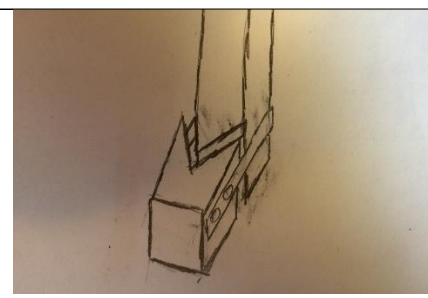


Figure A2-20: The Straps design.

“Electro-Magnet”

This concept uses a strong electro magnet to attach the frame to the tractor lift linkages. When the magnet it turned on it is strong enough to keep the attachment connected to the frame. This concept would allow for connection and adjustment without leaving the tractor cab. This concept was scrapped due to the high cost and electrical requirement.

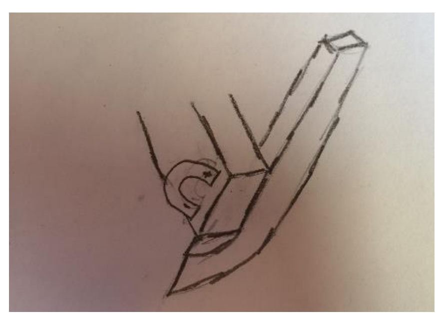
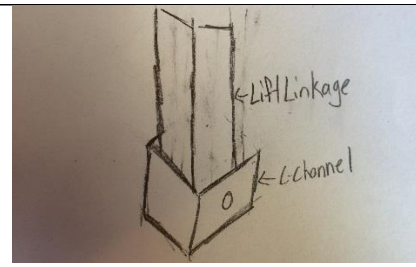
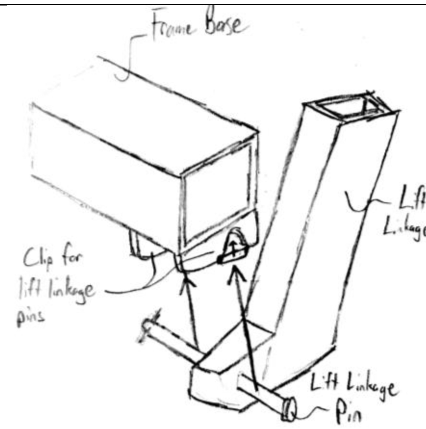
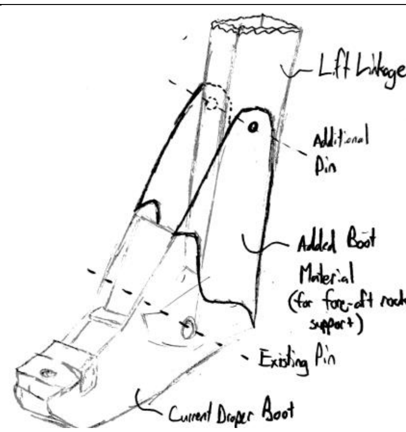


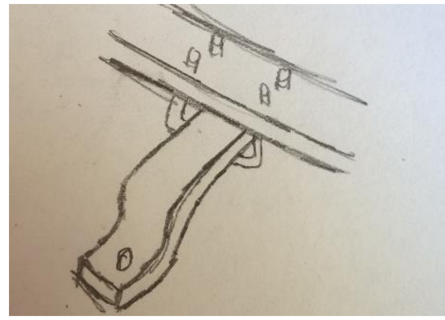
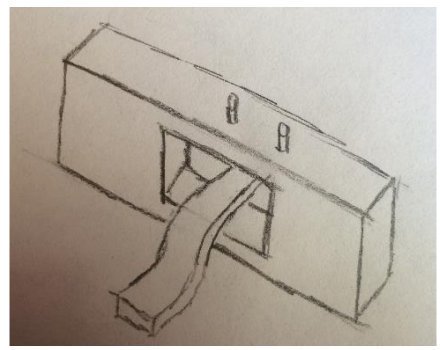
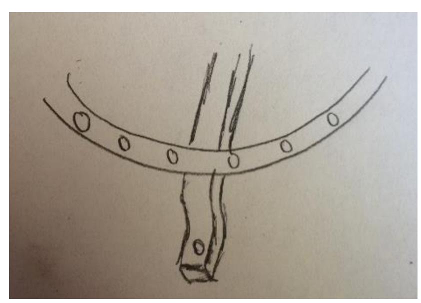
Figure A2-21: The Electro-Magnet design.

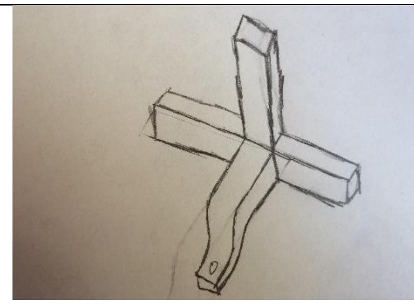
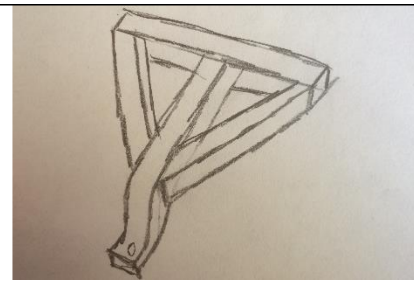
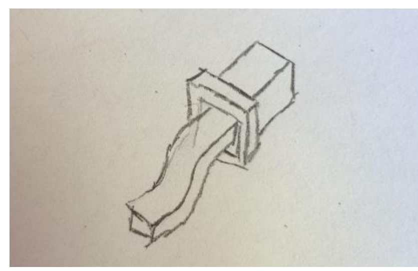
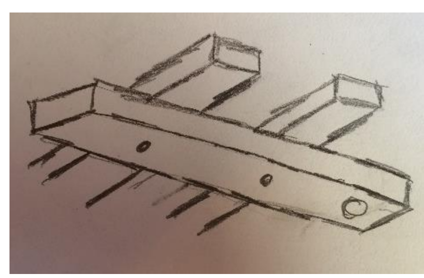
“C-Channel”	 Figure A2-22: The C-Channel design.
This concept uses a sheet metal c-channel welded to the attachment to connect to the lift linkages. One bolt hole must be drilled in each linkage to allow the bolt to be run through it. Once the lift linkages are in position, the bolts are simply slid through the c-channels and the linkages to mate the two.	
“Attachment Hooker”	 Figure A2-23: The Attachment Hooker design.
This concept is based on a pin being placed through each lift linkage that hooks into clips underneath the frame of the attachment. No modifications to the existing linkage are required, with the exception of long pins being added to the holes where the boot pins would go. The lift linkages would need to be lowered underneath the attachment and lifted up so that the pins clip in.	
“Real Tall Boot”	 Figure A2-24: The Real Tall Boot design.
For this concept, extra material is added to the side plates of the current draper boots. The extra material would extend and connect further up the lift linkages to provide fore-aft rocking support for the attachment, as opposed to connecting to the tilt cylinder. A new hole would have to be drilled through each lift linkage to pin or bolt down the additional boot material.	

1.3 Drawbar Connection Concepts

The following concepts for the superstructure and packaging subsection were generated individually and discussed as a group. They are shown in TABLE A2-III.

TABLE A2-III: A SUMMARY OF THE DRAWBAR CONNECTION CONCEPTS

“U-Bolts”	
In this concept, the drawbar is attached by two heavy duty u bolts running through the frame. This method allows the drawbar to be connected quickly and adjusted by multiple holes in the frame. The drawbar also requires a pin at the rear to handle the shear forces created when towing an implement.	 Figure A2-25: The U-Bolt design.
“Slotted Tube”	
In this concept, a slot is laser-cut into one of the frame tubes to create a slot for the drawbar. Two pins run through the member to limit the motion of the drawbar. The pins can also be moved to different holes to change the drawbar angle. The drawbar also requires a pin in the rear to resist the shear force from the implement pulling on the drawbar.	 Figure A2-26: The Slotted Tube design.
“U Shaped Plate”	
This concept is similar to hitches used in industry today. This method consists of a thick piece of steel plate laser-cut into a U shape with holes in it. The drawbar is cantilevered and pined to the frame with one pin at the back. The u shaped plate allows two pins to be installed to operate with the drawbar at many different positions.	 Figure A2-27: The U-Shaped Plate design.

“T Shape” In this concept, the drawbar is supported by being welded to a horizontal and a vertical steel tube. The steel tube is worked into the frame depending on which frame concept is chosen. This method relies heavily on weld strength. This method also minimizes the turning radius of the tractor.	 Figure A2-28: The T-shaped design.
“Triangulated” This concept allows the drawbar to be held by two welded steel tube members that triangulate out towards the drawbar connection. This provides significant lateral rigidity. This concept also minimizes the turning radius of the tractor.	 Figure A2-29: The Triangulated design.
“Receiver Hitch” In this concept, the drawbar is mounted to the frame similarly to a truck hitch. A steel hitch receiver is welded to the frame that fits the drawbar snuggly. A pin is then put through the steel member once the drawbar is in place to resist the shear forces of towing the implement.	 Figure A2-30: The Receiver Hitch design.
“2-Bolt” This concept is simplistic in nature. The drawbar is simply bolted to the frame using two heavy duty bolts. This requires two holes cut into the frame with weld nuts on the opposite side of the frame member.	 Figure A2-31: The 2-Bolt design.

“Under Plate”

This concept requires the drawbar attachment to be designed right into the frame. The frame must have a large area removed with a thick bottom plate. This plate steel on the bottom has holes in it to allow the angle of the drawbar to be adjusted. The drawbar protrudes through the frame and is pinned on the other side. This is to combat the cantilever and the shear forces from the implement.

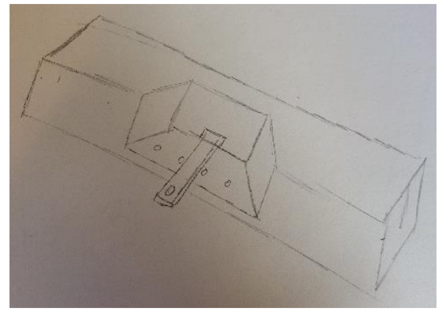


Figure A2-32: The Under Plate design.

“On Top of Frame”

In this concept, the drawbar is mounted on top of the frame. The back side of the drawbar is held down using a thick steel plate welded to the frame. The drawbar is also bolted to the frame to resist the pull from the implement. This concept only works if the frame is low enough that the drawbar is at an appropriate height.

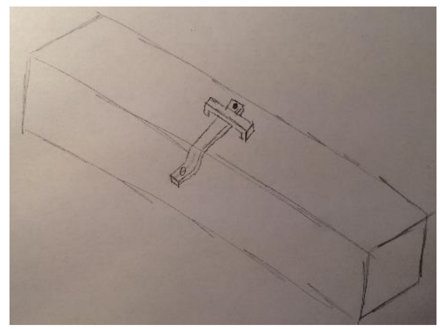


Figure A2-33: The On Top of Frame design.

“Mouth Tongue”

In this concept, the drawbar is mounted to the bottom of the frame. A thick steel plate is welded to the bottom of the frame to resist the hitch weight applied to the drawbar. The steel plate has several holes for pins to adjust the drawbar angle. The rear end of the drawbar is bolted into the frame to resist the pull from the implement.

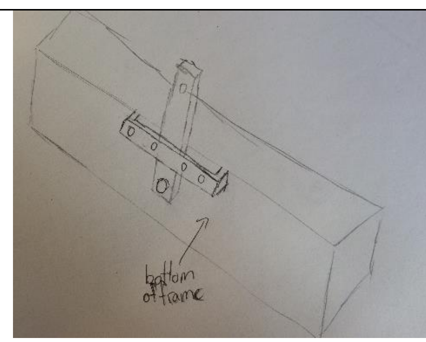


Figure A2-34: The Mouth Tongue design.

1.4 Attachment-Side Hydraulics Concepts

The concepts generated for each of these can be found in TABLE A2-IV, TABLE A2-V, and TABLE A2-VI, respectively.

TABLE A2-IV: MOTOR AND GEARBOX COMBINATION CONCEPTS

#	Concept Name	Description
1	75cc Rotary Motor/ No Gearbox	This concept uses the 75cc heavy duty hydraulic motor for the self-propelled rotary setup, MD#194563. The rotational speed of the motor is altered from the cab. The rotary disc block hydraulic setup is used.
2	Knife Drive Motor/ No Gearbox	This concept uses the D65 knife drive motor, MD#145392.The rotational speed of the motor is altered from the cab. The rotary disc block hydraulic setup is used.
3	Hydraulic Pump/ No Gearbox	This concept uses a hydraulic pump as a motor, MD#142944 or MD#142945. The first part number is for a 1000 RPM pump and the second is for 540 RPM pump. The rotary disc block hydraulic setup is used.
4	Rotary Pull Type Motor/ No Gearbox	This concept uses the hydraulic motor found on the rotary pull type, MD#194100 or MD#198610. The speed of the motor is altered from the cab. The rotary disc block hydraulic setup is used.
5	Dual Motor/ No Gearbox	This concept uses two individual hydraulic motors powered by two separate flows from the tractor. A clutch system would be designed that would allow both motors to power the same shaft. The speed of the motors is altered from cab.
6	75cc Rotary Motor/ Gearbox	This concept uses the 75cc heavy duty hydraulic motor for the self-propelled rotary setup, MD#194563. The speed of the motor is altered by using different gearing in the gearbox. The rotary disc block hydraulic setup is used.
7	Knife Drive Motor/ Gearbox	This concept uses the D65 knife drive motor, MD#145392. The speed is altered by using different gearing in the gearbox. The rotary disc block hydraulic setup is used.
8	Rotary Type Motor/Gearbox	This concept uses the hydraulic motor found on the rotary pull type, MD#194100 or MD#198610. The speed is altered by using different gearing in the gearbox. The rotary disc block hydraulic setup is used.
9	Dual Motor/ Gearbox	This concept uses two individual hydraulic motors powered by two separate flows from the tractor. A clutch system would be designed that would allow both the motors to power the same shaft. The speed is altered by using different gearing in the gearbox.
10	Two Different Motors	This concept uses one motor for 540 RPM and one for 1000 RPM. The motor would have to be outsourced.

TABLE A2-V: CONNECTION FROM TRACTOR HYDRAULICS TO ATTACHMENT CONCEPTS

#	Concept Name	Description
1	Individual Quick Couplers	This concept uses individual flat face quick couplers between the M Series and the hitch attachment.
2	Cam Lock Coupler	This concept uses the cam lock coupler found on the MacDon draper headers to connect auxiliary hydraulic lines from the tractor to the hitch attachment.
3	Thread Connection	This concept uses a threaded O-ring face seal (ORFS) connection between the tractor's hydraulic lines and the attachment hydraulic line and ports.

TABLE A2-VI: HYDRAULIC HOST MOUNTING TO ATTACHMENT CONCEPTS

#	Concept Name	Description
1	Hydraulic Block Thread Connection	For this concept, a new hydraulic block is created with threaded hose connections to allow for connection between the tractor and the attachment.
2	Auxiliary Sheet Metal Mount	This concept uses bulkhead fittings to attach female couplers for the aux. connections through a piece of sheet metal. The sheet metal can be reinforced if necessary.
3	Auxiliary Hydraulic Block	This concept uses a hydraulic block to mount the female couplers. The block is mounted to a cross beam.
4	Mounting Bracket	This concept uses mounting brackets designed to fit the female couplers to secure them to the attachment.

1.5 Tractor-Side Hydraulics Concepts

Some of the different methods our team came up with to accomplish this are contained within TABLE A2-VIII.

TABLE A2-VII: CONCEPTS FOR COMBINING HYDRAULIC FLOW FROM TWO PUMPS ON THE M SERIES

#	Concept Name	Description
1	Rotary Disk Block	This concept uses the MacDon rotary disc block add on which allows the tractor to combine the hydraulic flow from the first and second header hydraulic pump to run one motor.
2	Separate Flows	This concept takes separate flows from the knife drive, draper drive, and reel drive circuits off the tractor and combine the flows using a variety of "T" connections and check valves.
3	Custom Attachment Block	This concept takes separate flows from the knife drive, draper drive, and reel drive circuits off the tractor and combine the flows at a custom hydraulic block on the attachment.
4	Custom Tractor Block	For this concept, a hydraulic block is designed to combine the hydraulic flow from the knife drive and draper/reel drive hydraulic pumps on the M Series.

TABLE A2-VIII: CONCEPTS FOR ALLOWING THE M SERIES TO FUNCTION FULLY IN ENGINE-FORWARD

#	Concept Name	Description
1	Engine-Forward, Trick Hydraulics	For this concept our team would allow the cab position switch to send its normal signal to the WCM and create false signals from the WCM to trick the header hydraulics into working when in engine-forward orientation. We would also trick the traction drive range selector solenoids to allow the tractor to operate in low, medium, and high range.
2	Cab-Forward, Trick Traction Drive Range Selector	For this concept our team would send a false signal to the WCM telling it that the cab is in cab-forward orientation when it is actually in engine-forward. We would trick the traction drive range selector solenoids to allow the tractor to operate in low, medium, and high range.
3	Reprogram WCM and CDM	For this concept our team would create a new set program for the WCM and CDM that will allow the tractor to function fully in engine-forward when a selector switch is engaged.

2.0 Concept Screening

Brainstorming generated many concepts for each section of our design. Some of the concepts were much more feasible than others. Before weighting and comparing the concepts, some of the concepts that aren't realistic were ruled out for various reasons. Six concepts were ruled out in the frame, lift linkage, and attachment hydraulics sections. The reasons behind ruling each of these concepts out will now be discussed.

The majority of the frame concepts were feasible so they were ranked. The one exception was the Cable Tie concept. The cables that hold up the rectangular base connect to the tilt cylinder. The purpose of the tilt cylinder being incorporated into the attachment design is to resist the hitch from lifting while being towed or the whole attachment tilting down due to the hitch weight. The cables do not offer any compressive strength so the attachment can bounce upwards freely. This could potentially result in premature failure of some of the components due to excessive impact forces. For this reason, the Cable Tie concept was not investigated any further.

There were two lift linkage concepts that were dismissed before comparing them to other designs. The Weld On concept was ruled out due to the permanent nature of the concept. The lift linkage is supposed to be able to attach to draper and rotary headers without any permanent modification. By welding the frame on, this would no longer be possible. This would defeat the main purpose of the windrower tractor. The Electro-Magnet concept was also deemed unfeasible. The electro magnet would require a large constant source of electricity to maintain the connection. The tractor isn't designed to have such a large electrical demand. The electro magnet would also be too expensive to be worked into our $5000 budget.

The PTO and gear box concepts had three rejected concepts. The first concept rejected was the Hydraulic Pump/No Gearbox. The hydraulic pump can't actually run the PTO spindle without a hydraulic motor, so it wouldn't be able to meet the design needs. The second and third concepts to be rejected were the Dual Motor/No Gearbox and the Dual Motor/Gearbox. These concepts had two separate hydraulic motors running on separate hydraulic flows from the tractor and being combined using a clutch system to power one shaft. Both of these concepts were scrapped due to the complication of designing a clutch system. Such a system would also need to be tested and proven to be proficient and reliable. The rest of the hydraulic concepts were feasible, therefore they were all included in the weighted comparisons.

3.0 Concept Analysis and Selection

Weighted matrices and customer consultations were used to select the best concept from each subsection. The criteria for the weighted matrices were derived from the needs and specifications that were previously established for the attachment design. Each matrix uses a different combination of criteria, as each sub-section required different needs and specifications. The sub-sections of the attachment design that required concept selection were superstructure and packaging, lift linkage connection, drawbar connection, attachment-side hydraulics, and tractor-side hydraulics.

The superstructure and packaging section covers the main frame geometry of the attachment. The packaging component refers to the superstructure's ability to package other components, such as the PTO, auxiliary hydraulics, drawbar, wiring, and hoses. The connection of the attachment to the lift linkages is one concept that needs to be chosen. The drawbar connection to the frame of the attachment is another concept. It does not cover the geometry of the drawbar itself, as drawbar geometry is governed by standards. The attachment-side hydraulics includes the PTO motor and gearbox selection, hydraulic connections between the attachment and the M Series tractor, and the auxiliary coupler mounting. The tractor-side hydraulics and electrical section covers the allocation of hydraulic flow from the M Series, and how to bypass the M Series' safeties that are in place to prevent the tractor from running hydraulics in engine-forward orientation.

3.1 Superstructure and Packaging Concept Selection

A weighted concept selection matrix was used to select the Chariot concept for the main frame geometry design for the superstructure. The three highest weighted criteria were determined through criteria comparison in TABLE A2-IX were adheres to standards (PTO and drawbar standards), cost, and manufacturability. They had weights of 13.3%, 12.4%, and 11.4% respectively. The lowest ranked criterion was aesthetics at 0.0%.

The concept screening matrix in TABLE A2-IX used the Speed Boat concept as a reference and eliminated the L-Shape, Slide, Box Base, Scared Cobra, and Pylon designs. However, elements of the Box Base design, such as the rectangular base were included within the Chariot concept.

The Chariot design received the highest score of 4.15 through the concept scoring matrix in TABLE A2-XI. The second highest scoring concept was the Speed Boat, but it should be noted that the remaining concepts had close scores.

TABLE A2-IX: SUPERSTRUCTURE AND PACKAGING, CRITERIA COMPARISON

		Statically Self-Supported	Rigidity	Aesthetics	Center of Gravity	Adheres to Standards	Tilt Cylinder Inclusion	Serviceability	Safer Cab View	Manufacturability	Adaptive Design	Cost	Light Weight	Minimize Turning Radius	Durability	Strength
Criteria		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**
A	Statically Self-Supported		B	A	D	E	F	A	A	I	J	K	A	M	N	O
B	Rigidity			B	D	E	B	B	B	I	B	K	B	B	N	O
C	Aesthetics				D	E	F	G	H	I	J	K	L	M	N	O
D	Center of Gravity					E	D	D	D	I	D	K	D	D	N	O
E	Adheres Standards						E	E	E	E	E	E	E	E	E	E
F	Tilt Cylinder Inclusion							F	H	I	J	K	F	M	N	O
G	Serviceability								G	I	J	K	G	M	N	O
H	Safer Cab View									I	J	K	H	M	N	O
I	Manufactur-ability										I	K	I	I	I	I
J	Adaptive Design											K	J	J	N	O
K	Cost												K	K	K	K
L	Light Weight													M	N	O
M	Minimize Turning Radius														N	O
N	Durability															O
O	Strength															
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**
	Total Hits	4	8	0	9	14	4	3	3	12	7	13	1	6	10	11
	Weightings (%)	3.8	7.6	0.0	8.6	13.3	3.8	2.9	2.9	11.4	6.7	12.4	1.0	5.7	9.5	10.5

TABLE A2-X: SUPERSTRUCTURE AND PACKAGING, CONCEPT SCREENING

		Concepts									
		1	2	3	4	5	6	7	8	9	10 (Ref.)
Criteria		Trellis Triangle	L-Shape	Chariot	The Slide	Box Base	Attack Cobra	Scared Cobra	Chick Magnet	Pylon	Speed Boat
A	Statically Self-Supported	+	+	+	+	+	+	+	+	0	0
B	Rigidity	+	-	+	+	0	-	-	+	+	0
C	Aesthetics	+	0	+	-	-	+	-	+	-	0
D	Center of Gravity	-	0	0	-	0	-	+	+	+	0
E	Adheres Standards	+	+	+	+	+	+	+	+	+	0
F	Tilt Cylinder Inclusion	+	0	+	+	+	+	0	+	-	0
G	Serviceability	-	+	+	+	+	+	+	0	-	0
H	Safer Cab View	+	0	0	-	+	+	+	0	-	0
I	Manufacturability	-	0	-	-	-	-	-	-	-	0
J	Adaptive Design	-	0	+	-	0	0	0	-	-	0
K	Cost	-	-	-	-	-	-	-	-	-	0
L	Light Weight	-	-	-	-	-	-	-	-	-	0
M	Minimize Turning Radius	-	0	0	+	0	+	-	-	-	0
N	Durability	+	-	+	0	-	-	-	0	+	0
O	Strength	+	-	+	+	0	0	0	+	+	0
	Pluses	8	3	9	7	5	7	5	7	5	
	Same	0	7	3	1	5	2	3	3	1	
	Minuses	7	5	3	7	5	6	7	5	9	
	Net	1	-2	6	0	0	1	-2	2	-4	
	Continue?	YES	NO	YES	NO	NO	YES	NO	YES	NO	

TABLE A2-XI: SUPERSTRUCTURE AND PACKAGING, CONCEPT SCORING

	Criteria	Weight	Concept									
			Trellis Triangle		Chariot and Box Base		Attack Cobra		Chick Magnet		Speed Boat	
			Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
A	Statically Self-Supported	0.04	4	0.15	5	0.19	5	0.19	3	0.11	3	0.11
B	Rigidity	0.08	5	0.38	5	0.38	3	0.23	4	0.30	4	0.30
C	Aesthetics	0.00	4	0.00	5	0.00	4	0.00	5	0.00	3	0.00
D	Center of Gravity	0.09	3	0.26	4	0.34	2	0.17	5	0.43	3	0.26
E	Adheres Standards	0.13	3	0.40	4	0.53	5	0.67	4	0.53	3	0.40
F	Tilt Cylinder Inclusion	0.04	4	0.15	4	0.15	3	0.11	5	0.19	2	0.08
G	Service-ability	0.03	2	0.06	4	0.11	5	0.14	3	0.09	3	0.09
H	Safer Cab View	0.03	5	0.14	3	0.09	4	0.11	3	0.09	3	0.09
I	Manufac-turability	0.11	4	0.46	4	0.46	4	0.46	3	0.34	5	0.57
J	Adaptive Design	0.07	2	0.13	5	0.33	4	0.27	3	0.20	4	0.27
K	Cost	0.12	4	0.50	3	0.37	3	0.37	3	0.37	5	0.62
L	Light Weight	0.01	3	0.03	2	0.02	3	0.03	4	0.04	4	0.04
M	Minimize Turning Radius	0.06	3	0.17	3	0.17	5	0.29	3	0.17	3	0.17
N	Durability	0.10	4	0.38	5	0.48	3	0.29	4	0.38	4	0.38
O	Strength	0.10	4	0.42	5	0.52	3	0.31	4	0.42	3	0.31
		Total Score	3.63		4.15		3.64		3.67		3.69	
		Continue?	No		Develop		No		No		No	

3.2 Lift Linkage Connection Concept Selection

A weighted concept selection matrix was used to select the Draper Boots concept for the lift linkage geometry. The top two criteria determined through criteria comparison in TABLE A2-XII were cost and setup time with scores of 16.7% and 15.2%, respectively. There was a tie for the third most important criterion between ease of connection and center of gravity with scores of 12.1%. The lowest ranked criterion was light weight at 0.0%.

The concept screening matrix in TABLE A2-XIII use the Real Tall Boot concept as a reference and eliminated the Cinder Block Stilts, Wedge, C-Channel and Attachment Hooker concepts. The eliminated concepts were far enough removed in design from the remaining concepts that any features they had did not apply as advantages to the remaining concepts.

The Draper Boots design received the highest score of 4.35 through the concept scoring matrix in TABLE A2-XIV and TABLE A2-XV. The second highest scoring concept was the Rotary Boot concept with a score of 4.26, which is close. The main difference between the rotary and draper boot concepts is that MacDon sells more draper headers, making draper boots more common.

TABLE A2-XII: LIFT LINKAGE CONNECTION, CRITERIA COMPARISON

	Criteria	A Manufacturability	B Cost	C Strength	D Ease of Connection	E Light Weight	F Frame Integration	G Rigidity	H Serviceability	I Center of Gravity	J Adaptive Design	K Setup Time	L Innovative
A	Manufacturability		B	A	D	A	A	A	A	A	J	K	A
B	Cost			B	B	B	B	B	B	B	B	B	B
C	Strength				D	C	C	C	C	I	C	K	C
D	Ease of Connection					D	D	D	D	I	J	D	D
E	Light Weight						F	G	H	I	J	K	L
F	Frame Integration							G	F	I	F	K	F
G	Rigidity								G	I	G	K	G
H	Serviceability									I	J	K	H
I	Center of Gravity										I	K	I
J	Adaptive Design											K	K
K	Setup Time												K
L	Innovative												
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
	Total Hits	7	11	6	8	0	4	5	2	8	4	10	1
	Weightings (%)	10.6	16.7	9.1	12.1	0.0	6.1	7.6	3.0	12.1	6.1	15.2	1.5

TABLE A2-XIII: LIFT LINKAGE CONNECTION, CONCEPT SCREENING

		Concepts										
		1	2	3	4	5	6	7	8	9	10	11 (Ref.)
Criteria		Cinder Block Stilts	Built-In Boots	Hooks	Wedge	Draper Boots	Rotary Boots	Dual Boot	Straps	C-Channel	Attachment Hooker	Real Tall Boot
A	Manufacturability	+	+	+	-	+	+	-	+	+	-	0
B	Cost	+	+	+	+	+	+	+	+	+	-	0
C	Strength	-	0	-	-	+	+	0	-	-	-	0
D	Ease of Connection	-	0	+	+	+	+	+	+	-	+	0
E	Light Weight	+	+	+	0	+	+	-	+	+	+	0
F	Frame Integration	+	+	+	-	+	+	0	+	+	0	0
G	Rigidity	-	0	-	-	+	+	0	-	-	-	0
H	Serviceability	+	+	+	+	+	+	+	+	+	+	0
I	Center of Gravity	-	+	0	0	+	+	+	-	-	-	0
J	Adaptive Design	+	+	+	-	+	+	0	+	+	0	0
K	Setup Time	-	0	+	+	+	+	+	-	-	+	0
L	Innovative	-	+	0	+	0	0	+	+	-	+	0
	Pluses	6	8	8	5	11	11	6	8	6	5	
	Same	0	4	2	2	1	1	4	0	0	2	
	Minuses	6	0	2	5	0	0	2	4	6	5	
	Net	0	8	6	0	11	11	4	4	0	0	
	Continue?	NO	YES	YES	NO	YES	YES	YES	YES	NO	NO	

TABLE A2-XIV: LIFT LINKAGE CONNECTION, WEIGHTED FINAL SCORES, PART 1 OF 2

Criteria		Weight	Concepts							
			Built-In Boots		Hooks		Draper Boots		Rotary Boots	
			Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
A	Manufacturability	0.11	4	0.42	5	0.53	4	0.42	4	0.42
B	Cost	0.17	4	0.67	4	0.67	4	0.67	4	0.67
C	Strength	0.09	4	0.36	3	0.27	5	0.45	5	0.45
D	Ease of Connection	0.12	2	0.24	3	0.36	4	0.48	4	0.48
E	Light Weight	0.00	3	0.00	4	0.00	4	0.00	4	0.00
F	Frame Integration	0.06	3	0.18	5	0.30	3	0.18	3	0.18
G	Rigidity	0.08	4	0.30	2	0.15	5	0.38	5	0.38
H	Serviceability	0.03	3	0.09	5	0.15	4	0.12	4	0.12
I	Center of Gravity	0.12	4	0.48	3	0.36	5	0.61	5	0.61
J	Adaptive Design	0.06	3	0.18	5	0.30	4	0.24	5	0.30
K	Setup Time	0.15	2	0.30	3	0.45	5	0.76	4	0.61
L	Innovative	0.02	3	0.05	2	0.03	2	0.03	2	0.03
Total Score			3.29		3.59		4.35		4.26	
Continue?			No		No		Develop		No	

TABLE A2-XV: LIFT LINKAGE CONNECTION, WEIGHTED FINAL SCORES, PART 2 OF 2

Criteria		Weight	Concepts					
			Dual Boot		Straps		Real Tall Boot	
			Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
A	Manufacturability	0.11	3	0.32	3	0.32	3	0.32
B	Cost	0.17	3	0.50	4	0.67	4	0.67
C	Strength	0.09	4	0.36	2	0.18	3	0.27
D	Ease of Connection	0.12	5	0.61	3	0.36	3	0.36
E	Light Weight	0.00	3	0.00	5	0.00	2	0.00
F	Frame Integration	0.06	2	0.12	3	0.18	4	0.24
G	Rigidity	0.08	4	0.30	3	0.23	3	0.23
H	Serviceability	0.03	3	0.09	3	0.09	2	0.06
I	Center of Gravity	0.12	4	0.48	3	0.36	3	0.36
J	Adaptive Design	0.06	2	0.12	4	0.24	3	0.18
K	Setup Time	0.15	5	0.76	3	0.45	3	0.45
L	Innovative	0.02	5	0.08	3	0.05	3	0.05
		Total Score	3.74		3.14		3.20	
		Continue?	No		No		No	

3.3 Drawbar Connection Concept Selection

A weighted concept selection matrix was used to select the Mouth Tongue concept for the drawbar connection geometry.

The top two criteria determined through criteria comparison in TABLE A2-XVI were adheres to standards and cost with scores of 18.2% and 16.4% respectively. There was a tie for the third most important criterion between manufacturability and strength with scores of 12.7%. The lowest ranked criterion was light weight at 0.0%.

The concept screening matrix in TABLE A2-XVII used the Slotted Tube concept as a reference and eliminated the T-Shape, Triangulated, and Under Plate concepts. The eliminated concepts were far enough removed in design from the remaining concepts that any features they had did not apply as advantages to the remaining concepts.

The Mouth Tongue concept received the highest score of 4.44 through the concept scoring matrix in TABLE A2-XIV and TABLE A2-XV. The second highest scoring concept was the Receiver Hitch concept with a score of 4.16. The Mouth Tongue concept won because it was scored as more serviceable and easier to design within standards.

TABLE A2-XVI: DRAWBAR CONNECTION, CRITERIA COMPARISON

		Manufacturability	Cost	Strength	Adjustability	Adheres to Standards	Light Weight	Frame Integration	Serviceability	Innovative	Adaptable Design	Durability
Criteria		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
A	Manufacturability		B	A	A	E	A	G	A	A	A	A
B	Cost			B	B	E	B	B	B	B	B	B
C	Strength				C	E	C	C	C	C	C	C
D	Adjustability					E	D	D	D	D	D	K
E	Adheres to Standards						E	E	E	E	E	E
F	Light Weight							G	H	I	J	K
G	Frame Integration								G	G	G	K
H	Serviceability									H	J	K
I	Innovative										J	K
J	Adaptable Design											K
K	Durability											
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
	Total Hits	7	9	7	5	10	0	5	2	1	3	6
	Weightings (%)	12.7	16.4	12.7	9.1	18.2	0.0	9.1	3.6	1.8	5.5	10.9

TABLE A2-XVII: DRAWBAR CONNECTION, CONCEPT SCREENING

		Concepts									
		1	2	3	4	5	6	7	8	9	10 (Ref.)
Criteria		U-Bolts	Mouth Tongue	U-Shaped Plate	T-Shape	Triangulated	Receiver Hitch	2-Bolt	Under Plate	On Top of Frame	Slotted Tube
A	Manufacturability	+	+	+	+	+	+	+	-	+	0
B	Cost	+	0	0	-	-	0	+	-	0	0
C	Strength	+	+	+	+	+	+	+	+	+	0
D	Adjustability	0	0	+	-	-	0	-	+	+	0
E	Adheres to Standards	+	+	+	-	-	0	+	0	-	0
F	Light Weight	0	+	+	-	-	+	+	-	+	0
G	Frame Integration	+	+	-	-	-	+	+	-	-	0
H	Serviceability	+	0	+	-	-	0	-	0	+	0
I	Innovative	-	-	-	-	-	-	-	0	-	0
J	Adaptable Design	+	+	+	-	-	+	+	-	0	0
K	Durability	-	+	0	0	-	+	0	+	+	0
	Pluses	7	7	7	2	2	6	7	3	6	
	Same	2	3	2	1	0	4	1	3	2	
	Minuses	2	1	2	8	9	1	3	5	3	
	Net	5	6	5	-6	-7	5	4	-2	3	
	Continue?	YES	YES	YES	NO	NO	YES	YES	NO	YES	

TABLE A2-XVIII: DRAWBAR CONNECTION, CONCEPT SCORING, PART 1 OF 2

Criteria		Weight	Concepts							
			U-Bolts		Mouth Tongue		U-Shaped Plate		Receiver Hitch	
			Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
A	Manufacturability	0.13	5	0.64	4	0.51	3	0.38	4	0.51
B	Cost	0.16	5	0.82	4	0.65	4	0.65	4	0.65
C	Strength	0.13	3	0.38	4	0.51	3	0.38	5	0.64
D	Adjustability	0.09	4	0.36	4	0.36	5	0.45	4	0.36
E	Adheres to Standards	0.18	4	0.73	5	0.91	5	0.91	3	0.55
F	Light Weight	0.00	5	0.00	4	0.00	4	0.00	4	0.00
G	Frame Integration	0.09	4	0.36	5	0.45	2	0.18	5	0.45
H	Serviceability	0.04	4	0.15	5	0.18	3	0.11	4	0.15
I	Innovative	0.02	2	0.04	2	0.04	4	0.07	2	0.04
J	Adaptable Design	0.05	4	0.22	5	0.27	4	0.22	5	0.27
K	Durability	0.11	3	0.33	5	0.55	4	0.44	5	0.55
		Total Score	4.02		4.44		3.80		4.16	
		Continue?	No		Develop		No		No	

TABLE A2-XIX: DRAWBAR CONNECTION, CONCEPT SCORING, PART 2 OF 2

Criteria		Weight	Concepts					
			2-Bolt		On Top of Frame		Slotted Tube	
			Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
A	Manufacturability	0.13	5	0.64	4	0.51	3	0.38
B	Cost	0.16	5	0.82	4	0.65	4	0.65
C	Strength	0.13	2	0.25	5	0.64	2	0.25
D	Adjustability	0.09	2	0.18	4	0.36	4	0.36
E	Adheres to Standards	0.18	4	0.73	1	0.18	3	0.55
F	Light Weight	0.00	5	0.00	4	0.00	3	0.00
G	Frame Integration	0.09	5	0.45	2	0.18	3	0.27
H	Serviceability	0.04	3	0.11	4	0.15	2	0.07
I	Innovative	0.02	1	0.02	4	0.07	5	0.09
J	Adaptable Design	0.05	4	0.22	2	0.11	3	0.16
K	Durability	0.11	2	0.22	5	0.55	3	0.33
		Total Score	3.64		3.40		3.13	
		Continue?	No		No		No	

3.4 Attachment-Side Hydraulics Concept Selection

Attachment-side hydraulics include the PTO motor and gearbox combination, hydraulic connections, and auxiliary hydraulic coupler mounting. The attachment-side hydraulics do not include any hydraulic components outside the geometric confines of the attachment.

3.4.1.1 PTO Motor and Gearbox

The 75cc Rotary Motor/Gearbox concept was selected for creating a working PTO spindle for the attachment. Through preliminary flow calculations, it was determined that the adjustability of the hydraulic power from the tractor to a hydraulic motor would not be within the proper range to adjust the speed of the PTO from 540 to 1000 RPM without the use of a gearbox. The gearbox that MacDon stocks in inventory best suited for this application was the gearbox they used for their pull-type rotary mowers. These same mowers also housed PTO motors that could also be adapted to our needs.

Jeff Leachman from MacDon was asked to provide us with specifications on the rotary mower's gearboxes and hydraulic motors. The specifications confirmed that the rotary mower's hitch gearbox and hydraulic motor were the correct components to use to create a PTO spindle for the attachment.

3.4.1.2 Hydraulic Connections

After discussions internally and a meeting with our MacDon representative, Jeff Leachman, our team decided to use a threaded ORFS hydraulic connection between the M Series and the hitch attachment. This is currently the connection type used between the hydraulic hose end and the flat faced quick couplers on the M Series. Several of the quick couplers and hydraulic lines from the tractor can change depending on what style of header was previously on the windrower. This would mean changing a majority of the quick couplers for each connection each time the hitch attachment is installed. Since the hitch attachment would not have to be removed regularly, it was decided that an ORFS connection was the best alternative and the alternative recommended by MacDon.

3.4.1.3 Auxiliary Coupler Mounting

A weighted concept selection matrix was used to select the Mounting Brackets concept for mounting the auxiliary hydraulic quick connect couplers.

The top two criteria determined through criteria comparison in TABLE A2-XX were environmentally friendly and cost with scores of 18.2% and 16.4%, respectively. There was a tie for the third most important criterion between customer ease of use and rigidity with scores of 12.7%. The lowest ranked criterion was aesthetics at 0.0%.

The concept screening matrix in TABLE A2-XX used the Sheet Metal Mount concept as a reference and eliminated the Auxiliary Block concept. This eliminated concept were far enough removed in design from the remaining concepts that any features they had did not apply as advantages to the remaining concepts.

The Mounting Bracket concept received the highest score of 4.29 through the concept scoring matrix in TABLE A2-XXII. The Mounting Bracket concept won over the Sheet Metal Mount because of higher scores under most criteria.

TABLE A2-XX: ATTACHMENT-SIDE HYDRAULICS, AUXILIARY COUPLER MOUNTING, CRITERIA COMPARISON

		Cost	Frame Integration	Customer Ease of Use	Rigidity	Aesthetics	Ease of Repair	Multiple Port Configuration	Tractor Hose Connection	Innovative	Environmentally Friendly	Adaptable Design
	Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
A	Cost		A	A	A	A	A	A	A	A	J	A
B	Frame Integration			C	D	B	B	B	B	B	J	K
C	Customer Ease of Use				C	C	C	C	H	C	C	C
D	Rigidity					D	D	D	D	D	J	D
E	Aesthetics						F	G	H	I	J	K
F	Ease of Repair							F	H	F	J	K
G	Multiple Port Configuration								H	G	J	K
H	Tractor Hose Connection									H	J	H
I	Innovative										J	K
J	Environmentally Friendly											J
K	Adaptable Design											
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
	Total Hits	9	5	8	7	0	3	2	6	1	9	5
	Weightings (%)	16.4	9.1	14.5	12.7	0.0	5.5	3.6	10.9	1.8	16.4	9.1

TABLE A2-XXI: ATTACHMENT-SIDE HYDRAULICS, AUXILIARY COUPLER MOUNTING, CONCEPT SCREENING

		Concepts		
		1	2	3 (Ref.)
Criteria		Auxiliary Block	Mounting Brackets	Sheet Metal Mount
A	Cost	-	0	0
B	Frame Integration	-	+	0
C	Customer Ease of Use	+	+	0
D	Rigidity	+	+	0
E	Aesthetics	+	+	0
F	Ease of Repair	-	+	0
G	Multiple Port Configuration	-	-	0
H	Tractor Hose Connection	+	+	0
I	Innovative	0	0	0
J	Environmentally Friendly	+	+	0
K	Adaptable Design	-	0	0
	Pluses	5	7	
	Same	1	3	
	Minuses	5	1	
	Net	0	6	
	Continue?	NO	YES	

TABLE A2-XXII: ATTACHMENT-SIDE HYDRAULICS, AUXILIARY COUPLER MOUNTING, CONCEPT SCORING

Criteria		Weight	Concepts			
			Mounting Bracket		Sheet Metal Mount	
			Rating	Weighted Score	Rating	Weighted Score
A	Manufacturability	0.16	4	0.65	5	0.82
B	Cost	0.09	5	0.45	4	0.36
C	Strength	0.13	5	0.64	3	0.38
D	Adjustability	0.13	4	0.51	3	0.38
E	Adheres to Standards	0.00	4	0.00	3	0.00
F	Light Weight	0.05	4	0.22	3	0.16
G	Frame Integration	0.04	4	0.15	5	0.18
H	Serviceability	0.11	4	0.44	2	0.22
I	Innovative	0.02	3	0.05	2	0.04
J	Adaptable Design	0.18	5	0.91	3	0.55
K	Durability	0.09	3	0.27	5	0.45
		Total Score	4.29		3.55	
		Continue?	Develop		No	

3.5 Tractor-Side Hydraulics and Electrical

Tractor-side hydraulics includes all hydraulic components that are outside the geometric confines of the attachment, as well as the electrical components involved with bypassing the safeties required to operate hydraulics in engine-forward. Excluded are the PTO motor and gearbox combination and auxiliary hydraulic coupler mounting.

3.5.1.1 Hydraulic Flow from Tractor

The Rotary Disk Block concept was selected to be used to allocate enough hydraulic flow from the tractor. This concept selection came from consulting with Jeff Leachman. Our team presented our four concepts of using the available Rotary Disk Block, Allocating Separate Flows, creating a Custom Block Attachment or creating a Custom Tractor Block.

Jeff Leachman advised that the simplest and most cost effective solution would be to use the rotary disk block that MacDon creates. He also told us that the rotary disk block can be assumed to be already installed on the tractor, so the cost of the block does not have to be considered in our design.

3.5.1.2 Tractor Electronics

The Cab-Forward, Trick Traction Drive Range Selector concept was selected to allow the tractor to function fully while in engine-forward position. This concept was selected over the Engine-Forward, Trick Hydraulics and Reprogram WCM and CDM concepts.

After presenting Jeff Leachman from MacDon with these three concepts for bypassing the hydraulic safeties, Jeff clarified two very important details. The first detail being that the steering was completely mechanical and did not rely on any electrical manipulation in order to flip the steering left-to-right when switching from engine-forward to cab-forward. The second important detail was that the functionality of the GSL, which controls whether the tractor is being driven forward or backward, also does not change between cab-forward and engine-forward orientation. The only features of the tractor that need to be manipulated are the traction drive speed range selector and the seat position switch. These could be easily manipulated with a few signal wires and some switches.

Reprogramming the WCM and CDM would likely have resulted in work lying outside the intended scope of the project and should really only be attempted by a qualified electrical or computer engineer. Since the intent of the design is a prototype attachment, reprogramming software would not have been a cost effective solution for testing the overall design of the mechanics and geometry of the attachment.

With these details, the obvious choice in concepts was the Cab-Forward, Trick Traction Drive Range Selector concept. Our consult with Jeff Leachman solidified this selection.

Appendix 3 – Additional Design Analysis

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1.0 Tractor Tipping Scenarios

Tipping scenarios of the M Series were evaluated using vehicle dynamics calculations [Gillespie reference]. The different scenarios examined were the maximum allowable acceleration on level ground and the maximum allowable incline angle with no acceleration. Each scenario was examined at different hitch weights. The maximum hitch weight corresponded to the loading scenario defined by the maximum force allowed on a fully extended category 2 drawbar [drawbar reference].

Figure A3-1 shows the free-body-diagram (FBD) used to develop the equations for the tipping scenarios, which are shown in Figure A3-2 and Figure A3-3.

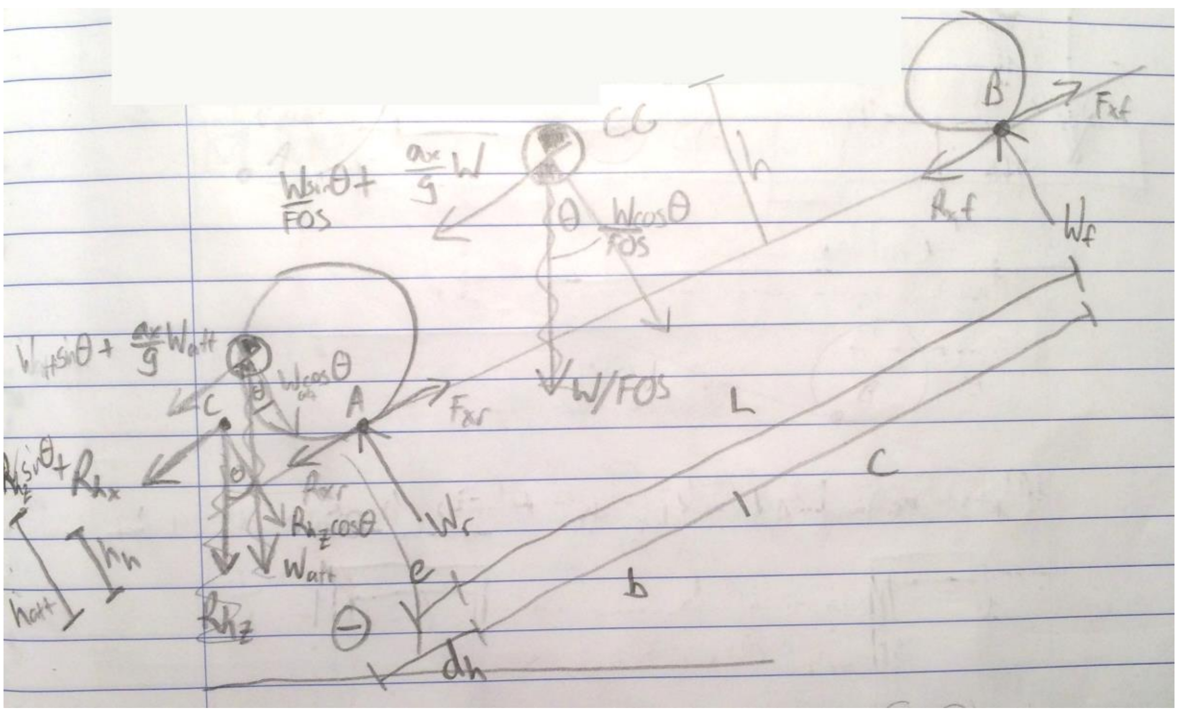

Figure A3-1: FBD of the M Series tractor with attachment on an uphill slope.

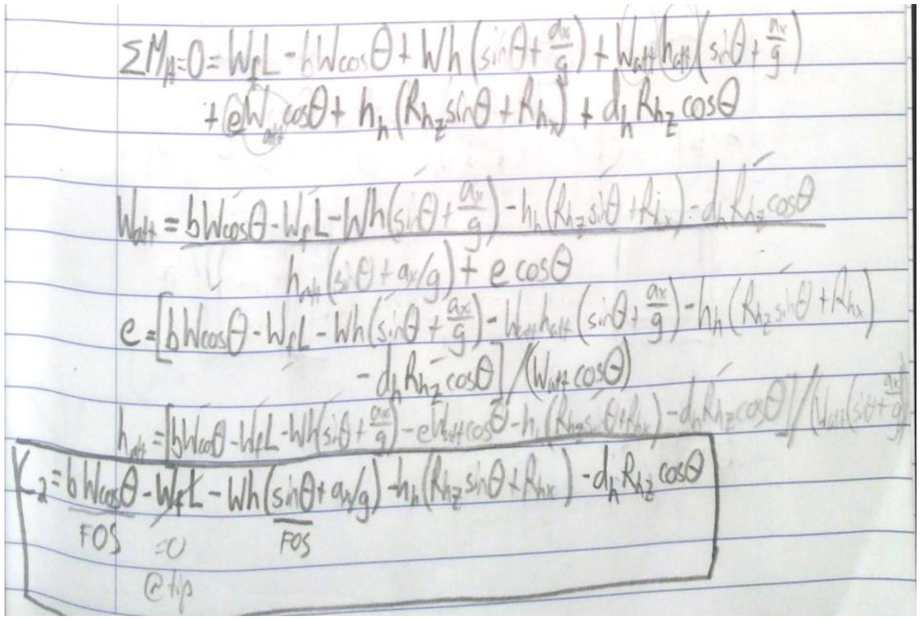

Figure A3-2: Equations derived from the FBD in Figure A3-1.

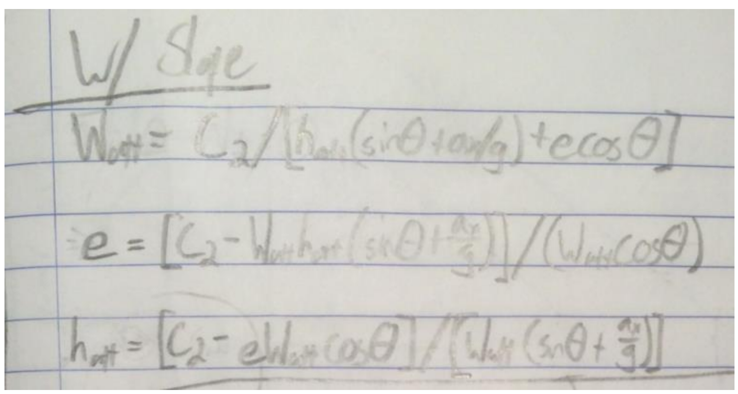

Figure A3-3: Equations for attachment CG weight, height, and distance from drive axle.

TABLE A3-I defines the variables used in the FBD and the equations. TABLE A3-II shows the maximum allowable acceleration before the tractor tips backward for varying hitch loads. TABLE A3-III is the same but it illustrates the maximum incline allowed instead of acceleration.

TABLE A3-I: DEFINITION OF VARIABLES

Description	Variable	Value	Units
Factor of Safety	FOS	1	-
Tractor Wheel Base	L	3.064	m
Distance from Tractor CG to Drive Axle	b	0.392821	m
Distance from Tractor CG to Caster Axle	c	2.671179	m
Height of Tractor CG	h	1.5	m
Height of Drawbar	h_h	0.481	m
Height of Attachment CG	h_{att}	0.668	m
Distance from Drive Axle to Attachment CG	e	0.952	m
Distance from Drive Axle to Hitch Load	d_h	1.694	m
Weight of Tractor	W	95647.5	N
Hitch Load	R_{hz}	8897.67	N
Draft Load	R_{hx}	2226.87	N
Acceleration of Gravity	g	9.81	m/s^2

TABLE A3-II: ALLOWABLE ACCELERATION TO PREVENT TIPPING

Hitch Weight			Acceleration [m/s^2]	Incline [deg.]
[N]	[kg]	[lb]		
11000	1121	2472	1.2	0
8898	907	2000	1.4	0
6671	680	1500	1.7	0
4450	454	1000	2.0	0
2225	227	500	2.2	0
0	0	0	2.5	0

TABLE A3-III: ALLOWABLE INCLINE ANGLE TO PREVENT TIPPING

Hitch Weight			Acceleration [m/s^2]	Incline [deg.]
[N]	[kg]	[lb]		
11000	1121	2472	0	6.72
8898	907	2000	0	8.12
6671	680	1500	0	9.61
4450	454	1000	0	11.10
2225	227	500	0	12.61
0	0	0	0	14.12

2.0 FEA Simulation Setup

Separate simulations were run for draft loads acting backward in line with the drawbar (Figure A3-4), and to the side at 90 degrees from the drawbar (Figure A3-5). The draft loading acting straight backward was applied to the rear-most face of the drawbar. The load acting at 90 degrees was applied to the side of the drawbar at the distance the drawbar pin would be. Since the draft load R_{hx} was only 500 lbf, the 90 degree application did not have much effect on the stresses of the frame. This report will focus on the draft load applied straight backward.

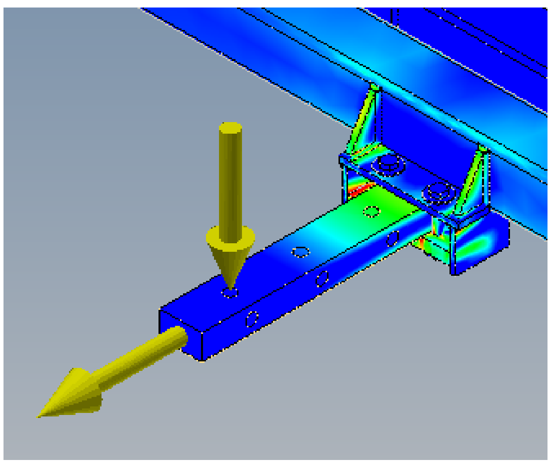

Figure A3-4: Application points of the vertical hitch load applied at the extended drawbar position, and the draft load aligned in the direction of the drawbar.

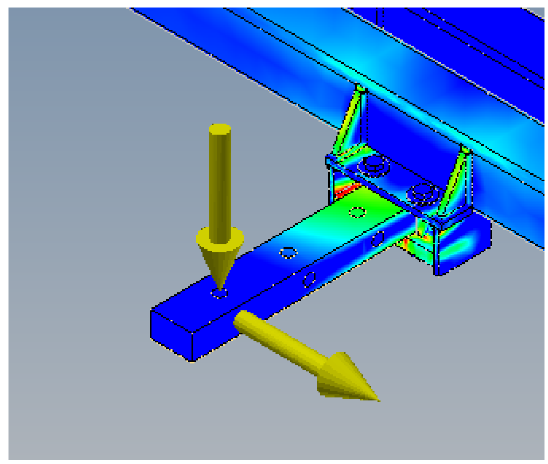

Figure A3-5: Application points of the vertical hitch load applied at the extended drawbar position, and the draft load aligned perpendicular to the drawbar.

There are three different distances at which the drawbar forces can be applied, according to the standards in Appendix 1. The maximum moment transferred to the drawbar mount depends on the distance from the drawbar pin-hole to the drawbar mount.

$$\boldsymbol{M_{max} = Force\ X\ Distance = F(T - x)}$$

Where:

F = hitch load on the drawbar, defined by standards [kN]

T = distance from PTO spindle tip to drawbar pin, defined by standards [mm]

x = distance from drawbar pin to drawbar mount, defined by design [mm]

Initially, it was assumed that the drawbar position applying the maximum moment to the drawbar mount would be extended drawbar position. This assumption was confirmed to be correct after the drawbar mount had been designed. The drawbar mount design resulted in a distance from the PTO spindle tip to the rearmost edge of the drawbar mount, x, of approximately 192 mm.

TABLE A3-IV: DRAWBAR MOUNT MOMENTS

Drawbar Position	Force [kN]	PTO to Pin Distance [mm]	Drawbar Mount to Pin Distance, x [mm]	Moment [Nm]
Short	22	250	192	1276
Regular	15	400	192	3120
Extended	11	550	192	3938

As TABLE A3-IV shows, the maximum moment applied to the drawbar mount is when the drawbar is in the extended position. This verifies the assumption made prior to the drawbar mount design.

A fixed constraint in the vertical and fore-aft directions was applied to the faces of the built-in boots shown in Figure A3-6. A fixed constraint in side-to-side movement was applied to the inner wall of one of the built-in boots, as seen in Figure A3-7. This constraint was applied to only one of the built-in boots so that the assembly would not be over constrained.

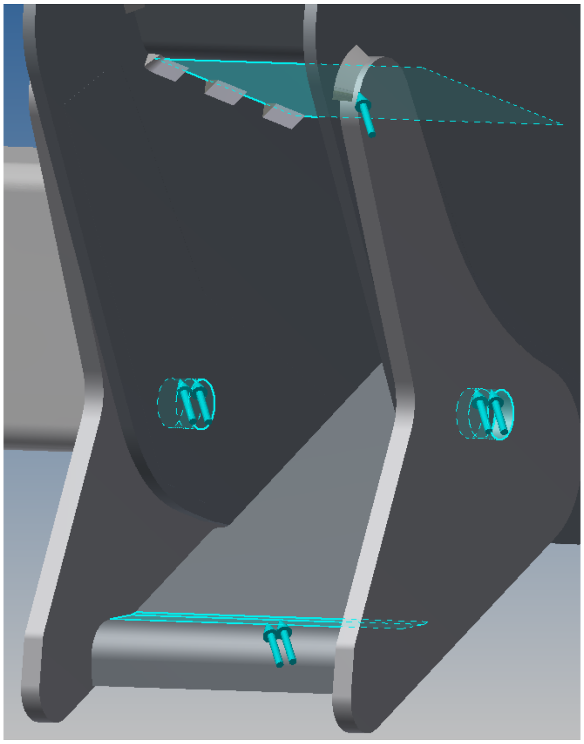

Figure A3-6: Constraint on inner faces of the built-in boots in the fore-aft and vertical directions.

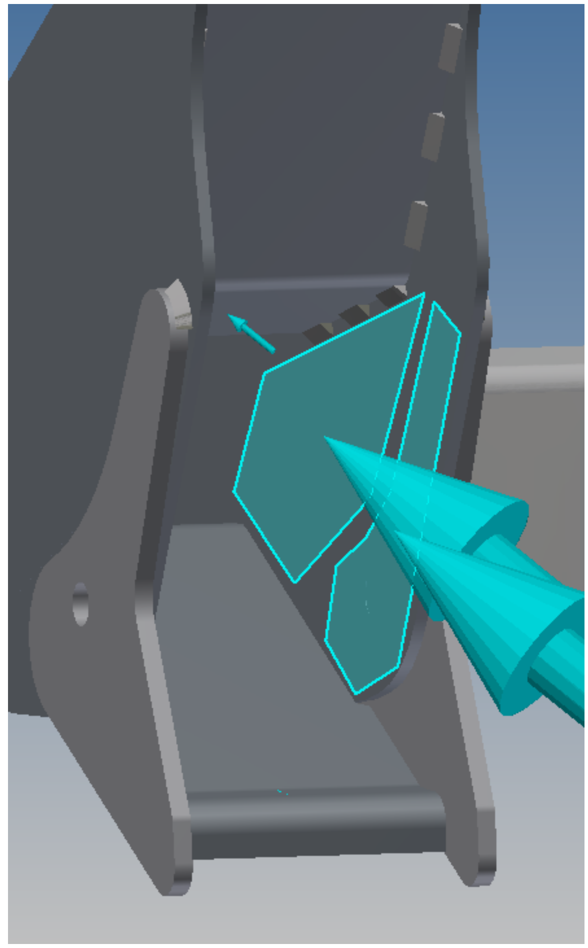

Figure A3-7: Constraint on the built-in boots in the side-to-side direction on the inner wall.

2.1 Convergence and Mesh

Autodesk Inventor has a convergence study feature that automates a mesh sensitivity analysis. This convergence study has five settings; maximum number of refinements, stop criteria, refinement threshold, what type of result to converge around, and what geometry to include in the mesh refinement.

The maximum number of refinements limits how many iterations of mesh refinement may be conducted. The stop criteria is a measure of what the user defines as convergent. If the maximum stress of the previous iteration is less than the percentage defined in the stop criteria of the latest iteration, the simulation ends. This means that the maximum number of refinements may not necessarily be run. The refinement threshold dictates how much the mesh is refined between iterations.

The convergence feature allows the focus of convergence to be on either Von Mises stress, first or third principal stress, or displacement. The included geometry can be set to include all assembly geometry, or to include or exclude specific geometry. Figure A3-8 displays the convergence settings used for the FEA simulations.

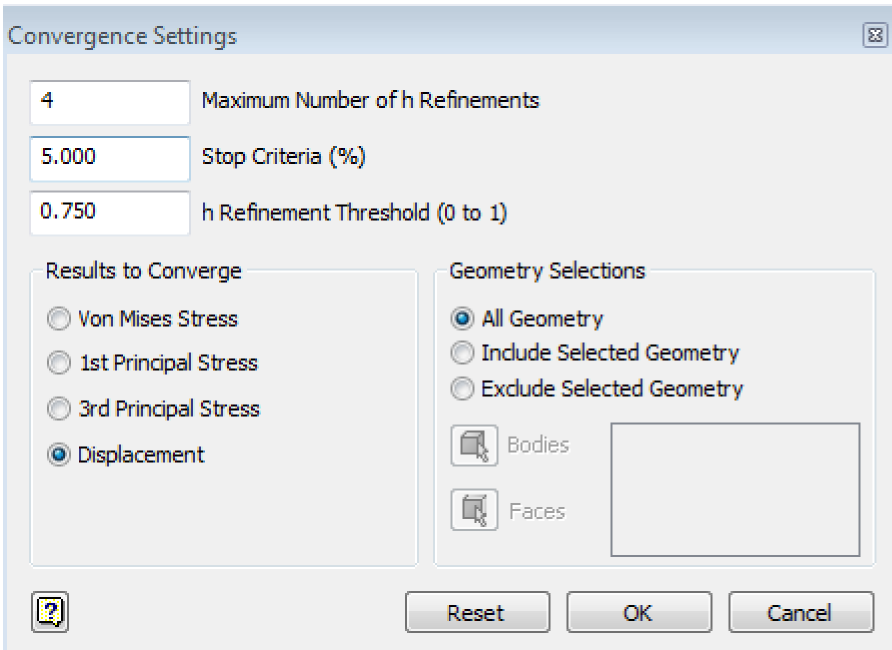

Figure A3-8: Convergence settings window in Autodesk Inventor.

The FEA simulation assembly is a weldment. The drawback of using weldments in an FEA is that the weld beads generated have sharp corners. These sharp corners create potential sources of singularities. Singularities in FEA are points at which the maximum stress does not converge as the mesh around the point becomes finer.

For this reason, convergence of the FEA results was set around displacement, not around Von Mises stress. The stress determined at a singularity can be neglected if the displacement of the material in the vicinity of a singularity converges and does not indicate failure. Figure A3-9 shows the displacement convergence plot of the full assembly FEA simulation.

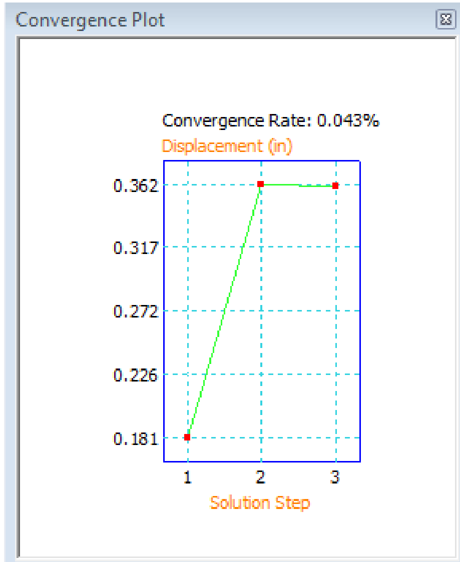

Figure A3-9: Convergence plot for the displacement convergence of the full assembly FEA.

The mesh settings used for all FEA simulations are summarized in Figure A3-10. Note that Autodesk inventor uses adaptive mesh refinement to optimize the mesh at each solution step or iteration.

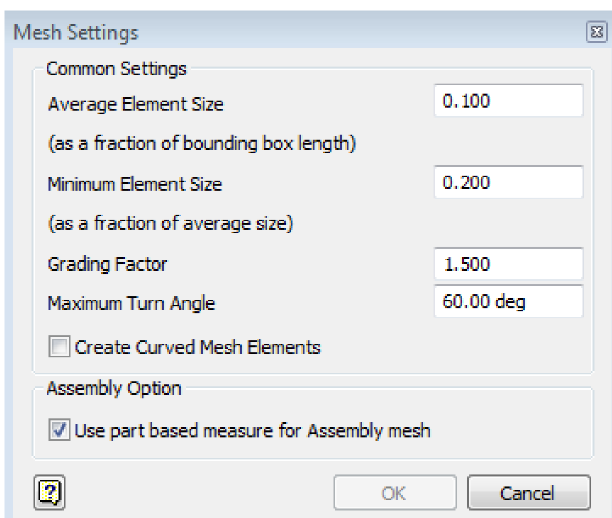

Figure A3-10: Preliminary mesh settings for FEA simulations.

3.0 Drawbar Mounting Bracket, Additional FEA Results

This section contains images of the FEA of the drawbar mounting bracket that were not critical in the understanding of the stress concentrations. They serve as additional views of the simulation.

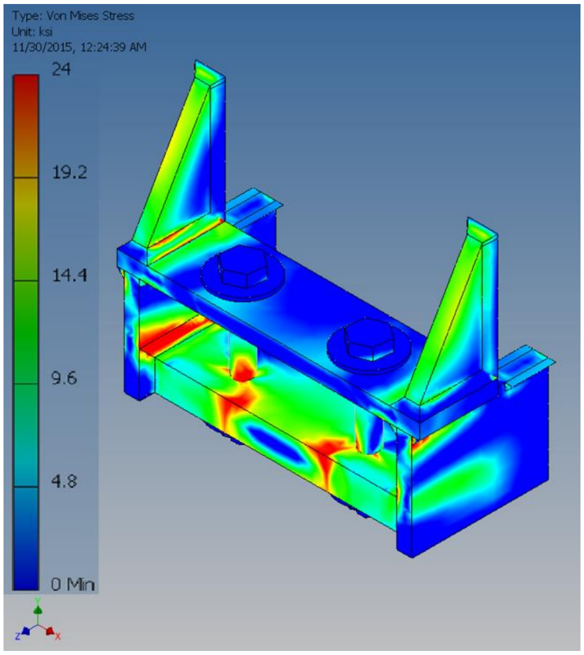

Figure A3-11: Top-rear-right view. Von Mises stress of drawbar mounting bracket.

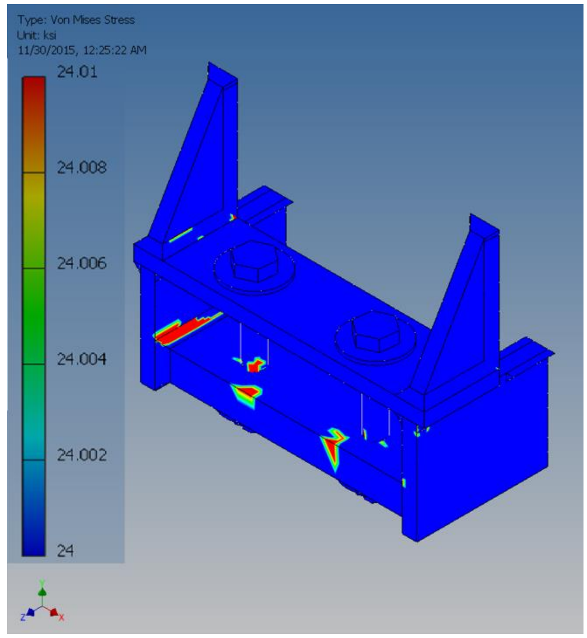

Figure A3-12: Top-rear-right view. Von Mises stress of drawbar mounting bracket, color bar shrunk to highlight stress concentrations.

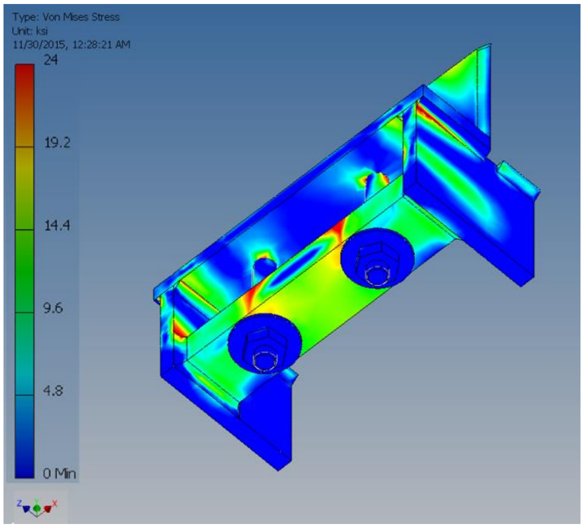

Figure A3-13: Bottom-rear-right view. Von Mises stress of drawbar mounting bracket.

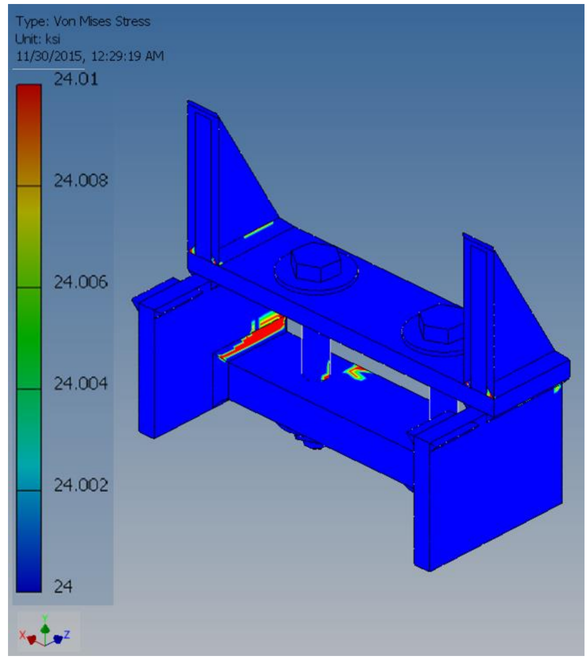

Figure A3-14: Top-front-left view. Von Mises stress of drawbar mounting bracket, color bar shrunk to highlight stress concentrations.

4.0 Frame FEA, Additional FEA Results

This section contains images of the FEA of the frame that were not critical in the understanding of the stress concentrations. They serve as additional views of the simulation.

Figure A3-15 shows the FEA of the entire frame. Figure A3-16 is the same view point as Figure A3-15, only zoomed in to highlight the stress concentrations resulting from the drawbar mounting bracket (not shown). Figure A3-17 shows the underside of the frame where the drawbar mounting bracket would be.

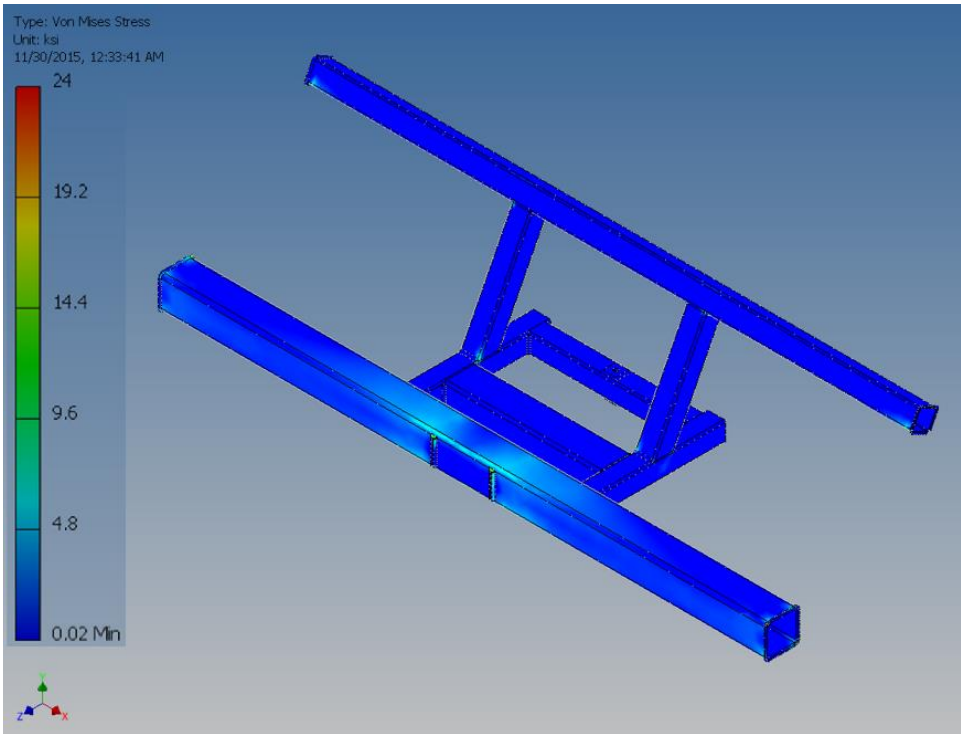

Figure A3-15: Top-rear-right view. Von Mises stress of attachment frame. Built-in boots and drawbar mounting bracket excluded.

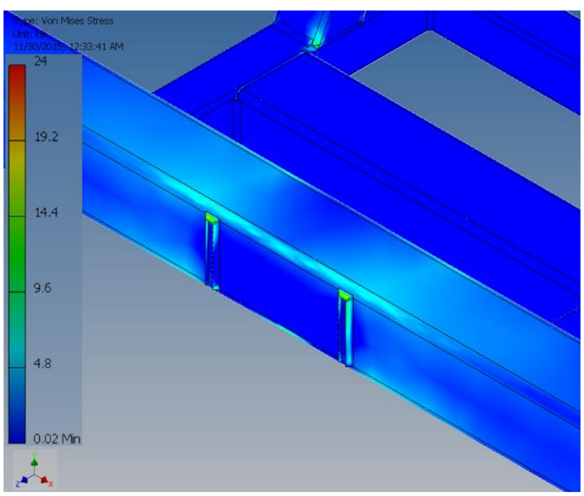

Figure A3-16: Top-rear-right view. Von Mises stress of attachment frame, zoomed in on location of drawbar mounting bracket.

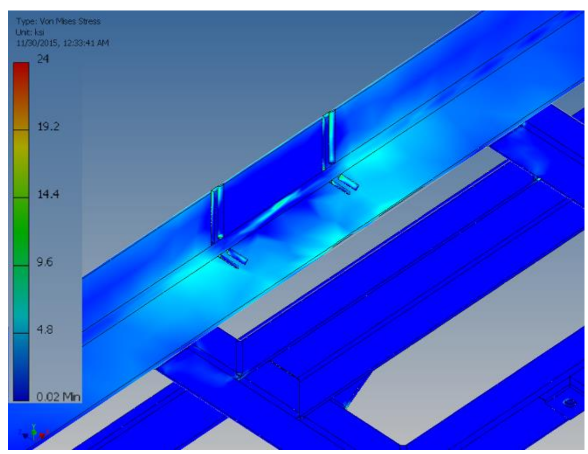

Figure A3-17: Bottom-rear-right view. Von Mises stress of attachment frame, zoomed in on location of drawbar mounting bracket.

Figure A3-18 and Figure A3-19 show the stress concentrations at the welds connecting the frame to the built-in boots. The stresses in these welds were less than the stresses at the center of the main beam seen in the previous figures.

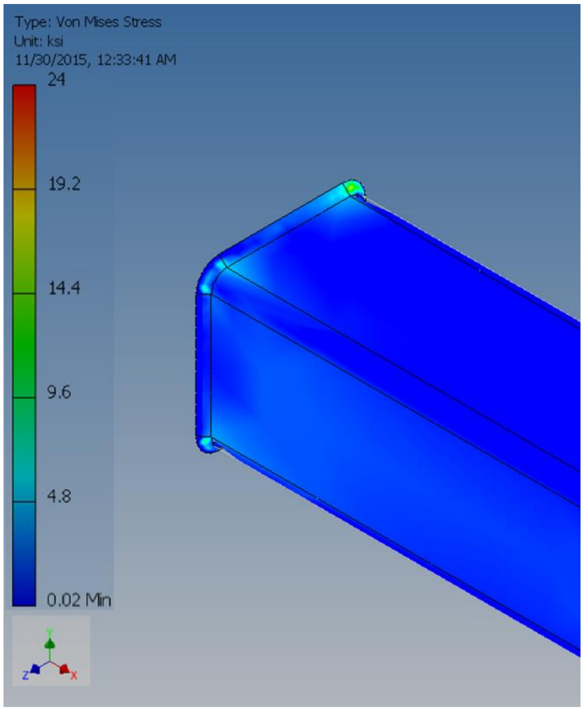

Figure A3-18: Top-rear-right view. Von Mises stress of attachment frame, zoomed in on the location of the attachment between frame member 2 and the built-in boot.

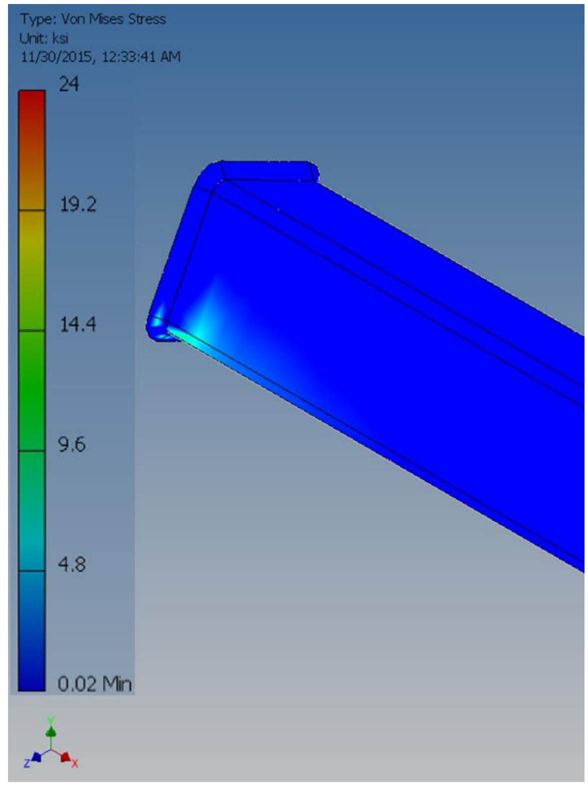

Figure A3-19: Top-rear-right view. Von Mises stress of attachment frame, zoomed in on the location of the attachment between frame member 3 and the built-in boot.

Figure A3-20 shows the location of the section view used for the screen captures of the frame FEA in Figure A3-21 through Figure A3-26. Figure A3-21 through Figure A3-24 show the stress concentrations on the inside of the main beam (frame member 2) around the location of the drawbar mounting bracket. Figure A3-25 and Figure A3-26 show the stress concentrations on the inside of frame member 3.

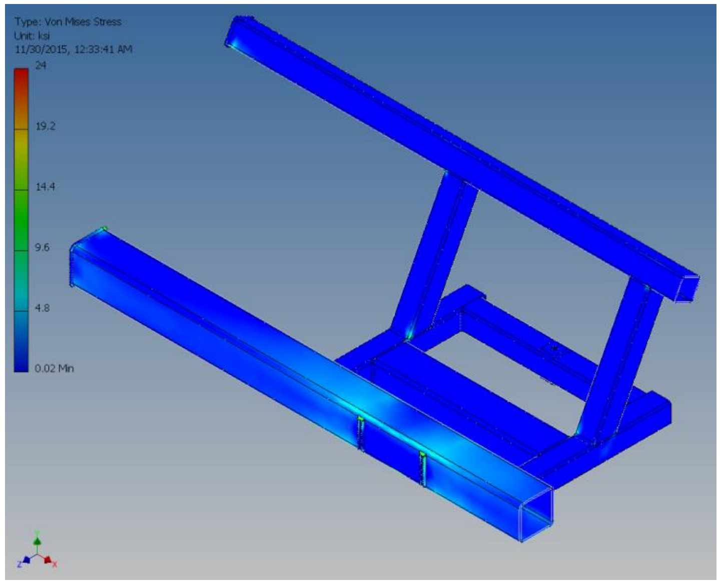

Figure A3-20: Section view used for Figure A3-21 through Figure A3-26.

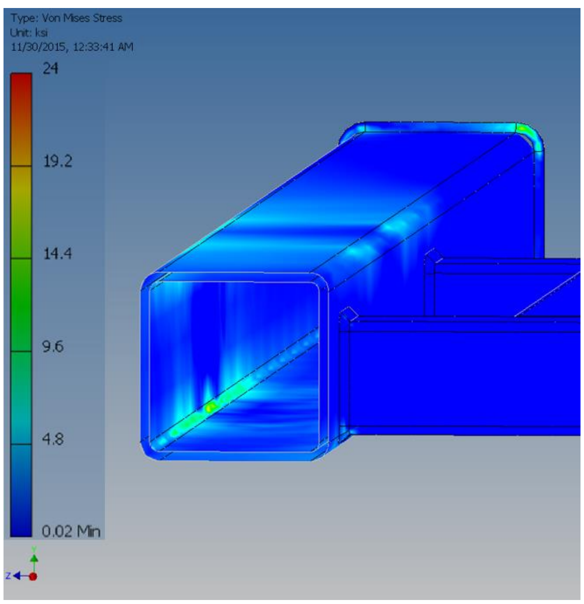

Figure A3-21: Von Mises stress concentration on the inside of the bottom-rear corner of frame member 2, beneath the drawbar mounting bracket.

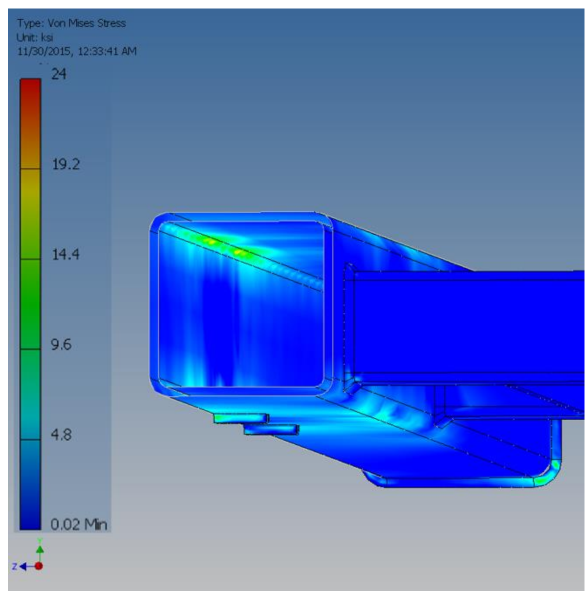

Figure A3-22: Von Mises stress concentration on the inside of the top-rear corner of frame member 2, beneath the drawbar mounting bracket.

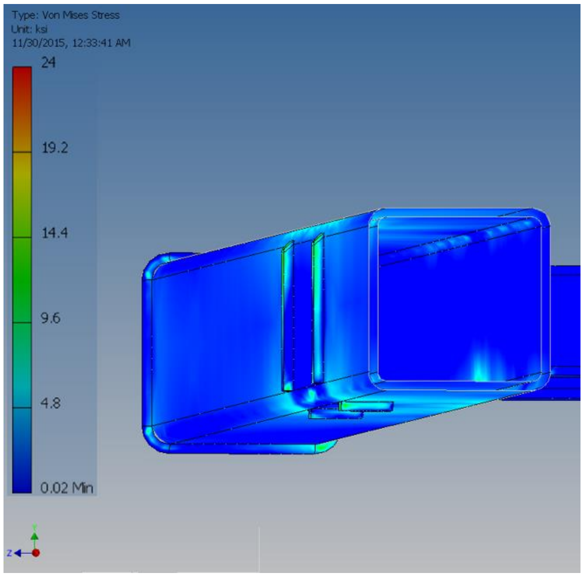

Figure A3-23: Von Mises stress concentration on the inside of the top-front corner of frame member 2, beneath the drawbar mounting bracket.

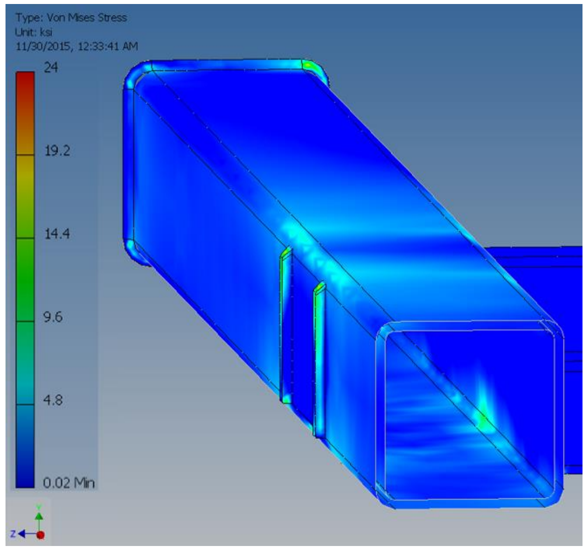

Figure A3-24: Von Mises stress concentration on the inside of the bottom-front corner of frame member 2, beneath the drawbar mounting bracket.

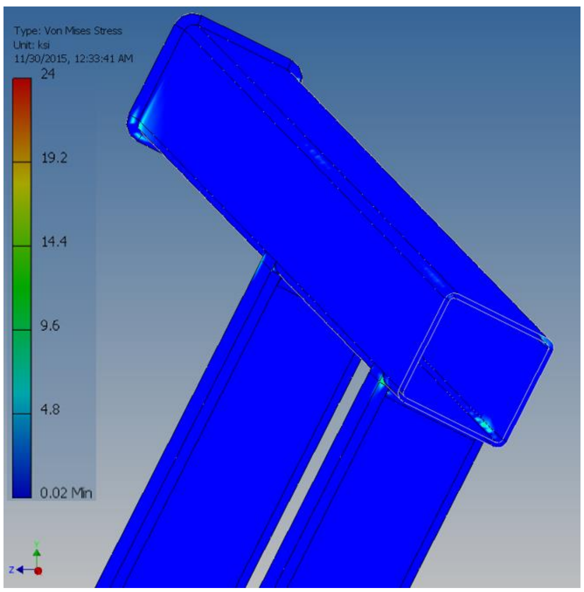

Figure A3-25: Von Mises stress concentration on the inside of the bottom-front corner of frame member 3 above member 6.

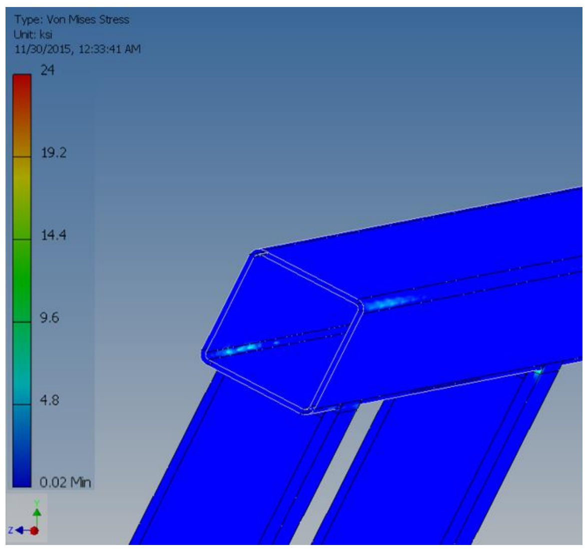

Figure A3-26: Von Mises stress concentration on the inside of the bottom-rear corner of frame member 3 above member 6.

5.0 Hose Calculations

To size the hoses for this design most of the hoses were selected based on the hose sizes of MacDon equipment with similar flow profiles. To check this sizing our team relied on industry standards that provide recommendations based on the application of the equipment being operated and the pressure and the volumetric flow rate of the fluid flows. The first step in determining the size of the hose to be used was to determine the flow rate and pressure available to run the PTO. The hydraulic line running to motor which powers the PTO shaft needs to have a hydraulic flow which can produce 100 HP. The following flow parameters were available to be used to deliver power to the PTO shaft.

- Pressure, p =4200 psi
- Volumetric flow rate, Q = 58 gpm

These hydraulic flow characteristics were determined based on the maximum flow output possible by combining the flow from two of the header hydraulic pumps. These flow characteristics should produce a hose power slightly above the required power of 100 HP, which is ideal considering that there will be losses encountered throughout the system. The direct power calculated from these flow parameters is given as follows using Eq. (5-1).

$$\boldsymbol{P = \frac{p \cdot Q}{1714}} \qquad \textbf{Eq. (5-1)}$$

$$P = \frac{4200\ psi \cdot 58\text{gpm}}{1714}$$

$$P = 142\ HP$$

The maximum possible power delivered to the PTO was calculated to be 142 HP. It should be noted that this power output at the PTO can only be achieved when the traction drive pumps are not drawing power from the engine. As the traction drive pumps begin to draw more and more power, there is less available to the header drive pumps which feed the PTO motor. This is due to the fact that both pumps are coupled to the same motor. To deliver the required flow rate, two hoses are used to feed a flow rate of about 29 gpm to 1 steel line connected to the motor. Two hoses are used to carry the flows separately up until the steel line before the motor to avoid a large amount of heat generation at a junction point early on down the line.

The hoses that are currently used on the rotary disc configured tractor are going to be implemented into the proposed design to carry a flow rate of 29 gpm each based on the MacDon technicians manual for this tractor. Therefore, to confirm that the size of these hoses is sufficient to deliver the required flow rate at the given pressure, flow capacity computations were performed based on industry standards.

Parker industries provides a technical manual to guide designers on how to determine a suitable hose size and corresponding hose fitting based on the flow capacities of different hydraulic applications (agricultural) and the equipment being operated [1]. Parker's technical hose manual, as well as other hydraulic industrial sources recommend the use of a hose size chart known as a nomogram which can be used to determine the hose I.D. (inner diameter) based on the flow rate. The nomogram is used, provided that the flow rate for the system is known. The next step is to draw a connecting line from the desired flow rate at the flow rate column across to the recommended flow velocity range at the velocity column. The point where this line crosses the inner diameter column is the selected inner hose diameter dimension. In the event that this connecting line intersects the hose inner diameter scale at a point between nominal inner diameter dimensions, standard conventions recommend using the closest higher inner diameter size. The nomogram used to determine hose size for given flow capacities is depicted in Figure 27.

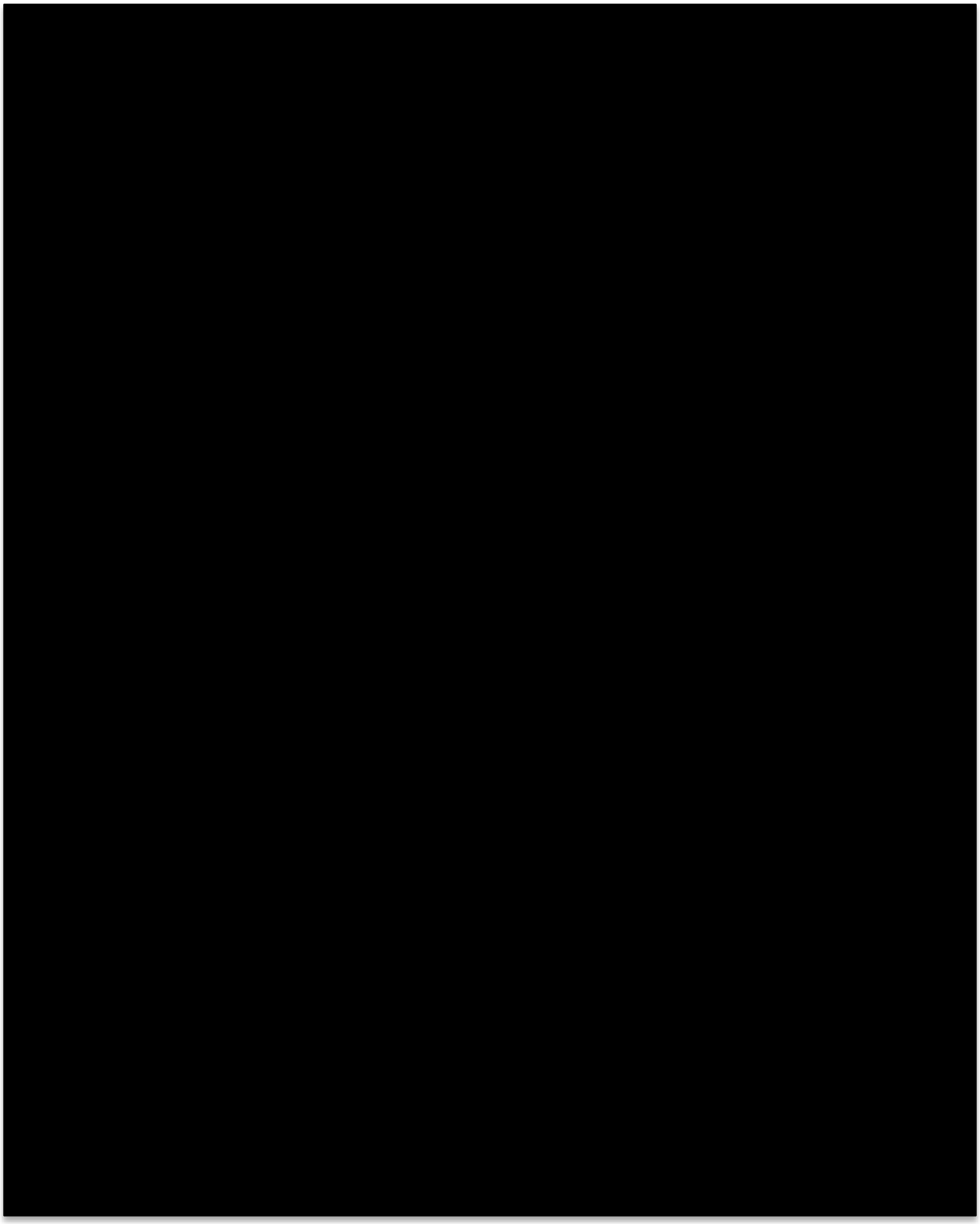

Figure 27: Nomogram used to determine hose size [1].

The hose size can also be determined through Eq. (5-2), from which the nomogram is also constructed.

$$D = \sqrt{\frac{Q \times 0.4081}{V}} \qquad \textbf{Eq. (5-2)}$$

Where:

- Q is the volumetric flow rate in gpm
- V is the flow velocity in ft/s
- D is the inner hose diameter in inches

As seen in Figure 27, and in industry standards, the nomenclature used to refer to hydraulic hose sizes is known as a “dash size”. From the nomogram, and in the flow velocity scale, we see that for a pressure line, a maximum flow velocity of 20 ft/s is recommended. Because we want to design a hydraulic hose to deliver this flow capacity to a device (the hydraulic motor), we select this as flow velocity of 20 ft/s as our flow parameter. Substituting in our design flow parameters into Eq. (5-2), we get the following result for the hose inner diameter for each of the two hoses connected to the one steel line:

$$D = \sqrt{\frac{29\ gpm \times 0.4081}{20\frac{ft}{s}}}$$

$$= 0.77\ in. = 19.5\ mm$$

If we compare this result to the diameter scale we see that this point lies between a value of 3/4” and 7/8”. Based on hose standard recommendations, we selected the next larger diameter size. In this case this will be 7/8” at a dash size 16. S similar process could be followed for the other hose sizes.

6.0 FMEA

For the FMEA conducted in the report, "M Series Attachment for Towing Farm Implements", a detail procedure was produced to aid the reader. Along with this procedure, the failure modes of the Design FMEA were elaborated upon to further explain the scenarios that may cause a design failure.

6.1 Procedure

To create the FMEA for a design, there are a number of consecutive steps that need to be followed. They are as follows:

1. List the components of a design. This is done by creating a process flowchart and determining all the design components. This also involves reviewing past documents and reports on a similar design and comparing the similar problems.
2. Create a list of potential failure modes. This is done by assembling the design team and brainstorming all the possible ways in which a system can go wrong.
3. List the effect of the potential failures. This involves identifying the various ways in which the customer or system is impacted when the process or component fails to meet its required functionality.
4. Rate how severe the effect is, with 1 being a low impact on the customer and 2 being detrimental or high impact. This ranking is based on a scale that is associated with the design such as the outcome on the user being able to operate the system or the potential harm on the user associated with the failure of the component.
5. Determine the cause of failure. This includes identifying the weakness in the design or the sources of error that bring about the potential failure.
6. Determine the controls in place to prevent or detect the failure mode. These controls are then ranked on a scale of 1 to 10 based on their effectiveness to detect the potential failure, with 1 meaning the current control is very likely to prevent failure and 10 meaning the controls cannot detect failure.

7. Determine the risk priority number (RPN) in order to assess the components or processes that require attention. This number identifies the risk associated with the design and where action needs to be taken. For example, if the results returned a score of 10 for severity (serious outcome), 10 for occurrence (frequent fails) and 10 for detection (no detection system) then the RPN number would be 1000. This means that the team needs to take a step back and review that component of the design.
8. Sort the RPN and identify the critical problems and decide which components the team should monitor or act on.
9. Define the action plan. These are suggested design improvements or considerations that would support the functionality of the component and mitigate the risk identified.
10. Calculate the new RPN with the revised actions. This process involves re-assessing the potential failure and evaluating the impact with the action plans in place.

The ranking that is used to assess the scale of the severity, occurrence and detection of the failure mode should be tailored to the purpose of the design [2]. The principal of six sigma, upon which the FMEA is built, provides a ranking system that can be used to rate the severity, occurrence and detection on a scale based on the effect on the customer. Some adaptations of six sigma also suggest that the design team customize a generic ranking scale to assess the scale on the failure modes, however, this is not an obligation. In addition, organization targeted ranking scales are suggested to be used by the design team in order to make the process of ranking simpler, however, once again this is not necessary [2]. Therefore, given these facts, the team based the ranking scale of the three FMEA evaluation criteria (severity, occurrence and detection) on a scale taken from Ford Motor Company [3] that seemed adaptable to the needs of the design. This association uses the following severity, occurrence and detection ranking scales.

TABLE A3-V: SEVERITY RATING SCALE [4]

Rating	Description	Definition (Severity of Effect)
10	Dangerously high	Failure could injure the customer or an employee.
9	Extremely high	Failure would create noncompliance with federal regulations.
8	Very high	Failure renders the unit inoperable or unfit for use.
7	High	Failure causes a high degree of customer dissatisfaction.
6	Moderate	Failure results in a subsystem or partial malfunction of the product.
5	Low	Failure creates enough of a performance loss to cause the customer to complain.
4	Very Low	Failure can be overcome with modifications to the customer's process or product, but there is minor performance loss.
3	Minor	Failure would create a minor nuisance to the customer, but the customer can overcome it without performance loss.
2	Very Minor	Failure may not be readily apparent to the customer, but would have minor effects on the customer's process or product.
1	None	Failure would not be noticeable to the customer and would not affect the customer's process or product.

TABLE A3-VI: FREQUENCY RATING SCALE [5]

Probability of Failure	Ranking	Possible Failure Rates
Remote: Failure is unlikely. No failures ever associated with almost identical processes.	1	<1 in 20,000
Very Low: Process is in Statistical Control. Only isolated failures associated with almost identical processes.	2	1 in 20,000
Low: Process is in Statistical Control. Isolated failures associated with similar processes.	3	1 in 4,000
Moderate: Generally associated with processes similar to previous processes which have experienced occasional failures, but not in major proportions. Process is in Statistical Control.	4 5 6	1 in 1,000 1 in 400 1 in 80
High: Generally associated with processes similar to previous processes that have often failed. Process is not in Statistical Control.	7 8	1 in 40 1 in 20
Very High: Failure is almost inevitable.	9 10	1 in 8 1 in 2

TABLE A3-VII: DETECTION RATING SCALE [5]

Likelihood of Detection		Ranking
Very High	Current controls will almost certainly prevent the failure (process automatically prevents most failures)	1,2
High	Current controls have a good chance of detecting the failure.	3,4
Moderate	Current controls may detect the failure.	5,6
Low	Current controls have a poor chance of detecting the failure.	7,8
Very Low	Current controls probably will not detect the failure.	9
Absolute Certainty of Non-Detection	Current controls will not or cannot detect the failure.	10

What is regarded as a permissible RPN? The RPN that is considered acceptable relies on what the organization is willing to tolerate [4]. For the purpose of this FMEA, the RPN will be determined for all potential failures and then items will be prioritized based on how high the RPN number is.

Action recommendations are then given to mitigate the risks of potential failures with a high RPN score. Since the three criteria used to weight the impact of the potential failure are based on a scale of 1 to 10, the highest RPN number that can be obtained for a potential failure is 1000. The dynamics of the RPN that shall be used in the FMEA analysis for this design are such that a potential failure will be considered critical if the ratings of the severity, occurrence, and detection scale are configured the following way:

TABLE A3-VIII: DYNAMICS OF THE RPN [5]

Sev	**Occ**	**Det**	**Result**	**Actions**
1	1	1	Ideal Situation	Monitor
1	1	10	Assured Mastery	Monitor
10	1	1	Failure does not reach user	Monitor
10	1	10	Failure reaches user	Act

1	10	1	Frequent fails, detectable, costly	ACT
1	10	10	Frequent fails, reaches user	ACT!
10	10	1	Frequent fails with major impact	ACT!
10	10	10	Big Trouble!	ACT!

According to the guidelines of the six sigma concept, the ratings that are assigned to potential failure modes are based on the decisions made by the design team and what the team considers a severe impact, a frequent failure, and an effective detecting control. This was the approach used in this FMEA to assign the rankings for the potential failure modes under the three failure criteria (severity, occurrence, and detection).

6.2 Description of Failure Modes

The first FMEA that is analyzed below is the Design FMEA. To begin, the design components are broken down into three sections. These sections are: superstructure, hydraulics and electronics. As given in the table below, the components that fit into these sections are:

1. Superstructure: the frame (of the attachment device); the drawbar attachment, the lift linkage boots and the tilt cylinder
2. Hydraulics: Hydraulic hose, gearbox PTO spindle attachment, the hydraulic oil pressure supply, the auxiliary hydraulic block connection with the auxiliary valve block.
3. Electronics: Trick traction drive range selector circuit, trick seat position circuit.

To clearly describe the risk analysis that was performed on the design, the failure mode for each row in the table below will be explained to understand the effect of the failure mode. This is done only for the design FMEA in order to demonstrate how the FMEA is applied. The process FMEA is given in less detail and only explained by the data in the respective table, once the design FMEA has been understood.

6.2.1 Failure Mode One

The first potential failure mode is associated with the auxiliary quick couplers. The potential failure mode, "detachment of quick coupler from frame", indicates that a failure may occur with the auxiliary quick coupler mounting design, if they become loose or are pulled from their mounted position on the frame. The potential effect or consequence of this failure, as given in the potential effect column, would be that the auxiliary hoses could violently detach or disconnect from either the port housing or the implement. The potential cause of this failure mode is the mounting bracket failing due to fatigue from vibrations imparted on the frame of the attachment from either the hydraulic motor or the tractor. A similar design for a pioneer quick coupler mounting bracket already exists and functions flawlessly in the MacDon CA35 combine adapter. Therefore this failure mode is only stated as a mode monitor after assembly. The current controls column refers to the methods or objects in place in the design to prevent or detect failure. For this proposed design of the attachment device, the current control in place, is the bolts and pins connecting the bracket to the frame. Currently the mounting bracket for the pioneer quick couplers is bolted to one frame member that runs between the lift linkages. A recommend modification to increase the rigidity of this connections to the frame is to reinforce the brackets with a sheet steel backing.

6.2.2 Failure Mode Two

The second failure mode involved the hydraulic hoses. The potential failure mode is the drive hoses getting pulled from their connection point to the motor. The effect that this would have is the hoses would become detached and the oil from the hydraulic reservoir on the tractor would rapidly be drained. This spray could also be dangerous if it came into contact with an operator. The potential cause that would lead the hoses to become disconnected may be large debris which could pass under the tractor and get caught on the frame. The tractor has a high clearance between the ground and the bottom of its frame. This may lead an operator to miss an object that is too large to pass under the attachment. The current controls in the design that would prevent this is a pipe tube (c-channel) that acts as a guide for the hoses.

Because of the low RPN of this potential failure mode, the recommended plan of action is to monitor the hoses during testing and record and instances of debris being hung up on the attachment.

6.2.3 Failure Mode Three

In the third row, the risk associated with the drawbar component is examined. A potential failure mode associated with this is the drawbar failing or deforming due to an excessively large loading scenario. The potential effect of this would be tensile loads being placed on the hoses and the PTO connection. A potential cause of this is an inadequate number of bolted connections at the drawbar mounting point to the frame. Currently there is only one, but this connection has been analyzed using hand calculated stress analysis. The current controls used to secure the draw bar is the "drawbar hoop", composed of two half inch steel plates welded to the frame at one end and a one inch thick steel bar at the other end. One M16 bolt on either side of the drawbar are used to secure the drawbar from moving side to side. A recommended action that could mitigate the risk of this failure mode would be to install gussets on either side of the half inch plates to help relieve some of the stress in the welded connection.

6.2.4 Failure Mode Four

A second failure mode related to the drawbar is a scenario in which the drawbar alignment to the frame does not fully meet the drawbar standards. The implications (potential effect) of this would be that the center of gravity may be offset causing the tractor to flip in extreme situations. A potential cause of this may be the limited number of positions to place the drawbar on the frame available for use while meeting the drawbar standards for the required distance to the PTO, the tractor, and the ground. The current controls holding the drawbar to its fixed position on the frame are "the drawbar hoop" at the front beam and the 1 bolted connected to the back beam of the frame. A recommended action to detect or counteract this may be to incorporate a weight box at the front engine side of the tractor to prevent the tractor from tipping back.

6.2.5 Failure Mode Five

Failure mode five is associated with the lift linkage attachment and the built in boots. The lift linkage could fail due to inadequate support at the point where it is connected to the frame. The potential effect of this would be that the frame would remain stationary while the tractor tries to accelerate. This could potentially cause the tractor to tilt backwards in engine forward mode and eventually flip backwards due to the mechanical center link connection. A potential cause of the boots failing is that the current design may have limited sites on the frame to which the boots could be connected. The current controls in the proposed design involve holding the boots to the frame using clevis pins with hair pins as a secondary holding mechanism. To avoid this failure and its effects, a recommended course of action is to run a safety strap around the lift linkage to serve as a secondary connection to the lift linkage.

6.2.6 Failure Mode Six

Another failure mode associated with the boots is related to the potential difficultly in mounting them to the lift linkages. The current proposed design requires that the tractor be driven forward until the front of the lift linkage is as far inserted into the built in boots as possible. At that time, a pin is installed through the boot and the lift linkage, locking them together. A potential failure mode could result if the tractor is not properly aligned with the boots when the attachment is being connected and thus the pins would not freely slide into position. As a potential effect the frame would not be able to be mounted to the tractor. The cause of this could potentially be the limited view of the lift linkage from the cab. The current controls would be to advise an operator to center the tractor with the center link connection on the frame of the attachment. Additionally a funnel or wedge type guide could be installed at the boot to help and operator get the attachment aligned properly.

6.2.7 Failure Mode Seven

A seventh failure mode for the frame sections is related to the mechanical center link that hooks onto the top member of the frame from the tractor. This center link could potentially break due to compression forces from the frame of the attachment.

A potential effect this would have would be the frame relying solely on the boots for support and thus being allowed to rock back and forth on the lift linkage pins. A potential cause of this would be the design calling for too low of a grade of turnbuckle center link, or the center link not being able to support the fatigue loading from the implement. A recommenced action plan would be to perform weekly inspections to check for cracks or other physical damage. Additionally a safety chain used in tension, or an additional mechanical link between the tractor and the attachment could be utilized.

6.2.8 Failure Mode Eight

A potential issue when using a PTO drive shaft to power a rotary cutter is that the telescoping clearance of the PTO driveline may be too long to operate said rotary cutter [6]. The concept shown in Figure A3-28 was adapted to our design as a potential solution to a failure that could occur when towing any implement with a long drive line. The potential effect of this failure is that it would not be possible to operate such an implement on the proposed attachment. The cause for this failure would ultimately result from there not being enough adjustability in the drawbar length. Additional position were added to the drawbar as a method of control the number of such failures. Also, another course of action would be to modify the driveline length by cutting the tube guards and sliding profiles to the working clearance length as shown in Figure A3-28.

Figure A3-28: PTO driveline modification [6]

6.2.9 Failure Mode Nine

A component of the hydraulic power transfer system that had a potential failure mode associate with it was the gearbox PTO spindle. Because there are only six splines on the spindle coming out of the gearbox, there is a potential for them to shear off under high power output scenarios. The effect this would have would be the gearbox free spinning and not transferring rotational power to the implement. The cause of such a scenario would be from attempting to transfer too much power through the six splined PTO connection. Current controls involve using a 21 to 6 spline adapter rated for power transfer of up to 125 HP. To further mitigate this risk, the 6 splined shaft in the gearbox should be switch with a 21 splined shaft.

6.2.10 Failure Mode Ten

Failure mode number ten deals with the hydraulic flow from the first two header drive pumps. The failure mode involves the relief pressure not being set correctly on the second hydraulic pump. Setting this relief pressure is a critical step taken when installing a disc drive block. If the pressure is not set correctly, backpressure could find its way to the second pump and potential cause a failure or a drop in performance. This could ultimately interrupt the transfer of power from the PTO shaft to the implement. The current control in place that prevents this is the aforementioned relief valve pressure setting. Additionally the pressures from the M1 and M2 port should be monitored on occasion to ensure a proper relief valve setting is maintained.

6.2.11 Failure Mode Eleven

The last section of the design is the electronics. The modifications being made to this system include tricking the traction drive range selector solenoids. With this concept, the tractor is tricked into perceiving that it is operating in cab forward while it is fact in engine forward. This is done since hydraulic functionality is electronically limited in engine forward orientation. A potential failure that has been identified involves the situation in which the switch running directly to the WCM malfunctions. This could result in the wrong signal reaching the WCM and forcing engine forward mode to engage, thus locking the hydraulic functionality. The current harness uses that switch as the main method of controlling the signal to the WCM. A recommended plan of action would be to instead to use a relay switch that controlled whether the tractor is in engine forward or cab forward. More realistically, the WCM and CDM could be reprogramed to include a third orientation specifically for the hitch attachment.

7.0 Cost Analysis and Bill of Materials

A cost analysis was performed on the design based on the bill of materials required to produce the attachment. The complete bill of materials with cost details and supplier information is provided in TABLE IX.

TABLE IX: BILL OF MATERIALS

Part Number	QTY	Description	Purpose	Unit Cost	Total Cost
112869	1	JOINT ASSEMBLY	Mechanical Center Link	$77.85	$77.85
102265	2	PIN - CLEVIS	For center link connection to tractor and adapter	$3.42	$6.84
102264	2	PIN - LYNCH	For center link connection to tractor and adapter	$0.54	$1.08
184678	3	Bolt, M16x120 , grade 8.8	Main drawbar bolt	$1.54	$4.62
135476	3	Locknut, M16, coarse thread, grade 8.8	For main drawbar bolt	$0.20	$0.60
184717	6	Washer, M16, wide	For main drawbar bolt	$0.07	$0.42
13125	2	PIN - HAIR	For lift linkage connection to boots	$3.42	$6.84
135408	2	PIN - CLEVIS	For lift linkage connection to boots	$0.54	$1.08
13125	1	PIN - HAIR (for clevis pin below)	For kick stand pin	$0.11	$0.11
101007	1	PIN - CLEVIS	For kick stand	$0.91	$0.91
136529	4	Bolt, M12x16, coarse thread, grade 8.8	For gearbox mounting	$0.10	$0.40
184652	7	Bolt, M8x25, coarse thread, grade 8.8	For quick coupler mounting	$0.07	$0.49
184687	5	Nut, M8, coarse thread, grade 8.8	For quick coupler mounting and cylinder locks	$0.01	$0.05
30625	2	Bolt, M8x90,coarse thread, grade 8.8	For cylinder locks	$0.10	$0.20
500001	2	0.25" Steel sheet part ($33.26/sqft) - 2.57 sqft	Outer sheet for built in boots	$85.48	$170.96
500002	1	0.25" Steel sheet part ($33.26/sqft) - 1.60 sqft	Top sheet for built in boots	$53.22	$53.22
500003	1	0.25" Steel sheet part ($33.26/sqft) - 0.85 sqft	Back sheet for built in boots	$28.27	$28.27
500004	1	0.25" Steel sheet part ($33.26/sqft) - 1.00 sqft	Bottom sheet for built in boots	$33.26	$33.26

500008	1	0.25" Steel sheet part ($33.26/sqft) - 1.28 sqft	Gearbox mounting bracket	$42.57	$42.57
500009	2	0.25" Steel sheet part ($33.26/sqft) - 0.15 sqft	Tilt cylinder mounting bracket	$4.99	$9.98
500010	1	3"x3"x0.25" steel tube - 0.5ft ($4.5/ft)	Outer tube for the kickstand	$2.25	$2.25
500011	1	2.25"x2.25"x0.25" steel tube - 2ft	Inner tube for the kickstand	$46.73	$46.73
500012	1	0.25" Steel sheet part ($33.26/sqft) - 0.17 sqft	Bottom plate for the kickstand	$5.65	$5.65
500013	2	0.25" Steel sheet part ($33.26/sqft) - 0.31 sqft	Lift cylinder mechanical safety stop	$10.31	$20.62
500014	2	0.125" Steel sheet part ($13.69/sqft) - 1.61 sqft	Hydraulic hose routing channel	$22.04	$44.08
500015	2	0.125" Steel sheet part ($13.69/sqft) - 0.06 sqft	Pioneer quick coupler bracket - double	$0.82	$1.64
500016	1	0.125" Steel sheet part ($13.69/sqft) - 0.11 sqft	Pioneer quick coupler mount 1	$1.51	$1.51
500017	1	0.125" Steel sheet part ($13.69/sqft) - 0.04 sqft	Pioneer quick coupler bracket - single	$0.55	$0.55
500018	1	0.125" Steel sheet part ($13.69/sqft) - 0.02 sqft	Pioneer quick coupler mount 2	$0.27	$0.27
500019	2	0.5" Steel sheet part ($38.11/sqft) - 0.11 sqft	Drawbar triangle plate	$4.19	$8.38
500020	2	0.5" Steel sheet part ($38.11/sqft) - 0.22 sqft	Drawbar U bracket plate 1	$8.38	$16.77
500021	1	0.5" Steel sheet part ($38.11/sqft) - 0.18 sqft	Drawbar upper plate	$6.86	$6.86
500022	1	1" steel bar (2" wide, 8.5" long)	Drawbar bottom plate	$16.94	$16.94
500023	1	5"x5"x.25" steel tube - 8ft ($12.35/ft)	Main frame tube	$98.80	$98.80
500024	1	3"x3"x0.125" steel tube - 8ft ($4.5/ft)	Back frame tube	$36.00	$36.00
500025	2	3"x3"x0.125" steel tube - 2ft ($4.5/ft)	Frame bottom	$9.00	$18.00
500026	2	3"x3"x0.125" steel tube - 1.5ft ($4.5/ft)	Back frame vertical member	$6.75	$13.50
500027	2	3"x3"x0.125" steel tube - 2.25ft ($4.5/ft)	Frame diagonal member	$10.13	$20.25
500028	1	3"x3"x0.125" steel tube - 2ft ($4.5/ft)	Back frame bottom member	$9.00	$9.00
500029	2	3"x3"x0.125" steel tube - 1ft ($4.5/ft)	Tilt cylinder vertical member	$4.50	$9.00
500030	1	3"x3"x0.125" steel tube - 2.75ft ($4.5/ft)	Tilt cylinder horizontal member	$12.38	$12.38

500033	1	2" steel bar (3.5"wide, 48" long)	Drawbar	$181.86	$181.86
500005	5	HOSE - Line from pioneer couplers to valve blocks.			
X135803		End A fitting	Crimp on straight female 6-4 ORFS fittings	$2.25	$2.25
X135803		End B fitting	Crimp on straight female 6-4 ORFS fittings	$2.25	$2.25
136890		Hose (~19 feet)	-4 Parker hydraulic hose	$0.97	$92.15
500006	1	HOSE - Case drain hose from motor to valve block.			
X135822		End A fitting	Crimp on straight female ORFS 12-10	$5.82	$5.82
X135822		End B fitting	Crimp on straight female ORFS 12-10	$5.82	$5.82
136897		Hose (~20 feet)	-10 Parker hydraulic hose	$1.45	$29.00
500007	3	HOSE – Pressure and return lines from motor steel line to M1 and M2			
135769		End A fitting	Crimp on straight male ORFS 16-16	$11.55	$34.65
135825		End B fitting	Crimp on straight female ORFS 16-16	$8.24	$24.72
136888		Hose (~19 feet)	-16 Parker hydraulic hose	$2.45	$139.65
500031	1	LINE - HIGH PRESSURE	Steel line from motor to 2 high pressure lines.	$75.99	$75.99
500032	1	LINE - RETURN	Steel line from motor to return hose.	$16.26	$16.26
114143	5	PIONEER QUICK COUPLERS	Allow for the attachment of auxillary hydraulic circuits	$14.30	$71.50
184462	5	FITTING - HYDRAULIC	Connection between pioneer coupler and auxiliary ciruit hydraulic hose.	$2.89	$14.45
135778	5	FITTING - HYDRAULIC	-6 ORB male to -6 ORFS male straight fitting between valve blocks and auxiliary circuit hydraulic hose	$1.05	$5.25
112866	2	4 BOLT (1.00) SAE SPLIT FLANGE ASSEMBLY (CODE 61)	Connect hydraulic hoses to hydraulic motor using split flange	$7.63	$15.26
135787	1	ADAPTER - HYDRAULIC	-10 ORB male to -12 ORFS male straight fitting between valve block and case drain	$3.04	$3.04
135821	1	FITTING - HYDRAULIC	-12 ORB male to -12 ORFS male 90 degree fitting between motor and case drain	$5.89	$5.89
135734	1	ADAPTER - HYDRAULIC	-16 ORB male to -16 ORFS male 90 degree fitting between vavle block and motor return line	$10.27	$10.27

135791	2	ADAPTER - HYDRAULIC	-16 ORB male to -16 ORFS male Straight adapter from M1 and M2 ports to hydraulic lines	$5.63	$11.26
135560	1	FITTING FOR RELIEF VALVE	Fitting between motor and relief valve	$20.24	$20.24
120377	1	VALVE - RELIEF	Relief valve for hydraulic motor	$7.49	$7.49
150487	1	75CC HYDRAULIC MOTOR	To convert hydraulic pressure to rotational energy for the PTO shaft	$995.43	$995.43
150879	1	SEAL	Seal between motor and gearbox	$20.42	$20.42
0332-00004	1	PTO SHAFT ADAPTER	Convert 6 spline to 21 spline (Hub City - Motion Canada)	$296.47	$296.47
194039	1	GEARBOX	To reduce the speed from the motor (will need a 21 spline output shaft)	$912.39	$912.39
148799	4	BOLT – HH FLANGE M12 X 1.75 X 45 LG ZP	Bolts between motor and gearbox	$0.51	$2.04
139974	1	ASSY – VALVE BLOCK AUX LIFT	Auxiliary circuit hydraulic valve block	$210.38	$210.38
163156	1	FITTING – ZERO LEAK GOLD #06, 9/16-18 UN 2A	Plug for aux. valve block	$5.88	$5.88
163143	1	VALVE – SOLENOID (FOR 5/8 IN. VALVE STEM)	Solenoid for second double acting circuit (P72)	$80.55	$80.55
163191	1	NUT – SPECIAL	Solenoid nut (goes with 163143)	$5.88	$5.88
163160	1	SEAL KIT	Solenoid seal (goes with 163143)	$4.95	$4.95
163154	1	COIL – TOUGH	Solenoid coil (goes with 163143)	$30.57	$30.57
163184	2	O-RING	O ring for sealing block P and T ports	$5.75	$11.50
163155	1	COIL – TOUGH	Solenoid coil (goes with 163142)	$27.29	$27.29
163142	1	VALVE – SOLENOID	Solenoid for second double acting circuit (P73)	$38.04	$38.04
49846	1	SEAL KIT	Solenoid Seal (goes with 163142)	$4.06	$4.06
163190	1	NUT – SPECIAL	Solenoid Nut (goes with 163142)	$1.24	$1.24
10948	2	BOLT – HH 3/8 NC X 5.5 LG GR 5 ZP	Bolts used to attach aux. valve block	$0.42	$0.84
109574	2	SWITCH	Range selector switch and seat bypass switch	$5.45	$10.90
	60	WIRE	For wiring things; electron tubes (16 ga.)	$0.20	$12.00
134103	2	CONNECTOR - ELECTRICAL	For seat position bypass circuit (female)	$0.60	$1.20

134040	2	CONNECTOR - ELECTRICAL	For seat position bypass circuit (male)	$0.64	$1.29
134028	2	CONNECTOR - ELECTRICAL	For traction drive range selector bypass circuit (female)	$0.33	$0.67
134029	2	CONNECTOR - ELECTRICAL	For traction drive range selector bypass circuit (male)	$0.40	$0.80
				Total	$4,278.76

8.0 Bibliography

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[3] R. Linkages, "Ford FMEA Handbook," [Online]. Available: http://www.bzpc.ir/FileManager/%D8%AA%D8%B5%D8%A7%D9%88%DB%8C%D8%B1/Article/PDF/fmeahandbookv4111-1310447612699-phpapp01-110712001630-phpapp01.pdf.

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[9] "Agricultural tractors - Rear-mounted power take-off types 1, 2, 3, and 4," International Organization of Standardization, 2014. [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:500:-1:ed-2:v1:en. [Accessed 29 September 2015].

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[11] "ANSI/ASABE AD6489-3:2004 JUN2009".

[12] A. S. 2011, "ASABE/ISO 500-3:2004 (DEC2010)".

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Appendix 4 – Drawing Package

Table of Contents

1.0 Introduction

One of the requirements for MacDon was a set of working drawings. Drawings have been made for all of the components that are not currently produced by MacDon. Any current production MacDon parts used are referenced in the assembly drawings using the appropriate MacDon part number. DXF files for all sheet metal parts are also included in the package sent to MacDon.

2.0 Drawings

The following subsections contain all of the working drawings. They are arranged such that the assembly drawing is shown first and then the parts used in that assembly. All of the new parts were given arbitrary part numbers starting at P500001 and assembly numbers starting at A500001. These part numbers and format were chosen to avoid conflicting with existing MacDon part number.

PART NUMBER A500001

NOT TO SCALE - DO NOT SCALE DRAWING

Item Number	Part Number	Author	Quantity
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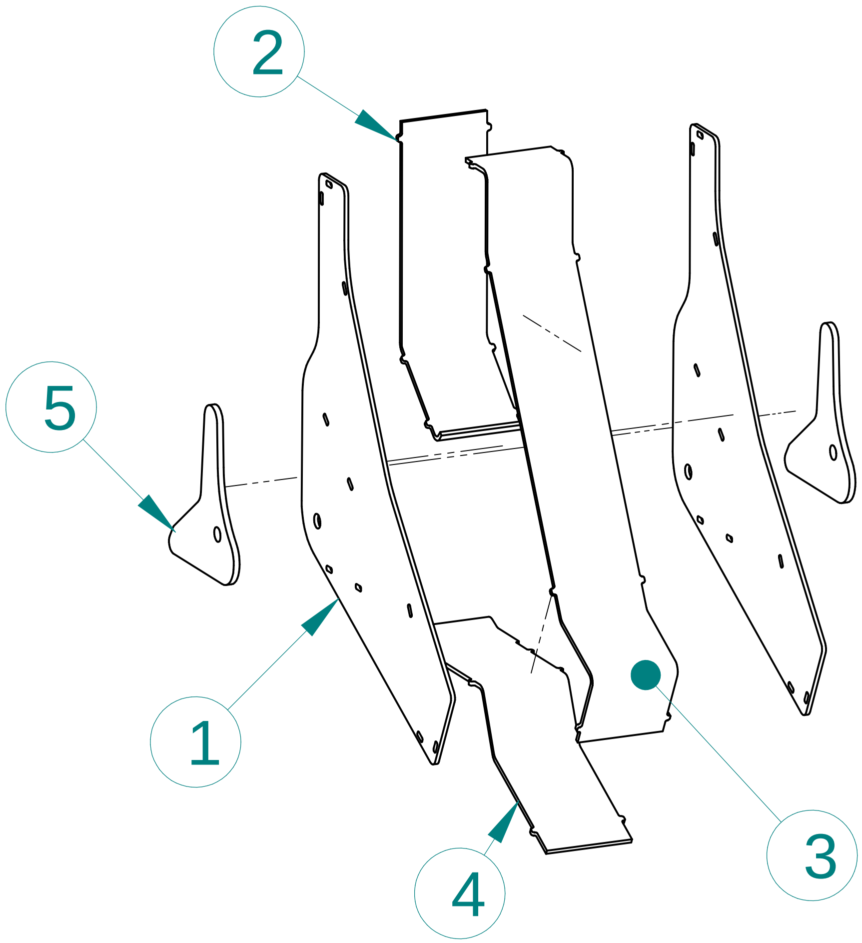
2	P500003	Jeff	1
3	P500002	Jeff	1
4	P500004	Jeff	1
5	163091		2



MATERIAL

DIMENSIONS ARE : MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME: BUILT IN BOOT ASSEMBLY

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER: A500001

DESIGNER: JB

MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

TYPE 558

SERV

A4-2 1 OF 2

C Size

OPPOSITE

28/11/2015

PART NUMBER **A500001**

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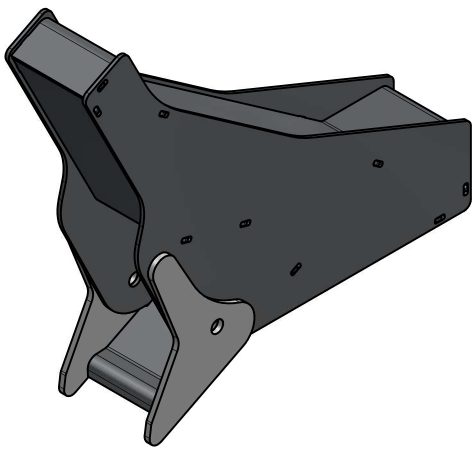

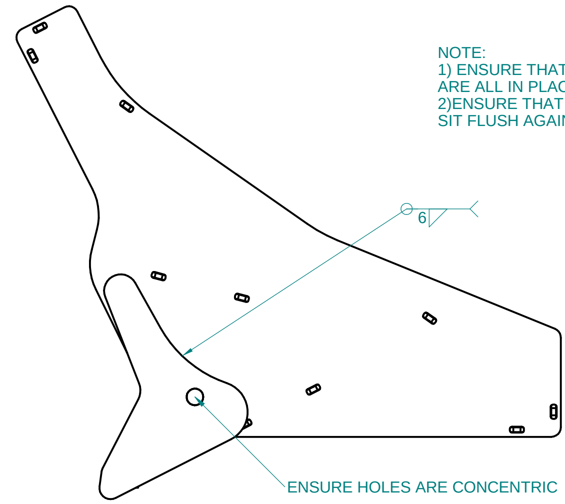

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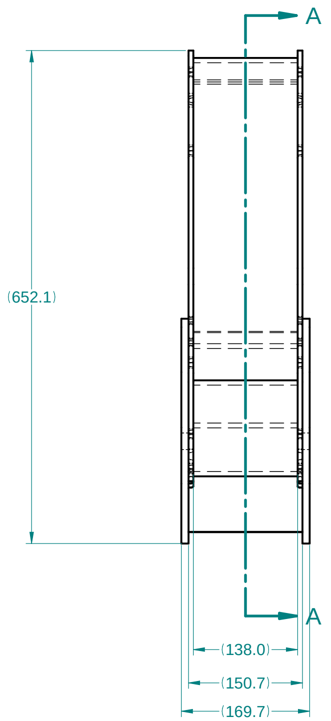
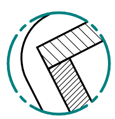
1) ENSURE THAT PARTS P500002, P500003, P500004 ARE ALL IN PLACE BEFORE WELDING BEGINS.
2)ENSURE THAT PARTS P500002, P500003, P500004 SIT FLUSH AGAINST PART P500001





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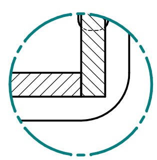

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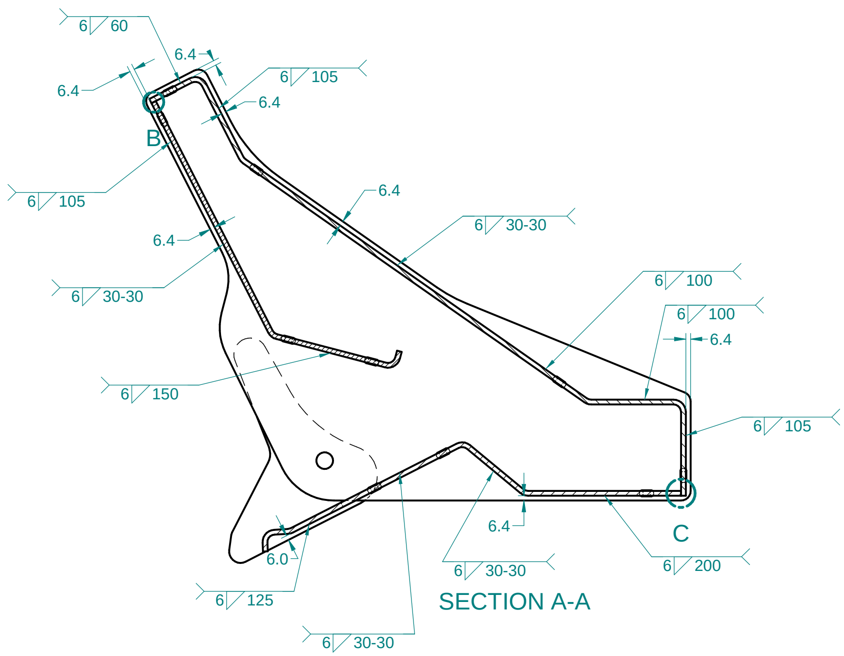

SECTION A-A

MATERIAL			
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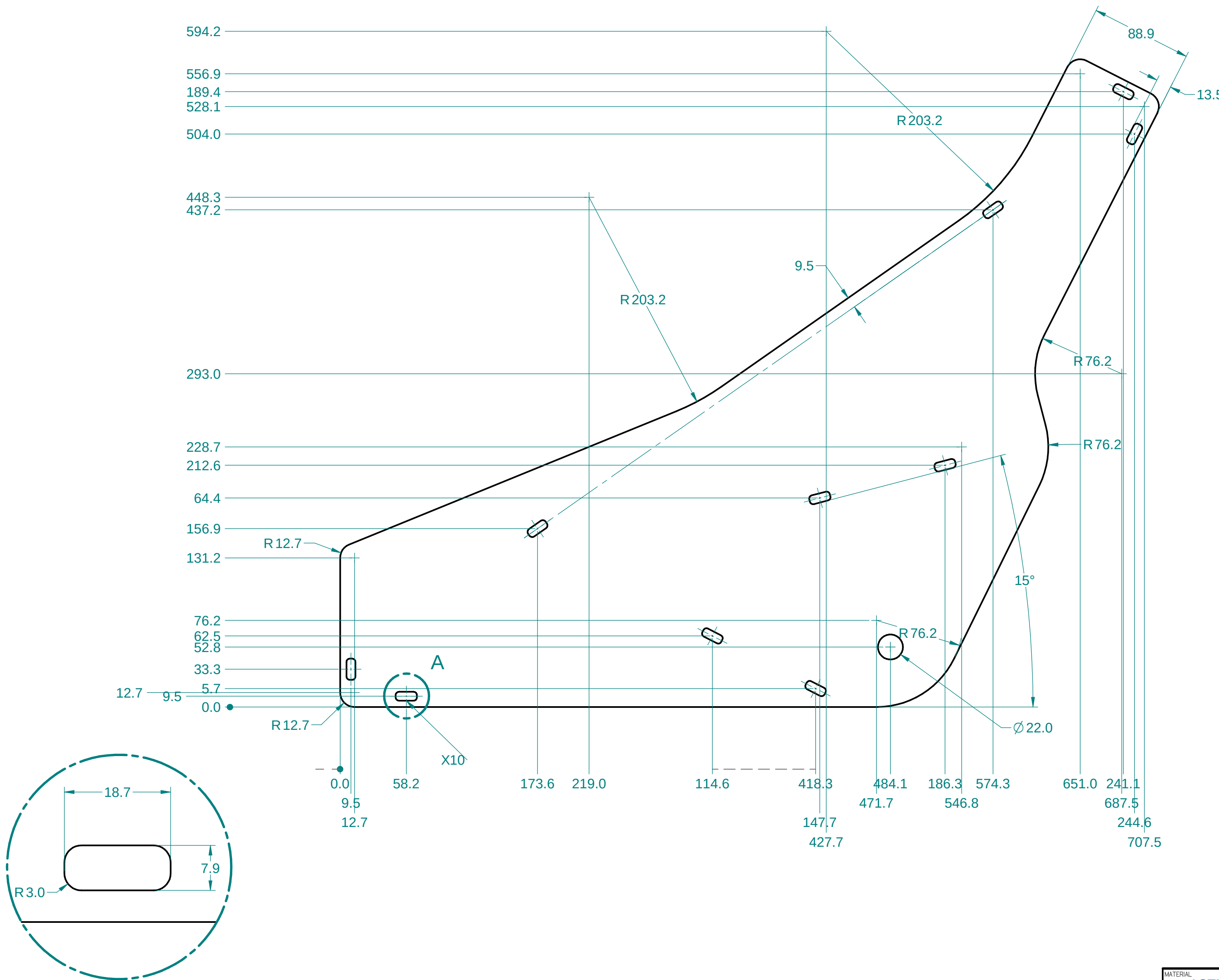
		PART NUMBER A500001	
DESIGNER JB	MacDon — MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba. Canada R3J 3S3	TYPE 558	
		SERV	A4-3 2 OF 2 C Size

28/11/2015

PART NUMBER P500001

NOT TO SCALE - DO NOT SCALE DRAWING



DETAIL A

MATERIAL ASTM A36 STEEL PLATE - .25" THICK

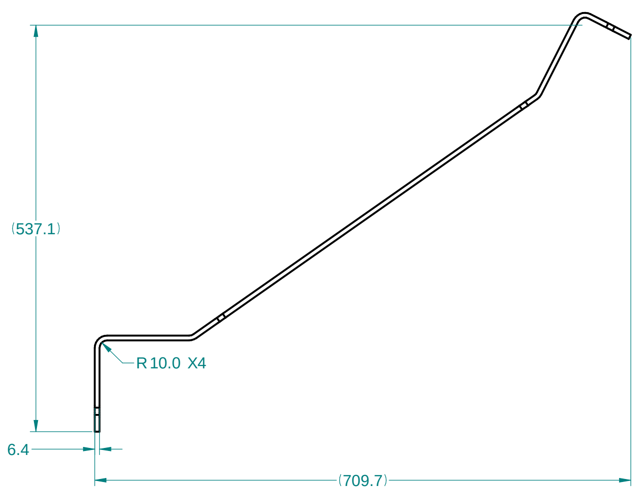
DIMENSIONS ARE: MILLIMETERS	NAME: BUILT IN BOOT - OUTER SHEET	NEXT ASSEMBLY	GROUP/BUNDLE
UNLESS SPECIFIED TOLERANCES ARE - = ± 2, .X = ± 1.0, .XX = ± 0.25, ANGLES = ± 1°	MacDon Industries Ltd, 680 Moray Street, Winnipeg, Manitoba, Canada R3J 3S3	PART NUMBER P500001	
DESIGNER JB		TYPE 558	SERV A4-4 OF

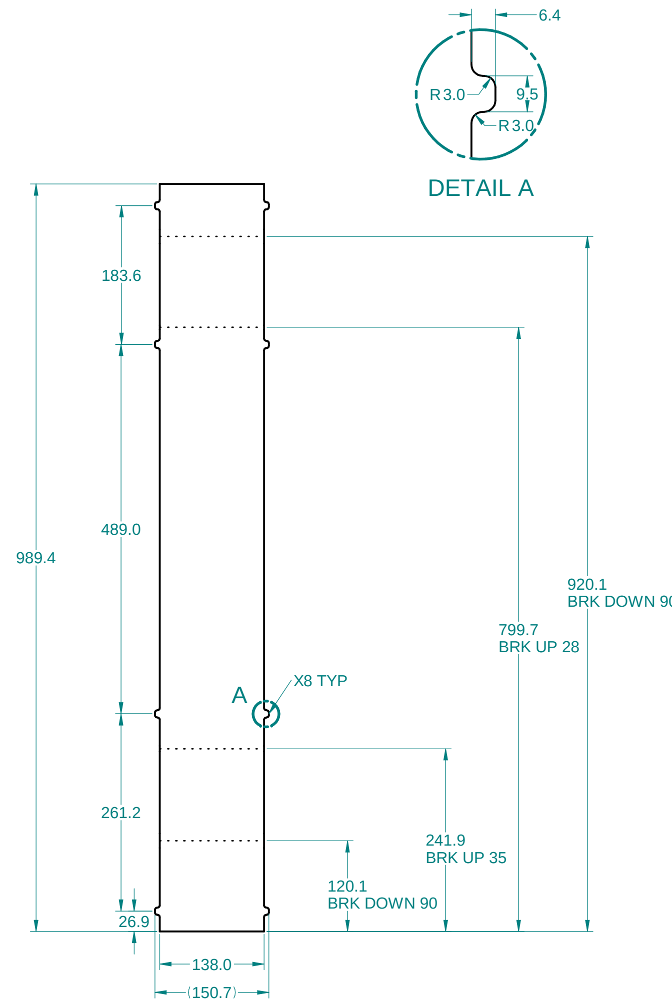
C Size

28/11/2015

PART NUMBER P500002

NOT TO SCALE - DO NOT SCALE DRAWING





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NAME	BUILT IN BOOT - TOP SHEET
NEXT ASSEMBLY	
GROUP/BUNDLE	
PART NUMBER	P500002
DESIGNER	JB
TYPE	558
SERV	
	A4-5 OF
	C Size

MacDon

MacDon Industries Ltd
680 Moray Street
Winnipeg, Manitoba
Canada R3J 3S3

28/11/2015

PART NUMBER P500003

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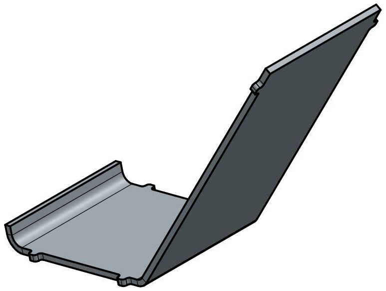

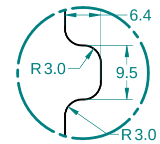

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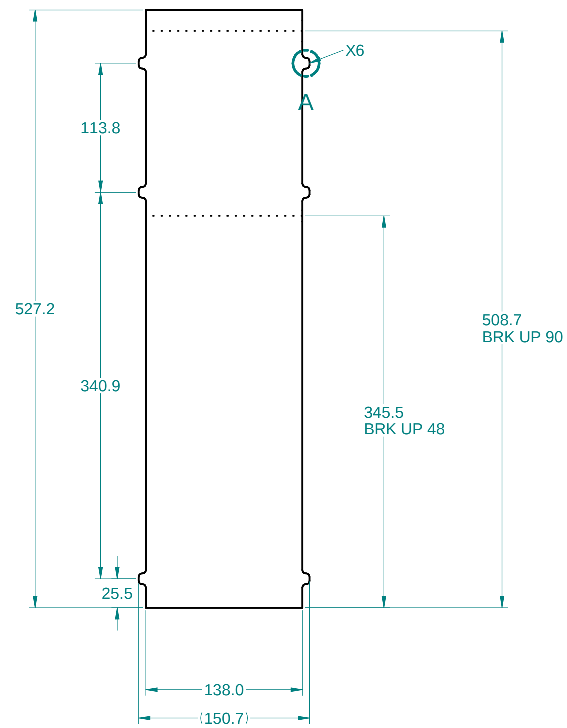

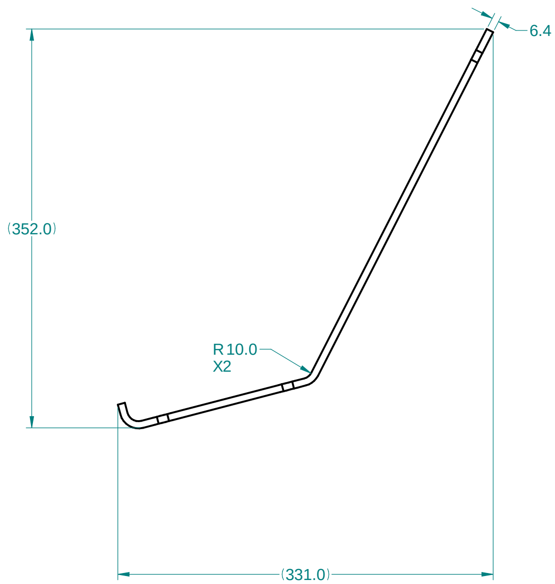

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DESIGNER	JB
NEXT ASSEMBLY	
GROUP/BUNDLE	
PART NUMBER	P500003
TYPE	558
SERV	
	A4-6
OF	
	C Size

MacDon Industries Ltd, 680 Moray Street, Winnipeg, Manitoba, Canada R3J 3S3

28/11/2015

PART NUMBER P500004

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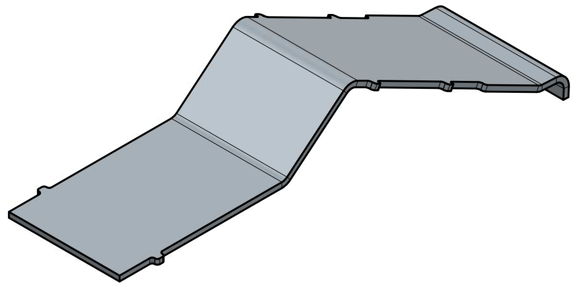

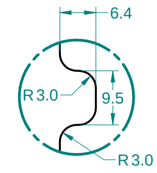

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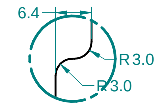

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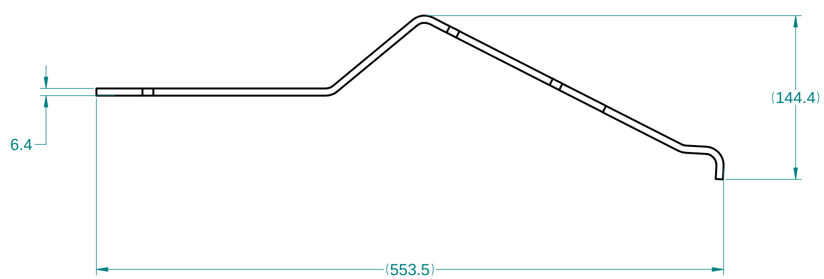

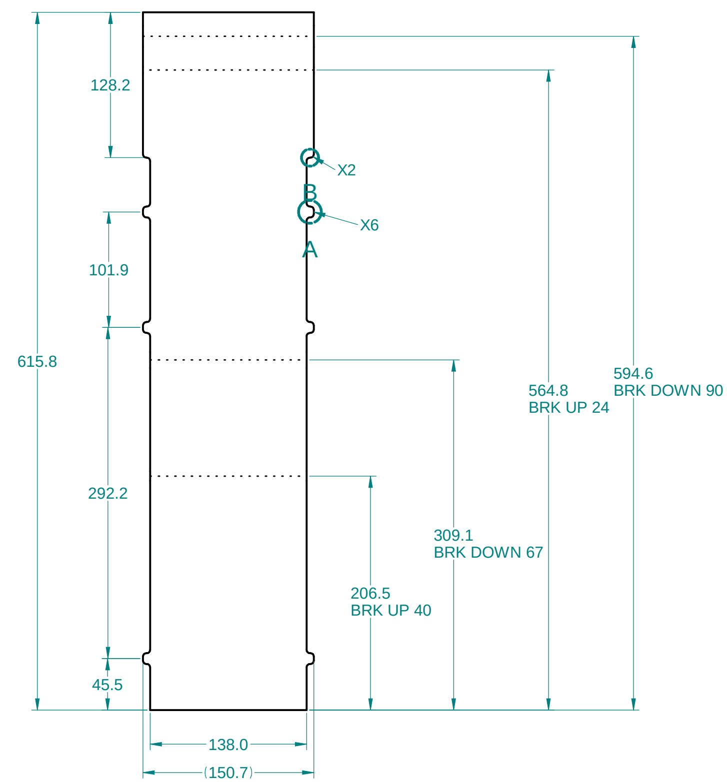

MATERIAL: ASTM A36 STEEL PLATE - .25" THICK

DESIGNER	JB
DIMENSIONS ARE:	MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE	- = ± 2; .X = ± 1.0; .XX = ± 0.25; ANGLES = ± 1°
NAME	BUILT IN BOOT - BOTTOM SHEET
NEXT ASSEMBLY	
GROUP/BUNDLE	
PART NUMBER	P500004
TYPE	558
SERV	

MacDon

MacDon Industries Ltd
680 Moray Street
Winnipeg, Manitoba
Canada R3J 3S3

A4-7 OF

C Size

28/11/2015

PART NUMBER A500002

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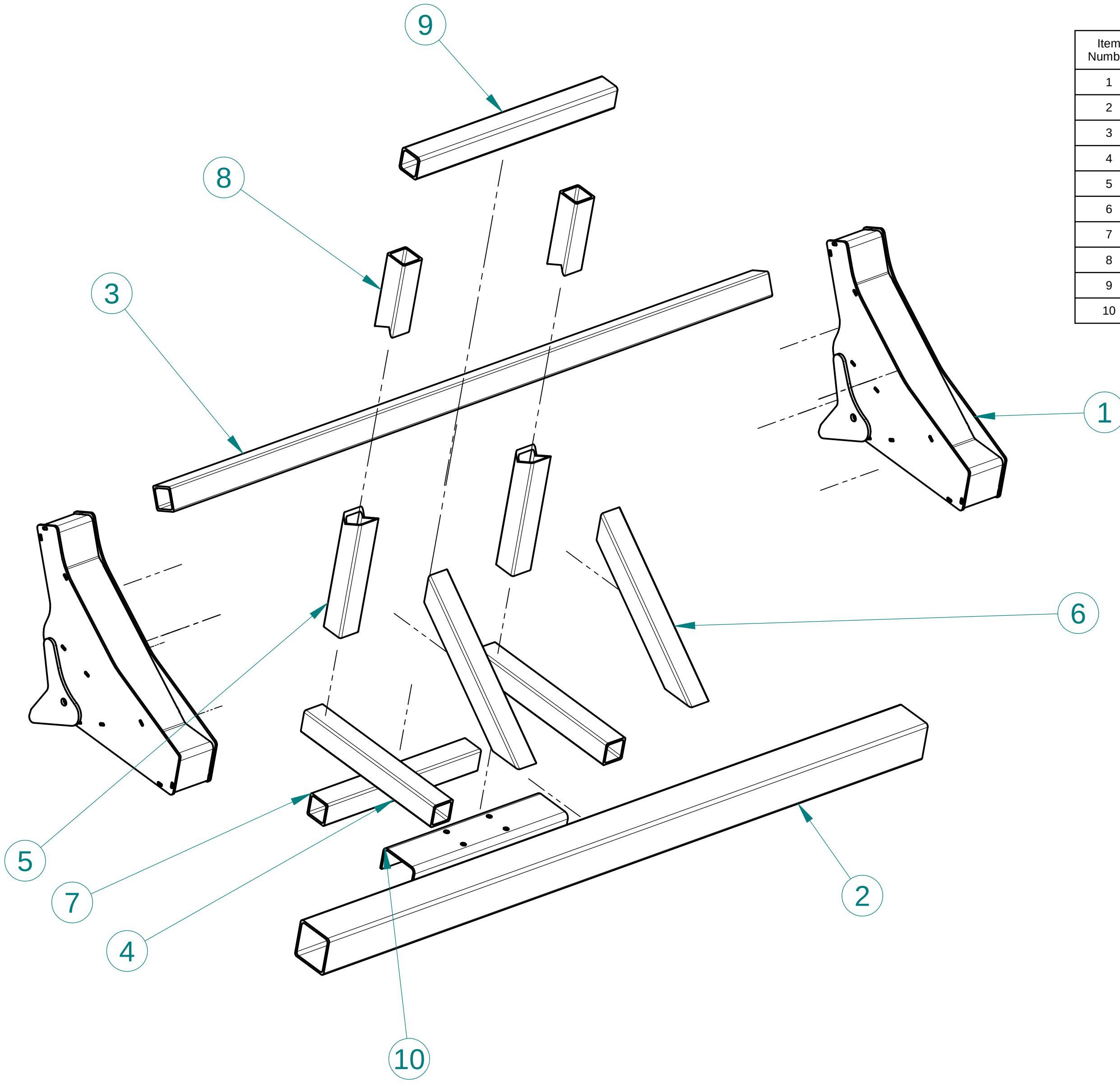

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7	P500028	Jeff	1
8	P500029	Jeff	2
9	P500030	Jeff	1
10	P500008	Jeff	1

MATERIAL

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UNLESS SPECIFIED TOLERANCES ARE
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME: FRAME - FULL ASSEMBLY

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER: A500002

DESIGNER: JB

MacDon

MacDon Industries Ltd
680 Moray Street
Winnipeg, Manitoba
Canada R3J 3S3

TYPE: 558

SERV: A4-8

1 OF 3

C Size

28/11/2015

PART NUMBER A500002

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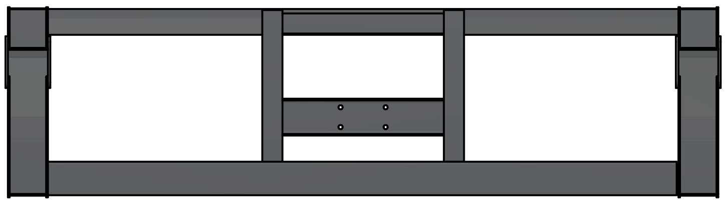

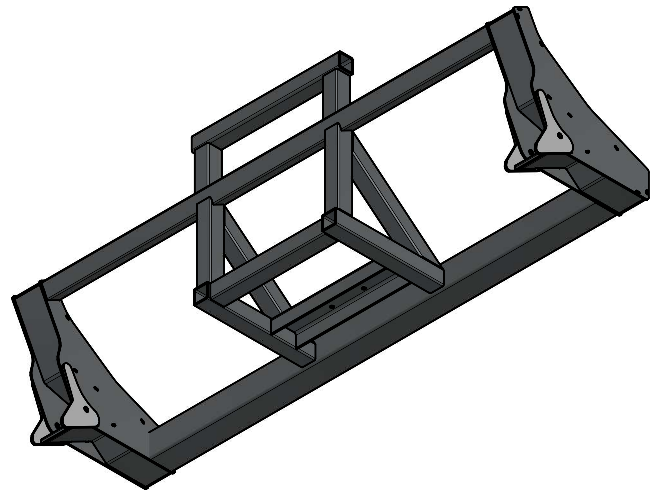

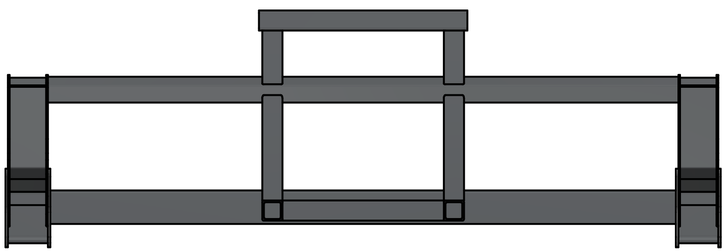

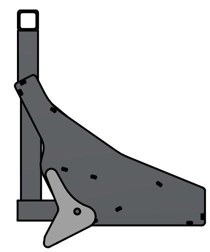

MATERIAL			
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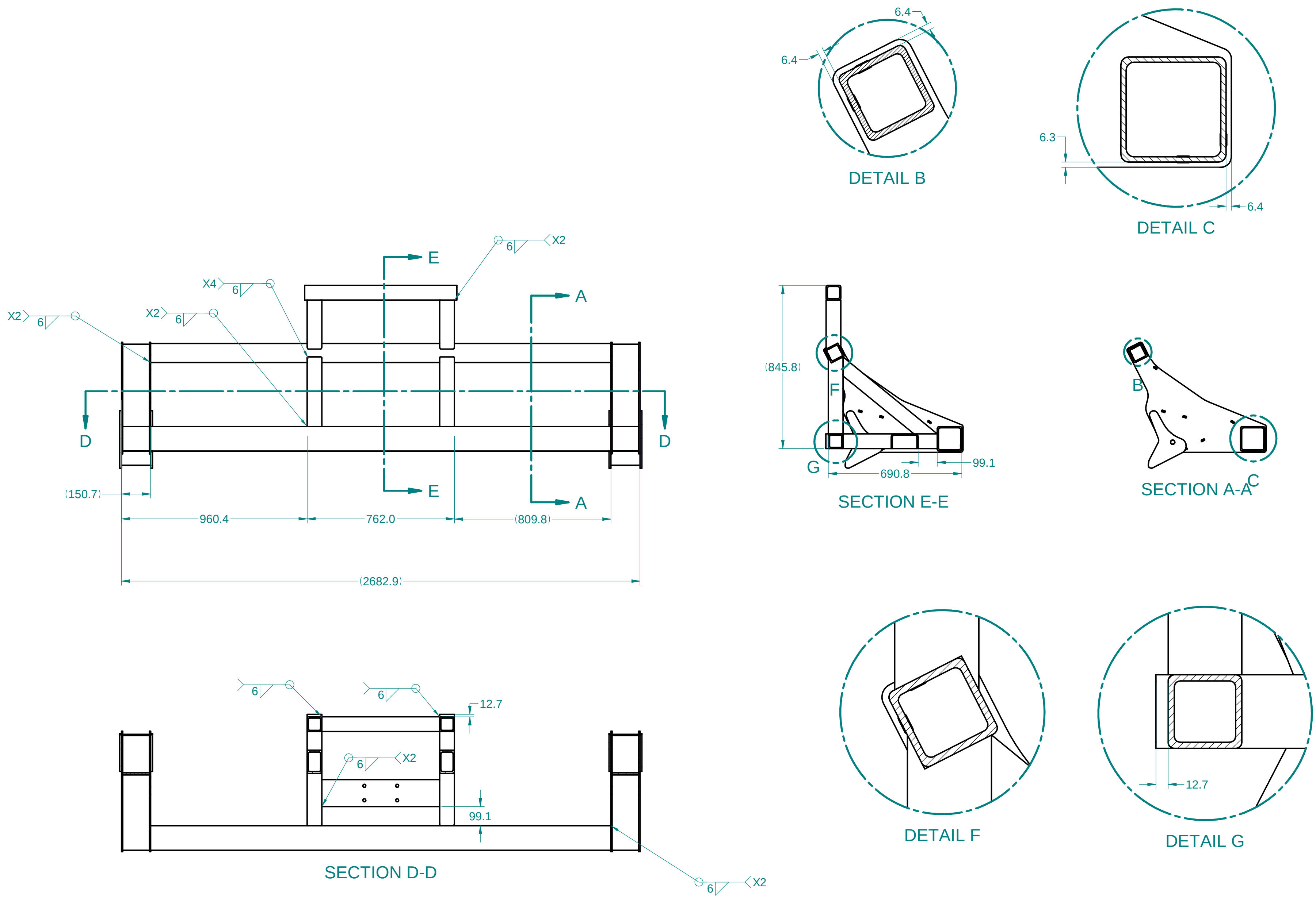
		PART NUMBER A500002	
DESIGNER: JB	MacDon MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba. Canada R3J 3S3	TYPE 558	OPPOSITE
		SERV	A4-9 2 OF 3 C Size

28/11/2015

PART NUMBER **A500002**

NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL			
DIMENSIONS ARE : MILLIMETERS UNLESS SPECIFIED TOLERANCES ARE : - = ± 2 .X = ± 1.0 .XX = ± 0.25 ANGLES = ± 1°	NAME FRAME - FULL ASSEMBLY	NEXT ASSEMBLY	GROUP/BUNDLE
		PART NUMBER A500002	
DESIGNER JB	MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba. Canada R3J 3S3	TYPE 558	
		SERV A4-10	3 OF 3

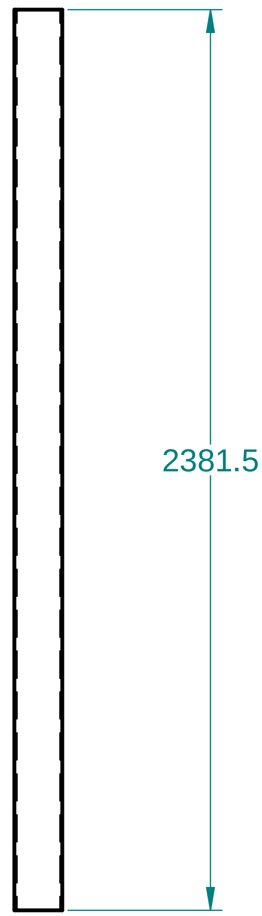
C Size

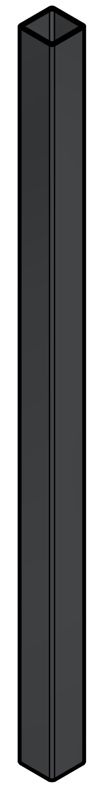
OPPOSITE

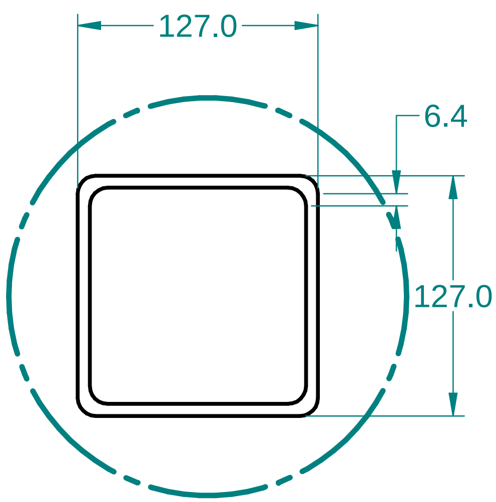
28/11/2015

PART NUMBER
P500023

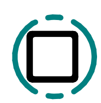
NOT TO SCALE - DO NOT SCALE DRAWING







DETAIL A



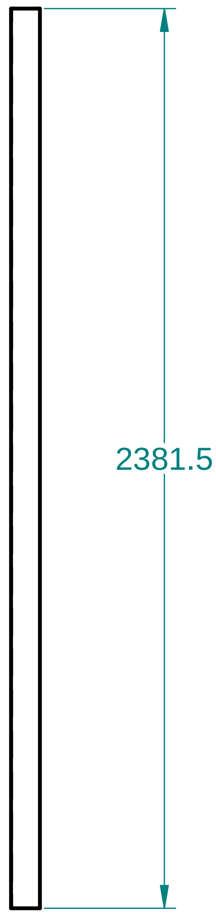
A

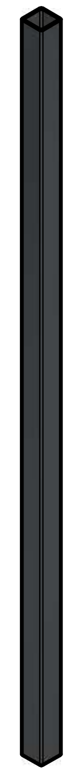
MATERIAL	ASTM A500 GRADE B - 5" X 5" X .25" WALL
DESIGNER	JB
DIMENSIONS ARE :	MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :	- = ± 2 .X = ± 1.0 .XX = ± 0.25 ANGLES = ± 1°
NAME	FRAME - 5 X 5 BEAM
NEXT ASSEMBLY	
GROUP/BUNDLE	
PART NUMBER	P500023
TYPE	558
SERV	4
	A4-11
SHEET	1 OF 1

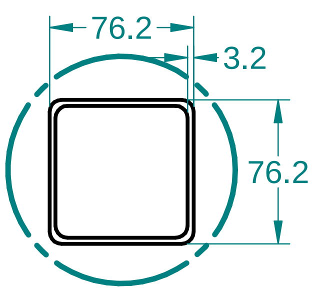
MacDon
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

PART NUMBER
P500024

NOT TO SCALE - DO NOT SCALE DRAWING







DETAIL A

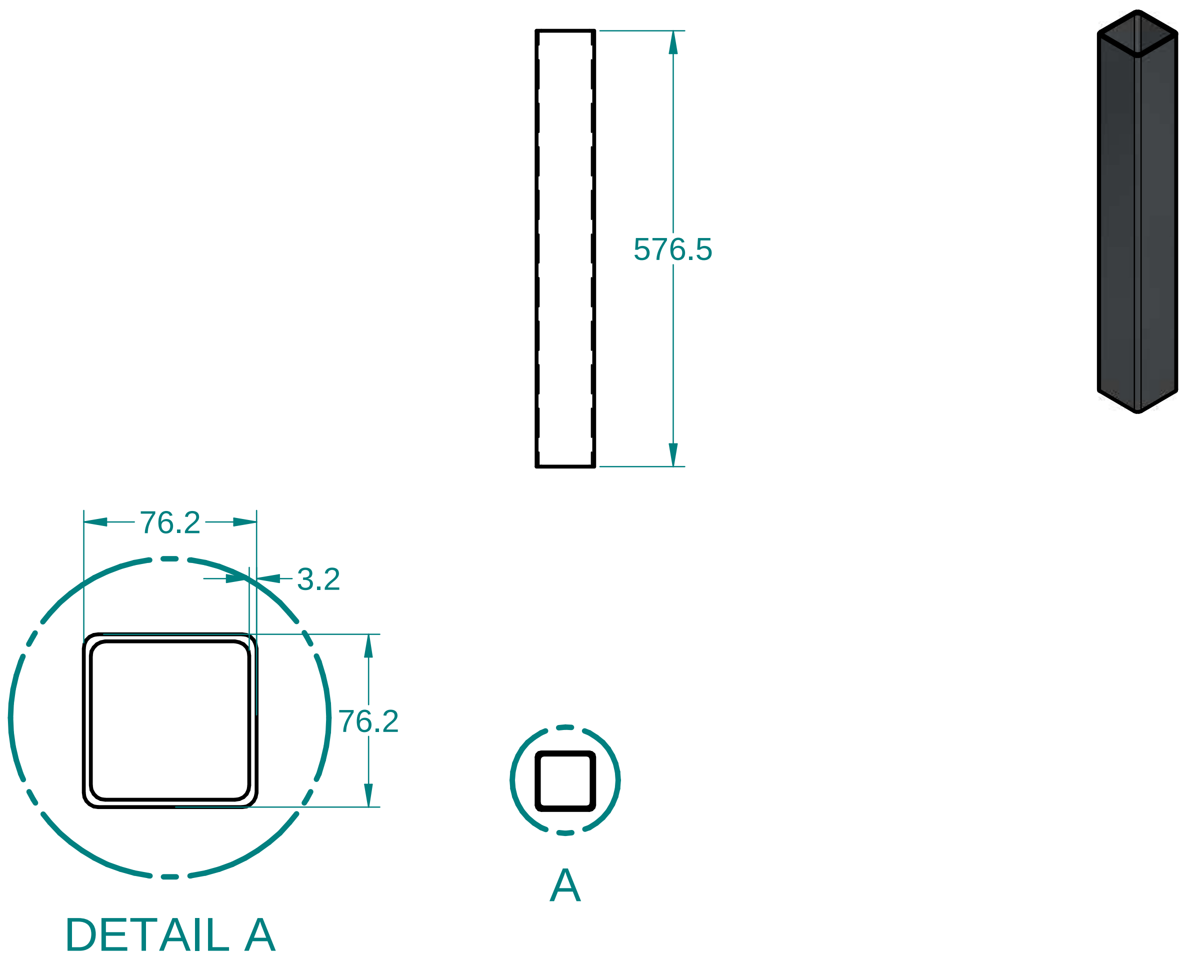
A

MATERIAL	ASTM A500 GRADE B - 3" X 3" X .125" WALL
DIMENSIONS ARE :	MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :	- = ± 2; .X = ± 1.0; .XX = ± 0.25; ANGLES = ± 1°
NAME	FRAME - 3 X 3 BEAM
DESIGNER	JB
NEXT ASSEMBLY	
GROUP/BUNDLE	
PART NUMBER	P500024
TYPE	558
SERV	4
SIZE	A4-12
SHEET	1 OF 1

MacDon
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

PART NUMBER
P500025

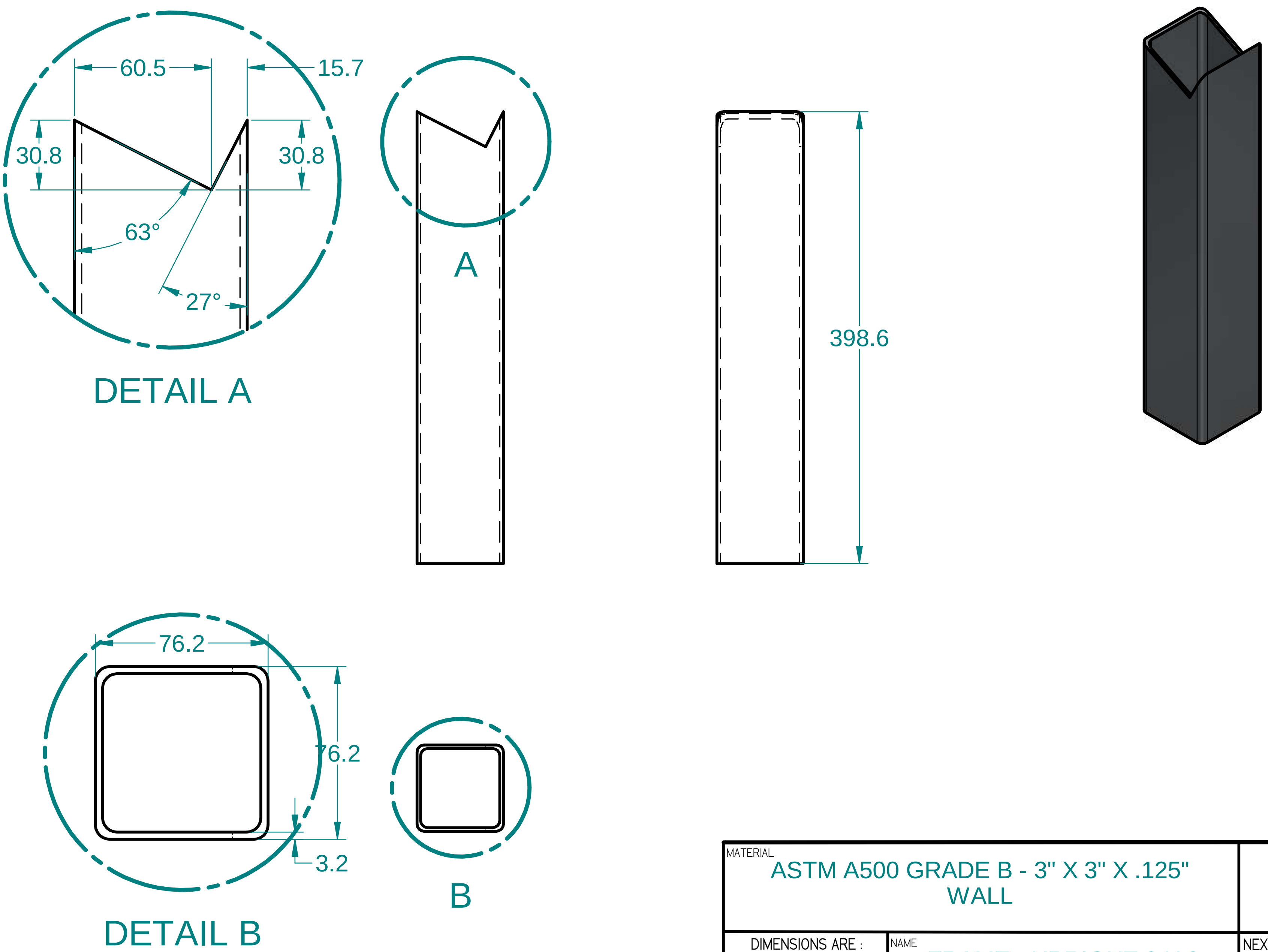
NOT TO SCALE – DO NOT SCALE DRAWING



MATERIAL ASTM A500 GRADE B - 3" X 3" X .125" WALL			
DIMENSIONS ARE : MILLIMETERS UNLESS SPECIFIED TOLERANCES ARE : - = ± 2 .X = ± 1.0 .XX = ± 0.25 ANGLES = ± 1°	NAME FRAME - BOTTOM 3 X 3	NEXT ASSEMBLY	GROUP/BUNDLE
DESIGNER JB	MacDon MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba. Canada R3J 3S3	PART NUMBER P500025	
		TYPE 558	A4-13
		SERV 4	SHEET 1 OF 1

PART NUMBER
P500026

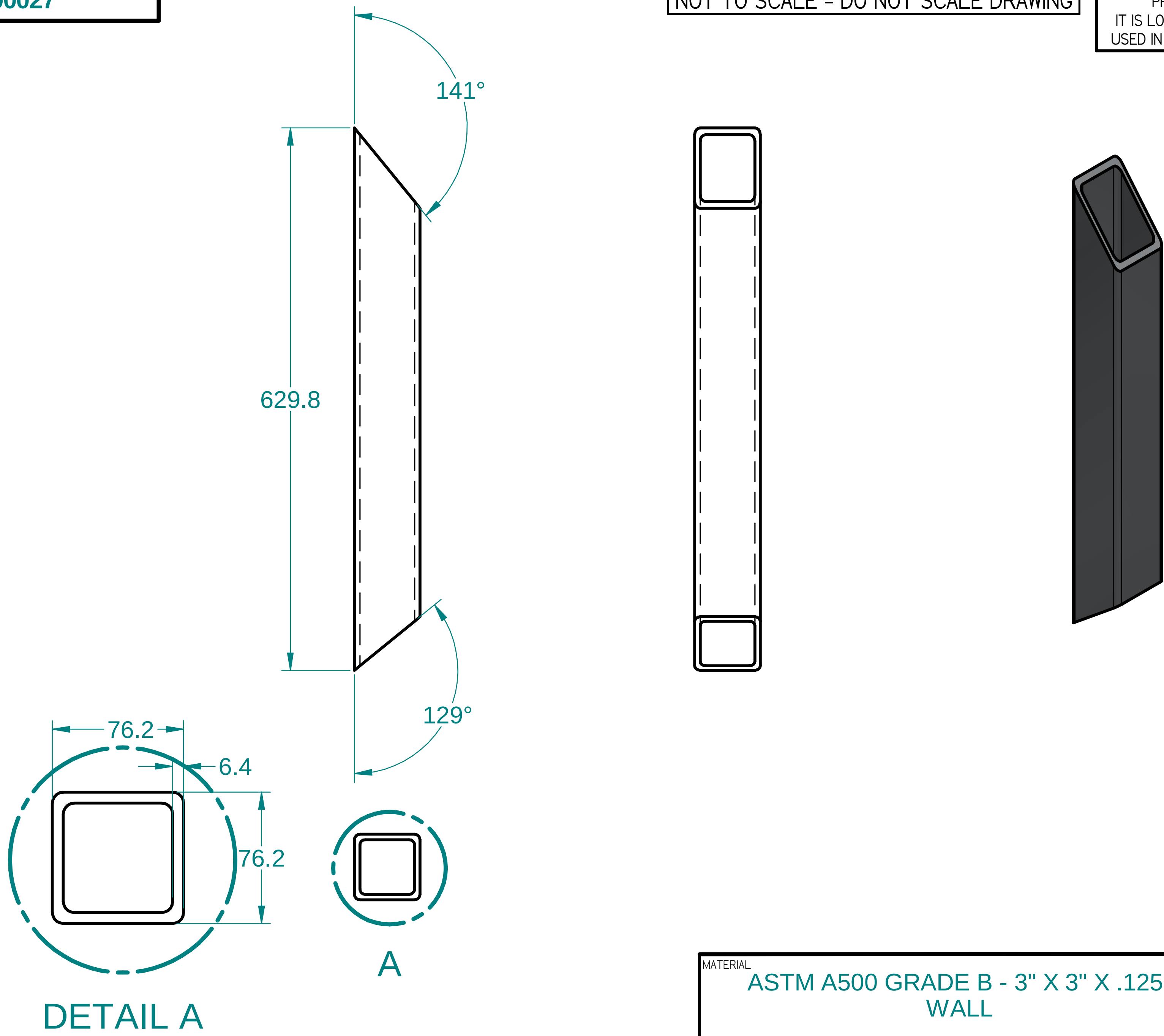
NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL: ASTM A500 GRADE B - 3" X 3" X .125" WALL			
DIMENSIONS ARE : MILLIMETERS UNLESS SPECIFIED TOLERANCES ARE : - = ± 2, .X = ± 1.0, .XX = ± 0.25, ANGLES = ± 1°	NAME: FRAME - UPRIGHT 3 X 3	NEXT ASSEMBLY	GROUP/BUNDLE
		PART NUMBER: P500026	
DESIGNER: JB	MacDon — MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba. Canada R3J 3S3	TYPE 558	A4-14
		SERV 4	SHEET 1 OF 1

PART NUMBER
P500027

NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL
ASTM A500 GRADE B - 3" X 3" X .125" WALL

DIMENSIONS ARE : MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
FRAME - DIAGONAL 3 X 3

DESIGNER
JB

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
P500027

MacDon

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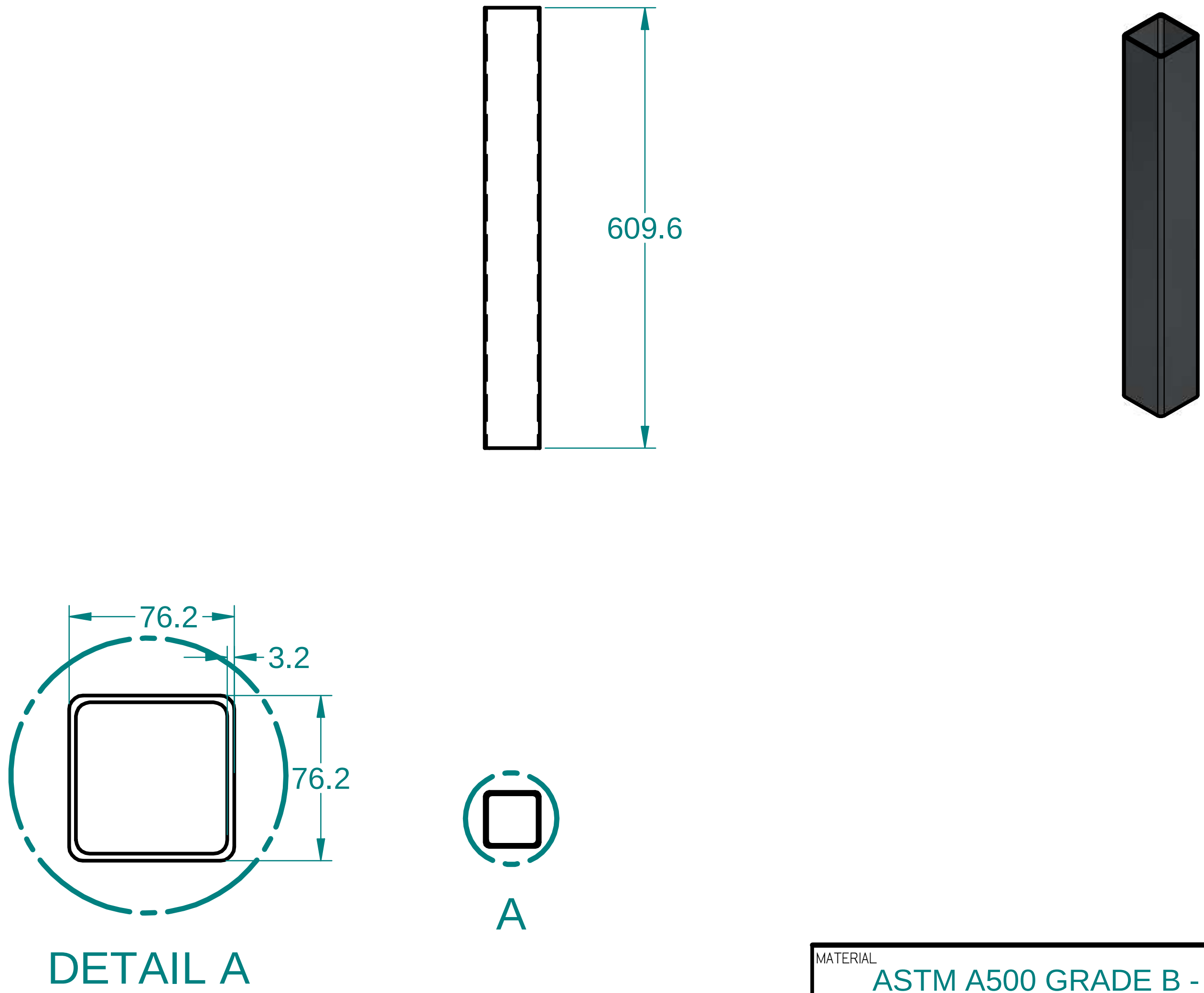
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

TYPE 558 A4-15
SERV 4 SHEET 1 OF 1

PART NUMBER
P500028

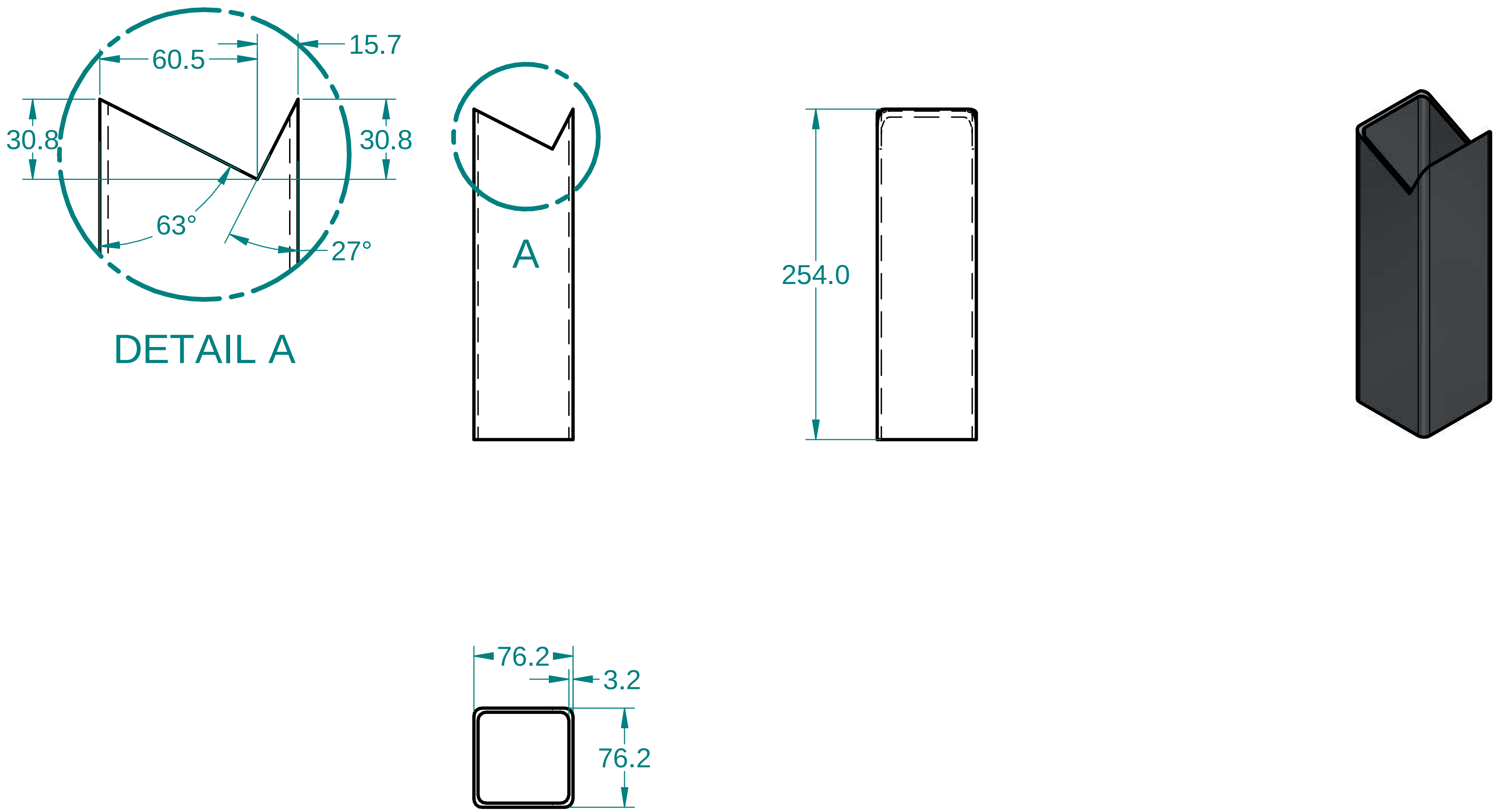
NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL: ASTM A500 GRADE B - 3" X 3" X .125" WALL			
DIMENSIONS ARE : MILLIMETERS UNLESS SPECIFIED TOLERANCES ARE : - = ± 2, .X = ± 1.0, .XX = ± 0.25, ANGLES = ± 1°	NAME: FRAME - BACK BOTTOM 3 X 3	NEXT ASSEMBLY	GROUP/BUNDLE
DESIGNER: JB	MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba. Canada R3J 3S3	PART NUMBER: P500028	
		TYPE 558	A4-16
		SERV 4	SHEET 1 OF 1

PART NUMBER
P500029

NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL
ASTM A500 GRADE B - 3" X 3" X .125" WALL

DIMENSIONS ARE :
MILLIMETERS
UNLESS SPECIFIED
TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
FRAME - TILT CYLINDER UPRIGHT

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
P500029

MacDon
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

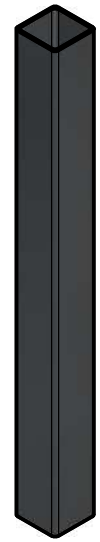
TYPE 558 A4-17

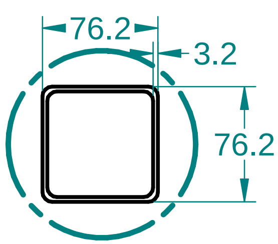
SERV 4 SHEET 1 OF 1

DESIGNER
JB

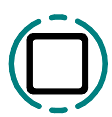
PART NUMBER
P500030

NOT TO SCALE - DO NOT SCALE DRAWING





DETAIL A



A

MATERIAL	ASTM A500 GRADE B - 3" X 3" X .125" WALL
DIMENSIONS ARE : MILLIMETERS	UNLESS SPECIFIED TOLERANCES ARE : - = ± 2; .X = ± 1.0; .XX = ± 0.25; ANGLES = ± 1°
NAME	FRAME - TILT CYLINDER TOP MEMBER
DESIGNER	JB
NEXT ASSEMBLY	GROUP/BUNDLE
PART NUMBER	P500030
TYPE	558
SERV	4
	A4-18
SHEET	1 OF 1

MacDon

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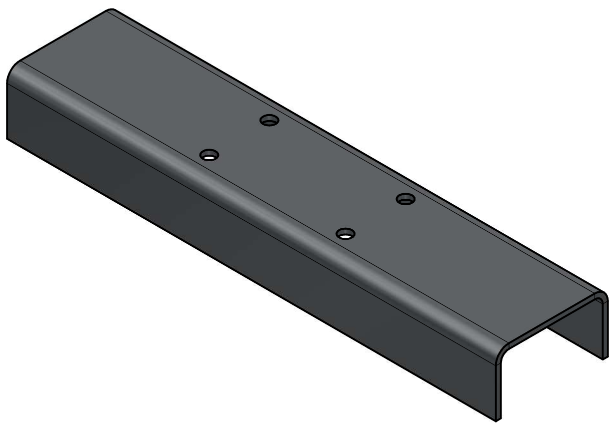
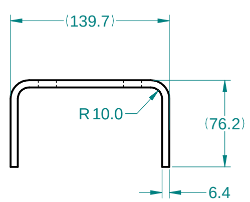
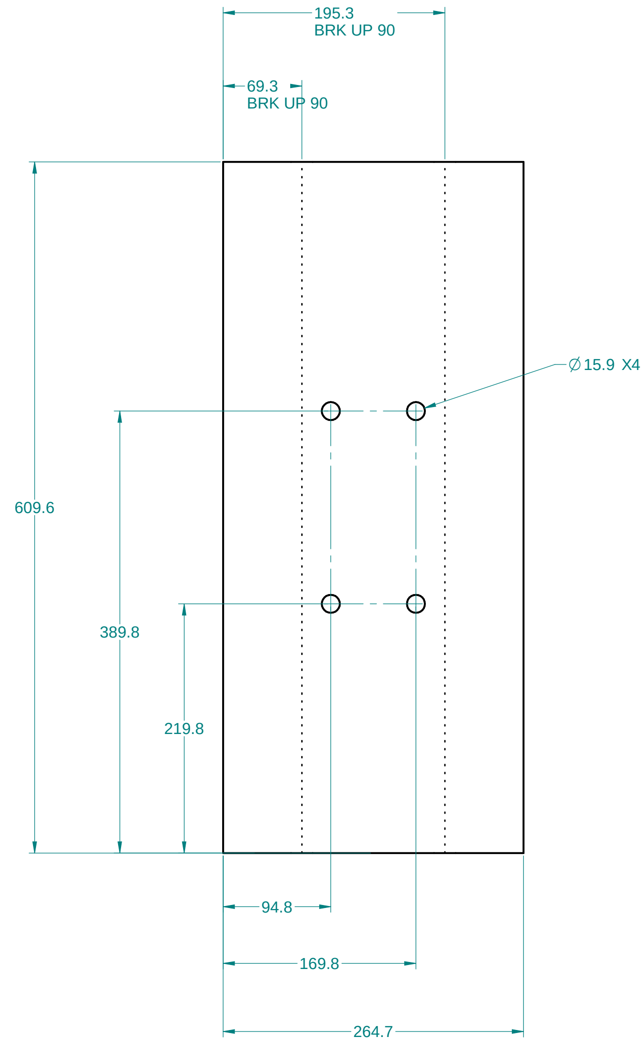
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

PART NUMBER P500008

NOT TO SCALE - DO NOT SCALE DRAWING







MATERIAL	ASTM A36 STEEL PLATE - .25" THICK
DESIGNER	JB
DIMENSIONS ARE :	MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :	- = ± 2; .X = ± 1.0; .XX = ± 0.25; ANGLES = ± 1°
NAME	FRAME - GEARBOX BRACKET
NEXT ASSEMBLY	
GROUP/BUNDLE	
PART NUMBER	P500008
TYPE	558
SERV	A4-19
OF	

MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

OPPOSITE

C Size

28/11/2015

PART NUMBER
A500003

NOT TO SCALE – DO NOT SCALE DRAWING

Item Number	File Name (no extension)	Author	Quantity
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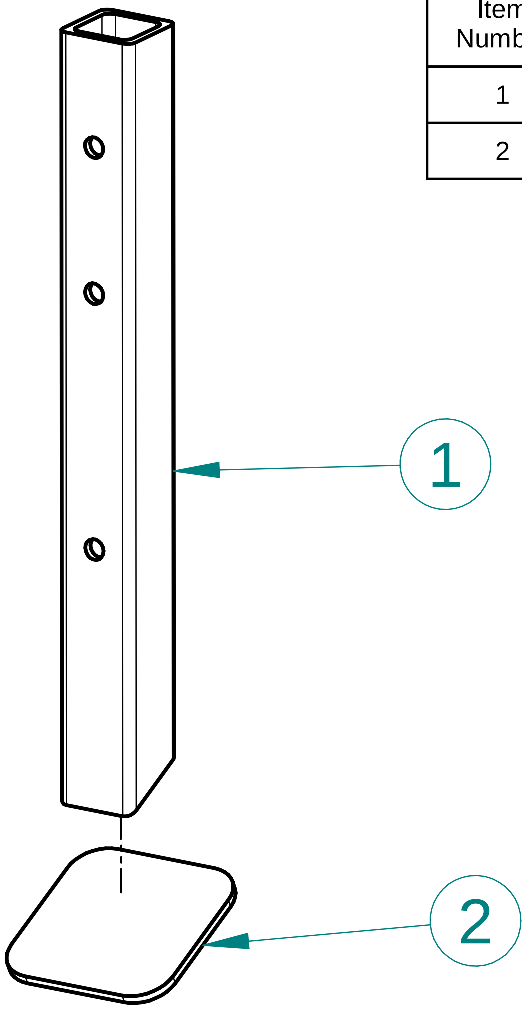
2	P500012	Jeff	1



MATERIAL

DIMENSIONS ARE : MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
KICKSTAND - ASSEMBLY

MacDon
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

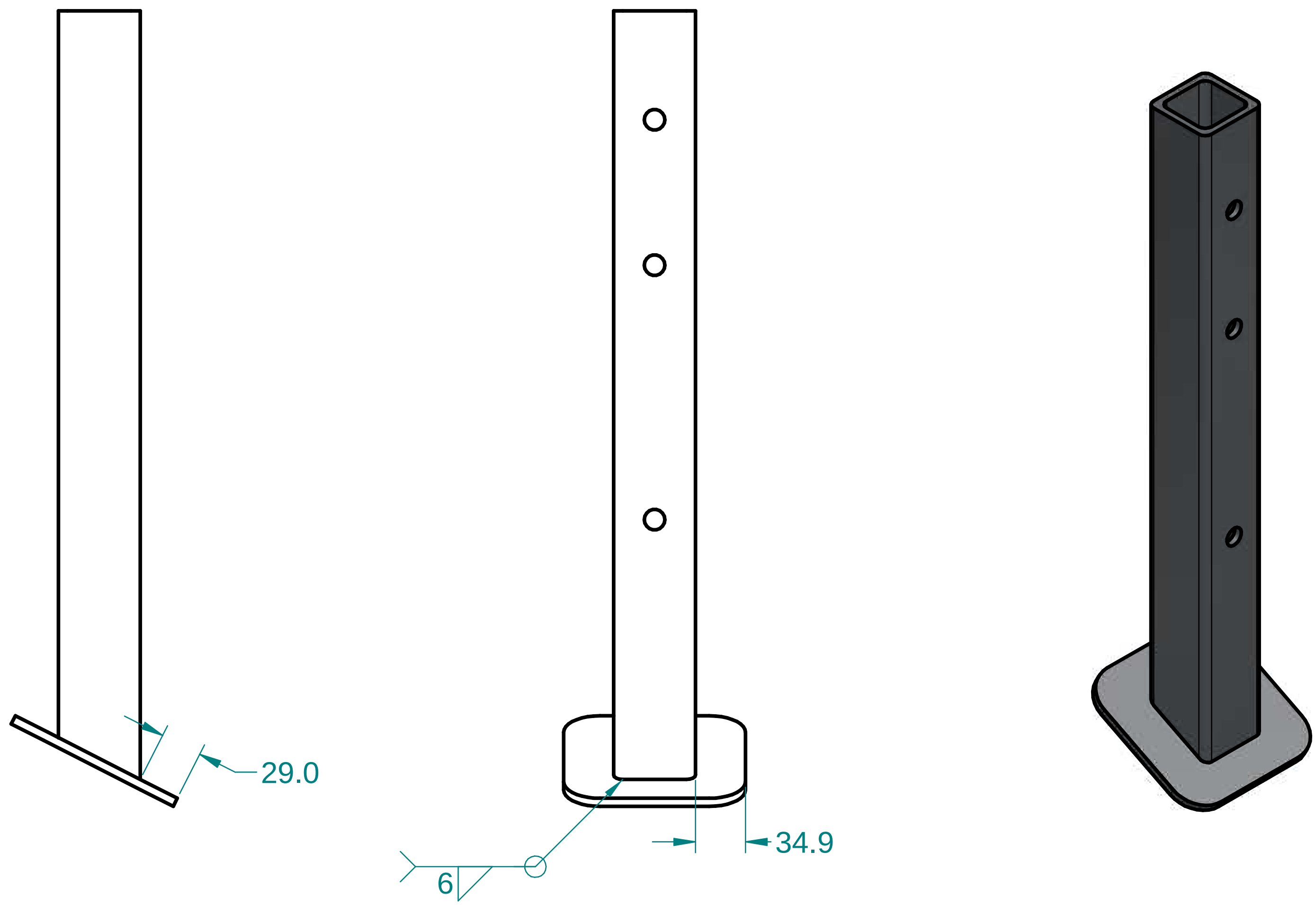
NEXT ASSEMBLY | GROUP/BUNDLE
PART NUMBER
A500003

TYPE 558 A4-20
SERV 4 SHEET 1 OF 2

DESIGNER
JB

PART NUMBER
A500003

NOT TO SCALE – DO NOT SCALE DRAWING



MATERIAL

DIMENSIONS ARE : MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
KICKSTAND - ASSEMBLY

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
A500003

DESIGNER
JB

MacDon

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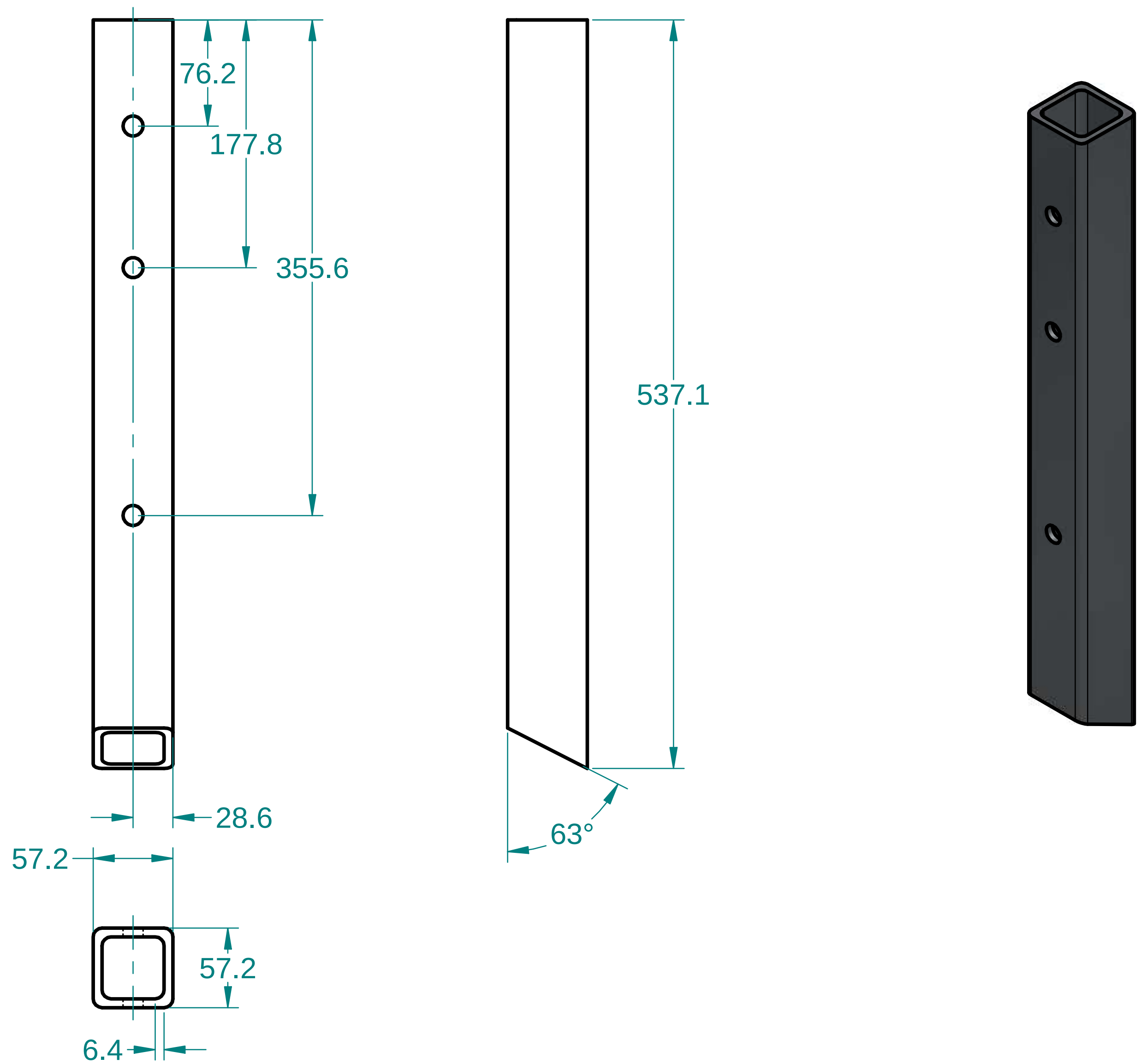
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

TYPE 558 A4-21
SERV 4 SHEET 2 OF 2

PART NUMBER
P500011

NOT TO SCALE - DO NOT SCALE DRAWING

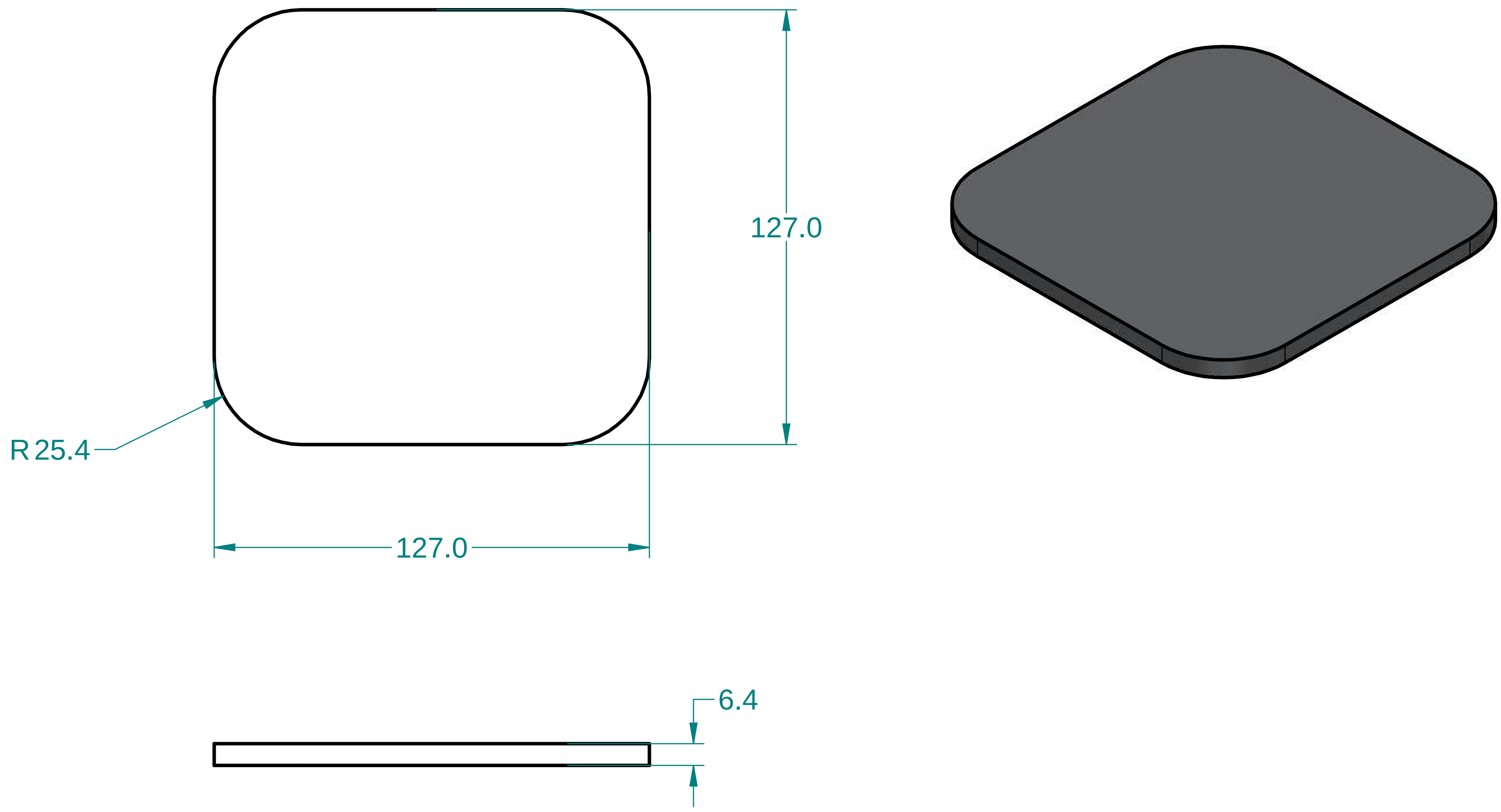


MATERIAL
ASTM A500 GRADE B - 2.25" X 2.25" X .25" WALL

DIMENSIONS ARE : MILLIMETERS	NAME KICKSTAND - INNER TUBE	NEXT ASSEMBLY / GROUP/BUNDLE
UNLESS SPECIFIED TOLERANCES ARE : - = ± 2; .X = ± 1.0; .XX = ± 0.25; ANGLES = ± 1°	MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba. Canada R3J 3S3	PART NUMBER P500011
DESIGNER JB		TYPE 558 A4-22
		SERV 4 SHEET 1 OF 1

PART NUMBER
P500012

NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL
ASTM A36 STEEL PLATE - .25" THICK

DIMENSIONS ARE :
MILLIMETERS
UNLESS SPECIFIED
TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
KICKSTAND - BOTTOM PLATE

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
P500012

DESIGNER
JB

MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

TYPE 558 A4-23
SERV 4 SHEET 1 OF 1

PART NUMBER
A500004

NOT TO SCALE - DO NOT SCALE DRAWING

Item Number	Part Number	Author	Quantity
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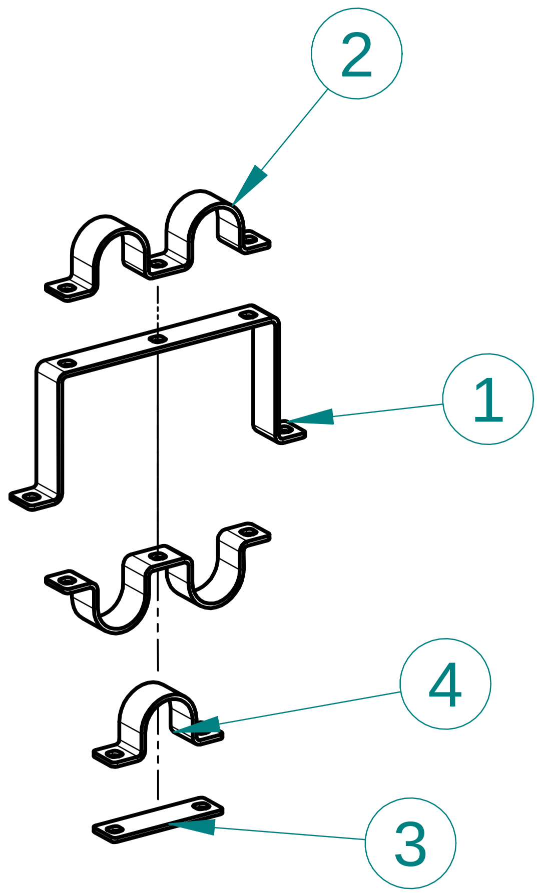
2	P500015	Jeff	2
3	P500018	Jeff	1
4	P500017	Jeff	1



MATERIAL

DIMENSIONS ARE :
MILLIMETERS
UNLESS SPECIFIED
TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
HOSE BRACKET ASSEMBLY

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
A500004

DESIGNER
JB

MacDon

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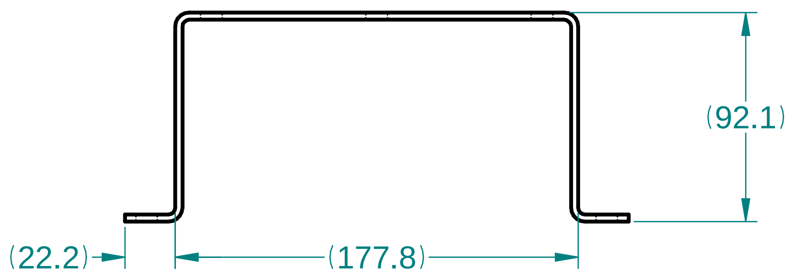
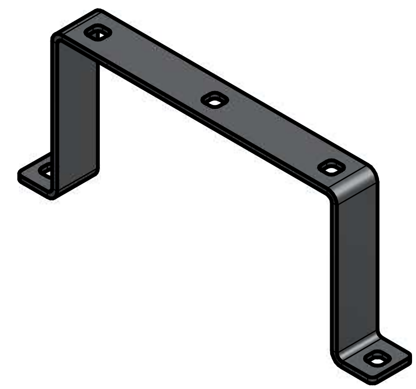
Winnipeg, Manitoba.
Canada R3J 3S3

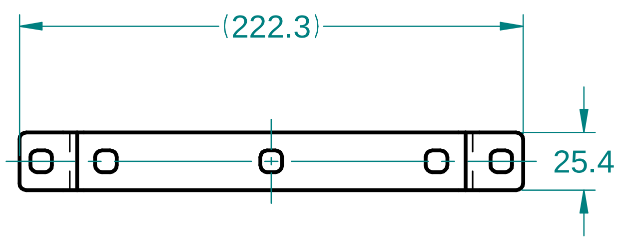
TYPE 558 A4-24
SERV 4 SHEET 1 OF 1

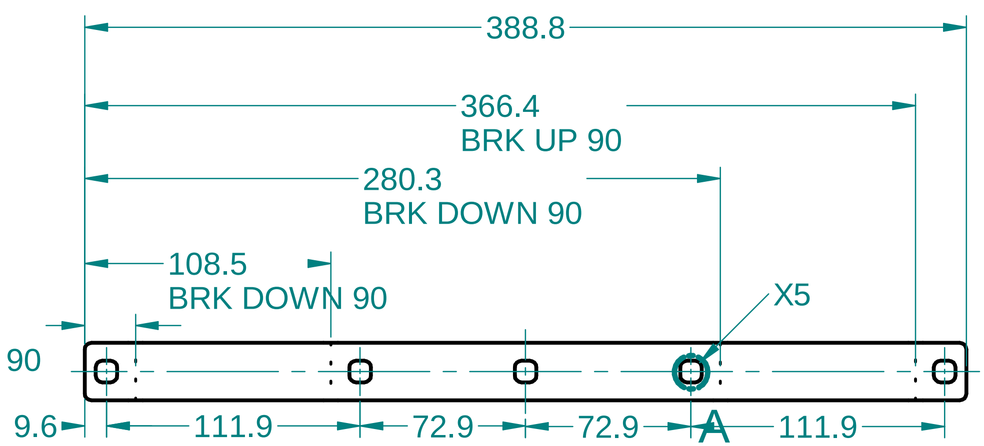
PART NUMBER
P500016

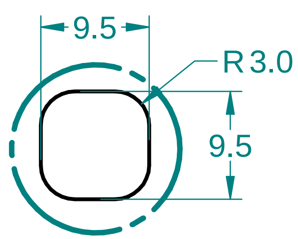
NOT TO SCALE - DO NOT SCALE DRAWING











DETAIL A

MATERIAL	ASTM A36 STEEL PLATE - .125" THICK
DIMENSIONS ARE :	MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :	- = ± 2 .X = ± 1.0 .XX = ± 0.25 ANGLES = ± 1°
NAME	HOSE BRACKET - DOUBLE MIDDLE
DESIGNER	JB
NEXT ASSEMBLY	
GROUP/BUNDLE	
PART NUMBER	P500016
TYPE	558
SERV	4
	A4-25
SHEET	1 OF 1

MacDon

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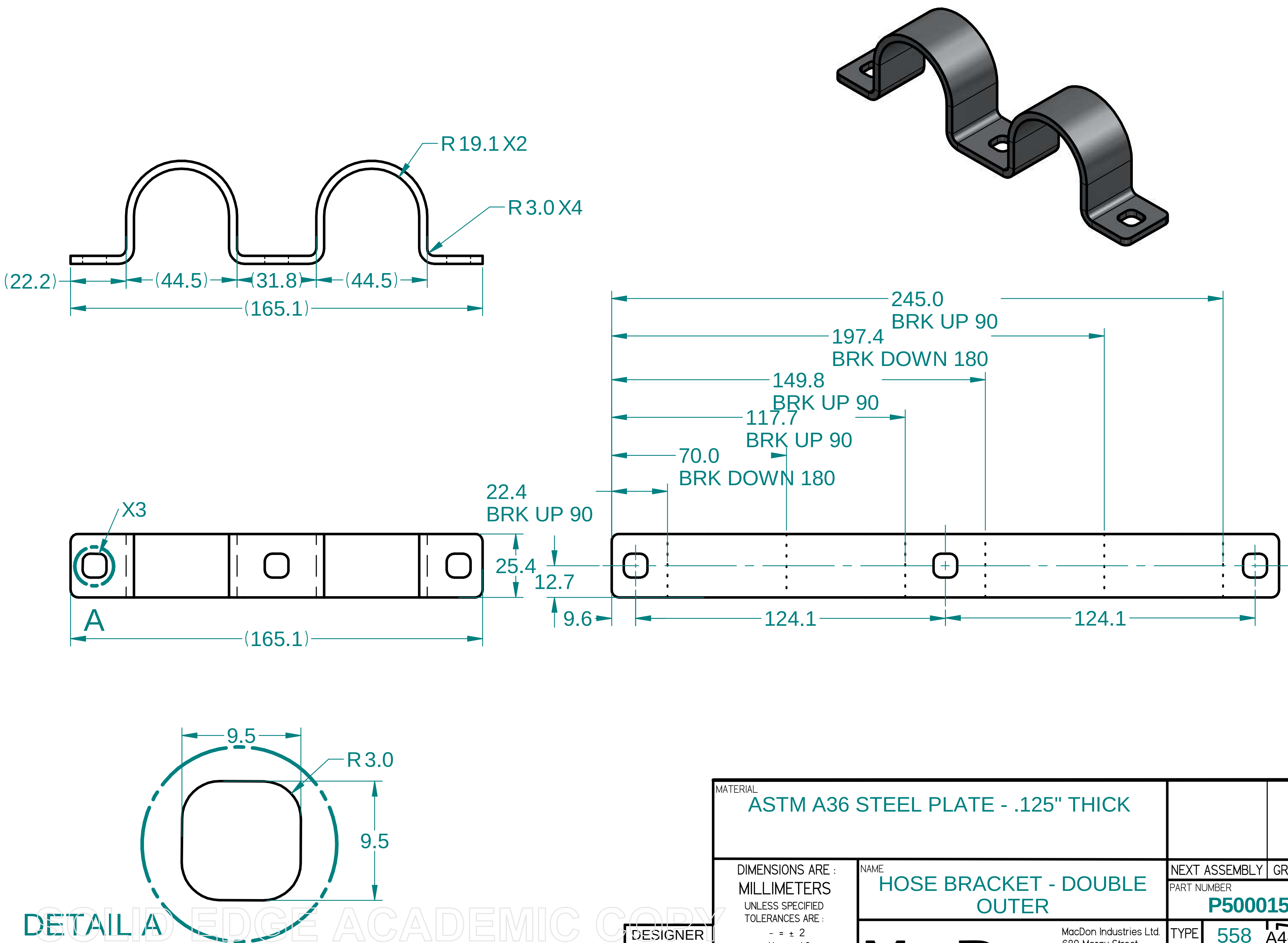
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

PART NUMBER
P500015

NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL
ASTM A36 STEEL PLATE - .125" THICK

DIMENSIONS ARE : MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

DESIGNER: JB

NAME
HOSE BRACKET - DOUBLE OUTER

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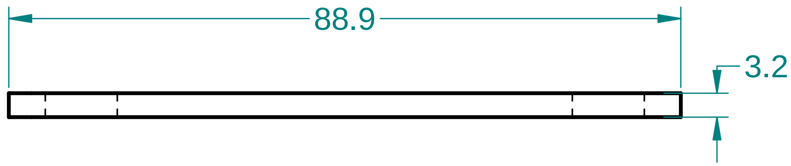
680 Moray Street
Winnipeg, Manitoba
Canada R3J 3S3

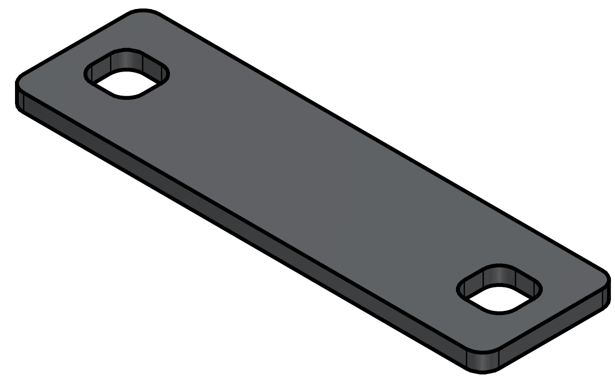
NEXT ASSEMBLY	GROUP/BUNDLE
PART NUMBER P500015	

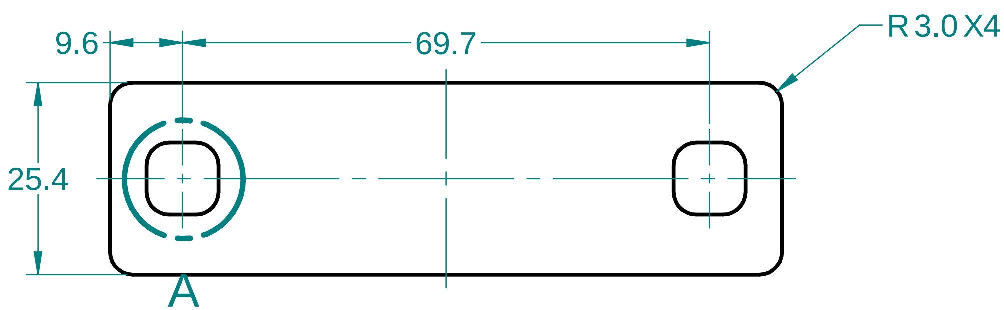
TYPE	558	A4-26
SERV	4	SHEET 1 OF 1

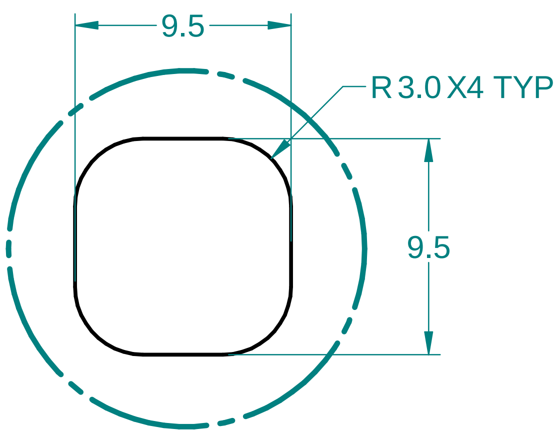
PART NUMBER
P500018

NOT TO SCALE – DO NOT SCALE DRAWING









DETAIL A

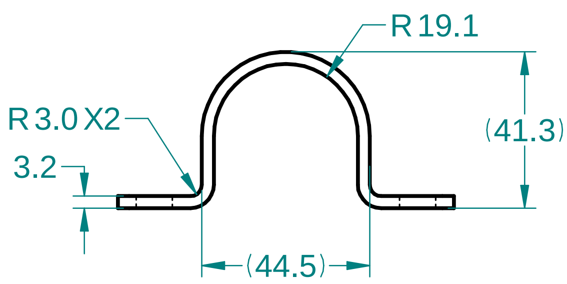
MATERIAL	ASTM A36 STEEL PLATE - .125" THICK
DESIGNER	JB
DIMENSIONS ARE :	MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :	- = ± 2 .X = ± 1.0 .XX = ± 0.25 ANGLES = ± 1°
NAME	HOSE BRACKET - SINGLE BOTTOM
NEXT ASSEMBLY	
GROUP/BUNDLE	
PART NUMBER	P500018
TYPE	558
SERV	4
A4-27	
SHEET	1 OF 1

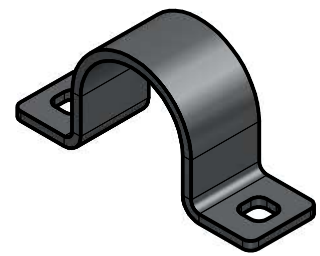
MacDon®

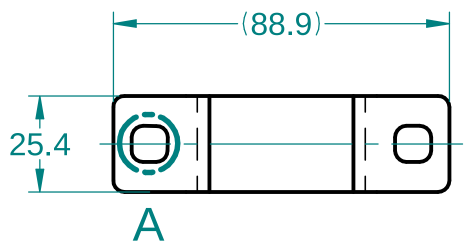
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

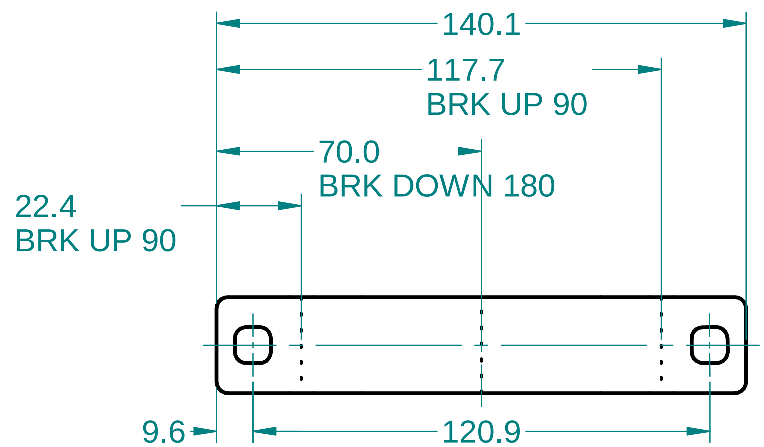
PART NUMBER
P500017

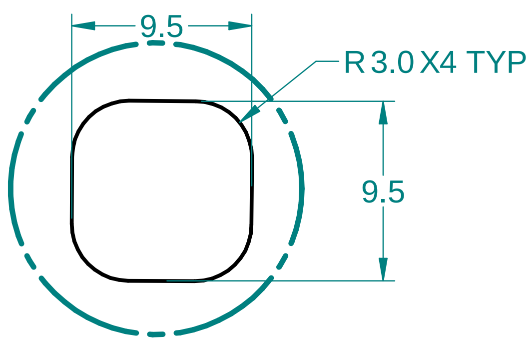
NOT TO SCALE - DO NOT SCALE DRAWING











DETAIL A

MATERIAL
ASTM A36 STEEL PLATE - .125" THICK

DESIGNER	JB
DIMENSIONS ARE :	MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :	- = ± 2 .X = ± 1.0 .XX = ± 0.25 ANGLES = ± 1°
NAME	HOSE BRACKET - SINGLE OUTER
NEXT ASSEMBLY	GROUP/BUNDLE
PART NUMBER	P500017
TYPE	558
SERV	4
	A4-28
SHEET	1 OF 1

MacDon

MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

PART NUMBER
A500005

NOT TO SCALE – DO NOT SCALE DRAWING

Item Number	Part Number	Author	Quantity
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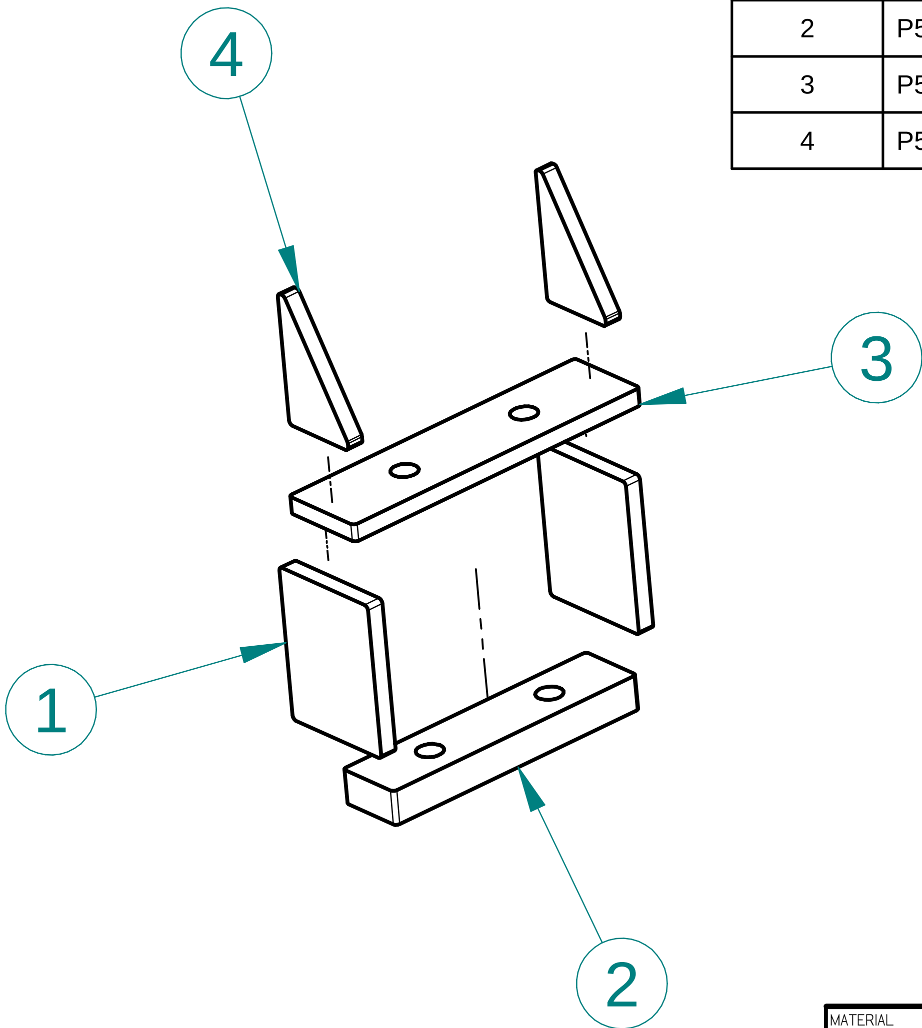
2	P500022	Jeff	1
3	P500021	Jeff	1
4	P500019	Jeff	2



MATERIAL

DIMENSIONS ARE :
MILLIMETERS
UNLESS SPECIFIED
TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
DRAWBAR - ASSEMBLY

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
A500005

DESIGNER
JB

MacDon

MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

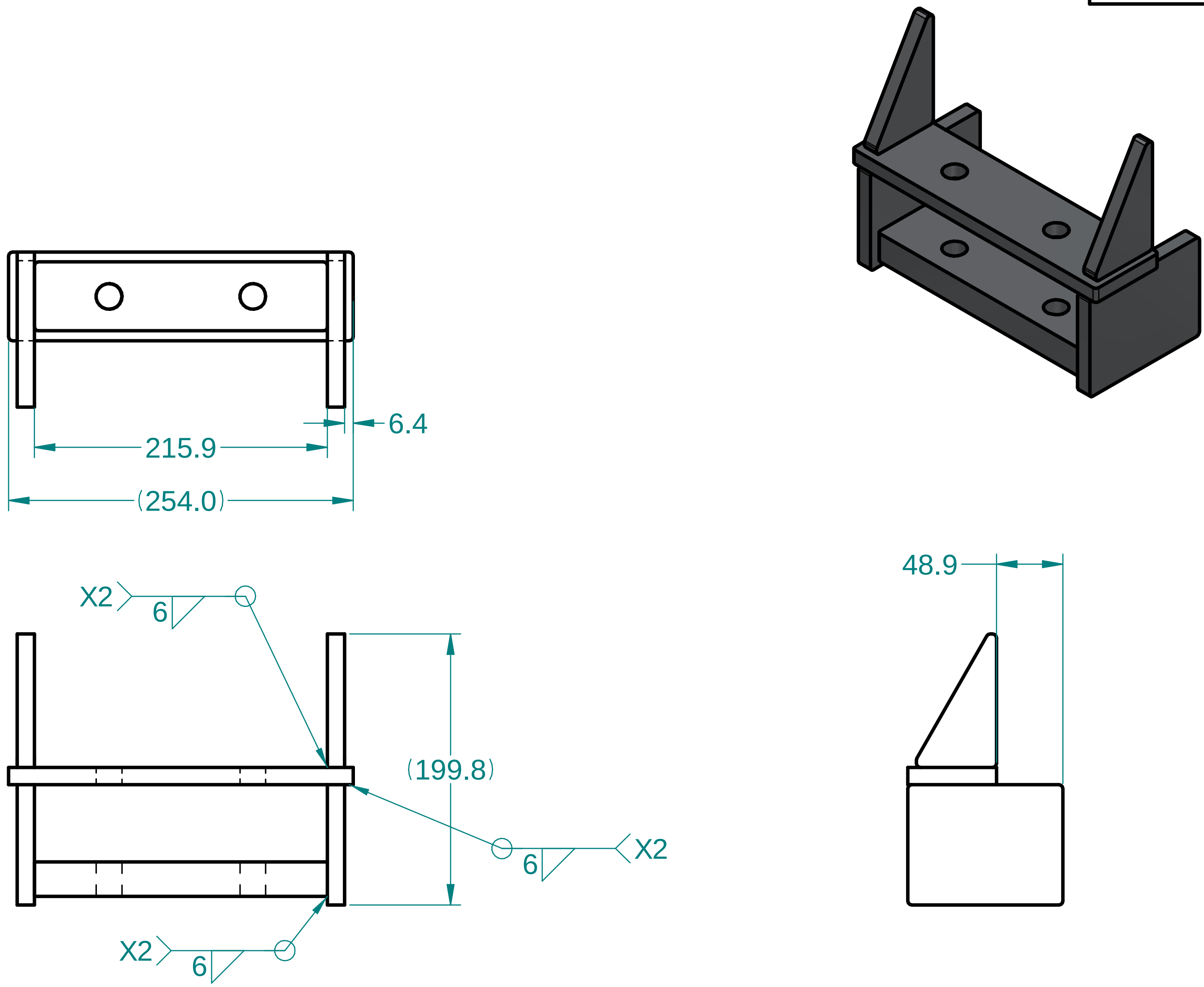
TYPE 558 A4-29

SERV 4

SHEET 1 OF 2

PART NUMBER
A500005

NOT TO SCALE – DO NOT SCALE DRAWING



MATERIAL

DIMENSIONS ARE :
MILLIMETERS
UNLESS SPECIFIED
TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
DRAWBAR - ASSEMBLY

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
A500005

MacDon
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

DESIGNER
JB

TYPE 558 A4-30

SERV 4

SHEET 2 OF 2

PART NUMBER
P500020

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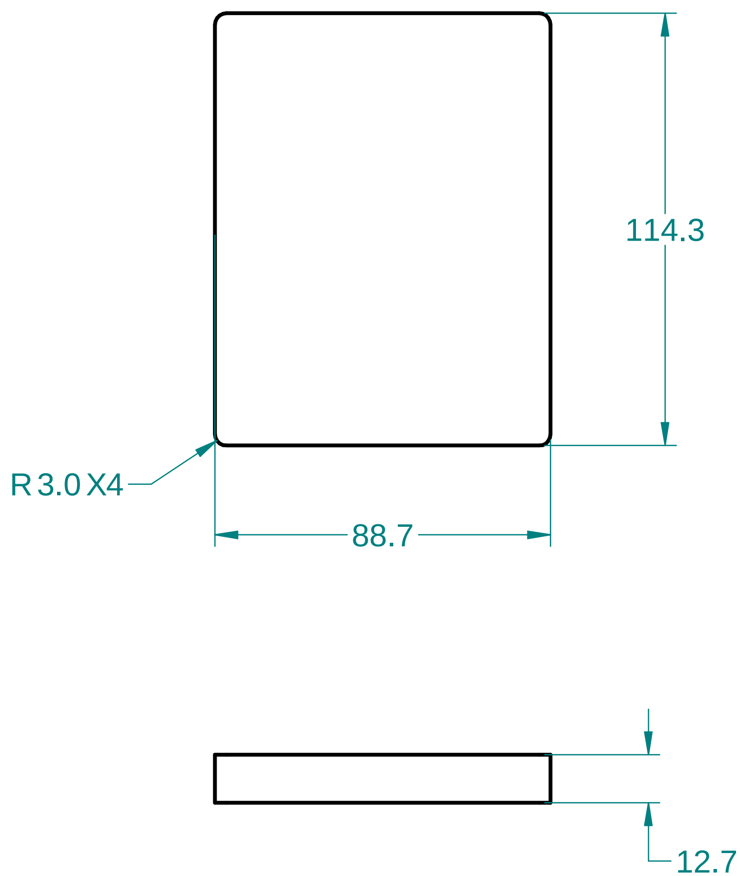
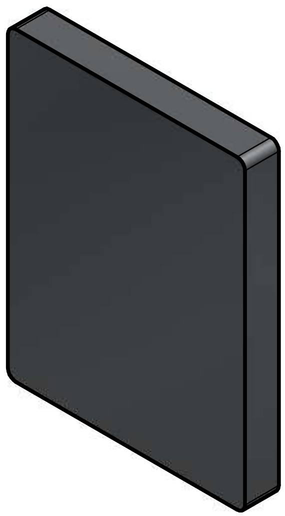


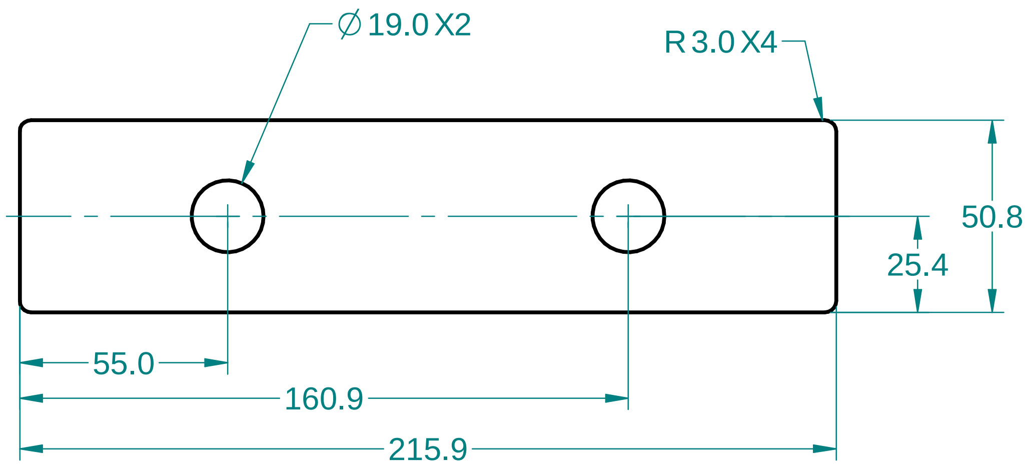


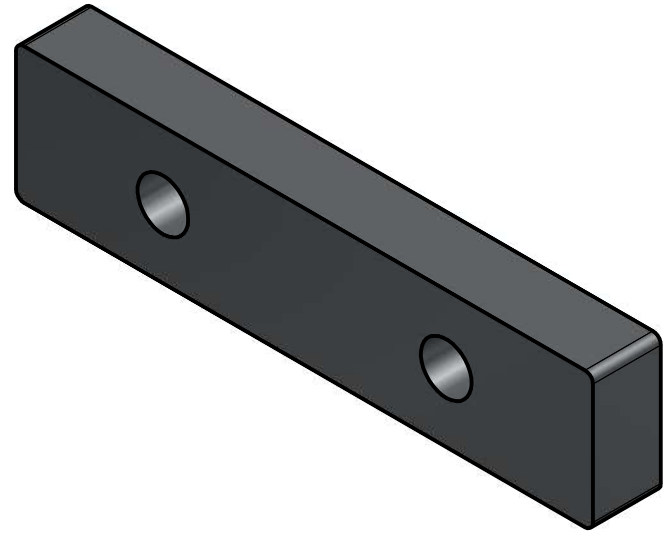
MATERIAL	ASTM A36 STEEL PLATE - .5" THICK
DIMENSIONS ARE : MILLIMETERS	UNLESS SPECIFIED TOLERANCES ARE : - = ± 2, .X = ± 1.0, .XX = ± 0.25, ANGLES = ± 1°
NAME	DRAWBAR - RECTANGLE PLATE
DESIGNER	JB
NEXT ASSEMBLY	
GROUP/BUNDLE	
PART NUMBER	P500020
TYPE	558
SERV	4
	A4-31
SHEET	1 OF 1

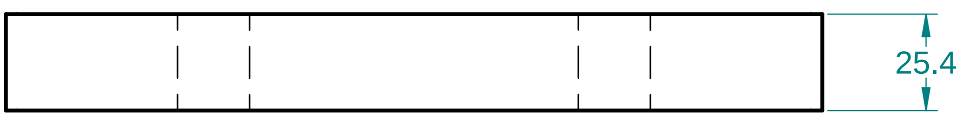
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

PART NUMBER
P500022

NOT TO SCALE – DO NOT SCALE DRAWING







MATERIAL
ASTM A36 STEEL PLATE - 1" THICK

DIMENSIONS ARE :
MILLIMETERS
UNLESS SPECIFIED
TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
DRAWBAR - BOTTOM PLATE

MacDon

MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
P500022

TYPE 558 A4-32

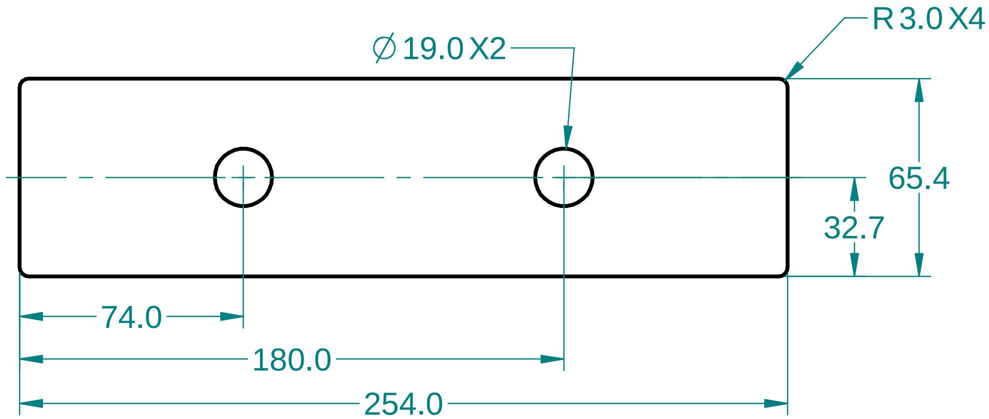
SERV 4

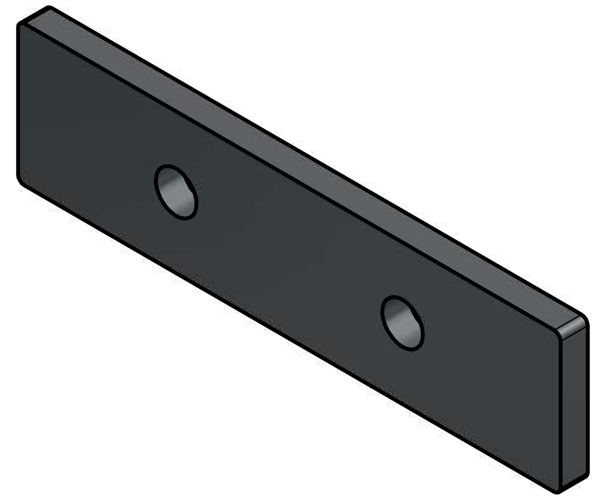
SHEET 1 OF 1

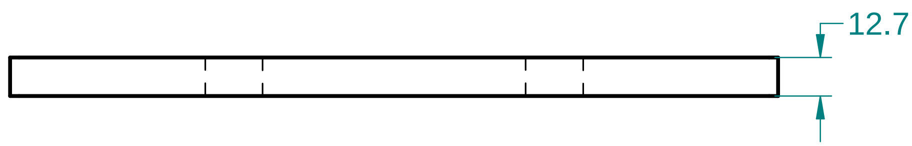
DESIGNER
JB

PART NUMBER
P500021

NOT TO SCALE – DO NOT SCALE DRAWING







MATERIAL
ASTM A36 STEEL PLATE - .5" THICK

DIMENSIONS ARE : MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
DRAWBAR - UPPER PLATE

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
P500021

DESIGNER: JB

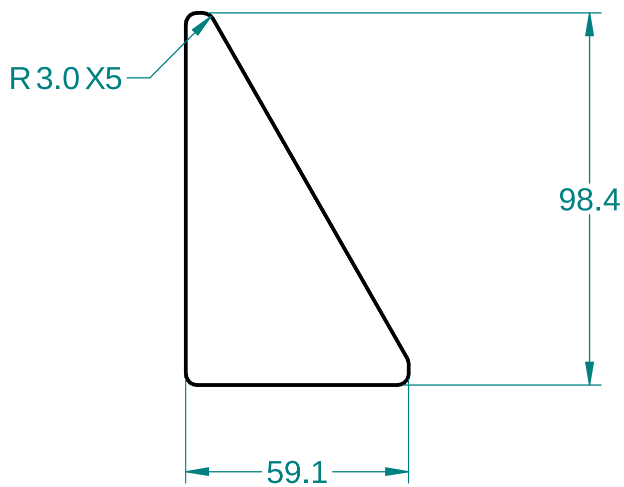
MacDon

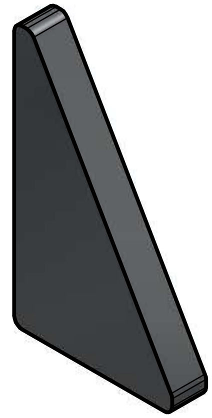
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

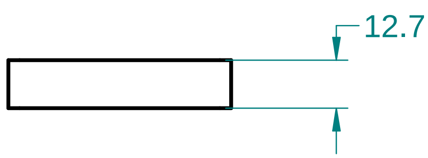
TYPE 558 A4-33
SERV 4
SHEET 1 OF 1

PART NUMBER
P500019

NOT TO SCALE – DO NOT SCALE DRAWING





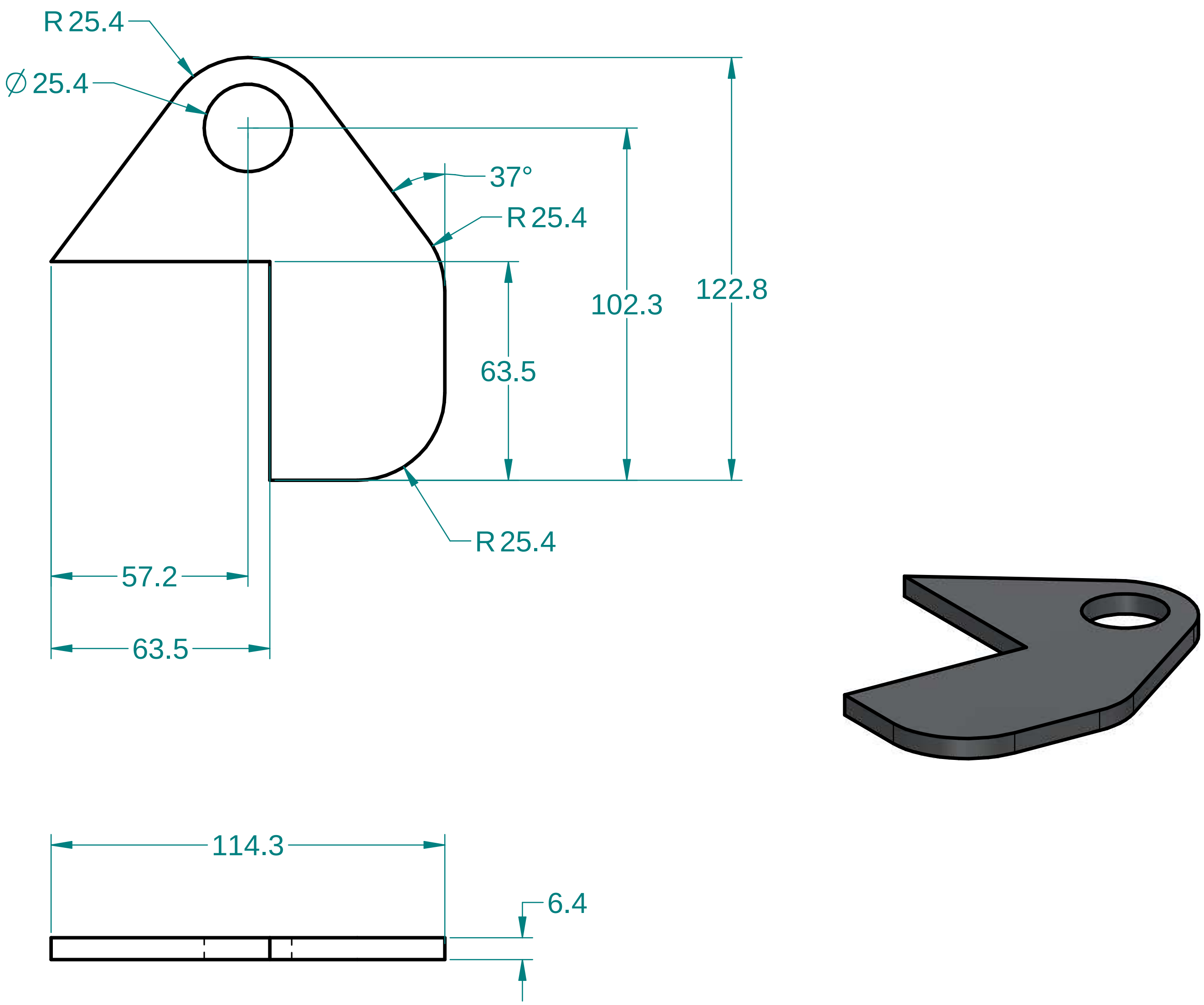


MATERIAL	ASTM A36 STEEL PLATE - .5" THICK
DIMENSIONS ARE : MILLIMETERS	NAME: DRAWBAR - TRIANGLE PLATE
UNLESS SPECIFIED TOLERANCES ARE : – = ± 2; .X = ± 1.0; .XX = ± 0.25; ANGLES = ± 1°	NEXT ASSEMBLY / GROUP/BUNDLE
DESIGNER: JB	PART NUMBER: P500019
TYPE: 558	A4-34
SERV: 4	SHEET 1 OF 1

MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

PART NUMBER
P500009

NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL
ASTM A36 STEEL PLATE - .25" THICK

DIMENSIONS ARE :
MILLIMETERS
UNLESS SPECIFIED
TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
FRAME - TILT CYLINDER BRACKET

NEXT ASSEMBLY	GROUP/BUNDLE

PART NUMBER
P500009

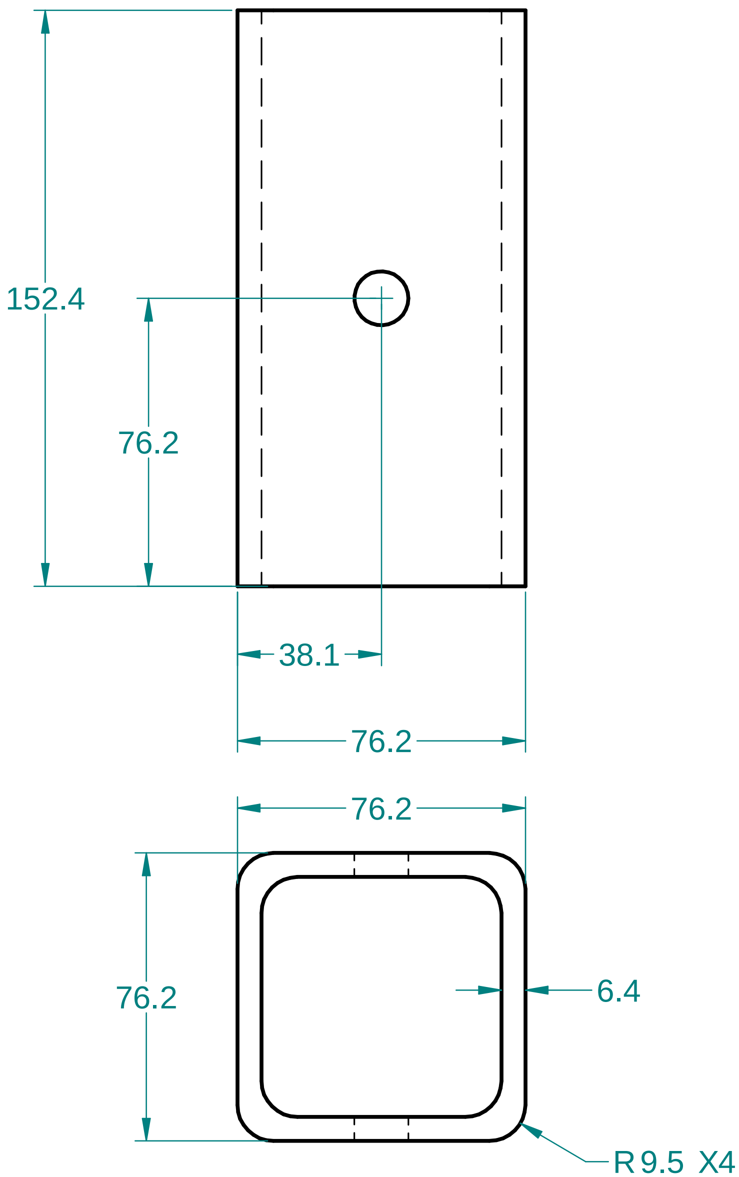
TYPE	558	A4-35
SERV	4	SHEET 1 OF 1

DESIGNER
JB

MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba
Canada R3J 3S3

PART NUMBER
P500010

NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL
ASTM A500 GRADE B 3" X 3" X .25" WALL

DESIGNER
JB

DIMENSIONS ARE :
MILLIMETERS
UNLESS SPECIFIED
TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
KICKSTAND - OUTER TUBE

MacDon
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
P500010

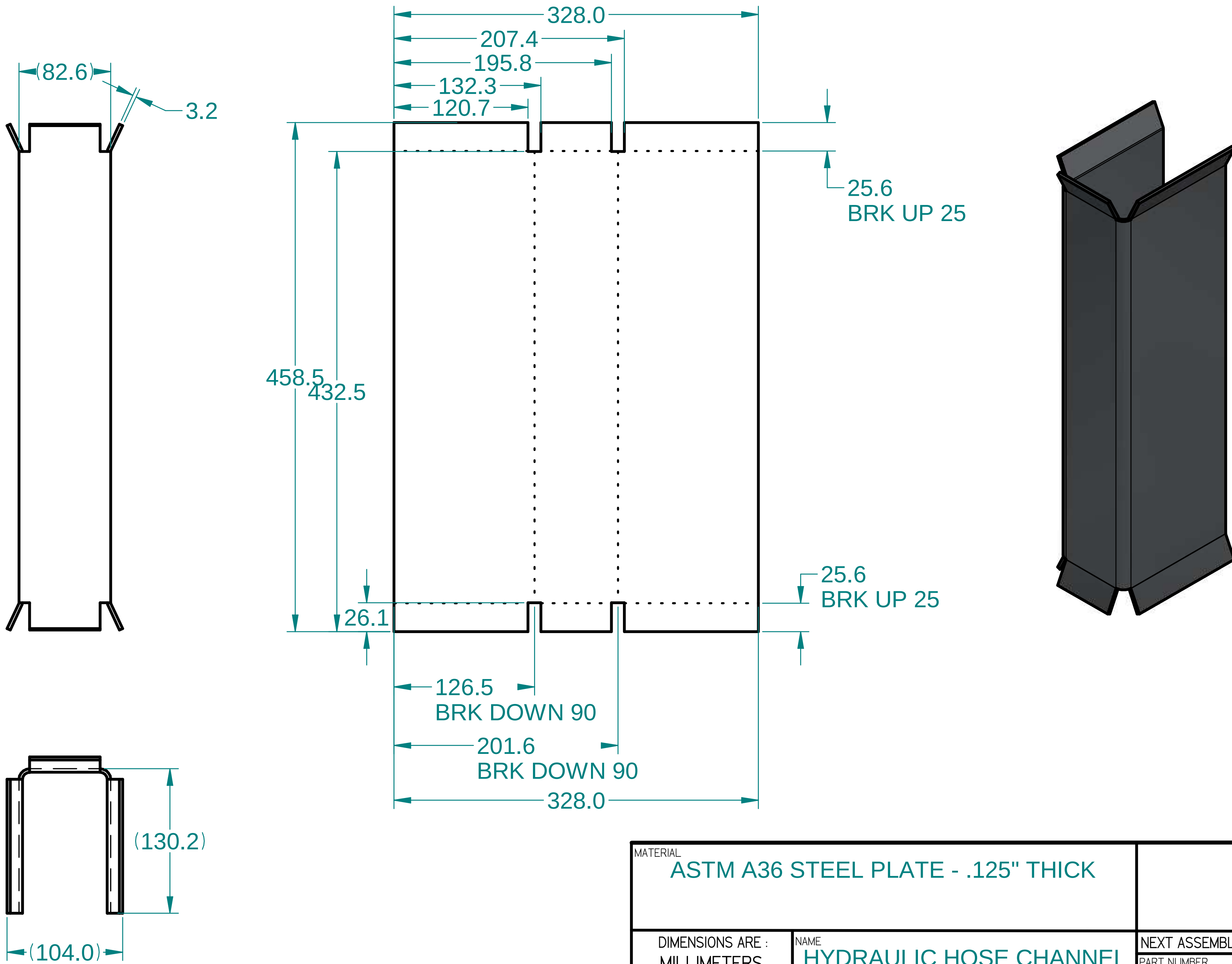
TYPE 558 A4-36

SERV 4

SHEET 1 OF 1

PART NUMBER
P500014

NOT TO SCALE - DO NOT SCALE DRAWING

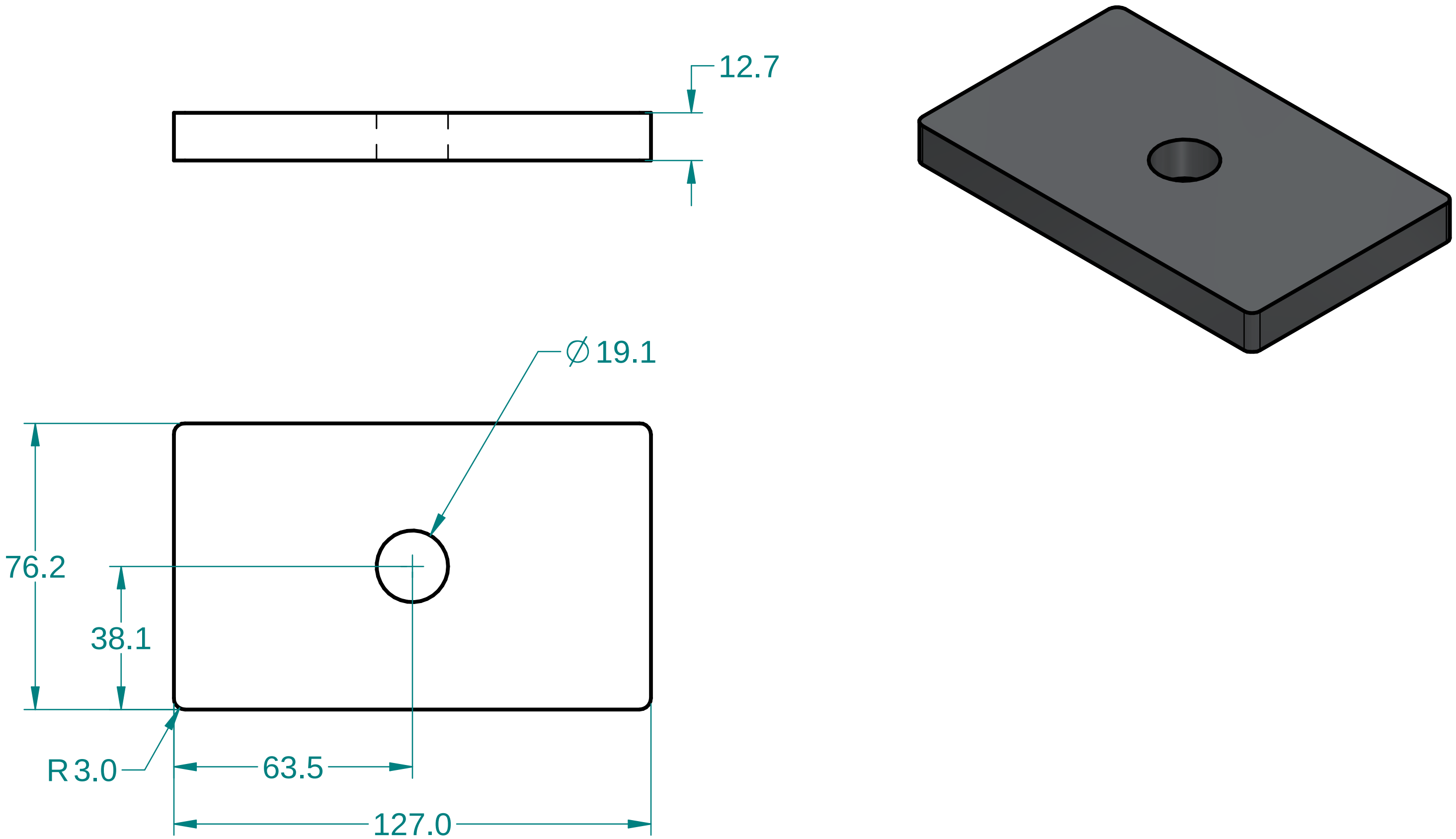


MATERIAL
ASTM A36 STEEL PLATE - .125" THICK

DIMENSIONS ARE : MILLIMETERS UNLESS SPECIFIED TOLERANCES ARE : - = ± 2 .X = ± 1.0 .XX = ± 0.25 ANGLES = ± 1°	NAME HYDRAULIC HOSE CHANNEL	NEXT ASSEMBLY	GROUP/BUNDLE
		PART NUMBER P500014	
DESIGNER JB	MacDon MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba. Canada R3J 3S3	TYPE 558	A4-37
		SERV 4	SHEET 1 OF 1

PART NUMBER
P500034

NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL
ASTM A36 STEEL - .5" THICK

DIMENSIONS ARE :
MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
DRAWBAR SPACER

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER
P500034

MacDon
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

DESIGNER
JB

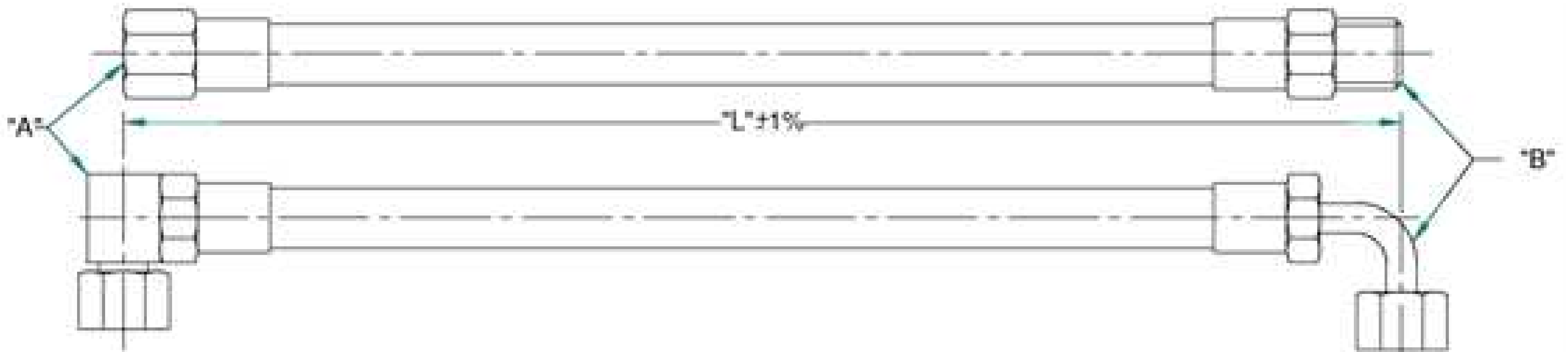
TYPE 558 A4-38

SERV 4

SHEET 1 OF 1

PART NUMBER **P500005**

HYDRAULIC HOSE ASSEMBLY



HOSE MATERIAL
SAE 100 R17 AT or
SUPERIOR NON SAE HOSE

DESCRIPTION: HYDRAULIC HOSE WITH BLACK RUBBER COVER REINFORCED BY:
COMPACT 1 OR 2 WIRE BRAID

	MPa	PSI
WORKING PRESSURE	21	3000
PROOF TEST	42	6000
MIN. BURST PRESS.	84	12000

NOMINAL HOSE I.D. **0.25** (inch)	LENGTH "L" = **5555** (mm)	
HOSE ENDS (PERMANENTLY ATTACHED)	"A"	"B"
TYPE OF FITTING	STRAIGHT FEMALE SWIVEL 37-DEG FLARED	STRAIGHT FEMALE SWIVEL 37-DEG FLARED
THREAD OR FITTING SIZE	9/16-18UNF	9/16-18UNF
SAE FITTING NUMBER PER SAE J516	6-4 240193	6-4 240193

NOTES:

1. Hose assembly must conform to the current requirements of SAE J517 and SAE J343.
2. Inside of hose must be clean and free of foreifn particles.
3. Male hose ends to be capped with push on plastic caps.
4. Female hose ends to have threaded plastic or metal plugs.

DESIGNER JB

MATERIAL

DIMENSIONS ARE : MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME HOSE-HYDRAULIC

MacDon
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER **P500005**

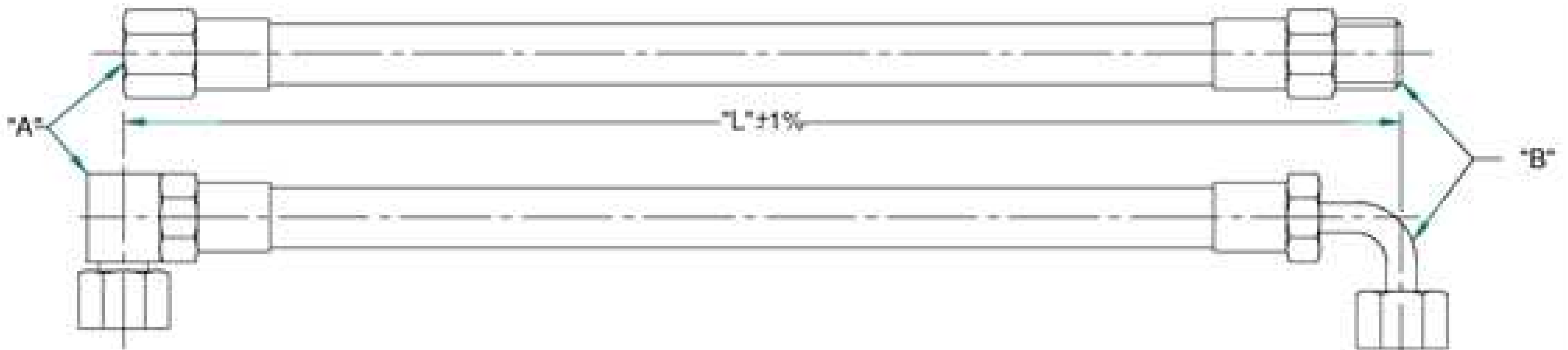
TYPE 348.1
SERV 1
SHEET A4-39 OF

OPPOSITE

A Size

PART NUMBER	
P500006	

HYDRAULIC HOSE ASSEMBLY



HOSE MATERIAL SAE 100 R17 AT or SUPERIOR NON SAE HOSE	DESCRIPTION: HYDRAULIC HOSE WITH BLACK RUBBER COVER REINFORCED BY: 1 WIRE BRAID	
NOMINAL HOSE I.D. **0.75** (inch)	LENGTH "L" = **5870** (mm)	
HOSE ENDS (PERMANENTLY ATTACHED)	"A"	"B"
TYPE OF FITTING	MALE STRAIGHT THREAD O-RING BOSS	STRAIGHT FEMALE SWIVEL 37-DEG FLARED
THREAD OR FITTING SIZE	1 1/16-12UNF	3/4-16UNF
SAE FITTING NUMBER PER SAE J516	12-10 180193	8-10 240193

	MPa	PSI
WORKING PRESSURE	21	3000
PROOF TEST	42	6000
MIN. BURST PRESS.	84	12000

NOTES:

1. Hose assembly must conform to the current requirements of SAE J517 and SAE J343.
2. Inside of hose must be clean and free of foreifn particles.
3. Male hose ends to be capped with push on plastic caps.
4. Female hose ends to have threaded plastic or metal plugs.

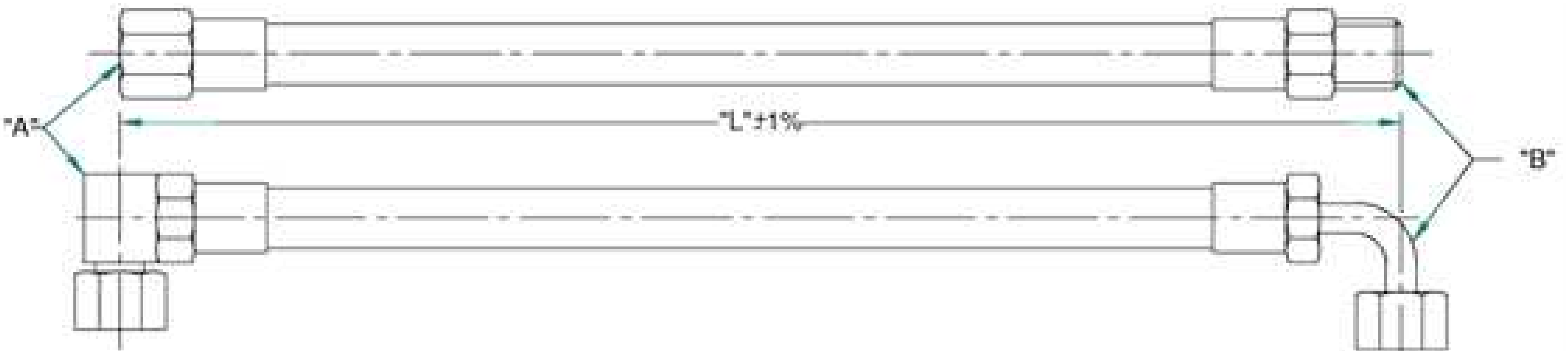
DESIGNER JB	MATERIAL		
DIMENSIONS ARE : MILLIMETERS UNLESS SPECIFIED TOLERANCES ARE : - = ± 2 X = ± 1.0 XX = ± 0.25 ANGLES = ± 1°	NAME HOSE-HYDRAULIC	NEXT ASSEMBLY	GROUP/BUNDLE
	MacDon	PART NUMBER P500006	
	MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba Canada R3J 3S3	TYPE 348.1	
		SERV 1	SHEET A4-40 OF

OPPOSITE

A Size

PART NUMBER **P500007**

HYDRAULIC HOSE ASSEMBLY



HOSE MATERIAL SAE 100 R17 AT or SUPERIOR NON SAE HOSE	DESCRIPTION: HYDRAULIC HOSE WITH BLACK RUBBER COVER REINFORCED BY: 1 WIRE BRAID	
NOMINAL HOSE I.D. **1.00** (inch)	LENGTH "L" = **5620** (mm)	
HOSE ENDS (PERMANENTLY ATTACHED)	"A"	"B"
TYPE OF FITTING	STRAIGHT FEMALE 0-RING FACE SEAL	90 DEG DEMALE SPLIT FLANGE(HIGH PRESSURE-CODE 62)
THREAD OR FITTING SIZE	1 11/16-12	SAE #16 (I)
SAE FITTING NUMBER PER SAE J516	16-16 530179	NO SAE NUMBER

	MPa	PSI
WORKING PRESSURE	21	3000
PROOF TEST	42	6000
MIN. BURST PRESS.	84	12000

NOTES:

1. Hose assembly must conform to the current requirements of SAE J517 and SAE J343.
2. Inside of hose must be clean and free of foreifn particles.
3. Male hose ends to be capped with push on plastic caps.
4. Female hose ends to have threaded plastic or metal plugs.

MATERIAL

DIMENSIONS ARE : MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :
- = ± 2
X = ± 1.0
XX = ± 0.25
ANGLES = ± 1°

NAME: HOSE-HYDRAULIC

NEXT ASSEMBLY | GROUP/BUNDLE

PART NUMBER: P500007

MacDon
MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba
Canada R3J 3S3

DESIGNER: JB

TYPE 348.1

SERV 1

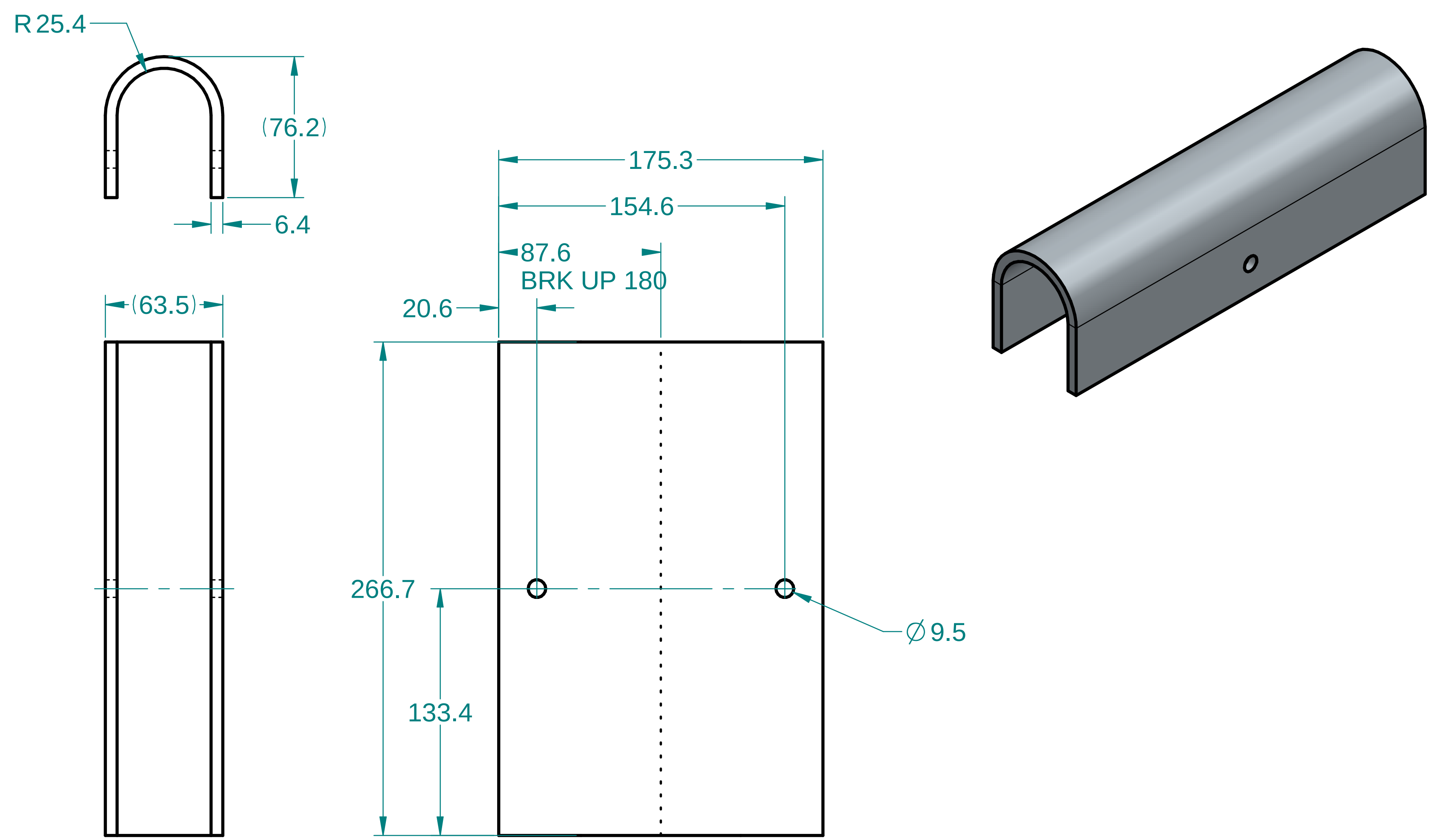
SHEET A4-41 OF

OPPOSITE

A Size

PART NUMBER
P500013

NOT TO SCALE - DO NOT SCALE DRAWING



MATERIAL
ASTM A36 STEEL PLATE - .25" THICK

DIMENSIONS ARE :
MILLIMETERS
UNLESS SPECIFIED
TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

NAME
LIFT CYLINDER BLOCK

NEXT ASSEMBLY	GROUP/BUNDLE

PART NUMBER
P500013

MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

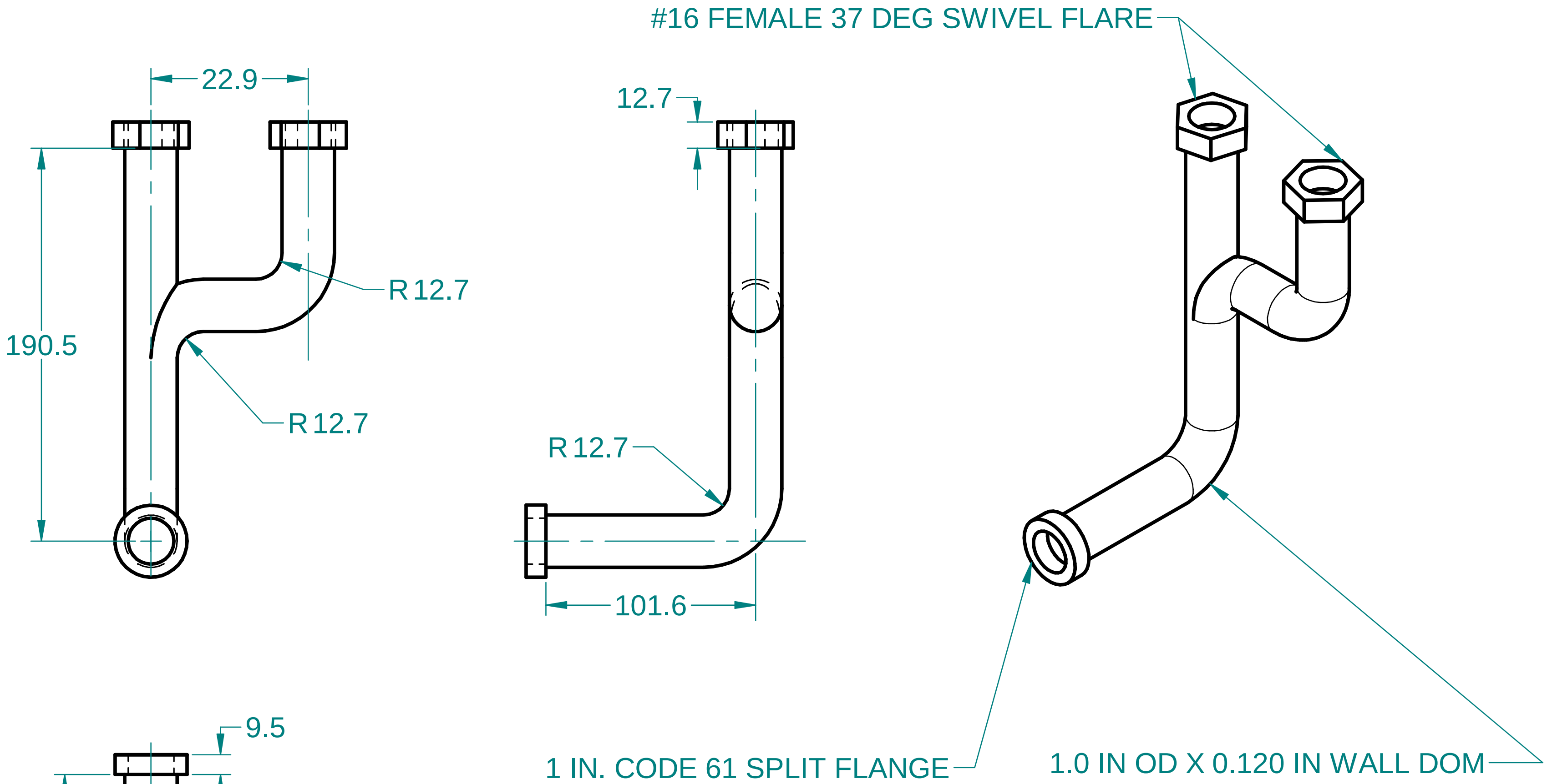
DESIGNER
JB

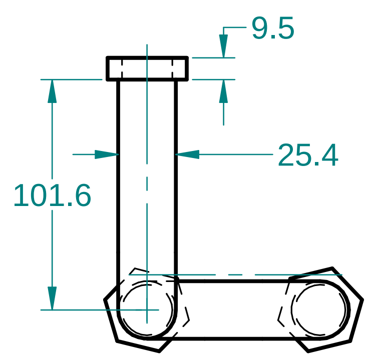
TYPE 558 A4-42
SERV 4 SHEET 1 OF 1

PART NUMBER

P500031

NOT TO SCALE - DO NOT SCALE DRAWING





NOTES:

1) ZINC DICHROMATE PLATE, YELLOW PER ASTM B633 TYPE II, MINIMUM THICKNESS 8uM (MUST WITHSTAND 48 HOUR WHITE CORROSION RESISTANCE TO ASTM B117 SALT FOG SPRAY)

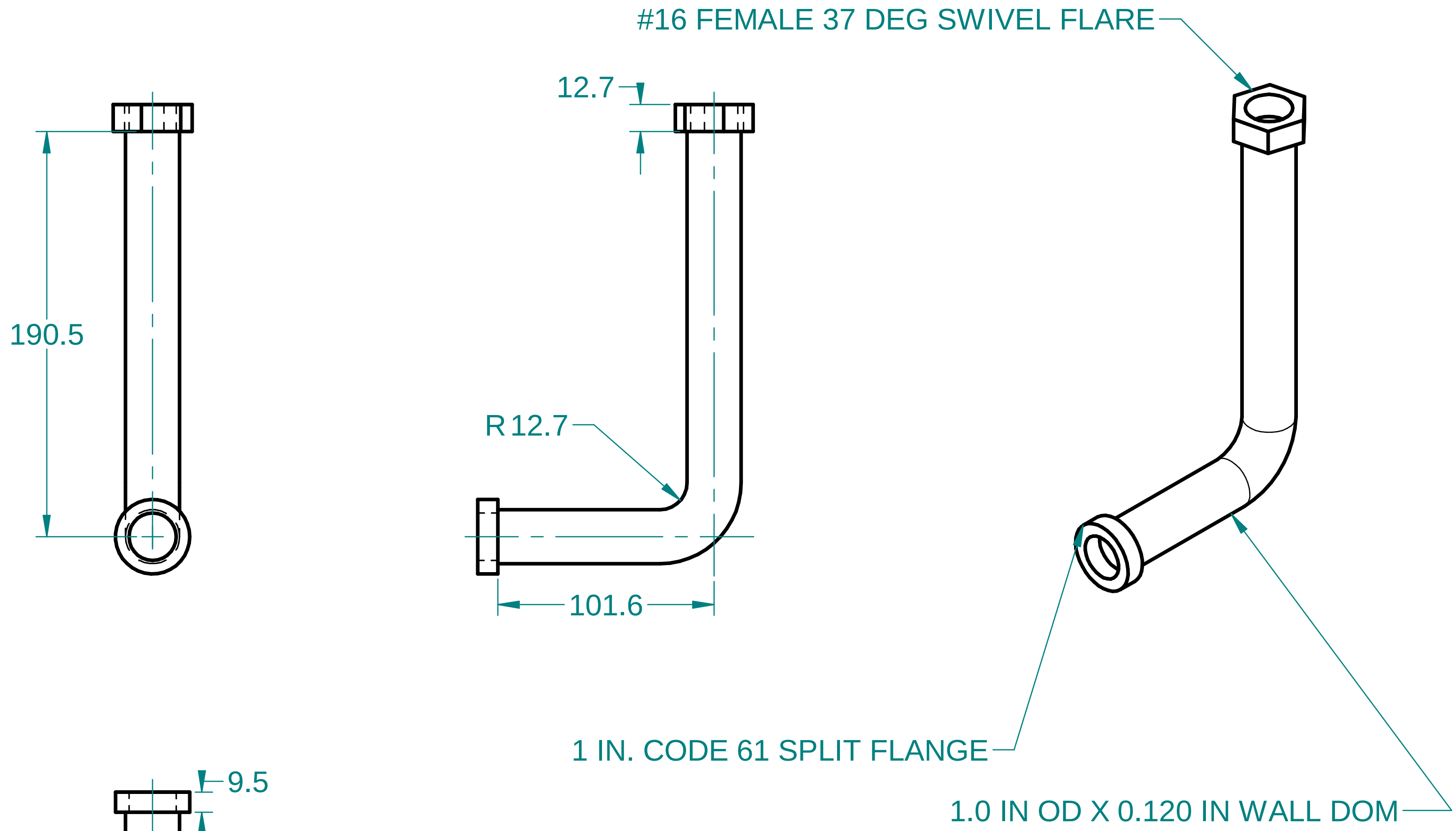
2) ALL TOLERANCES +/- 3mm (1/8 in.)

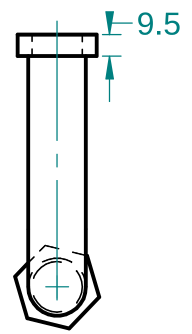
MATERIAL

DIMENSIONS ARE : MILLIMETERS UNLESS SPECIFIED TOLERANCES ARE : - = ± 2 .X = ± 1.0 .XX = ± 0.25 ANGLES = ± 1°	NAME LINE - HIGH PRESSURE	NEXT ASSEMBLY	GROUP/BUNDLE
		PART NUMBER **P500031**	
DESIGNER JB	MacDon MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba. Canada R3J 3S3	TYPE 558	A4-43
		SERV 4	SHEET 1 OF 1

PART NUMBER
P500032

NOT TO SCALE - DO NOT SCALE DRAWING





NOTES:

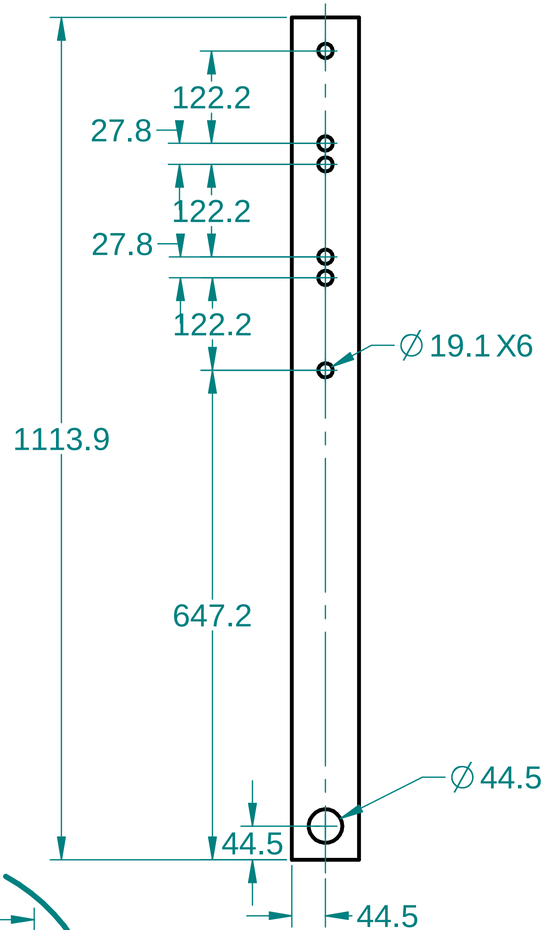
1) ZINC DICHROMATE PLATE, YELLOW PER ASTM B633 TYPE II, MINIMUM THICKNESS 8uM (MUST WITHSTAND 48 HOUR WHITE CORROSION RESISTANCE TO ASTM B117 SALT FOG SPRAY)

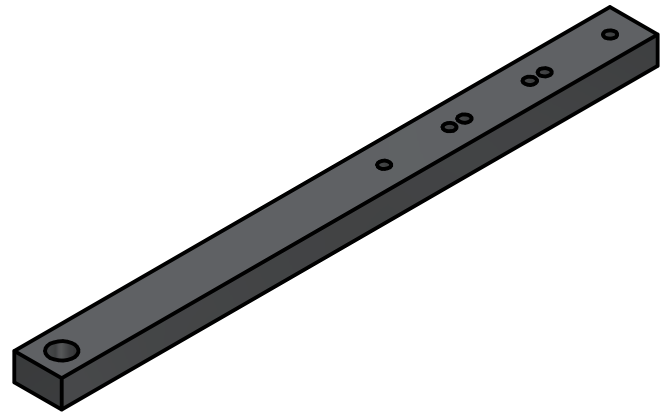
2) ALL TOLERANCES +/- 3mm (1/8 in.)

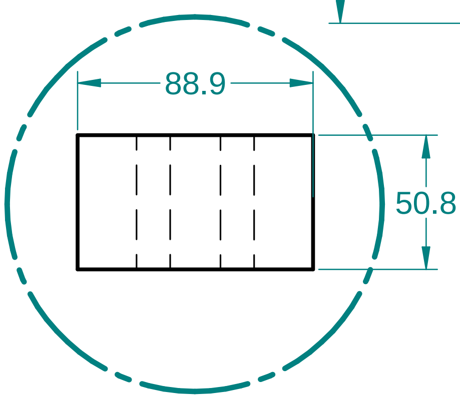
MATERIAL			
DIMENSIONS ARE : MILLIMETERS UNLESS SPECIFIED TOLERANCES ARE : - = ± 2 .X = ± 1.0 .XX = ± 0.25 ANGLES = ± 1°	NAME LINE - RETURN	NEXT ASSEMBLY	GROUP/BUNDLE
DESIGNER JB	MacDon MacDon Industries Ltd. 680 Moray Street Winnipeg, Manitoba. Canada R3J 3S3	PART NUMBER P500032	
		TYPE 558	A4-44
		SERV 4	SHEET 1 OF 1

PART NUMBER
P500033

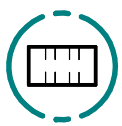
NOT TO SCALE - DO NOT SCALE DRAWING







DETAIL A



A

MATERIAL	ASTM A36 STEEL - 2" THICK
NAME	DRAWBAR
NEXT ASSEMBLY	GROUP/BUNDLE
PART NUMBER	P500033
DESIGNER	JB
TYPE	558
SERV	4
	A4-45
SHEET 1 OF 1	

DIMENSIONS ARE : MILLIMETERS
UNLESS SPECIFIED TOLERANCES ARE :
- = ± 2
.X = ± 1.0
.XX = ± 0.25
ANGLES = ± 1°

MacDon

MacDon Industries Ltd.
680 Moray Street
Winnipeg, Manitoba.
Canada R3J 3S3

Appendix 5 – Installation Guide Package

Table of Contents

Table of Figures

1.0 Overview

This hitch attachment for the M155 is equipped with a power take off shaft connection from a reduction gearbox powered by a hydraulic motor. It is attached to the M Series tractor through a built in boot connection and solid mechanical center link in the place of a tilt cylinder. The following guide elaborates on the steps which should be taken to install the attachment package. It should be noted that the MacDon disc drive kit (MD#B4657) should be installed prior to attempting to install the hitch attachment. The central tilt cylinder should also be removed from the tractor along with any hydraulic hoses accompanying it.

2.0 Connect to Lift Linkage and Attach Center Link

1. Drive tractor slowly up to the attachment so that the bottom of the lift linkages slide smoothly into the built in boots. Ensure the lift linkage is as far into the boots as possible before placing the tractor in park and exiting the machine.

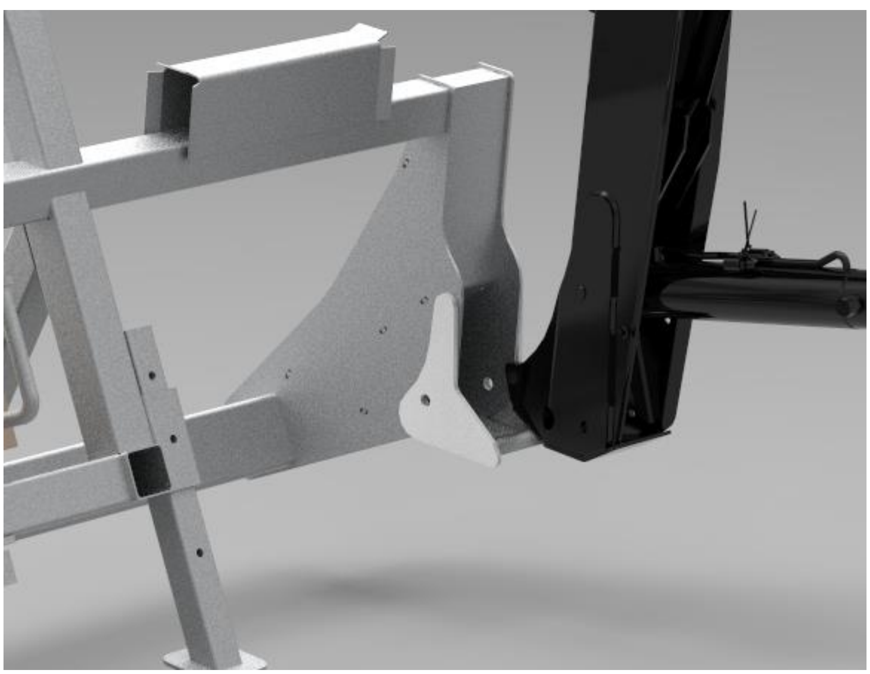


Figure A5-1: Example of tractor approaching attachment and lining the lift linkage up with the boot. Wheel removed for clarity.

2. Slide the pins (MD#135408) in through one side of the built in boot, through the lift linkage and out the other side. Install the hair pin (MD#13125) on the main pin once it has been slid all the way through. Do this for both lift linkages.

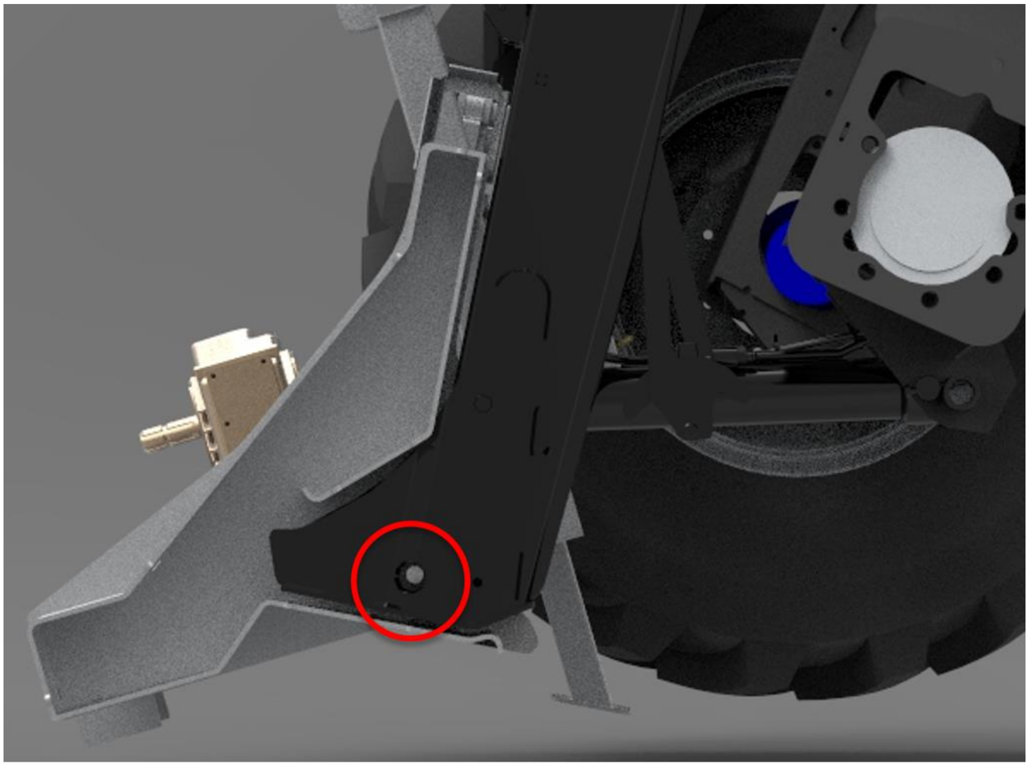


Figure A5-2: Lift linkage inserted into built in boot of attachment. Hole for pin is circled in red.

3. Raise lift linkage until the attachment is sufficiently off the ground that the new lift cylinder lock can be moved into position. Move this lockout into position on both sides and lower the lift cylinder back down until the weight sits on the lock.
4. Install the mechanical center link (MD#112869) between the frame of the tractor and the attachment frame. Use a clevis pin (MD#102265) and a lynch pin (MD#102264) for each side. Adjust the center link so that it is tight but not so tight as to start removing weight from the lift linkages. Raise the kick stand into field position.

Figure A5-3: Mechanical center link placed in position on attachment frame.

3.0 Install the Drawbar.

5. Slide the drawbar through the front slot and insert the M16 bolt (MD#184678) at the desired location. Install nut (MD#135476) and torque to 170 N-m.

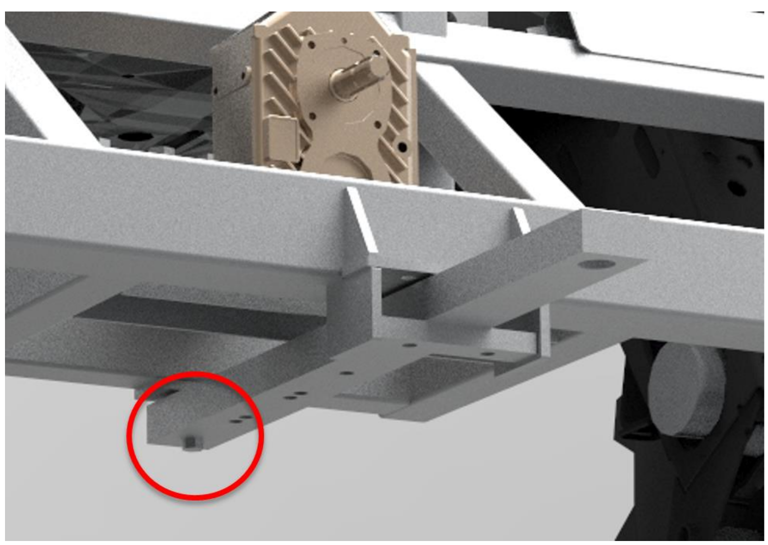


Figure A5-4: Drawbar position when installed. Main drawbar bolt circled in red.

4.0 Connect Hydraulics

6. Take the first steel line (Part Number) and connect it to the pressure port at the back of the hydraulic motor on the attachment. This line should have a split flange fitting on one end and two -16 ORFS female fittings at the other end. Use the split flange assembly (MD#112866) to connect the line to the motor. Torque the bolts to 46 N-m.
7. Take the second steel line (Part # P500032) and connect it to the return port at the back of the hydraulic motor on the attachment. This line should have the same split flange on one end, but only a single -16 ORFS female fitting at the other end. Use the split flange assembly (MD#112866) to connect the line to the motor. Torque the bolts to 46 N-m.
8. Install a 12-12 ORB to ORFS 90 degree, male-male fitting (MD#135821) into the case drain port on the motor and torque to 126 N-m. Ensure the ORFS end faces towards the tractor.
9. Install a 16-16 ORB to ORFS straight male to male fitting (MD#135791) into the M1 and M2 ports on the knife drive and disc drive block on the stair side of the tractor. Torque to 185 N-m.
10. Install a 16-16 ORB to ORFS straight male to male fitting (MD#135791) into the C port on the header drive block on the stair side of the tractor. Torque to 185 N-m.
11. Install a 10-12 ORB to ORFS straight male-male fitting into the T3 port on the multifunction control block. Torque to 79 N-m.
12. Collect two of the -16 hydraulic hoses (Part #P500007) and connect the female to the fitting in the M1 port and the second to the fitting in the M2 port. Torque both to 158 N-m. Route these hoses along the side of the tractor, through the tube between the cab and the tire, around the corner and into the channel on the attachment. Connect the ends to the forked steel line. Torque connection to 158 N-m.
13. Collect the third -16 hydraulic hose (Part #P500007) and connect the female fitting to the fitting in the C port. Torque to 158 N-m. Route this hose along the

side of the tractor, through the tube between the cab and the tire, around the corner and into the channel on the attachment. Connect the end to steel line running to the motor return. Torque connection to 158 N-m.

14. Collect the -10 hydraulic hose (Part #P500006) and connect the female fitting to the fitting in the T3 port. Torque to 121 N-m. Route the hose along the same path as the pressure and return lines and connect it to case drain fitting on the motor. Torque to 121 N-m.
15. Install the auxiliary valve block based on the instructions contained within the bundle (MD#B5269).
16. Remove the -4 hoses running from the reel lift and fore-aft circuits. For the reel lift circuit, remove the hose at the speed adjustment valve.
17. Install the 6-6 ORB male to ORFS female fittings (MD#135778) in the auxiliary hydraulic ports. These include the J and K ports on both of the auxiliary blocks and into the end of the flow adjustment valve coming out of the D port on the multifunction control block. Torque to 28 N-m.
18. Install the -4 hoses (Part #500005) onto the J and K port fittings. Torque to 42 N-m.
19. Install the last -4 hydraulic hose onto the 6-6 ORB to ORFS fitting in the valve. Torque to 42 N-m.
20. Run all five -4 hydraulic hose under the tractor frame, and around the right non step side of the tractor. Route them through the hose tube, then through the hose channel on the attachment frame.
21. Install the 10-6 ORB male to ORFS female fitting into the pioneer quick coupler (MD#114143). Torque to 79 N-m.
22. Install on pioneer quick coupler (MD#114143) onto the end of each of the five -4 hydraulic hoses. Torque to 42 N-m.
23. Install pioneer quick couplers into the mounting brackets on the adapter. Torque bolts to 29 N-m.

5.0 Install Wiring Harnesses

24. Disconnect the P32 and P33 connectors from the seat position switches.
25. Install the intermediate wiring harness into the P32 and P33 connectors as per the wiring diagram as shown in Figure A5-5.

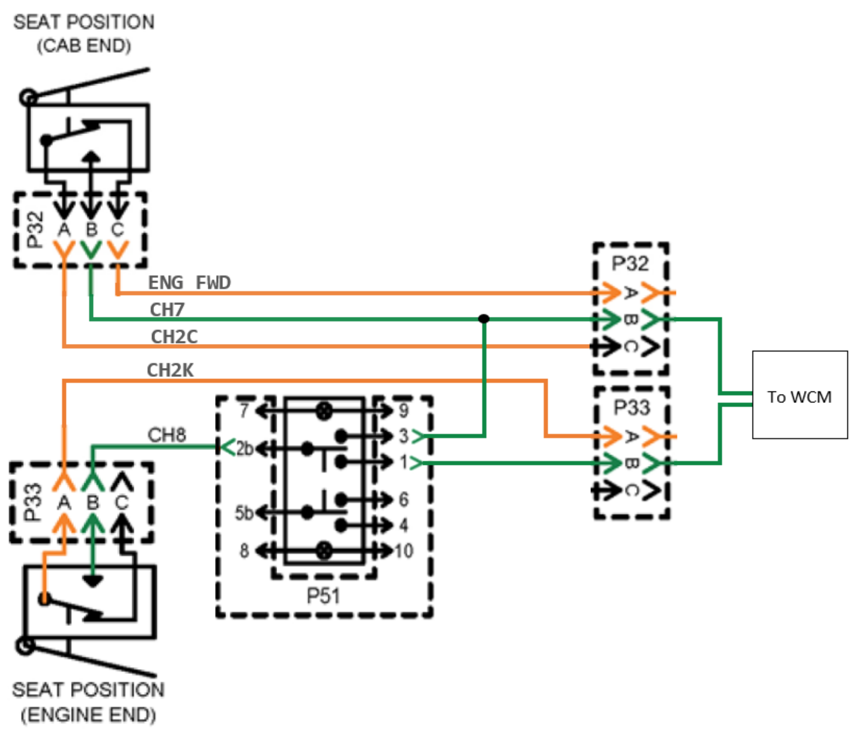


Figure A5-5: Intermediate wiring harness used to bypass the signal from the seat position switch.

26. Route the wires in such a way that the switch is positioned near the drivers counsel. Ensure all wires are tucked away to prevent them from getting snagged or pulled on.
27. Disconnect the P60 and P61 connectors from their solenoids on the multifunction control block.
28. Install the intermediate wiring harness into the P60 and P61 connectors as per the wiring diagram as shown in Figure A5-6.

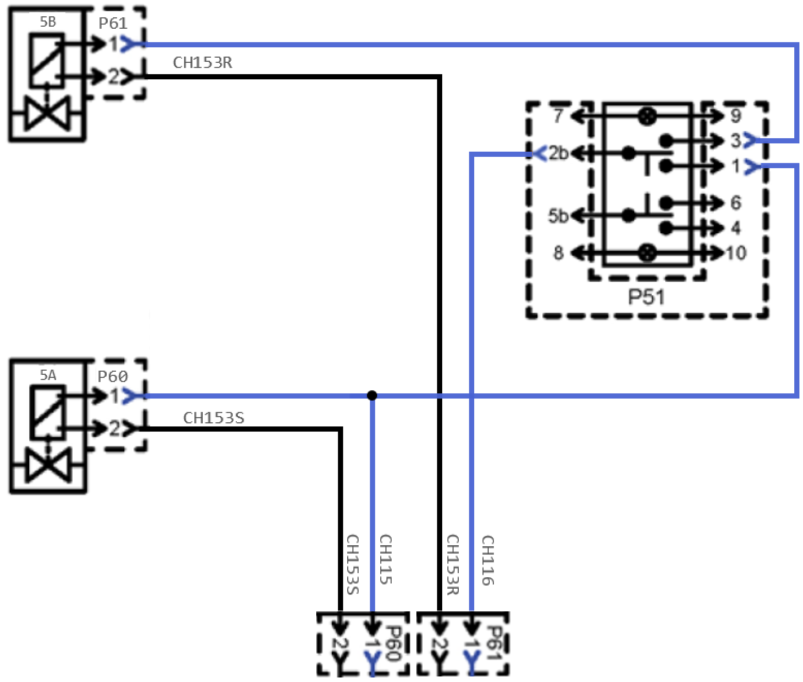


Figure A5-6: Intermediate wiring harness used to manually select the traction drive range.

29. Route the wires in such a way that the switch is positioned near the drivers counsel. Ensure all wires are tucked away to prevent them from getting snagged or pulled on.