2015

Varitrac Engineering Report

MacDon Industries, LTD.

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Introduction

MacDon Industries is an original equipment manufacturer based out of Winnipeg, Manitoba. They have been world leaders in the technology, innovation and manufacturing of high quality, high performance harvesting equipment for over 65 years now, beginning back in 1949. Currently, they sell their products in over 40 countries, on six continents as Figure 1 shows. These products range from hay equipment like rotary and auger headers, to pick-up and draper headers for combines. Additionally, they produce a line of self-propelled windrowers designed to operate rotary, auger and draper headers for a variety of uses to producers.

Figure 1. A Brief Display of Countries with a Strong MacDon Presence

Canola is currently the primary crop produced in Canada. For this reason, MacDon self-propelled windrowers have a wide wheel base and 45.7" below –frame clearance to allow bushy crops like canola to pass under the machine after cutting. This can be seen below, in Figure 2. However, this wide wheel-base means transporting these machines can be time-consuming and costly. MacDon's current design contains a sliding tube held in place by bolts and weld-nuts, where the tube can slide in and out from the main frame when not bolted in place. These "legs" as they are called, require a significant amount of time to adjust, because the machine must be lifted off the ground to allow easy sliding. To this point, the system works because the legs are usually only adjusted to load machines onto trucks, and then to prepare for its working life.

Figure 2. Illustration of Bushy Canola and MacDon's Wheel Clearance

For the purposes of this project, Varitrac Engineering intends on creating a system that will complete this task in much less time than before, with less user effort. By streamlining this process, it could have benefits in multiple areas for MacDon. With this option installed, it would significantly decrease the time required to load these machines onto trucks for shipping around the continent. This would apply to farmers as well if they ever required trucking their machine from one location to another.

More importantly, development of a feature like this would have huge benefits in the European market. Their road systems require strict adherence to lane widths, which the MacDon machine exceeds when the wheels are in a "working" position. However, by streamlining the process of sliding the wheel legs in, a producer could easily move the wheels in to drive between fields, and then quickly spread the wheels for operation again. This feature would make self-propelled windrowers from MacDon much more appealing to European producers, potentially increasing sales.

With all of these benefits in mind, Varitrac Engineering intends on accomplishing this project with the following problem statement in mind:

The goal of this project is to create an innovative, cost-efficient and reliable system that quickly adjusts the wheel width on a MacDon M155 Self-Propelled Windrower.

This project covers the design, testing, and prototyping of an M155 windrower to add a system to quickly adjust wheel width of the machine. The two desirable positions are at full width (field width) and narrowed width (transport width.) The cost of the system should be minimized to make the system more desirable. The deliverables are to include the ability to change the width of both the front and back axle, as well as adjusting the ladder to accommodate the transport width.

The task list for the completion of this project is outlined below:

Table 1. Task List for Project Completion

Task List	Finish Date
Define Client Requirements	10/08/14
Research applicable patents	10/15/14
Establish Multiple Design Ideas	11/05/14
Run Calculations/Analysis on Ideas	11/18/14
Write Design Presentation	12/01/14
Gain Client Approval of Final Design	12/04/14
Construction of 1st Revision	3/23/15
Test and validation of 1st Revision	3/30/15
Evaluation, and Addition design revisions	4/1/15
Completion of Prototype Assembly	04/09/15
Final Presentation and Report	04/30/15

Customer Requirements

For this project, we will need to design a system that enables operators of an M155 self-propelled windrower to quickly adjust the wheel spacing on both sets of tires. MacDon has recommended the transition to occur while the machine is in motion, to reduce frictional forces between the tires and the ground. Regardless of the design, the final locking system must be mechanical in order to ensure safety of the system when locked into position.

This system will only have two (2) settings: Field (Wide) or transport (narrow), in order to accommodate the European road systems and allow for quick loading onto trucks. On the caster (rear) wheels, there are dampening cylinders that prevent excessive wobbling of those tires at high speeds, as shown in Figure 3. The relationship of frame mounting point to the tire must remain constant in both positions, in other words, the distance the cylinder reaches cannot change regardless of wheel spacing.

Figure 3. Damping Cylinder on Caster Tire

Ideally, we would like the operator to accomplish this task alone, without the assistance of other people to perform this adjustment. On top of that, a goal for the team would be to minimize the number of trips in and out of the cab of the machine in order to complete this step. This will be once at the minimum for the assumption that the header of the machine must be removed or attached prior to wheel width adjustment, as defined by MacDon.

The system used to accomplish this task also has spatial requirements. In order to maintain optimal machine performance, alterations to the current hydraulic or frame setup should be minimized. Also, nothing can be installed below the existing frame of the machine, to retain the “window” size for bushy crop to flow under without interference. This frame clearance also applies to the ladder. With the ladder installed and wheels in transport (narrow) position, the ladder sticks out farther than the wheel width. Therefore, a re-design of the ladder is necessary to bring it within the wheel constraints. This must also allow the ladder platform to be moved into different positions as is standard on the MacDon machine. This is illustrated in Figure 4 and Figure 5, which demonstrates the difference between the two positions.

Figure 4. Platform Locked in Rear Position for Service

Figure 5. Platform Locked in Forward Position for Operation

MacDon has also asked that we use the current valves and circuits for this project, meaning no modifications can be done to either system. As shown in Figure 6, in some places these systems take up a lot of space. This system has also been assigned as a dealer-installed kit, so it must be designed so that a machine can be configured with or without the width adjustment, but with necessary components to make installation possible at a dealership.

Figure 6. Hydraulic Blocks and Connection Points of a MacDon Windrower

MacDon has also requested we do an estimate of cost/build for this project, in order to maximize its usefulness as an option. This is outlined in Table 5.

Engineering Specifications

- 7" difference between transport/field wheel widths on front tires
- 18" difference between transport/field wheel widths on rear tires
- Existing hydraulic valves and circuitry (design within the bounds of current system)
- All added components must not exceed machine constraints, both underneath and wide
- Limit of $25 for frame adjustments

Market Research

Currently, John Deere, Apache, CNH, AGCO, and Versatile all have existing systems by which track spacing can be adjusted on their self-propelled sprayers, as a standard feature. While all of these companies advertise this feature, specific technical information is difficult to find. Most of these systems are hydraulically adjusted, and a few have mechanical locking systems for safety purposes. At one point, John Deere offered this feature as an option, which could be added to a sprayer for around $4,376. This gives a target range for when projecting costs for this project.

Campers have frames that expand and contract for being on the road and actual "living" situations. These systems are vital to analyze for their friction reduction system, whether it be a plastic skid or otherwise for friction reducing concepts.

Mechanical locking system from a cattle gate could be implemented on an axle if done properly. The concept is intriguing because it only requires user input for the unlocking stage of use. As the gate shuts, it raises the latch mechanism on either side, then gravity forces the latch back down to securely lock the gate, shown in Figure 7. This idea is especially useful when designing mechanical locks as it helps reduce the operator input when activating the system.

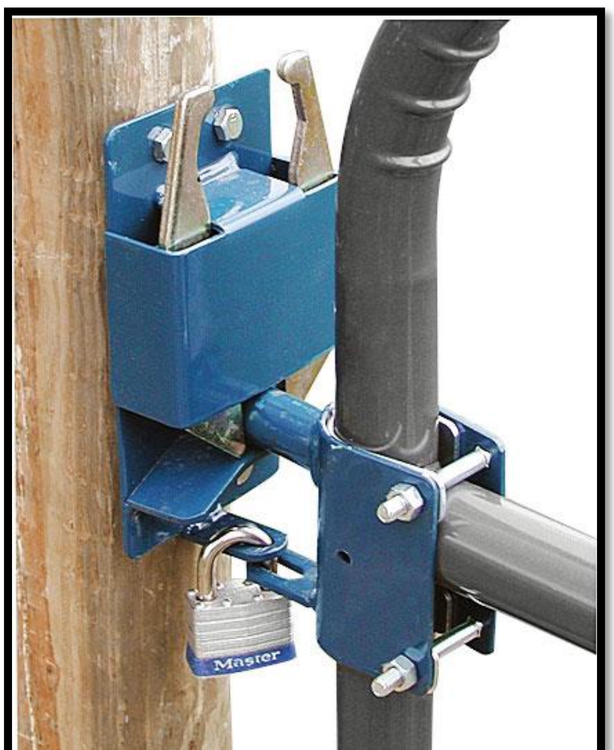


Figure 7. Two-Way Gate Locking Mechanism

An impact wrench could be used to adjust the wheel spacing, although the setup is less than ideal due to stresses and time constraints. This system, as shown in Figure 8, uses a handheld impact wrench to retract the wheels. This system proved viable when one farmer successfully installed such a system on his self-propelled sprayer, as in Figure 8, but with no axle to slide the concept would need to be implemented differently for this project's purpose.

Figure 8. Impact Wrench Mechanism for Sprayer

Any design that adjusts heavy frame components will create pinch points. Also, the reliability of a hydraulic cylinder to retain its position should be secondary to a mechanical locking system per customer requirements. Therefore, for safety purposes a mechanical lock would be preferred. An electronic system could also be implemented as a fail-safe in case of operator error.

Multiple patents were discovered during the research process, all pertaining to wheel adjustment systems. For example, the High Clearance Vehicle Wheel Spacing Adjustment patent (no. 3964565) showed a fairly simplistic hydraulic design, as shown in Figure 9. Here, slider bearings reduced the sliding force on the tube itself. This allowed for single-person operation to complete the process. However, the locking system required tools, and some disassembly and assembly was required to complete the operation. The simplicity of this design appeals to MacDon, but there fails to be a quick transition and doesn't have stops implemented into the system that this project requires.

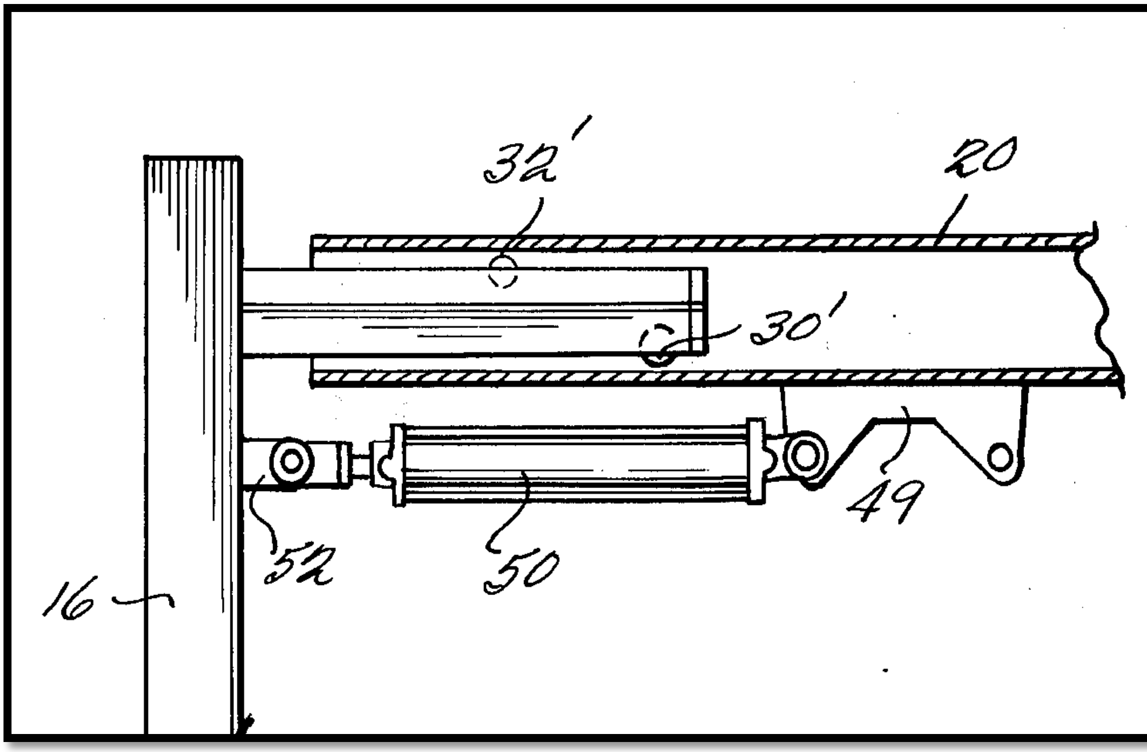


Figure 9. Simplicity of US Patent 3964565

Another patent had some useful concepts as well (patent no. 4619340). A linkage system served to change the wheel width, meaning no sliding friction, and no tools were needed for adjustment. The major drawback with this design was its complication which is well illustrated in Figure 10. It had many features that MacDon would not find desirable, and it also adjusted the height of the machine. This system also had additional hydraulic components, which added unnecessary cost. While this design came from a different approach and sparked new ideas, it would affect the structural configuration of the machine too much, which is not desired by the client.

Third, we found an adjustable vehicle axle patent (no. 4040643). This was a very simple mechanism, utilizing a clamping force from bolts that held the axles into place. Also, a small tab was used as a physical stop. The problem here was the split-frame configuration, as well as the necessity for the tires to be raised off the ground for completion. The design was very simplistic, but did not allow for the adjustment to be completed within five minutes or less. The client asked that the adjustment to be rather quick to maximize productivity.

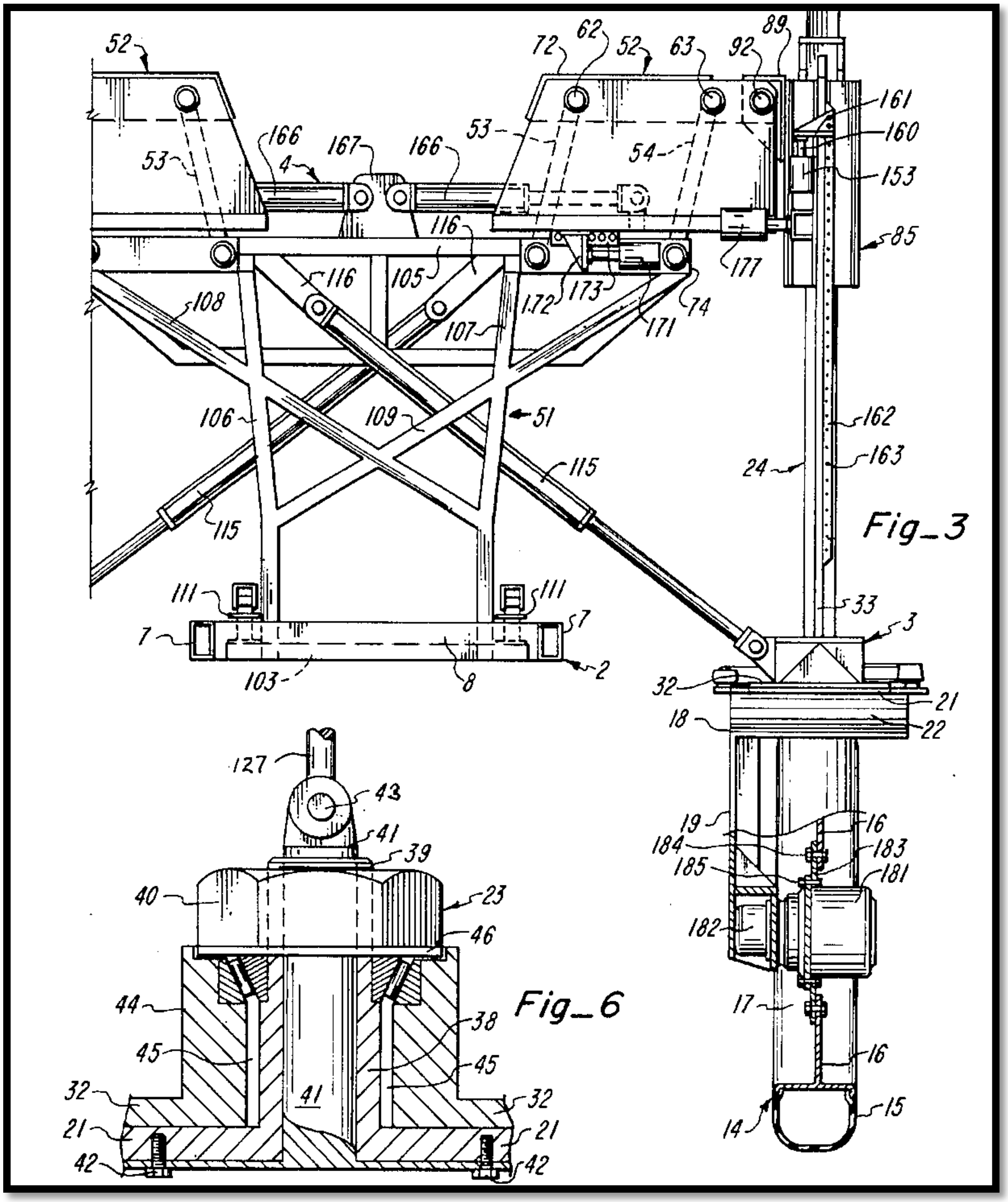


Figure 10. Complication of US Patent 4619340

Finally, the Multi-Position Track Width Sensor for Self-Propelled Agricultural Sprayers (no. 7163227) was an interesting concept. This system was high tech, with an LED grid indicating the position of each wheel. Very little was required electronically; the system uses four linear potentiometers, shown in Figure 11, and an array of LEDs. On the other side, the five different positions are excessive for the purposes of this project. Also, fatigue from vibration during normal machine operation could eventually lead to failure if the linear potentiometer wasn't properly mounted and sized. Our client needs the ability to ensure proper lockout of axles in either position, so we could use some sensor setup of similar nature to warn the operator if the system malfunctioned for some reason. This idea has the potential to be taken a step further by programming some additional functions into the current on board computer to control the mechanism, where it won't be able to move unless the machine is moving in order to reduce the required force significantly.

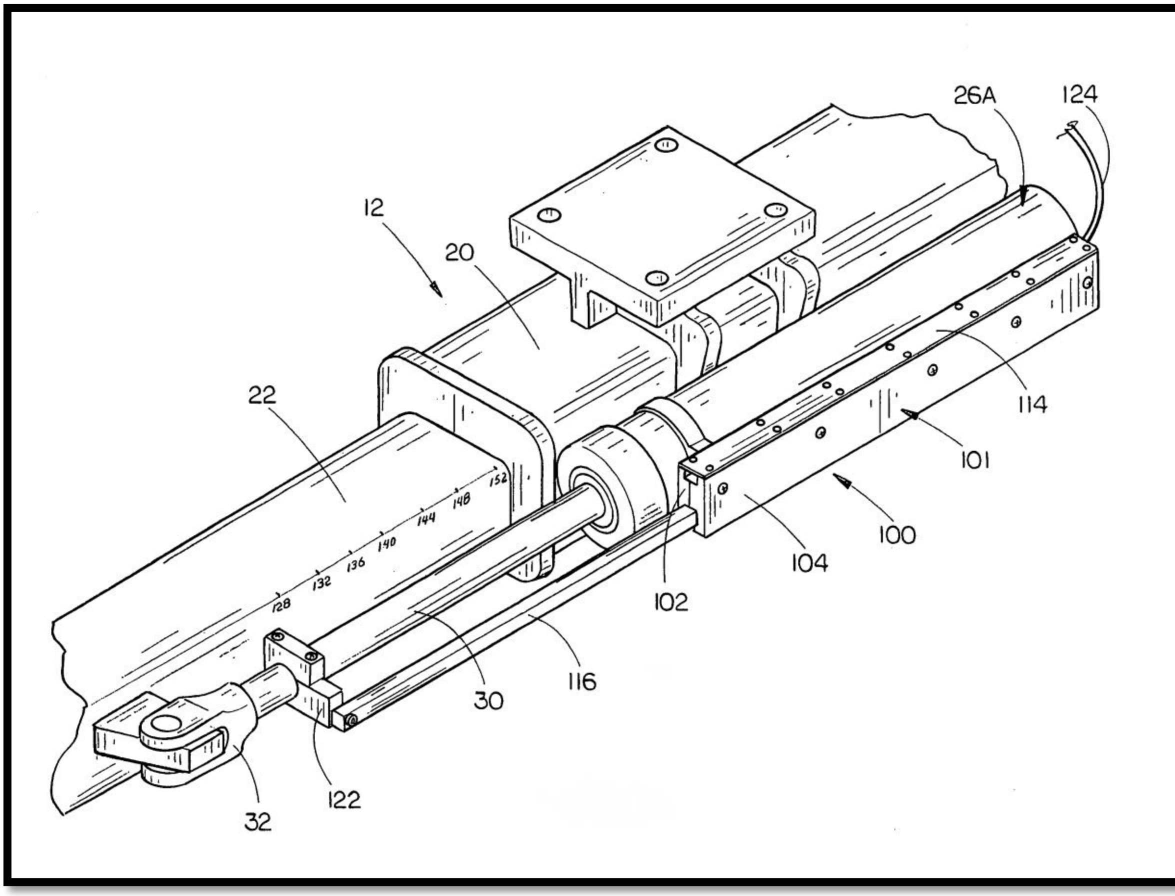


Figure 11. Linear Potentiometer Setup of US Patent 7163227

Project Impact

Because this is a heavily-mechanical project, the environmental, global, and societal risks are low. There is potential for an added hydraulic system, but the closed system will ideally have no problems. The biggest impact of this project is economically. MacDon will be able to utilize this product both in North America and beyond, potentially increasing sales of their self-propelled windrowers. By being able to collapse the wheels quickly, the shipping process has significant steps removed, saving MacDon both time and money when transporting these machines to dealerships. Also, European application will allow customers to quickly go from one field to another, without having to worry about the road constraints. As strict as these constraints are, the MacDon M155 will fit easily when the wheels are collapsed. If this is a quick process, so will be the process of switching fields.

Other aspects to be considered involve safety. Working with a large piece of equipment, safety is always an immediate concern. MacDon has specifically requested the involvement of mechanical locks in this system despite what is used to adjust the wheels, as mechanical locks are much more trustworthy than potential failure in hydraulic or electrical systems. Also, the cylinders will be sized in a way that they will reach their stops if the lock ever did fail. This ensures that the axle will be held to the machine. Pinch points will also be an issue worthy of looking into, as large components of the machine will be moving to accomplish the task of adjusting the wheels. To counter this, special attention will be given to the operator's role in the process. This includes anything from what tasks he will do outside of the machine, to exactly where the operator should be located while the adjustment is taking place. By planning to these aspects, safety for all people involved can be assured.

Design Concepts

One of the initial concepts drawn up involves the instrumentation of a hinged axle. As shown in Figure 12, the rear axles would pivot either forward or to the rear of the machine. This way, they could be kept clear of interference. The benefit of this method was the purely mechanical system used, where a lock on the hinge could engage and disengage by the operator and driving the machine would create the force necessary to move the wheels. However, there are many drawbacks to this idea. First, this concept cannot be used on the front set of tires, because they are not free to rotate like the casters. Additionally, the balance of the machine could be greatly thrown off with respect to the “axle” distances. This could cause the machine to tip forward much easier, as well as creating other balance issues at road speeds. While not a design consideration, this idea also eliminates the potential for multiple width positions to be used on the back axle.

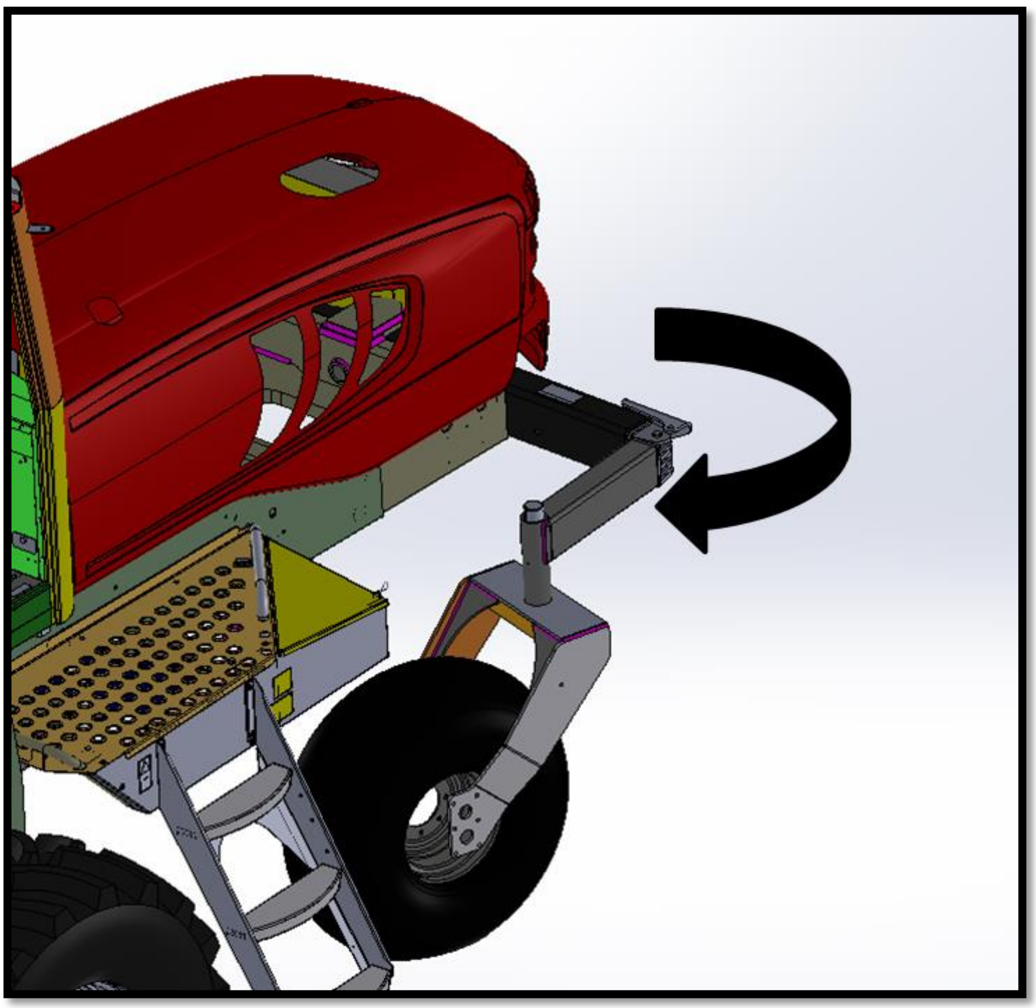


Figure 12. Concept Model of the hinge on the machine rear

Next, we discussed the idea of a rack and pinion driving the wheel movement, as shown in Figure 13 and Figure 14. The operator would use an impact wrench on each tire, one at a time, and crank the wheels in or out until the desired position is reached. Again, the benefit of this would be a purely mechanical system, without the need for hydraulic or electrical modifications. However, this would be a very primitive design. With the operator out of the cab, the machine could not be rolling to reduce friction of the tires sliding on the ground. This creates a greater force requirement, but also causes a significant amount of stress. Additionally, with an exposed system dirt and debris could easily interfere and cause problems. This would be the most time-consuming option as well.

Another option would be to use a hydraulic motor attached to the pinion gear to move the axles in and out. As seen in Table 3 and Table 3 the calculations have been carried out to size a hydraulic motor. For the front wheels alone the hydraulic motor sized properly would cost two hundred dollars for just one motor. The rear wheels would need two hydraulic motors each one costing one hundred fifty dollars. The total costs of just the hydraulic motors alone would be seven hundred dollars which seems to be expensive for a kit option. Also, the rack and pinion could possible interfere with hydraulic hoses that are run inside the axle tube. This could cause several hydraulic leaks and possible failure of the wheel adjustment system.

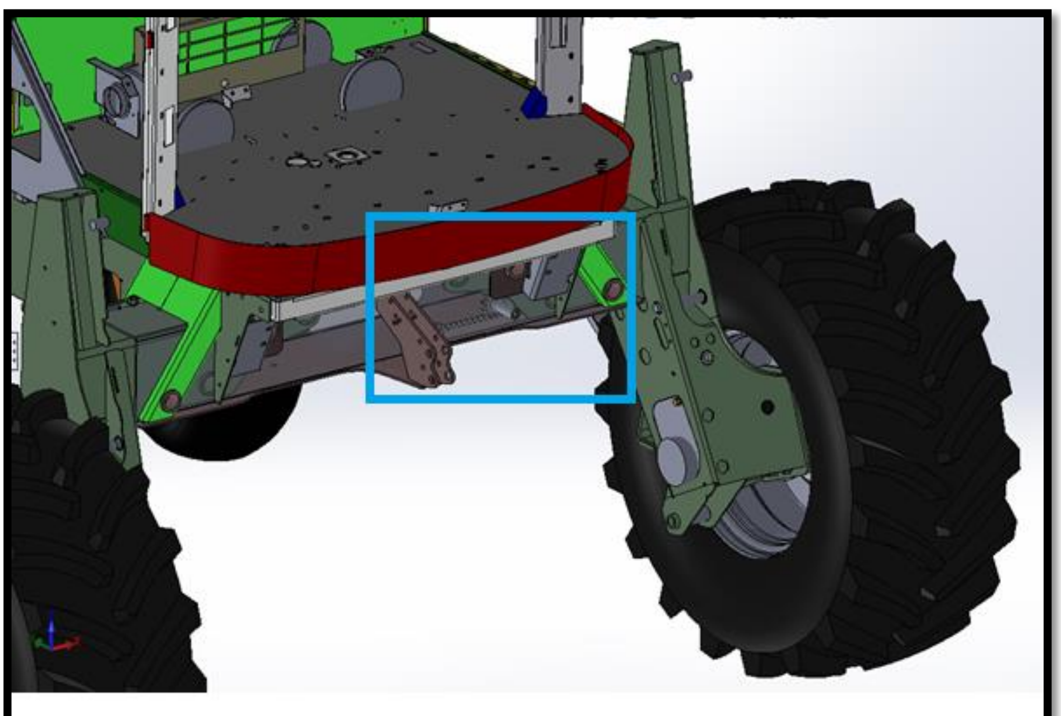


Figure 13. View of rack and pinion concept

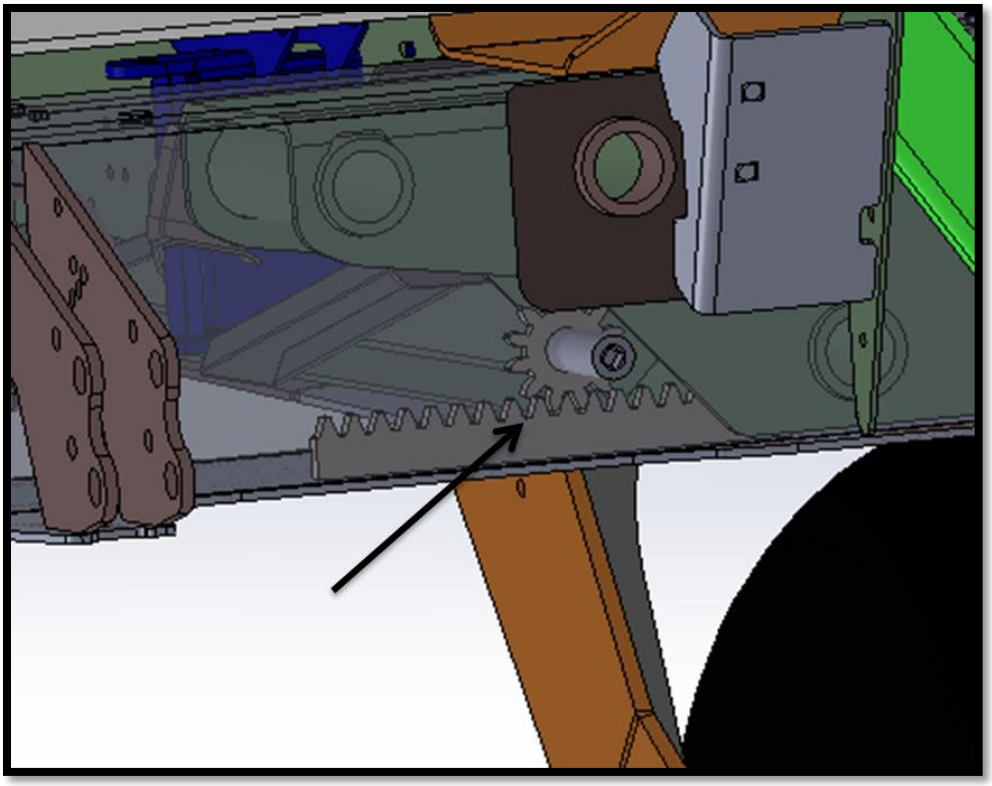


Figure 14. Zoomed view of rack and pinion concept

Table 2. Weight Distribution of a MacDon Windrower

Approximate Weight Distribution (lbs)	
NOTE: If any individual axle weight exceeds the	
	Field
	Header on
Gross vehicle Weight	11200
Drive wheels - A	7224
Tail wheels - B	[redacted]
Tail wheels - C	3976
Combined Gross Vehicle Weight	[redacted]

Table 3. Calculated Force for Rack and Pinion Design

Front Wheels

Weight (Fw)	3612	lbs
Coefficient of Friction (μ)	0.8	
Total Force Required (Ff)	2889.6	lbf.
Pinion Diameter	4	in
Required Torque (τ)	5779.2	lb-in

Hydraulic Pressure (P)	2400	psi
Motor Displacement (D)	15.13	in3

Hydraulic Motor Cost	$200

Rear Wheels

Weight (Fw)	1988	lbs
Coefficient of Friction (μ)	0.8	
Total Force Required (Ff)	1590.4	lbf.
Pinion Diameter	3	in
Required Torque (τ)	2385.6	lb-in

Hydraulic Pressure	2400	psi
Motor Displacement	6.25	in3

Hydraulic Motor Cost	$150

Equations used in calculations above:

$$Fw = \frac{W}{2}$$

$$Ff = \mu * Fw$$

$$D = \frac{2 * \pi * \tau}{P}$$

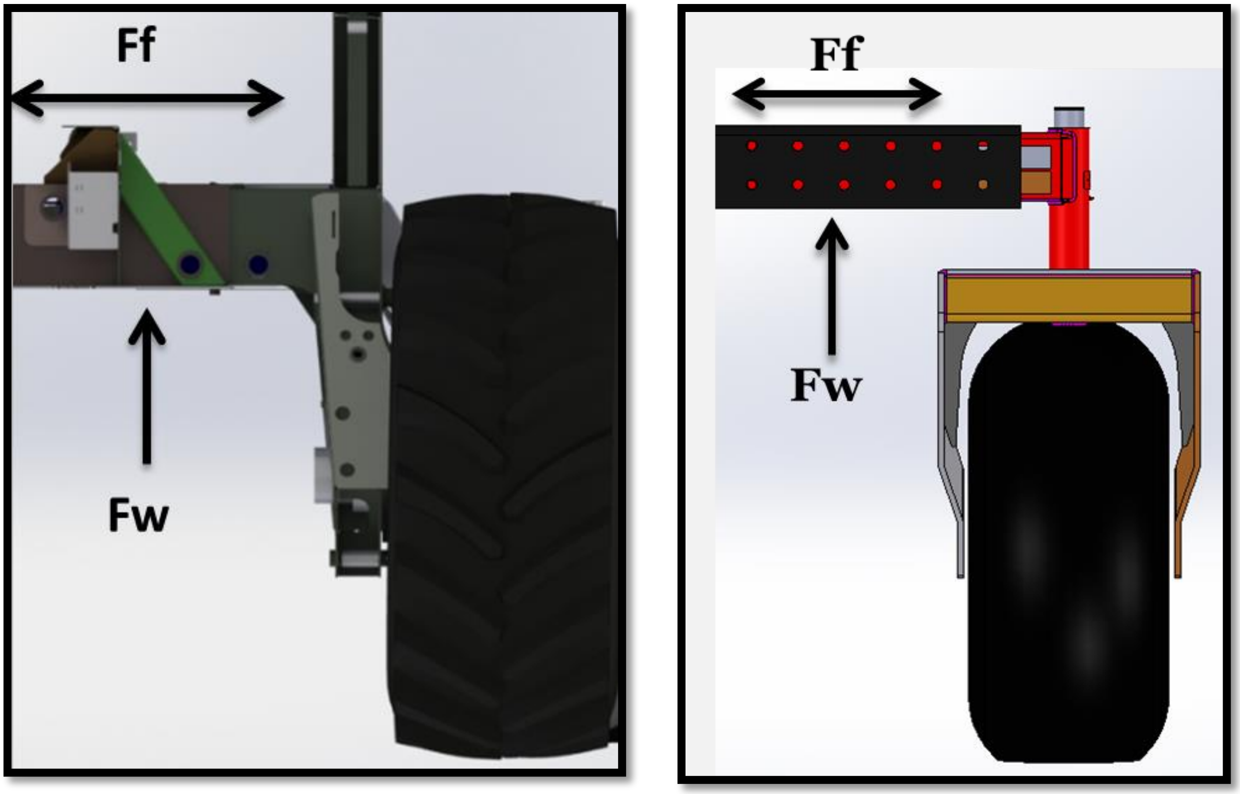


Figure 15. Free Body Diagrams of Front and Rear Wheels

Finally, the idea of hydraulics was discussed and researched. The machine is already equipped with a hydraulic system that would be suitable to support hydraulic actuators with the proper pressures. With a simple static analysis shown in Table 4, the total force required to move the axles in and out is calculated. The free body diagrams seen in Figure 15 apply to the hydraulic design as well. As seen in the Table 4, there are many assumptions made during the calculations. The calculated forces are assumed to be very conservative compared to the actual required force. The idea of using hydraulics would be very efficient for the operator to use. A hydraulic quick connection, which is already equipped on the machine, could be utilized to power the axle hydraulic cylinders. Next, the operator would only need to unlock the mechanical locks before returning to the cab to begin the transformation.

Table 4. Force Calculation for Hydraulic Design

Front Wheels		
Weight	3612	lbs
Coefficient of Friction	0.8	
Total Force	2889.6	lbf.
Pressure	2400	psi
Area	1.204	in^2
Total Force Generated	2889.6	lbf.

Rear Wheels		
Weight	1988	lbs
Coefficient of Friction	0.8	
Total Force	1590.4	lbf.
Pressure	2400	psi
Area	0.662662	in^2
Total Force Generated	1590.388	lbf.

Assumptions:
Machine is moving during operation of hydraulics
Metal is not clean or lubricated
Coefficient of Friction: http://www.engineeringtoolbox.com/friction-coefficients-d_778.html
Center of gravity of the machine is located at centerline of machine
No side to side forces are generated between tire and ground

Equations used in previous calculation:

$$Ff = \mu * Fw$$

$$Fw = \frac{W}{2}$$

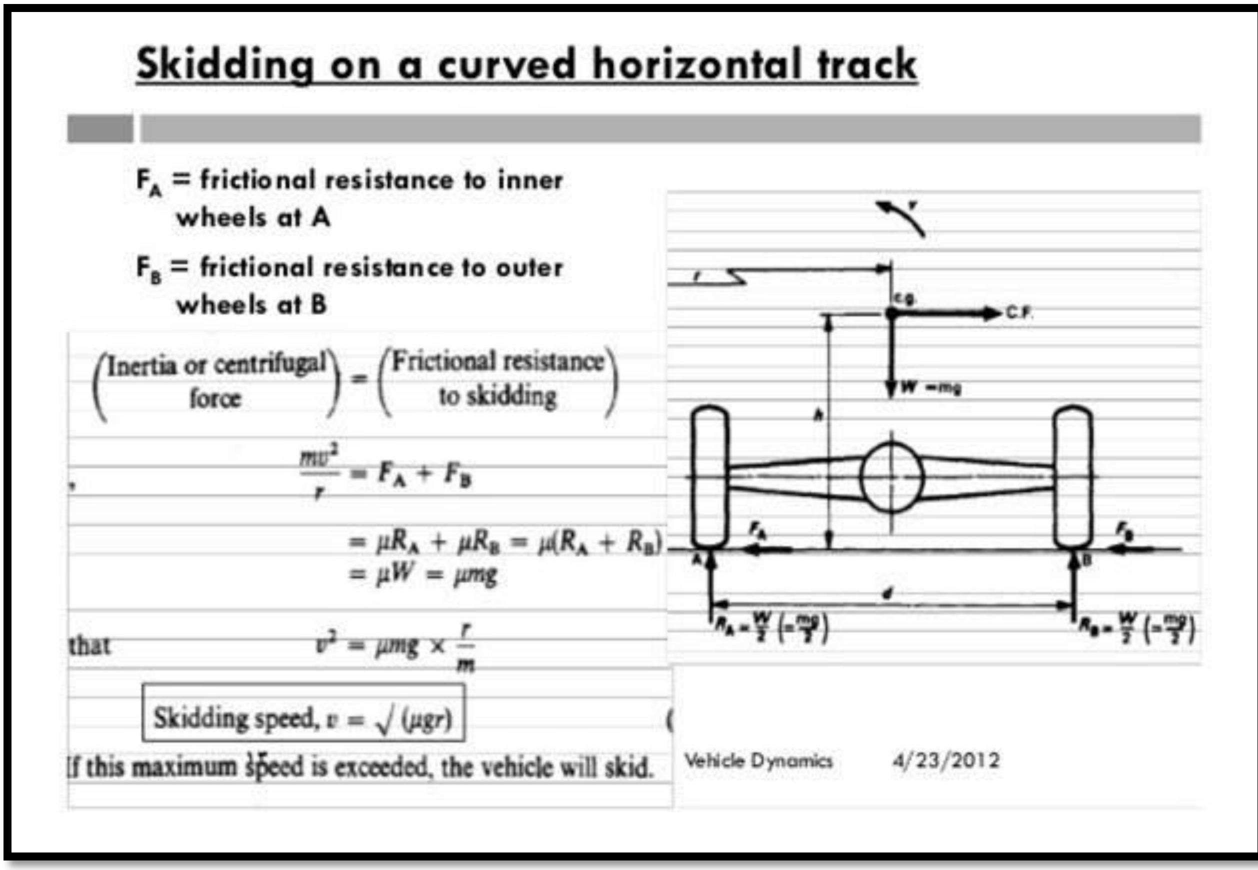


Figure 16. Calculation of Side Loading

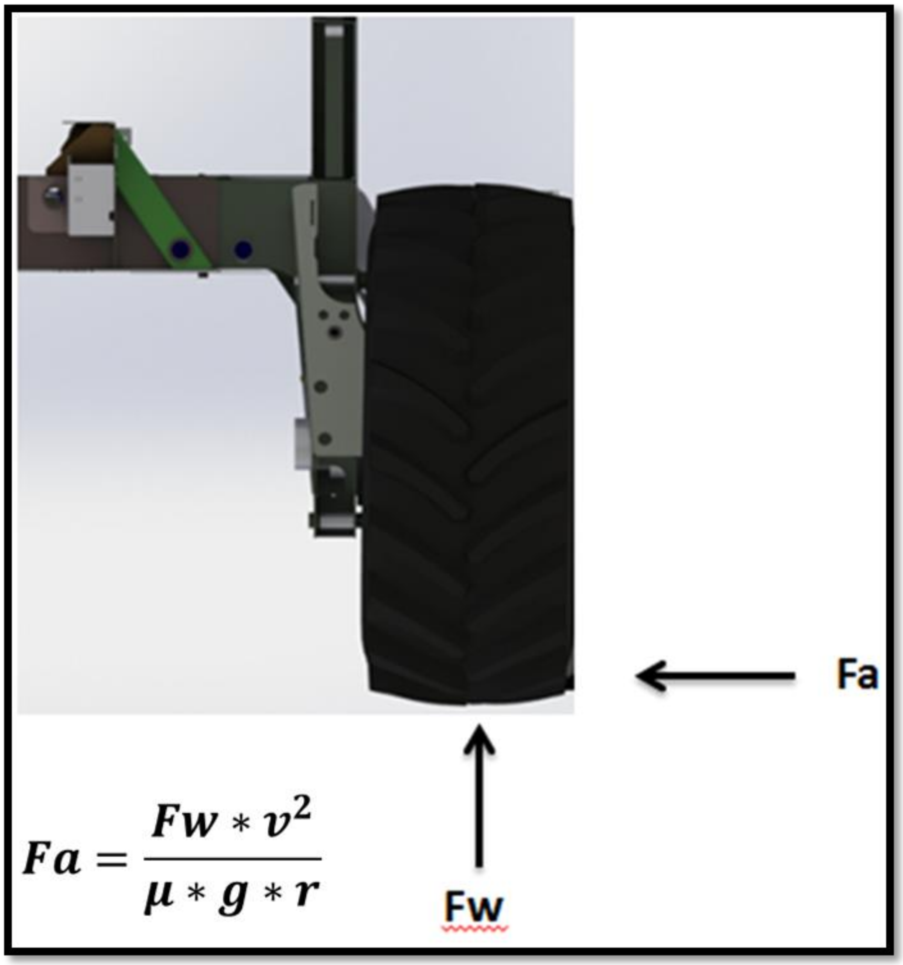


Figure 17. Free Body Diagram for Side Loading

An important factor to consider is the side-loading of the wheels. As a hydraulically driven and steered machine, the side loads can potentially be very high. This machine has the capacity to turn around at high speeds with a single wheel stopped, generating large forces on the system. Therefore, the system developed must be able to withstand those forces. Our calculations were done based on varying turn radii and turn speed. This gave us force outputs to size our components off of, as shown in Figure 18. The calculations were made as conservative as possible, using the lowest cylinder area, lowest pressure available, maximum weight on a single leg, a coefficient of friction of 1, and turning conditions that exceed machine field capability slightly. This load should be able to be held by the mechanical locking system for field and transport operations.

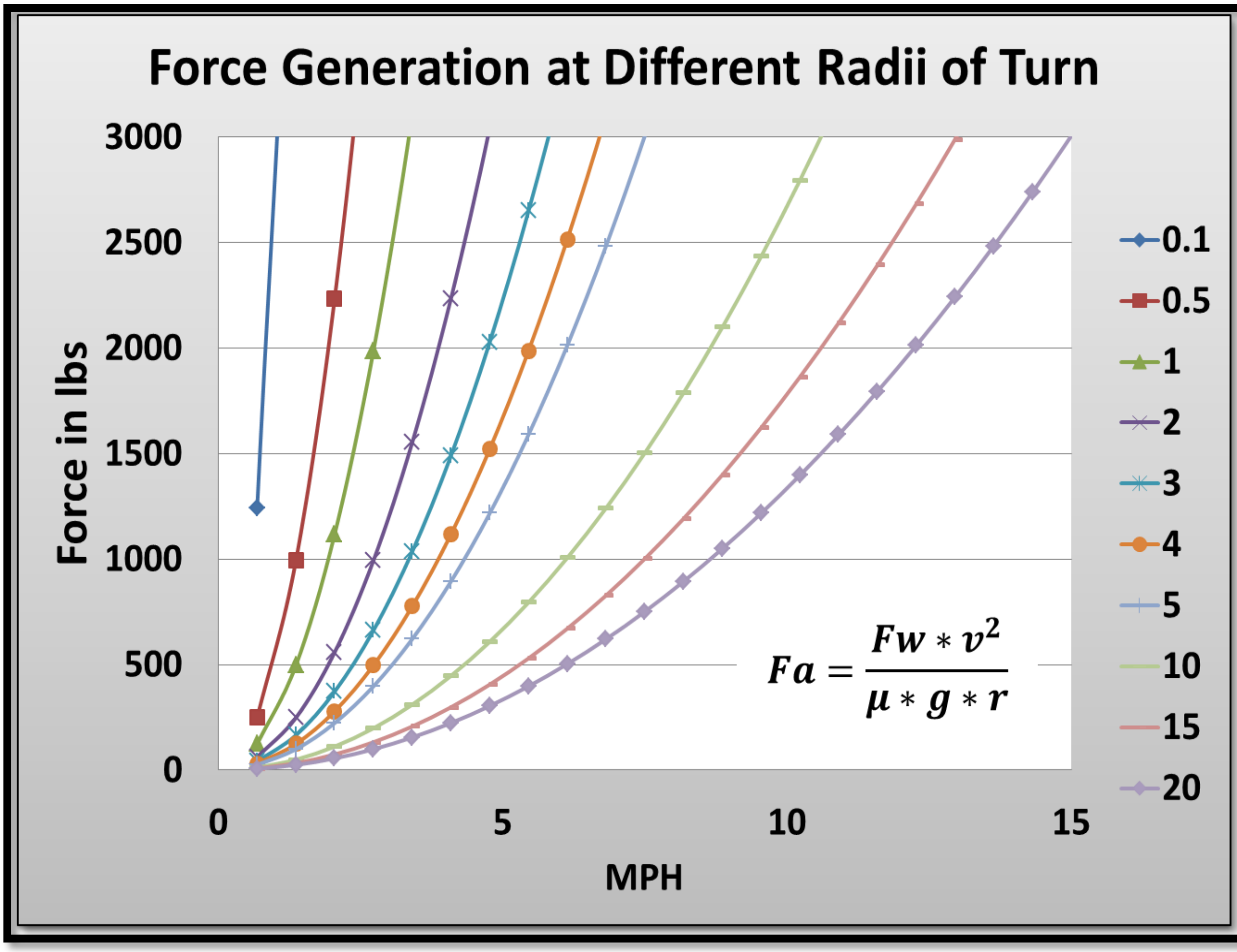


Figure 18. Force Generation at Various Turn Radii

Ladder Design

As a part of the design process, the team was assigned two groups of freshmen. These teams were assigned the task of designing an improved ladder that would also fit the wheel width requirement. Each team came up with a unique idea to accomplish the goal, the first decided to fold the ladder under the machine, and the second used a hinge to rotate the ladder under the machine. As seen in Figure 19, the folding design uses a simple hinge and latch mechanism and an existing ladder rail. The design also has the advantage of increasing ground clearance.

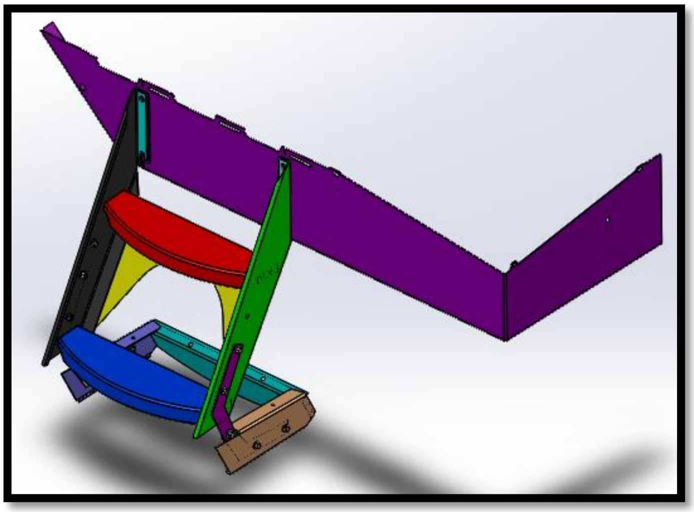


Figure 19. Folding Ladder Design

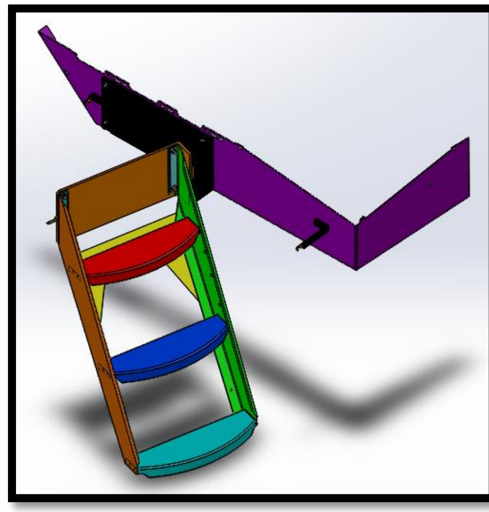


Figure 20. Rotating Ladder Design

The second design, shown in Figure 20, rotates the ladder on a hinge, locking on the platform itself. The rotating method would be relatively simple to install as it uses the existing ladder and adds a hinged bracket in the existing holes for the ladder. Both designs show promise, but do need more work and some force analysis to ensure the safety of the user.

Fabrication

The designs proposed at the conclusion of fall semester failed to identify a key issue with the front leg. By removing the two pins that hold each leg in position, the clearances between the leg and tube are too great to re-align the pin holes easily. This issue is illustrated in Figure 21. Also, there was a large concern of the leg's ability to hold the weight of the machine without the pins, as the design of the machine forces the machine weight through the pinned locations. For this reason, an alternative solution was created to allow the pins to stay inserted through the tube/leg assembly. This concept is illustrated in Figure 22 and Figure 23, where the leg is slotted to allow movement while keeping the pins supporting the machine weight. After the leg was removed from the machine the current bushings were cut out. The new slotted bushing was constructed using four separate pieces. A piece of pipe was cut in half length wise then two pieces of plate was place between the pipe halves. At the weld joints a bevel was ground to allow ease of welding operations. The four pieces where welded together and the welds were ground flat. Next, the material between the two pin locations was removed to allow room for the new slot bushings. Special care was taken to ensure that slots were placed within the tolerances of the pin locations. Once the slots were verified to be in the correct locations, the bushings where fully welded. To complete the fabrication on the front axle two cylinder mounts were welded to the leg and the frame of the machine.

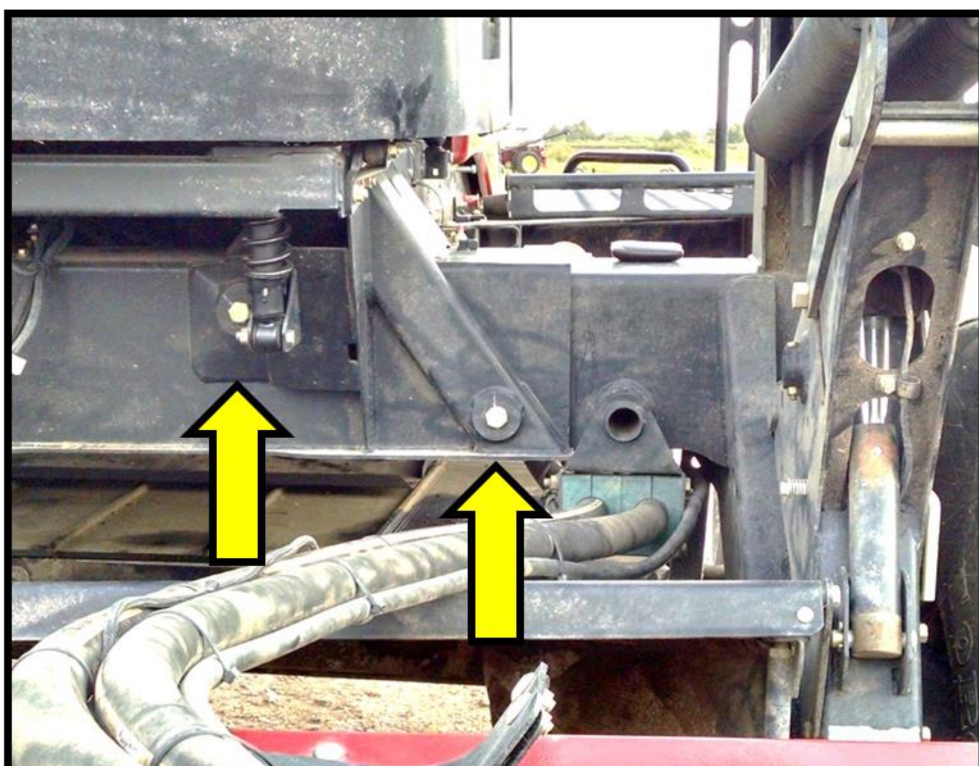


Figure 21. Pins supporting machine weight

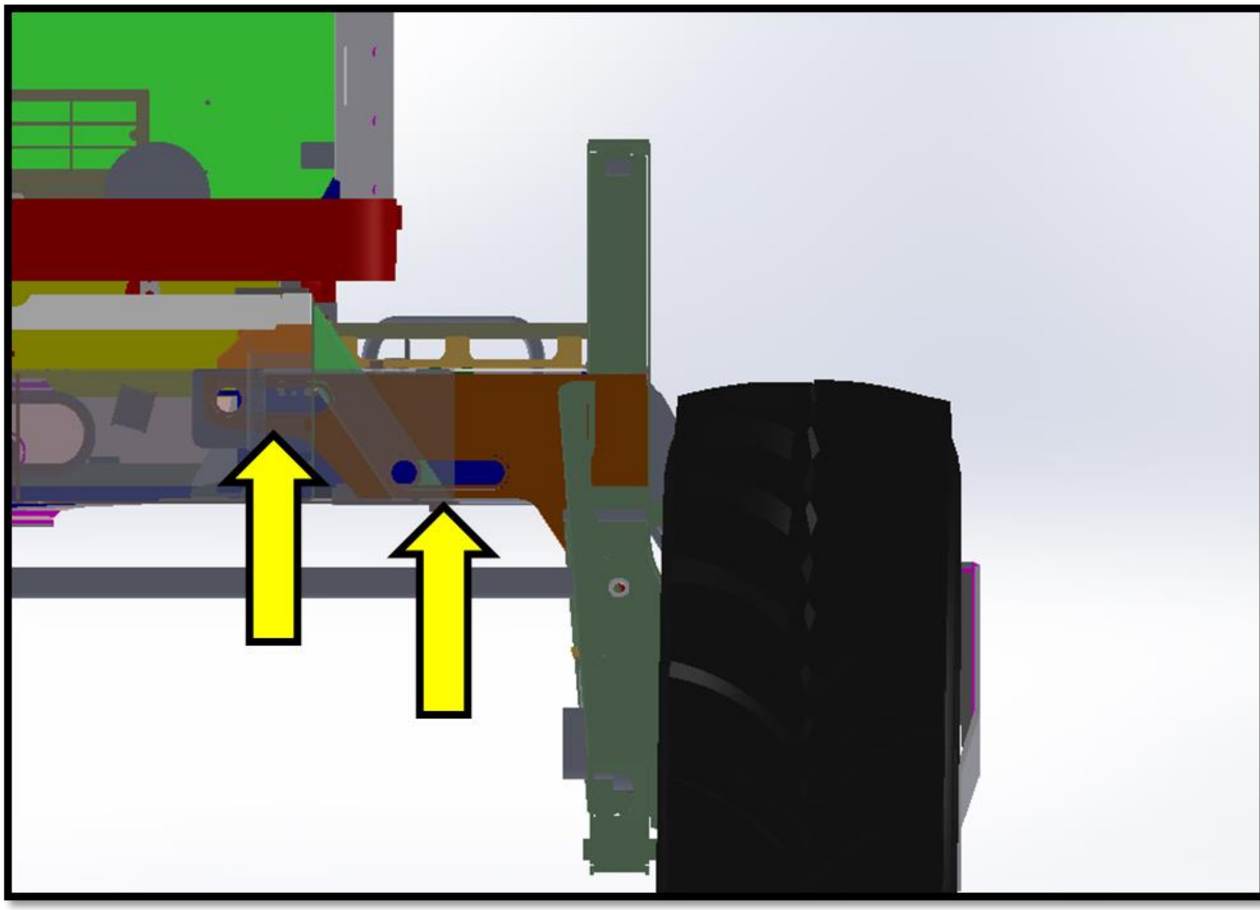


Figure 22. Slotted Design Replacing Pins

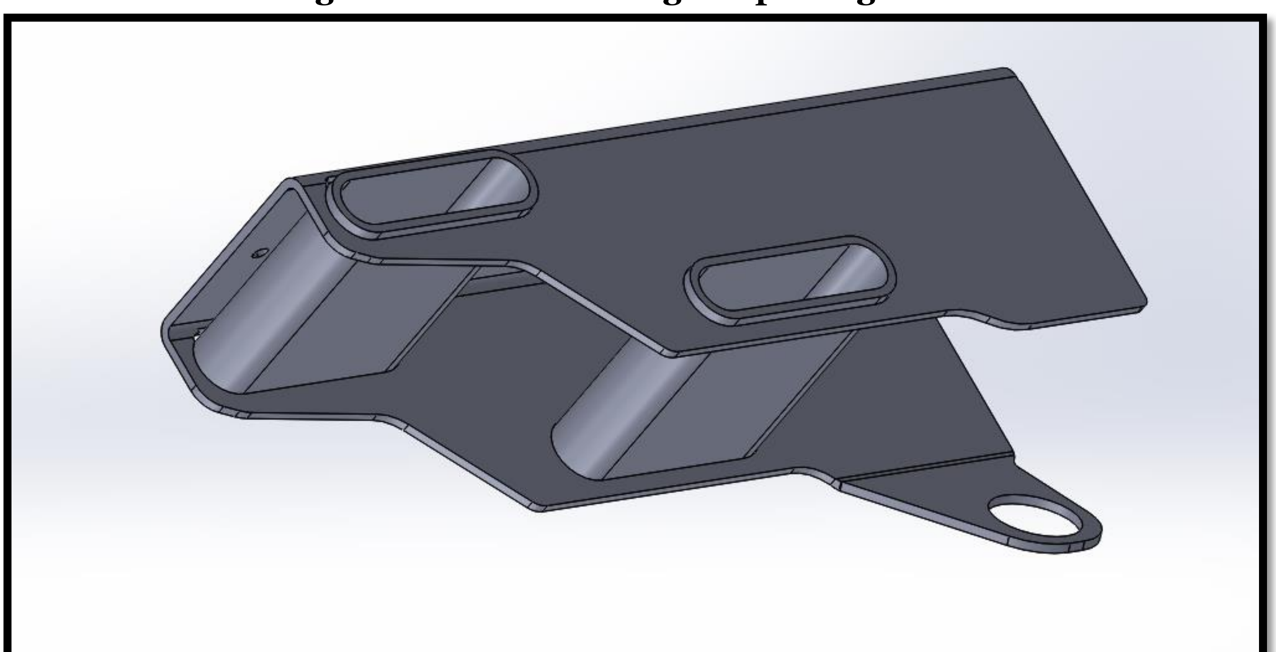


Figure 23. Isometric of the modified leg with slots

Our final design for the ladder was a modification of the rotating design proposed by our freshman team. This design was modified slightly to account for material strengths, and also a handle and lock were added to allow execution of moving the ladder from the ground and on top of the platform. The mount is shown in Figure 24, which can be simply bolted onto the platform for easy installation. The handle that extends vertically contains the latch mechanism that can be operated from both the ground and on top of the platform. This latch is shown in Figure 25. This way, the ladder can be quickly rotated to either position depending on the situation.

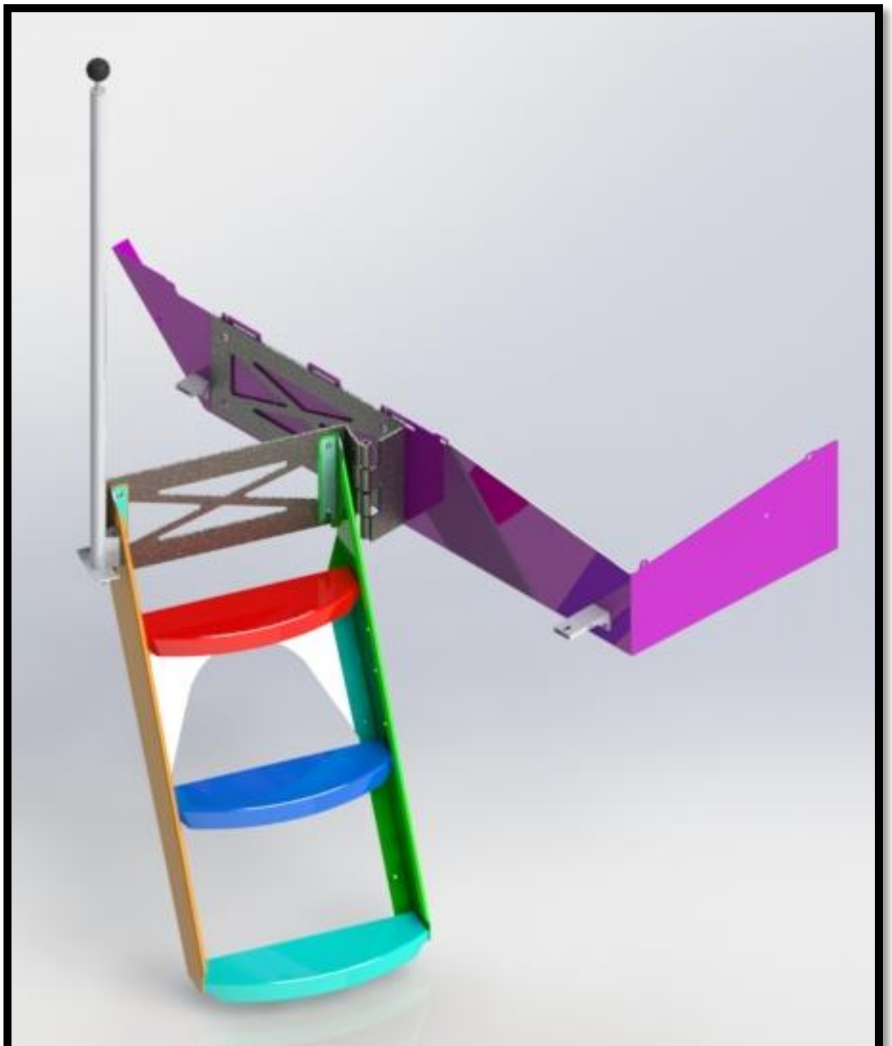


Figure 24. Improved Ladder Design

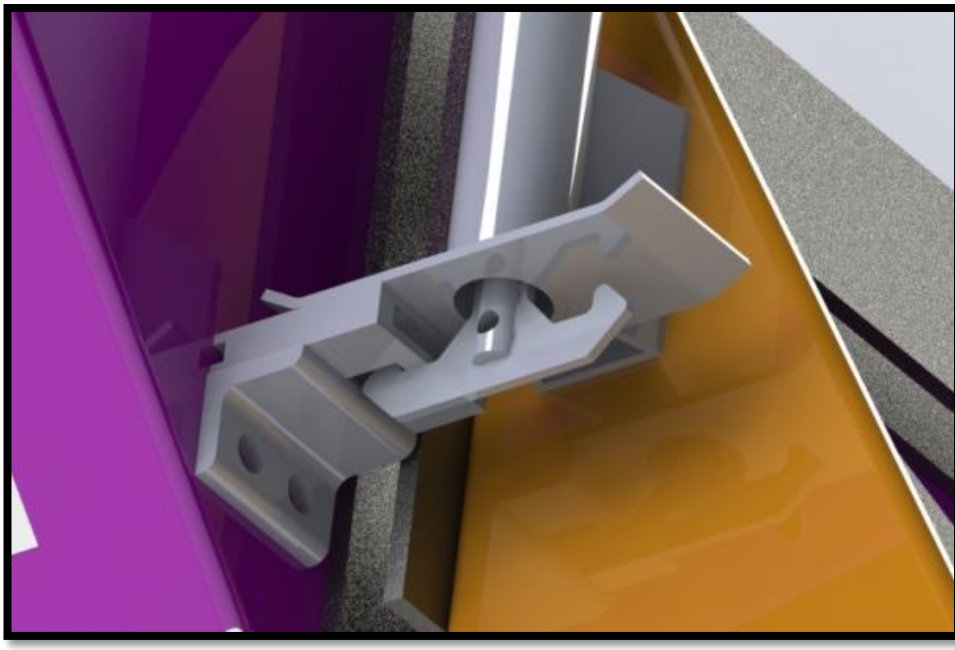


Figure 25. Latch Design for Improved Ladder

The mounts for the hydraulic cylinders were difficult to complete due to the location chosen for the cylinders to be placed. However, this was achieved on one end with a simple triangular plate. The triangular shape allows force absorption to gradually flow into the frame, rather than being focused on one point. For the leg mount, space was limited and therefore an alternative design was used. These two mounts can be seen in Figure 26. Finite Element Analysis in Figure 27 shows that the mounts would hold with a factor of safety of 2 with the forces seen from the cylinder.

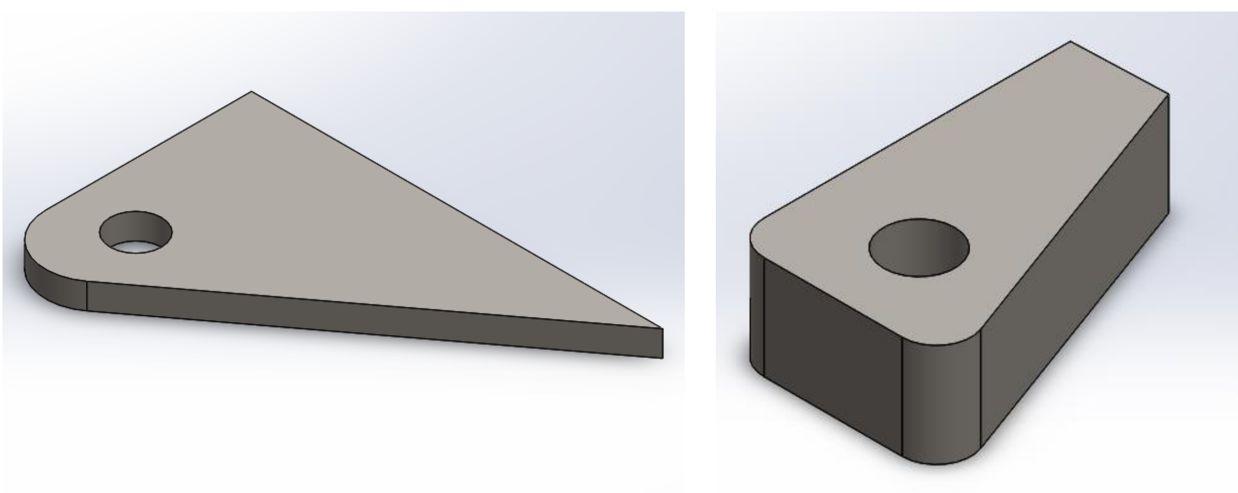
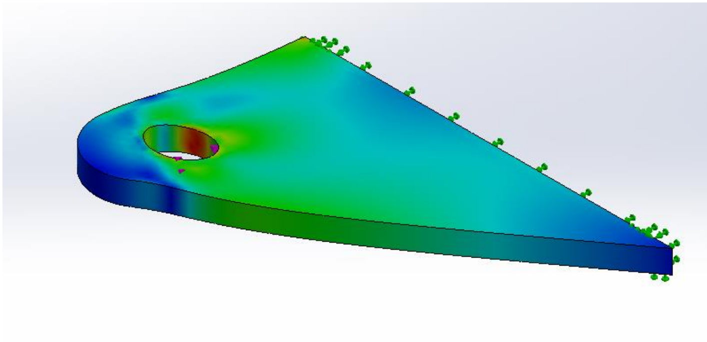


Figure 26. Inner (Left) and Outer (Right) Cylinder Mounts



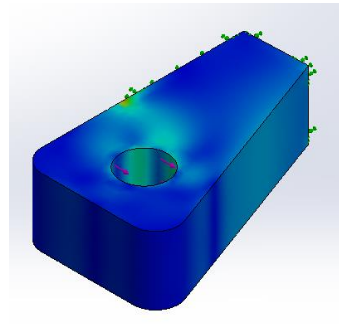


Figure 27. FEA Analysis on Stress of Cylinder Mounts

The mechanical locks caused a lot of issues when the team attempted to incorporate the lock into the frame. Instead, the mechanical aspect was decidedly added to the hydraulic cylinder itself, as shown in Figure 28 and Figure 29. This is a fairly simplistic design that still functions as a failsafe in case of hydraulic failure, as requested by MacDon. Finite element analysis again proved that this “dog bone” piece would be strong under extreme loading conditions.

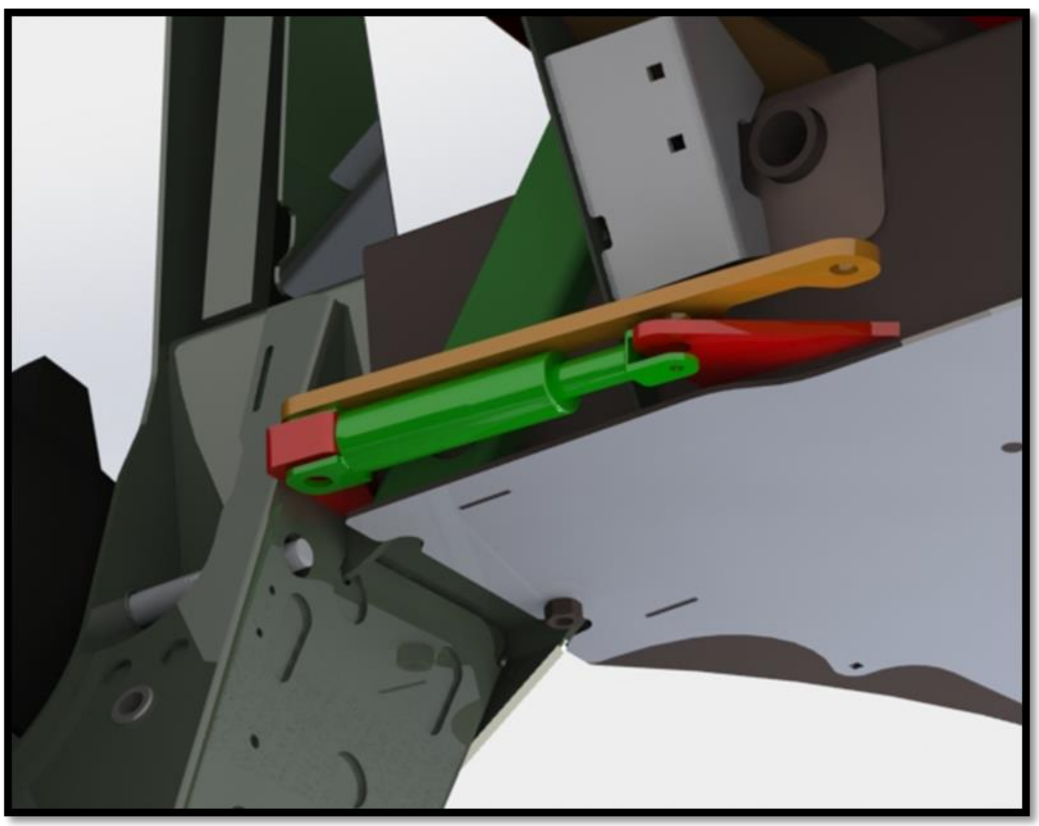


Figure 28. Mechanical Lock over the Cylinder

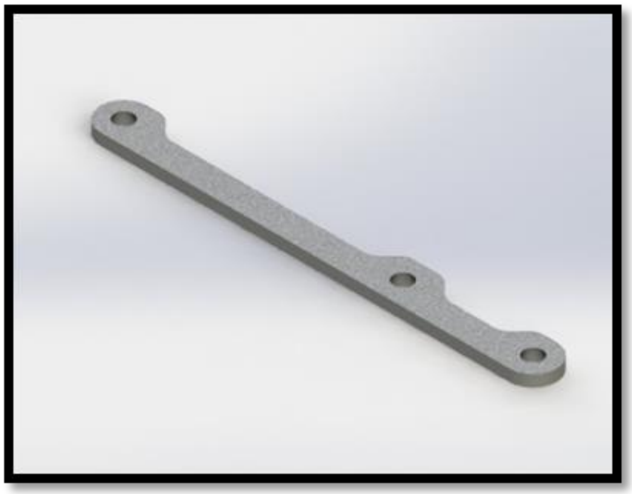


Figure 29. Design for the Mechanical Lock

A number of aspects went into the plastic design. First, the plastic needed to be able to hold considerable force in compression, so that it wouldn't fail under the machine load. Cutting slots in the leg opened up the possibility of fore/aft rotation of the leg within the tube, meaning possible contact and friction with two surfaces. For this reason, the leg was lined with plastic on the front and rear faces to account for all sources of contact. This is shown in Figure 30, where the plastic was fastened onto the leg assembly.

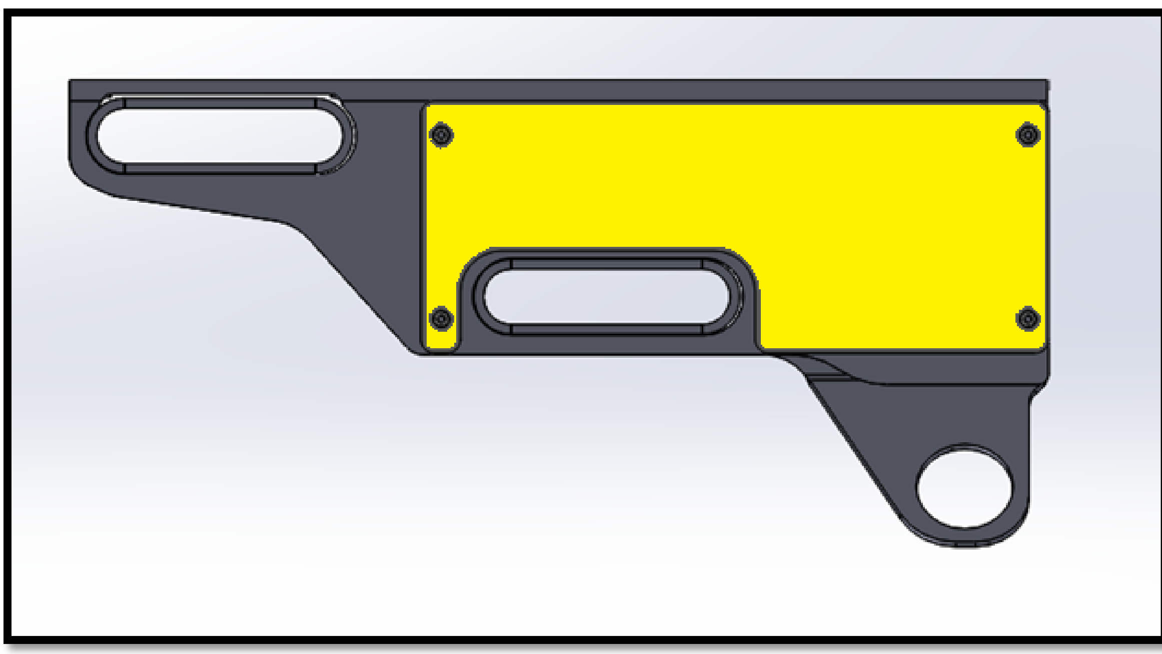


Figure 30. Plastic Covering Slotted Leg

Routing and controlling the system turned out to be fairly easy with the system MacDon already has in place on the machine. By utilizing the reel fore/aft and DWA lift blocks, the system could function quite easily. As shown in Figure 31, the charge pump supplies a pressure of 2900psi to the block(s). Using the controls from in the cab, these blocks can be pressurized in either direction. By plumbing our cylinders into ports J & K, we can pressurize either side of the cylinders used for the wheel width control. Putting all four cylinders in parallel will reduce flow through the system, but pressure will remain constant. This means that the full hydraulic force available will be used at each wheel as it extends or retracts. The other advantage to this method is that it utilizes the existing electrical controls. From the cab, the operator only needs to use the reel fore/aft control on the ground speed lever (GSL) to extend or retract the wheels.

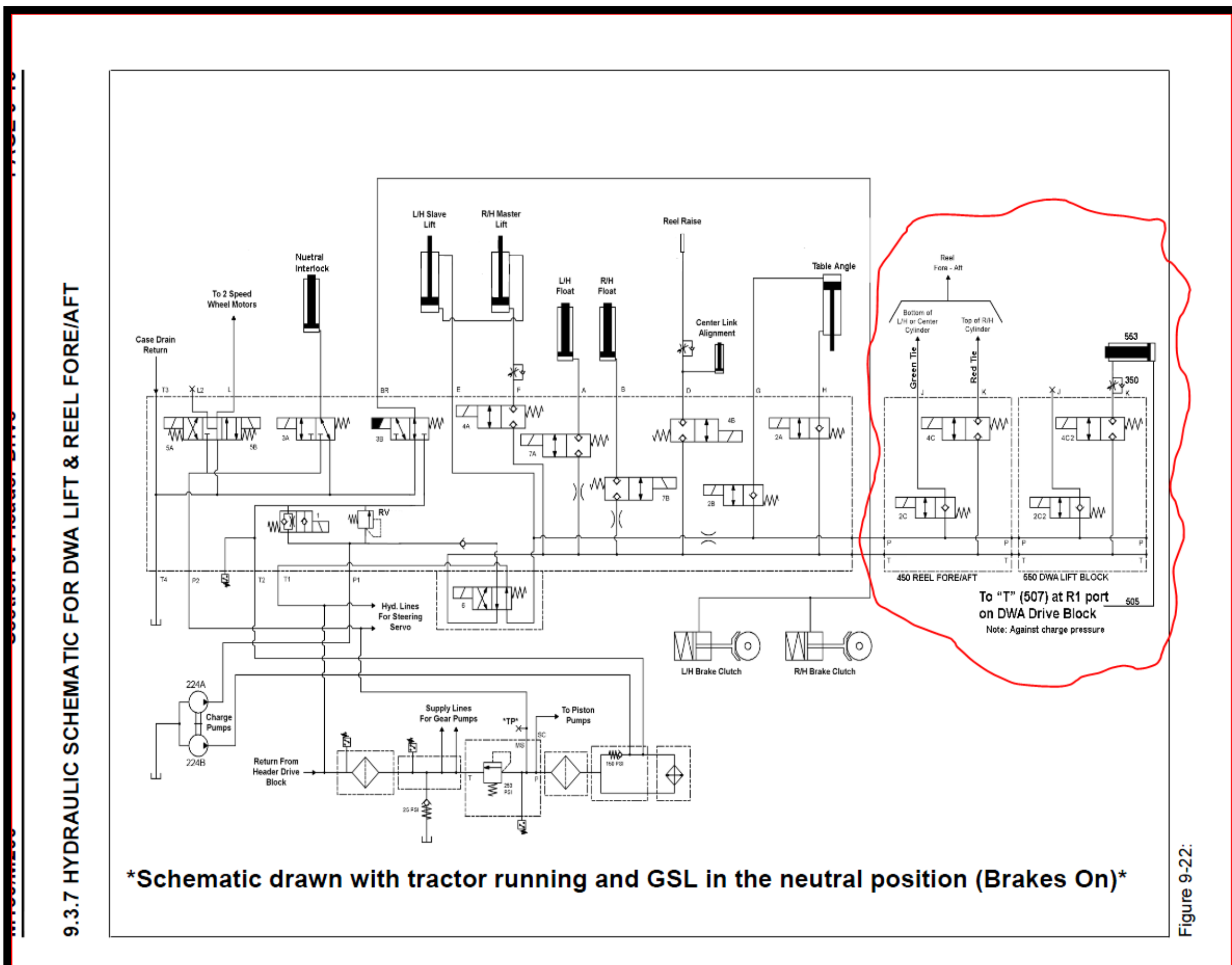


Figure 31. Hydraulic Schematic of M155 DWA Lift & Reel Fore/Aft

Fabrication of the rear axle was less involved compared to the front axle. To begin fabrication the rear axle was moved to the most inward position before the addition of the cylinder mounts and axle position indicator was attached. Next the cylinder mount located on the inner tube was place against the lip of the outer tube and welded into place. The cylinder mount on the outer tube was located the proper distance away and welded into place. To finish the fabrication the position indicator was placed on the against the outer tube lip on the opposite side of the cylinder mounts. This design can be seen better in

Figure 32. Rear Leg Final Assembly

Figure 33. Mechanical Lock on Rear Leg

Testing and Evaluation

After fabrication was complete the leg was installed back onto the machine. Soon the additional cylinder mount were attached to the frame and along with the hydraulic actuator. Next, the cylinder was plumbed and the first test was ready to be conducted. The initial test was conducted without the weight of the machine, due to concerns with the pins binding inside the slots. There was no evidence of binding or any other issues observed. Following this the machine was removed from the jack stand and was under its own weight. No deflection was observed as the machine was slowly put under its own weight. Before testing of the system occurred, the machine was driven around to confirm fabrication didn't cause any underlying issues with the machine function. Moving at a slow roll (less than 2 mph) the cylinder was pressurized and the leg was able to move in and out. The final test for the system was with the machine in a static mode (no forward movement) and the machine successfully completed the wheel width adjustment in both directions.

After construction of the rear leg was complete, testing immediately began by pulling all bolts out of the rear leg, allowing it to slide freely with the new hydraulic cylinder. At this point the team noticed that the inner leg had rotated on a transverse axis inside of the tube. Upon testing, this proved to create excessive friction in the system, and the leg failed to move. Even after applying grease to the inner tube, the leg moved but with lots of noticeable resistance. To counter this torque on the inner tube, shown in Figure 34, the machine was repositioned to put the caster tire in line with the tube, as illustrated in Figure 35. This eliminated the torque on the leg and allowed it to slide freely. This made the result of the design less than ideal due to the need to align the rear wheel.

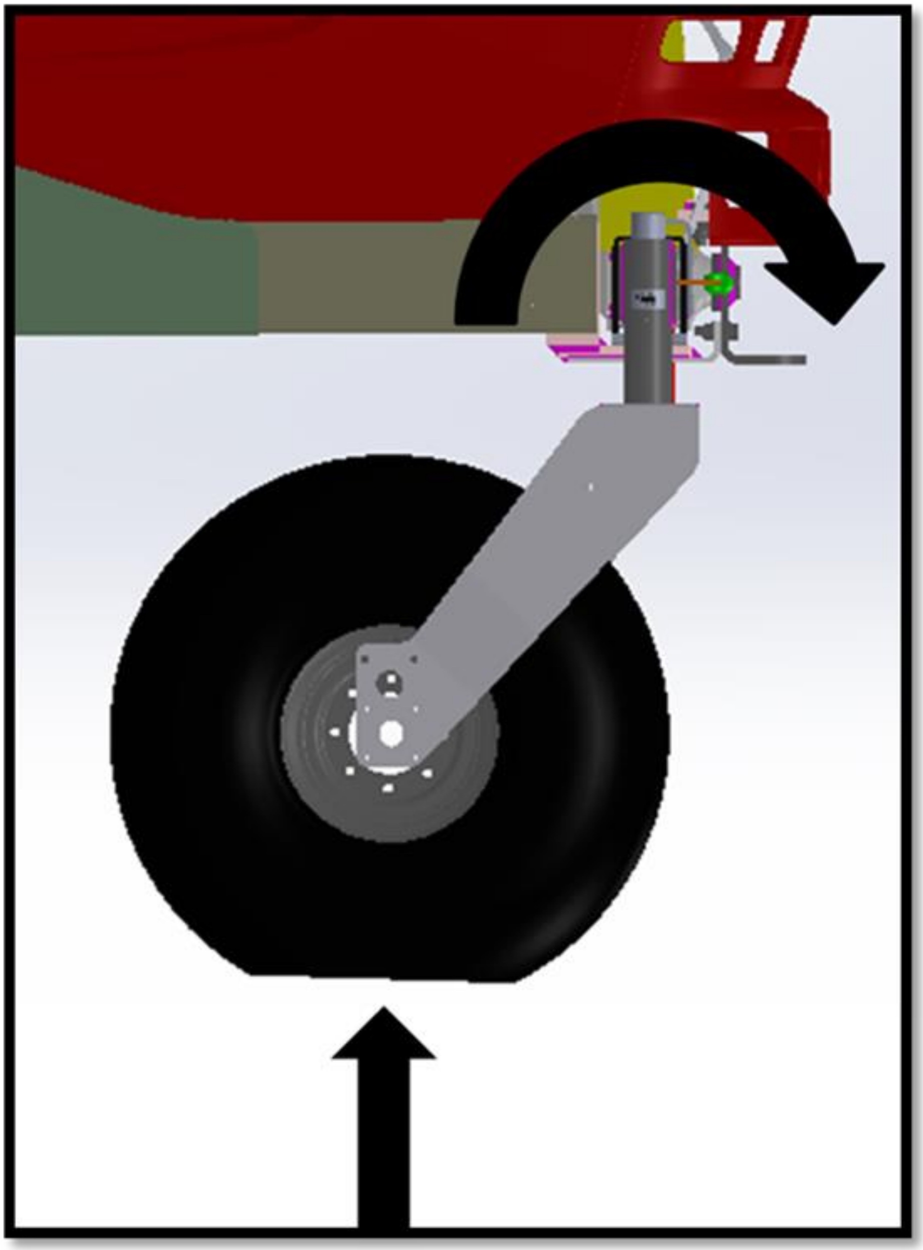


Figure 34. Torque Created by Offset Rear Wheel

Figure 35. Alignment of Rear Tire and Tube for Testing

Hydraulic routing for the prototype was relatively simple. The M155 provided for the project was already equipped with an Auxiliary Block installed, as shown in Figure 36. Therefore, our cylinders were plumbed into ports J & K as discussed previously. These lines were split inside of the frame to allow flow to travel between the front and rear cylinders, and they would act in extension or retraction simultaneously, or one at a time if the friction was different between individual wheels.

Figure 36. Auxiliary Block on Prototype Machine

The in-cab controls were modified to allow easy control of the cylinders for the operator. Although a DWA raise/lower switch was installed on the machine, that control could be switched to the GSL stick via options in the Central Display Module (CDM). This way, the operator would not have to take his hand off the joystick to operate the system. This is helpful because of the assumption that the machine will be moving during all wheel adjustments. After testing, there were no hydraulic problems encountered.

The ladder design worked fairly well for a first revision. The mount easily bolted on to the platform, and the existing ladder was bolted on to the mount just as easily. The final setup is shown in Figure 37 and Figure 38. The only issues encountered with the ladder pertained to the latch itself. The original design had two connection points, high and low. With the new design, a small gap was created between the platform and ladder, and the connection was reduced to a single point at the latch. Because of this, there were slight stability issues on that side of the ladder, causing it to be wobbly on that side alone. While this was minor and not a significant safety issue, it was something that was less than ideal for the project. Additionally, while the latch worked perfectly as designed, the spring used in the handle was far too strong to be operated quickly. Again, it was a minor issue but something to be improved upon in the future.

Figure 37. Ladder in Transport Position

Figure 38. Ladder in Working Position

Final Cost Analysis

The final budget for the project is shown in Table 5. Budget for Project On the left were the exact receipts and charges for every aspect of the project, including report printing and other miscellaneous costs. On the right, there is a cost estimate for MacDon to implement the system for four wheels on a machine.

Table 5. Budget for Project

Varitrac Cost			Implementation Cost	
Ag Duplicating (Report Printing)	$ 78.79		Hydraulic Lines/Fittings	$ 317.72
Lowe's	$ 71.26		Plastic	$ 271.48
Bur Surplus Center	$ 40.45		Fabrication	$ 357.08
Online Metals	$ 212.82		Hydraulic Cylinders	$ 560.94
Cope Plastics	$ 271.48			
NAPA Auto Parts	$ 317.72			
Atwoods	$ 99.96			
O'Reilly Auto Parts	$ 215.98			
Dalton Bearing & Hydraulic	$ 280.47			
Stillwater Steel and Welding	$ 32.55			
	$ 1,621.48			$ 1,507.22

Future Recommendations

MacDon has multiple options for the hydraulic setup they may choose to run for this option. The DWA raise/lower block was used for the prototype, but not all machines may have that option. The actual reel fore/aft block functions exactly the same as the DWA raise/lower block. This system could be plumbed into that block, where a simple "T" near the block could control functionality between the reel system and the wheel adjustment. During transition, the flow could be redirected and dedicated to the wheel system, and then returned to reel control once the wheels are locked back out. It could be as simple as a handle that controls the valve, making it easy for operator use. Another option would be to create a bracket that attaches to the end of the reel fore/aft hoses, so when the quick connect is pulled from the header the operator can immediately plug it into a quick connect for the wheel system on the M155. This quick connect on the machine is shown in Figure 39. Additionally, the auxiliary blocks for DWA lift and Swath Roll control could be used like the prototype did. If proper wiring was installed, either of those blocks could be used if the machine did not use both a DWA and Swath Roll. Even if he did, the valve block arrangement allows for a third auxiliary block to be installed on the machine, leaving a dedicated valve block for the wheel width system to utilize. There are some spatial concerns with installing a third block on top of the other two, but if that can work it would allow dedicated use of a block to the wheel adjustment system.

Figure 39. Hydraulic Quick Connect for Draper Headers

MacDon has some options with the fabrication and distribution of the front leg as well. Although modifying the leg was not ideal for the dealer-installed kit, MacDon could produce a few of these legs and send them per request. This new leg would include slots as well as the new cylinder mount. The other mount would then have to be installed by the dealership itself, but with MacDon supplying the plate the difficulty of the task could be reduced. The benefit here is reduced time for the operator to adjust the wheel width.

On the back axle, an alternative method was used. Here, the bolts require operator input to switch the machine between field and transport positions. This makes dealer assembly much more possible, but increases the time for the operator to complete the task in the field.

Another issue with the rear leg was the position of the cylinder. As shown in Figure 40, one of the four bolts is covered by the cylinder. While it is relatively simple to unpin and move the cylinder out of the way for access, fine adjustments to the cylinder mount could prevent this issue on future revisions.

Figure 40. Bolt Covered by Cylinder on Rear Leg

As shown in Figure 41, our calculations missed a small detail regarding the size of the cylinder. Because of this, the team experienced contact between the head of one of the pins that support the front leg and the cylinder installed to extend it. Small alterations to the dimensions of the cylinder mounts would be able to solve this clearance issue.

Figure 41. Cylinder Contact with Bolt Head

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Varitrac Engineering

Project Overview

Varitrac Engineering

The Team

MacDon

Taylor Cole Nick Jacobsen Travis Biggerstaff

MacDon Industries Ltd.

MacDon

- Winnipeg, MB
- OEM Company
  - Windrowers
  - Combine Headers

All pictures courtesy of MacDon Industries Ltd.

MacDon Industries Ltd.

Global Presence

Industry Preferred

All Colors

Problem Statement

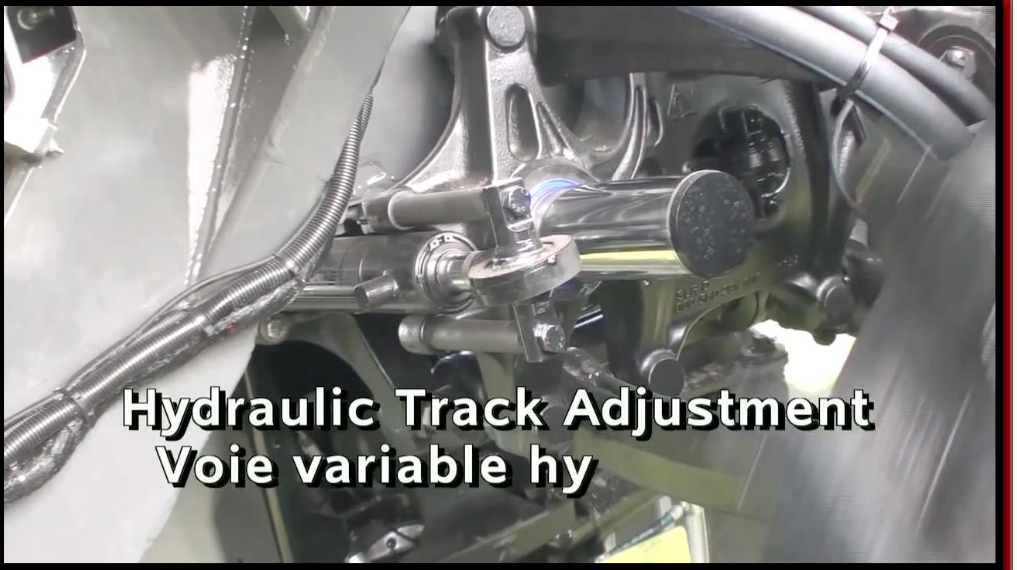
- Primary Canadian Crop – Canola
- Wide & Tall Frame – Transport Issue
- Quick & Easy Wheel Width Adjustment System
- Applications
  - European Standards
  - Shipping

Problem Statement

The goal of this project is to create an innovative, cost-efficient and reliable system that quickly adjusts the wheel width on a MacDon M155 Self-Propelled Windrower

Research

- Standard Feature For All Row-crop Sprayers
  - JD, CNH, Apache, AGCO, Versatile
  - John Deere Had As Option - Cost $4376
- Hydraulic Cylinders
- Mechanical Locks (Some)



http://youtu.be/9w1uKR15LoA

MacDon Requirements

- Mechanically Locked
- Two Positions: Field And Transport
- No Modification Of Damping Cylinder On Casters

Varitrac Engineering

Engineering Specifications

MacDon

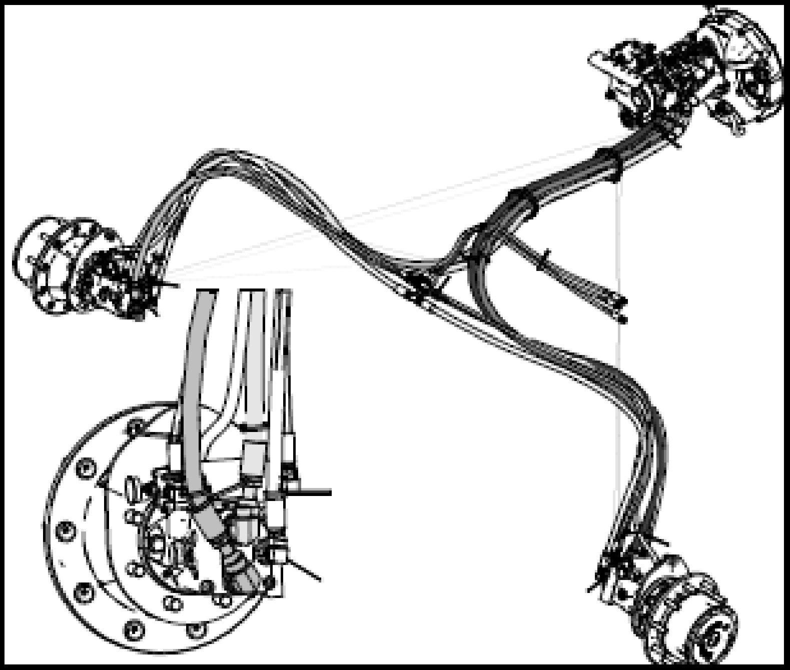
- Maintain Current Hydraulic/Electrical Setup
- Cost/Build Estimate
- Frame Modifications - Max $25
- 7” Difference – Front
- 18” Difference – Rear

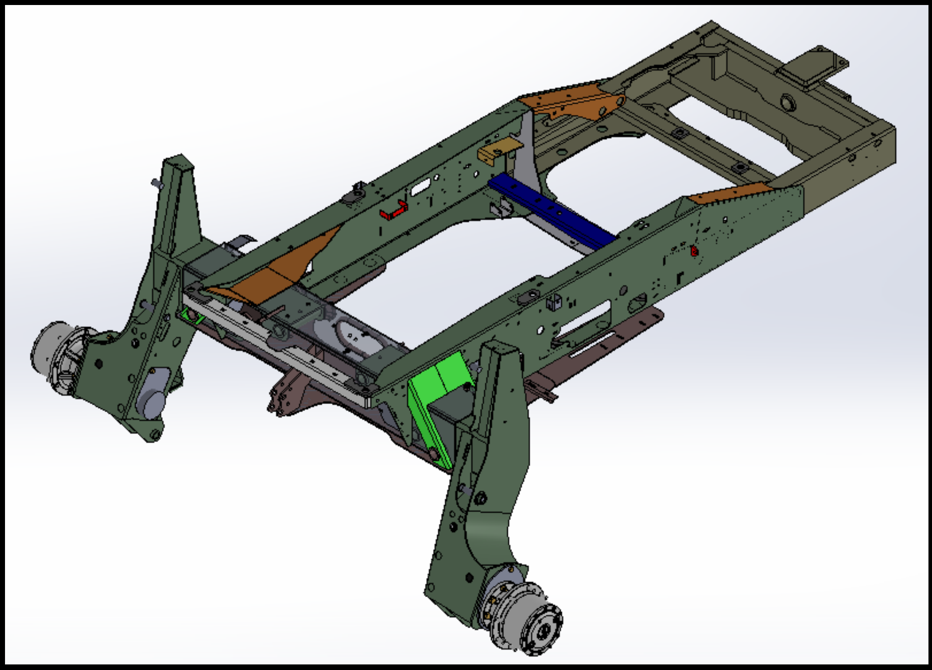
Constraints

- Spatial
  - Swath Clearance - Underneath
  - 36" x 45.7" Swath Area
  - Header Clearance – Front

Constraints

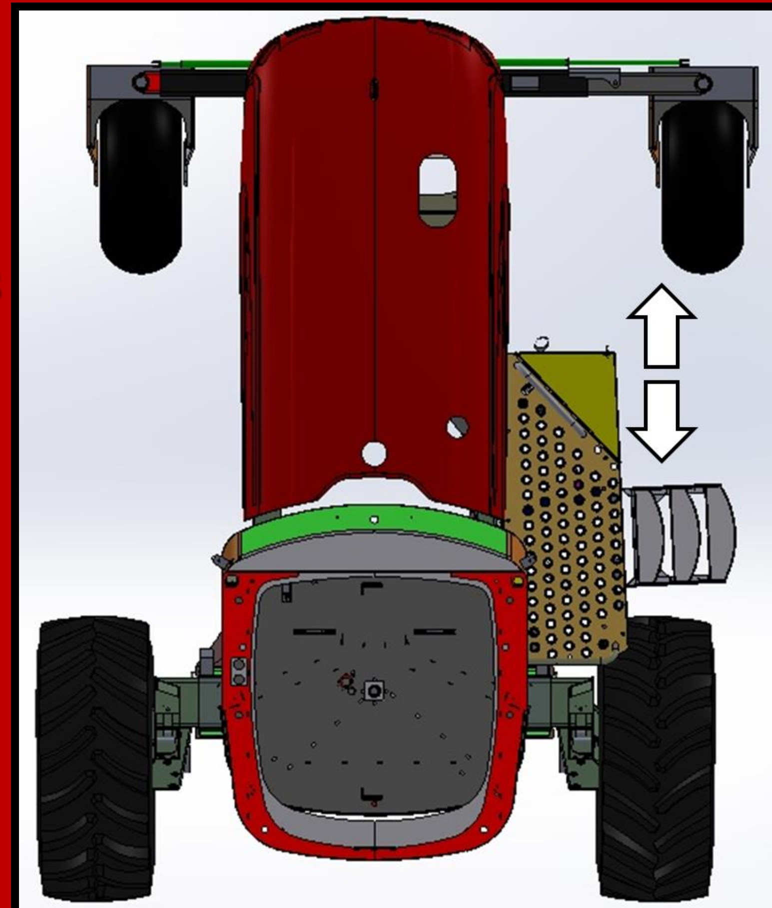
- Hydraulic Routing
  - Front Frame Tubing – Inside
  - Hoses/Blocks – Axial Rails





Constraints

- Mechanical
  - Platform – Multiple Positions
  - Header Lift Arms
  - Ladder – Extension Outside Tires

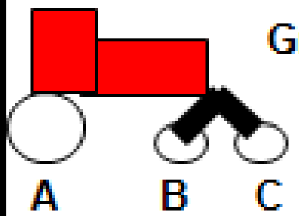


Design Considerations

- Weight Is Centered
- Coefficient of friction between contacting tubes 0.8
- Machine Will Be Moving Forward Slowly (No Side Resistance)
- Header Will Be Removed

Approximate Weight Distribution (lbs)

NOTE: If any individual axle weight exceeds the



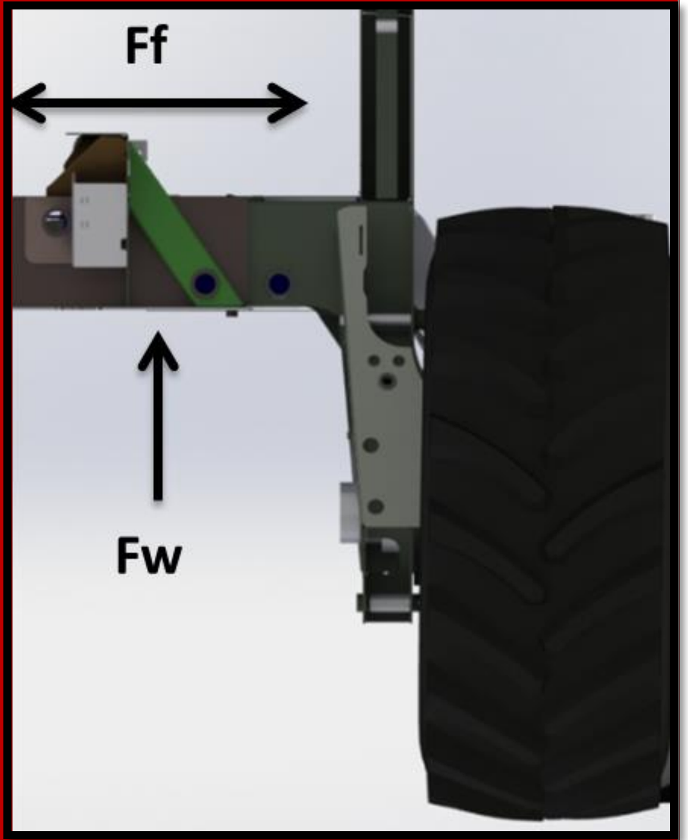
	Field
	Header on
Gross vehicle Weight	11200
Drive wheels - A	7224
Tail wheels - B	
Tail wheels - C	3976
Combined Gross Vehicle Weight	

Slotted Front Leg

MacDon

Front Wheels		
Weight (F_w)	3612	lbs
Coefficient of Friction	0.8	
Total Force Required (F_f)	2889.6	lbf.

Hydraulic Pressure (P)	2400	psi
Total Force Generated	2889.6	lbf.
Required Cross Sectional Area of Cylinder	1.204	in^2



$$Ff = \mu * Fw$$

$$A = Fw * P$$

$$Fw = \frac{W}{2}$$

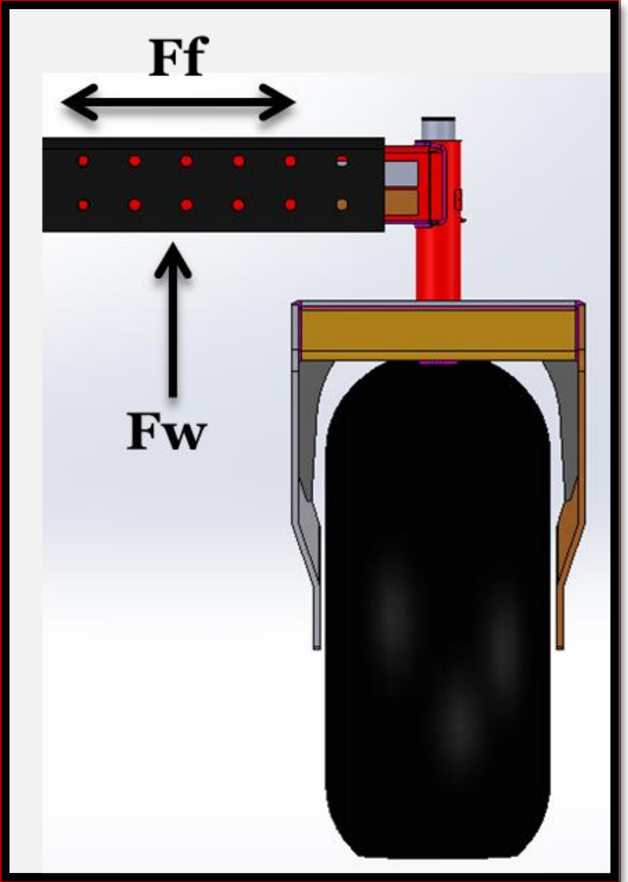
Rear Leg Forces

Rear Wheels		
Weight (F_w)	1988	lbs
Coefficient of Friction	0.8	
Total Force Required (F_f)	1590.4	lbf.
Hydraulic Pressure (P)	2400	psi
Total Force Generated	1590.4	lbf.
Required Cross Sectional Area of Cylinder	0.663	in^2

$$Ff = \mu * Fw$$

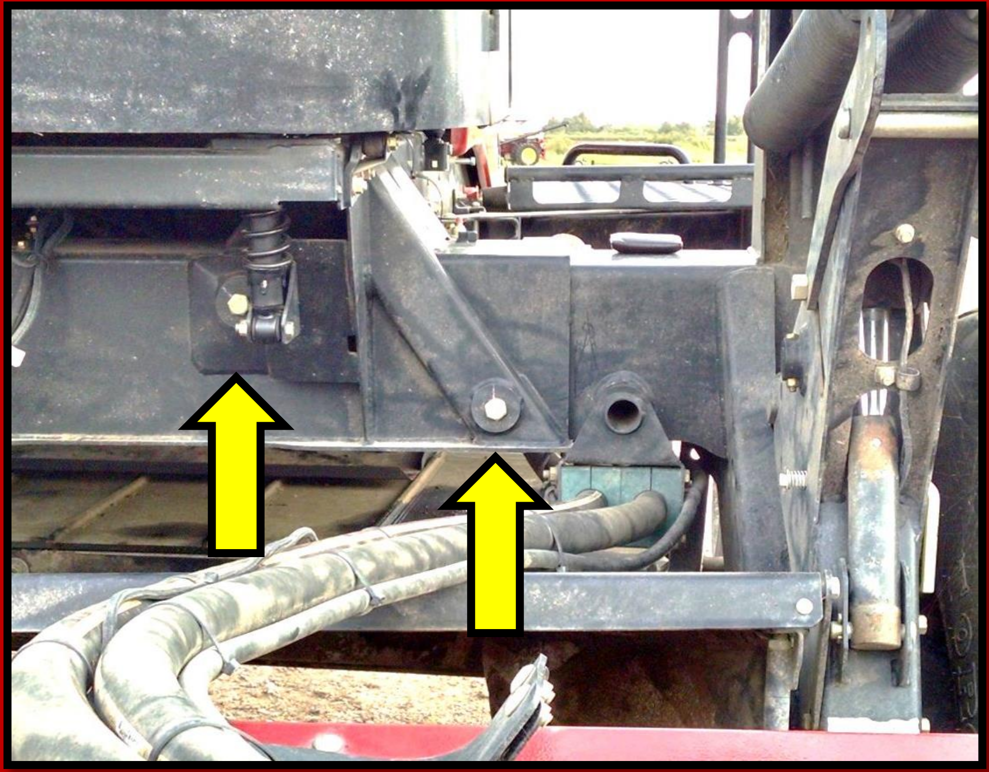
$$A = Fw * P$$

$$Fw = \frac{W}{2}$$



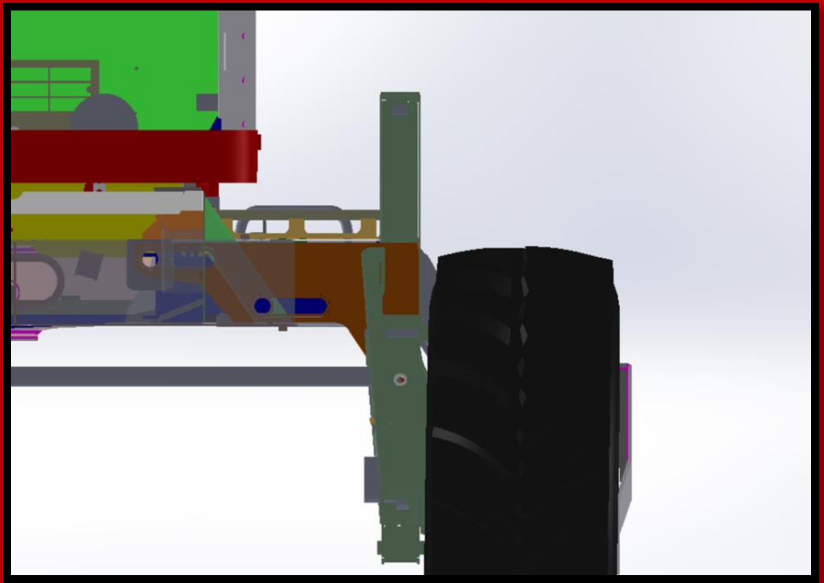
Challenges

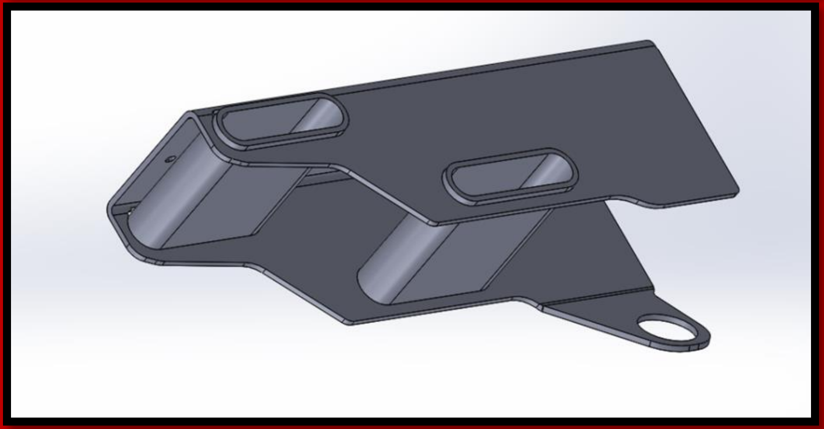
- Weight Distribution On Pins
- Leg Clearance From Frame
- MacDon Scope
  - Frame Modification
  - Dealer Install



Slotted Front Leg

- Freedom Of Movement Between Positions
- Exterior Lock
- Friction-Reducing Plastic
- Fabrication



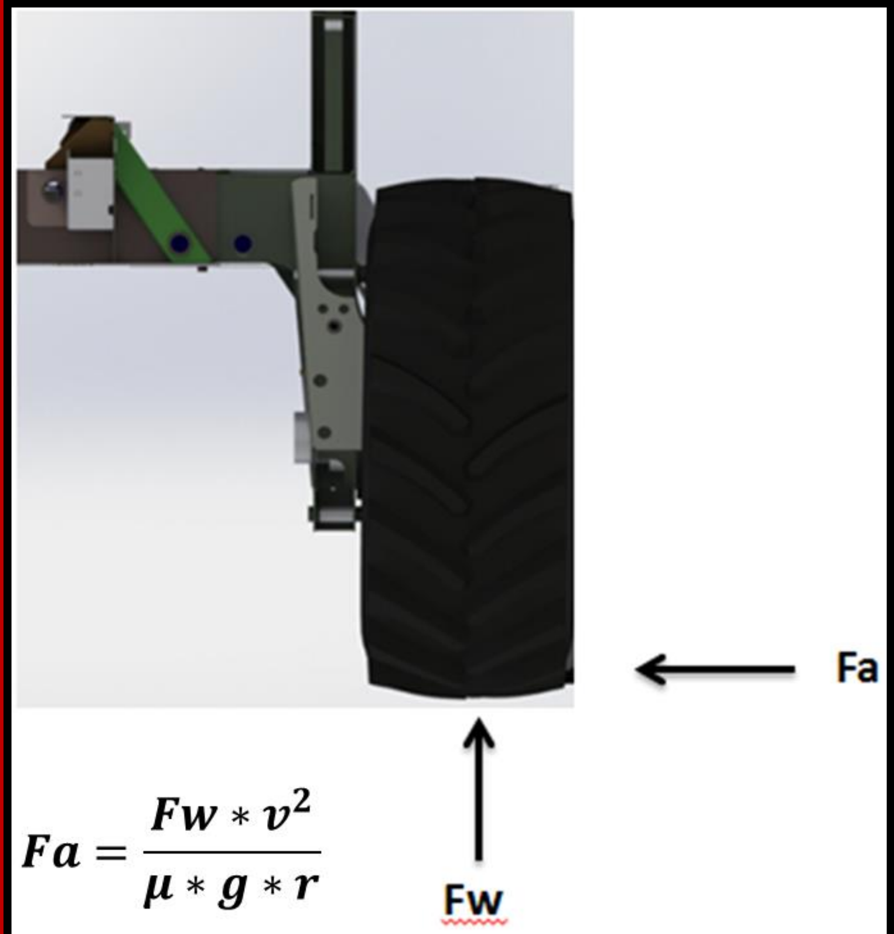


Varitrac Engineering

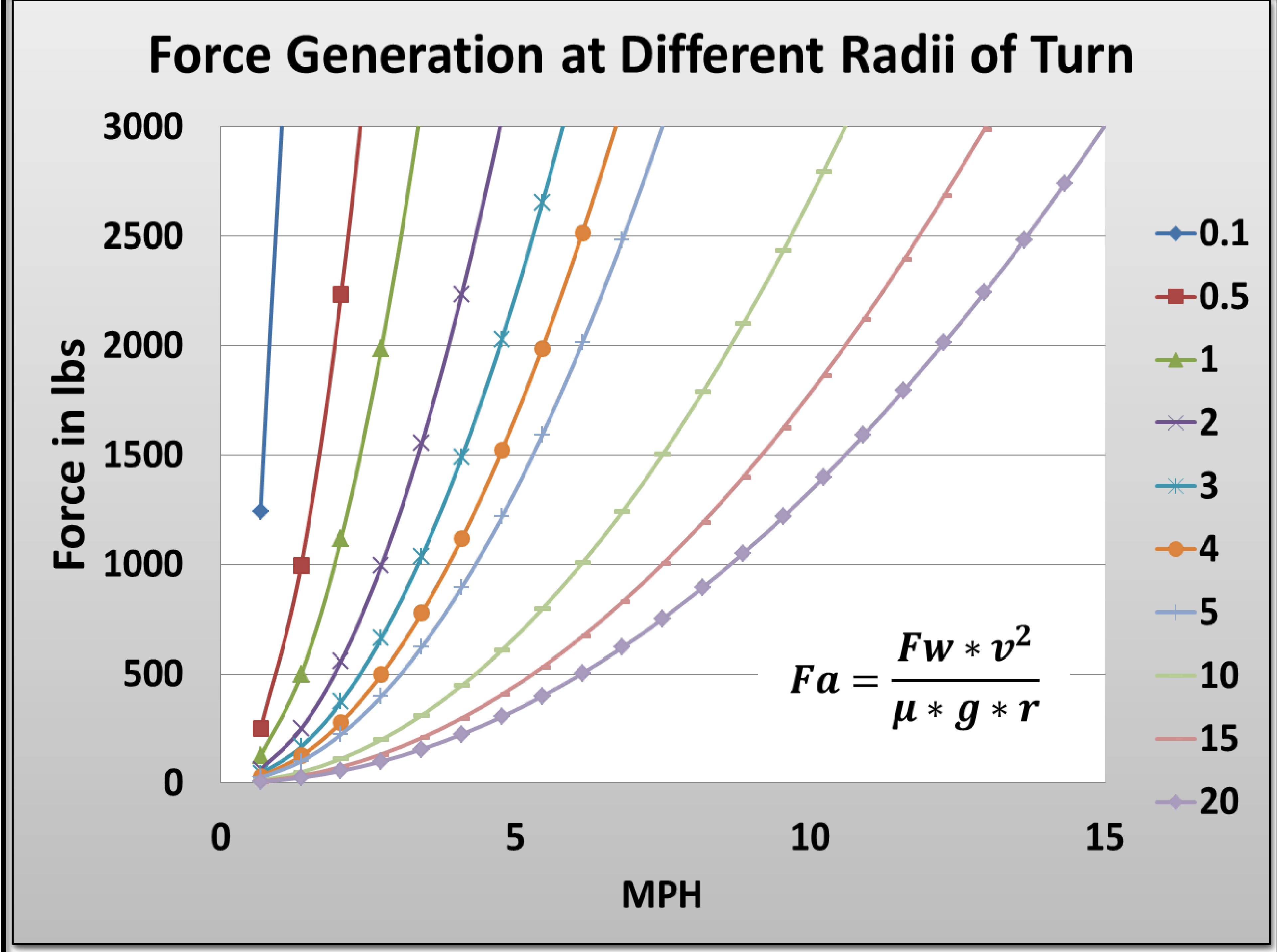
Side Load Calculations

MacDon

- Calculations Made On Cylinder Capacity
- Centripetal Force Is Equal To Side Loading Force
- Different Speeds And Radii
- Assuming No Sliding (Coefficient Of Friction Equal To 1)
- Weight Assumed To Be 4000lbs



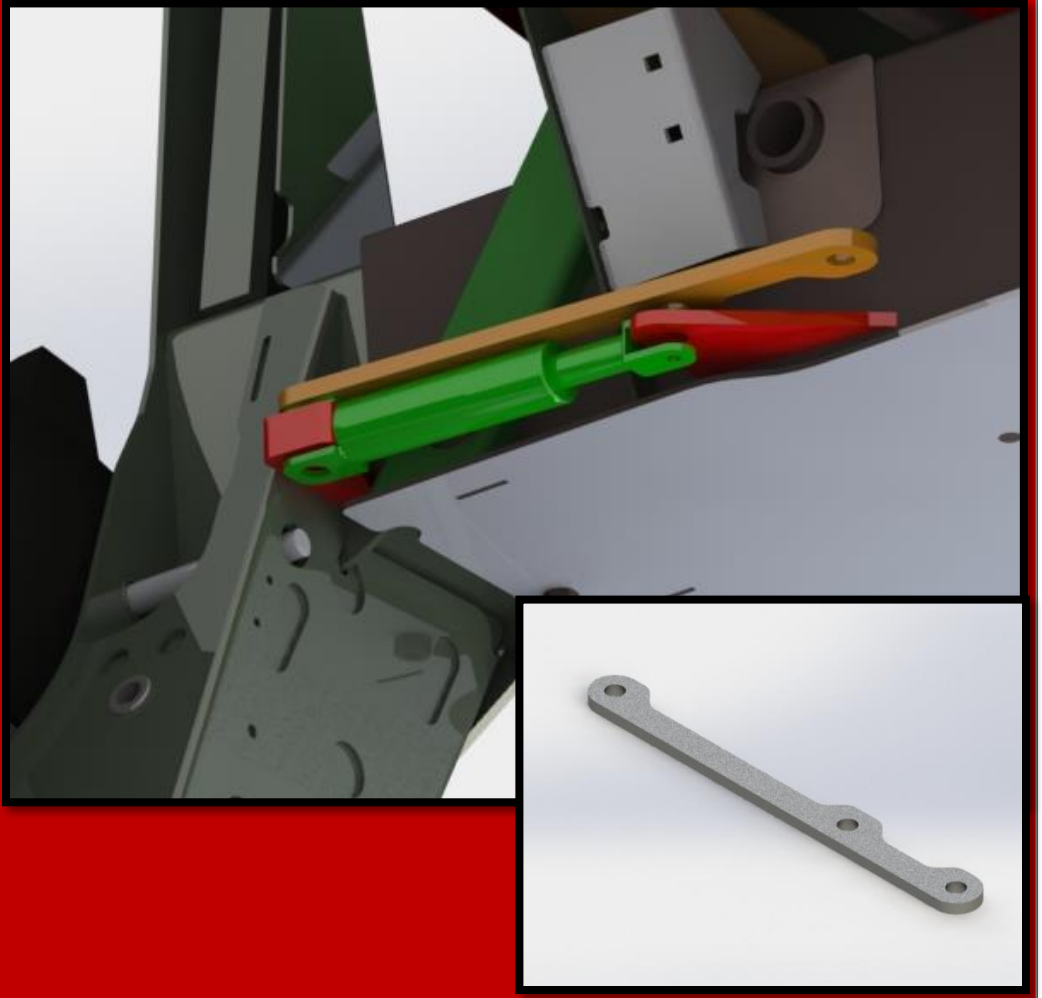
$$Fa = \frac{Fw * v^2}{\mu * g * r}$$



Force Generation at Different Radii of Turn
Force in lbs
3000
2500
2000
1500
1000
500
0
0
5
10
15
MPH
0.1
0.5
1
2
3
4
5
10
15
20
$Fa = \frac{Fw * v^2}{\mu * g * r}$

Mechanical Locks

- Simple To Unfasten
- Uses Existing Mounting Pins
- Will Not Allow Cylinder Movement



Varitrac Engineering

Rear Leg

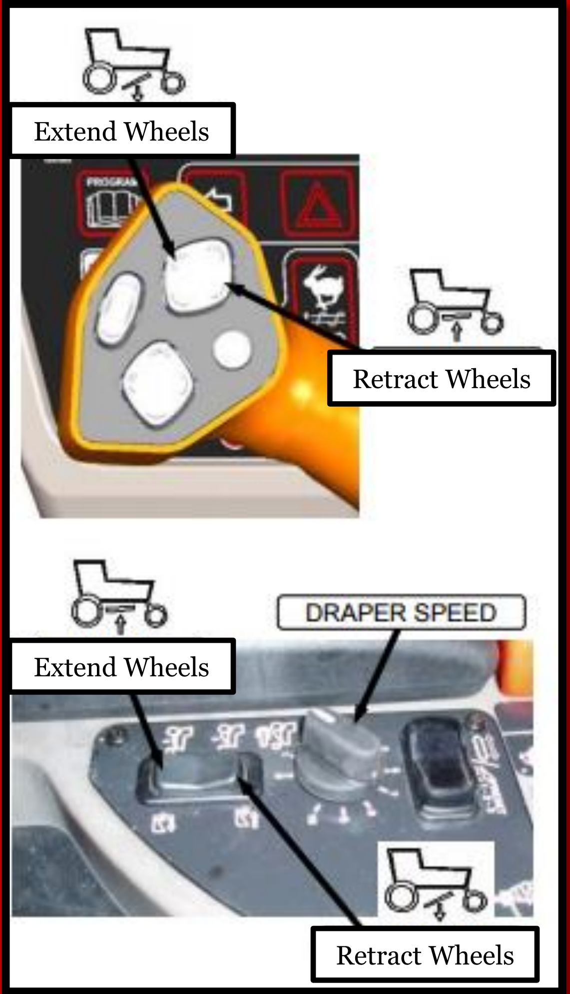
MacDon

- No Frame Modifications
- Added Cylinder Mounts And Stop Mechanism
- Six Bolts Act As Locking System
- No Modification To Damping Cylinders

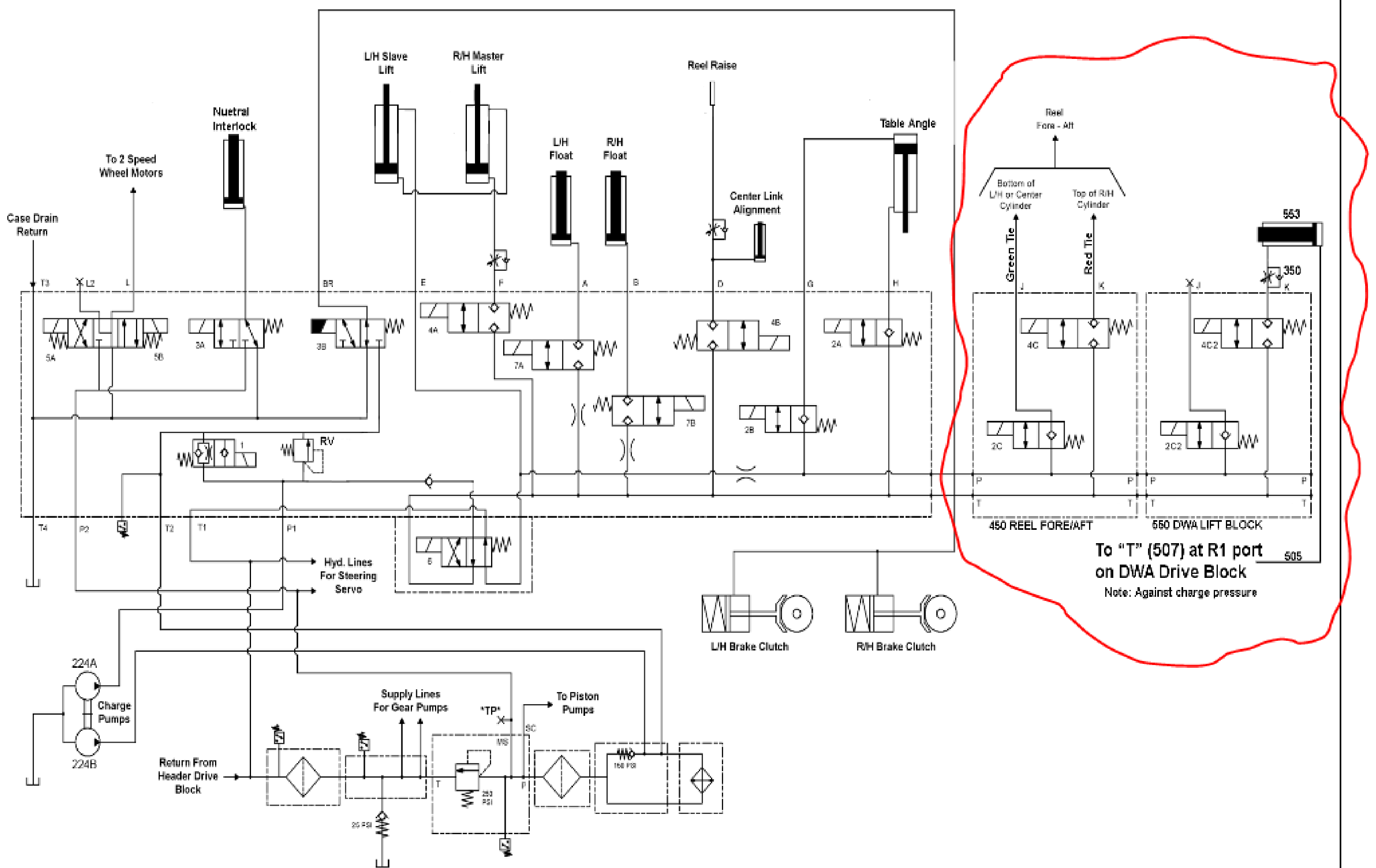
Hydraulic System

- Utilize Auxiliary Lift Block
- Cab Control
- Various Options For Addressing Individual Setups
- No Electrical Modification

Hydraulic System



9.3.7 HYDRAULIC SCHEMATIC FOR DWA LIFT & REEL FORE/AFT

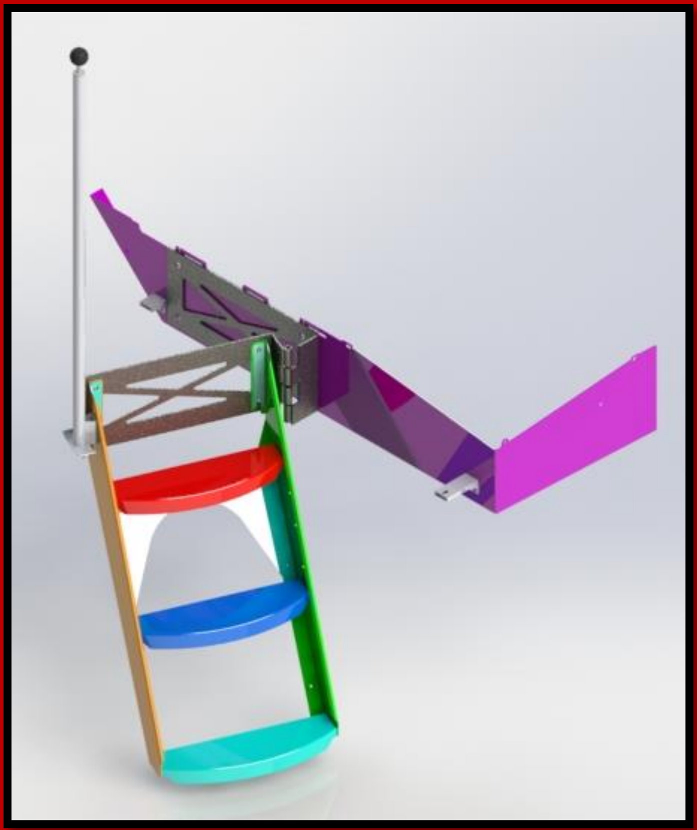


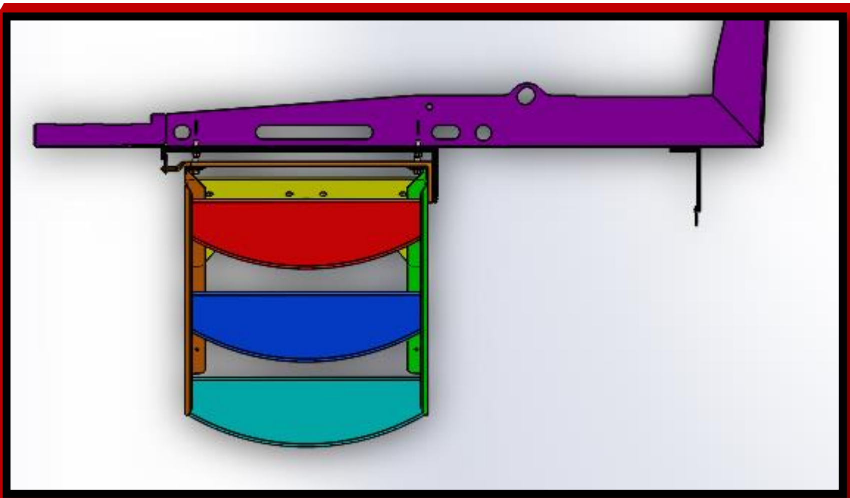
Schematic drawn with tractor running and GSL in the neutral position (Brakes On)

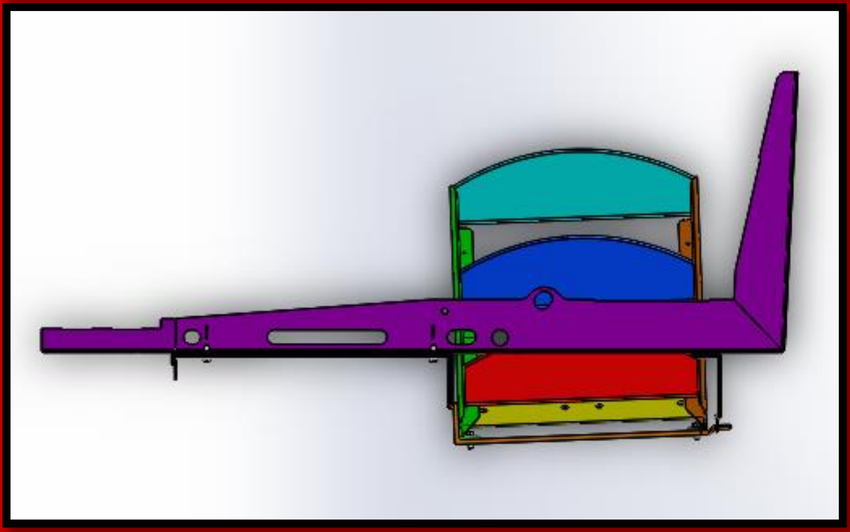
Figure 9-22:

Ladder Design

- Rotating Design







Ladder Design

- Rotating Design
- Spring Loaded Latch
- Accomplished From Ground Or Platform

Leg Movement

Ladder

Budget

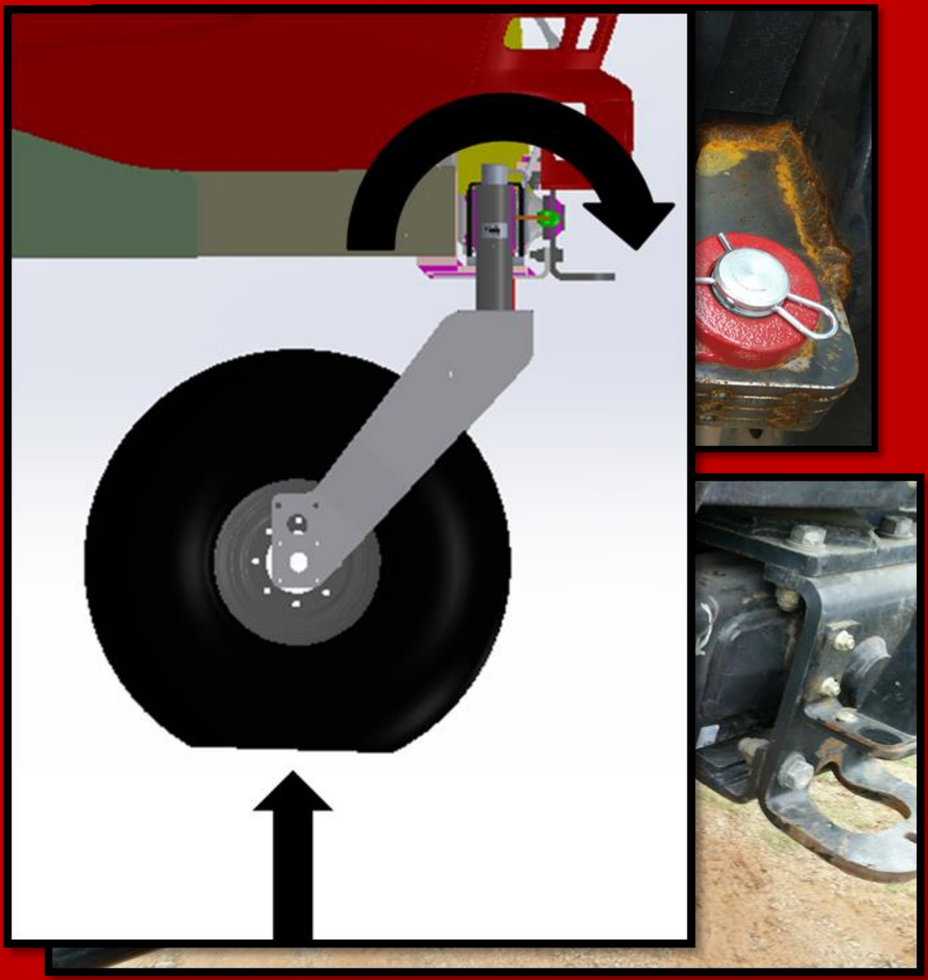
Varitrac Cost			Implementation Cost	
Ag Duplicating (Report Printing)	$ 78.79		Hydraulic Lines/Fittings	$ 317.72
Lowe's	$ 71.26		Plastic	$ 271.48
Bur Surplus Center	$ 40.45		Fabrication	$ 357.08
Online Metals	$ 212.82		Hydraulic Cylinders	$ 560.94
Cope Plastics	$ 271.48			
NAPA Auto Parts	$ 317.72			
Atwoods	$ 99.96			
O'Reilly Auto Parts	$ 215.98			
Dalton Bearing & Hydraulic	$ 280.47			
Stillwater Steel and Welding	$ 32.55			
	$ 1,621.48			$ 1,507.22

Future Recommendations

- Hydraulic Options
  - Reel Fore/Aft Block
  - Auxiliary Block
  - Selector Valve
- Slotted Leg
  - Dealer Build
  - Dealer Exchange
  - Standard Feature

Future Recommendations

- Rear Leg
  - Dealer Build
  - Standard Feature
- Ladder
  - Stability
- Fine-tuning Of Designs
  - Cylinder Contact
  - Rear Cylinder Mount
  - Rear Plastic Liner



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  - Joe Preston
  - Jason Walker
  - Nick Semter
  - Nick Fleming
- Mr. Scrub Dollins
- Dr. Paul Weckler

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2014

Varitrac Engineering Report

MacDon Industries, LTD.

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12/4/2014

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Introduction

MacDon Industries is an original equipment manufacturer based out of Winnipeg, Manitoba. They have been world leaders in the technology, innovation and manufacturing of high quality, high performance harvesting equipment for over 65 years now, beginning back in 1949. Currently, they sell their products in over 40 countries, on six continents as Figure 1 shows. These products range from hay equipment like rotary and auger headers, to pick-up and draper headers for combines. Additionally, they produce a line of self-propelled windrowers designed to operate rotary, auger and draper headers for a variety of uses to producers.

Figure 1. A Brief Display of Countries with a Strong MacDon Presence

Canola is the primary crop produced in Canada currently. For this reason, MacDon self-propelled windrowers have a wide wheel base and 45.7" below –frame clearance to allow bushy crops like canola to pass under the machine after cutting. This can be seen below, in Figure 2. However, this wide wheel-base means transporting these machines can be time-consuming and costly. MacDon's current design contains a sliding tube held in place by bolts and weld-nuts, where the tube can slide in and out from the main frame when not bolted in place. These "legs" as they are called, require a fair amount of time to adjust, because the machine must be jacked off the ground to allow easy sliding. To this point, the system works because the legs are usually only adjusted to load machines onto trucks, and then to prepare for its working life.

Figure 2. Illustration of Bushy Canola and MacDon's Wheel Clearance

For the purposes of this project, Varitrac Engineering intends on creating a system that will complete this task in much less time than before, with less user effort. By streamlining this process, it could have benefits in a variety of areas for MacDon. With this option installed, it could significantly decrease the time required to load these machines onto trucks for shipping around the continent. This could apply to farmers as well, if they ever required trucking their machine from one location to another.

More importantly, development of a feature like this could have huge benefits in the European market. Their road systems require strict adherence to lane widths, which the MacDon machine exceeds when the wheels are in a "working" position. However, by streamlining the process of sliding the wheel legs in, a producer could easily move the wheels in to drive between fields, and then quickly spread the wheels for operation again. This feature would make self-propelled windrowers from MacDon much more appealing to European producers, potentially increasing sales.

With all of these benefits in mind, Varitrac Engineering intends on accomplishing this project with the following problem statement in mind:

The goal of this project is to create an innovative, cost-efficient and reliable system that quickly adjusts the wheel width on a MacDon M155 Self-Propelled Windrower.

This project covers the design, testing, and prototyping of an M155 windrower to add a system to adjust wheel width from the cab. The two desirable positions are at full width (field width) and narrowed width (transport width.) The cost of the system should be minimized to make the system more desirable. The deliverables are to include the ability to change the width of both the front and back axle, as well as adjusting the ladder to accommodate the transport width.

The task list for the completion of this project is outlined below:

Table 1. Task List for Project Completion

Task List	Finish Date
Define Client Requirements	10/08/14
Research applicable patents	10/15/14
Establish Multiple Design Ideas	11/05/14
Run Calculations/Analysis on Ideas	11/18/14
Write Design Presentation	12/01/14
Gain Client Approval of Final Design	12/04/14
Construction of 1st Revision	01/29/15
Test and validation of 1st Revision	02/05/15
Evaluation, and Addition design revisions	03/26/15
Completion of Prototype Assembly	04/09/15
Final Presentation and Report	04/30/15

Customer Requirements

For this project, we will need to design a system that enables operators of an M155 self-propelled windrower to quickly adjust the wheel spacing on both sets of tires. MacDon has recommended the transition to occur while the machine is in motion, to reduce frictional forces from the ground. Regardless of the design, the final locking system must be mechanical in order to ensure safety of the system when locked into position.

This system will only have two (2) settings: Field (Wide) or transport (narrow), in order to accommodate the European road systems and allow for quick loading onto trucks. On the caster (rear) wheels, there are dampening cylinders that prevent excessive wobbling of those tires at high speeds, as shown in Figure 3. The relationship of frame mounting point to the tire must remain constant in both positions, in other words, the distance the cylinder reaches cannot change regardless of wheel spacing.

Figure 3. Dampening Cylinder on Caster Tire

Ideally, we would like the operator to accomplish this task alone, without the assistance of other people to perform this adjustment. On top of that, a goal for the team would be to minimize the number of trips in and out of the cab of the machine in order to complete this step. This will be once at the minimum for the assumption that the header of the machine must be removed or attached prior to wheel width adjustment, as defined by MacDon.

The system used to accomplish this task also has spatial requirements. In order to maintain optimal machine performance, we cannot make any major alterations to the current hydraulic or frame setup. Also, nothing can be installed below the existing frame of the machine, to retain the "window" size for bushy crop to flow under without interference. This frame clearance also applies to the ladder. With the ladder installed and wheels in transport (narrow) position, the ladder sticks out too far. Therefore, a re-design of the ladder is necessary to bring it within the wheel constraints. This must also allow the ladder platform to be moved into different positions as is standard on the MacDon machine. This is illustrated in Figure 4 and Figure 5, which demonstrates the difference between the two positions.

Figure 4. Platform Locked in Rear Position for Service

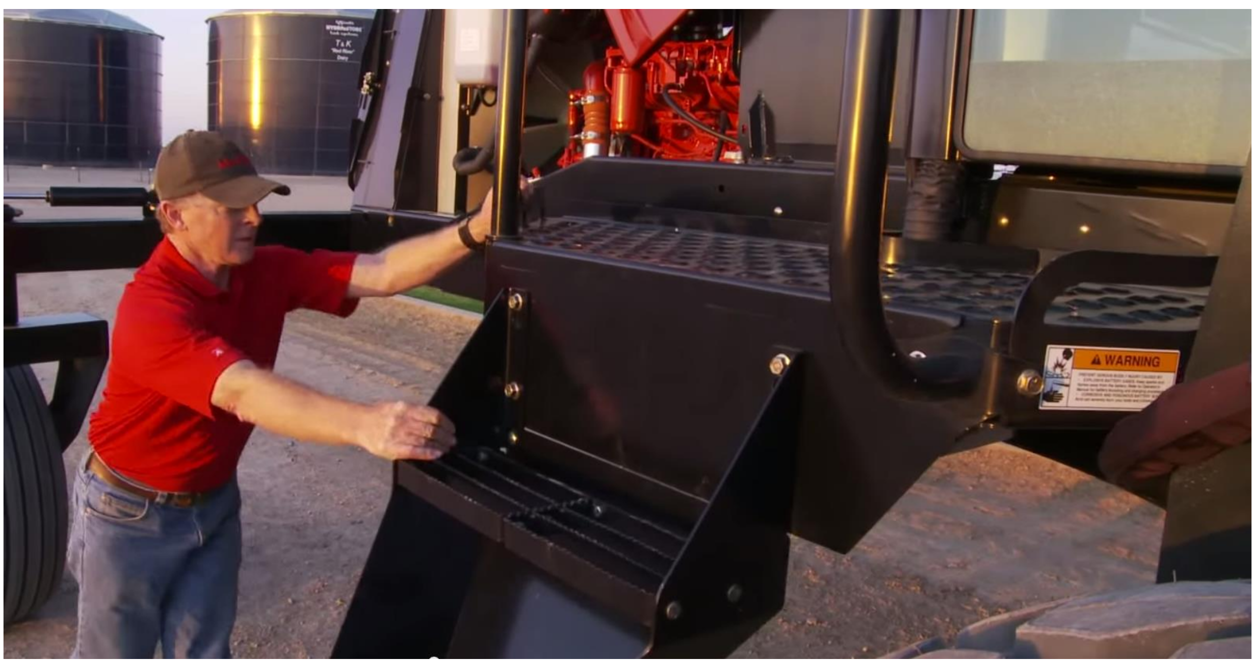


Figure 5. Platform Locked in Forward Position for Operation

MacDon has also asked that we use the current valves and circuits for this project, meaning no modifications can be done to either system. As shown in Figure 6, in some places these systems take up a lot of space. This system has also been assigned as a dealer-installed kit, so it must be designed so that a machine can be configured with or without the width adjustment, but with necessary components to make installation possible at a dealership.

Figure 6. Hydraulic Blocks and Connection Points of a MacDon Windrower

MacDon has also requested we do an estimate of cost/build for this project, in order to maximize its usefulness as an option. This is outlined in Table 5.

Engineering Specifications

- 7" difference between transport/field wheel widths on front tires
- 18" difference between transport/field wheel widths on rear tires
- Existing hydraulic valves and circuitry (design within the bounds of current system)
- All added components must not exceed machine constraints, both underneath and wide
- Limit of $25 for frame adjustments

Ladder Design

As a part of the design process, the team was assigned two groups of freshmen. These teams were assigned the task of designing an improved ladder that would also fit the wheel width requirement. Each team came up with a unique idea to accomplish the goal, the first decided to fold the ladder under the machine, and the second used a hinge to rotate the ladder under the machine. As seen in Figure 7, the folding design uses a simple hinge and latch mechanism and an existing ladder rail. The design also has the advantage of increasing ground clearance.

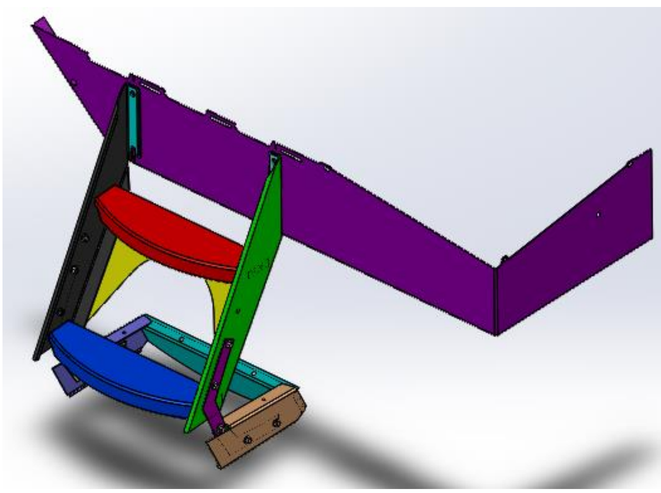


Figure 7. Folding Ladder Design

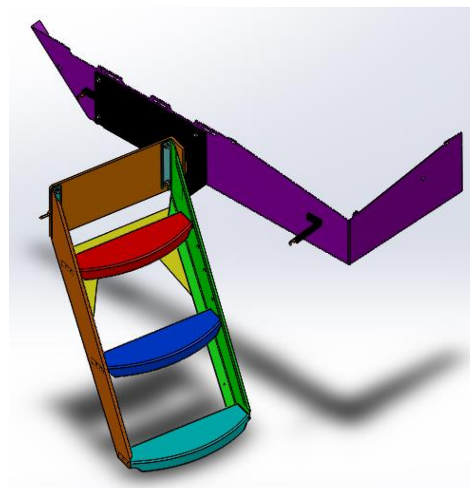


Figure 8. Rotating Ladder Design

The second design, shown in Figure 8, rotates the ladder on a hinge, locking on the platform itself. The rotating method would be relatively simple to install as it uses the existing ladder and adds a hinged bracket in the existing holes for the ladder. Both designs show promise, but do need more work and some force analysis to ensure the safety of the user. These groups have not finalized their designs yet, and so the team decided to wait to perform any analysis until that is done.

Market Research

Currently, John Deere, Apache, CNH, AGCO, and Versatile all have existing systems by which track spacing can be adjusted on their self-propelled sprayers, as a standard feature. While all of these companies advertise this feature, specific technical information is difficult to find. Most of these systems are hydraulically adjusted, and a few have mechanical locking systems for safety purposes. At one point, John Deere offered this feature as an option, which could be added to a sprayer for around $4,376. This gives a target range for when projecting costs for this project.

Campers have frames that expand and contract for being on the road and actual "living" situations. These systems are vital to analyze for their friction reduction system, whether it be a plastic skid or otherwise for friction reducing concepts.

Mechanical locking system from a cattle gate could be implemented on an axle if done properly. The concept is intriguing because it only requires user input for the unlocking stage of use. As the gate shuts, it raises the latch mechanism on either side, then gravity forces the latch back down to securely lock the gate, shown in Figure 9. This idea is especially useful when designing mechanical locks as it helps reduce the operator input when activating the system.

Figure 9. Two-Way Gate Locking Mechanism

An impact wrench could be used to adjust the wheel spacing, although the setup is less than ideal due to stresses and time constraints. This system, as shown in Figure 10, uses a handheld impact wrench to retract the wheels. This system proved viable when one farmer successfully installed such a system on his self-propelled sprayer, as in

Figure 10, but with no axle to slide the concept would need to be implemented differently for this project's purpose.

Figure 10. Impact Wrench Mechanism for Sprayer

Any design that adjusts heavy frame components will create pinch points. Also, the reliability of a hydraulic cylinder to retain its position should be secondary to a mechanical locking system per customer requirements. Therefore, for safety purposes a mechanical lock would be preferred. An electronic system could also be implemented as a fail-safe in case of operator error.

Multiple patents were discovered during the research process, all pertaining to wheel adjustment systems. For example, the High Clearance Vehicle Wheel Spacing Adjustment patent (no. 3964565) showed a fairly simplistic hydraulic design, as shown in Figure 11. Here, slider bearings reduced the sliding force on the tube itself. This allowed for single-person operation to complete the process. However, the locking system required tools, and some disassembly and assembly was required to complete the operation. The simplicity of this design appeals to MacDon, but there fails to be a quick transition and doesn't have stops implemented into the system that this project requires.

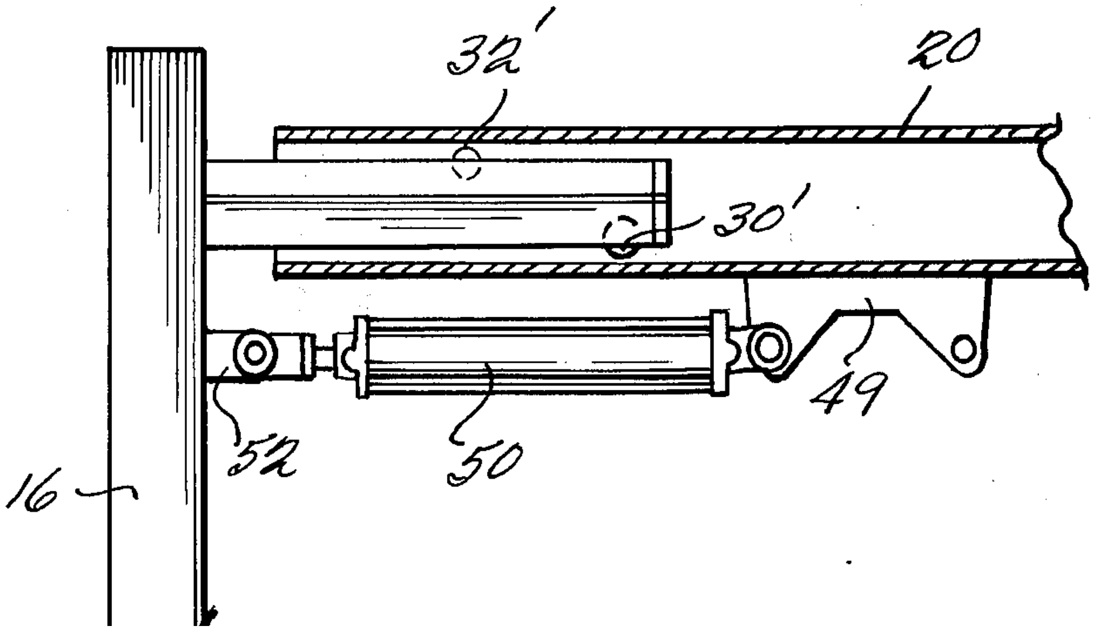


Figure 11. Simplicity of US Patent 3964565

Another patent had some useful concepts as well (patent no. 4619340). A linkage system served to change the wheel width, meaning no sliding friction, and no tools were needed for adjustment. The major drawback with this design was its complication which is well illustrated in Figure 12. It had many features that MacDon would not find desirable, and it also adjusted the height of the machine. This system also had additional hydraulic components, which added unnecessary cost. While this design came from a different approach and sparked new ideas, it would affect the structural configuration of the machine too much, which is not desired by the client.

Third, we found an adjustable vehicle axle patent (no. 4040643). This was a very simple mechanism, utilizing a clamping force from bolts that held the axles into place. Also, a small tab was used as a physical stop. The problem here was the split-frame configuration, as well as the necessity for the tires to be raised off the ground for completion. The design was very simplistic, but did not allow for the adjustment to be completed within five minutes or less. The client asked that the adjustment to be rather quick to maximize productivity.

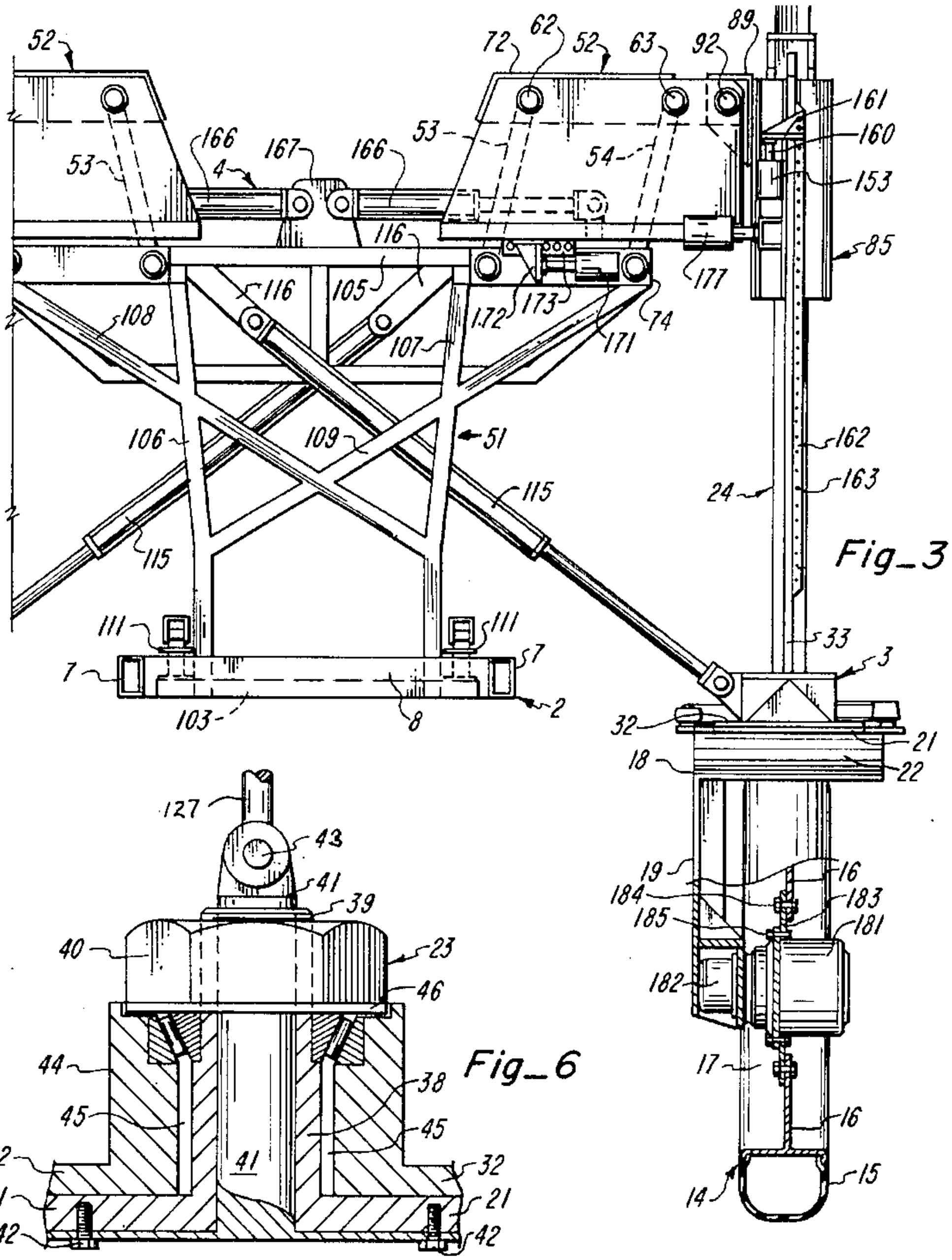


Figure 12. Complication of US Patent 4619340

Finally, the Multi-Position Track Width Sensor for Self-Propelled Agricultural Sprayers (no. 7163227) was an interesting concept. This system was high tech, with an LED grid indicating the position of each wheel. Very little was required electronically; the system uses four linear potentiometers, shown in Figure 13, and an array of LEDs. On the other side, the five different positions are excessive for the purposes of this project. Also, fatigue from vibration during normal machine operation could eventually lead to failure if the linear potentiometer wasn't properly mounted and sized. Our client needs the ability to ensure proper lockout of axles in either position, so we could use some sensor setup of similar nature to warn the operator if the system malfunctioned for some reason. This idea has the potential to be taken a step further by programming some additional functions into the current on board computer to control the mechanism, where it won't be able to move unless the machine is moving in order to reduce the required force significantly.

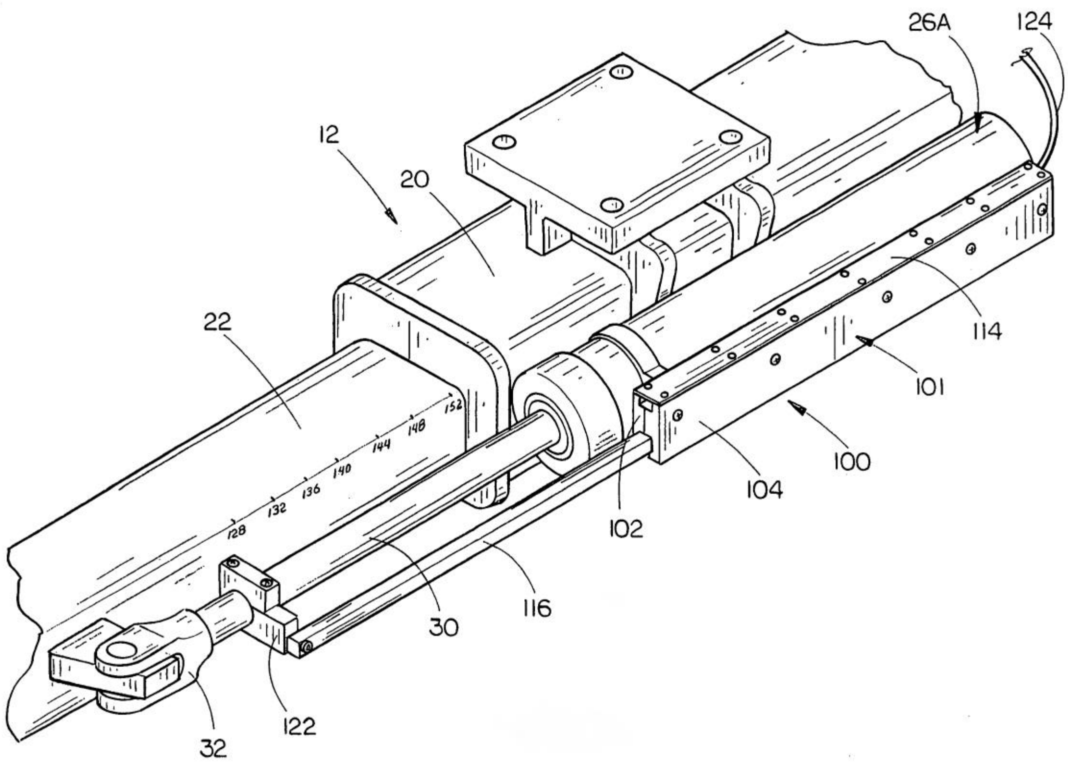


Figure 13. Linear Potentiometer Setup of US Patent 7163227

Project Impact

Because this is a heavily-mechanical project, the environmental, global, and societal risks are low. There is potential for an added hydraulic system, but the closed system will ideally have no problems. The biggest impact of this project is economically. MacDon will be able to utilize this product both in North America and beyond, potentially increasing sales of their self-propelled windrowers. By being able to collapse the wheels quickly, the shipping process has significant steps removed, saving MacDon both time and money when transporting these machines to dealerships. Also, European application will allow customers to quickly go from one field to another, without having to worry about the road constraints. As strict as these constraints are, the MacDon M155 will fit easily when the wheels are collapsed. If this is a quick process, so will be the process of switching fields.

Other aspects to be considered involve safety. Working with a large piece of equipment, safety is always an immediate concern. MacDon has specifically requested the involvement of mechanical locks in this system despite what is used to adjust the wheels, as mechanical locks are much more trustworthy than potential failure in hydraulic or electrical systems. Also, the cylinders will be sized in a way that they will reach their stops if the lock ever did fail. This ensures that the axle will be held to the machine. Pinch points will also be an issue worthy of looking into, as large components of the machine will be moving to accomplish the task of adjusting the wheels. To counter this, special attention will be given to the operator's role in the process. This includes anything from what tasks he will do outside of the machine, to exactly where the operator should be located while the adjustment is taking place. By planning to these aspects, safety for all people involved can be assured.

Design Concepts

One of the initial concepts drawn up involves the instrumentation of a hinged axle. As shown in Figure 14, the rear axles would pivot either forward or to the rear of the machine. This way, they could be kept clear of interference. The benefit of this method was the purely mechanical system used, where a lock on the hinge could engage and disengage by the operator and driving the machine would create the force necessary to move the wheels. However, there are many drawbacks to this idea. First, this concept cannot be used on the front set of tires, because they are not free to rotate like the casters. Additionally, the balance of the machine could be greatly thrown off with respect to the "axle" distances. This could cause the machine to tip forward much easier, as well as creating other balance issues at road speeds. While not a design consideration, this idea also eliminates the potential for multiple width positions to be used on the back axle.

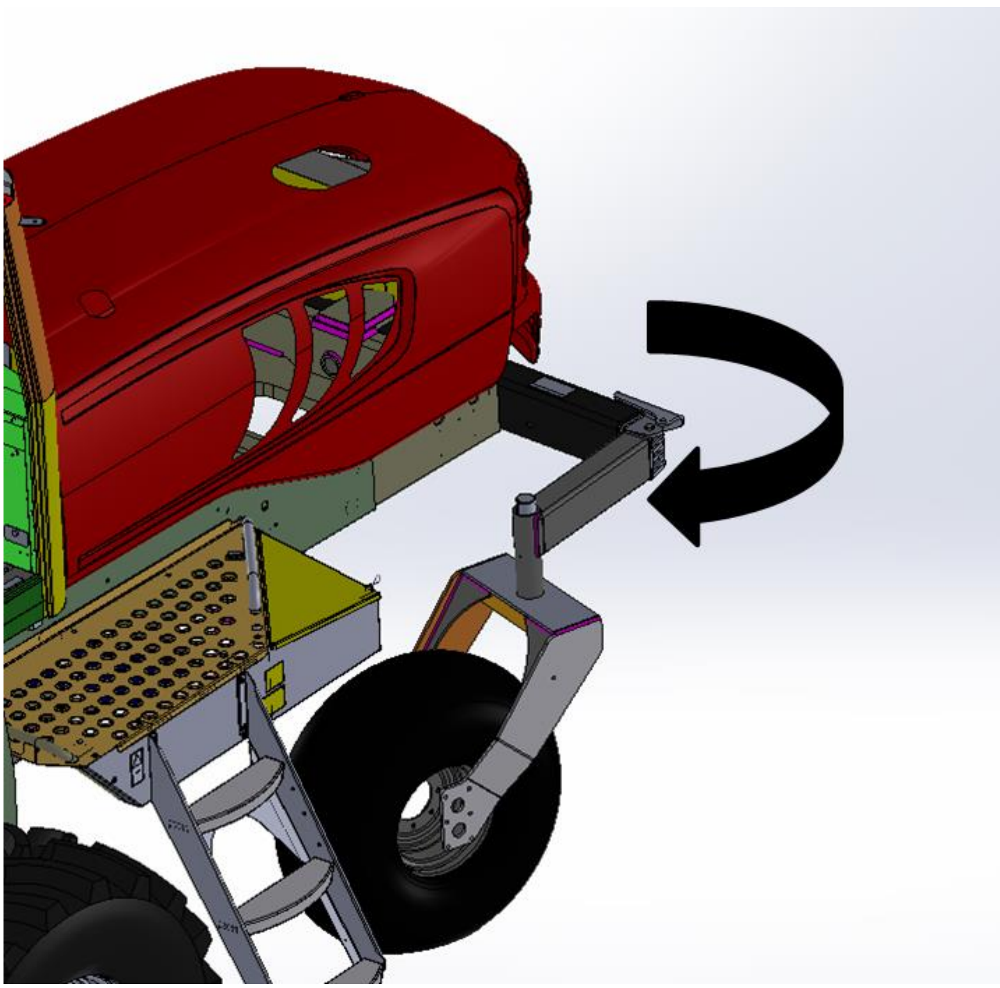


Figure 14. Concept Model of the hinge on the machine rear

Next, we discussed the idea of a rack and pinion driving the wheel movement, as shown in Figure 15 and Figure 16. The operator would use an impact wrench on each tire, one at a time, and crank the wheels in or out until the desired position is reached. Again, the benefit of this would be a purely mechanical system, without the need for hydraulic or electrical modifications. However, this would be a very primitive design. With the operator out of the cab, the machine could not be rolling to reduce friction of the tires sliding on the ground. This creates a greater force requirement, but also causes a significant amount of stress. Additionally, with an exposed system dirt and debris could easily interfere and cause problems. This would be the most time-consuming option as well.

Another option would be to use a hydraulic motor attached to the pinion gear to move the axles in and out. As seen in Table 3 and Table 3 the calculations have been carried out to size a hydraulic motor. For the front wheels alone the hydraulic motor sized properly would cost two hundred dollars for just one motor. The rear wheels would need two hydraulic motors each one costing one hundred fifty dollars. The total costs of just the hydraulic motors alone would be seven hundred dollars which seems to be expensive for a kit option. Also, the rack and pinion could possible interfere with hydraulic hoses that are run inside the axle tube. This could cause several hydraulic leaks and possible failure of the wheel adjustment system.

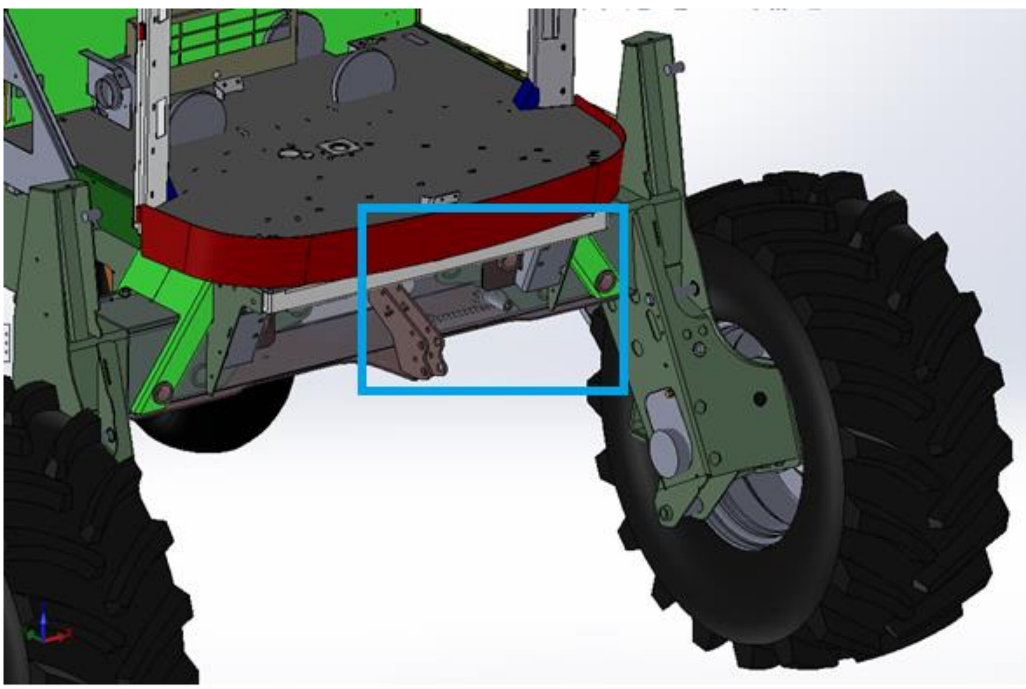


Figure 15. View of rack and pinion concept

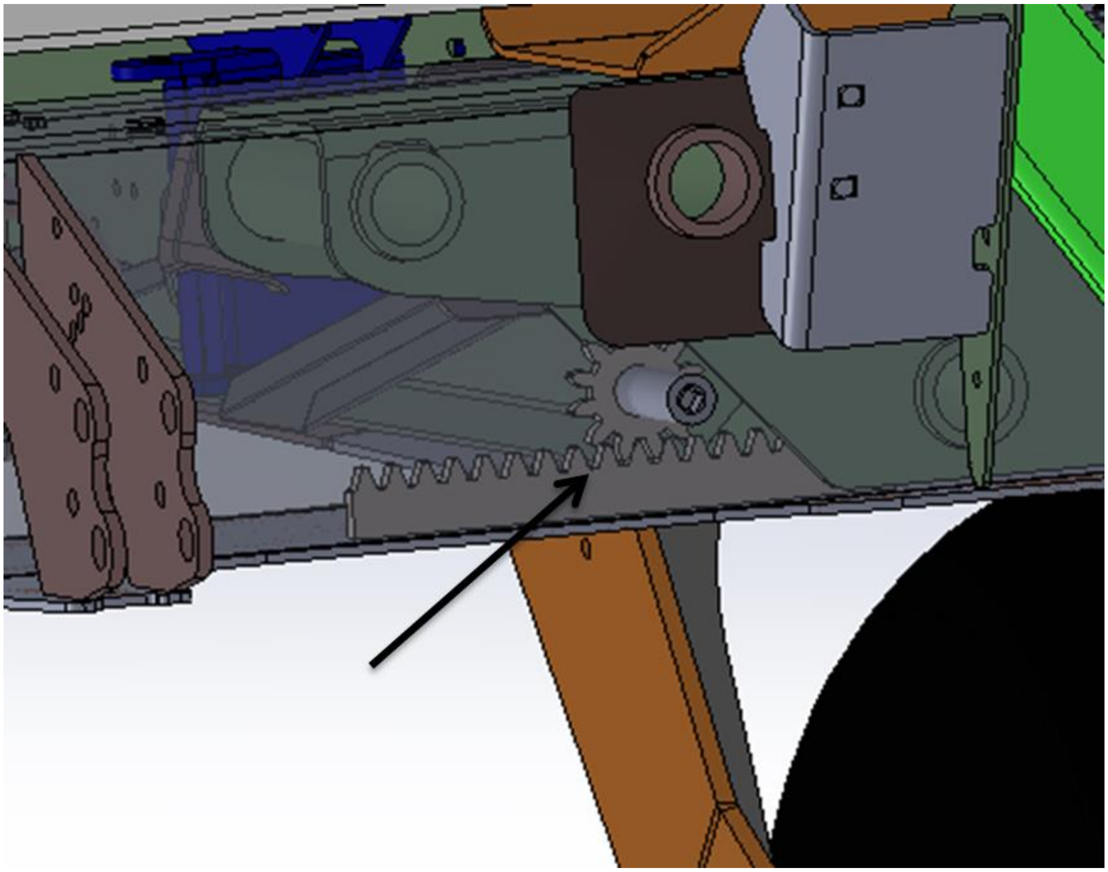


Figure 16. Zoomed view of rack and pinion concept

Table 2. Weight Distribution of a MacDon Windrower

Approximate Weight Distribution (lbs)	
NOTE: If any individual axle weight exceeds the	
	Field
	Header on
Gross vehicle Weight	11200
Drive wheels - A	7224
Tail wheels - B	
Tail wheels - C	3976
Combined Gross Vehicle Weight	

A B C

Table 3. Calculated Force for Rack and Pinion Design

Front Wheels		
Weight (Fw)	3612	lbs
Coefficient of Friction (μ)	0.8	
Total Force Required (Ff)	2889.6	lbf.
Pinion Diameter	4	in
Required Torque (τ)	5779.2	lb-in

Rear Wheels		
Weight (Fw)	1988	lbs
Coefficient of Friction (μ)	0.8	
Total Force Required (Ff)	1590.4	lbf.
Pinion Diameter	3	in
Required Torque (τ)	2385.6	lb-in

Hydraulic Pressure (P)	2400	psi
Motor Displacement (D)	15.13	in3

Hydraulic Pressure	2400	psi
Motor Displacement	6.25	in3

Hydraulic Motor Cost	$200

Hydraulic Motor Cost	$150

Equations used in previous calculations:

$$Fw = \frac{W}{2}$$

$$Ff = \mu * Fw$$

$$D = \frac{2 * \pi * \tau}{P}$$

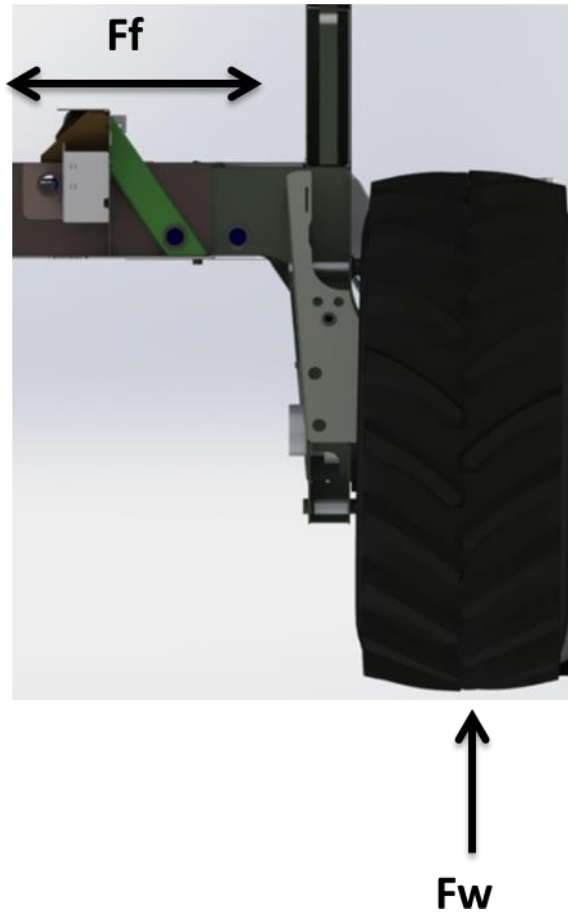


Figure 17. Free Body Diagram of Front Wheel

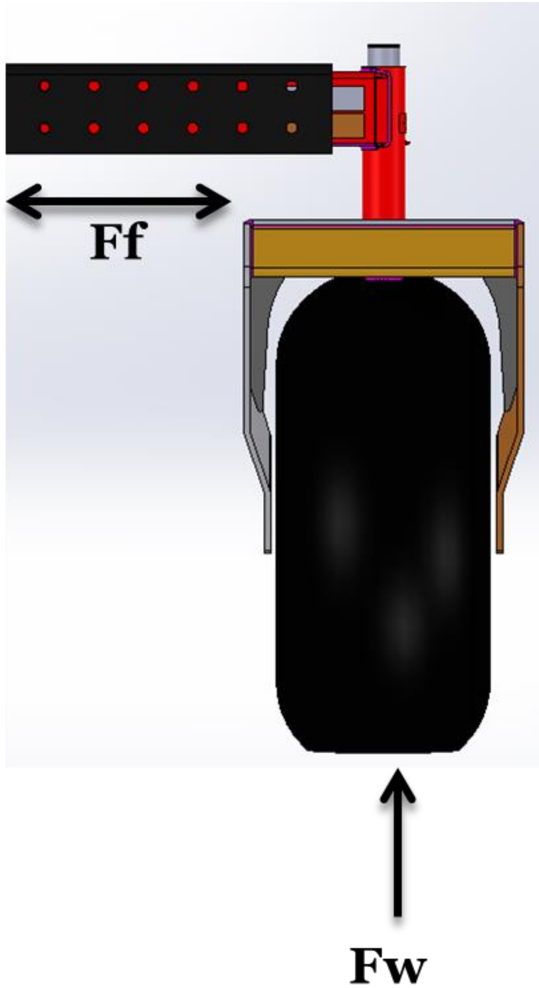


Figure 18. Free Body Diagram of Rear Wheel

Finally, the idea of hydraulics was discussed and researched. The machine is already equipped with a hydraulic system that would be suitable to support hydraulic actuators with the proper pressures. With a simple static analysis shown in Table 4, the total force required to move the axles in and out is calculated. The free body diagrams seen in Figure 17 and Figure 18 apply to the hydraulic design as well. As seen in the Table 4 there are many assumptions made during the calculations. The calculated forces are assumed to be very conservative compared to the actual required force. The idea of using hydraulics would be very efficient for the operator to use. A hydraulic quick connection, which is already equipped on the machine, could be utilized to power the axle hydraulic cylinders. Next, the operator would only need to unlock the mechanical locks before returning to the cab to begin the transformation.

Table 4. Force Calculation for Hydraulic Design

Front Wheels		
Weight	3612	lbs
Coefficient of Friction	0.8	
Total Force	2889.6	lbf.
Pressure	2400	psi
Area	1.204	in^2
Total Force Generated	2889.6	lbf.

Rear Wheels		
Weight	1988	lbs
Coefficient of Friction	0.8	
Total Force	1590.4	lbf.
Pressure	2400	psi
Area	0.662662	in^2
Total Force Generated	1590.388	lbf.

Assumptions:
Machine is moving during operation of hydraulics
Metal is not clean or lubricated
Coefficient of Friction: http://www.engineeringtoolbox.com/friction-coefficients-d_778.html
Center of gravity of the machine is located at centerline of machine
No side to side forces are generated between tire and ground

Equations used in previous calculation:

$$Ff = \mu * Fw$$

$$Fw = \frac{W}{2}$$

Future Plans

Looking into future plans for this project, there are still a few things that need to be addressed. The most important of these is acquiring a machine on which to build the prototype. This machine will be important not only for the future build, but also for some design aspects. Specifically, this will help ensure clearance from the electrical and hydraulic components present on the machine. Due to file size limitations, these were not included on the model provided by MacDon, so having a machine would allow more specific evaluations.

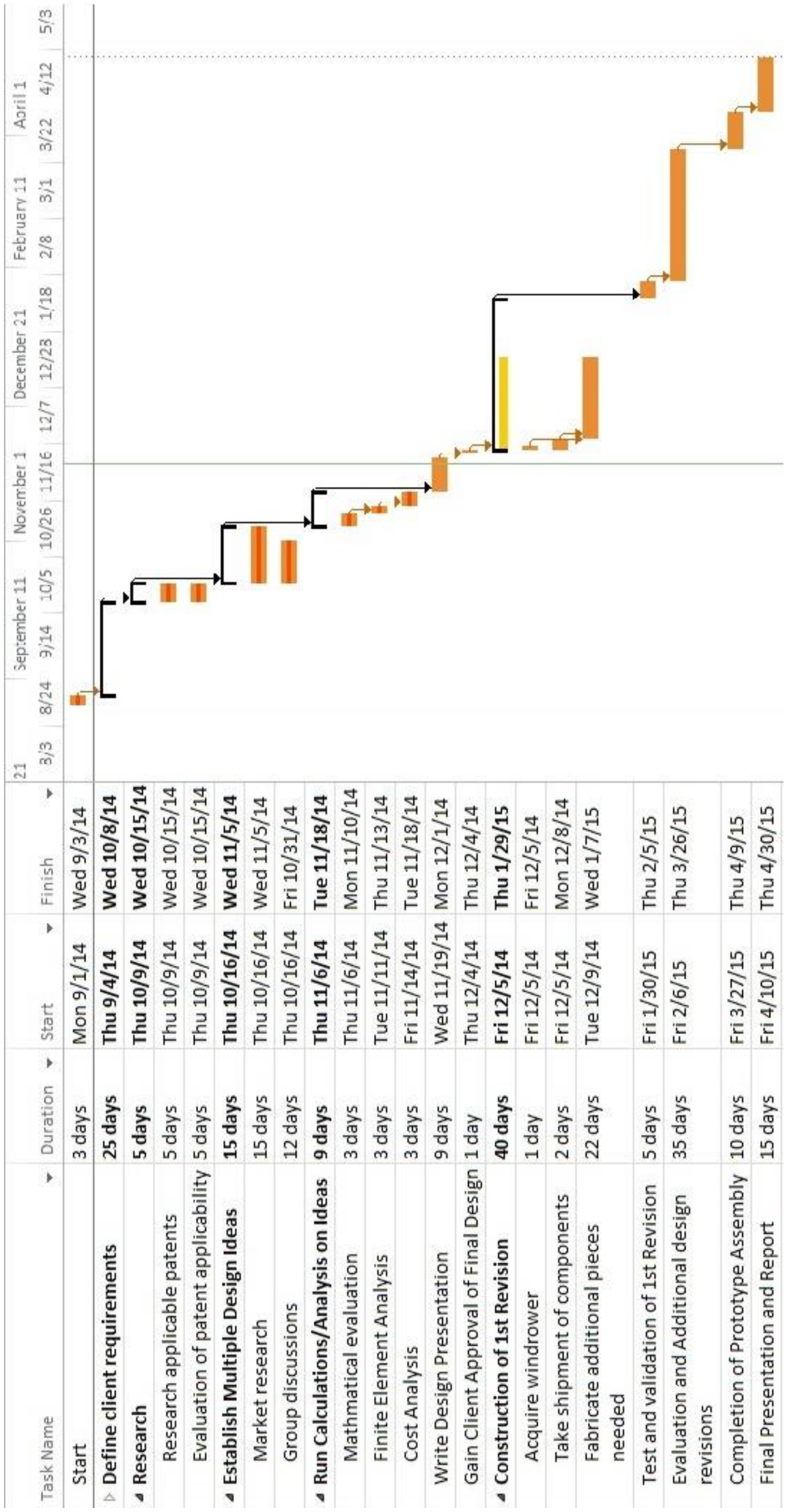
Next, since the team has started sizing and pricing components, purchasing will begin. MacDon has supplied options for vendors, so using those resources cylinders and hoses can be purchased.

As far as design goes, a few things remain for evaluation. First, the team will evaluate the different ladder designs presented to us by our freshman teams. Once evaluated, these can begin to be fabricated and installed on a machine for testing. Next, a mounting design needs to be decided for the hydraulic cylinders. This will allow fabrication to begin, which will be one of the first steps in the prototype build. Next, we need to determine the specific details of the hydraulic system as far as connections, valves and possible valve blocks that will be utilized by the design. Also, plastic liners have been an early decision to reduce wear on the rubbing metal pieces, so research must begin there, with some decisions starting to be put in place. This also goes for the mechanical locking system the team will design, however this is last on the list because other design components could potentially interfere with a mechanical lock.

In more of a big picture, the finalization of designs is coming in the near future. As these are completed, they will be fabricated or purchased to install on a machine. This prototype build will be the main focus of next semester, which the team hopes to get done with plenty of time for testing. With any design, there is some potential for failure and error, so the team intends to account for this by completing the prototype build quickly.

Project Schedule

The proposed schedule for this project is illustrated in Figure 19.



Task Name	Duration	Start	Finish
Start	3 days	Mon 9/1/14	Wed 9/3/14
Define client requirements	25 days	Thu 9/4/14	Wed 10/8/14
Research	5 days	Thu 10/9/14	Wed 10/15/14
Research applicable patents	5 days	Thu 10/9/14	Wed 10/15/14
Evaluation of patent applicability	5 days	Thu 10/9/14	Wed 10/15/14
Establish Multiple Design Ideas	15 days	Thu 10/16/14	Wed 11/5/14
Market research	15 days	Thu 10/16/14	Wed 11/5/14
Group discussions	12 days	Thu 10/16/14	Fri 10/31/14
Run Calculations/Analysis on Ideas	9 days	Thu 11/6/14	Tue 11/18/14
Mathmatical evaluation	3 days	Thu 11/6/14	Mon 11/10/14
Finite Element Analysis	3 days	Tue 11/11/14	Thu 11/13/14
Cost Analysis	3 days	Fri 11/14/14	Tue 11/18/14
Write Design Presentation	9 days	Wed 11/19/14	Mon 12/1/14
Gain Client Approval of Final Design	1 day	Thu 12/4/14	Thu 12/4/14
Construction of 1st Revision	40 days	Fri 12/5/14	Thu 1/29/15
Acquire windrower	1 day	Fri 12/5/14	Fri 12/5/14
Take shipment of components	2 days	Fri 12/5/14	Mon 12/8/14
Fabricate additional pieces needed	22 days	Tue 12/9/14	Wed 1/7/15
Test and validation of 1st Revision	5 days	Fri 1/30/15	Thu 2/5/15
Evaluation and Additional design revisions	35 days	Fri 2/6/15	Thu 3/26/15
Completion of Prototype Assembly	10 days	Fri 3/27/15	Thu 4/9/15
Final Presentation and Report	15 days	Fri 4/10/15	Thu 4/30/15

Figure 19. Gantt Chart for Project Timeline

Proposed Budget for Prototype

Table 5. Estimated Budget for Project

Component	Qty	Cost
Hydraulic Cylinder (Front)	2	$144.99
Hydraulic Cylinder (Rear)	2	$129.99
Electrical Wiring	TBD	$25
Hydraulic Hoses	4	$100
Valve Block	1	$100
Testing Supplies	1	$500
Plastic Skid	4	$20
Miscellaneous	-	$300
Total	-	$2000

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Varitrac Engineering

Project Overview

The Team

Taylor Cole   Nick Jacobsen   Travis Biggerstaff

Varitrac Engineering

MacDon Industries Ltd.

MacDon

- Winnipeg, MB
- OEM Company
  - Windrowers
  - Combine Headers

All pictures courtesy of MacDon Industries Ltd.

MacDon Industries Ltd.

Global Presence

Industry Preferred

All Colors

Problem Statement

- Primary Canadian Crop – Canola
- Wide & Tall set Frame – Transport Issue
- Quick & Easy Wheel Width Adjustment System
- Applications
  - European
  - Trucking

Problem Statement

The goal of this project is to create an innovative, cost-efficient and reliable system that quickly adjusts the wheel width on a MacDon M155 Self-Propelled Windrower

MacDon Requirements

- Dealer-Installed
- Mechanically Locked
- Two Positions: Field and Transport
- No Modification of Damping Cylinder on Casters

MacDon Requirements

- Process
  - Field End
  - Remove Header
  - System Preparation
    - Mechanical Locks
    - Hydraulics
  - In Cab
    - Wheel Adjustment Made
    - Ready for Transport

Engineering Specifications

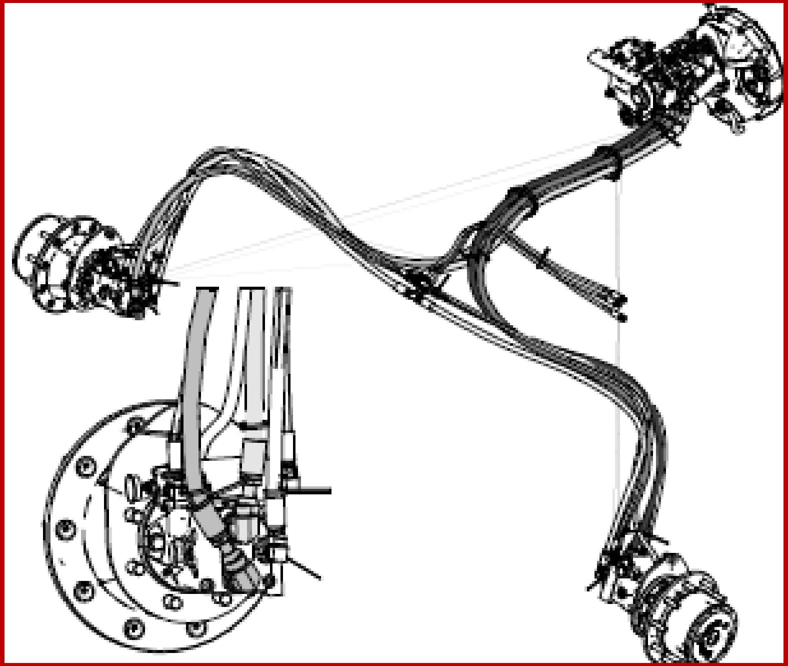
- Maintain Current Hydraulic/Electrical Setup
- Cost/Build Estimate
- Frame Modifications - Max $25
- 7” Difference – Front
- 18” Difference – Rear

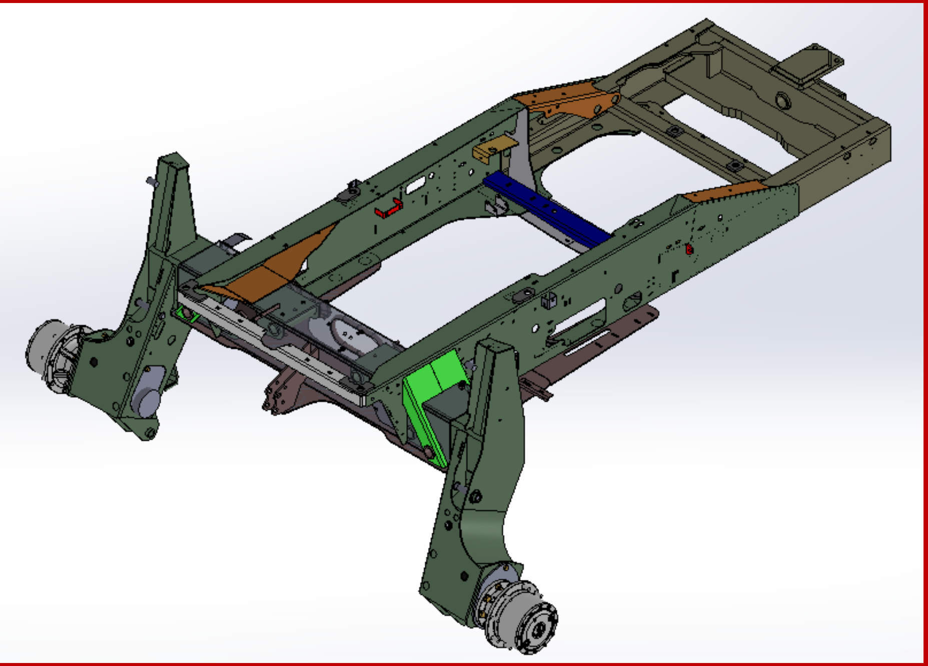
Constraints

- Spatial
  - Swath Clearance - Underneath
  - 36" x 45.7" Swath Area
  - Header Clearance – Front

Constraints

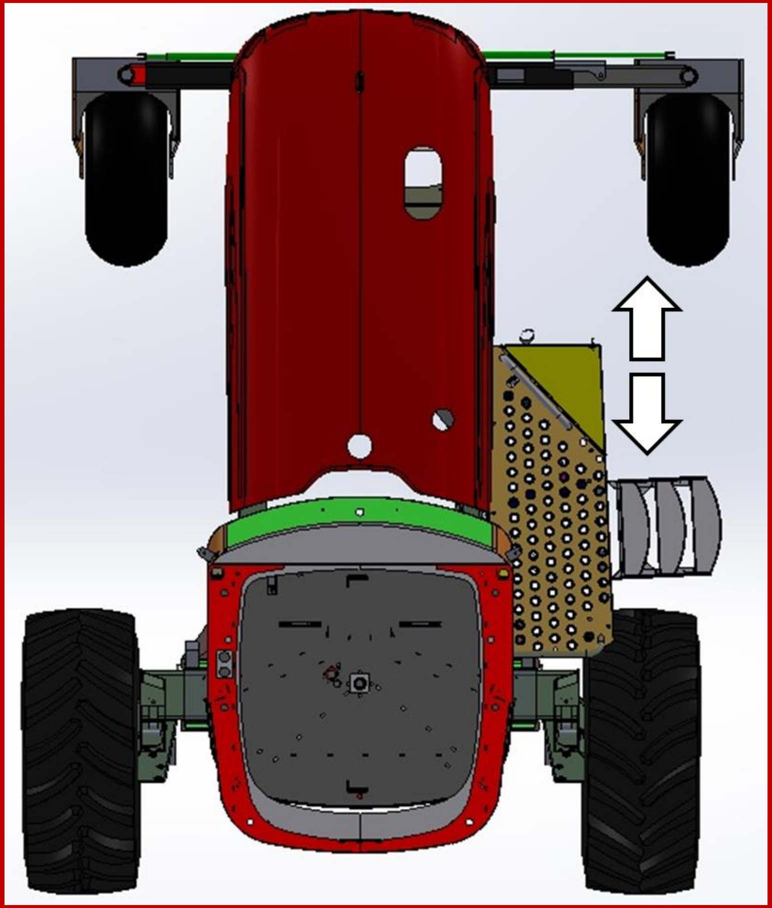
- Hydraulic Routing
  - Front Frame tubing – inside
  - Hoses/Blocks – axial rails





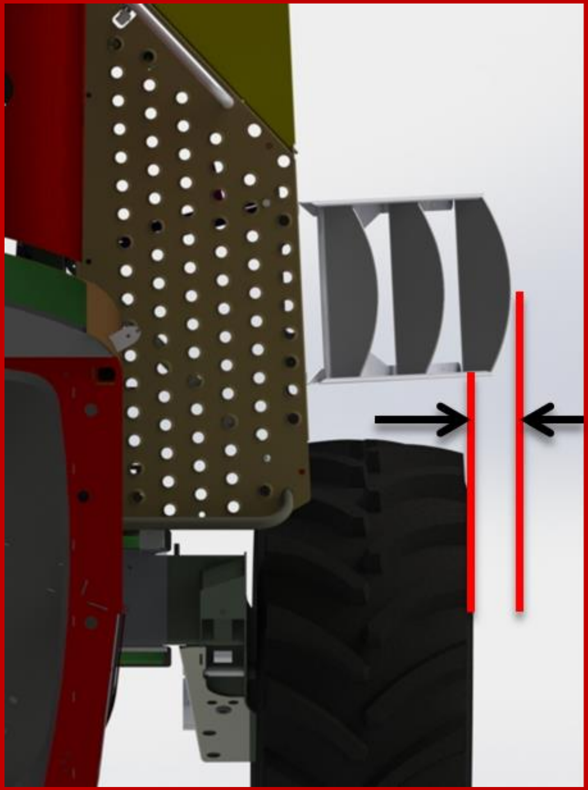
Constraints

- Mechanical
  - Platform – Multiple Positions
  - Header Lift Arms
  - Ladder – Extension Outside Tires



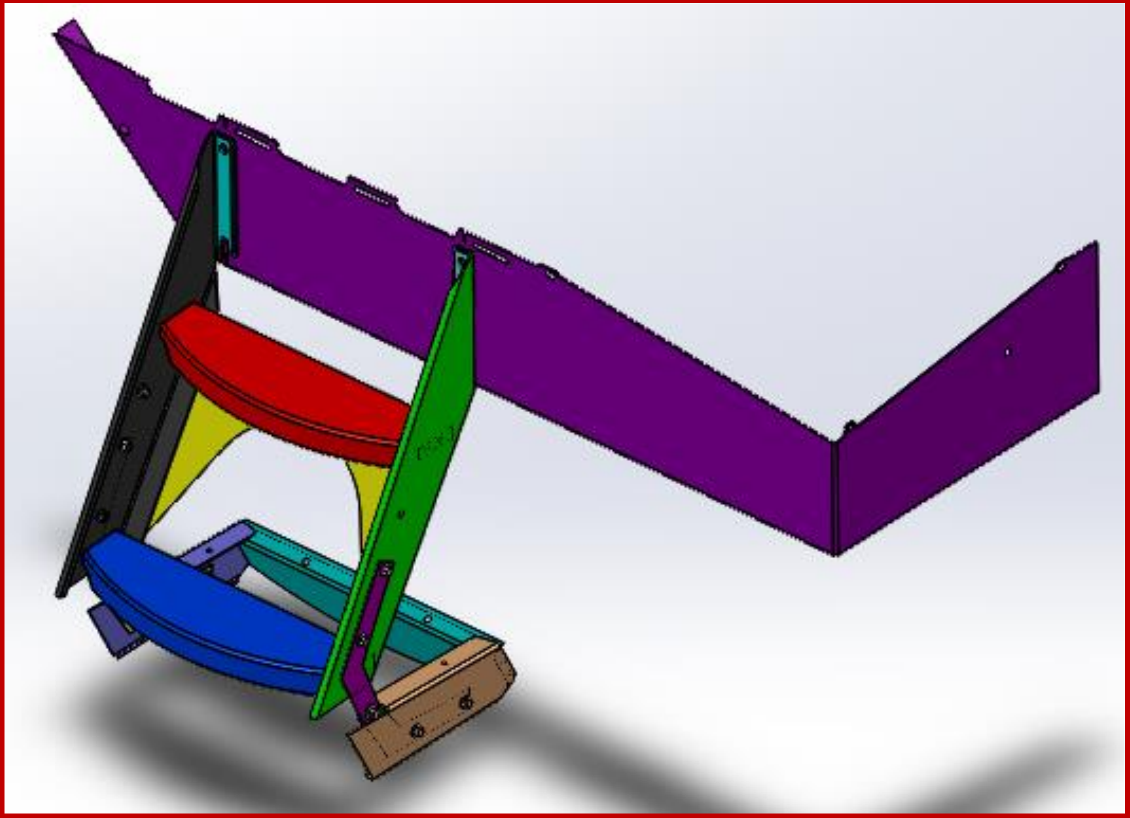
Freshmen Teams

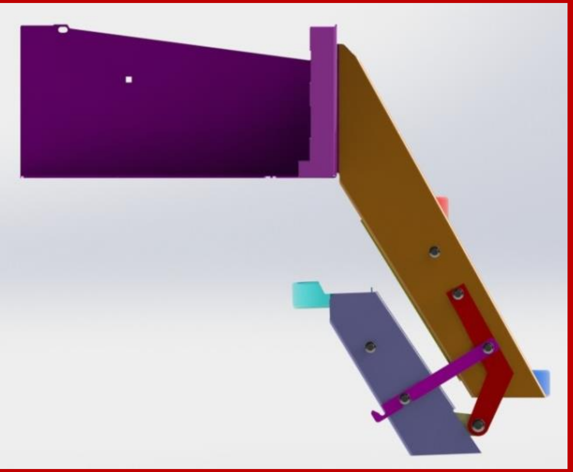
- Ladder Design
  - "Folding" Method
    - Bottom of ladder breaks away for transport
  - "Rotate" Method
    - Ladder pivots underneath platform

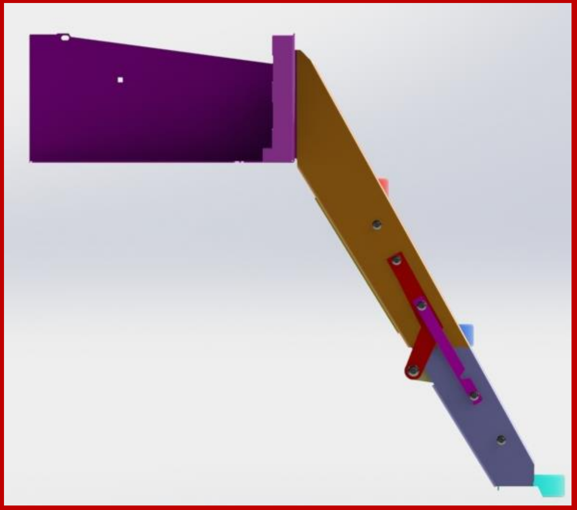


Freshmen Teams Cont.

- Folding Design

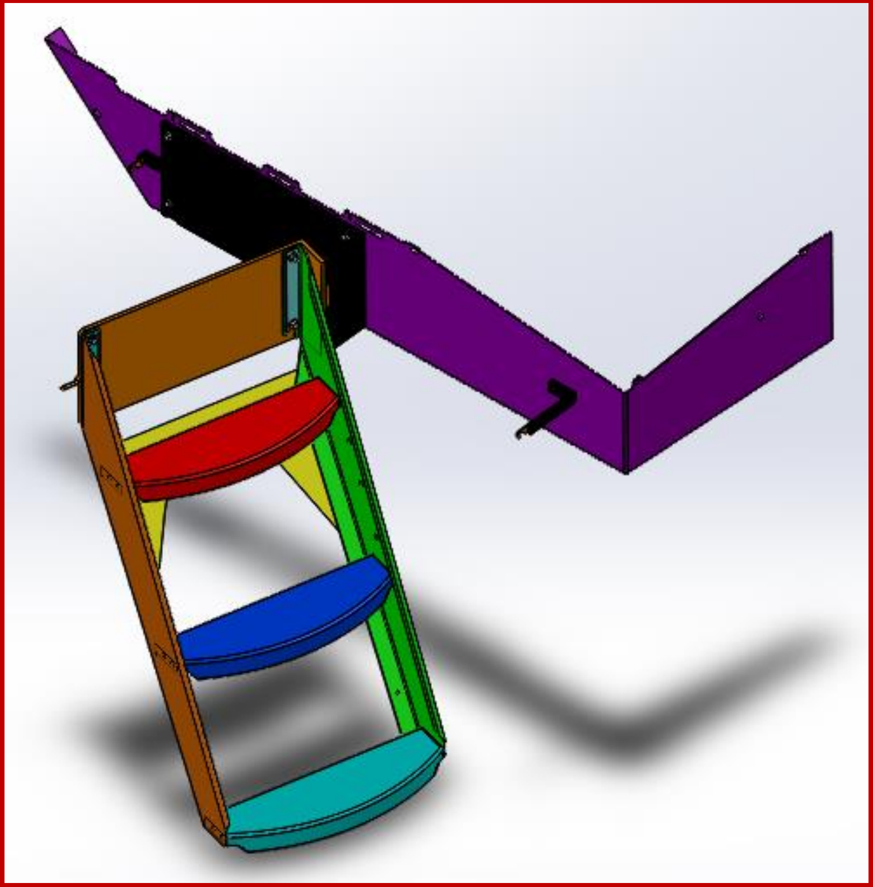


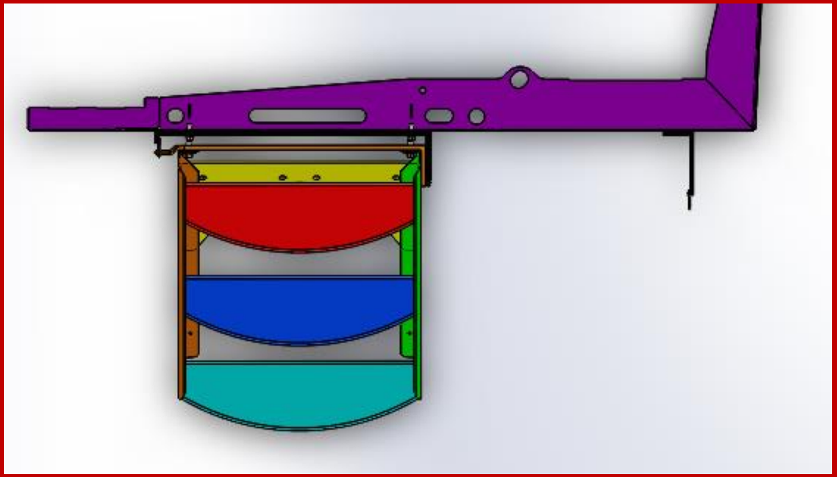


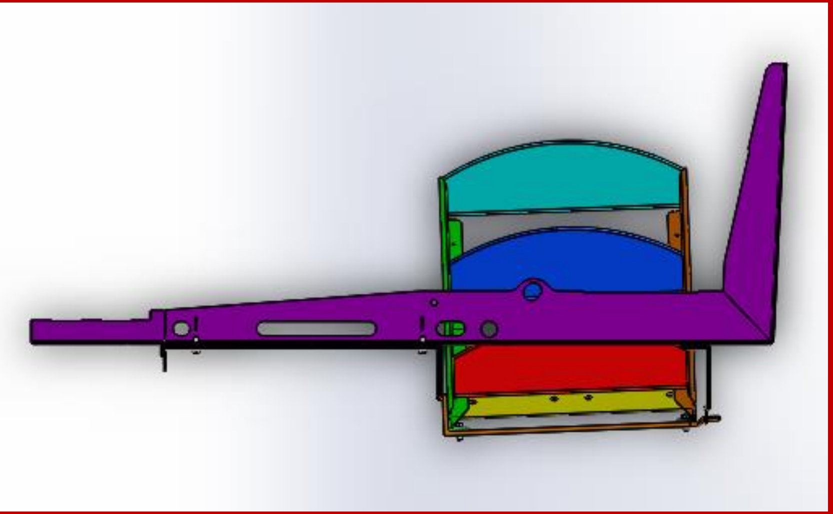


Freshmen Teams Cont.

- Rotating Design

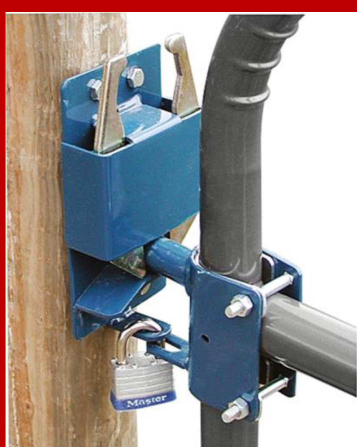






Research

- Campers
- Cattle Gate Lock
- Impact Wrench



http://goo.gl/q0O2Mu

http://goo.gl/yScdAi

Kanaal van Danny323f. 2014.

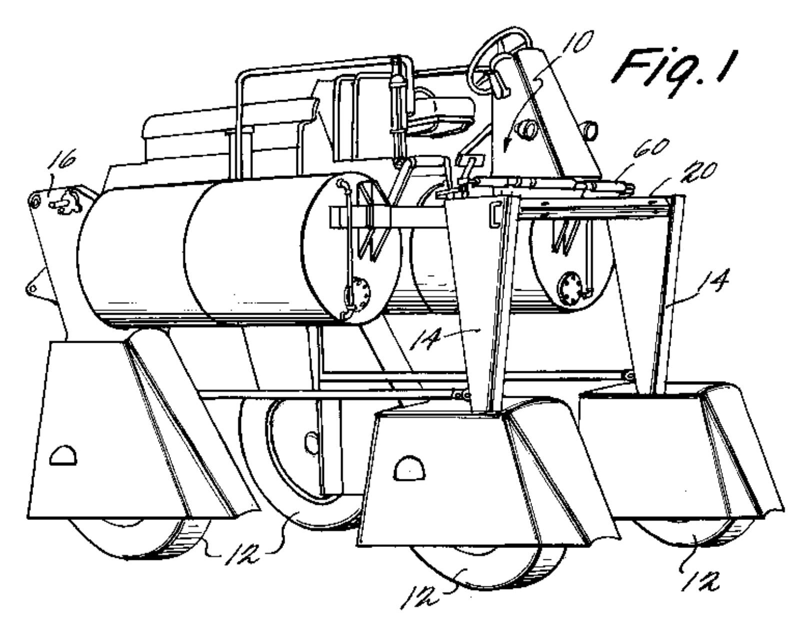
Research

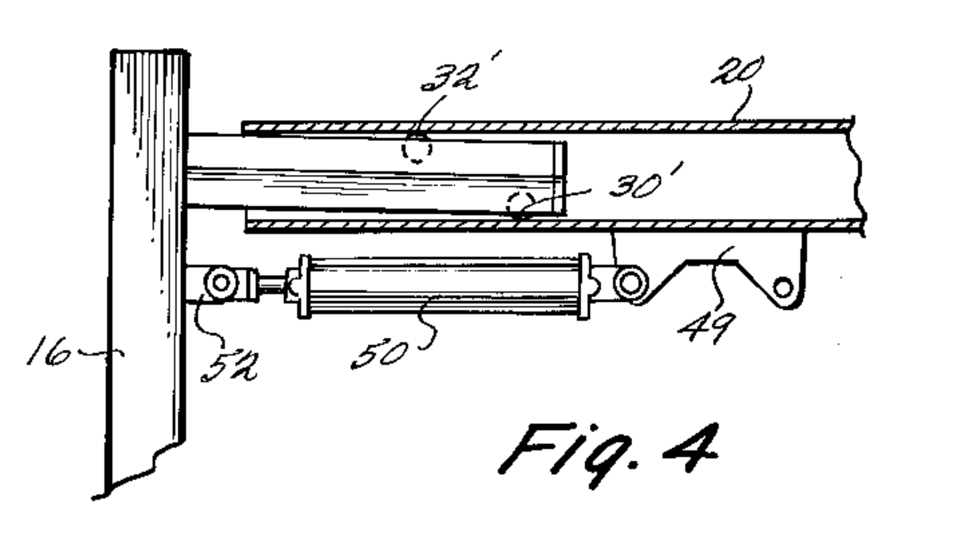
- Standard feature for all Row-Crop Sprayers
  - JD, CNH, Apache, AGCO, Versatile
  - John Deere had as option - cost $4376
- Hydraulic Cylinders
- Mechanical Locks (some)

http://youtu.be/9w1uKR15L0A

Research

- U.S. Patent No. 3964565
- High clearance vehicle wheel spacing adjustment



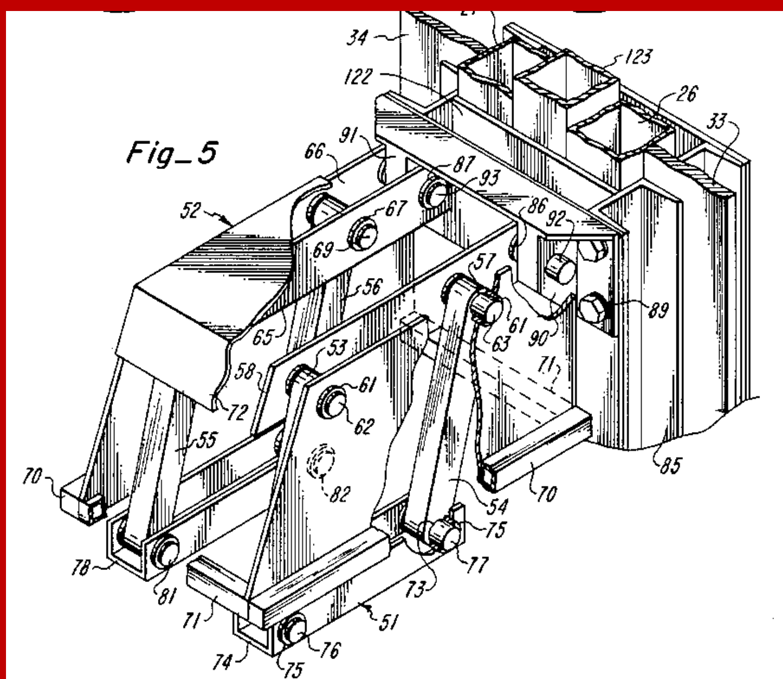


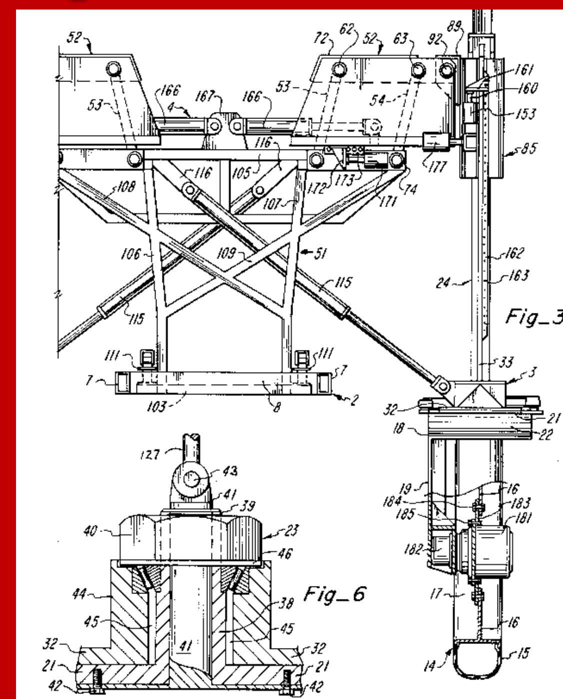
Varitrac Engineering

Research

MacDon

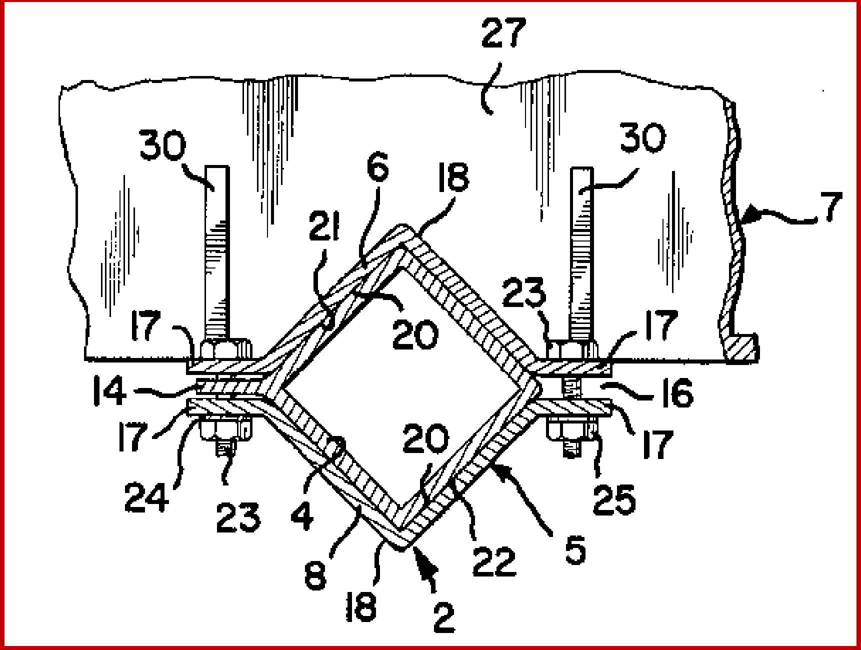
- US Patent No. 4619340
- High clearance self-propelled vehicle with variable clearance and variable wheel spacing

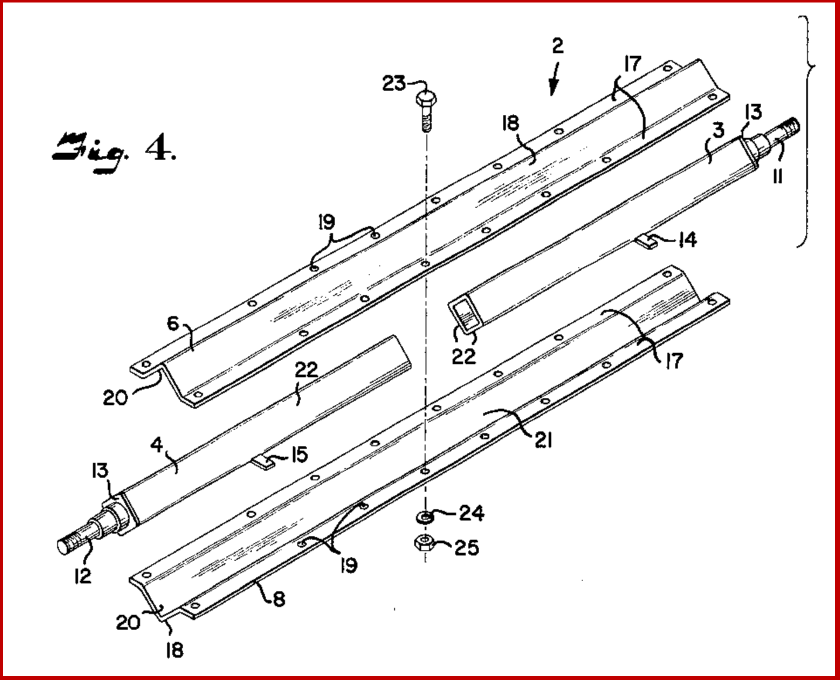




Research

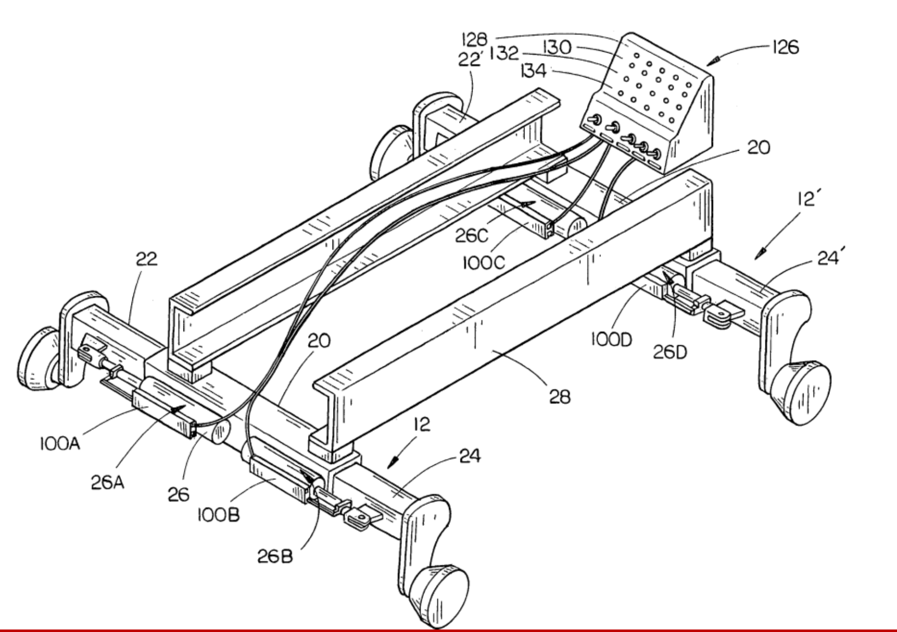
- US Patent No. 4040643
- Adjustable Vehicle Axle

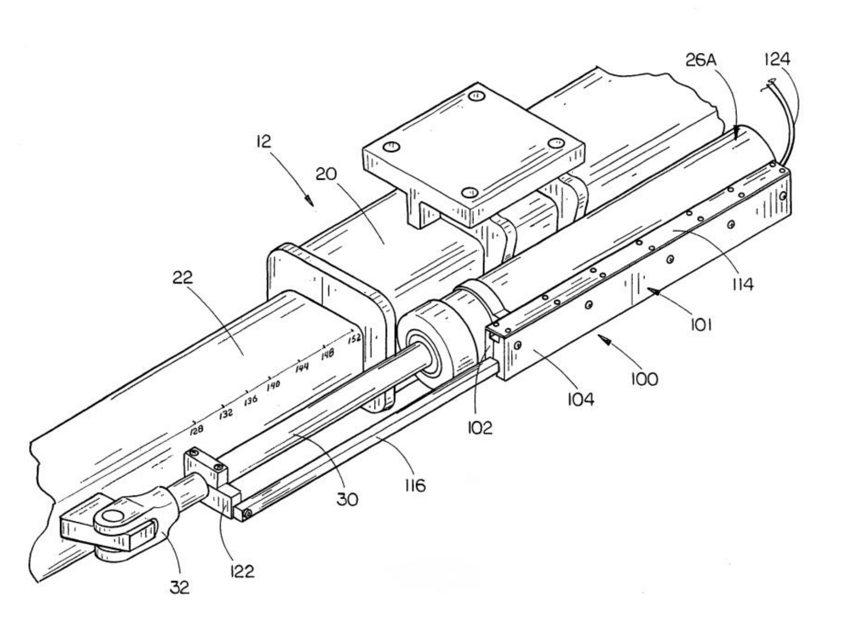




Research

- US Patent No. 7163227
- Multi-position track width sensor for self-propelled agricultural sprayers



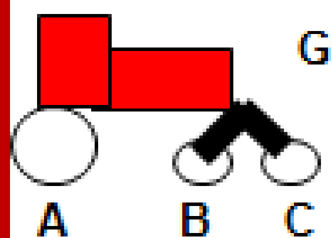


Assumptions for Design

- Weight is Centered
- Minimal Friction
- Machine will be moving
- Header will be removed

Approximate Weight Distribution (lbs)

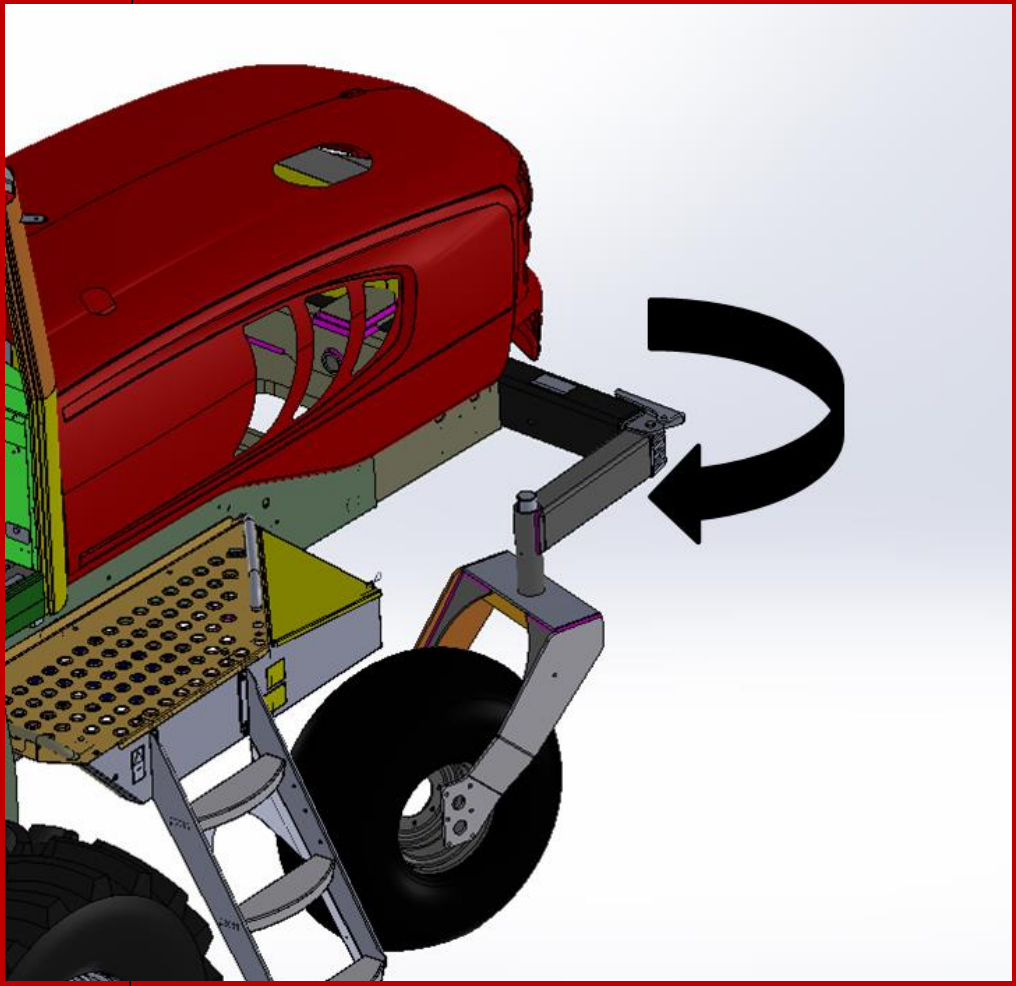
NOTE: If any individual axle weight exceeds the



	Field
	Header on
Gross vehicle Weight	11200
Drive wheels - A	7224
Tail wheels - B	
Tail wheels - C	3976
Combined Gross Vehicle Weight	

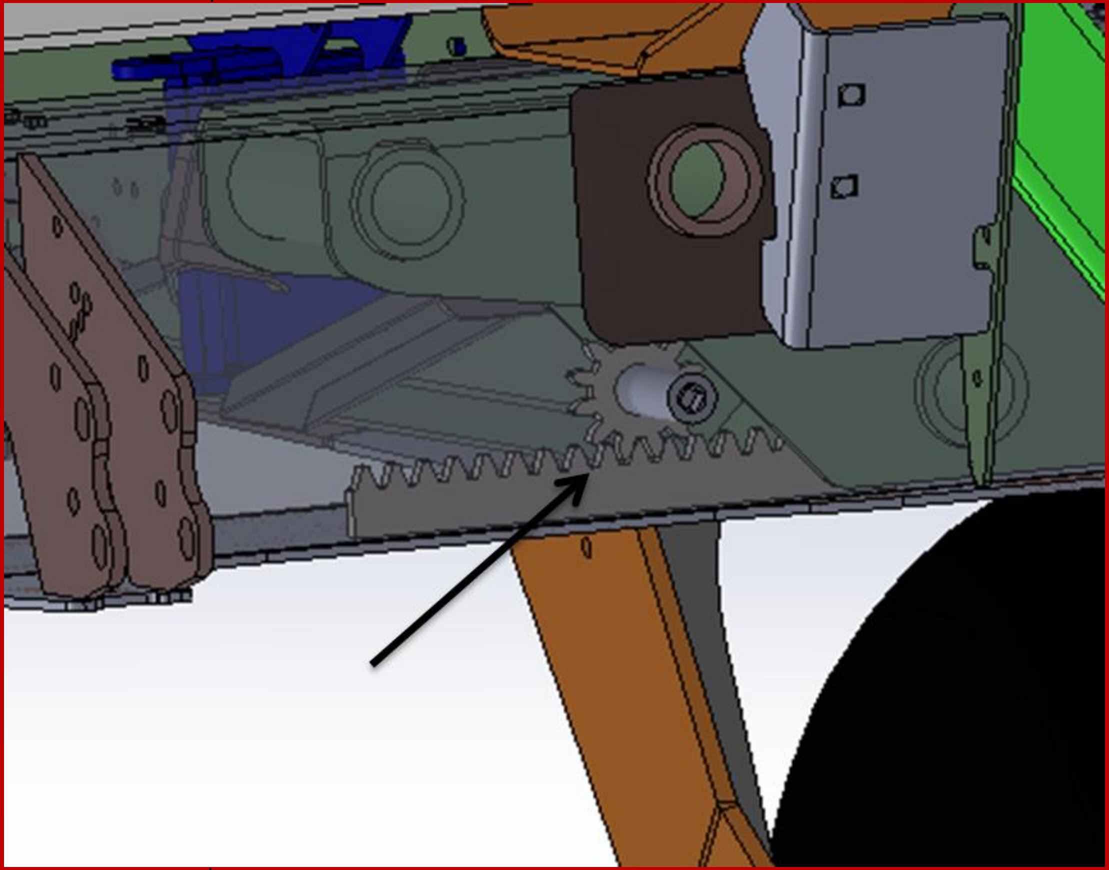
Design Concept #1

- Hinged Rear Tube
- Advantages
  - Purely Mechanical
  - Simple and cost effective design
- Limitations
  - Front Wheels
  - Negatively affect the machine handling



Design Concept #2

- Rack and Pinion
- Advantages
  - Purely Mechanical
- Limitations
  - Dirt/Debris
  - High Stress
  - Poor Serviceability
  - High costs



Design Concept #2 Cont.

MacDon

Front Wheels		
Weight (F_w)	3612	lbs
Coefficient of Friction (μ)	0.8	
Total Force Required (F_f)	2889.6	lbf.
Pinion Diameter	4	in
Required Torque (τ)	5779.2	lb-in

Hydraulic Pressure (P)	2400	psi
Required Motor Displacement	15.13	in^3
Hydraulic Motor Cost	$200	

$$Ff = \mu * Fw$$

$$Fw = \frac{W}{2}$$

$$D = \frac{2 * \pi * \tau}{P}$$

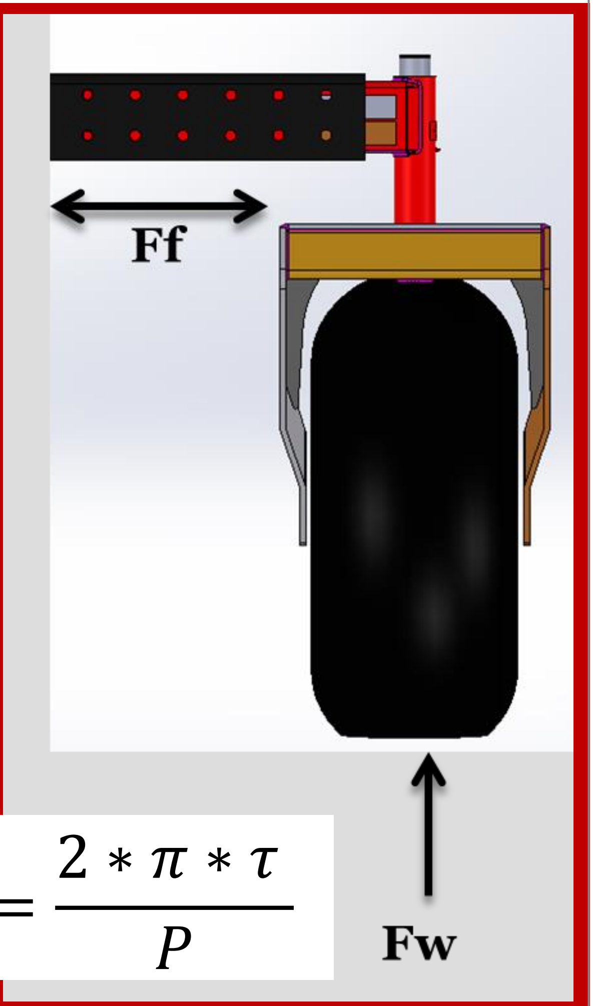
Design Concept #2 Cont.

Rear Wheels		
Weight (F_w)	1988	lbs
Coefficient of Friction (μ)	0.8	
Total Force Required (F_f)	1590.4	lbf.
Pinion Diameter	3	in
Required Torque (τ)	2385.6	lb-in
Hydraulic Pressure	2400	psi
Required Motor Displacement	6.25	in^3
Hydraulic Motor Cost	$150	

$$Ff = \mu * Fw$$

$$Fw = \frac{W}{2}$$

$$D = \frac{2 * \pi * \tau}{P}$$



Design Concept #3

- Hydraulic Cylinders

- Advantages
  - Easy Dealer Install
  - Good Serviceability
  - Relatively cheap to manufacture
  - Hydraulic power supply already equipped on machine

Limitations

Hydraulic Involvement

Electrical Requirements

Design Concept #3 Cont.

Varitrac Engineering

MacDon

Front Wheels		
Weight (F_w)	3612	lbs
Coefficient of Friction	0.8	
Total Force Required (F_f)	2889.6	lbf.
Hydraulic Pressure (P)	2400	psi
Total Force Generated	2889.6	lbf.
Required Cross Sectional Area of Cylinder	1.204	in^2
Cost	$	144.99

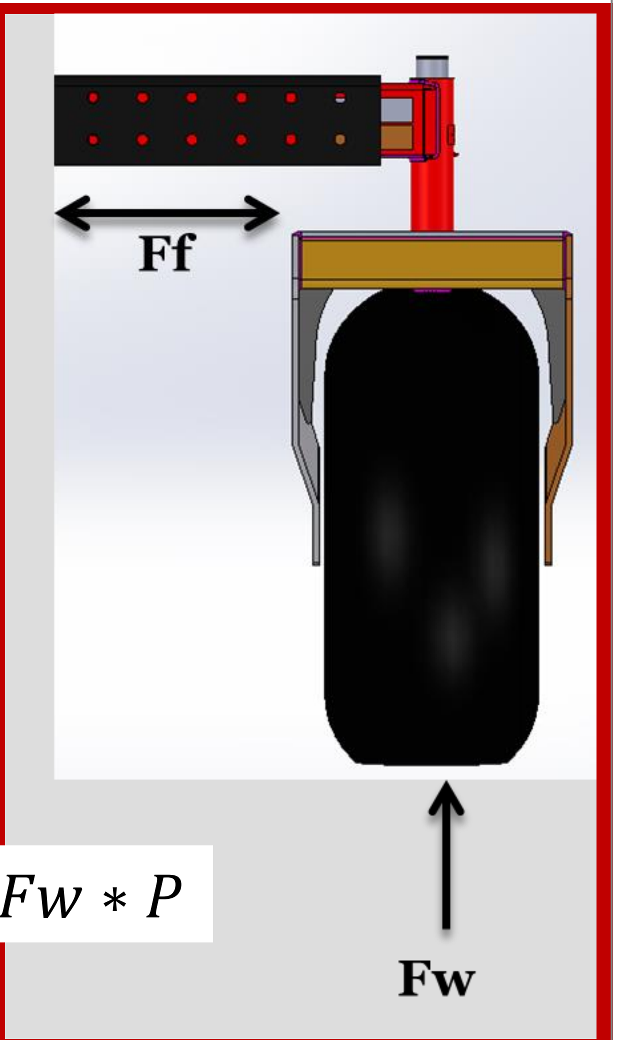
$$Ff = \mu * Fw$$

$$Fw = \frac{W}{2}$$

$$A = Fw * P$$

Design Concept #3 Cont.

Rear Wheels		
Weight (F_w)	1988	lbs
Coefficient of Friction	0.8	
Total Force Required (F_f)	1590.4	lbf.
Hydraulic Pressure (P)	2400	psi
Total Force Generated	1590.4	lbf.
Required Cross Sectional Area of Cylinder	0.663	in^2
Cost	$	154.99



$$Ff = \mu * Fw$$

$$Fw = \frac{W}{2}$$

$$A = Fw * P$$

Varitrac Engineering

Safety

MacDon

- Pinch Points
- Sharp Edges
- Hydraulic Reliability
  - Mechanical Locking

http://goo.gl/Uc2VkM

Preferred Design

- Design Concept #3 Hydraulic Actuators
  - Hydraulic power already present on machine
  - Cost effective design
  - Good serviceability and maintenance
  - Dealer installed kit
  - One operator task

Preferred Design

- Electrical
  - Draper Header Configuration on Cap
- User Interface
  - In-Cab Controls
- Hydraulic Valve Block
  - Existing Block

Work Breakdown Structure

Varitrac Engineering

MacDon

	Task Name	Duration	Start	Finish
1	**Start**	3 days	Mon 9/1/14	Wed 9/3/14
2	**Define client requirements**	25 days	Thu 9/4/14	Wed 10/8/14
3	Identify Project Scope	25 days	Thu 9/4/14	Wed 10/8/14
4	Acquire windrower model	13 days	Thu 9/4/14	Mon 9/22/14
5	Acquire part and technical manuals	12 days	Thu 9/4/14	Fri 9/19/14
6	**Research**	5 days	Thu 10/9/14	Wed 10/15/14
7	Research applicable patents	5 days	Thu 10/9/14	Wed 10/15/14
8	Evaluation of patent applicability	5 days	Thu 10/9/14	Wed 10/15/14
9	**Establish Multiple Design Ideas**	15 days	Thu 10/16/14	Wed 11/5/14
10	Market research	15 days	Thu 10/16/14	Wed 11/5/14
11	Group discussions	12 days	Thu 10/16/14	Fri 10/31/14
12	**Run Calculations/Analysis on Ideas**	9 days	Thu 11/6/14	Tue 11/18/14
13	Mathmatical evaluation	3 days	Thu 11/6/14	Mon 11/10/14
14	Finite Element Analysis	3 days	Tue 11/11/14	Thu 11/13/14
15	Cost Analysis	3 days	Fri 11/14/14	Tue 11/18/14
16	**Write Design Presentation**	9 days	Wed 11/19/14	Mon 12/1/14
17	**Gain Client Approval of Final Design**	1 day	Thu 12/4/14	Thu 12/4/14
18	**Construction of 1st Revision**	48 days	Fri 12/5/14	Tue 2/10/15
19	Acquire windrower	26 days	Fri 12/5/14	Fri 1/9/15
20	Take shipment of components	20 days	Fri 12/5/14	Thu 1/1/15
21	Fabricate additional pieces needed	22 days	Mon 1/12/15	Tue 2/10/15
22	**Test and validation of 1st Revision**	15 days	Wed 2/11/15	Tue 3/3/15
23	**Evaluation and Additional design revisions**	25 days	Wed 3/4/15	Tue 4/7/15
24	**Completion of Prototype Assembly**	10 days	Wed 4/8/15	Tue 4/21/15
25	**Final Presentation and Report**	9 days	Wed 4/22/15	Mon 5/4/15

Budget

Component	Qty	Estimated Cost per unit
Hydraulic Cylinder (Front)	2	$144.99
Hydraulic Cylinder (Rear)	2	$154.99
Electrical Wiring	TBD	$25
Hydraulic Hoses	4	$100
Valve Block	1	$500
Testing Supplies	-	$500
Plastic Liner	4	$20
Miscellaneous	-	$300
Total	-	$2500

Future Plans

- Acquire Machine
  - Limited Model
- Purchase Parts
- Ladder

In Progress

- Plastic Liner
- Damping Cylinder Plate
- Hydraulics
- Mounting System
- Locking System

Future Plans

- Prototype Build
- Testing
- Evaluation
- Re-Design

Acknowledgments

- Dr. John Long
- Mr. Jeff Leachman
- Mr. Donny Putro
- Mr. Wayne Kiner
- Dr. Paul Weckler

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