Design of a Large Tandem Disc Harrow with Minimum Transport Size

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Abstract

Production agriculture depends heavily on soil tillage as an effective means of removing excess biomass, eradicating weeds, easing planting tasks, and ultimately increasing the production efficiency of the land. As with any investment venture, the efficiency and effectiveness of such a task determines its feasibility and usefulness. Agronomists who need to till large acreages require implements suited for the task, and this has led to a growth in both tillage implement size and tractor power ratings. However, the product line for today's large implements is not yet complete. Only a handful of companies provide tandem disc harrows, an implement useful for chopping biomass, leveling soil, and preparing seedbeds, in the size ranges that today's tractors are capable of pulling. Furthermore, of the companies that do provide large disc harrows, the implements are hazardous to transport from field to field due to their large size. Western Plains Engineering of Stillwater, Oklahoma and Agri-Industries of Cordell, Oklahoma have combined knowledge and resources in an attempt to provide an easily transported and effective tandem disc harrow. Western Plains Engineering used structures such as bridges, overpasses, and overhead power transmission lines to define transport dimensions and considered agronomist demands to define field working widths for this project. The result of this effort is a tandem disc harrow that offers agronomists working widths of up to 42 feet but transport widths and heights of 17 feet and 13 feet, respectively. Each of these aspects, combined with the effectiveness of the tandem disc harrow itself, has not only satisfied Agri-Industries, the project sponsor, but has also impressed several agronomists during testing.

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Introduction

Primary tillage has been and continues to be a vital part of production agriculture for many producers around the world. Primary tillage, which is the tillage pass that cuts and shatters soil, is usually the most aggressive and deepest tillage pass that is performed during a season (Buckingham, 1984, pg. 4). This pass is important for the root growth and availability of nutrients for the plant, as well as important for the infiltration of rainwater into the soil.

A common tool often used for primary tillage as well as secondary tillage, or the subsequent tillage passes following primary tillage, is a disc harrow (Buckingham, 1984, pg. 5). The disc harrow utilizes concave discs to cut through and roll the soil and requires less draft than other tillage methods (Buckingham, 1984, pg. 22). This produces a much more desirable seedbed and less costs for the producer.

The senior design class of the Biosystems & Ag Engineering Department (BAE) at Oklahoma State University, under the direction of Dr. Paul Weckler, has led to the creation of Western Plains Engineering (WPE). WPE has been contacted to design a disc that can be used as a primary tillage tool throughout the Great Plains region.

Problem Definition

The tasks related to agricultural production has changed immensely over the last century, largely due to the invention of the diesel and gasoline powered tractor. Today's producers are able to successfully prepare, plant, and harvest literally thousands of acres with very little labor input when compared to the turn of the century, or even fifty years ago. However, this would be impossible if the rest of agriculture did not advance in parallel with the technology that drives the advancements in power production. As tractor power outputs grow, agricultural equipment manufacturers must produce larger and more efficient implements that utilize the full abilities of these tractors. This allows producers to expand their operations and increase production acres. These large acreage operations can increase profits for the producer by optimizing production and minimizing costly labor. In effect, this summarizes the mutual dependence that exists between farm size, technology, and implement design.

However, as implements grow in size, so does their folded transport size, but the surrounding environments in which producers must utilize the implement do not. This places a burden on the producer, requiring them to plan or alter routes to and from fields so that no obstacles are encountered and the tractor and implement can access the ground that must be tilled. Civil structures, such as bridges and highway overpasses, as well as field entry points, such as gates and ditch crossings, seem to limit the size of the implement that the producer can own and efficiently use, effectively regulating the size of the producer's operation.

Often, the only alternative to this situation is to plan inconvenient, out of the way routes to and from fields, wasting precious fuel and time and increasing hassles and dangers for surrounding communities. Another alternative to the situation that agronomists all too often incorporate is the use of implements which are of the correct size but incorrect construction for performing the task at hand. Implements intended for secondary tillage, which are less heavily built than primary tillage implements, are utilized in primary tillage because their light weight allows for simpler folded positions and smaller transport dimensions. This results in near misses for tillage depth goals and improper seedbed preparation, as well as increased implement wear and maintenance downtime. All of these shortcomings are costly to the producer and hinder the producer's efficiency.

Disc harrows, due to the necessity of a rigid shaft for the cutting blades to rotate upon, have historically utilized structural members, called sections, with large overall dimensions. This is a primary reason that transport widths and heights for these implements have not been able to attain dimensions small enough to be transported effectively. The large width of the sections on which the cutting discs hang produces a very large base when working in the field. This translates into a situation where the implement does not conform effectively to the land that the disc is tilling. Terraces and other changes in the terrain of the field cause the edges of the sections to cut deeply into the soil while the centers of the sections are pushed away from the soil. This results in skips throughout the field, or places where tillage was not performed effectively.

WPE feels that these situations can be alleviated through thoughtful and careful implement design. The problem which must be solved consists not only of producing a disc harrow which can be transported easily over existing roads and work effectively on large plots of land. The machine must be able to perform in the field as well as or better than other disc harrows—able to reach tillage depths equivalent to those needed for performing primary tillage. The implement should also require no more maintenance or servicing than that of other discs. Most important of all, however, the implement design should be as safe and reliable as possible.

Statement of Work

Agri-Industries, located in Cordell, OK, currently builds chisels and field cultivators and has been doing so since 1973. They produce the well-known Javorsky Culti-King® line of field cultivators. Their field cultivators range in widths from 3-section 21 ft. models to 5-section 54 ft. models to 7-section 80 ft. models. They currently provide quality tools at less cost to agriculture producers, sometimes at as little as half the cost of their competitors.

Agri-Industries is now investigating expansion of their product line to include large disc harrows. In the fall semester, the design team from Western Plains Engineering visited the factory in Cordell and met with their production manager, Jim Burrow.

After discussing several issues concerning the project, WPE and Agri-Industries determined that the project should consist of the conceptual design, construction, and testing of a large functional tandem disc harrow. This prototype disc should provide an alternative to the transport and tillage pass skipping problem. In addition, the prototype should also be both affordable for the consumer as well as economically feasible for Agri-Industries. WPE felt that providing these results, while demanding, would not be impossible and would fulfill the needs of both Agri-Industries as well as those of agricultural producers.

Product Research

Patent Research

The idea of turning over soil to both aerate and gain access to vital plant nutrients has been a staple of agriculture since as early as 6000 B.C.(Buckingham, 1984, pg. 8). Because of this long history, Western Plains Engineering found that many of the patents concerning tandem disc harrows and related components are well over 20 years old. However, of those patents that have not expired, some of the more notable ideas involve the use of ultra-high molecular weight (UHMW) polymers for wear protection on bearing surfaces, linkages for folding methods and depth adjustments, and disk gang arrangement. Most of the design features of a standard disc are simply common components that are not patentable.

Figure 1: Deere C-Spring

Figure 2: Krause C-Spring

The most important patent that our design team discovered was how the disc gangs are attached to the frame. Sunflower®, a well-known tillage tool manufacturer in Beloit, Kansas, has the patented C-flex™ design that allows for disc gang flexibility and also allows the gang to absorb shock loads due to impacts with rocks, stumps, and loads encountered during normal discing. Deere & Company have what they call a “C-Spring” design, shown in Figure 1, that is very similar to Sunflower’s®. The only visible difference is that Deere’s design has a smaller radius of curvature on their C-Spring. Krause, shown in Figure 2, and Case New Holland also have comparable designs, but with different radiuses of curvature and slightly different design. However, the general concepts of all three designs are very similar.

Because of the obvious benefits of the concept, such as extended bearing and disc life, WPE inquired about the ability to implement such a design into the prototype. Difficulty, however, was encountered in this area because of the cost of developing the forging process necessary for Agri-Industries to produce their own spring shank.

Market Research

Western Plains Engineering gained valuable market information through several channels, including willful cooperation from both tillage implement resale and manufacturing entities. Contact was made with several disc harrow manufacturers for nationally based market information while local resale contacts both verified and reinforced the information for the western Oklahoma area. WPE’s research concluded that a 35 to 36 ft. implement width was the most commonly sold tandem disc harrow both nationally and locally. The team felt that the market was saturated with discs of this size and smaller. However, WPE believes that there is a market demand for discs over 35 ft. Due to the fact that Agri-Industries is just entering the area of disc manufacturing, WPE feels that focusing on larger discs initially was wise.

A summary of the general specifications of competitors' discs with working widths of 35 ft. and greater is shown in Table 1. As the table shows, discs of 40 ft. and larger have transport widths of up to 22 ft. and transport heights of up to 19 ft. Other information is shown in the table, such as transport heights and widths, overall disc weights, and weight per blade. This information acted as a benchmark for WPE's prototype disc, so that a superior product could be produced. Following the table is Figure 3, which shows the different weight classifications for disc harrows.

Models	Width (ft)	Transport Width (ft)	Transport Height (ft)	Weight (lbs)	Weight per blade (lbs)	Blade dia. (in)	Sections	Gang Angle	Disc Spacing (in)
Big G 3040	40	NA	NA	21500	205	26	3	NA	9 or 10
Big G 5045	45	16.5	NA	26500	225	24	5	NA	9,9
Big G 5050	50	16.5	NA	27500	212	24	5	NA	9,9
Big G 5055	55	16.5	NA	28500	201	24	5	NA	9,9
Big G 5060	60	16.5	NA	29500	187	24	5	NA	9,9
Summer 9K3827	38.5	22	16	22853	243	26	3	19, 18	9,9 10,10
Summer 9K4427	44.5	22	19	25445	232	26	3	19, 18	9,9 10,10
Krause 2495	35.6	16	15.6	19393	206	24	3	NA	9,10
Krause 7400-41N	41.5	17.5	NA	23036	177	24	3	20, 17	8
Krause 7400-46N	45.5	21.5	NA	24298	171	24	3	20, 17	8
Krause 4995-46W	35.5	16	15.75	15522	158	24	3	19, 17	9,9
Howard 1200	39	9.8		33396	347	26	2	NA	NA
Sunflower 1544-42	42	22	14.5	27200	223	24	4	NA	8.75,8.75
Sunflower 1544-44	44.5	22	15.7	28975	223	24	4	NA	8.75,8.75
Sunflower 1444-40	40	19.75	15.3	23850	209	24	4	NA	8.5,8.5
John Deere 637	37.8	NA	NA	NA	NA	24	NA	NA	9,9

Table 1: Disc Model Comparison (Available Through Each Respective Manufacturers Market Data)

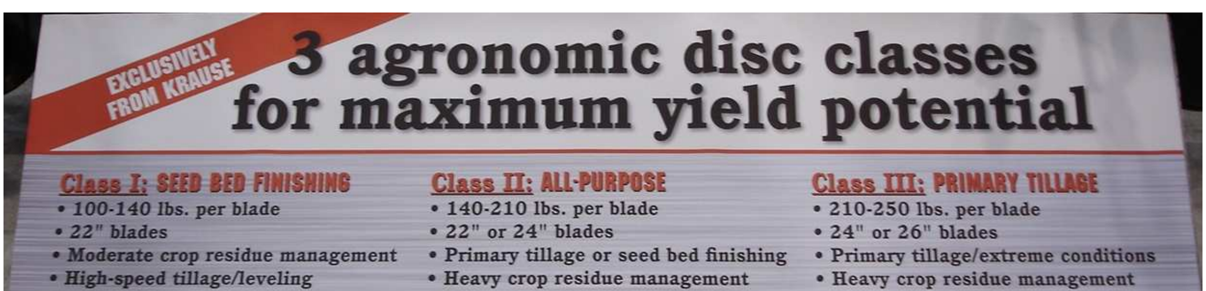


Figure 3: Disc Classifications As Defined By Krause Plow Corporation of Hutchinson, Kansas

Design Specifications

Once patent and market research was performed, WPE began to determine the specific criteria to which the end product must conform. After careful consideration and discussing the results with Agri-Industries, WPE finalized these criteria. The following are the results and are the goals for the disc harrow:

- The disc should be capable of being used as a primary tillage tool or "stubble disc" (>210 lbs/blade)
- The disc should have a working width of 40 ft. or greater.
- The disc should have a transport width of no more than 19 ft. and transport height of no more than 16 ft.
- The disc frame should be made as flexible as possible to follow uneven terrain and terraced fields
- Disc framework and components should be relatively similar for different size discs, so that the prototype could be scaled down to provide a model for smaller working widths
- The disc should perform as well as or better than competitors discs in the field

Attaining these specifications will provide Agri-Industries with an advantage in the tandem disc harrow market.

Design Development and Alternatives

With design specifications established, WPE proceeded to begin the design of the prototype through the use of Pro-Engineer, a three dimensional CAD modeling program. This tool allowed WPE to visualize and modify several different aspects of the design, both individually and as an integrated system. During this phase of the design, several alternative methods were tested and evaluated for their strengths and weaknesses. Some of the more important of these methods included the use of a three section versus a five section disc, wheel transport mechanism, a "drop hinge" versus a conventional pivot point for wing connection and fold-up, and alternative self leveling linkages.

Three-Section Layout versus Five-Section Layout

As discussed previously, today's conventional large disc designs have large transport dimensions. This can be attributed largely to the fact that the designs utilize three sections—a center section that is attached to the hitch combined with two outer sections that comprise the folding wings. An illustration of this design style can be seen in Figure 4. This does not allow much freedom in the final transport dimensions. For example, if the width

Figure 4: Three Section Disc

decreases, the height must increase in order to maintain field width, and vise versa.

During the design process, WPE analyzed this style of design as well as the use of a 5 section design. The 5 section design allowed the center section of the prototype to be narrowed with the excess length added to the wing sections. These wing sections were then each spit into two separate sections, allowing the wing to double over on itself, as can be seen in Figure 5. Using this style of design rather than the conventional 3 section style allowed WPE to narrow transport widths and decrease overall transport heights when compared to the 3 section. Because this characteristic was needed in order to meet one of the design specifications, the 5 section design was selected for development.

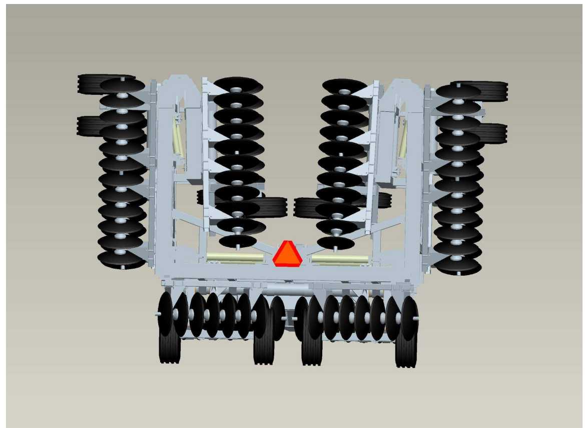


Figure 5: Five Section Disc

Wheel Transport Mechanism

One issue that created some concern with the design team was the number of tires needed on the center section for road transport. Standard designs usually contain four tires on the center section. WPE would like the prototype disc to weigh at least 27,000 lbs. This translates to 6,750 lbs. per tire on a typical four transport tire design. However, load ratings on standard large implement tires are approximately 4,200 lbs. per tire. This problem could be solved by simply adding more tires to the center section, but this obviously complicates the design and increases cost.

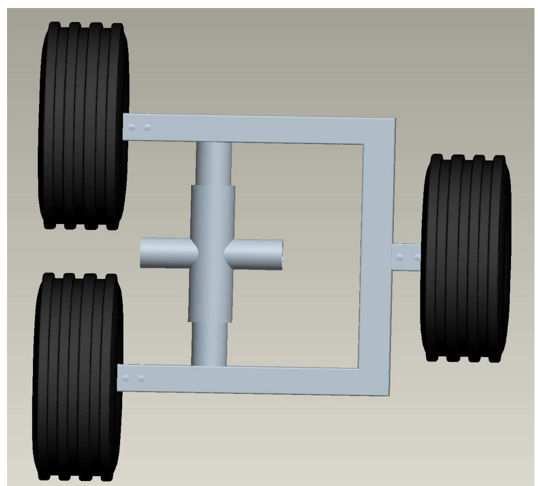


Figure 6: Center Section Walking Beam

WPE researched competitors' models and found it evident that many tillage tool manufacturers exceed these recommended load ratings on implement tires. WPE discussed this situation with Firestone® tire engineers and found that overloading tires in this manner, while possible, leads to increased tire wear and premature failure, something WPE obviously wants to avoid. To solve this problem, WPE proposed placing six tires on the center section. The team's design would allow for both front-to-back and side-to-side flexibility, thus keeping six tires on the ground at all times. WPE's design would also allow for equal weight distribution among the six tires. To carry the load, 11L-15FL Load Range F tires will be used, which are rated at 4000 lbs/tire. The proposed walking beam design can be seen in Figures 6. While this situation still overloads the center section tires, this overloading is a minimum 400 lbs rather than an outrageous 2500 lbs.

Drop Hinge versus Conventional Hinge

In order for a disc harrow to be effective, the discs must maintain contact with the ground at all times. This requires that the wing sections of the disc are able to float over terrain and do not remain rigid in reference to the center section. However, because of the dynamics of the hinge linkage used in a conventional hinge design, this movement is sometimes impaired due to the disc gang's shaft coming in contact with another gang's shaft. As the wing drops to conform to the curvature of a terrace or hill, a hinge with a pivot point that is not in the center of the gang shaft will cause the gang shafts to strike each other if the angle becomes too great.

In order to avoid this scenario, WPE analyzed a hinge design similar to the one shown in Figure 7. When compared to the hinge design shown in Figure 8, a dropped hinge design will allow much more degrees of floatation during field working. While this is a great advantage when working extremely uneven terrain, the added cost and complexity of such a design would be much too great to justify in normal field conditions. A conventional hinge

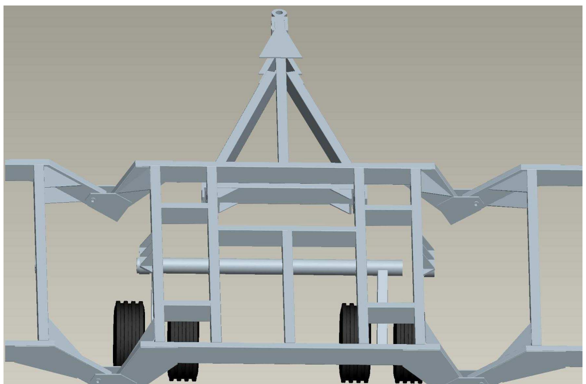


Figure 7: Drop Hinge Design

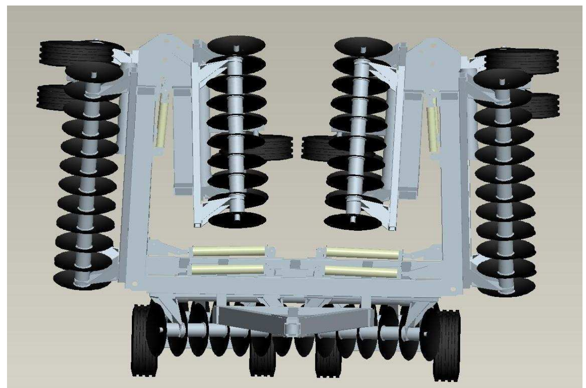


Figure 8: Conventional Hinge Design

design still allows 8 degrees of movement down, which is greater than that necessary to negotiate normal field curvatures. Therefore, WPE continued its design process with a concentration on the conventional hinge design.

Self Leveling Linkage Alternatives

WPE recognized that the prototype would not be used in the same soil type each time it was utilized and set out to create a method for dealing with differing soil conditions. When using the disc as a primary tillage tool, the front gangs require a variable amount of added force in order to cut into unpredictable hard and tough soils, while secondary tillage use demands level, balanced pulling scenarios due to the looseness of the soil. Several disc manufacturers address this problem by providing an adjustment mechanism that allows the user to transfer weight to and from the front gangs of discs.

In order to provide a competitive product for Agri-Industries, WPE felt that a similar mechanism should be incorporated into the prototype. WPE first determined that the mechanism should allow the user to move the hitch ten degrees to allow for weight transfer in the field, as well as allow the user to adjust the entire linkage itself to allow for different hitch heights on various tractors. An initial design idea can be seen in Figure 9. This design used a 4 inch stroking cylinder to adjust the weight on the front gangs and an adjustable length linkage to allow for varying hitch heights. However, after analyzing the linkage and its associated forces, WPE determined that the force that must be carried by the cylinder, approximately 10,000 pounds, was far too great to ensure acceptable design life.

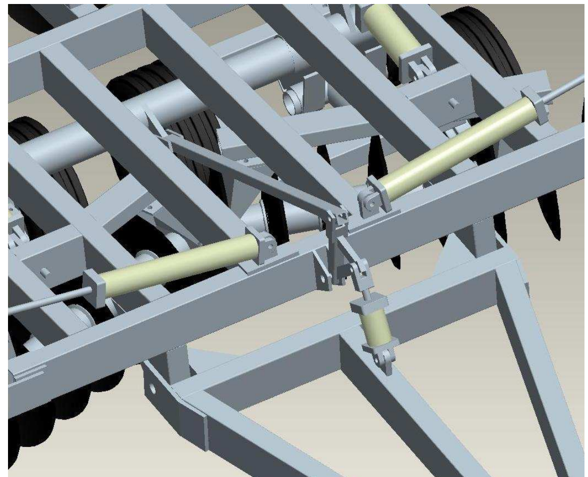


Figure 9: Self Leveling Linkage without Spring

The linkage was then redesigned to lower the forces encountered by the cylinder. WPE also took into consideration the impact loads and varying terrain which the prototype may encounter and responded to the issue by incorporating a spring mechanism to minimize the shock loads and allow the hitch to float when necessary. This linkage can be seen in Figure 10. Because this linkage was able to provide weight transfer with the added benefit of elongated life for several components, WPE proceeded to incorporate the alternative into the design.

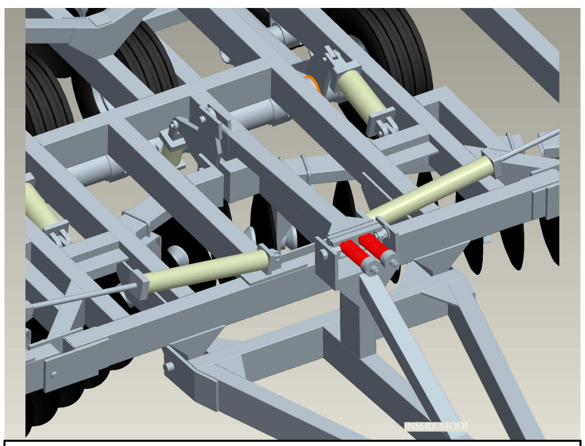


Figure 10: Self Leveling Linkage with Spring

Stress Analysis

During the design process, WPE felt it was necessary to calculate the strength of several critical pins, beams, and structures on the disc frame. WPE determined that assuring each of these components's integrity was paramount to the safety and life of the disc, and therefore spent a great deal of time analyzing several different aspects. Microsoft Excel spreadsheets were used to numerically determine structure sizes and dimensions needed for frame components, pins and collars, and lever arms, while finite element analysis (FEA) provided an in-depth look at stress concentrations.

To set the basis for the analysis, WPE utilized maximum forces generated by a 500 horsepower tractor traveling at 4.5 mph. This analysis differs greatly from one that incorporates the forces produced by working the soil in several aspects. While a soil based analysis would produce forces and reactions that are encountered in normal field work, WPE feels these forces create a false sense of security and do not take into account peak loads or loads due to stationary objects, such as large rocks and tree stumps which the disc may encounter. A tractor based analysis assures that the structure of the disc could fully withstand the forces that could bring a 500 hp tractor to a halt, which is the largest force that could be encountered. Three main scenarios of this type were performed, including straight line draft, an offset draft (so as to simulate the disc's wings hitting a stationary object in the field), and a turning draft.

A primary concern for safety includes the wing lock-up, which is the connection where the user can pin the primary wings in a safe position for transport. Figure 10 shows the location of one of these pins. WPE determined that this connection necessitated 1 ½ in. cold-rolled pins, producing a safety factor of 11.6 to insure integrity.

Another area concerning safety during transport as well as integrity in the field concerned the sizes of the pins that are used to hinge the primary wing. These pins can also be located in Figure 11. WPE used 1 ½ in. cold-rolled pins for this purpose as well, providing a safety factor of 6.3 and producing only 5,800 psi of shear-stress. Figure 12 shows the FEA analysis that was performed on the inner wing hinge using ProMechanica.

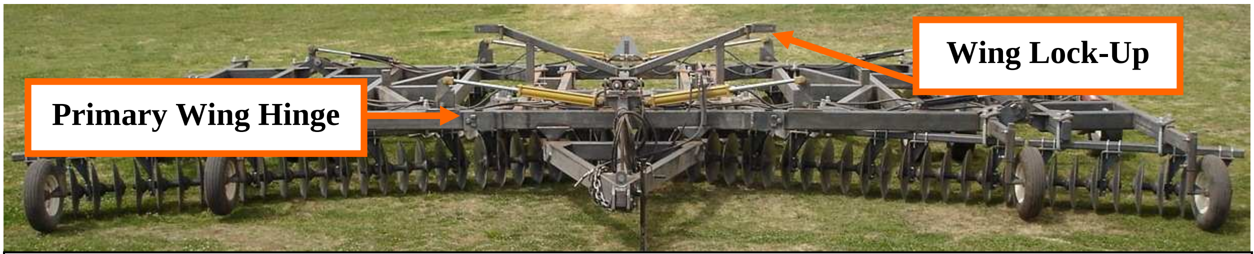


Figure 11: Primary Wing Hinge & Lock-Up Pins

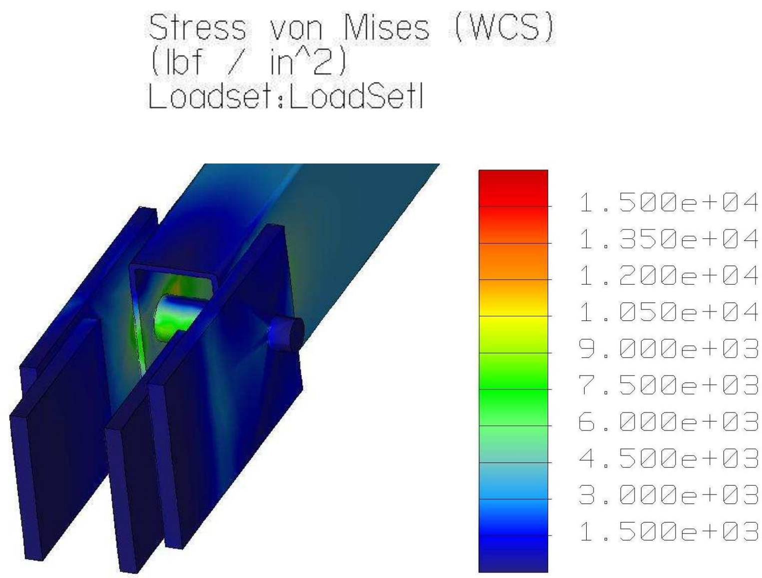


Figure 12: Primary Wing Hinge FEA

Design Testing

Once WPE finished fabricating the disc, several components of the disc needed to be verified and tested. Wing folding linkages and hinges were tested at the Biosystems and Agricultural Engineering Laboratory with a John Deere 8100, while gang angles, lift arms, and structural joints could only be tested through actual field testing. For this reason, WPE contacted several Stillwater, OK area farmers and agriculture equipment dealerships in search of land and tractors suitable for testing purposes.

Industry standard suggests 10 hp per foot for a primary tillage disc. Therefore, the design team sought out tractors that could be used for testing. Blackwell Equipment provided WPE with a 425 brake horsepower John Deere 9420 four wheel drive tractor while Warren CAT of Enid provided a 450 brake horsepower 855 CAT Challenger track style tractor. Both tractors were important for the verification of several different features. For example, the John Deere was equipped with 710 R42 metric tires which were used to verify that the disc's hitch was short enough to prevent a jackknife, while the CAT was used to verify compatibility with track style tractors. As an extra benefit, the 855 CAT was equipped with an engine monitoring system which was able to provide the percent load of the engine during working and transport operations. When being used as a secondary tillage tool approximately 3 inches deep, percent load ranged from 60-68%. However, when tested in a primary tillage pass approximately 5-6 in. deep, percent load ranged from 80-100%.

Several area farmers provided a variety of soil types for testing purposes. Land ranging from loose, cultivated ground to heavily compacted graze-out wheat was tilled according to each farmer's preference.

Figure 13: Folded Up Turning

On initial hook up, both tractors worked well with the design, with no interferences during turning while the implement was folded up. Once the disc was unfolded, both tractors were able to pivot the disc on the outside wing wheel during a turn without interference. Both of these aspects provide for ease of maneuverability in both transport and field working modes. See Figures 13 and 14.

Figure 14: Unfolded Turning

Loose, cultivated land was worked at 6-7 mph, while firmer, cultivated and graze-out land was tilled at 5-6. In both conditions, the disc performed well, leaving a smooth, un-ridged field. Ridging at the wings, which is a common occurrence for most heavy discs, was non-existent in both loose and firm fields. The center chisel shank left no noticeable ridge in loose fields but did produce a slight but noticeable valley in firm tilled ground when the disc was used at a depth greater than 4 inches.

After this testing phase, WPE determined that the performance of the disc was acceptable. Each of the agronomists who provided land for the testing conveyed their satisfaction in the job performed and noted how quickly the acreage was tilled. Overall, WPE felt that all goals concerning the performance of the disc in the field were met and surpassed.

Design Recommendations

During fabrication and testing, WPE found several design flaws that were not apparent during conceptual design. While each of these flaws was undesirable, they were not unexpected and could be easily corrected. In order to provide Agri-Industries with the best possible design, the design team feels that providing an alternative to these flaws will enhance the quality of the product.

Hinge Tolerances

During designing, WPE felt that allowing large tolerances for correct fit would prevent hassles during fabrication and assembly of the disc. As a result, several of the hinge points were designed with ½ to ¾ inch tolerances. WPE planned to fill these tolerances with washers to prevent slack in the wings. However, during fabrication, WPE found that the design of the hinge points for the primary wings required a large amount of welding in order to fill the gaps which were present. The excessive welding due to the large hinge tolerance can be seen in Figure 15. The result of such a design not only requires a large amount of filler metal and labor, but the area also showed visual signs of a large heat affected zone (HAZ). This zone frequently indicates an area of decreased strength due to excessive heat affecting the grain structure of the base metal, and therefore may affect the overall integrity of the frame. WPE feels that this scenario can be avoided by simply reducing the tolerances in each hinge point.

The current design uses a ¾ inch plate as a spacing plate between the frame member and the hinge plate. Reducing this spacing plate to a ¼ inch dimension rather than ¾ inch would greatly reduce the necessary welding time and materials, as well as limiting the extent of the HAZ.

Figure 15: Hinge Tolerance

Gang Shaft Material

During the design phase, WPE recognized that the internal forces that can be found on the gang shaft can become quite large and specified cold-worked, 1 ¾ inch shaft for this component. Because no disc blades are currently manufactured with center holes larger than this size, this design made the assembly as structurally stable as economically possible. However, when the material was ordered, a failure in communication produced hot-rolled rather than the specified ANSI 1020 cold worked shaft. WPE immediately recognized the mix up, but, due to time constraints, were forced to continue fabrication with the hot rolled material.

While testing was successful with the hot rolled shaft, threading of the shaft was extremely troublesome due to soft and hard spots found in hot rolled material, and the gang shaft castle nuts had to be frequently retightened as the shaft stretched due to over-stressing. Although WPE recognizes that this situation was unavoidable, we would like to stress that hot-rolled shaft would not be recommended in the production models.

Gang Shaft Thread Specifications

After initial design of the disc, WPE proceeded to locate materials for the construction of the disc. In order to provide the best possible estimation of costs, WPE concentrated on using Agri-Industries current vendors. However, the current vendor of hardware for Agri-Industries does not stock 1 ¾ inch UNC castle nuts, which were specified for the gang assembly. While this proved inconvenient for the specified design, WPE was able to obtain fine thread castle nuts from the vendor, and felt that this modification in design for the prototype would not significantly impact testing results. Therefore, the fine thread nuts were used in the final assembly.

During construction, however, WPE encountered several problems while cutting the thread on the 1 ¾ inch gang shaft as well as during assembly of the gangs. These problems included easily stripped threads, cross-threaded nuts, and over- and under-tightening, as well as the added effort required to properly tighten fine threaded shafts. In order to eliminate these hassles and inconveniences, WPE would like to recommend that Agri-Industries locate and obtain course threaded castle nuts and shafts for the production design.

Collar Design

While designing the secondary wing, WPE placed collars over the hinge pin with the intention of minimizing the wear on hinge pins during fold-up. During fold-up, the lever arm of the hinge contacts the surface of this collar and uses it as a fulcrum. The collar can be seen in Figure 16. However, once the full weight of the disc gangs were added to the wings at final assembly, the thin wall of the tubing was not thick enough to prevent the deformation of the collar, causing the pin to bind inside of the collar. As a result of this binding action, not only does wear on the pin increase but removal of the pin is also difficult.

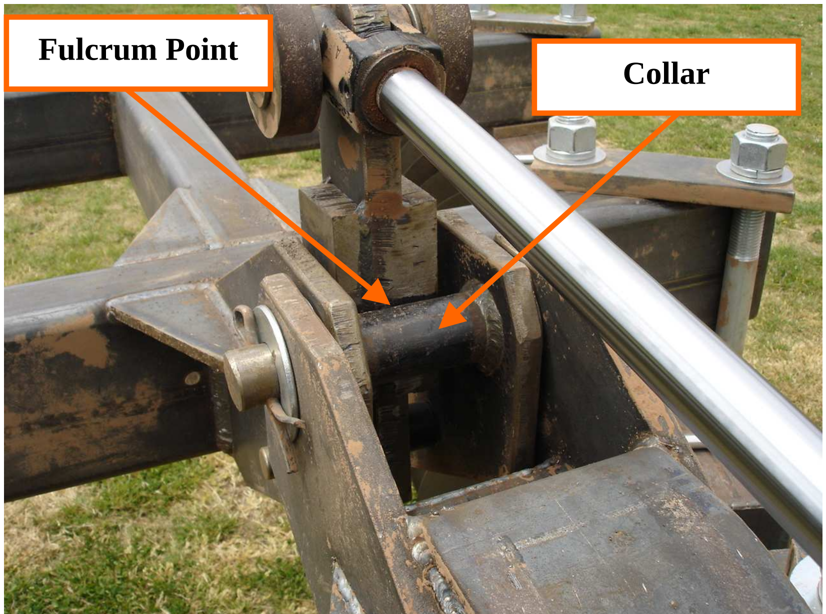


Figure 16: Outer Wing Hinge Collar

This current collar specification calls for nominal pipe with ¼ inch wall thickness in order to eliminate extra material and machining costs. In order to correct the situation, WPE recommends Agri-Industries use machined collar material with ½ inch wall thickness rather than the current material.

Sequencing

Also during secondary wing fold-up, WPE observed the primary wing began lifting before the secondary wing was fully folded. While this scenario is not detrimental to the functionality of the disc, WPE feels that a sequenced fold up would greatly enhance the aesthetic qualities of the disc. This problem resulted from discrepancies in estimated weight during the design process and the actual weight once fabricated, and was not expected at the time of design. First, the disc spools that were received were heavier than previous estimates. Since there are roughly 120 spools on the disc, this added considerable weight to the disc. Second, one disc and one spool were added to each rear, outside gang to ensure that the front, outer gangs did not leave a ridge in the field.

WPE feels that this flaw can be corrected by using 3 ½ inch cylinders to pull the aforementioned lever arms rather than the current 3 inch cylinders. This increase in cylinder size would ensure enough force to completely fold the secondary wing before pressures were high enough to begin folding the primary wing.

Rockshaft Cylinder Base Arms

The design of the disc allows the user to adjust each cylinder's initial placement in order to level the frame when lifted to its full unfolded height. The method which WPE used to accomplish this incorporates threaded shaft through a collar on a frame member. While this method proved successful when the disc is in normal working conditions, an instance where the secondary wings were folded to reduce width caused one of the threaded shafts to fail. The failure occurred due to the extreme stress induced by the extra weight of the outer wing folded onto the inner wing. Once the part was inspected, WPE determined that the threaded shaft which was ordered as SAE grade-5 material was mistakenly replaced with lower grade material. The failure point can be seen in Figure 17.

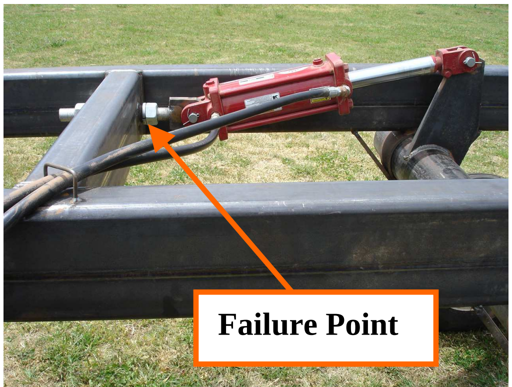


Figure 17: Lift Cylinder Adjustment

While the situation in which the shaft failed was not the intended method for use, WPE feels that the structural integrity of such parts are a priority and would like to provide two recommendations for its redesign. An initial solution would be to replace the lower grade shaft with stronger SAE grade-5 material. This would allow the shaft to sustain the stresses which could be encountered in such a situation. A secondary solution would be to modify the placement of the shaft and collar on the frame member so that the cylinder forces react axially on the shaft.

Cost Analysis

WPE recognizes that the cost of an implement is often the deciding factor concerning both whether or not a producer will purchase the machine and whether or not the manufacturer can make the venture work economically. Therefore, WPE also performed a cost analysis over the construction of the prototype and projected cost estimates for producing the disc harrow in volume.

Proposed Budget

The proposed budget for the prototype disc is shown in Table 2. These prices were obtained from vendors that Agri-Industuries used for the project. Highlighted values indicate estimated values that could not be obtained. Miscellaneous items not included in this budget contain but are not limited to: ½ in. plate, ¾ in. plate, 1in. plate, 1 ½ in. plate, 1 ¼ in. pins, 1 ½ in. pins, 2 in. pins, rockshaft sleeving, 1 ¾ in. gang shaft, and the material needed for the center section walking-beams. The amount of these materials needed and the cost for these materials was not known at the time of estimation. However, the cost of these materials was expected to be relatively low compared to the rest of the disc material. Overall, WPE did not expect the total cost of materials to exceed $28,000.

Item	Unit Price	# Units	Cost
4x8 1/4" wall tubing (ft)	$11.78	291.5	$3,433.87
4x8 3/8" wall tubing (ft)	$14.00	128.7	$1,801.80
4x6 1/4" wall tubing (ft)	$6.10	15	$91.50
3x6 1/4" wall tubing (ft)	$6.00	82	$492.00
6" rockshaft tubing (ft)	$20	30	$600.00
24" disc blade	$30.00	112	$3,360.00
9" disc spools	$10.20	100	$1,020.00
3"bore --18" stroke cylinder	$190.40	4	$761.60
4"bore --28" stroke cylinder	$338.70	4	$1,354.80
5" bore--10" stroke cylinder	$181.40	2	$362.80
4 3/4" bore -- 10" stroke cylinder	$181.40	2	$362.80
4 1/2" bore -- 10" stroke cylinder	$152.15	2	$304.30
6000lb, 8 bolt hub w/bearings & seals	$105.00	12	$1,260.00
6000lb, 14" long spindle	$40.00	12	$480.00
11L-15FL Load Range F tire	$100.00	12	$1,200.00
8"x15", 8 bolt rim	$21.00	12	$252.00
Gang Bearings (Miller)	$57.47	40	$2,298.80
1/2" 3500 psi hydraulic hose (ft)	$1.00	400	$400.00
Welding (in)	$0.15	4000	$600.00
		Total	$20,436.27

Table 2: Estimated Material Costs (does not include miscellaneous items)

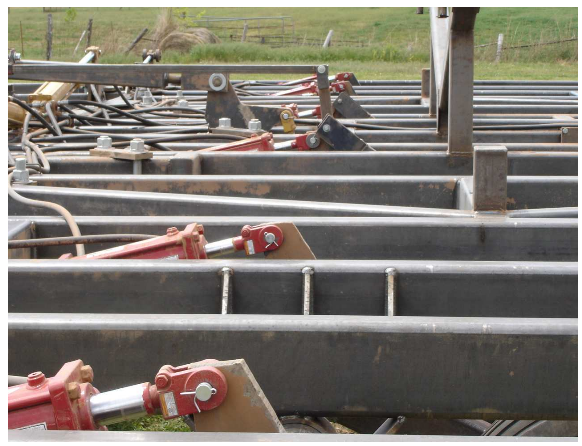
Actual Expenditures

The actual cost for the prototype disc is shown in Table 3. The total cost shown in Table 3 includes all leftover material from the project. Adjusting for these extra materials, the cost of only the materials in the disc is $29,918. This exceeded the estimated budget of $28,000 by $1,918. This extra cost is attributed to a number of factors. For instance, several of the estimates for different components were obtained through individual suppliers and retailers and prices were compared for each part. During ordering, however, a number of the parts were purchased through Agri-Industries preferred suppliers rather than the suppliers with the lowest cost, contributing largely to the underestimate. Steel price fluxuations and incidental costs, such as hydraulic restrictors, hose lengths, and other parts which could only be determined and specified once the product was physically constructed also explain a great portion of this underestimate.

Supplier	Piece	Quanity	Unit Price	Cost
Boyd Metals	3/4 x 8	60'	$8.01	$480.42
	1/2 x 8	60'	$5.34	$320.28
	1 x 8	40'	$10.90	$436.00
	4 x 8 x 1/4	280'	$10.85	$3,038.00
	4 x 8 x 3/8	160'	$15.70	$2,512.00
	4 x 6 x 1/4	24'	$9.11	$218.64
	4 x 4 x 1/4	40'	$7.46	$298.40
	6" SCH 80	42'	$18.65	$783.30
	Saw cost			$360.00
	4" SCH 80	21'	$9.50	$199.50
	1-3/4" HR	100'	$3.55	$355.00
	5" SCH 120	21'	$25.49	$535.29
	3 x 6 x 1/4	160'	$6.34	$1,014.00
	1/2 x 10	100'	$6.17	$616.98
	2-1/2 x 3/16	40'	$1.12	$44.90
	1/4 x 5	80'	$1.51	$120.70
	1 x 8	20'	$10.63	$212.55
Rother Bros.	Gang End Caps	45	$16.50	$742.50
	Gang Washers	40	$0.81	$32.40
	Spring	1	$163.57	$163.57
Railroad Yard	7-5/8" Pipe	25.5'	$6.49	$165.47
SMA	Spools/Discs/Bearings			$8,113.90
Dallas Fasteners	Bolts			$2,241.00
M&W Components	Wheels/Tires/Hubs	12		$2,616.08
	Cylinders	15		$4,297.19
	Hydraulic Hose	320'		$693.00
Agri-Industries	Gauge Wheel Assm.	4	$120.40	$481.60
	O-ring to Pipe Adapters	30	$1.73	$51.90
	Restrictors	12	$5.73	$68.76
	Tees	12	$2.93	$35.16
	90° Fittings	16	$3.65	$58.40
	Crosses	2	$3.88	$7.76
	45° Fittings	2	$1.97	$3.94
			Total	**$31,318.59**

Table 3: Actual Material Costs
(includes scrap material)

Final Design



References

Buckingham, F. 1984. *Fundamentals of Machine Operation: Traction*. 2nd ed. Moline, IL. Deere & Company Service Training.

Appendix A – Assembley Drawings

Design of Large Disc Harrow

Senior Design 2004-2005

BAE 4012

BAE 4022

Design Team:

Levi Johnson

G.L. Slaughter

Adam Steinert

Mission & Problem Statement

- Western Plains Engineering is dedicated to being an innovative leader in the design of large scale agricultural equipment.
- It is the goal of Western Plains Engineering to design a large disc for Agri-Industries for primary tillage in western Oklahoma with small transport width and height.

Western Plains Engineering

Agri INDUSTRIES, INC. Javorsky Culti-King™

Design Specifications

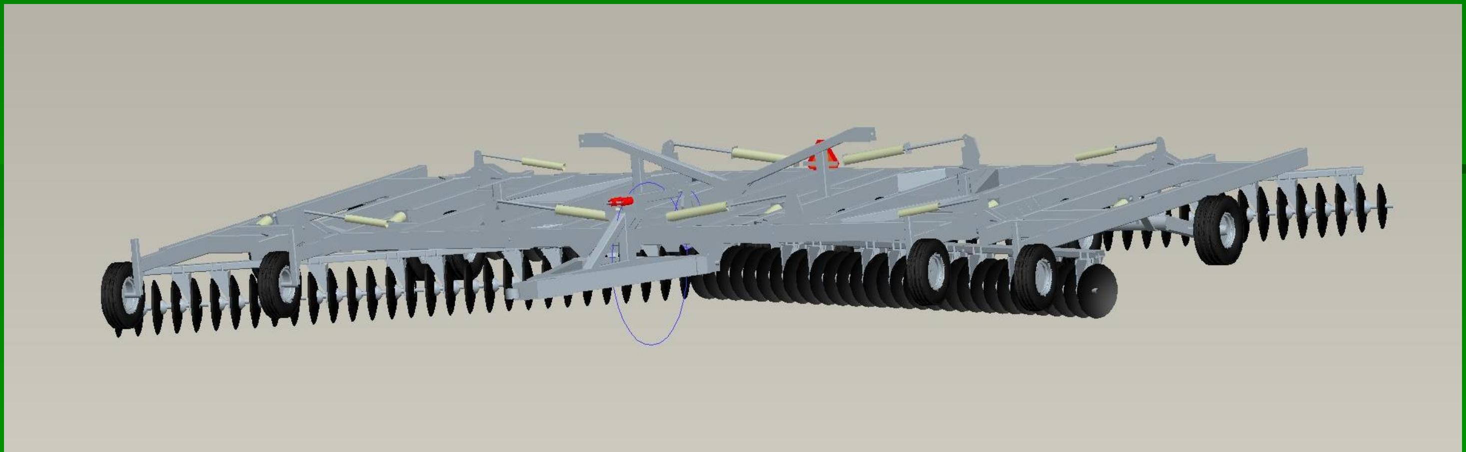
- Primary tillage tool (>210 lbs/blade).
- Working width of at least 40 ft.
- Flexible frame for terraced fields.
- Transport width of less than 19ft.
- Transport height of less than 16ft.

- 229 lbs/blade (27,900 lbs total)
- 42 ft working width
- 5 section frame
- 17 ft transport width
- 13ft transport height

Western Plains Engineering

Agri INDUSTRIES, INC. Javorsky Culti-King™

5-Section Disc

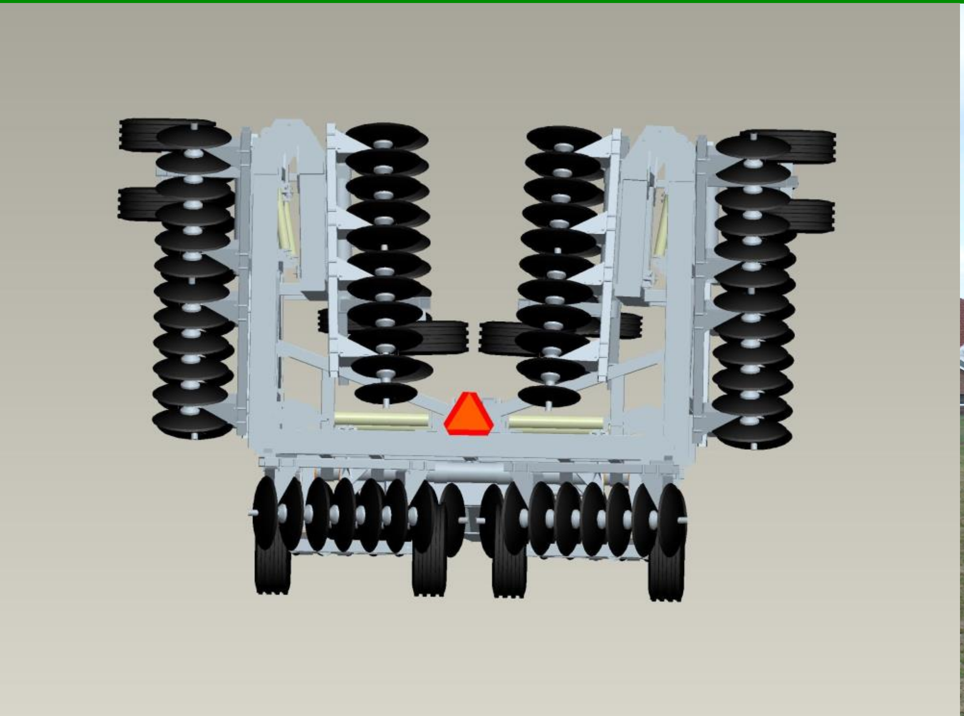


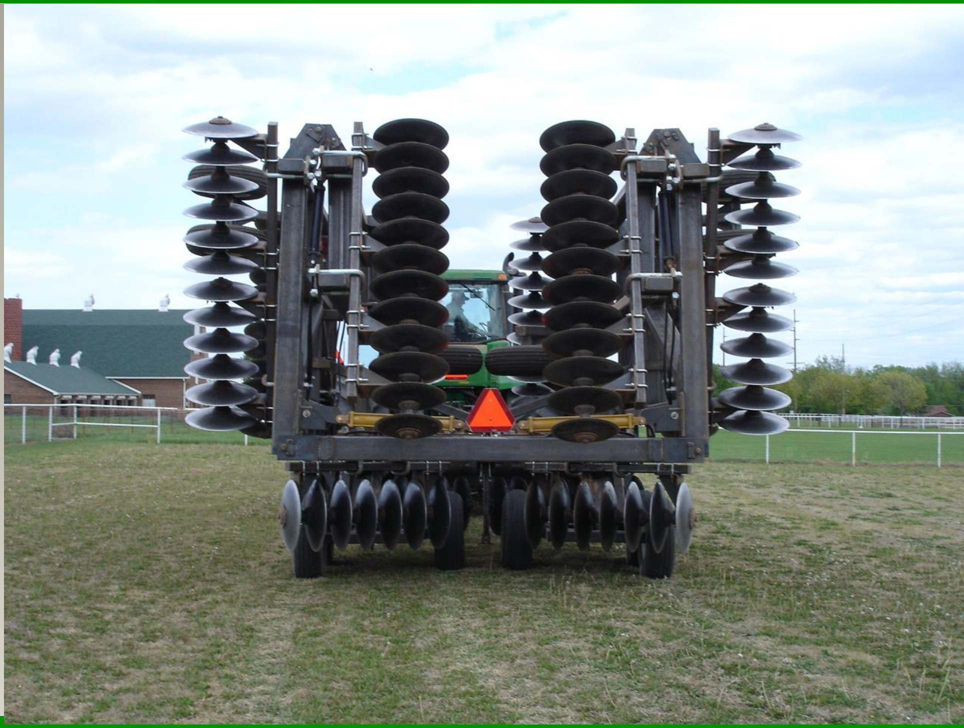
Working Position

Western Plains Engineering

Agri INDUSTRIES, INC. Javorsky Culti-King™

5-Section Disc





Transport Position

Western Plains Engineering

Agri Industries, Inc. Javorsky Culti-King™

Fold/Unfold

Western Plains Engineering

Agri INDUSTRIES, INC. Javorsky Culti-King™

Self-Leveling Hitch

- Weight transfer

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Javorsky Culti-King™

Flexibility

- Primary wing – 10 degrees of travel
- Secondary wing – 7 degrees of travel

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Agri INDUSTRIES, INC.
Javorsky Culti-King™

Primary Tillage

- 25 ac/hr in extreme conditions

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Primary Tillage

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Secondary Tillage

- 33 ac/hr for seedbed preparation

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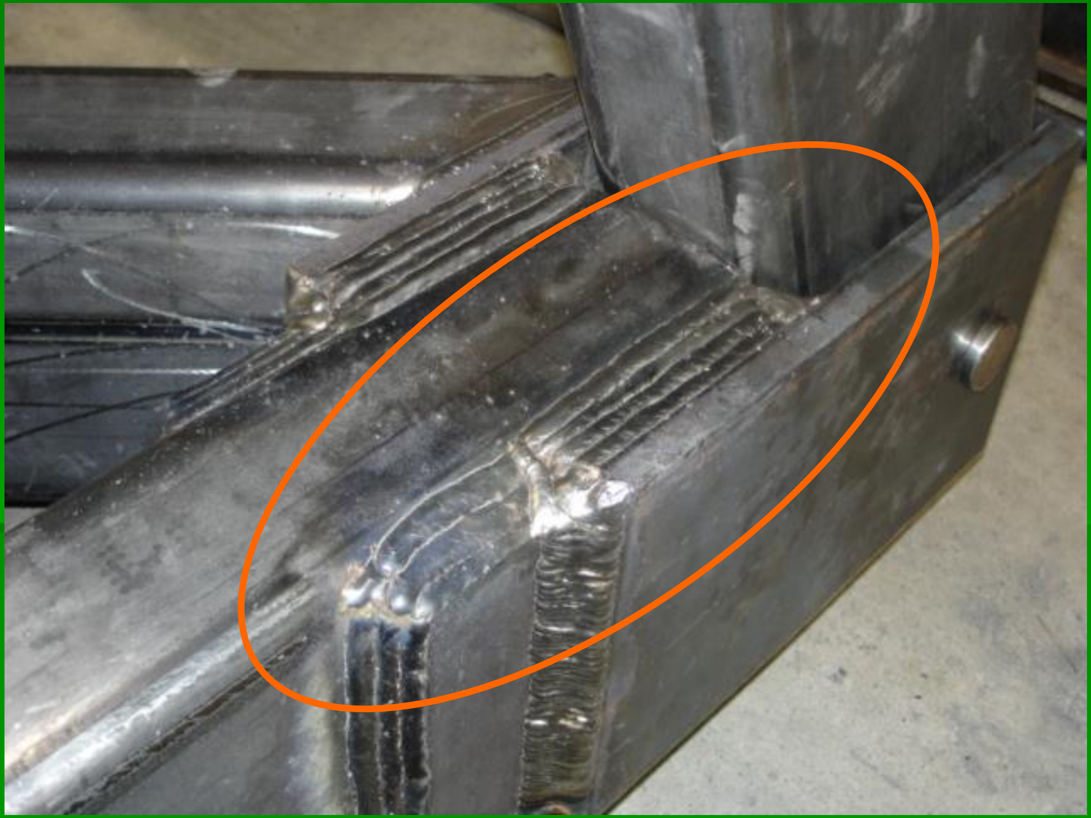
Transport

Western Plains Engineering

Agri INDUSTRIES, INC. Javorsky Culti-King™

Recommendations

- Heat Affected Zone

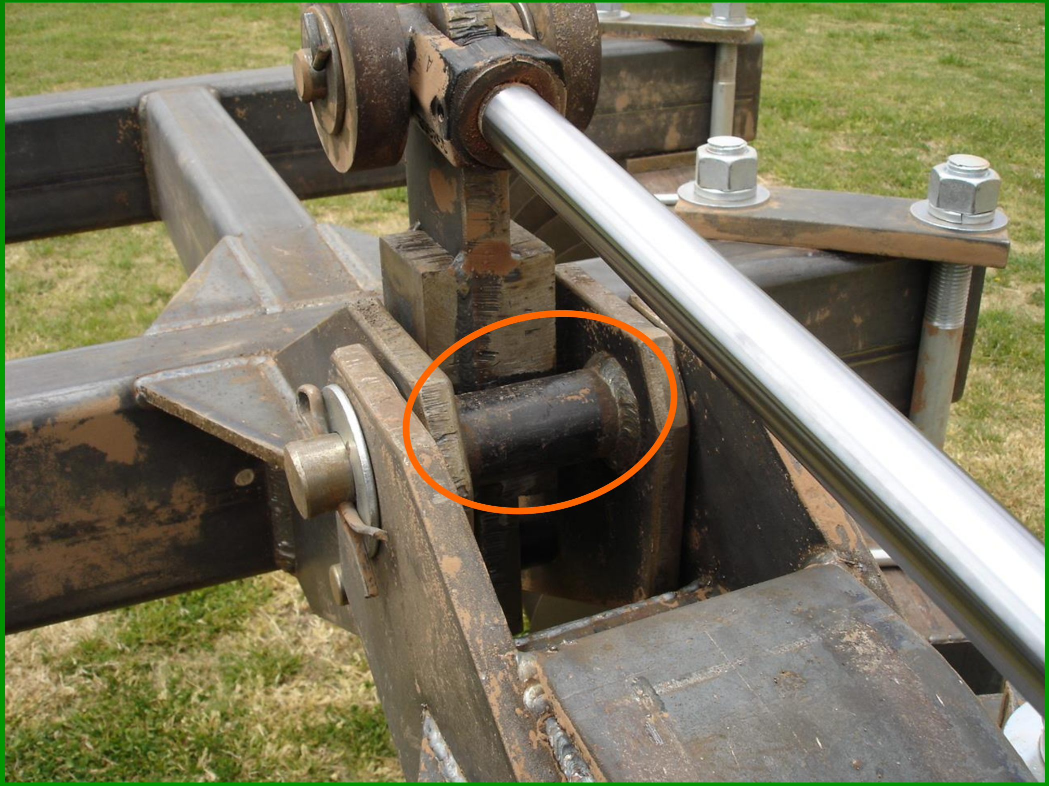


Western Plains Engineering

Agri Industries, Inc.
Javorsky Culti-King™

Recommendations

- Increase thickness of outer wing bushing



Recommendations

- Increase outer wing cylinder size to 3 ½”

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Recommendations

- Higher grade adjustment bolt
- Align adjustment bolt with cylinder

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Javorsky Culti-King™

Cost/Budget

	Fall 2004	Actual
Frame Tubing	$9,500	$9,711
Gang Assembly	$7,600	$9,052
Cylinders	$3,146	$4,298
Wheel Assembly	$3,192	$2,616
Gauge Wheel Assembly	$400	$481
1/2" 3500 psi hydraulic hose	$500	$693
Hydraulic Fittings	$300	$226
Bolts	$1,500	$2,241
Welding	$600	$644
Total	$26,738	$29,962

Western Plains Engineering

Agri Industries, Inc.
Javorsky Culti-King™

Special Thanks

- Dr. Weckler
- Wayne Kiner
- Jim Williams
- Dwight Rymer
- Delles Eggers
- Larry Snowden
- Blackwell Equipment
- Warren CAT

Western Plains Engineering

Agri INDUSTRIES, INC.
Javorsky Culti-King™

Questions???

BAE 4012

12/17/04

Design Team:
Levi Johnson
G.L. Slaughter
Adam Steinert

Mission Statement

Western Plains Engineering is dedicated to being an innovative leader in the design of large scale agricultural equipment.

Problem Statement

It is the goal of Western Plains Engineering to design a large disc for Agri-Industries for primary tillage in Western Oklahoma with small transport width and height.

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Problem Introduction

Primary tillage has been, and continues to be, a vital part of production agriculture for many producers around the world. A common tool often used for primary tillage is a disc harrow. Numerous disc designs are currently in production from many equipment manufacturers. The senior design class of the Biosystems & Ag Engineering Department (BAE) at Oklahoma State University, under the direction of Dr. Paul Weckler, has led to the creation of Western Plains Engineering (WPE). WPE has been contacted to design a disc that could be used as a primary tillage tool throughout the Great Plains region.

Statement of Work

Agri-Industries, located in Cordell, OK, is currently building chisels and field cultivators and has been doing so since 1973. They produce the well-known Javorsky Culti-King® line of field cultivators. Their field cultivators range in widths from 3-section 21 ft. models to 5-section 54 ft. models to 7-section 80 ft. models. They currently provide quality tools at less cost to agriculture producers, sometimes as little as half the cost of their competitors. They are now looking to possibly expand their product line to include large disc harrows. The design team from Western Plains Engineering visited the factory in Cordell and met with their production manager, Jim Burrow. A number of issues concerning the project were discussed, which will be addressed here along with a detailed description of the design problem.

One of the first issues that the design team faces on this project is trying to determine the size of disc to design. Agri-Industries has given WPE wide latitude in this area, and instructed the design team to determine a size based on the team's judgment and any research that was necessary in this area. Obviously, the design for a 40 ft. disc will vary significantly from that of a 25 ft. disc, so determining the size of disc to design is a critical first step. After researching this problem and talking with other manufacturers it appears that 35-36 ft. discs are by far the most popular size and most widely sold, especially in western and northwestern Oklahoma.

Perhaps the single most important issue that Agri-Industries described was that of road transport. Competitors' discs larger than 35 ft. have transport widths of up to 22 ft. and transport heights up to 18 ft. WPE believes that it would be in its best interest as well as Agri-Industries best interest to design a large disc with a transport width less than 19 ft. and a transport height less than 16 ft. Preliminary research suggests that farmers want bigger equipment but are limited by the fact that they cannot transport the equipment down the road or get it inside existing structures for storage and maintenance. To deal with the transport issue, the design team is strongly studying a 5-section disc design as opposed to a typical 3-section disc. This would produce transport widths as narrow as 14 ft. and transport heights as low as 12-15 ft. Also, a five section disc allows for greater flexibility on uneven terrain and terraced fields compared to a 3-section disc.

Another concern of the design team is making sure the disc itself is heavy enough to be used as a primary tillage tool. Agri-Industries felt that the disc should be designed heavy enough to be used as a primary tillage tool or "stubble disc" in the wheat fields of western Oklahoma. In studying competitors' discs, the design team found that "heavy-duty" models have in excess of 200 pounds per blade. This appears to be an industry standard for heavy discs. WPE's design will have to have enough frame weight to exceed 200 pounds per blade or have some capability to add weight in other forms. Also, as frame weight is increased, rockshafts, axles, and hubs will also need to be heavier to support that weight.

Yet another issue with a disc design is how the tool will be raised and lowered. WPE has already discussed two different options. One would be to use rephasing cylinders to lift each section independently. The other option would be to run a continuous rockshaft to each section, connected with turnbuckles, and use a single point lift. Of course, the team is always looking for new, innovative design ideas and this problem is no exception.

Finally, there are numerous other issues that the design team must address as this project moves forward. The team faces many challenges in the weeks and months ahead. But it is the goal of Western Plains Engineering to provide Agri-Industries with a large disc harrow that can be used as a primary tillage tool and also be easily transported.

Patent Research

The idea of turning over soil to both aerate and gain access to vital plant nutrients has been a staple of the last few hundred years of agriculture. Because of this long history, Western Plains Engineering was not surprised to find that many of the patents concerning tandem disc harrows and related components were well over 20 years old. However, of those patents that had not expired, some of the more notable ideas involved the use of UHMW polymers for wear protection on bearing surfaces, linkages for folding methods and depth adjustments, and disk gang arrangement. Most of the design features of a disc are simply common components that are not patentable.

Perhaps the most important patent that our design team has discovered is how the disc gangs are attached to the frame. Sunflower®, a well-known tillage tool manufacturer in Beloit, Kansas, has the patented C-flex™ design that allows for disc gang flexibility and also allows the gang to absorb shock loads due to impacts with rocks, stumps, and loads encountered during normal discing. Deere & Company have what they call a "C-Spring" design, shown in Figure 1, that is very similar to Sunflower's®. The only visible difference is that Deere's design has a smaller radius of curvature on their C-Spring. Krause, shown in Figure 2, and Case New Holland also have comparable designs, but with different radiuses of curvature and slightly different design. However, the general concepts of all three designs are very similar. At this time, WPE is uncertain what type of mounting bracket Agri-Industries will use for the prototype design. However, the design team feels this problem can be resolved during the spring semester.

Figure 1. Deere C-Spring

Figure 2. Krause C-Spring

Market Research

Western Plains Engineering gained valuable market information through several channels, including willful cooperation from both tillage implement resale and manufacturing entities. Contact was made with several disc harrow manufacturers for nationally based market information while local resale contacts both verified and reinforced the information for the western Oklahoma area. WPE's research concluded that a 35 to 36 ft. implement width was the most commonly sold tandem disc harrow both nationally and locally. The team at this time feels that the market is saturated with discs of this size and smaller. However, WPE believes that there is a market demand for discs over 35 ft. Due to the fact that Agri-Industries is just entering the area of disc manufacturing, WPE feels that focusing on larger discs initially is wise. Table 1 shows a summary of the general specifications of competitors' discs with working widths of 35 ft. and up. As the table shows, discs of 40 ft. and larger have transport widths of up to 22 ft. and transport heights of up to 19 ft. The team feels this is an area that should be highly focused on. Other information such as weight per blade, disc spacing, and gang angle will also be important in the design of a prototype.

Models	Width (ft)	Transport Width (ft)	Transport Height (ft)	Weight (lbs)	Weight per blade (lbs)	Blade dia. (in)	Sections	Gang Angle	Disc Spacing (in)
Big G 3040	40	NA	NA	21500	205	26	3	NA	9 or 10
Big G 5045	45	16.5	NA	26500	225	24	5	NA	9,9
Big G 5050	50	16.5	NA	27500	212	24	5	NA	9,9
Big G 5055	55	16.5	NA	28500	201	24	5	NA	9,9
Big G 5060	60	16.5	NA	29500	187	24	5	NA	9,9
Summer 9K3827	38.5	22	16	22853	243	26	3	19, 18	9,9 10,10
Summer 9K4427	44.5	22	19	25445	232	26	3	19, 18	9,9 10,10
Krause 2495	35.6	16	15.6	19393	206	24	3	NA	9,10
Krause 7400-41N	41.5	17.5	NA	23036	177	24	3	20, 17	8
Krause 7400-46N	45.5	21.5	NA	24298	171	24	3	20, 17	8
Krause 4995-46W	35.5	16	15.75	15522	158	24	3	19, 17	9,9
Howard 1200	39	9.8		33396	347	26	2	NA	NA
Sunflower 1544-42	42	22	14.5	27200	223	24	4	NA	8.75,8.75
Sunflower 1544-44	44.5	22	15.7	28975	223	24	4	NA	8.75,8.75
Sunflower 1444-40	40	19.75	15.3	23850	209	24	4	NA	8.5,8.5
John Deere 637	37.8	NA	NA	NA	NA	24	NA	NA	9,9

Table 1. Disc Model Comparison

Design Specifications

- Disc should be capable of being used as a primary tillage tool or "stubble disc" (>170 lbs/blade).
- Disc should have a working width of 40 ft. or greater.
- Disc should have a transport width of no more than 19 ft. and transport height of no more than 16 ft.
- Disc frame should be made as flexible as possible to follow uneven terrain and terraced fields.
- Disc framework and components should be relatively similar for different size discs.

Modeling

The design of a scale model for any design concept generation does not appear useful or cost effective for this design project. WPE will rely on computer model designs to develop design concepts. Validating and testing the team's design ideas is an area of concern. At this time, WPE feels that the best option would be to build a full scale prototype. The team believes that this would provide the best and most useful results in testing a prototype design. A full scale prototype would allow WPE to obtain necessary information regarding the machine's performance. With a scaled down model, the team feels that little can be learned how a full scale version will perform in the field. No simulation, testing, or equipment is needed at this time for design development. However, adequate shop space will be needed to build a full scale prototype. A detailed build schedule for the spring semester is shown in Appendix A.

Recommended Design

Currently, WPE is working on a 40 ft., 5-section, tandem disc design. The lift system utilizes a rephasing system, nearly identical to Agri-Industries' current rephasing lift design on their field cultivators. The proposed design weighs 23,700 lbs. with 24 in. blades and 9 ¼ in. spacing. With the current design, disc size could easily be adjusted by the manufacturer, either by removing the outside wings to offer a smaller, three-section disc or adding width to both the first and second wings to create a disc larger than 40 ft. Either way, the current design would allow for the center section to be nearly identical for all models. For a three-section design, possible sizes range from 24 ft. up to the most common 35-36 ft. sizes.

The rephasing lift system consists of two, 5 in. bore, 10 in. stroke master cylinders on the center section, mechanically linked by the center rockshaft. These master cylinders require a working pressure of 1470 psi. The lift cylinders on the inner wing are 4 ¾ in. bore, 10 in. stroke cylinders. The outer wing lift cylinders are 4 ½ in. bore, 10 in. stroke cylinders. This step down in size of the lift cylinders allows for steady, even lifting of the disc. The fixed ends of all the lift cylinders will be tied to the frame by 1 ½ in. bolts, allowing for fine-tuned disc leveling. Figure 3 shows the lift system for the entire disc. The rephasing lift system was chosen over a single point lift system for two main reasons. First, to lift a 24,000 lb. implement using one cylinder would require a very large, industrial-size cylinder. Second, using a single point lift system requires running a rockshaft the entire width of the implement. To accomplish this, turnbuckles must be used to connect the rockshafts at the wing hinge points, and turnbuckles are a common weak point in all types of heavy tillage equipment.


Figure 3. Proposed Lift System

One issue that has created some concern with the design team is the number of tires needed on the center section for road transport. Standard designs usually contain four tires on the center section. WPE would like the prototype disc to weigh at least 20,000 lbs. This would mean at 5,000 lbs. per tire on a typical four transport tire design. However, load ratings on standard large implement tires are approximately 4,200 lbs. per tire. This problem could be solved by simply adding more tires to the center section, but this obviously complicates the design and increases cost. Nevertheless, after researching competitors' models, it is clear that many tillage tool manufactures exceed these recommended load ratings on implement tires. After talking with Firestone® tire engineers, it is evident that overloading tires in this manner leads to increased tire wear and premature failure, something WPE obviously wants to avoid. To solve this problem, WPE is proposing putting six tires on the center section. The team's design would allow for both front-to-back and side-to-side flexibility, thus keeping six tires on the ground at all times. WPE's design would also allow for equal weight distribution among the three tires. To carry the load, 11L-15FL Load Range F tires will be used, which are rated at 4000 lbs/tire. The proposed walking beam design can be seen in Figures 4 and 5.

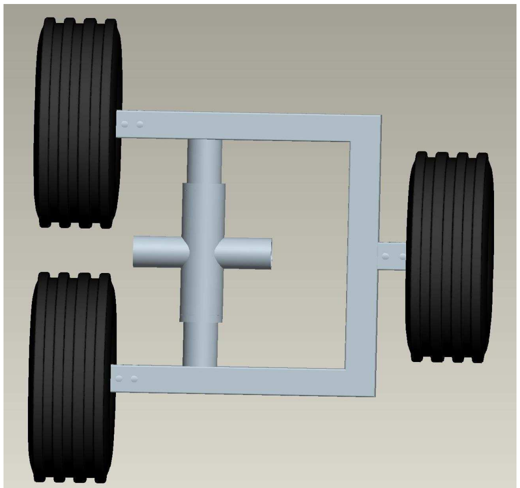

Figure 4. Center-Section Walking Beam

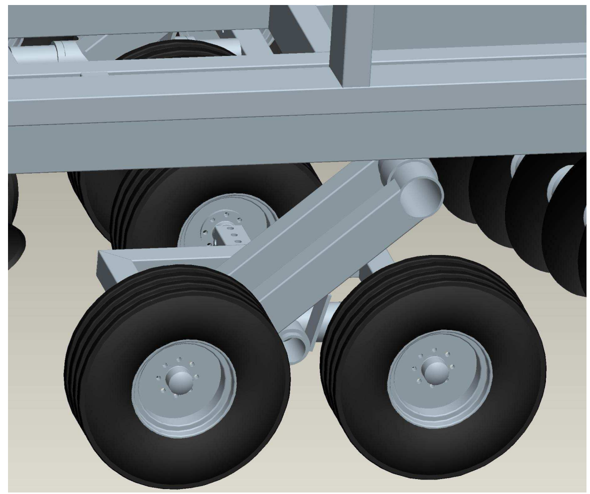

Figure 5. Right Side Center Section

Another aspect of the project that has proven to be difficult for the design team is the issue of folding linkages for the outer wings of the disc. The design of the outer wing is difficult because this wing must be folded nearly 180 degrees and then lay only inches above the inner wing. The design team has looked at several other 5-section tillage tools to study their wing hinges in order to better understand how linkages work for 180 degree folds. WPE is proposing using two, 3 in. bore, 18 in. stroke cylinders to fold the outer wing. Using two cylinders allows for the use of smaller cylinders and prevents frame twisting, which could be a problem if only one fold cylinder is used. As Figures 6 and 7 show, 4 in. rollers are used on end of the cylinder, which will come in contact with the frame when the outer wing folds over center.

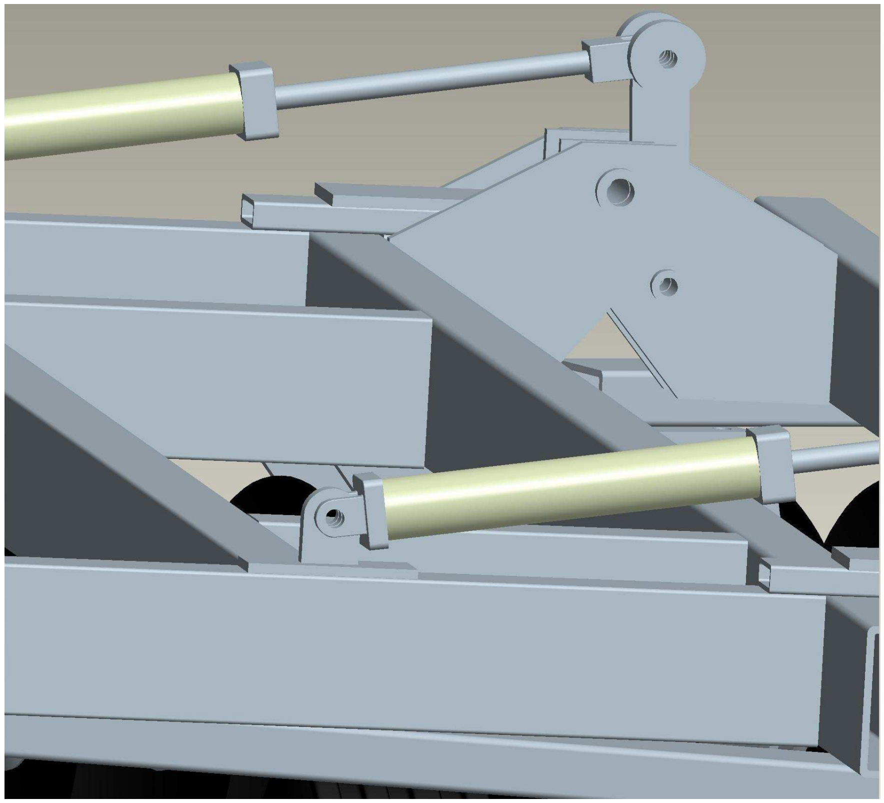

Figure 6. Outer-Wing Linkage Unfolded

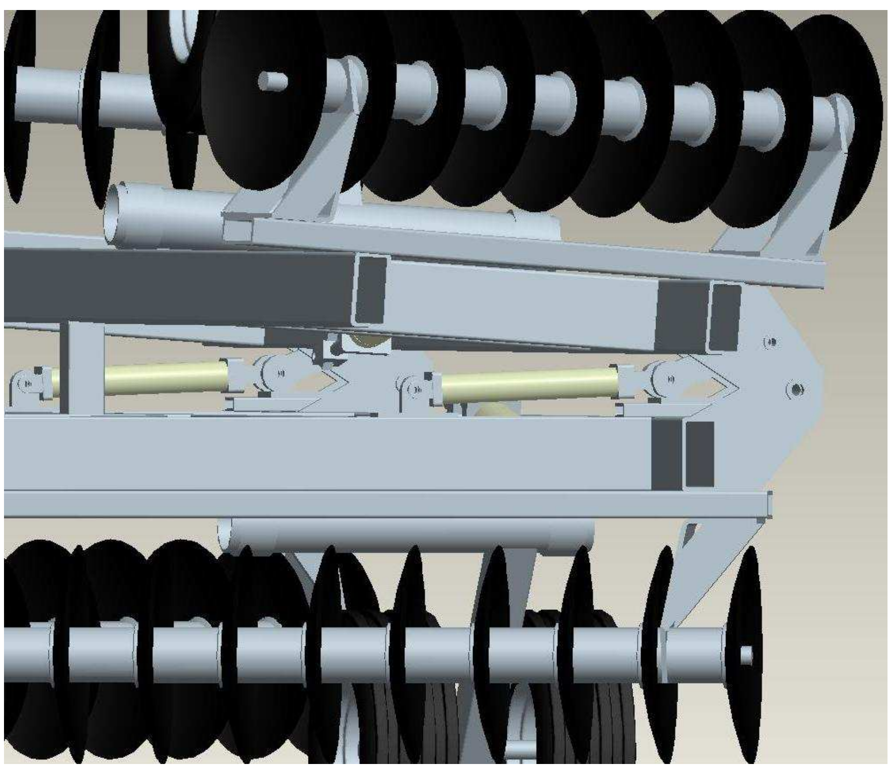

Figure 7. Outer-Wing Linkage Folded

The inner wing fold consists of two, 4 in. bore, 28 in. stroke cylinders with 12 in. lever arms. The inner wing folds to exactly 90 degrees where it can pinned up for transport from the ground using 1 in. pins. The inner and outer wing fold cylinders are sized so that the outer wing cylinders require less pressure than the inner wing cylinders and therefore begin to act first when folding. The outer wing requires 1300 psi., while the inner wing requires 1500 psi. The folded prototype can be seen in Figure 8.

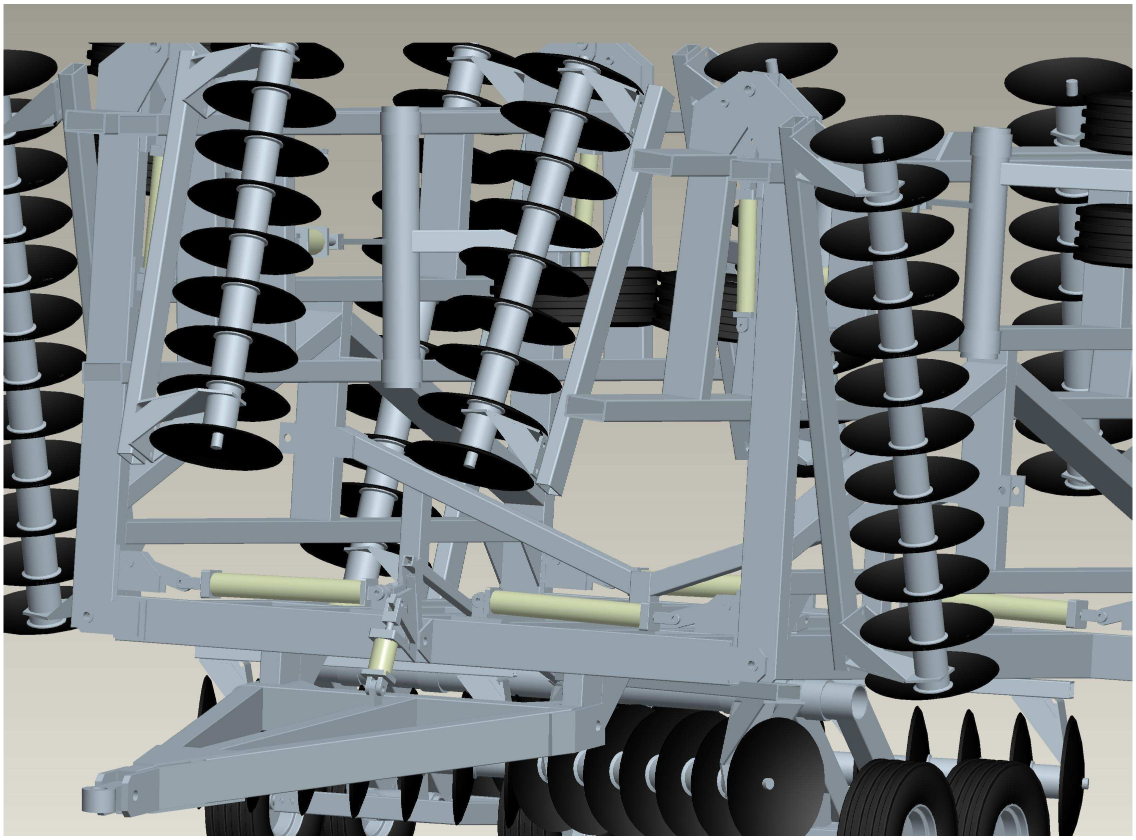

Figure 8. Folded Front View

Another important part of the team's recommended design is the self-leveling hitch linkage. This critical linkage allows the operator to transfer weight from the tractor to the front gangs to increase cutting capability in hard soils. It also allows the operator to raise the front gangs during field operation to make gradual turns. This can be accomplished by hydraulically adjusting the 4 in. bore, 4 in. stroke cylinder located on the hitch. It also allows the disc to remain level in both the fully raised and fully lowered position. This linkage can be seen in Figure 9.

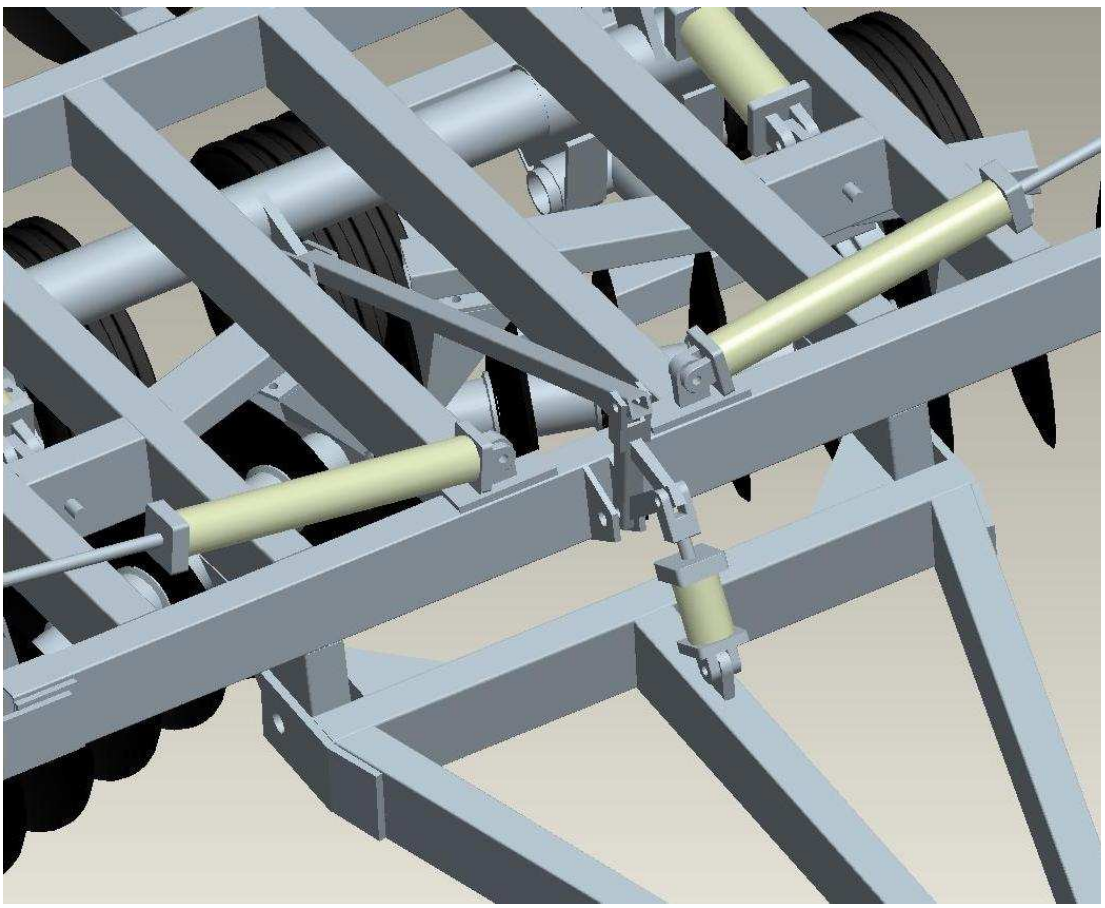

Figure 9. Self-Leveling Hitch Linkage

Perhaps the most important aspect of WPE's proposed design is the disc's transport dimensions. The current prototype design has a transport height of less than 14 ft., over 2 ft. below the initial design specification. The disc also has an overall transport width of 18 ft. More importantly however, is the fact that the center section wheel-to-wheel width is only 11 ft, allowing for easier transport on narrow roads and bridges.

Proposed Budget

The proposed budget for the prototype disc is shown in Table 2. Highlighted values indicate estimated values that could not yet be obtained. Items not included in this budget contain but are not limited to: ½ in. plate, ¾ in. plate, 1in. plate, 1 ½ in. plate, 1 ¼ in. pins, 1 ½ in. pins, 2 in. pins, rockshaft sleeving, 1 ¾ in. gang shaft, and the material needed for the center section walking-beams. The amount of these materials needed and the cost for these materials is not known at this time. However, the cost of these materials will be relatively low compared to the rest of the disc material. Overall, WPE does not expect the total cost of materials to exceed $28,000.

Item	Unit Price	# Units	Cost
4x8 1/4" wall tubing (ft)	$11.78	291.5	$3,433.87
4x8 3/8" wall tubing (ft)	$14.00	128.7	$1,801.80
4x6 1/4" wall tubing (ft)	$6.10	15	$91.50
3x6 1/4" wall tubing (ft)	$6.00	82	$492.00
6" rockshaft tubing (ft)	$20	30	$600.00
24" disc blade	$30.00	112	$3,360.00
9" disc spools	$10.20	100	$1,020.00
3"bore --18" stroke cylinder	$190.40	4	$761.60
4"bore --28" stroke cylinder	$338.70	4	$1,354.80
5" bore--10" stroke cylinder	$181.40	2	$362.80
4 3/4" bore -- 10" stroke cylinder	$181.40	2	$362.80
4 1/2" bore -- 10" stroke cylinder	$152.15	2	$304.30
6000lb, 8 bolt hub w/bearings & seals	$105.00	12	$1,260.00
6000lb, 14" long spindle	$40.00	12	$480.00
11L-15FL Load Range F tire	$100.00	12	$1,200.00
8"x15", 8 bolt rim	$21.00	12	$252.00
Gang Bearings (Miller)	$57.47	40	$2,298.80
1/2" 3500 psi hydraulic hose (ft)	$1.00	400	$400.00
Welding (in)	$0.15	4000	$600.00
		Total	$20,436.27

Table 2. Material Costs

Appendix A-Gantt Chart

Design of Large Disc Harrow

Senior Design 2004-2005

BAE 4012

BAE 4001

Design Team:

Levi Johnson

G.L. Slaughter

Adam Steinert

Project Sponsor

- Agri-Industries – Cordell, Ok
  - Barkley Tackitt – Owner
  - Jim Burrow – Production Manager
- Application Engineers
  - Jim Friesen – Weatherford, OK
  - Paul Walenciack – Weatherford, OK

Project Sponsor

- Currently producing Javorsky™ line of chisels and field cultivators since 1973.
  - Produce high quality equipment at less cost to producers.
  - Visit them at: www.agri-industriesinc.com

Western Plains Engineering

Agri INDUSTRIES, INC. Javorsky Culti-King™

Mission Statement

- Western Plains Engineering is dedicated to being an innovative leader in the design of large scale agricultural equipment.

Problem Statement

- It is the goal of Western Plains Engineering to design a large disc for Agri-Industries for primary tillage in western Oklahoma with small transport width and height.

Western Plains Engineering

Agri Industries, Inc. Javorsky Culti-King™

Design Specifications

- Should be capable of being used as a primary tillage tool (>150 lbs/blade).
- Working width of 40 ft or greater.
- Flexible frame to follow uneven terrain and terraced fields.
- Transport width of less than 19ft.
- Transport height of less than 16ft.

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Market Research

Models	Width (ft)	Transport Width (ft)	Transport Height (ft)	Weight (lbs)	Weight/ blade (lbs)
Big G 3040	40	20	19.5	21500	205
Sunflower 1544-42	42	22	14.5	27200	223
Sunflower 1444-40	40	19.75	15.3	23850	209
Krause 7400-41N	41.5	17.5	14.75	23036	177
Krause 7400-46N	45.5	21.5	14.75	24298	171

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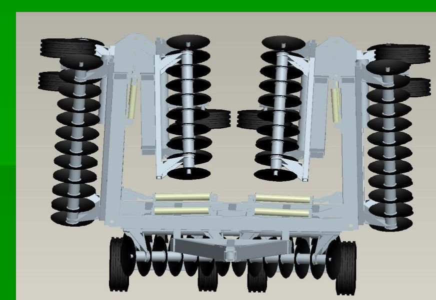
Initial Design Issues

- Frame Design
  - 3-Section
  - 4-Section
  - 5-Section
- Lift System
  - Rephasing
  - Single Point
- Working Width

Krause 7400-46

Sunflower 1544



SHD 4000

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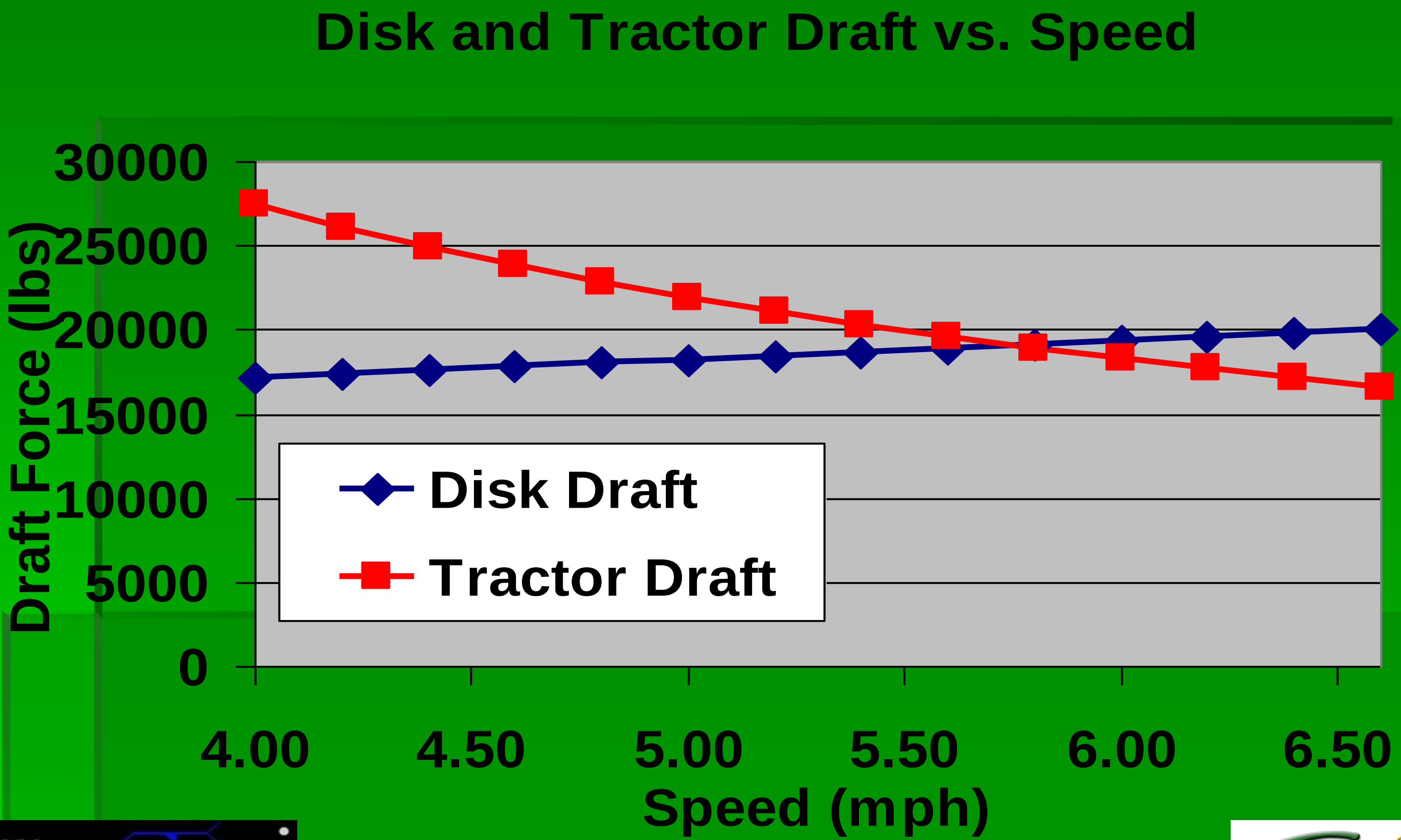
Draft Calculations



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Problems

- Folding a 5-Section Implement
- Transporting 24,000 lbs
- Fabrication of Components/Framework
- Transportation to Customer from Factory
- Cost

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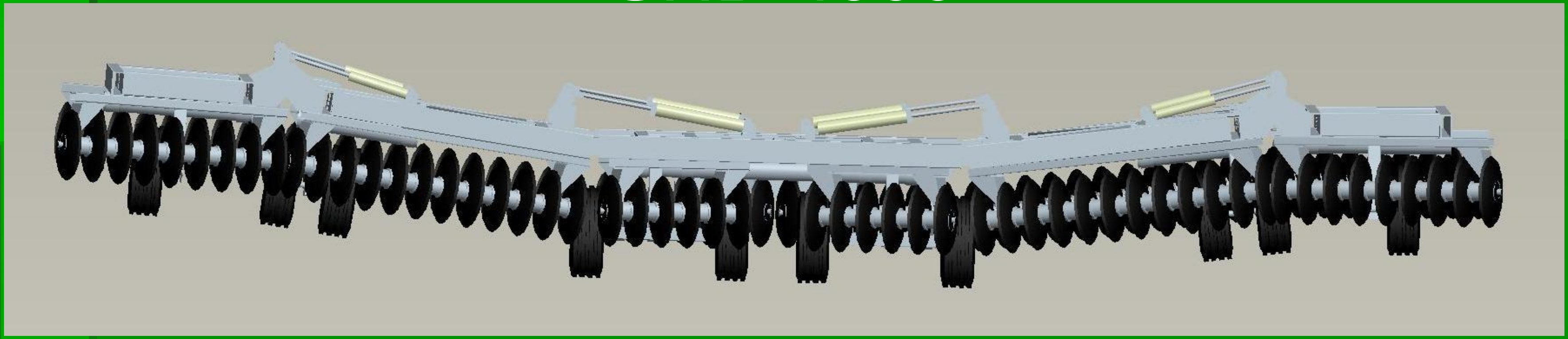
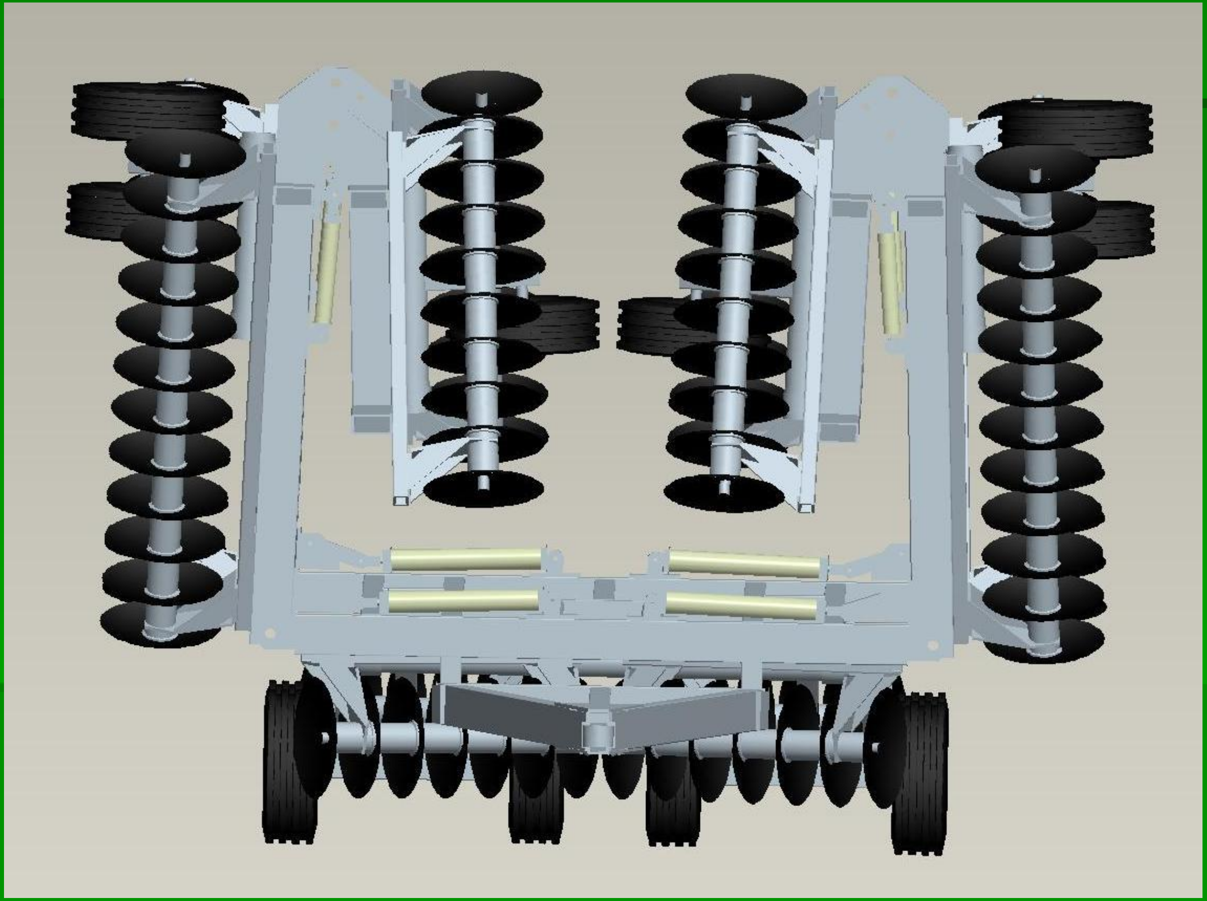
5-Section Disc

Sunflower 1544

SHD 4000



Road Transport



Front View

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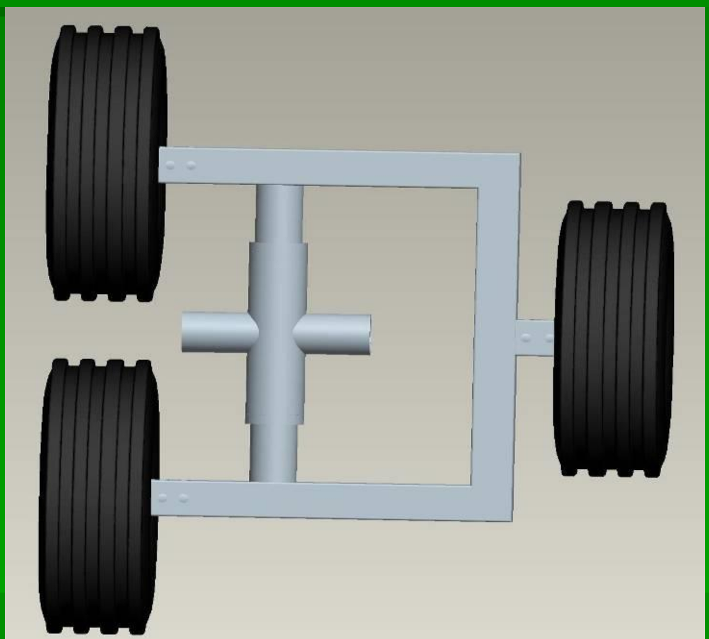
Road Transport

Miller Disc



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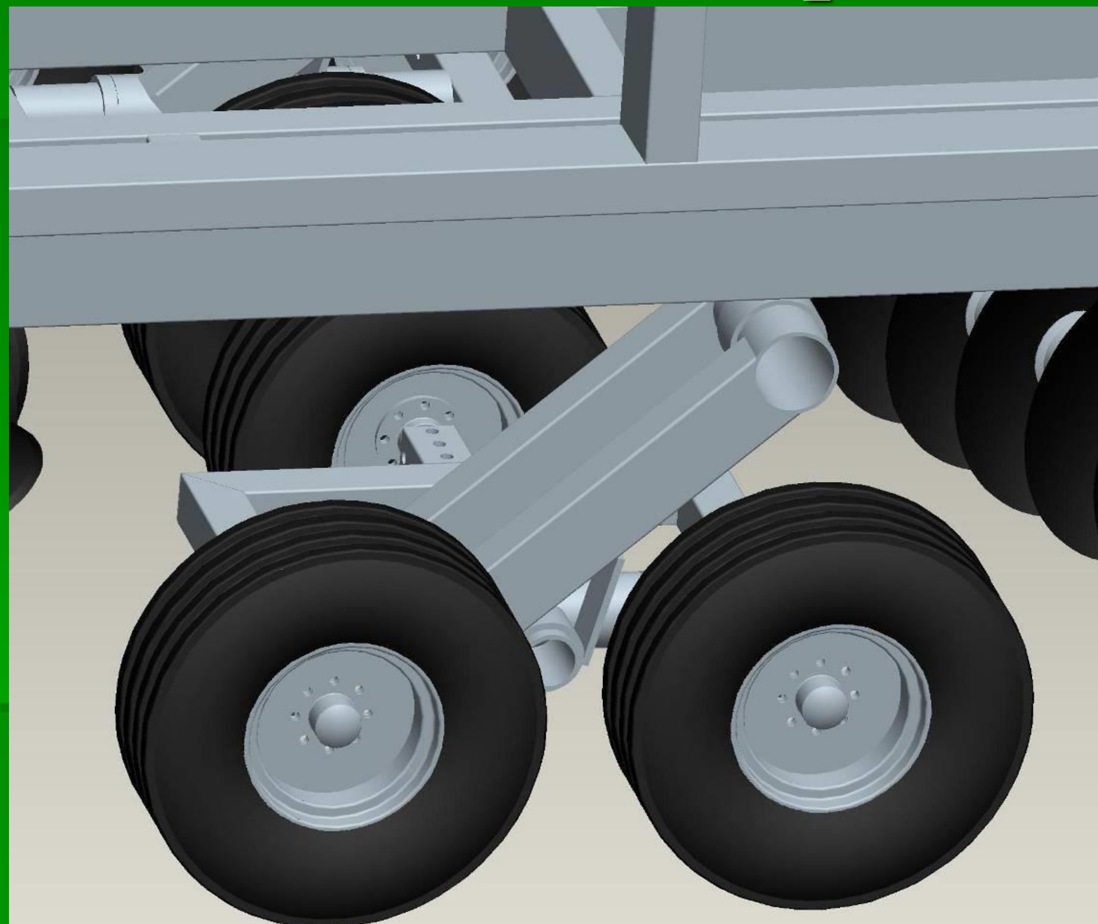
Road Transport



Right Side Center Section

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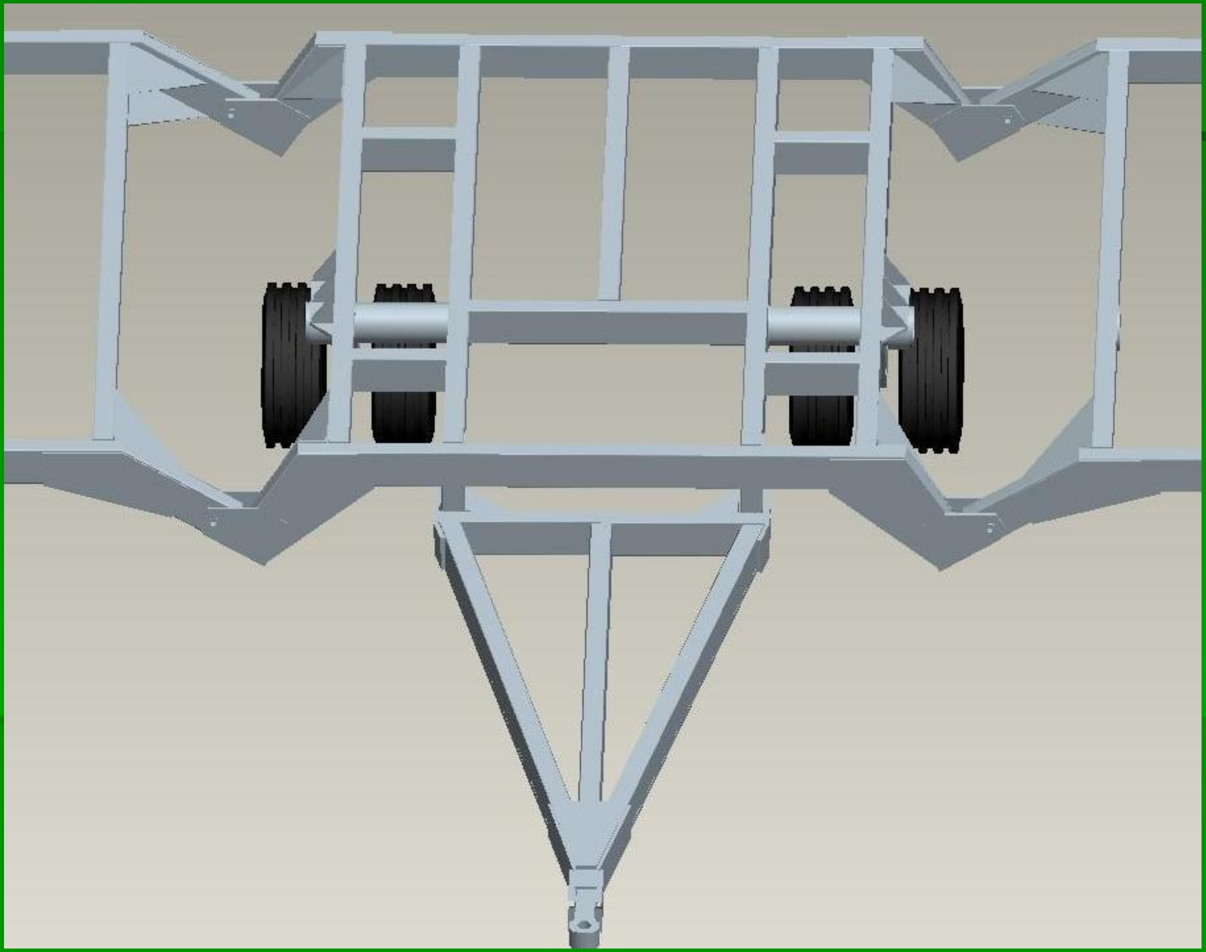
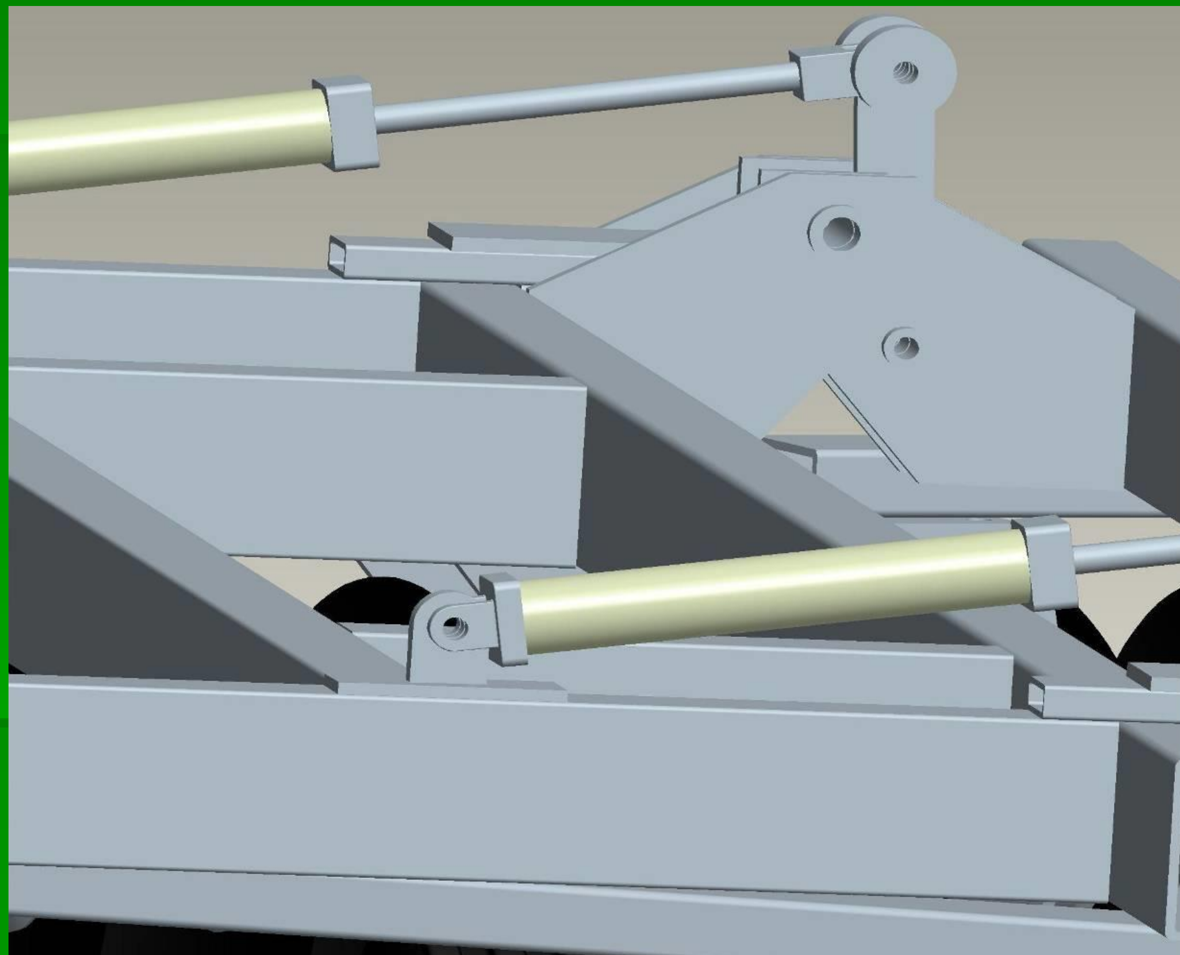
Alternative Design



Drop Down Wing Hinge

5-Section Disc



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Outer Wing Hinge

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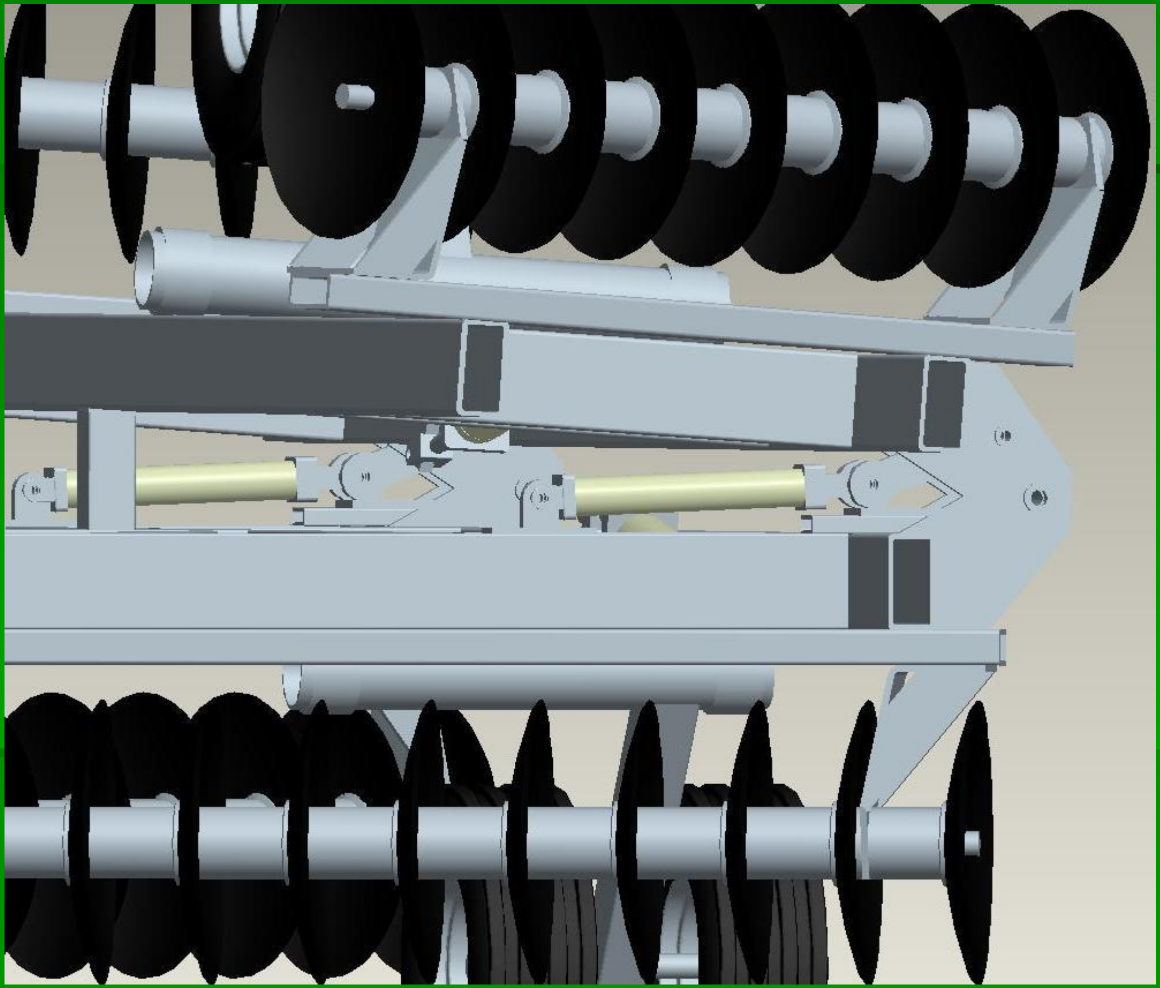
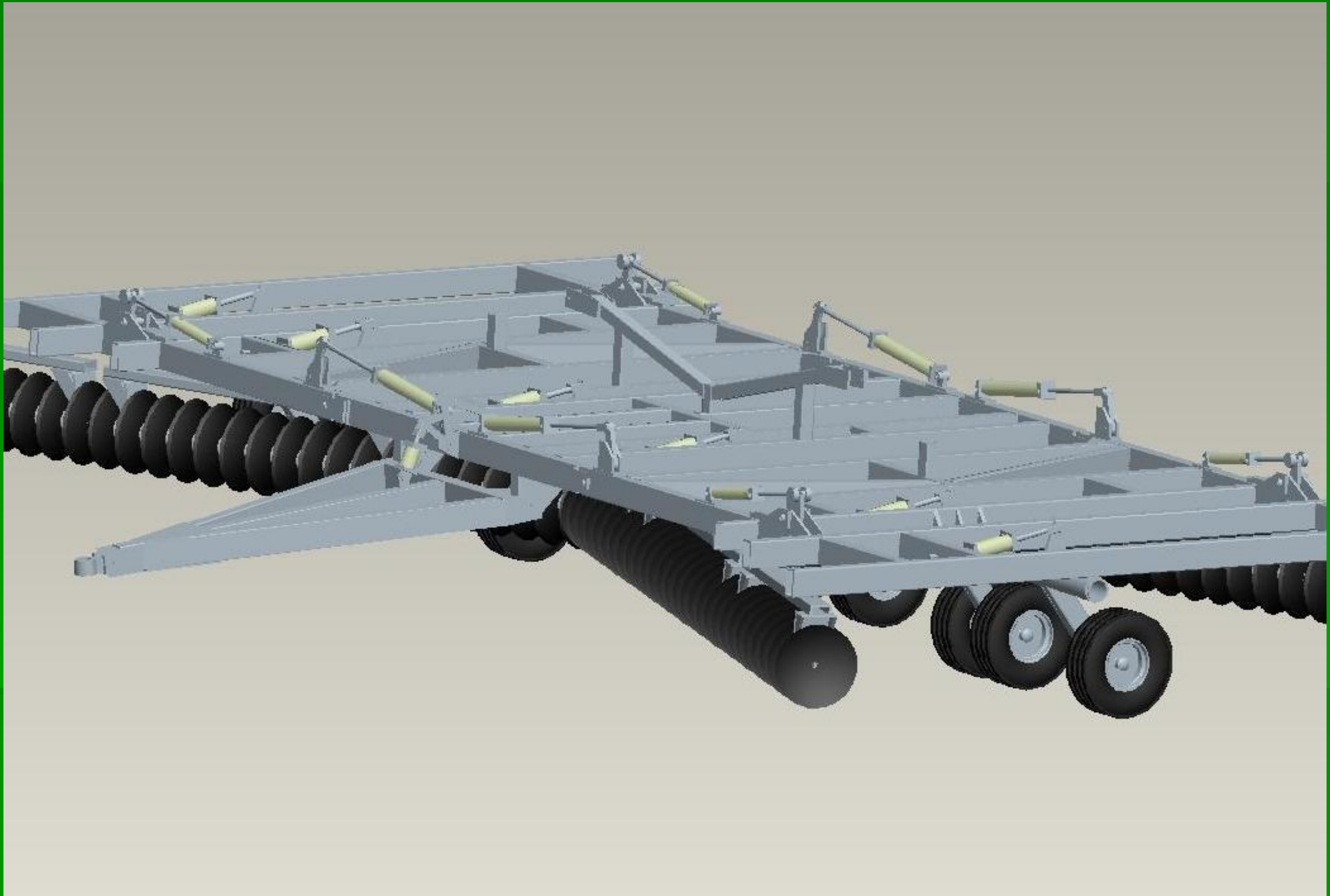
5-Section Disc



Outer Wing Hinge

5-Section Disc



SHD 4000

Hydraulic Design

Linkage	Cylinder Bore (in)	Maximum Demanded Pressure (psi)
Outer Wing Fold	3	1300
Inner Wing Fold	4	1500
Master Lift Cylinder	5	1470

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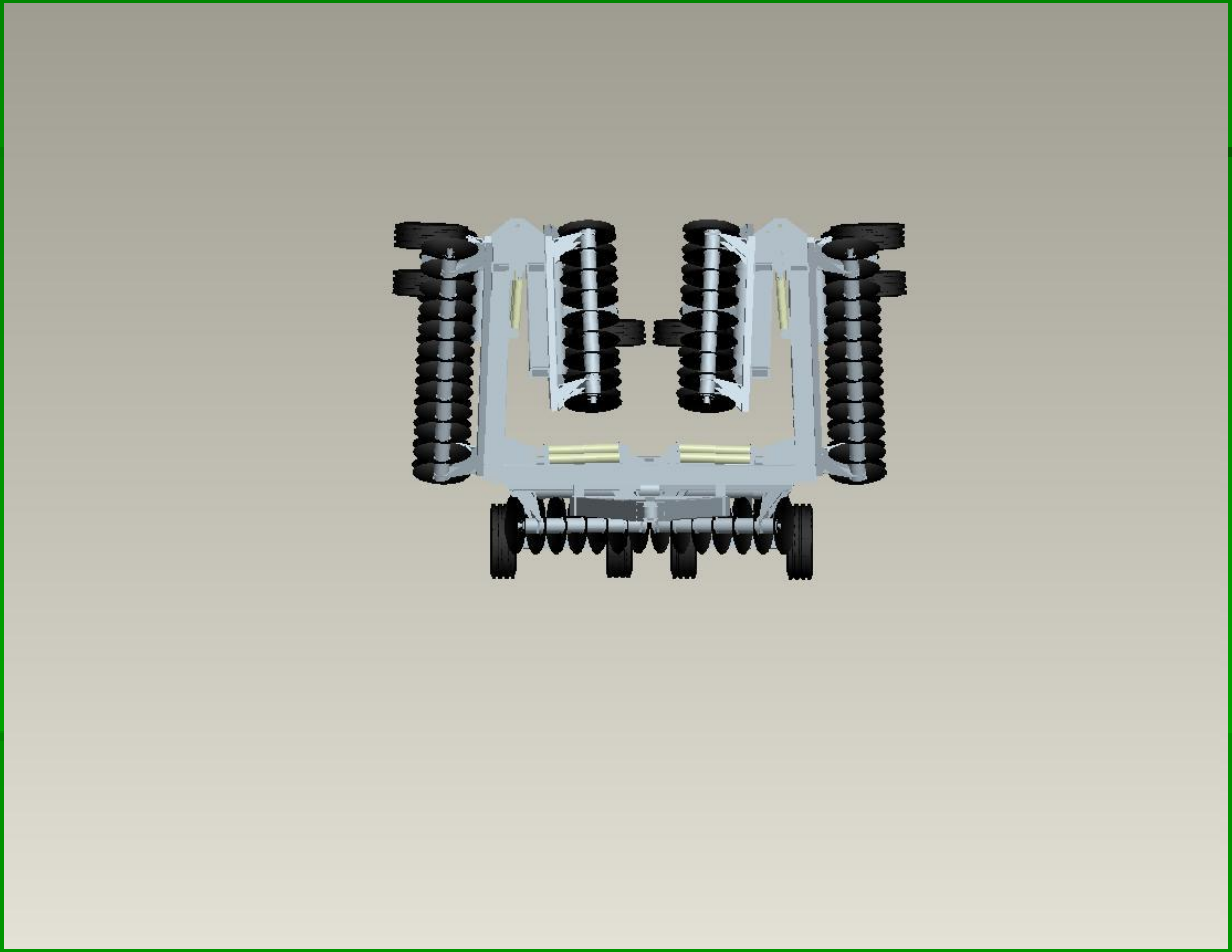
5-Section Disc



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Cost/Budget

Frame Tubing	$5,885.00
6" rockshaft tubing	$600.00
24" Disc Blades	$3,360.00
9" Disc Spools	$1,020.00
Cylinders	$3,146.00
6000lb, 8 bolt hubs w/bearings & seals	$1,260.00
14" Spindles	$480.00
11L-15FL Load Range F Tires	$1,200.00
8"x15", 8 bolt rims	$252.00
Gang Bearings (Miller Assembly)	$2,298.00
1/2" 3500 psi hydraulic hose	$400.00
Welding (in)	$600.00

Total	$20,501.00

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What's to Come?

- BUILD!!!
- Validating Frame Fold Design
- Field Testing

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Special Thanks

- Jim Burrow
- Jim Friesen
- Paul Walenciak
- Dr. Paul Weckler
- Dr. Glenn Brown
- Wayne Kiner

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