The Design of a multi-purpose EZ Connect Ballast for 200-300 hp tractor models

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Design Report

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1. Introduction:

Customers need a more productive and efficient ballast for 200-300 hp tractor models. With rapidly growing societal demands for food and nutrients, farmers are put under increasing pressure to produce more crops. The farmers are in need of tools and farm vehicles that will limit losses due to slippage and loss of efficiency. These losses can be lowered by the development of a ballast. A ballast improves traction on large or small tractors which benefits the farmer and society as a whole. The savings that the farmer receives from a more efficient tractor directly affect the market and the price of food. When the farmers are able to produce more goods with a lower overhead, the end consumer will always benefit.

The ballast is used to balance forces on the tractor by increased weight on the front tires, while lowering the force on the back. The ballast is designed to be attached and detached from the inside of the cab. The operator is required to perform less work because they do not have to manually remove the heavy ballast from the tractor; simply operating a lever removes it. Decreasing stress on a farmer that may be under pressure to finish plowing, planting, or harvesting keeps morale high. The ballast also decreases slippage which gives increased power from the engine, allowing for faster speeds or larger implements use depending on the task. Limiting slippage lowers fuel consumption, resulting in savings during crop production.

Society as a whole also benefits from a more improved ballast because production of crops is easier. The ballast allows tractors to pull a larger implement which allows coverage of more area in less time, lowering the cost of produce. Since the ballast improves fuel consumption, farmers need less fuel, creating less demand on the fuel market and lowering gas prices.

Ballasting also improves the safety of a tractor. Having an equal amount of force around the center of gravity of the tractor makes it less likely to roll over. The ballast is meant to help keep all four tires on the ground to avoid the situation shown in Figure 1 by providing the maximum amount of traction which the tractor can create (Tractor Safety, 2007). In environments with hills and other potentially dangerous features, a ballast creates stability and prevents accidents.

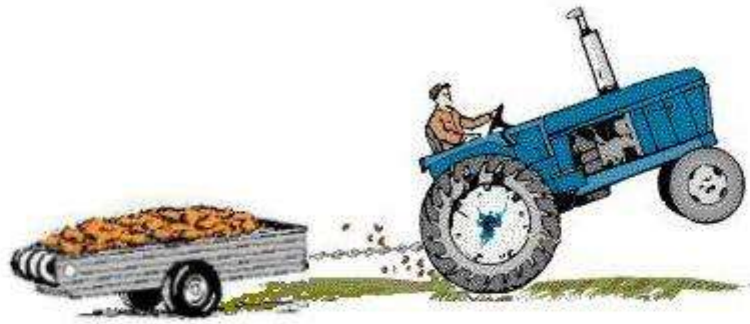

Figure 1 - An illustration of the unsafe effects of an improperly ballasted tractor.

The reason for ballasting a tractor is to control wheel slip. Ideally, wheel slip for a running tractor should be between 10 to 15% for a 2WD or 8 to 12% for a 4WD or Front Wheel Assist tractor (Friesen, 2012). An over-ballasted tractor causes increased fuel consumption due to extra weight and excessive wear to the drivetrain of the tractor. An under-ballasted tractor leads to increased slip and increased fuel consumption due to more required revolutions of the tires to travel the same distance as a properly ballasted tractor.

Ballast weight also needs to be properly distributed over the tractor to satisfy various conditions ranging from the tractor type to the task being performed. Some guidelines for weight distribution from front axle to back axle are: 30% front/70% rear for 2WD, 40% front/ 60% rear for FWA, and 55% front/ 45% rear for 4WD tractors (Schuler, 1987). The purpose of keeping these weight-splits over the front and rear axles is to maintain enough downward force on the driving axle and achieve the necessary traction to pull an implement.

Previous and current ballasting methods include detachable ballast boxes, which are typically steel boxes filled with sand or cement. Figure 2 shows an example of a ballast box filled with sand. The ballast boxes are then mounted to an implement attached to the tractor's three point hitch system. In some cases the three point hitch is designed to raise and lower itself to aid in attaching and detaching the weights. In order to make the ballast easier to move and store, some designs allow the ballast to stand alone when detached from the system.

Figure 2 - An example of a ballast box

Such methods can be undesirable for smaller tractors and applications, as well as being difficult to move, attach, and detach from the system. It can also be difficult to control the position of such ballast boxes in order to manipulate weight distribution and gain the desired stability of the tractor.

A second ballasting method includes the use of suitcase weights, an example of which is shown in Figure 3. Suitcase weight systems involve a special support that is mounted from the hitch on the tractor. The weights are specially shaped cast plates that fit on the support in a manner to be self-aligning and remain firmly attached to the support (Quik-Tatch, 2012). While this allows for a wide range of weight variation, the design is rigid and requires the operator to manually mount and dismount the weights from outside the tractor, exerting physical force and using more time than would be desired.

Figure 3 - An example of a suitcase weight ballast system.

Another ballast design incorporates a shiftable ballast in which the ballast moves to allow even distribution of weight between the two front tires. Turning the tractor creates unbalanced weight distribution which the ballast will prevent by using an arcuate mounting ring which spins the weights creating a more even distribution.

1.1 Objective:

The objective of this design project was to develop an automated ballast system for 200-300 hp tractor models. The ballast or "EZ Ballast," the name selected for this project, is for two tractor applications. The first application is a lightweight system intended for transportation and low-ballast situations. This application of the system provides lighter ballast weight which provides improved fuel consumption. The concerns for the lighter ballast applications are meeting European Union Regulations, and system and axle weight regulations. The heavier application is for large ballast requirements, which is optimal for heavy draft applications. The main goals for this system are to obtain the necessary weight to control tire slip by adding approximately 4000 lbs. of ballast weight to the tractor and maintain a 60/40 weight split between the rear and front axles. The engineering challenge for this project is to come up with a flexible system to meet both light and heavy ballast needs as well as easy connecting and disconnecting of ballast. The system will be designed to be connected and disconnected from inside the cab.

2. Methodology:

A John Deere 7R series tractor is being used for this project. The 7R series tractors range from rated 200 to 280 horsepower (hp) depending on the model, fitting the range of tractor size that the project is designed for. Table 1 shows the unballasted and maximum weights for different 7R series tractors.

Table 1: Unballasted and maximum weights for JD 7R series tractors.

Tractor		Unballasted Weight			Maximum Weight	
	Rated hp	Front Axle	Rear Axle	Total	Front Axle	Rear Axle
7200R	200	3400 kg (7497 lb)	5266 kg (13,395 lb)	9023 kg (19,892 lb)	6500 kg (14,330 lb)	10,500 kg (23,149 lb)
7215R	215	3400 kg (7497 lb)	5266 kg (13,395 lb)	9023 kg (19,892 lb)	6500 kg (14,330 lb)	10,500 kg (23,149 lb)
7230R	230	3400 kg (7497 lb)	5266 kg (13,395 lb)	9023 kg (19,892 lb)	6500 kg (14,330 lb)	10,500 kg (23,149 lb)
7260R	260	3898 kg (8594 lb)	6302 kg (13,895 lb)	10,201 kg (22,489 lb)	6500 kg (14,330 lb)	10,500 kg (23,149 lb)
7280R	280	3898 kg (8594 lb)	6302 kg (13,895 lb)	10,201 kg (22,489 lb)	6500 kg (14,330 lb)	10,500 kg (23,149 lb)

A brainstorming session was held with freshmen of the Agricultural and Biosystems Engineering program to gain additional ideas for project designs and details. During this session, methods such as fluid ballasting were discussed and eliminated from further consideration. Fluid ballasting was eliminated due to concerns with temperature effects on the fluid and its ballasting quality for the project. Other concepts were discussed as being necessary details in the design of this ballast system. One such concept that was mentioned in the brainstorming session was the presence of a locking mechanism to take pressure off of any hydraulic system being used.

Research was done regarding the tractors for which the ballast systems were to be designed. Group members studied a John Deere 7R tractor and analyzed potential system locations on the tractor as shown in Figures 4.1-4.3.

Figure 4.1 - Shows clearance for front end of tractor and underside

Figure 4.2 - Current front mount for 7R series

Figure 4.3 - Displays other possible locations for the ballast to be placed.

Four different initial designs were considered in the beginning of the project. All the designs were then studied and analyzed based on various design criteria. The criteria included the safety of the design, the ease of disconnecting and connecting the weight, the clearance of the system from the ground, the durability of the system, the parts used in the system, and the manufacturing cost of the system.

<u>2.1 Alternative Designs</u>:

The following initial designs were created to provide several potential methods of accomplishing the objectives of this project.

2.1.1 <u>Front Quick-tach ballast</u>

This system utilizes the already existing hydraulic system that the tractor has. The system is based off of the already tested version of the Quick-Tach attachment system used by most of the compact equipment available. This ballast performs very well in the “cost” and “use of standard parts” criteria. The most significant part to this ballast is mounting the lift that connects the weight to the tractor. As can be seen in Figure 5, this is accomplished by utilizing the existing holes in the frame to mount the ballast lift. This design for the ballast requires some pre-installed parts to the tractor. This ballast system does let the user connect the weights to the tractor from inside the cab. The safety aspect is relatively high because after the initial mount is installed, everything else can be done from within the inside of the cab.

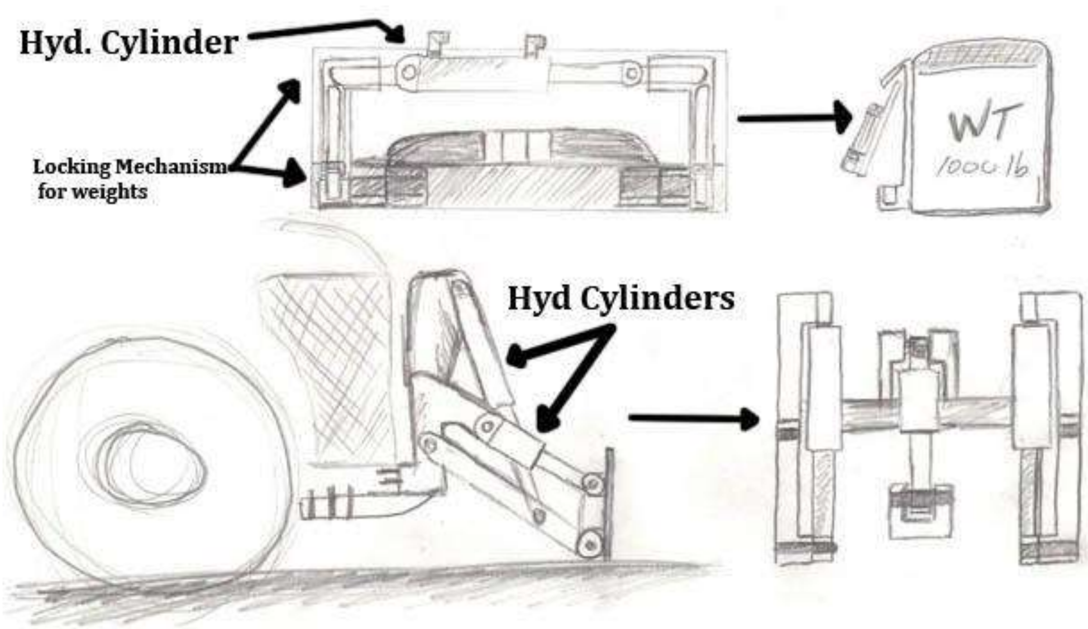

Figure 5 - Initial sketches of Front Quick-tach

2.1.2 Ballast Box

Alternate design two consists of a box with weights that add up to 5000 lbs. As seen in Figure 6, these weights are allowed to slide on rails contained inside the box. The box dimensions are roughly 4 ft. long and 2 ft. wide, and the height is to be determined later when calculations for clearance under the chassis are determined. The box has a handle on each of the top corners allowing the cylinders, attached to the underside of the tractor, to lift and lower the box. These 4 cylinders run off of the hydraulic pump already installed in the tractor, eliminating the need for an additional pump, which would raise the cost. Having the weights all in one assembly makes attachment and removal of the ballast an easy process. Also the box is quite safe as all the weights are inside with no way for it to fall out and damage an implement or the tractor. The weights can be moved inside the box using a hydraulic telescoping cylinder. Using a telescoping cylinder creates a shorter length requirement for the cylinder because of its compact size. The telescoping cylinder has the ability to move the weight to both ends of the box. There is a back-plate that prevents the weights from hitting the cylinder as well. The operator uses a lever to control both the telescoping cylinder and the raising and lowering cylinders from inside the cab. One drawback for this design is the visibility of the box when trying to attach it to the tractor because the tractor itself blocks the line of sight for the operator. Also, the box is very heavy and requires some other vehicle, such as a skid steer, to move it.

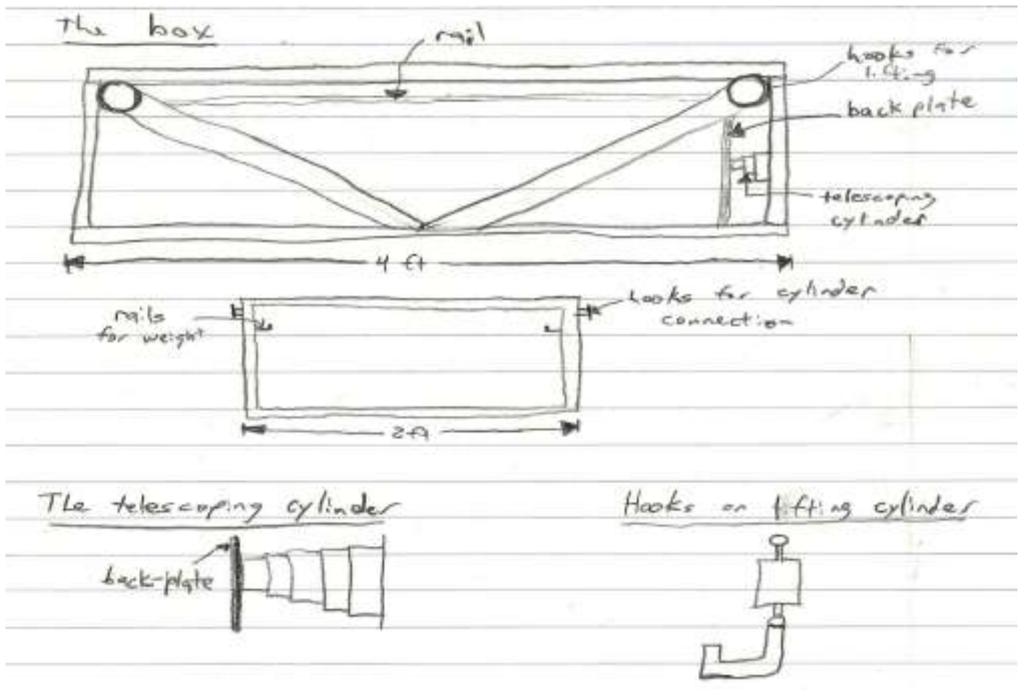

Figure 6 - Initial sketches of Ballast Box.

2.1.3 Front Forks

Figure 7 displays another initial design which is a system that is mounted underneath the frame in the front of the tractor. It consists of a fork that can be raised and lowered hydraulically (cylinders 1 and 2) as well as moved forward and backward hydraulically (cylinders 3 and 4). The fork drops down and moves forward out in front of the tractor to pick up weights, then is raised and brought back towards the frame of the tractor. The weights are raised high enough that the fork mounting can be locked onto a rail, relieving pressure from cylinders 1 and 2. Once locked onto the rail, the weights can be moved forward and backward as needed by cylinders 3 and 4 pushing them along the rail.

This design is safe, allowing the tractor operator to change weights without leaving the cab. The weight changing process is simple, with the only potential issue lying in how much the nose of the tractor might interfere with the operator's line of sight while picking up weights. Cost effectiveness and the use of standard parts are not causes for any problems. Clearance from the ground is an area that requires further calculation and evaluation to determine if it causes problems or not.

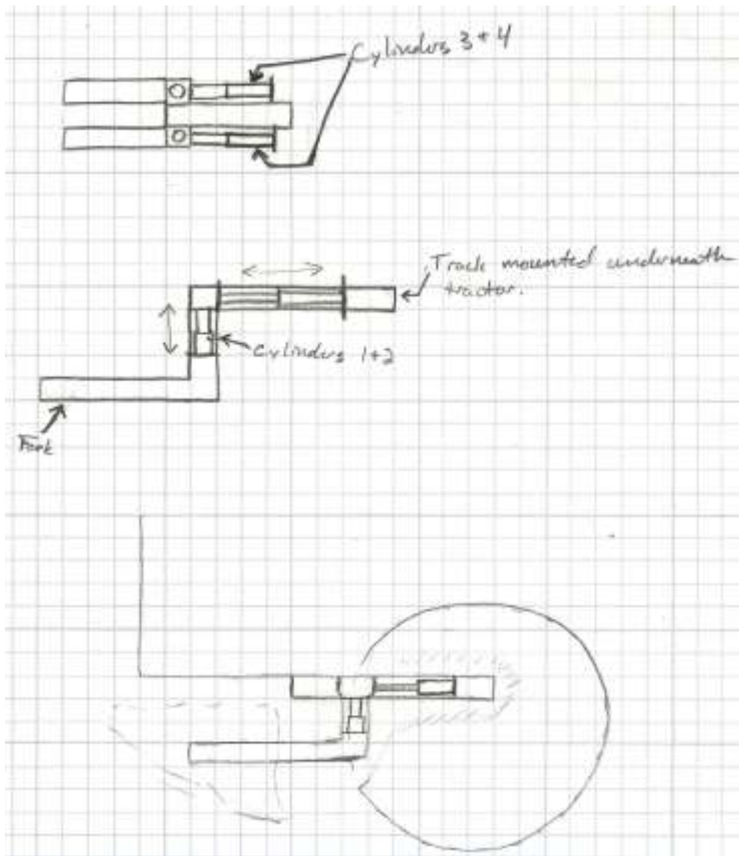

Figure 7 - Initial sketches of Front Forks.

2.1.4 <u>Under-Belly Ballast</u>

Following the analysis of the previous three designs, the concept of an under-chassis system was discussed after determining that the other initial designs were too close to currently marketed designs. The goal of the system is that the system makes one very large weight change, ideally from unballasted to nearly maximum ballast of the tractor. Due to its uniqueness and fundamental differences, the under-chassis design more easily and efficiently accomplishes the massive weight changes described in the objective. After a brainstorming session, Figures 8.1-8.3 were created with the intention of representing the final design. The use of modified suitcase weights was also discussed and partially developed as seen in Figure 8.4. A final decision was made to not use them because it would be cheaper to use one solid cast. Having one solid cast will also allow for increased clearance under the tractor giving it a higher score in the selection process.

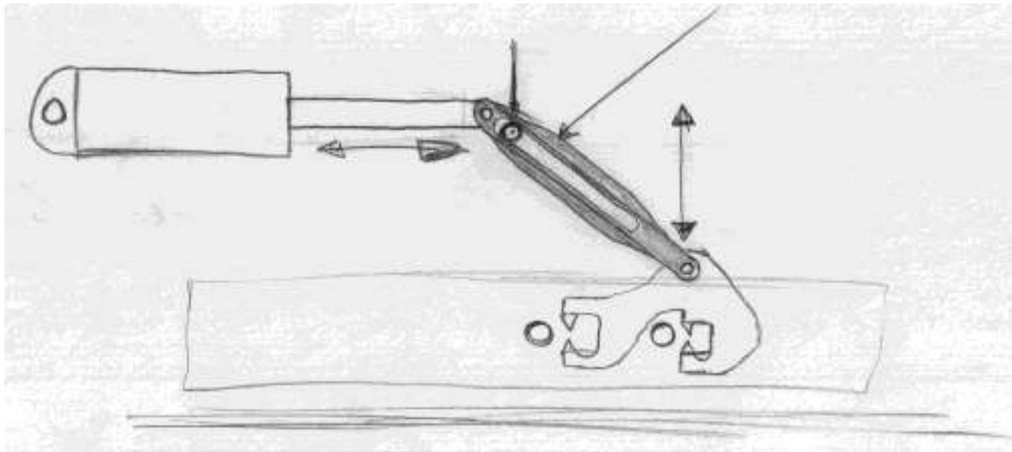

Figure 8.1 - Side view of final initial sketch

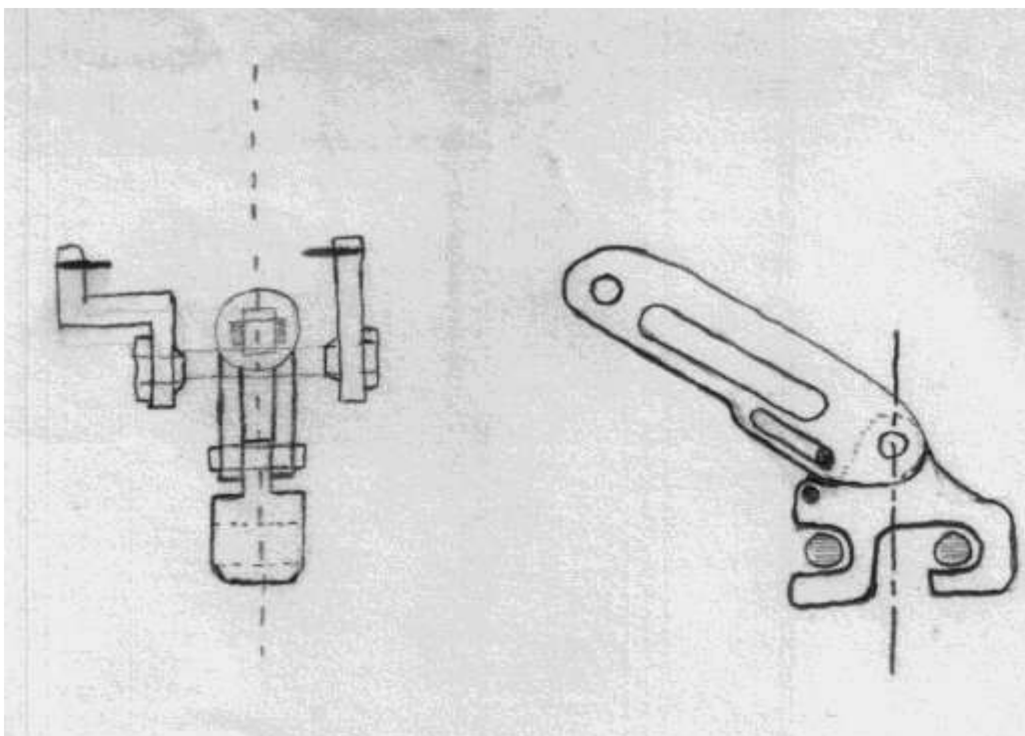

Figure 8.2 - Sketch of weight arm and hooks

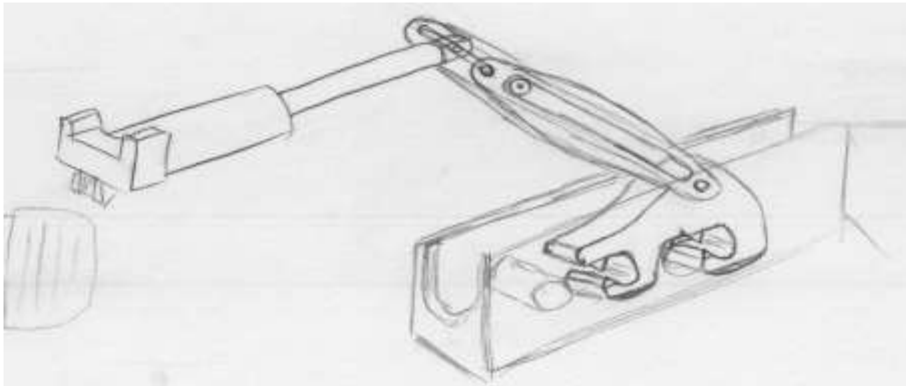

Figure 8.3 - Isometric sketch of intended final design.

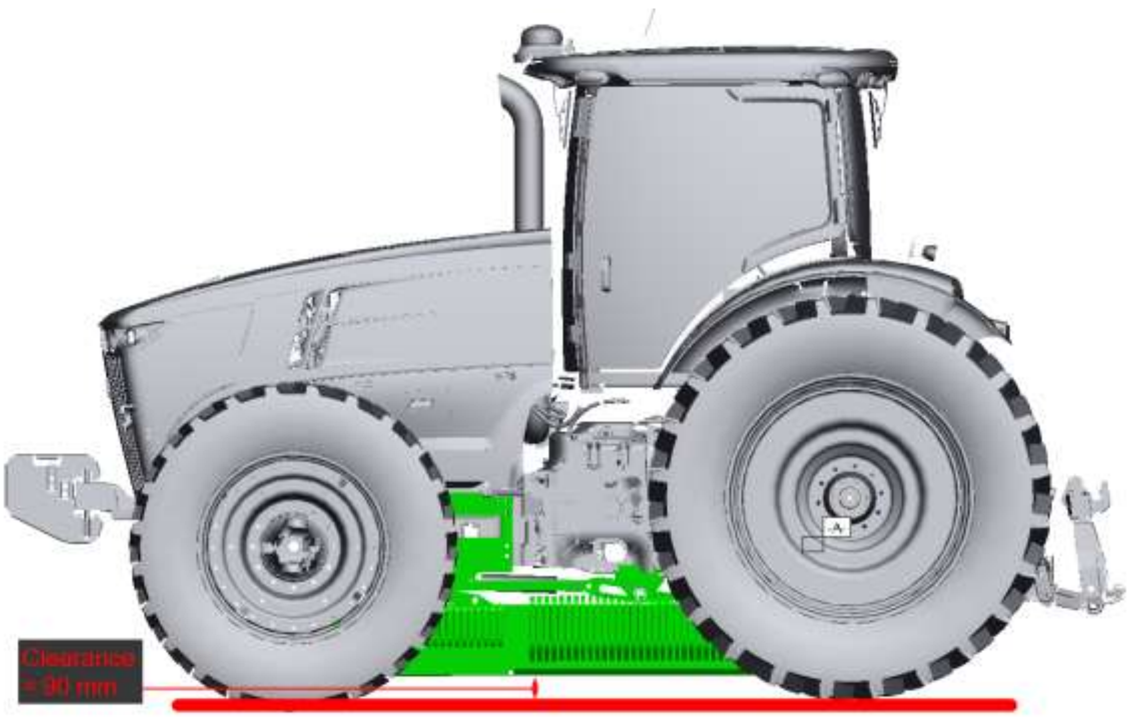

Figure 8.4 - Under-Belly design using modified suitcase weights.

2.2 Selection of Ballast Design Based on Criterion

Table 2 shows the criteria on which the designs were analyzed for selection. For each criterion, each design was examined and rated on a scale of 1-10. Each rating was then multiplied by the weight assigned to its respective criteria, and the totals were added up. A perfect score for this system is 1000. The highest weight is given to the weight exchange and cost because they are the driving limitations to the design. Clearance was another highly weighted criteria because clearance is necessary for in-field activities. Safety is a highly weighted criterion as well because the design must be safe for the operator to use.

Table 2: Results of design criteria analysis.

Criteria	Weight	Front Quick-tach	Ballast Box	Front Forks	Under-Belly
Safety	15	9	9	9	9
Weight Exchange	20	8	6	8	9
Connection/Disconnection	10	8	7	8	8
Clearance	15	8	6	7	9
Transportation	5	7	7	7	6
Durability	10	10	10	10	10
Standard Parts	5	9	7	8	7
Cost	20	7	6	7	7
Total (weight*score)	1000	815	705	795	835

The final design was selected based off the criteria used for the selection process. The best rated design that was picked was the Under-Belly ballast because it scored highest in the most categories. The chosen design has been further analyzed and manipulated to try and achieve the goals of the project. The Front Quick-tach design was not selected to be the overall final design because it relates too closely to products on the market currently.

2.3 Design Calculations:

Design calculations were completed to know forces of the system and the locations of where the forces would be applied. Knowing the location of forces allowed the design to be properly placed around the center of gravity maintaining the 40/60 weight split between the front and rear axle respectively. The two calculations both use summation of moments about a selected point. For equation (1), the moments are summed about the front axle. For equation (2) the moments are summed about the pivot pin.

Calculations to find the center of gravity of the 7260R tractor were completed using equation (1).

$$\sum M_{fa} = (W_{CG}) * x - (R_a) * 115.16in = 0 \qquad (1)$$

W_{CG} = unballasted weight of tractor

R_a = max rear axle weight

x = distance from front axle

$$\sum M_a = F_y * x - F_x * y = 0 \qquad (2)$$

F_y = weight of ballast

F_x = hydraulic force required

x, y = distance from pivot pin

Figure 9 shows where certain points are located for the calculation. Values used in the calculations were taken from Table 1. The wheelbase of the tractor is 115.16 inches. The center of gravity of the tractor was found to be 71.15 inches from the front axle of the tractor.

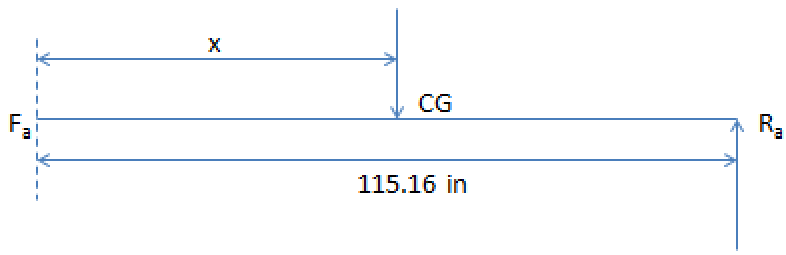

Figure 9 - Diagram used in calculations for the center of gravity of the tractor

The calculations for the amount of force the hydraulic cylinder needed uses equation (2). Figure 10 shows the location of specific variables. The values used in the calculations were recorded from the amount weight of the ballast and the geometry of the system which can be found in the previous figures. The max force needed is when the ballast is on the ground with ϴ=27.35˚ is 12,058 lbs. From these calculations a standard hydraulic cylinder with piston diameter of 1.5 inches was chosen. This size cylinder is able to produce the needed amount of force according to manufacturing specifications.

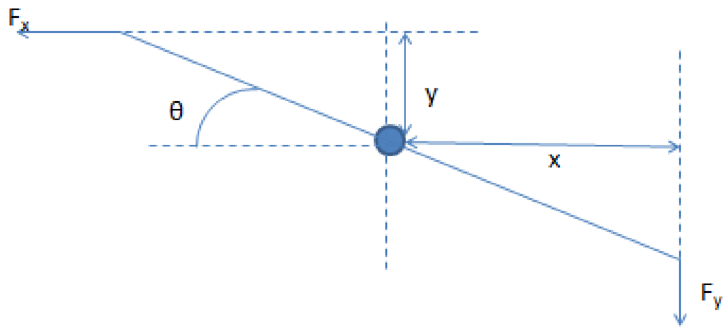

Figure 10 - Diagram used in calculations for the force needed by the hydraulic cylinder

2.4 Failure Mode Effects Analysis (FMEA)

After the under-belly ballast design was sketched, it was examined for potential modes of failure. The components that were deemed to have a potential to fail were analyzed by grading it on a scale of 1-10 for severity, occurrence, and detection with 10 being the worst and 1 being the best. Table 3 displays the component, its function, and ways it could fail. The severity of most of the failures is relatively low because there are no human consequences from the failure other than customer dissatisfaction. The failures would be rare occurrences because the materials used for the components are heavy and sturdy. Also calculations were done before the components were dimensioned which allowed the parts to be built to the correct size without failure. Detection of the failures will be difficult when the ballast is in use in the field because the system is out of sight from the operator. Although the system is out of sight, once failure occurs, the operator would notice a difference in how the tractor is handling and action to fix the problem could be completed. The RPN (risk priority number) is calculated by multiplying severity by occurrence by detection. Typical protocol regarding RPN is that any failure mode with an RPN greater than 100 needs to be immediately addressed to resolve the issue. The CRIT (criticality number) is calculated by multiplying severity by occurrence. The maximum number CRIT can equal is 100. If the CRIT value is greater than 50, redesigning of the component may be necessary.

Table 3: FMEA, including description of component, function and grades given to severity, occurrence, and detection with the risk priority and criticality number displayed. The action taken is also described

Component:	Function	Potential Failure Mode	Potential Effects of Failure	Severity (1-10)	Potential Cause(s) of Failure	Occurence (1-10)	Current Process Contols	Detection (1-10)	RPN	CRIT	Action Taken
Pivot Pin	Weight rack pivots on the pins to be lifted from the ground	Component failure	Weight rack falls, causing it to drag along ground/falls off entirely, damage to hydraulic cylinder, customer dissatisfaction, damage other components/machinery	7	Vibration, wear of pin/metal sleeve, pin falls out	2	Design Calculations for forces on members	4	56	14	Overdesigned the pin to take the forces applied, (larger diameter)
Lifting arm	Link that connects hydraulic cylinder to the weight hooks	Component failure	Weight rack falls, causing it to drag along ground/falls off entirely, damage to hydraulic cylinder, customer dissatisfaction, damage other components/machinery	5	Vibration, wear, jarring,	2	Design Calculations for forces on members	5	50	10	Increased number of arms per weight hook to 2
Hydraulic Cylinder	Lifts/lowers weight from/to gound	Component failure	Weight rack falls causing it to drag along ground/falls off entirely, customer dissatisfaction, damage other components/machinery, weight doesn't lift	7	jarring of weight rack, piston bends, seals leak	2	Design Calculations for forces on member	2	28	14	Oversized cylinder capable of producing enough force to lift weight
		lost connection to lever in tractor	damage to hydraulic cylinder, weight rack falls	2	hydraulic line damage, input unplugged	2	output shown in tractor as inactive	1	4	4	
Locking Mechanism	Locks weight in place when lifted off the ground	Component failure	Weight not secure, weight rack falls causing damage to other components/machinery	3	pins not in position, weight rack not fully on hooks	4	N/A	3	36	12	Design weight rack to aligned properly on hooks
		Inability to lock	Weight unable to be secured, arms will not fully lock and lift weight	1	Debris in locking channel, locking arm deformed	4	N/A	5	20	4	Inspect locking channel before and after use

The most sever component failure was given to the pivot pins because if that component fails it could potentially cause other components to fail as well. All other components have a backup safety lock which will hold the weight box in position if a component fails. As seen in Table 3, the RPN numbers are all relatively low which demonstrates that the design was well prepared before analysis was completed.

3. Selected Design - Under-Belly Ballast

The overall final design that was selected is the Under-Belly ballast. It is suspended under the chassis between the front and rear axles, at the center of gravity of the tractor as seen in Figure 11. All parts of the ballast are displayed in Figures ___-___ with a simplified version in Table 4. Table 5 displays the properties of the materials used in the manufacturing of the system. The materials were selected based off of agricultural and engineering standards displayed in Table 5.

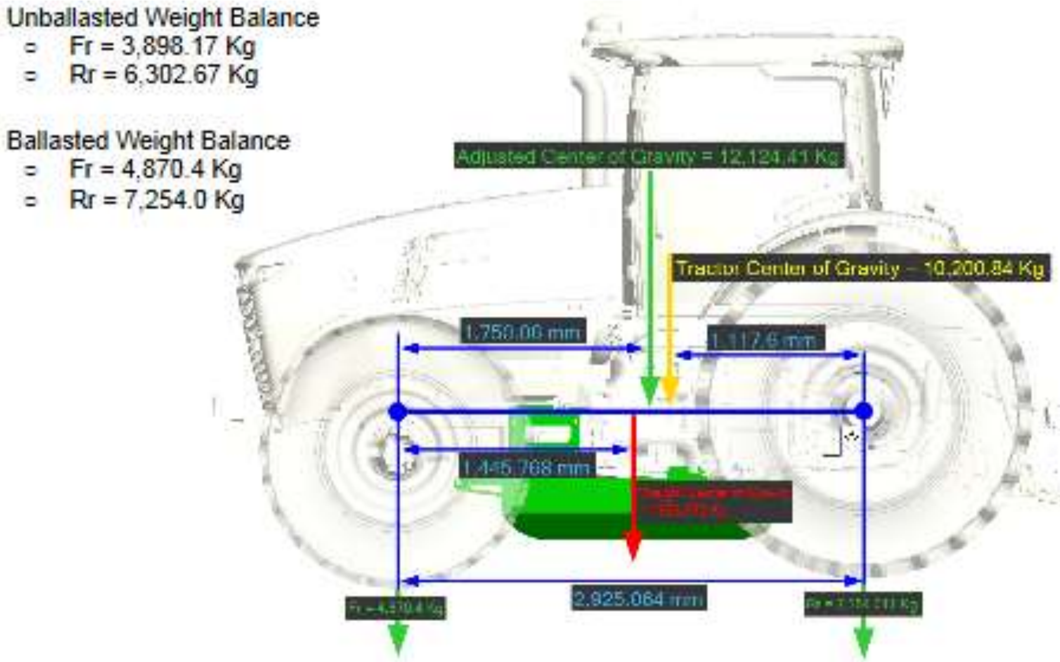

Figure 11 - Displays the tractors center of gravity and the force changes when the design is added.

Table 4: Bill of Materials

Level 1	Part Number	Part Name	Quantity	Material	Description
BL	BL-0009	Ballast Assembly	1	Steel	Sleeve For Main Shaft
	BL-0000	Front Mount Single	1	Grey Cast Iron	Front Mount Using One Lift Arm
	BL-0002	Hydraulic Cylinder	1	STOCK	Hydraulic Cylinder
	BL-0003	Hydraulic Pin	1	Steel	Hydraulic Pin
	BL-0004	Right Mount	1	Grey Cast Iron	Right Mount
	BL-0005	Left Mount	1	Grey Cast Iron	Left Mount
	BL-0006	Steel Bearing	4	Steel	Steel Bushing
	BL-0007	Main Shaft	2	Steel	Main Shaft
	BL-0008	Sleeve	2	Steel	Sleeve For Main Shaft
	BL-0010	Drop Arm Left	2	Grey Cast Iron	Sliding Drop Arm Left
	BL-0011	Spacer	4	Steel	Spacer between drop arm and connecting arm
	BL-0012	Connecting Arm	2	Steel	Main Arm
	BL-0013	Spacer	4	Steel	Spacer Lock
	BL-0014	Left Connecting Arm Asy	1	Steel	Left Arm Assembly
	BL-0015	Right Connecting Arm Asy	1	Steel	Right Arm Assembly
	BL-0016	Spacer	1	Steel	Spacer for second drop-arm
	BL-0026	Hook	2	Steel	Hook
	BL-0027	Small Slide Pin	2	Steel	Hook Small Slide Pin
	BL-0028	Large Hook Pin	2	Steel	Large Hook Pin
	BL-0029	Small Hook Arm	2	Steel	Small Hook Arm
	BL-0030	Drop Arm Right	2	Grey Cast Iron	Sliding Drop Arm Right
	BL-0031	Drop Arm Large Bushing	2	Steel	Large Bushing For Drop Arm
	BL-0032	Drop Arm Large Pin	2	Steel	Large Pin For Drop Arm
	BL-0033	Drop Arm Small Pin	2	Steel	Drop Arm/Hook Small Pin
	BL-0034	Drop Arm Small Bushing	2	Steel	Small Bushing For Drop Arm
	BL-0035	Washer Hook	2	Steel	Washer For Slide Hook Pin
	BL-0036	Solid Ballast	2	Grey Cast Iron	Solid Cast Ballast
	BL-0037	Locking Arm	2	STOCK	Locking Arm For Hook
	BL-0038	Washer	2	STOCK	1" Washer
	BL-0039	Hyd Bolt	1	STOCK	1.0 X 4.0 Bolt
	BL-0040	Hyd Nut	1	STOCK	1.0 Nut

Table 5: Material Properties

Material				
Type	Grey Cast Iron		Type	Mild Steel
Standard	ASTM 40		Standard	SAE 1090
Density	441 lb/ft^3		Density	491.4 lb/ft^3
Modulus of elasticty	18000 ksi		Modulus of elasticty	29300 ksi
Tensile Strength	40000 psi		Tensile Strength(cold drawn and annealed)	101000 psi
Elongation	1%		Yield Strength(cold drawn and annealed)	78300 psi
Shear Strength	58000 psi		Elongation Strength(cold drawn and annealed)	10%
Compressive Yield Strength	120000 psi		Hardness Strength(cold drawn and annealed)	92 RB
Fatigue Strength	20000 psi		Tensile Strength(hot rolled)	122000 psi
Wear Resistance	Low		Yield Strength(hot rolled)	66700 psi
Corrosion Resistance	Low		Elongation(hot rolled)	10%
Weldability	Low		Hardness(hot rolled)	98 RB
Machinability	Good			
Castability	High			

As shown in Figure 12, the hydraulic cylinder is fixed to the chassis along with two other pins on which the arms of the ballast pivot. The pins have bushings on them, shown in Figure 13, which allow for easy repair when worn out. The weight rack of the ballast is attached to the two arms by a mechanism which will lock the weight when a force is applied as shown in Figures 14.1 and 14.2. This mechanism decreases the degrees of freedom the ballast had, limiting twisting actions on the arms which lengthens their life span. The cylinder will retract to lift the weight, which creates less exposed cylinder piston, decreasing the possibility of bending. Once the cylinder is fully retracted the weight is locked into place by a groove on the arm seen in Figure 15 (which is now horizontal) and the pivot pins. To lower the ballast, the cylinder extends with enough force to remove the weight from the groove and extend the arm to the ground. With no force applied to the locking mechanism, the operator can reverse the tractor away from the ballast and raise the arms again to lock them in the upright position for traveling.

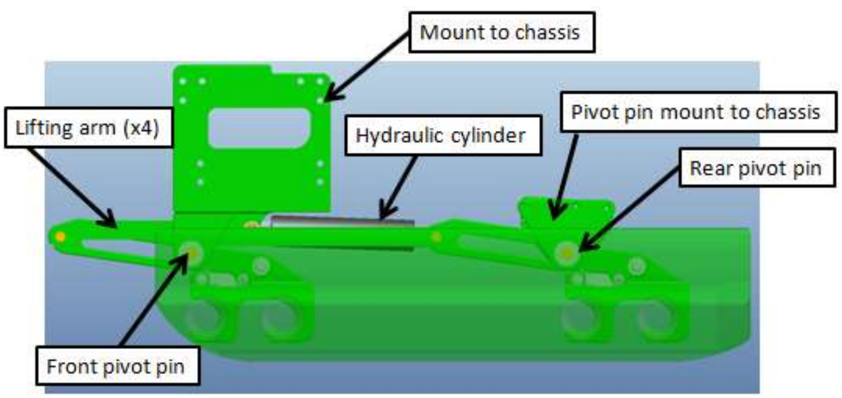

Figure 12 - View of system in upright position with the weight rack transparent.

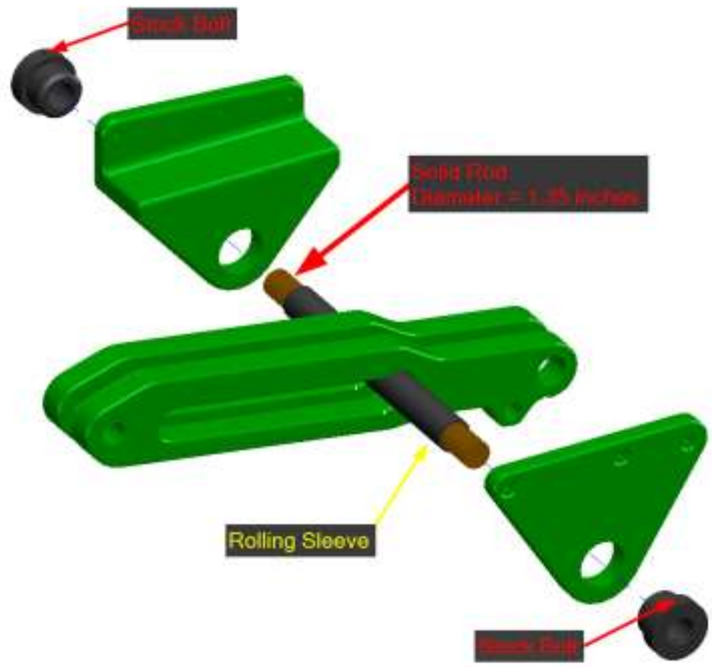

Figure 13 - Exploded view of arm, pivot pin, and rolling sleeve.

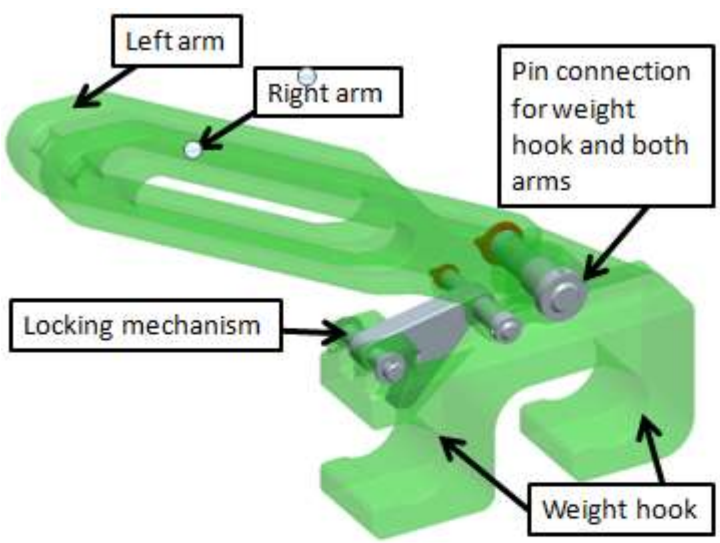

Figure 14.1 - Displays lifting arm with locking mechanism

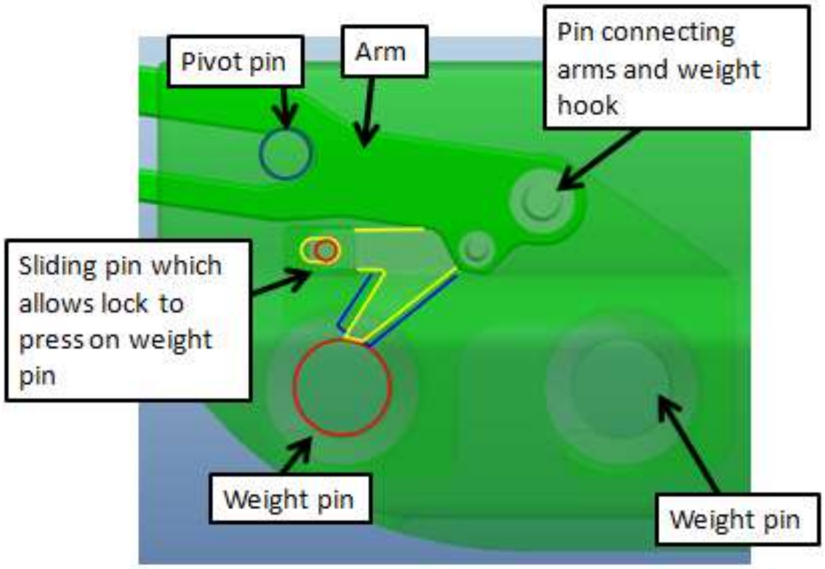

Figure 14.2 - Displays locking mechanism in detail

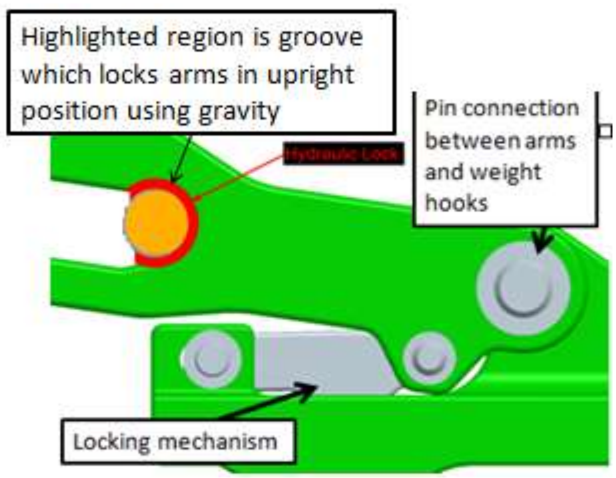

Figure 15 - Displays hydraulic lock when in upright position.

Alignment during the ballast weight attachment process was considered. As can be seen from Figure 16, the chamfers on the rear end of the weight rack allow the tractor to be off alignment with the weight hooks. The operator is allowed to be a few inches to either side of the system and still hook up the weight. The weight pins themselves had a balancing feature to them. The pins have an outward chamfer on the ends which forces the weight to the center of the weight hooks. This allows the tractor to pull over the weight, lower the arms, and then pull the rest of the way forward until the weight pins are in the hooks.

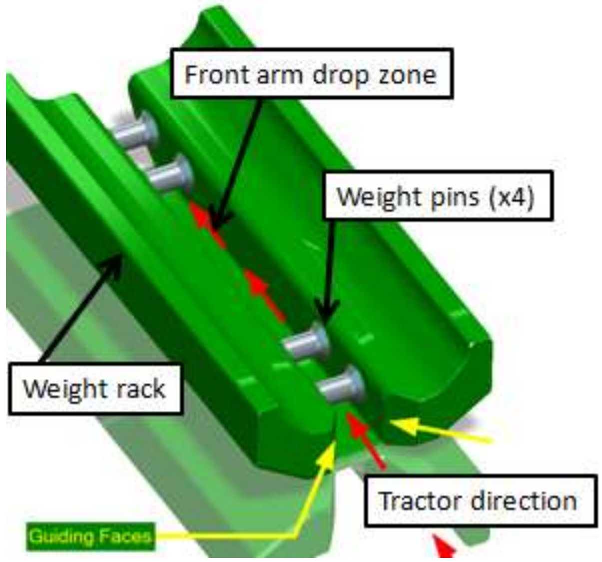

Figure 16 - Displays detailed view of weight rack.

Figures 17.1-17.7 are different views of the system. They show where the ballast is located and how the final design looks when attached to the tractor. Figure 17.1 illustrates the forces that the weight rack applies on the hooks (displayed in red) and the calculated hydraulic force necessary to lift the weight rack (Fc, displayed in yellow). The link connecting the arms together allows the system to be powered by a single hydraulic cylinder.

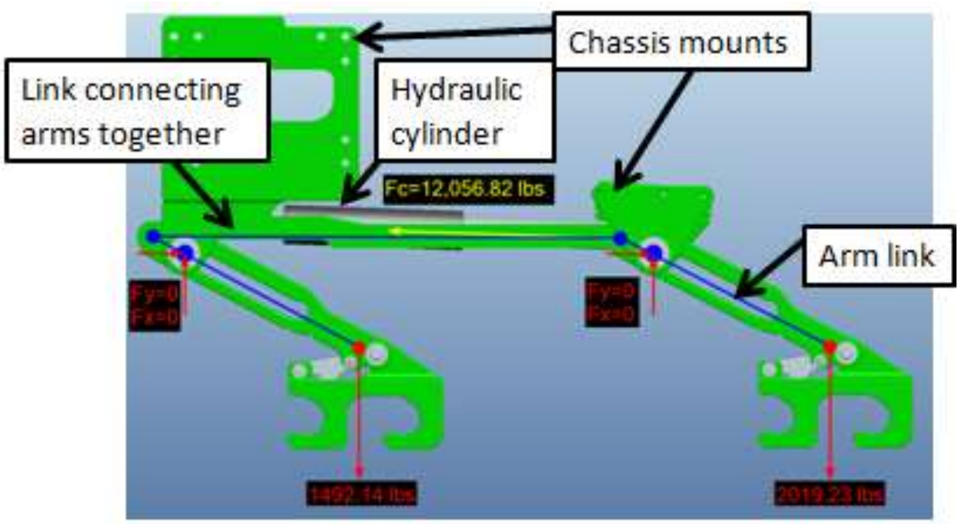

Figure 17.1 - Side view of system without weight rack attached.

Figures 17.2-17.4 show different views of the system with the weight rack attached. Figure 17.2 displays how the design of the weight rack increases ground clearance by wrapping around the mounts.

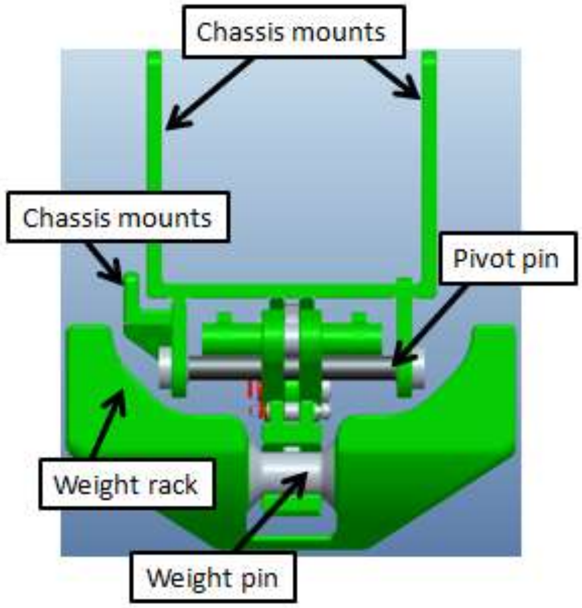

Figure 17.2 - Front view of system with weight rack in the raised position.

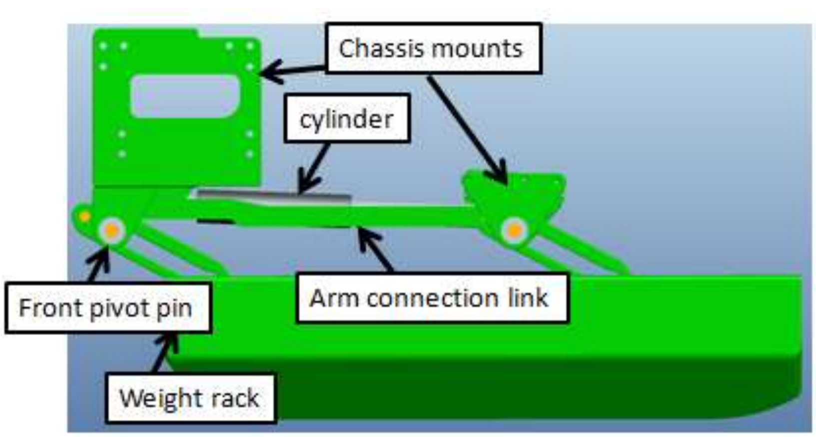

Figure 17.3 - Side view of entire system with weight rack in lowered position

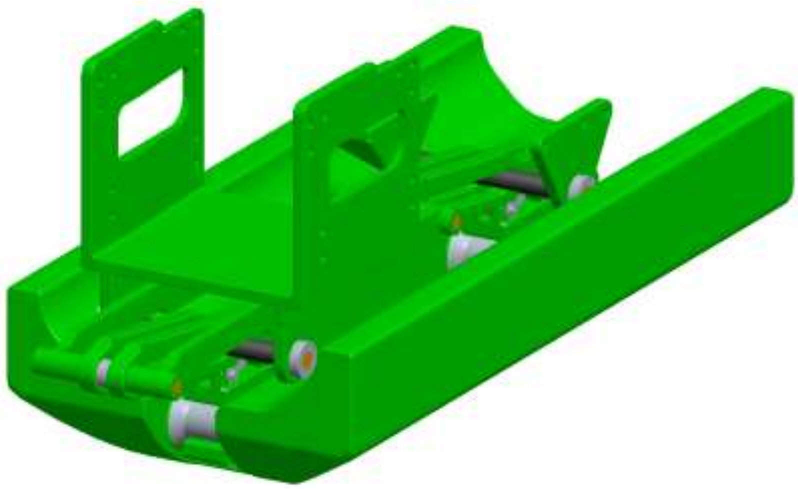

Figure 17.4 - Isometric view of entire system in upright position.

The location of the system once attached to the tractor can be seen in Figures 17.5 and 17.6. Figure 17.7 illustrates the ground clearance of the system underneath the tractor from a front view.

Figure 17.5 - Side view of entire system in lowered position

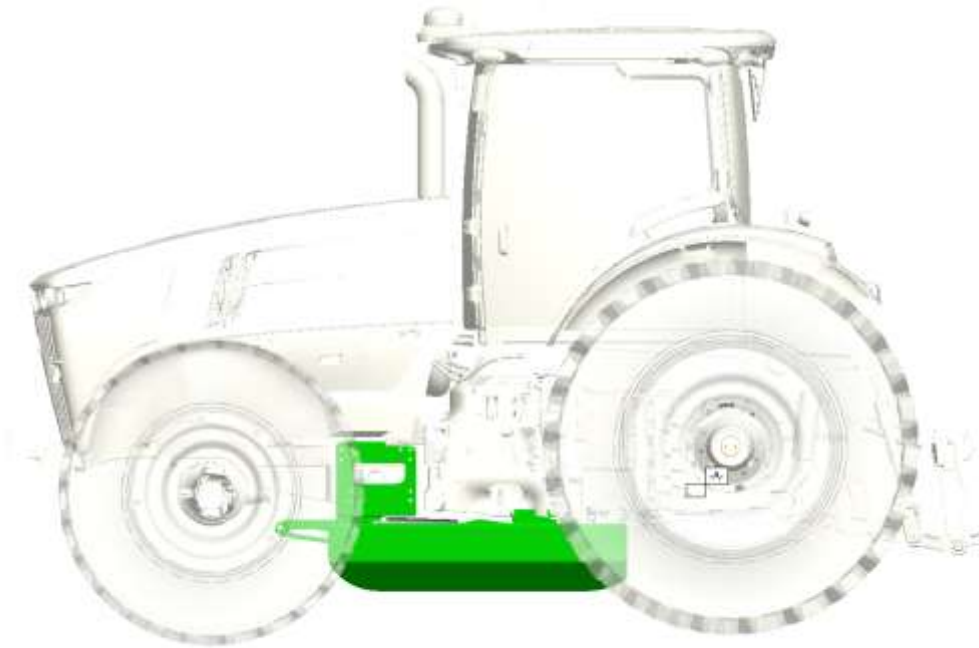

Figure 17.6 - Side view of entire system in the raised position

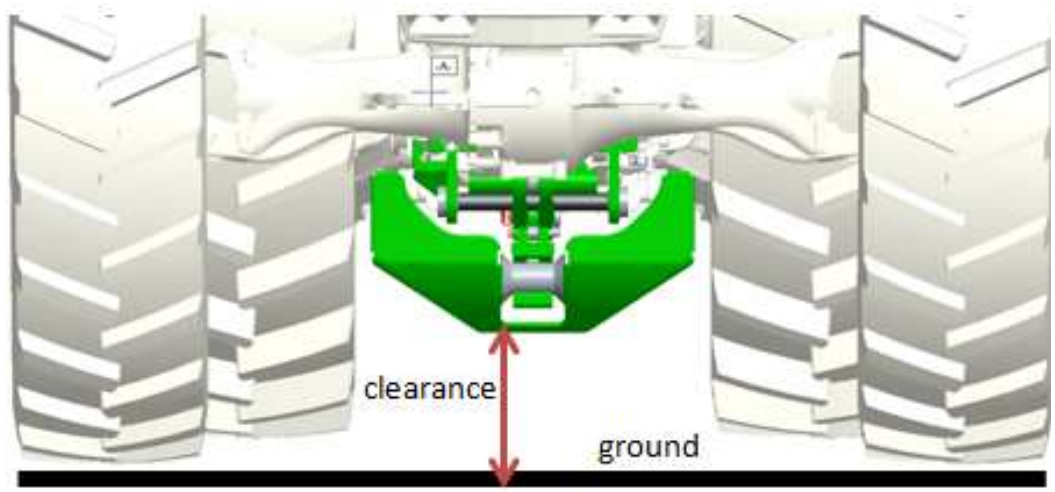

Figure 17.7 - Front view of system attached to tractor raised from the ground. The ground clearance is 9.77 in.

3.1 Parts Description:

Materials for the building of the system were selected based off standard agriculture materials. Full page detailed drawing of all components can be found in Appendix III.

1. Mounting brackets - Displayed in Figures 18.1 and 18.2, the mounting brackets attach the lifting system to the frame of the tractor.

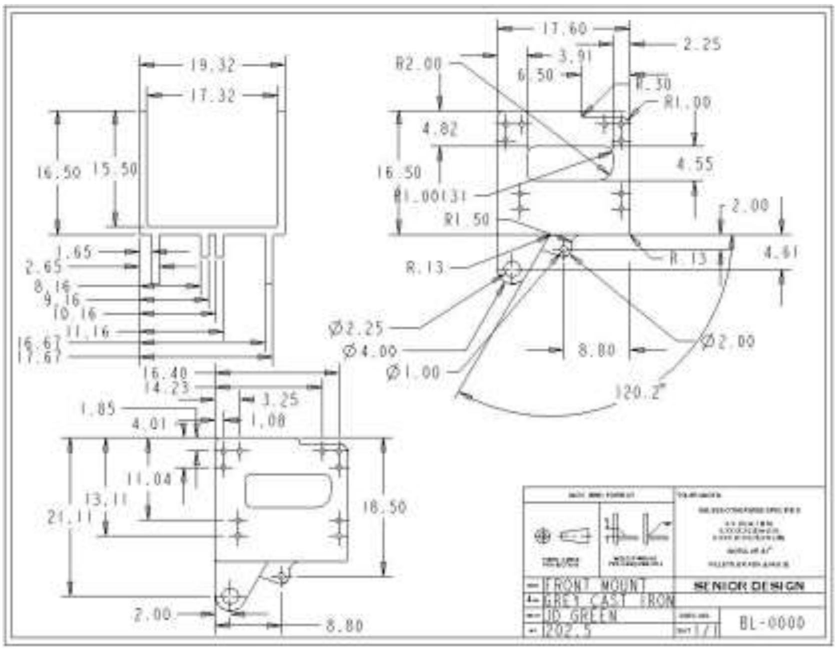

Figure 18.1 - Drawing of large mount that holds hydraulic cylinder and front pivot pin in place.

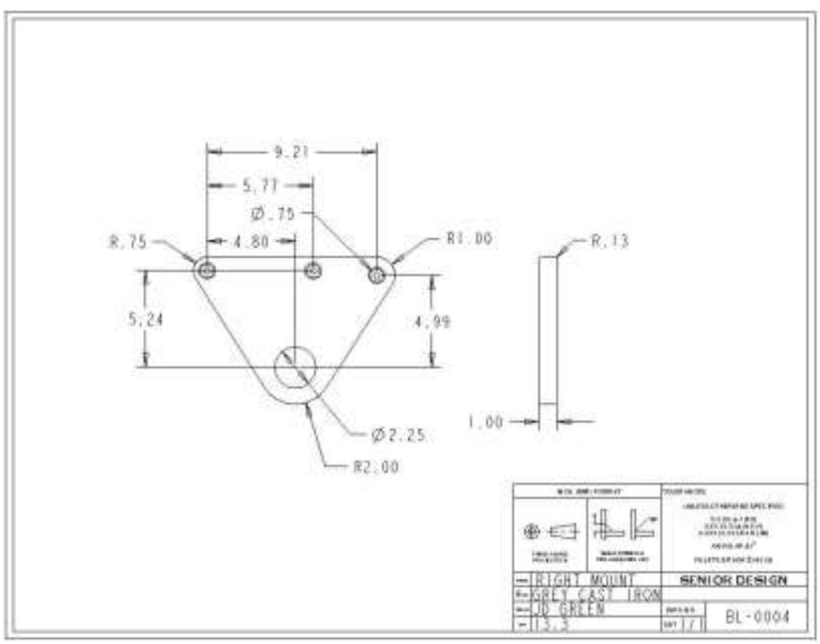

Figure 18.2 - Rear pivot pin mount drawing.

2 Hydraulic cylinder - the hydraulic cylinder is used to provide the power necessary to lift the weight rack off the ground. This design uses a hydraulic cylinder with a 3 in. bore, 1.5 in. diameter rod, 12 in. stroke, and 3000 psi. The pin that holds the cylinder to the mounts is displayed in Figure 19.

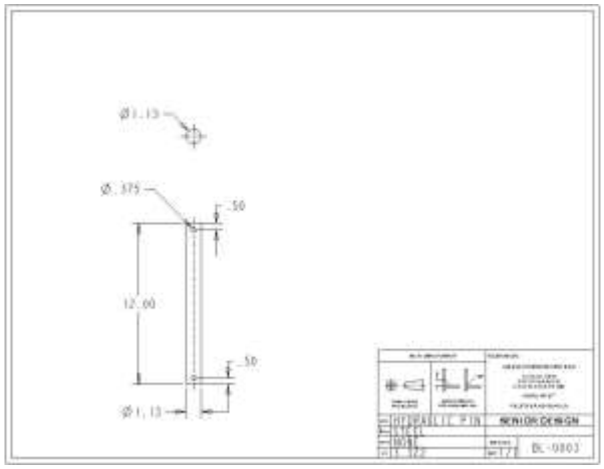

Figure 19 - Drawing of hydraulic pin that holds hydraulic in place to the mount

3 Arms - Displayed in Figure 20, the arms are the links from the hydraulic cylinder to the locking mechanism that pivot on the pins which allow the weight to be raised.

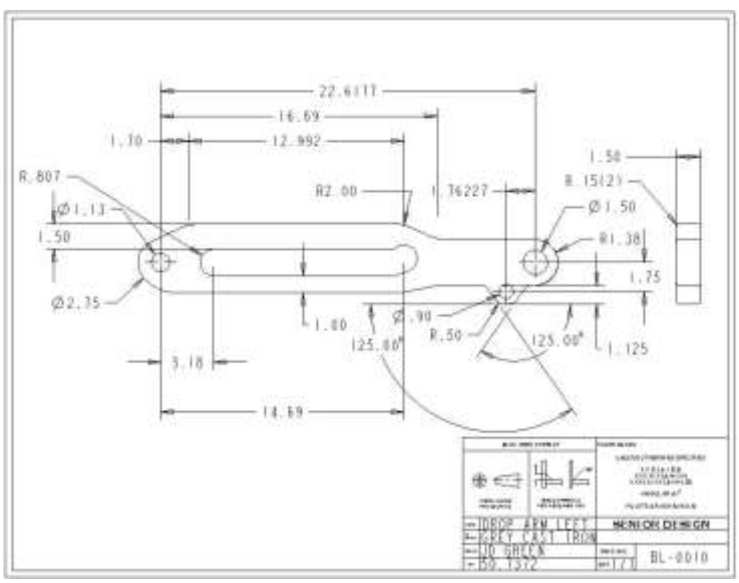

Figure 20 - Detailed drawing of left arm. The hydraulic lock groove is clearly visible in the drawing. Also holes for the pins of the locking mechanism, the hydraulic cylinder, and the weight hook are clearly displayed.

4 Weight hook - Displayed in Figures 21.1 and 21.2, the weight hook is the link that locks the weight to the arms. It also provides balance to the weight rack. This mechanism was designed to reduce the degrees of freedom the system has.

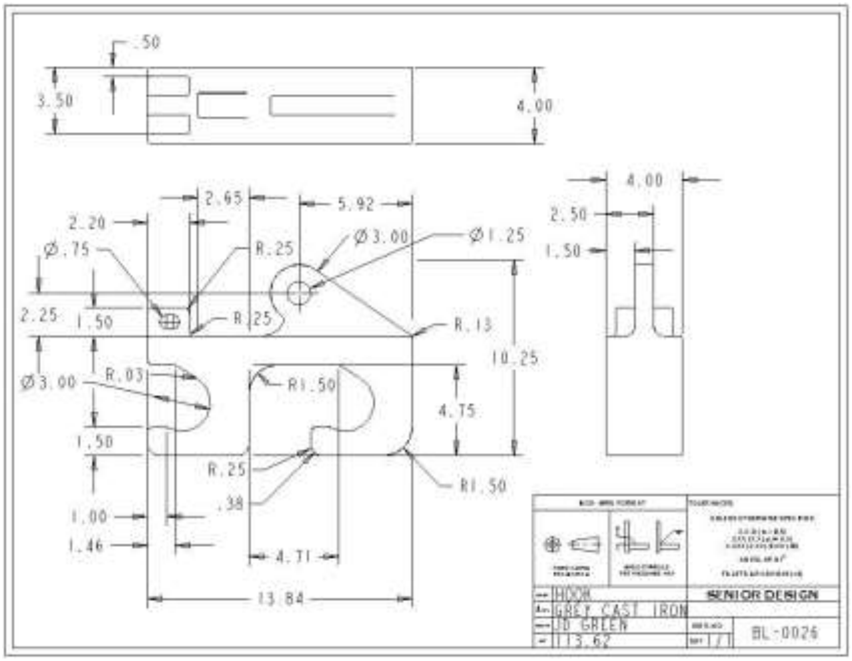

Figure 21.1 - Detailed drawing of the weight hooks for the weight rack. The sliding hole for the locking mechanism is clearly shown on the hook.

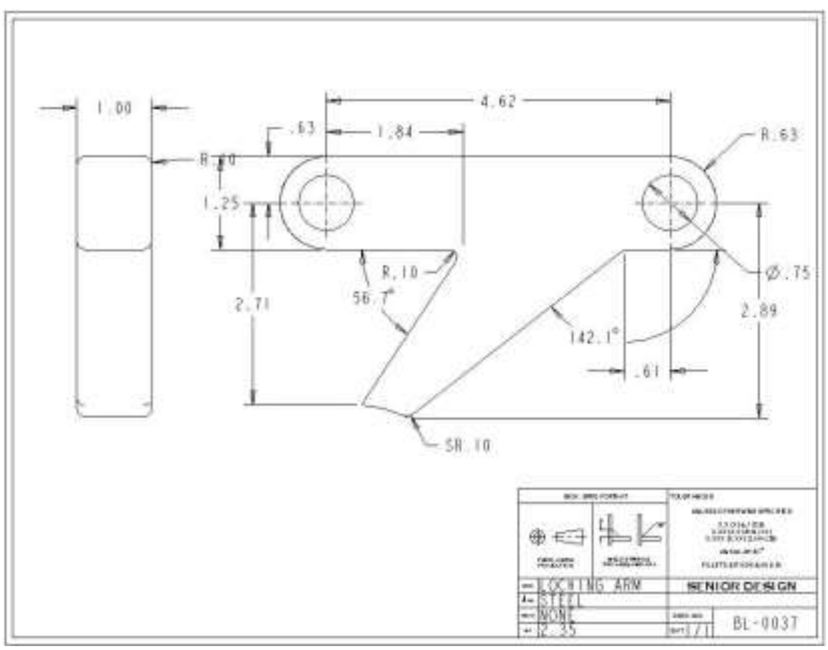

Figure 21.2 - Detailed drawing of locking mechanism. The geometry of the link allows it to slide and change position with respect to the weight hook and lock the weight pins in position on the weight hooks.

5 Weight rack - Displayed in Figure 22, the weight rack is the cast ballast weight that is picked up and lowered by the lifting system. The weight rack provides the majority of the weight in the system, weighing 3511.37 lbs.

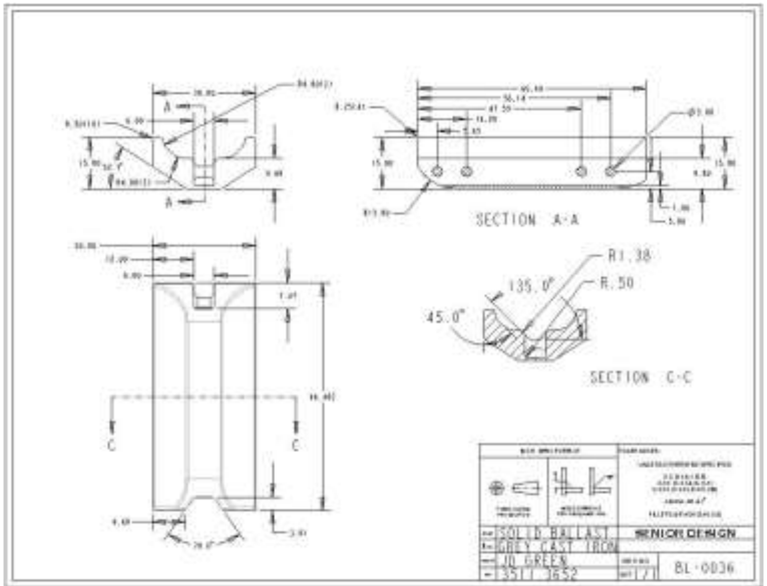

Figure 22 - Detailed drawing of weight rack. The guidance grooves are clearly displayed. Also displayed is geometry which allowed the ballast to increase the clearance under the tractor by wrapping around the chassis mounts. The general shape of the weight rack resembles a boat because if low clearance is an issue it would glide through the soil like a boat gliding through water.

6 Bushings- Displayed in Figure 23, the bushings provide a space between the pivot pins and the arms. Bushings provide protection to the pivot pins and arm reducing wear and increasing the lifespan of the parts.

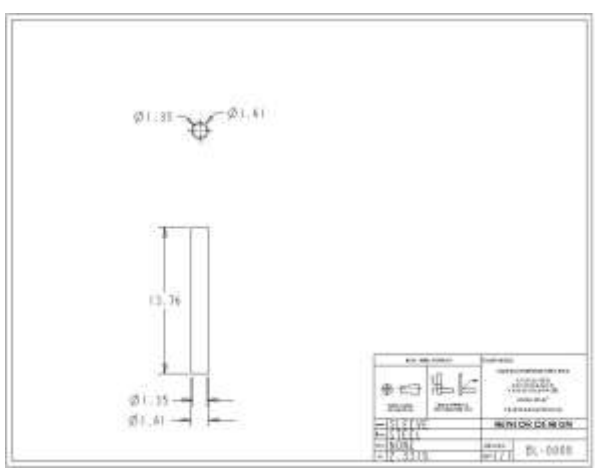

Figure 23 - Drawing of steel bushing which goes around the pivot pins.

7 Misc. -

a Pins - Displayed in Figure 24, pins are the pivot points that connect the arms and lift the weight from the ground. The pins are standard hitch pins which allow the cost of the design to be minimized.

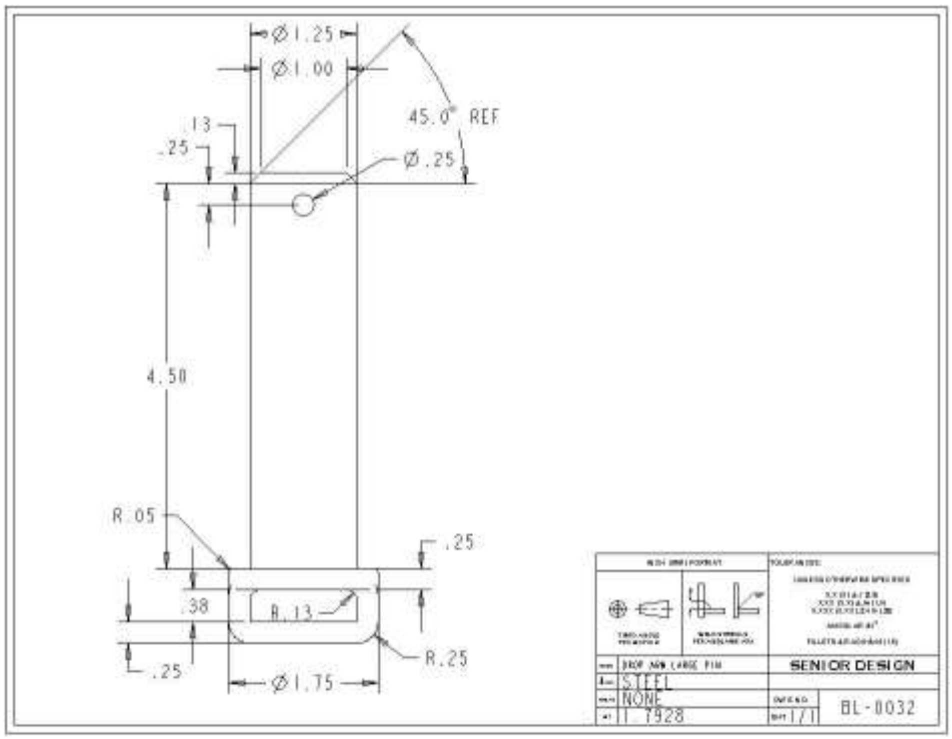

Figure 24 - Displays the pin connecting the arms to the weight hook. Other pins are similar in size and can be found in the Appendix. Each pin was over designed because if failure was to occur it would cause other components to fail as well.

b Bolts - Standard bolts connect the lifting system to the tractor.

4. Results:

A ballasting system has been designed that is able to be used for light and heavy tractor applications. The total weight of the ballast system is 4240.75 lb. The weight rack itself weighs 3511.37 lbs. The hydraulic cylinder of piston diameter 1.5 in. produces 15,896 lbs. of force which allows the ballast to be raised and lowered. The ballast is removable from inside the cab as the hydraulic cylinder is tied into one of the hydraulic outputs of the tractor. The operator is able to raise and lower the system with a lever by driving over the top of the ballast and aligning the arms with the weight rack. The ballast improves efficiency of switching weights for different agricultural tasks because it allows for rapid, large weight swings. A farmer is able to go from full ballast plowing a field to unballasted spraying a different field within minutes. Discussion of this concept with potential users showed great enthusiasm for the potential to be able to quickly change ballast on such a large scale and decrease the need for current, inconvenient methods such as wheel weights. In comparison, very little concern was expressed regarding the lower clearance underneath the tractor.

5. Conclusion:

The system that has been designed meets all objectives stated in section 1.1 of this report. It is an adaptable system that fits both light tractor applications as well as heavy tractor applications. The operator is able to change from heavy ballast to light ballast, and vice versa, rapidly and easily by using controls inside the cab. The system meets the goal of an approximate weight addition of 4000 lb., adding an actual 4240.75 lb. to the tractor while remaining within European Union regulations and axle weight regulations. The location of the system also maintains the desired 60/40 weight split between axles.

6. Gantt Chart:

To keep up with the deadlines and workflow a Gantt chart was created to track and maintain an efficient work process. The timeline which was followed in the completion of the project displays tasks which were listed. The timeline is displayed in the Appendix.

7. Works Cited

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8. Appendix

I. Gantt Chart
II. Full page FMEA table
III. Full page component drawings

Appendix I – Gantt Chart

Appendix II – Full Page FMEA Table

Component:	Function	Potential Failure Mode	Potential Effects of Failure	Severity (1-10)	Potential Cause(s) of Failure	Occurence (1-10)	Current Process Contols	Detection (1-10)	RPN	CRIT	Action Taken
Pivot Pin	Weight rack pivots on the pins to be lifted from the ground	Component failure	Weight rack falls, causing it to drag along ground/falls off entirely, damage to hydraulic cylinder, customer dissatisfaction, damage other components/machinery	7	Vibration, wear of pin/metal sleeve, pin falls out	2	Design Calculations for forces on members	4	56	14	Overdesigned the pin to take the forces applied, (larger diameter)
Lifting arm	Link that connects hydraulic cylinder to the weight hooks	Component failure	Weight rack falls, causing it to drag along ground/falls off entirely, damage to hydraulic cylinder, customer dissatisfaction, damage other components/machinery	5	Vibration, wear, jarring,	2	Design Calculations for forces on members	5	50	10	Increased number of arms per weight hook to 2
Hydraulic Cylinder	Lifts/lovers weight from/to gound	Component failure	Weight rack falls causing it to drag along ground/falls off entirely, customer dissatisfaction, damage other components/machinery, weight doesn't lift	7	jarring of weight rack, piston bends, seals leak	2	Design Calculations for forces on member	2	28	14	Oversized cylinder capable of producing enough force to lift weight
		lost connection to lever in tractor	damage to hydraulic cylinder, weight rack falls	2	hydraulic line damage, input unplugged	2	output shown in tractor as inactive	1	4	4	
Locking Mechanism	Locks weight in place when lifted off the ground	Component failure	Weight not secure, weight rack falls causing damage to other components/machinery	3	pins not in position, weight rack not fully on hooks	4	N/A	3	36	12	Design weight rack to aligned properly on hooks
		Inability to lock	Weight unable to be secured, arms will not fully lock and lift weight	1	Debris in locking channel, locking arm deformed	4	N/A	5	20	4	Inspect locking channel before and after use

Appendix III – Full Page Component Drawings