Design of a Folding V-Scraper with Roller for Orchard Applications

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ABSTRACT

This senior project discusses the design of a folding 15 ft. wide leveler for orchard use. This design utilized a category 2 three-point hitch to connect the implement to a tractor. The folding mechanism uses the tractor's hydraulic system to actuate the folding movement using hydraulic cylinders. The blades, when wings in operational position, are rigid with one another after some assembly. When the implement is folded the width is reduced to nine feet.
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INTRODUCTION

Almond harvest is one of the most important times for an almond farmer. One almond harvest season consists of many steps to complete the actual harvesting of the almonds. One of the more important steps is shaking the almond tree. This step drops almost all the almonds on the ground. Once the almonds are on the ground they are ready for the next step, which is to be swept into windrows using a sweeper machine.

For these two steps to be successful, without losing any nuts, the ground of the orchard row must be properly prepared. The weeds in the row must be tilled under or mowed short. All the potholes and gopher holes must be filled in. The overall shape of the soil in the row should be level and flat. All of these row management practices should be done to minimize loss of nuts in the shaking and sweeping steps.

Currently, Ulrich Farms is using an implement called an orchard float, seen in Figure 1, to accomplish this pre-harvest row preparation. The orchard float has blades in an “x” orientation and has a large roller on the back. It uses the blades to push the soil inward then outward all in the same pass spreading the soil around in one pass filling in the low spots and cutting the high spots.

![Figure 1. Ulrich Farms Current Float.](image)

One main downside to this current float is that it is only 8ft wide. The almond row spacing at Ulrich Farms is 20ft. To make a complete pass down one row the float must go on both sides. Sometimes though, if there is a big hole or rut, another
pass must be done to sufficiently fill it in. This could add up to a total of 4 passes to complete one row or even more if conditions are bad.

Ulrich farms would have liked to purchase a wider float but most commercially available floats are too wide to be safely transported down a public road. This limits the width to what they have now. A wider float would result in half the necessary passes because the float would be able to cover the whole row.

The objective of this senior project was to design a wide enough float that can fold into a smaller width when it needs to be transported. The working width of 15ft was proposed by Ulrich Farms, with a transport width of 8ft. The float had to be able to connect to the Ulrich Farm’s current tractor, a New Holland T4.105 which has a category 2 three-point hitch.
A search was conducted to find any x-blade configuration float that folds into a more compact configuration. No such implement has been found. There are similar implements that use components that would be necessary to create a folding ground leveler.

Sweco and T.G. Schmeiser are both companies that produce orchard implements. T.G. Schmeiser sells a V-blade leveler, Figure 2, that can be purchased in widths from 8 to 18 feet.

There are two versions of their V-blade leveler, one with a roller in the back and one without a roller. According to the website, the roller allows for less dirt build up at the end of each row by not allowing soil to continuously build up in front of it. This releases soil under and behind the roller instead of capturing all the cut soil and dragging it to the end of each row. T.G. Schmeiser also provides a picture of how their V-blade leveler moves the dirt in the row when in use. This is pictured in Figure 3 (T. G. Schmeiser Equipment, 2015).
The soil, in Figure 3, starts out not level before the leveler is pulled over it. The first two blades move the outer soil towards the center, filling in any holes and cutting any high points. This is done again with the last two blades but pushing the excess soil back out towards the center filling in any more holes and cutting more high spots that were missed. This leaves the soil after the leveler level and compact.

Sweco also offers a version of an orchard leveler called an Angle Blade Scraper, Figure 4. This piece of equipment is offered in widths from 8 to 16 feet, also with no compact folding configurations. This implement has a very similar design to Schmeiser’s V-blade lever without the roller (Sweco Products, 2015).
Sweco does have an implement that folds into a more compact configuration. This is a disc implement called the 610-W Wing Disc, Figure 5.

This is an 18 to 27 foot wide field disc. This implement has wings that fold up hydraulically to allow the disc to become compact enough to travel down the road. Each wing, containing two rows of discs so four wings total, has its own hydraulic cylinder and is locked into place with a locking pin. The hinge mechanism looks more complicated than a standard hinge. There appears to be 3 pivot points on the part that is connected to the Hydraulic cylinder. The hinge connecting the wing seems to be a separate piece (Sweco Products, 2015).

The hinge mechanism in Figure 5 appears to be similar to a hinge found on an implement that was seen on a field in Wasco, California, pictured in Figure 6.
The hinge in Figure 6 looks like it is a great hinge for using the hydraulic cylinder's force to keep the wing locked in the down position while running. Although it is very complicated something similar to this would be great in an implement where the down position always needs to be locked in the same position while being used.

On the account that no design for a folding x blade configuration float could be found another search was conducted to find any related information, data, or parts, to assist in the design of such an implement.

**Three-Point Hitch**

The implement must be attached to a medium sized tractor. Information of the tractors are critical for a good design. Two tractor manufacturers were used to gather information about the possible tractors this implement would be attached to. Kubota provides a medium sized tractor called the M100GX. This tractor is a common orchard tractor and would be able to handle the weight of such an implement. Specifications required of the tractor are hydraulic, hitch, and power details. (Kubota Tractor Company, 2015) New Holland also provides a commonly used orchard tractor which is the T4.105 (New Holland Equipment, 2015). Both of these tractors are equipped with a category 2 three-point hitch. The T4.105 can handle 5,620 lbs 24 inches out from the lower pin. (New Holland Equipment, 2015)
ASABE provides the standard measurements for all categories of three-point hitches. It also has a list of proper terminology for each part of a three-point hitch. The measurements for a category 2 three-point hitch are used in the design to meet the American standards. Figure 7 shows a standard three-point hitch configuration.

![Figure 7. A Standard three-point hitch configuration](image)

Efficiency and power relation on three-point hitches is located in 3 sources. Portes (2013), Bentaher (2008), and Molari (2014) all provide information of the three-point hitch. Portes (2013) provides information of power savings that is related to the three-point hitch. This is related to Molari (2014). Molari (2014) provides information on how to design a three-point hitch system that will maximize lifting performance. Both mention how important the location of where the three-point mounting points are on the implement. Mostly how important of where it is placed in the vertical axis of the implement. The horizontal axis is not as important because the placement there is most likely going to be centered. Depending on what the implement is designed to do, they determined the best position for the three-point hitch based on location of center of gravity and what kind of forces will be acting on the implement itself. Bentaher (2008) provides information on the relation of tractor and implement while using a three-point hitch. This also provides efficiency information but is based purely on the forces applied at the three-point hitch during operation.
Hydraulics

Because the implement may have wings that power fold a search was done to find information on plausible systems that could be used to lift the wings.

If hydraulic rams were to be used the New Holland T4.105 produces 16.9 gpm of flow with its hydraulic system (New Holland Equipment, 2015).

Stepanek (1995) provides information on how implements using hydraulics should be connected to a tractor. It gives different limits on the different categories of tractors. The category II tractor information is what was mostly used as the tractor that this implement is meant for is a category II.

The Industrial Hydraulics Manual gives information on hydraulic parts such as motors and rams. This book provides all the equations and standards needed to properly design a hydraulic circuit. (Eaton, 2010)

These sources used together are great for designing a system using the hydraulic pressure provided from the tractor. Knowing the properties of hydraulic rams and the available pressure, a sufficient hydraulic wing lifting mechanism can be designed.

Frame Design

ASCE provides strength information for most common types of structural steel components. Because this implement is made out of steel this source was used to test the stress characteristics in certain members. Most of the implements seen utilize rectangular tubing or channel.

Budynas (2011) provides similar information, in that it gives the stress characteristics of welds and bolts and other fasteners. These two sources together provide sufficient information to properly design the frame of this implement.
Frame Design

Frame Member Layout. The frame is the main connection between the tractor, providing power, and the blades, applying that power to the soil. The frame must have been sturdy enough to support not only the weight of the blades, roller, and other mechanisms but also handle the force the soil will be applying to the blades. The frame needed to be laid out properly so that the blades will be able to connect to the frame. Also, the frame had to be able to fold for transportation but also become rigid when in unfolded and in use.

As can be seen in Figure 1 above, the frame is designed to spread out the forces that the three-point hitch is imparting on the implement. This triangular design also provides many locations for the blades to connect. The middle section front triangular members don’t meet up in the middle. The spot they meet up is where the lower connections of the three-point hitch will be located. This allows the beam, that the three-point hitch is connected to, to be more stable.

The frame is split into three sections to fold. The middle section is stationary because it is what is connected to the tractor and the two outer sections fold up into the middle. When the whole frame is unfolded it is 15.5ft wide. When the frame is folded it is 9ft wide. This meets the requirement of being able to safely transport this implement down a public road.
All frame members except those attached to the three-point hitch mounts are made up of 4x2x0.188 inch rectangular tubing. The members attached to the three-point hitch mounts are 4x2x0.25 inch rectangular tubing. Because of the added stress on these members they had to be more thick to not yield. All other members are smaller because they do not see as much stress and helps make the implement lighter.

**Three-Point Hitch Placement on Frame.** The three-point hitch connects the frame to the tractor. The location of the three-point hitch is important for good force transfer from the tractor to the implement. It’s also important to be sure the three-point is located properly to allow for full range of motion in the three-point so the implement can be set at the proper height while in use or being transported. The three-point is connected to the frame by uprights that come off of the main frame, as can be seen in Figure 9. There are supports that are connected to this upright to help transfer the torque that is applied to the upright more towards the center and rear of the implement.

![Figure 9. Three-point hitch location.](image)

As can be seen above there are plates that the pieces with the holes weld to instead of just being welded straight to the frame. These plates are there to assist in the tear out force that the member would have on the frames 2x4. With the three point members welded to this 3/8 inch plate, it helps spread out the welds on the frame member which also spreads out the force on the frame
member. Spreading out this force will not allow these three-point attachment pieces not come off under their operational loading conditions.

The bottom links are angled up to allow for the upper and lower three-point arms coming from the tractor to be in a position optimizing the force applied from the tractor to the implement. It is important for the vertical plane of the three-point hitch to remain as vertical as it can while in use. This helps to not waste any force that the three-point system applies. (Molari, Mattetti, & Guarnieri, 2014)

**Side Panels.** Welded to the side of each wing are side panels. The side panels are quarter inch thick and 15 inches high. These side panels run the whole length of the frame and more. They offer connections to the outside edges of the blades as well as the outer rollers. Because this side panel is welded to the frame it is made shorter than the ground surface. This is so that it will not wear, instead there is a runner at the base that is the same thickness that is four inches tall. This runner hangs down past the bottom edge of the side panel and will be at about the same level as the bottom of the blades. As seen in figure 10, this runner is adjustable so when it wears down it can be lowered to remain at the level of the blades. The two holes in the front and in the back are where the blades connect on the inside of the panel. The slot in the back, open on the bottom, is for the rear roller and its shaft to go through.

![Figure 10. Side panel.](image)

There is also a sliding door on the rear of the side panel. This door can be slightly raised or removed to allow for dirt to exit out of the rear blades instead of having the dirt contained within the implement the whole time. This helps when the rows have a lot of weeds. When weeds go under the rear blades and the rollers they make holes and groves. Instead, when the doors on the side panels are raised or removed the weeds can escape without causing too many ruts. Below in figure 11 the door is removed exposing the rear blade.
Blade Design

Blade Location. The blades connect to the frame and have a special sharpened cutter attached to them. They are the main piece in contact with the soil. The angle at which the blades are located is important. With an angle that is too perpendicular to the direction of travel with the tractor, the soil will not move left or right instead just get pushed forward like a scraper. The blades were set at an angle of 24 degrees. A higher angle would be more desired, but that could not be achieved due to the weight limitation. The gap between the two front blades needs to be big enough for all the dirt being moved towards the center to travel through to the back blades. The gap was set to be three feet, as seen in figure 12.
The blades in the front of the implement stick out of the frame towards the tractor. This was done to maximize the angle of the blades without causing the center of gravity to move to far away from the rear of the tractor.

**Blade Connection.** The blade connection to the frame is very important to the actual functionality of the implement. The way the blades are connected needs to be very rigid so the blades do not flex or chatter as they scrape the soil. Also as time goes by the blades eventually wear and don’t cut as deep. This creates a non-level finish in the row after the implement is used. To fix this the blades need to be able to be adjustable.

The blades on this design have two type of connections. First, on the far outside blades there is a plate welded to the back of the blades that has slotted holes on it. Those are attached to the side panels welded to the left and right edges of the frame. As seen in figure 13, the slots are 5/8in in size and allow 1.75 inches of movement up and down.
The second type of connection is used in the middle of the frame to connect the blades to the frame. This connection uses two components, a hinge-like rear horizontal support and a vertical adjustable support.
Figures 14 and 15 show the two components. The vertical component is made of 1 inch all thread. This will offer blade height adjustments using a nut above and below the angle piece attaching it to the frame member. The horizontal round stock connected to the all thread rod is fitted into a hole of a plate welded to the back of the blade. The round stock has a pin in the end of it so that it does not slip out of the fitted hole. The horizontal support, figure 14, has a 20 inch lever arm and is made of 3/8 inch thick 3 inch bar. That is connected to a 3/8 inch thick drop down piece that welds to a frame member. The drop down piece and the three inch bar must be hinged at their connection to allow for the vertical adjustments of the blade. The opposite end of the three inch bar is welded to a plate that is welded to the back of the blade.
Figure 16 shows that there are multiple locations for both horizontal and vertical supports on both blades. Because the blades split when the wings are folded up, they must be supported near the split location as well as the outside edges.

**Separate Blade Design.** The blades are made up of schedule 40, 20 inch diameter steel pipe cut into a six inch segment. Each blade on the wings and center are separate but when the wings are folded down they are connected together by a plate welded to the end of each blade where the split it. When the blades come together those plates are bolted together to make the two separate blade pieces one rigid piece, as shown in figure 17.
Welded to the back of the length of each blade is a piece of 2x2x0.125 inch angle iron. This is added to help the blades be more rigid. Blades without the angle iron are strong enough to move dirt but in the occasional chance that a blade comes in contact with a large buried rock it can bend the blade very easy because of the sudden point load. The angle is added to help prevent that bending. The cutters attached to the bottom of each blade come in many different thicknesses and variations. The one chosen for this application is a four inch tall, half inch thick, cutter. The cutter is sharpened to a point on one end of the length. This is the side that goes down and cuts the dirt. Shown below in figures 18 and 19 are the front and back views of a blade assembly.
In the middle of the frame, in front of where the rear blades start, is a small blade. Because where the rear blades come together there is a gap between the cutters that are bolted on, shown in figure 20.

To fix this a small adjustable blade is set just in front of it. This blade uses the same blade cutters that are on the long blades. Because these blade cutters are much shorter they will be able to be welded together easily and bolted on to the attachment. Figure 21 shows the small blade.
Roller Design

The rollers in the back of this implement are the final step that the soil goes through. They slightly compact the soil leaving a smooth level finish. The rollers, unlike the blades, do not come together. There are three separate rollers: one attached to each wing and one attached to the middle section of the frame. The rollers attached to the wing fold up with the wing when it is folded up in the transport position. The roller in the middle sits under the frame and is wider than the middle frame width. This allows the workable width of the middle roller to overlap with the workable width of both side rollers. Doing this ensures that all soil within the fifteen feet workable width of the implement will be rolled by the rollers. Figure 22 shows the layout of the rollers.
Because the roller in the middle had to be under the frame, the roller diameter was limited to eight inches. The material used to make the rollers was eight-inch schedule 40 steel pipe. The rollers are attached to a shaft that goes through the whole roller and attaches to bearings on each end. Plates with a hole in the center connect the shaft to the roller. The plates act as a rim holding the roller in place. The two outside rollers only have these plates on the end, but the middle roller also has one in the middle to help stabilize the extra length of the longer roller and shaft. In figure 23 below, the end of a roller assembly is shown.

Because the rollers on the wings stick out, there is danger of running them into another object when backing up. The shaft was sized based on this worst case
scenario, knowing that sizing the shaft for this situation would over design it for its true use. Based on the calculations shown in Appendix B, the shaft is one and a quarter inch in diameter and it would be able to handle an impact to the center of the roller at about 10 miles per hour without damage to the shaft. This was considered sufficient.

For the outside rollers the bearings that hold onto the shaft on either end are connected to a member that is welded to the wing frame. On the outside of the wing the bearing is bolted to the long side panel, shown in figure 24. The other side is bolted to a half inch piece of steel welded to the wing frame, shown in figure 25.

Figure 24. Roller bearing bolted to side panel.
The bearings are on the inside of the attachment pieces to minimize the bending load seen on the bearing from the shaft. It was important to get the bearings as close to the plate connecting the shaft and the roller. The total distance from the plate to the bearing is a quarter of an inch. The bearings are bolted to the mounting members using slots to allow the rollers to be adjusted up or down depending on the user’s preference. When the wing is folded down and in operating position the inside mounting members act as a bumper in between the wing frame and the center frame. An eighth inch shim is tack welded to this member where the frame hits to allow the shim to be worn down over time and easily replaced. Because this is attached to the back of the gap between the wing frame and the center frame, there were two more bumpers attached to the center and front of this gap, both also being a half inch plate with a tacked eighth inch plate to it. The roller on the other wing is attached the exact same way.

The middle roller is attached similarly, as the bearing is attached to a plate that is connected to the middle frame. Except because the middle roller is wider than the middle frame the attachments had to be wider than the points where it can be welded. Shown below in figure 26, is the attachment piece that middle roller bearings are attached to.
The attachment piece is bumped out three and a half inches to allow for the bearing to be on the inside and also so the roller could overlap the outside rollers by one inch on each side. Like the outer roller attachments, this attachment also has an eighth inch shim to be easily replaced. The middle roller is attached the same way on the other side.

**Folding Mechanism Design**

Folding the wings for transportation needs to be both a simple and quick process. The only bolts that need to be removed are the ones connecting the blades together, a total of eight bolts. The tractors hydraulics will be used to control two hydraulic cylinders, one for each wing. These cylinders are three inch bore with a 24 inch stroke. The hydraulic cylinders are connected to an attachment piece on the wing and the middle frame, as shown below in figure 27.
The middle mounting plate is a one inch plate that connects both cylinders. It is welded to the middle beam of the middle frame. One inch pins connect the cylinder to the plate. The rod is connected to a half inch plate with a one inch pin. This connector on the wing is welded to a 3/8 inch plate, this plate helps spread the welds across the beam it is welded to in the wing frame. The max force required is when the wing is down in the operational position and just starts to fold up. The weight of one wing is under 700 pounds, but is assumed to get up to 700 hundred pounds accounting for dirt that cakes on the implement. The max psi required in the cylinder to initiate this movement is 2323PSI, while the max psi the cylinder can handle is 3000. Calculations are shown in appendix b.

Shown below, in figure 28, is the maximum that the frame wings can fold. This is ideal because the frame wings do not protrude too high up in the air as well as not stick out over the sides of the required travel width.
Located on each hinge are stops for when the wings are being folded up into transport mode. The operator will fold the wings until the hinge hits the stop. This will ensure that the wings will not be folded too far causing possible damage to the frame.

**Notable Repair Points**

Certain items on this design are going to need to be replaced or need routine maintenance. The roller bearings were mounted to allow for easy greasing. All grease zerks are pointed toward the rear of the implement for easy access. The bolts mounting the roller bearings are on the outside of the mounting plate with the nuts toward the roller. The nut isn’t inside of the roller making it easy for a wrench to reach it. Slots for the shaft on the mounting plate are cut all the way down to allow for the roller to be easily removed when a bearing needs to be changed.

As mentioned above the eighth inch shims in the gap between the wing frame and the middle frame will need to be replaced. It will only be tacked on making it easy to remove and replace.

Anything that comes in contact with the ground while this implement is in use, such as the blade cutters, will wear down. All of these parts are bolted on to allow...
for easy replacement. They are also attached to a slot so they can be easily adjusted in case they do not wear evenly. The rails that run along the bottom of the side panels are also reversible. If the front is wearing faster than the rear of the rail it can be flipped around to help the rail wear more even.
RESULTS

The implement will level a width of fifteen feet two inches of soil. It folds using the tractor’s hydraulic system for safer transportation. All blades, rollers, and wear points are adjustable. It contains a category two three-point hitch able to hook up to Ulrich Farm’s New Holland T4.105 tractor. Shown in table 1 are various lengths and weights of the implement.

Table 1 Lengths and weights of implement

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<td>Unfolded Width</td>
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<td>Folded Width</td>
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<tr>
<td>Workable Width</td>
<td>15 ft 2 inches</td>
</tr>
<tr>
<td>Wing Width</td>
<td>3 ft 8 inches</td>
</tr>
<tr>
<td>Total Weight</td>
<td>2630 pounds</td>
</tr>
<tr>
<td>Outside Roller Weight</td>
<td>121 pounds</td>
</tr>
<tr>
<td>Middle Roller Weight</td>
<td>292 pounds</td>
</tr>
</tbody>
</table>

All members on this design are mild steel except the bearings and the hydraulic cylinders. Figures 29, 30, and 31 show the final design of the implement.
Figure 29. Overall view of implement

Figure 30. Front view of implement
Figure 31. Top view of implement
This implement is very large and contains a lot of parts. It will be difficult to build due to all the large pieces. The side panels should prove a very difficult build because of all the holes and slots that must be put into such a large piece of steel. The weight of this implement is just under the three-point hitch maximum capability of the New Holland T4.105. If there is significant dirt build up on the implement when the user lifts it off the ground it may overload the three-point hitch. As long as the blades and rollers are adjusted correctly this implement should leave a smooth level finish on the soil.
This design weighs a lot. It should weigh less to put less strain on the tractor. If all the blades were brought forward a little more toward the tractor, then the frame could be shorter and the center of mass would be closer to the tractor making the torque smaller on the three-point hitch. If this implement did weigh less it would be recommended to make the frame member that the three-point hitch attaches to, a 4x4 of the same thickness. Although the 4x2 will withstand the forces put on it. Over time these implements see a lot of pounding and wear. With a 4x4 in that members place the implement would probably last longer as that member feels a lot of the stresses. If the person constructing this implement does not have access to a CNC cutter, like a plasma or laser, some components may be difficult to cut out. The shape of these components may have to change to accommodate a hand cutter for an easier cut.
REFERENCES

1. American Society of Agricultural and Biological Engineers. 2015. AD730: Agricultural wheeled tractors – Rear-mounted three-point linkage – Categories 1N, 1, 2N, 2, 3N, 3, 4N, and 4.


Appendix A

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR
HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

**Major Design Experience**

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes fundamental elements as outlined below. This project addresses these issues as follows.

**Establishment of Objectives and Criteria.** The objectives and criteria of Ulrich Farms was met within this design.

**Synthesis and Analysis.** Stress analysis and calculations on important components on this design were completed. Their findings aided in member size selection. Loading analysis on the tractor was also analyzed to help aid in the design process of this implement.

**Construction, Testing and Evaluation.** Solidworks finite element analysis was used to test certain members. Evaluation of the design was made using the information of the finite element analysis results.

**Incorporation of Applicable Engineering Standards.** All bending stresses meet the AISC standard for allowable bending stresses. The three-point hitch meets ASABE standards for category two-three point hitches.

**Capstone Design Experience**

The BRAE senior project is an engineering design project based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge/skills from these key courses.

- BRAE 129 Lab Skills/Safety
- BRAE 133 Engineering Graphics
- BRAE 151 AutoCAD
- BRAE 234 Mechanical Systems
- BRAE 421/422 Equipment Engineering
Design Parameters and Constraints

This project addresses a significant number of the categories of constraints listed below.

Physical. This implement is made of steel and has a workable width of fifteen feet two inches. It can connect to a New Holland T4.105 tractor and will fit on a gooseneck trailer.

Economic. Because this implement only needs to go down an orchard row once instead of twice with a narrower float, it will save diesel. It will also save labor cost because the time to finish an orchard will be cut in half.

Environmental. This implement is wide enough to level an orchard row in one pass as opposed to a narrower float. This means the tractor is running half the time as before. With the tractor running less time, there will be less total exhaust gas emitted.

Sustainability. When the float goes down the row, it is constantly cutting and mixing the soil. The weeds on the soil get mixed under after the float passes over. These die and turn into nutrients for the tree to use to grow.

Manufacturability. This implement was designed in a way to make it possible to mass produce. A lot of the material used for this design was attempted to stay the same throughout different areas of the design. For instance, most items that must be cut out of large sheet of steel were made to be 3/8 inch thick, making mass production easier.

Health and Safety. The implement has safety locks so when the wings are in the travel position they will not unexpectedly fall. The implement has many points where it can be properly chained to a trailer to safely travel down a public road.
**Ethical.** During the design of this implement calculations and decisions were made to determine the strength of this implement. All decisions were made to meet safety standards. Corners were not cut to save time or money while making these decisions.

**Social.** This implement will require the operator to have an elevated level in skill. The implement is relatively large and needs to be skillfully maneuvered. Also knowledge of hydraulic systems is required to properly hook and unhook this implement.

**Political.** This implement requires only one pass down an orchard row as opposed to multiple with a narrower float. In turn, this reduces fuel consumption and pollution. Lowering both are a political plus to using this implement.

**Aesthetic.** The overall look of the implement is streamline and functional with no members looking awkward or out of place. The implement can be easily spray painted to become aesthetically pleasing to the buyer.
APPENDIX B

DESIGN CALCULATIONS
DESIGN CALCULATIONS

Three-Point Hitch Calculations

Finding the force on each pin while implement is lifted off the ground:

Weight was added to implement weight assuming addition of hydraulic oil and dirt that stuck itself to the implement equaling 2700 pounds.

\[
\sum M_B = 0 \\
0 = T_x \cdot 24\text{in} - 2700\text{lbs} \cdot 48.2\text{in} \\
T_x = 5422.5\text{lbs} \\
\sum F_x = 0 \\
0 = 5422.5 + 2B_x \\
B_x = -2711.3\text{lbs} \\
T \cos(15^\circ) = 5422.5\text{lbs} \\
T = 5613.8\text{lbs} \\
T_y = 5613.8\text{lbs} \cdot \sin(15^\circ) \\
T_y = 1453.0\text{lbs}
\]

Figure 32. Three-point calculation drawing
\[ \sum F_y = 0 \]

\[ 0 = 2B_y - 2700lbs - 1453.0lbs \]

\[ B_y = 2076.5lbs \]

Tear out calculations on 3 point connections:

\[ P = T \]

\[ l = 2in \]

\[ t = .75in \]

\[ Tearout\ Stress = \frac{P}{2l + t} \]

\[ Tearout\ Stress = \frac{5613.8lbs}{2 \times 2in + .75in} \]

\[ Tearout\ Stress = 1871.3\ PSI \]

Finding the force on each pin while implement is in use on soil:

Draft Force:

\[ P = \frac{F(lbs) \times V(mph)}{375} \]

\[ \frac{375 \times P}{V} = F \]

\[ F = \frac{375 \times 115HP}{3mph} \]

\[ F = 14,375lbs \]
\[ \sum M_B = 0 \]
\[ 0 = T_x \times 24 in + 14375 lbs \times 16 in - 2630 lbs \times 48.5 in \]

\[ T_x = -4160.8 lbs \]
\[ \sum F_x = 0 \]
\[ 0 = 2B_x - 14375 lbs + (-4160.8 lbs) \]

\[ B_x = 9267.5 lbs \]

\[ T \cos(15^\circ) = 4160.8 lbs \]

\[ T = 4307.6 lbs \]

\[ T_y = 4307.6 lbs \times \sin(15^\circ) \]

\[ T_y = 1114.9 lbs \]
\[ \sum F_y = 0 \]
\[ 0 = 2B_y - 2700 lbs - 1114.9 lbs \]

\[ B_y = 1907.45 lbs \]

Tear out calculations on three-point connections:
\[ P = B_x \]
\[ l = 2 \text{in} \]
\[ t = .75 \text{in} \]

\[
\text{Tearout Stress} = \frac{P}{2 \times l \times t} 
\]

\[
\text{Tearout Stress} = \frac{9267.5 \text{lbs}}{2 \times 2 \text{in} \times .75 \text{in}} 
\]

\[
\text{Tearout Stress} = 3089.2 \text{ PSI} 
\]

**Middle Frame Front Member Selection.** The front member on the frame that is connected to the lower points of the three-point hitch sees all immediate loading. It sees the loading in the x direction by the draft force and in the y direction by the weight of the implement. A 4 x 2 x 0.25 member was initially chosen and calculations were done to determine if it will handle the loading it sees. Because the front member is supported by a cross member directly behind the location of the force, the force is supported like a truss and not just by the front member alone, shown below in figure 34. The first calculation done was to find the area moment of inertia of this truss.

![Figure 34. Frame members in question, orange arrows show loading](image-url)
X direction:
Max force on lower member from above calculations is Bx when draft force is present.

Area moment of inertia: All data in figure 35 was found using Solidworks.

Figure 35 shows the cross section of the truss under question.

\[
I = (1.53702in^4 + 2.589049in^2 \times (16.648822in)^2) + (1.286447in^4 + 2.018840in^2 \times (21.351178in)^2)
\]

\[
I = 1640.8in^4
\]

Stress on member = \( \frac{MC}{I} \)

Where,

\[
M = 9267.5lbs \times 30.25in = 280,342in lbs
\]

\[
C = 17.648822in
\]

\[
I = 1640.8in^4
\]
\[
\text{Stress} = \frac{280,342 \text{ in lbs} \times 17.648822 \text{ in}}{1640.8 \text{ in}^4}
\]
\[
\text{Stress} = 3015.4 \text{ PSI}
\]

Y direction:
The max Y direction force from calculations for lower pin force is without draft force included, By.

\[
B_y = 2076.5 \text{ lbs}
\]
\[
M = 2076.5 \text{ lbs} \times 30.25 \text{ in} = 62,814.1 \text{ in lbs}
\]
\[
C = 2 \text{ in}
\]
\[
I = 4.694295 \text{ in}^4
\]
\[
\text{Stress} = \frac{62,814.1 \text{ in lbs} + 2 \text{ in}}{4.694295 \text{ in}^4}
\]
\[
\text{Stress} = 26,761.8 \text{ PSI}
\]

**Wing Frame and Hydraulic Cylinder Calculations**

Calculations were done to size the hydraulic cylinder necessary to lift the wing. Calculations were also done to determine the strength of the hinges.

**Hydraulic Cylinder Sizing.** Two calculations were done to figure the worst case scenarios for both folding and unfolding motions.

Folding Worst Case: The worst case is right when the cylinder begins the motion.
Figure 36. Worst case for initial lifting conditions, arrow shows force

Figure 37. Hydraulic cylinder and wing layout folding

$$\sum M_{hinge} = 0$$

$$0 = -700\text{lbs} \times 26.71\text{in} + F\sin(84^\circ) \times 2.5\text{in} - F\cos(84^\circ) \times 10\text{in}$$

$$F = 12,974.8\text{lbs}$$

Due to availability a 3" bore cylinder with a one and three eighths rod was selected and tested.
\[ \text{Cylinder Pressure} = \frac{12974.8\text{lbs}}{\pi \cdot 3^2} \times \frac{\pi \cdot 1.375^2}{4} \]

\[ \text{Cylinder Pressure} = 2323.7 \text{ PSI} \]

The max PSI posted by manufacturer is 3000PSI.

This cylinder will be tested for the unfolding motion:

Figure 38. Worst case for initial unfolding conditions, arrow shows force

Figure 39. Wing unfolding worst case
\[ \sum M_{\text{hinge}} = 0 \]

\[ 0 = -700\text{lbs} \times 25.54\text{in} + F \cos(5.55^\circ) \times 1.369\text{in} + F \sin(5.55^\circ) \times 10.72\text{in} \]

\[ F = 7366.6\text{lbs} \]

\[ \text{Cylinder Pressure} = \frac{7366.6\text{lbs}}{\pi \times 3\text{in}^2} \]

\[ \text{Cylinder Pressure} = 1042.2 \text{ PSI} \]

**Hydraulic Cylinder Wing Attachment.** The hydraulic cylinder wing attachment was tested for tear out and bending

![Figure 40. Wing attachment, arrow shows force](image)

**Bending Calculations:**

A force of 12974.8 pounds is applied to the pin hole on the wing attachment shown above in figure 40.

\[ M = 12,974.8\text{lbs} \times 5\text{in} = 64,874\text{in lbs} \]

\[ C = 7.5\text{in} \]

\[ I = \frac{0.5\text{in} \times (15\text{in})^3}{12} = 140\text{in}^4 \]
\[
Bending \ Stress = \frac{64.874 \text{in lbs} \times 7.5 \text{in}}{140\text{in}^4} \\
Bending \ Stress = 3,475.5 \text{ PSI}
\]

Tear Out Calculations:

\[
P = 12,974.8\text{lbs} \\
l = .85\text{in} \\
t = .5\text{in} \\
Tear \ out \ Stress = \frac{12,974.8\text{lbs}}{2 \times 0.85\text{in} \times 0.5\text{in}} \\
Tear \ out \ Stress = 15,264.5\text{PSI}
\]

**Wing Hinge Calculations.** Calculations were done on the wing hinge to analyze for pin shear, pin tear out, weld shear calculations, and bending if wing is impacted. Wing hinge is shown below in figure 41.

![Wing Hinge Diagram](image)

Figure 41. Wing hinge, arrow shows force

Bolt Shear Calculations: Worst case is when the wing is just beginning to lift.

\[
\sum F_x = 0
\]
\[ 0 = F - 12974.8 \text{lbs} \times \sin(84) \]
\[ F = 12928.8 \text{lbs} \]
\[ F = 2 \text{ bolts} \]
\[ F_{1 \text{bolt}} = 6464.4 \text{lbs} \]
\[ \text{Shear stress} = \frac{6464.4 \text{lbs}}{\pi \cdot \frac{12}{4}} \]
\[ \text{Shear Stress} = 8,230.7 \text{ PSI} \]

Pin tear out calculations:

\[ F = 6464.4 \text{lbs} \]
\[ l = 1 \text{in} \]
\[ t = .75 \text{in} \]
\[ \text{Tear out stress} = \frac{6464.4 \text{lbs}}{2 \cdot 1 \text{in} \cdot .75 \text{in}} \]
\[ \text{Tear out stress} = 4309.6 \text{ PSI} \]

Weld shear calculations:

\[ F = 12974.8 \text{lbs} \]
\[ F_{1 \text{hinge}} = 6487.4 \text{lbs} \]
\[ h = .25 \text{in} \]
\[ l = 6 \text{in} \]
\[ \text{Weld Shear} = \frac{6487.4 \text{lbs}}{2 \cdot (7.07 \cdot .25 \text{in} \cdot 10 \text{in})} \]
\[ \text{Weld Shear} = 1835.2 \text{ PSI} \]

Impact on wing calculations: Impact force is assumed to be similar to force when roller is impacted. Roller impact force used.

\[ \text{Impact force at 10mph} = 13079.8 \text{lbs} \]
\( M = 13079.8\text{lbs} \times 3\text{in} = 39,239\text{in lbs} \)
\( M_{\text{hinge}} = 19619.7\text{in lbs} \)
\( C = .375\text{in} \)
\( I = .351563\text{in}^4 \)
\[ Bending\ Stress = \frac{19619.7\text{lbs} \cdot .375\text{in}}{.351563\text{in}^4} \]
\[ Bending\ Stress = 20,927.7\ PSI \]

**Roller Calculations**

Roller shaft calculations were done assuming worst case scenario would not be during operation but if the roller impacted an immovable object, such as a pole or a tree. Energy was used to determine the force that the impact would have on the roller. It was assumed that 100% of the energy will be absorbed in the shaft although this is not likely in the real world. The calculations were modeled this way for simplicity and to determine the absolute worst case. After energy was used to determine the force applied, bending calculations were done from there to determine the stress on the shaft.

\[ E = \frac{1}{2}mv^2 = \frac{1}{2}kx^2 \]

Where,
\[ k = \frac{F}{\Delta} = \frac{3EI}{l^3} \]
\[ \Delta = \frac{Fd^3}{3EI} \]

Substitute and solve for F
\[ F = \left( \frac{mv^2l^3}{3EI} \times 3EI \right) / l^3 \]

Excel was used to easily substitute many variations of numbers. The numbers that yielded the best result were:

- \( m = \text{weight of tractor + weight of implement} \)
- \( m = 11006\text{lbf} = 341.8\text{lbm} \)
- \( v = 10\text{mph} = 176\text{in/sec} \)
- \( l = 44.75\text{in} \)
- \( E = 29000000\ PSI \)
\[ I = 0.119842in^4 \]

\[ F = 13079.8lbf \]

The gap between the bearing and the plate holding the shaft is a quarter of an inch.

\[ M = 13079.8lbs \times 0.25in = 3269.9in\ lbs \]

\[ C = 0.625in \]

\[ I = 0.11963in^4 \]

\[ \text{Bending stress on shaft} = \frac{3269.9in\ lbs \times 0.625in}{0.11963in^4} \]

\[ \text{Bending stress on shaft} = 17083.6\ PSI \]

\[ \text{Shear stress on shaft} = \frac{13079.8lbs}{1.227in^2} \]

\[ \text{Shear stress on shaft} = 10,658.3\ PSI \]
APPENDIX C

Solidworks Part Drawings