Gleaner Distribution Auger Testing System

AGCO Corporation

BAE 4023: Senior Design Final Report

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Mission Statement:

To develop an accurate and consistent testing method in order to determining the performance of distribution augers currently utilized on Gleaner Combines, and to implement design improvements over current production models.

Problem Statement:

The purpose of this project is to create a testing system to determine the efficiency of distribution augers located in the grain cleaning process of Gleaner combines. Design Modifications made to distribution augers will be evaluated to determine the impact on the performance of the system.

Background:

With the world's growing demand for food and its heavy dependence on grain, today's famers are pressed to produce and harvest more grain in the shortest amount of time possible. Currently the worldwide wheat production is 700 million metric tons. In order to meet this demand, the combine harvester plays a vital role in efficiently reaping, threshing, and separating grain from material other than grain (MOG). AGCO (Allis-Gleaner Corporation) is a leading global manufacturer of agricultural equipment who produces several brands of combine harvesters. While AGCO's North American combine brands consist of Challenger, Gleaner, and Massey Ferguson, the Gleaner is the most unique and is the subject of the group's project.

In 1923, the Baldwin brothers of Nickerson, Kansas created a self-propelled combine harvester. The name "Gleaner" was used because a gleaner was considered to be someone who would collect leftover crops from fields. Thus, the name implied to a customer that a Gleaner combine would not leave grain on the field[1]. This emphasis on efficiency is still in practice today. The Gleaner's uniqueness is based on the design of the rotor (the rotor is the circular mechanism that is used to thresh the wheat). The rotor sits transversely with respect to the machine, while other competitor's machine's rotors are fixed axially within the combine. With the S7 and S8 models, Gleaner boasts a system that is leading the industry in obtaining the cleanest grain with the fewest losses from the rear of the machine. Last year, 600 S7 Gleaner units were produced at the AGCO factory in Hesston, Kansas.

The cleaning system is the target of the group's attention. In the current design of Gleaner combines, the rotor sits above a trough that houses two conveyer augers and two accelerator rollers. The augers' purpose is to feed and evenly distribute the material before it is dropped into the accelerator rollers. The accelerator rollers are present to speed up the materials descent from the auger conveyers. Without the accelerator rollers "throwing down" the material, the material leaving the augers would be falling at the speed of gravity. This does not necessarily pose a problem when the combine is on level ground, but when the machine is harvesting on a slope, a problem arises. Because the distance between the rollers and the grain pan (where the grain falls after leaving the rollers) is significant, gravity plays a major role in determining where and how the grain and MOG distributes. Thus, the accelerator rollers reduce the influence of gravity. On a slope, if the rollers were not present, the material would overload on one side. Side-overloading can cause spilling of grain from the side of the cleaning shoe. Because air from a fan is used to separate the MOG from the grain as soon as the material drops from the rollers, a constant velocity of air will not be reaching all of the material at the same time. This will result in unclean grain entering the grain tank which ultimately penalizes the producer.

We found several patents that were useful to our project. Patent number 4444208 is a patent for the current production model of the Gleaner combine that was filed in 1984. Therefore, this patent has already expired. Patents 4457316 and 4458697 were also very good to look at. We found that in these patents, AGCO used one distribution auger instead of two to distribute material over the accelerator rolls. However, both of these patents have expired as well. AGCO doesn't have to worry about infringing on anybody else's patents because they have the only transverse rotor in the industry.

For this project, the group is to submit an improved design of the current production conveyer augers. After performing a baseline test with the current Gleaner design, the team will observe and analyze the results in order to determine several possible solutions. These designs will then be tested in the same manner as the baseline trials. After analyzing the data and after discussion with AGCO's clients, the group will make a selection of the most practical design.

Project Objectives:

1. Establish an effective and repeatable testing apparatus using current production parts and assemblies found on Gleaner combines.

2. Determine the baseline performance of current production distribution augers on the Gleaner combine.

3. Analyze the effect of auger speed and material distribution on performance of distribution augers.

4. Suggest the best solution based on experimental data collected during testing.

Project Scope:

The project will include an analysis of the current distribution augers by developing a testing apparatus that can consistently reproduce the conditions seen by the Gleaner combine in the field. Design changes will then be implemented to the auger system, and the performance of the modifications will be tested under the same conditions using the same apparatus.

Budget/Financial Analysis:

For this project, the group was allotted a budget of $2000. The following figures outline both the estimated budget prior to beginning construction, and the final totals spend.

Table 1: Preconstruction economic estimation

Build Materials	Quantity	Estimated Cost	Total
3x3 Tubing ($/ft)	57	$7.42	$422.91
2x2 Tubing ($/ft)	160	$3.29	$527.04
1x1 Square Tubing ($/ft)	4	$1.03	$4.11
16 Gage Sheet Metal	2	$79.20	$158.40
14 Gage Sheet Metal	2	$99.00	$198.00
1 in Strap ($/ft)	10	$0.86	$8.60
Pillow Block Bearings	2	$13.95	$27.90
Ply Wood	1	$15.00	$15.00
Conveyor Drum	1	$20.00	$20.00
Labor	1	$250.00	$250.00
Power Transmission Supplies			
5 HP Motor	1	$495.95	$495.95
Motor Starter	1	$95.99	$95.99
10 HP Pulley	1	$40.95	$40.95
Accelerator Roll Pulley	1	$28.95	$28.95
5 HP Pulley	1	$20.95	$20.95
Distribution Auger Pulley	1	$52.95	$52.95
Key Stock	1	$15.00	$15.00
Drive Line	1	$199.99	$199.99
Hydraulic Hose Tip Male	2	$10.99	$21.98
Hydraulic Hoses	2	$11.99	$23.98
Miscellaneous			
Conveyor Tarp	1	$100.00	$100.00
Straw	3	$0.00	$0.00
Grain	2	$0.00	$0.00
Final Predicted Total			$2,728.65

Table 2: Final total spent on project

Build Materials	Quantity	Final Cost
Stillwater Steel		1025.5
Surplus Center		972.85
McMaster-Carr		12.41
Grainger		93.86
Napa Auto Parts		20.64
Lowe's		95.08
Atwoods		47.96
Walmart		79.82
Hunzicker Brothers		19.74
Total		$2,367.86

After completing all of the design and fabrication, the team was able to come in slightly under budget due in great part to the generosity of the men at the BAE lab who devoted a great deal of time and labor towards the project at a discounted price.

Testing Methods:

In order to obtain an accurate performance representation of the distribution augers; it is essential to design a testing method which will operate under conditions which can be consistently repeated. The testing system currently used by the AGCO engineering department utilizes a tarp system that is loaded with material, and is then wound around a spool to introduce material into the system. An example of this testing system can be seen in the following figures.

Figure 1: Overview of AGCO testing system.

Weighing the experience and expertise of our advisors at AGCO, our group has decided to utilize this type of testing system in our design. This apparatus will allow for variation in introduction of the material into the system as well as allowing for mechanical means of powering the system. Figure 4 illustrates the method of powering the conveyor via a hydraulic motor which will allow for a wide range of material flow rate adjustment. By powering the conveyor system in this manner it eliminates the possibility of human error found in systems which require manual labor to power. The tarp conveyor will be loaded with 30.6 pounds of material consisting entirely of straw. The amount of material needed to achieve our desired flow rate of twenty-five tonne/hour was calculated using equations and numbers outlined in table 3.

Table 3: Material Flow rate Calculations

Material Flowrate Calculations			
Parameter	**Description**	**Equation**	**Value**
Q_{mog}	Material other Grain Flowrate (tonne/hour)	$Q_{mog} = v * b * w * \frac{1}{707.12}$	25.00
C1	lb/tonne	Conversion Factor	2204
C2	seconds/hour	Conversion Factor	3600
Q_a	Actual Flowrate (lb/s)	$Q_a = Q_{mog} * \frac{C1}{C2}$	15.31
Wm	Weight of Material (lb)	Scale Reading	30.00
b	bushels of wheat/acre	User Defined	100
w	width of header (ft)	User Defined	40
v	velocity of tractor (mph)	User Defined	4.42
l	length of conveyor (in)	From SolidWorks Model	120
r	radius of spool (in)	From SolidWorks Model	0.75
ω	Angular Velocity of Spool (RPM)	Variable on flowrate	775
t	time required to roll up entire conveyor (sec)	$t = \frac{l}{\omega * 2\pi r \div 60}$	1.97
Q_c	Flowrate produced by conveyor (lb/s)	$Q_c = \frac{W_m}{t}$	15.21

The desired flow rate needed was determined using the top equation which represents a combine in the field traveling at a given velocity, v, width of header, w, and bushels per acre of wheat, b. Using this equation the optimal flow rate needed for testing was found to be 25 metric tonnes per hour. This number was then converted into English units of pounds of material per second (Qa), using the second equation. After converting and determining the pounds of material per second required, the speed of the conveyor was calculated. Knowing the amount of material in pounds that could be distributed onto the tarp, the time to completely empty the conveyor was calculated. With 30.6 lb of material, the conveyor would need to empty completely in 2 seconds to achieve the flow of MOG seen in real combines.

Once the flow rates had all been calculated, the baseline data trials were designed. To begin, the material will be distributed in three different loadings. Evenly distributed, right side overloaded, and left side overloaded was used across the area of the tarp for the trials. A grid of 20” x 20” squares was drawn onto the tarp to ensure a repeatable loading system was used throughout all trials the material was weighed, and distributed into each of the squares. Figure 2 shows Kyle Mueggenborg placing pre weighed material onto the grid system on the tarp.

Figure 2: Placing desired weight of material onto the grid system

Examples of material distribution on the tarp can be seen in figures three and four. This material mixture and flow rate was suggested by AGCO to accurately reflect the material entering the distribution augers of combines harvesting in the field.

Figure 3: Material Conveyor system loaded evenly.

Figure 4: Material conveyor with left side over loaded.

Following the decision to utilize this type of conveyor system to introduce material into the system, other physical requirements were then considered. One such consideration was the height of which the conveyor will need to be elevated off of the ground in order to properly insert material into the distribution augers. Through observation of the test stand provided by AGCO it was decided that the conveyor will need to be approximately 2 feet higher than the distribution augers in order for the momentum of the material to translate laterally the distance from the edge of the test stand to the center of the augers. Secondly, the strength of the stand holding the conveyor system and material was considered. A stand was designed using 3in. square tubing and cross bracing to support the conveyor system. The top of said stand will be covered with a small gauge sheet metal in order to give the tarp a smooth surface to slide on. Locking casters were then added to the stand to allow easy movement around the shop during loading and operating of the feeding system. In order to ensure that the test stand would withstand all of the loading of the material, and the weight of individuals walking around on the platform, a strengths analysis was conducted on the conveyor. This analysis can be seen in Table 4, and the SolidWorks model which was used to simulate the test stand and to gain an knowledge of weights and dimensions can be seen if Figure 5.

Figure 5: Final model of material conveyor used for testing

A test stand was constructed by the engineers at AGCO in order for us to begin testing and modifying the current design. The testing apparatus is a modified threshing system from a Gleaner combine, and was assembled using new parts in Hesston, Kansas. It will not have the rotor in it, but it has the distribution augers and accelerator rolls required for testing. The absence of the rotor will allow for easier access for delivering material into the system as well as help in the observation of material flow via an overhead view. The power requirements of the system were determined using the power and speed diagram provided by AGCO Engineering,

Figure A1. The power requirements for factory performance are 25 horsepower at 1050 revolutions per minute. Figure 6 presents the test stand in its current condition as it is being utilized for testing.

Figure 6: Final assembled test stand

Two electric motors and the power take off on a tractor are used to completely power the test stand. The PTO on the tractor is being used to provide power to the rear distribution auger, and to allow for speed adjustability by either manipulating the throttle on the tractor or changing the PTO from 540 to 1000 RPM. The driveline from the tractor to the stand can be seen in figure 7.

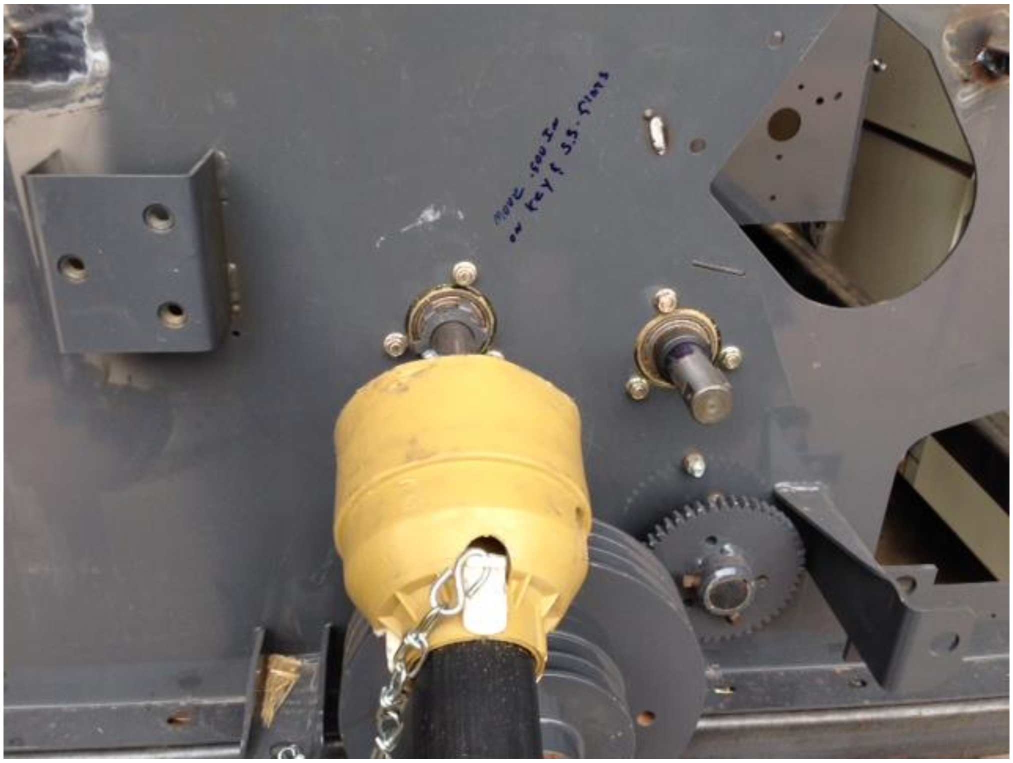

Figure 7: PTO powering the rear distribution auger

A ten horsepower electric motor provided by AGCO is being used to provide power to the accelerator rolls. This was accomplished using a V-Belts power transmission system which was designed using Shigley's Mechanical Engineering Design. The design calculations for the v-belt powering systems for both electric motors can be seen in Table 4.

Table 4: V-Belt design calculations

Parameter	Description	Equation	Value	
			5 hp	10 hp
d	small sheive diameter (in.)	constant	5	6.5
D	large sheive diameter (in.)	constant	12.75	10.75
ω_R	DriveR Speed (RPM)	Known	1750	1750
R	Reduction	$R = \frac{d}{D}$	0.392	0.605
ω_N	DriveN Speed (RPM)	$\omega_N = R * \omega_R$	686	1058
C	center-to-center distance (in.)	constant	19.375	19.75
n_d	design factor	Table 17-15	1.1	1.1
L_p	Pitch Length (in.)	$L_p = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$	66.85	66.58
H_{nom}	nominal power (hp)	Known	5	10
H_d	design power (hp)	$H_d = H_{nom} K_s n_d$	6.05	12.1
H_a	power allowable (hp)	$H_a = K_1 K_2 H_{nom}$	4	7.8
V	belt speed (ft/min)	$V = \frac{\pi d \omega_R}{12}$	2289.6	2976.5
K_s	Service Factor	Table 17-15	1.1	1.1
K_1	Angle of Contact Correction	Table 17-13	0.8	0.78
K_2	Belt Length Correction	Table 17-14	1.0	1.0
N_b	number of belts	$N_b = \frac{H_d}{H_a}$	1	2
B_s	Belt Cross section	Table 17-12	B	B

After performing all of the calculations for the power transmission system, it was determined that one cross section B belt would be used for the 5 hp motor, and two B belts would be used for the 10 hp motor. Figure 8 is an illustration of the accelerator roll power transmission system used throughout the duration of testing.

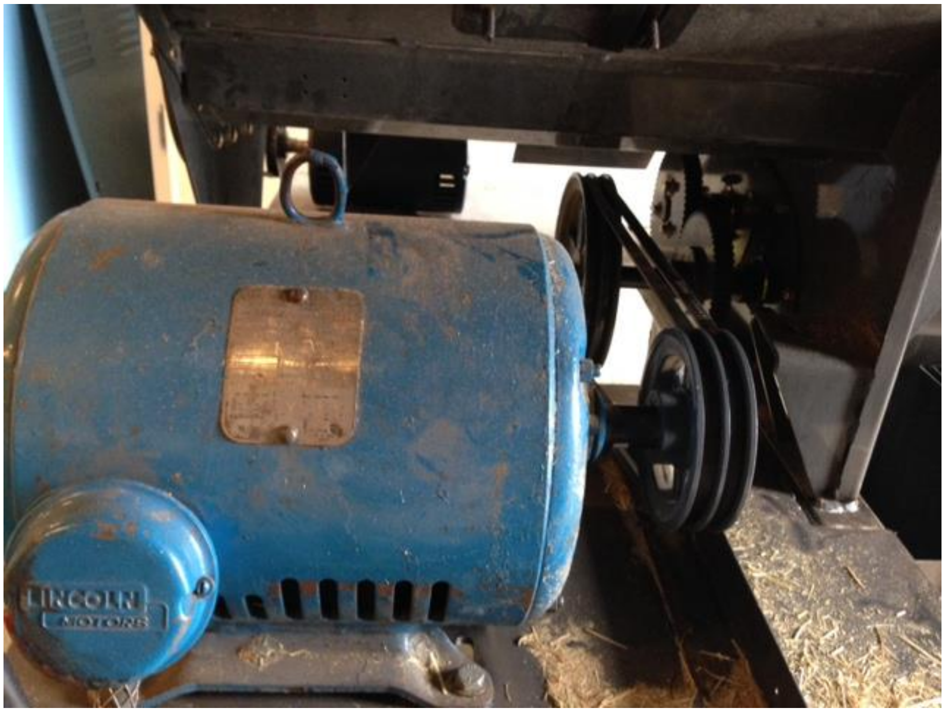

Figure 8: Accelerator roll power transmission system

The second electric motor on the test stand is being used to provide constant speed and power to front distribution auger. After consulting AGCO and the power and speed diagram it was determined that a five horsepower motor would be sufficient to power the lone auger. Figure 9 Shows the electric motor purchased from Surplus Center, and the manner in which it is transmitting power to the distribution auger.

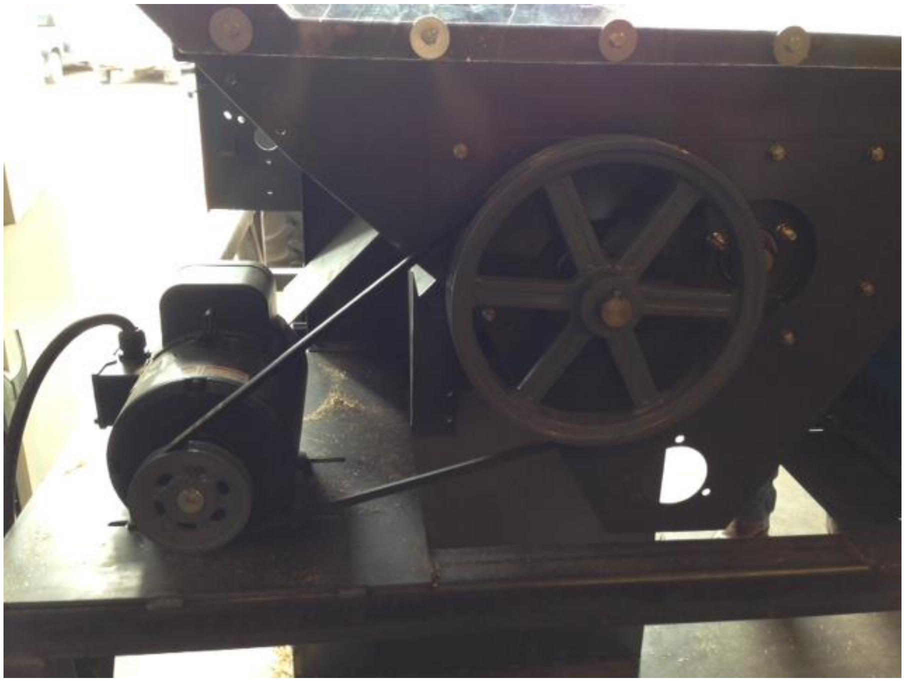

Figure 9: Front Distribution Auger Power System

The entire testing system can be seen in figure 10, and in this picture the elevated material conveyor is on the left hand side, and the test stand is on the right side and the PTO driveline for the tractor can be seen in yellow.

Figure 10: Entire Testing Apparatus

In order to ensure that both the conveyor and test stand frame could withstand both the static and dynamic stresses placed on them a strengths analysis was conducted. This analysis was performed after initial modeling and material selection was completed, but before any fabrication began. The calculations and equations used can be seen in Table 5.

Table 5: Strengths Analysis of Testing Apparatus

Parameter	Description	Equation	Value	
			5 hp	10 hp
d	small sheive diameter (in.)	constant	5	6.5
D	large sheive diameter (in.)	constant	12.75	10.75
ω_R	DriveR Speed (RPM)	Known	1750	1750
R	Reduction	$R = \frac{d}{D}$	0.392	0.605
ω_N	DriveN Speed (RPM)	$\omega_N = R * \omega_R$	686	1058
C	center-to-center distance (in.)	constant	19.375	19.75
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L_p	Pitch Length (in.)	$L_p = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$	66.85	66.58
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H_a	power allowable (hp)	$H_a = K_1 K_2 H_{nom}$	4	7.8
V	belt speed (ft/min)	$V = \frac{\pi d \omega_R}{12}$	2289.6	2976.5
K_s	Service Factor	Table 17-15	1.1	1.1
K_1	Angle of Contact Correction	Table 17-13	0.8	0.78
K_2	Belt Length Correction	Table 17-14	1.0	1.0
N_b	number of belts	$N_b = \frac{H_d}{H_a}$	1	2
B_s	Belt Cross section	Table 17-12	B	B

After performing all of the calculations two values stand out the most; the first is the deflection of the longest support beams in both stands. Both of these numbers are more than acceptable due to the small amount of deflection calculated. The second value which of the most importance is the factor of safety for stress failure, and on both the test stand and conveyor the factor of safety is over 20 which will ensure infinite life. The factor of safety was selected to be so high in order to ensure safety to those individuals walking on top of the conveyor platform, and to ensure that the vibrations felt by the test stand frame would not have a significant impact on the life of the testing apparatus.

` Performance testing will be conducted in two phases. The first phase will be to analyze the current distribution augers in the assembly. Doing so will provide the team with a base line performance characteristics of the system; as well as uncovering the flaws in the system. Anticipated performance characteristics will be one in which the material is not distributed evenly before entering the accelerator roll, but rather the material will be biased to one side of the system or the other. Upon gathering the results of the baseline testing, design modifications will be finalized. Phase two of the testing will begin at this point, consisting of analyzing the impact of variable speed rates of the augers on the efficiency of material distribution and removal of a plate covering the far right hand side of the auger trough. The plate that was mentioned can be seen in Figure 11.

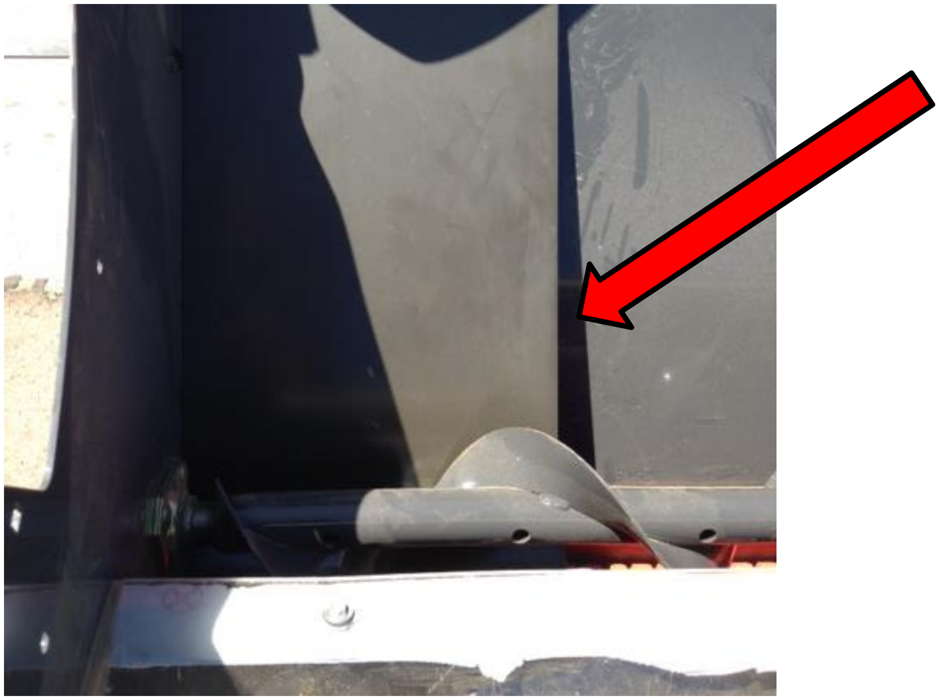


Figure 11: Plate partially covering accelerator rolls

Both the original and modified designs will be tested in the same manner in which the material exiting the accelerator rolls will be collected in four bins, seen in figure 12, distributed evenly across the bottom of the stand. These bins will collect the material which will subsequently be weighed to determine the distribution of the material. A minimum of three trials per flow rate per speed will be conducted in order to minimize the relative error associated with conducting a single trial, and a three trial minimum was suggested by both AGCO and Dr. Randy Taylor.

Figure 12: Collection Bins.

Data Collection:

Data was collected for each trial by measuring the tare weight of each collection bin prior to the trial and the final weight of the bin after the material had been processed by the system and discharged into the bins. In order to receive an accurate representation of the material leaving a rotor, gridlines were drawn onto the feeding tarp to create 20 in. x 20 in. squares. This allowed for accurate and repeatable distribution of the material onto the feeding tarp. At times, more MOG drops from one side of the rotor than the other or vice versa. In order to represent this scenario, material was heavily loaded on one side of the tarp for one trial, and then heavily loaded on the other side of the tarp for another trial. These trials were executed alongside a trial where the material was evenly distributed on the tarp. After the material was processed by the distribution augers and discharged into the bins, each bin was weighed a second time to determine the amount of material in each bin. The tare weight, final weight, and material weight was then recorded in a data sheet and entered into the sample excel sheet shown in table 5, the entire data collection numbers can be seen in appendix C. The material weight was calculated using equation one.

Equation 1: Calculation of final weight of material

Material weight (lb) = final weight (lb) - tare weight (lb)

Table 5: Sample data collection and material calculation sheet

		Even Distribution (25/25/25/25)			
		Bin	Tare Weight	Final Weight	Material Weight
BASELINE	Trial 1	1	62.40	70.25	7.85
		2	62.60	72.90	10.30
		3	62.60	70.85	8.25
		4	62.60	65.90	3.30
	Trial 2	1	62.40	69.25	6.85
		2	62.60	73.65	11.05
		3	62.60	71.10	8.50
		4	62.60	67.55	4.95
	Trial 3	1	62.40	70.75	8.35
		2	62.60	74.75	12.15
		3	62.60	70.45	7.85
		4	62.60	65.65	3.05
	Average	1	Left		7.68
		2	Left Center		11.17
		3	Right Center		8.20
		4	Right		3.77
			Standard Deviation		0.62
					0.76
					0.27
					0.84

Upon completion of all testing and data collection of the current production model, the data collected was graphed in excel to visually represent the numbers recorded. By doing so it is easier to observe how exactly the material is distributed when exiting the accelerator rolls. Figure 13 presents the data collected in first baseline trials in which an even material distribution was laid out on the conveyor.

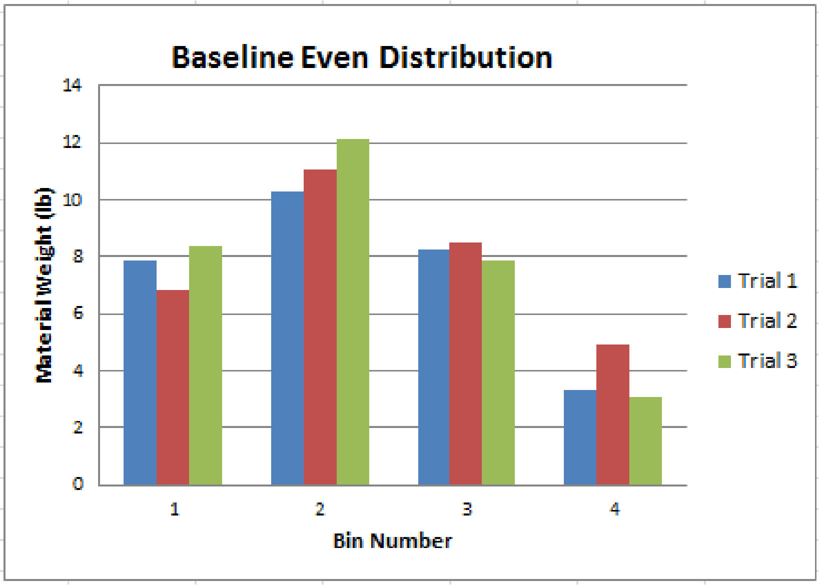


Figure 13: Baseline even distribution chart

It is easily seen that there is a repeated trend in each of the three trials in which the most material is deposited into bin 2 and the least amount of material is deposited in bin 4. After completing the even distribution trials, the team then began to test the various material distribution in which one side of the conveyor would be overloaded, graphical representation of this can be viewed in figure 14.

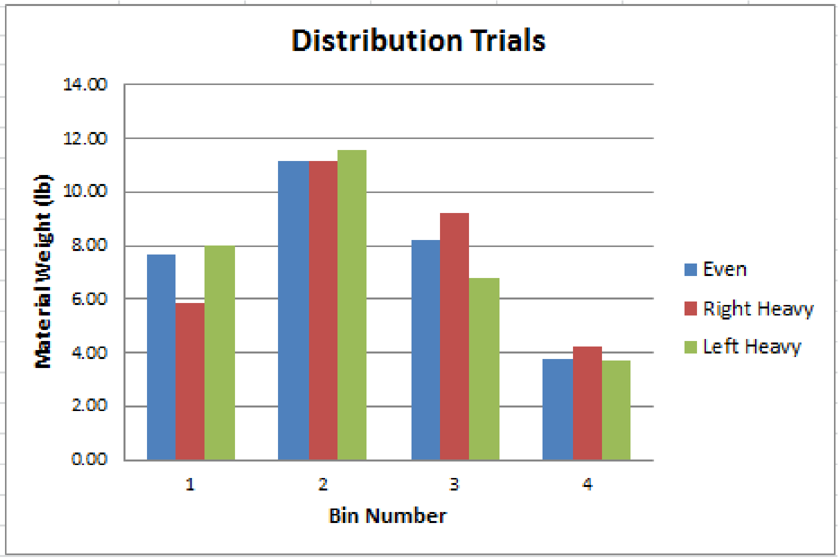


Figure 14: Modified distribution trials

A similar trend was observed during these trials, and the same general shape of the distribution remained the same. Although this was not desirable to see that the material was not evenly distributed before exiting the accelerator rolls, it was a great accomplishment to be able to observe repeated data. By having data that continuously remained the same, the team was able to achieve its main objective of developing a testing apparatus which would produce consistent results. After determining the base line performance of the distribution augers, design modifications were then considered.

Design Considerations:

A. Assumptions

1. The testing apparatus accurately reflects the conditions of material entering the distribution augers found in the field.

2. The new design shows improved distribution of material as it exits the accelerator rolls based on data collected during testing.
3. The alternate design is compatible with current production cleaning system.
4. The augers will perform the same regardless of the crop being harvested

B. Proposed Design Changes

Speed

Auger speed will be manipulated and resulting performance will be measured. In order to properly test the effect of changing the speed of the augers, they will be required to be powered independently of the accelerator rolls. To accomplish this task, the accelerator rolls will remain powered by the 10 HP motor, and one distribution auger will be powered by a smaller 5HP electric motor. The remaining distribution auger will powered by the PTO of the tractor allowing excellent control of the auger speed.

Plate Removal

Based on the performance observed and data collected during baseline trials it was determined that the plate covering the far right side of the auger trough was hindering the MOG from entering that side of the accelerator roll. The far right side continuously received the least amount of material deposited into the collection bin, and this could be attributed to this plate. By removing the plate, the team expected to see improved distribution results.

Design/Test Stand Alterations:

As stated earlier, the first step was to operate one of the augers at a different speed. Two different speeds were used. The first test consisted of one auger running at 400 RPM and the second test consisted of running the same auger at 900 RPM these wide range of RPMs was selected in order to immediately determine whether or not speed was an influencing factor on distribution. By conducting a really high and low speed test, the team was able to eliminate wasted time on testing in steps if there turned out to be no relationship between speed and distribution of material. During speed testing, the team continued to use three trials for each modification. The data was collected in the same manner, and the results can be seen in Figure 15.

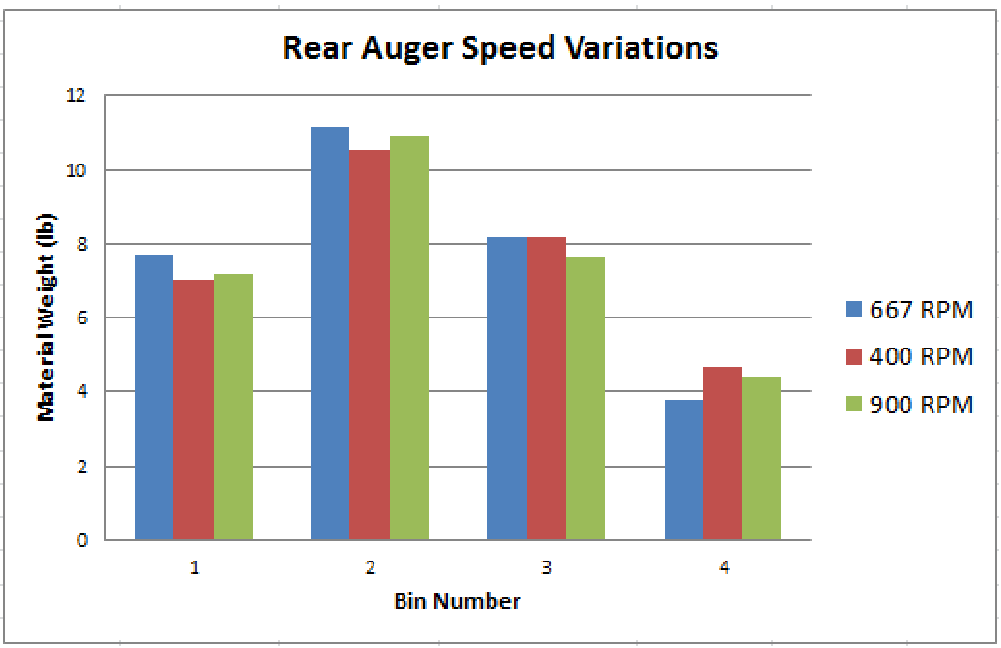


Figure 15: Speed trial graphical data

After examining the data received from these tests it was obviously confirmed that there is no correlation between speed and distribution of the material by the distribution augers. Baseline data is plotted next to the speed variations, and all three speeds produce the same results. This entire data is outlined in Appendix C.

After evaluating videos of the previous test runs, the group found a modification that could be made to improve the material distribution to the fourth bin. Above the conveyer augers on the right side of the trough, a plate was mounted that was intended to keep grain from overloading on the right side. From testing the group found that the MOG was being blocked from entering the augers where that plate was mounted. Although the plate serves a purpose on production Gleaner combines, the group decided to remove the plate for several tests. These tests consisted of material evenly weighed on the tarp and with the augers set at 677 RPM, which was the setup for the baseline testing. These tests resulted in a significant improvement in the overall distribution of material in each bin which can be seen in Figure 16.

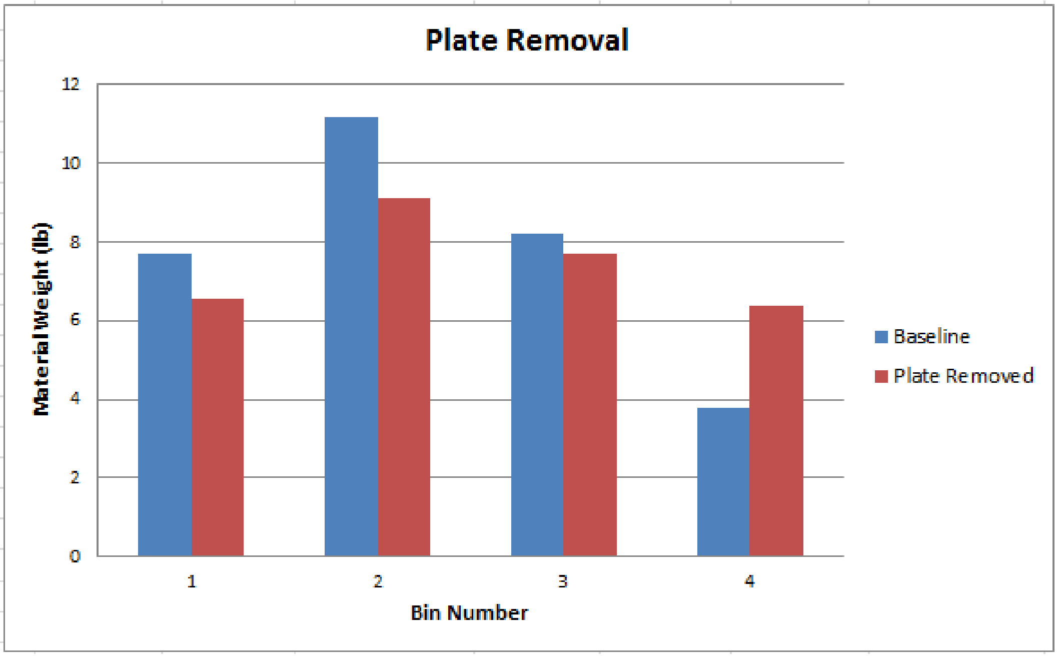


Figure 16: Material Distribution with plate removed

The data displayed in Figure 16 reveals that the best performance solution found during testing was to remove the plate covering part of the distribution augers. In doing so the material collected in bin four was increased and material in bin two; consistently the highest, was decreased which resulted in a better distribution across the width of the accelerator rolls.

Conclusions

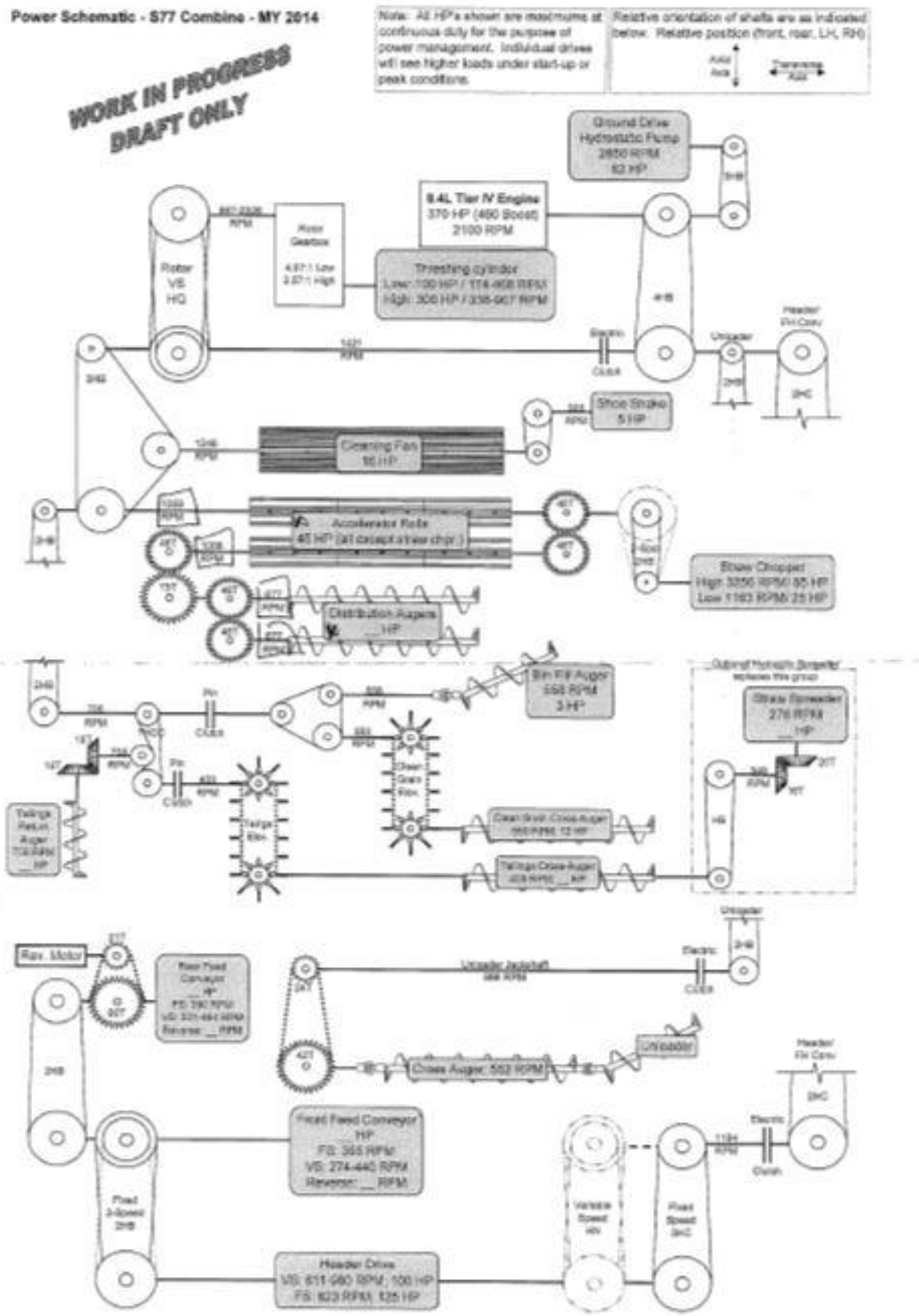
Upon completion of all testing and data collection, the team reevaluated the project objective and scope of work in order to ensure that all of the criteria of the project had been met. When going over the objectives it was clear that all four objectives set out for the team had been accomplished. The first objective of establishing a repeatable testing apparatus using current production gleaner parts was completed early in the spring semester, and the data collected during testing supports that the test stand produces results which can easily be reproduced. Using the test stand and conveyor constructed, baseline performance of current production setup was evaluated. This was completed in three stages in which different material distributions were used prior to the material ever entering the augers. The data collected from all nine of these trial runs produced results which all related to each other in the way the material exited the accelerator rolls. The third objective of analyzing auger speed on distribution performance was analyzed next, and the data collected from these trials showed that there is no correlation between the speed at which the rear distribution auger is operated at and the distribution of the material when exiting the accelerator rolls. After removing a piece of plate steel covering the far right edge of the auger trough, and collecting improved distribution data, the team was able to suggest the best solution to improving the performance of the distribution augers. This suggestion comes backed by the entire data set collected and analyzed during the project. The team's suggestion for optimizing the performance of the distribution augers will be to manipulate the flighting of the augers in order to move more material other than grain to the right side of the accelerator rolls. Upon designing a better flighting system it is the teams' opinion that the Gleaner combine will show improved performance not only in the laboratory setting, but also in the fields harvesting crops.

References:

1. Buescher, Walter M. (1991), *Plow Peddler*, Macomb, Illinois, USA: Glenbridge Publishing
2. Budynas, Richard G., J. Keith. Nisbett, and Joseph Edward. Shigley. *Shigley's Mechanical Engineering Design*. New York: McGraw-Hill, 2011. Print
3. Hibbeler, R. C. *Engineering Mechanics Statics and Dynamics*. Upper Saddle River, NJ: Pearson, 2013. Print

Appendix:

Appendix A: Power and Speed Diagram



Appendix B: SolidWorks Models and Drawings

Appendix C: Data

BASELINE	Distribution Auger Performance Evaluations												
	Material Distribution												
		Even Distribution (25/25/25/25)				Right Overload (35/35/15/15)				Left Overload (35/35/15/15)			
		Bin	Tare Weight	Final Weight	Material Weight	Bin	Tare Weight	Final Weight	Material Weight	Bin	Tare Weight	Final Weight	Material Weight
	Trial 1	1	62.40	70.25	7.85	1	62.40	68.00	5.60	1	62.40	70.50	8.10
		2	62.60	72.90	10.30	2	62.60	73.75	11.15	2	62.60	74.15	11.55
		3	62.60	70.85	8.25	3	62.60	72.10	9.50	3	62.60	69.30	6.70
		4	62.60	65.90	3.30	4	62.60	67.00	4.40	4	62.60	66.60	4.00
	Trial 2	1	62.40	69.25	6.85	1	62.40	68.30	5.90	1	62.40	70.50	8.10
		2	62.60	73.65	11.05	2	62.60	73.85	11.25	2	62.60	74.50	11.90
		3	62.60	71.10	8.50	3	62.60	71.50	8.90	3	62.60	69.20	6.60
		4	62.60	67.55	4.95	4	62.60	65.85	3.25	4	62.60	66.15	3.55
	Trial 3	1	62.40	70.75	8.35	1	62.40	68.45	6.05	1	62.40	70.13	7.73
		2	62.60	74.75	12.15	2	62.60	73.70	11.10	2	62.60	73.95	11.35
		3	62.60	70.45	7.85	3	62.60	71.85	9.25	3	62.60	69.75	7.15
		4	62.60	65.65	3.05	4	62.60	67.65	5.05	4	62.60	66.25	3.65
	Average	1	Left		7.68				5.85				7.98
		2	Left Center		11.17				11.17				11.60
		3	Right Center		8.20				9.22				6.82
		4	Right		3.77				4.23				3.73
			Standard Deviation		0.62				0.19				0.17
					0.76				0.06				0.23
					0.27				0.25				0.24
					0.84				0.74				0.19

Table 1: Baseline data

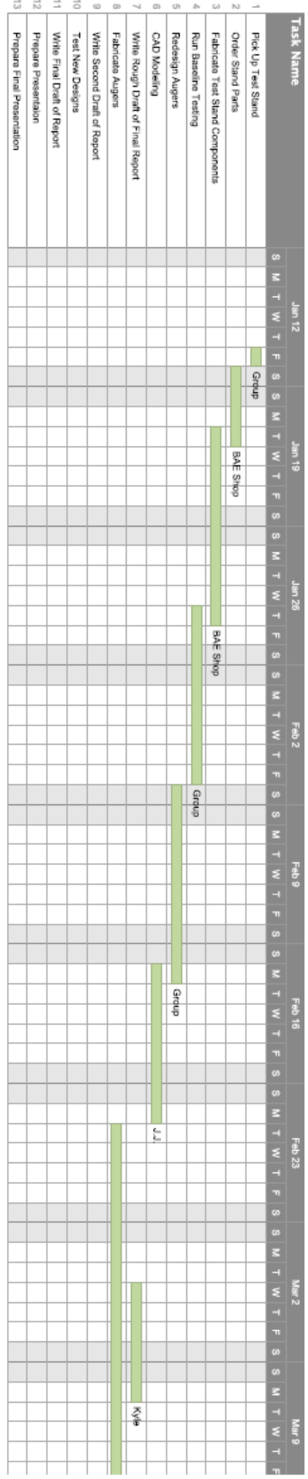
Speed Trials		400 RPM				900 RPM			
		Even Distribution (25/25/25/25)				Even Distribution (25/25/25/25)			
		Bin	Tare Weight	Final Weight	Material Weight	Bin	Tare Weight	Final Weight	Material Weight
	Trial 1	1	62.40	69.15	6.75	1	62.40	69.80	7.40
		2	62.60	72.40	9.80	2	62.60	73.85	11.25
		3	62.60	70.90	8.30	3	62.60	70.45	7.85
		4	62.60	68.35	5.75	4	62.60	66.80	4.20
	Trial 2	1	62.40	69.40	7.00	1	62.40	69.00	6.60
		2	62.60	73.90	11.30	2	62.60	74.00	11.40
		3	62.60	70.55	7.95	3	62.60	70.50	7.90
		4	62.60	66.70	4.10	4	62.60	67.05	4.45
	Trial 3	1	62.40	69.75	7.35	1	62.40	69.90	7.50
		2	62.60	73.15	10.55	2	62.60	72.65	10.05
		3	62.60	70.95	8.35	3	62.60	69.75	7.15
		4	62.60	66.75	4.15	4	62.60	67.25	4.65
	Average	1	Left		7.03				7.17
		2	Left Center		10.55				10.90
		3	Right Center		8.20				7.63
		4	Right		4.67				4.43
			Standard Deviation		0.25				0.40
					0.61				0.60
					0.18				0.34
					0.77				0.18

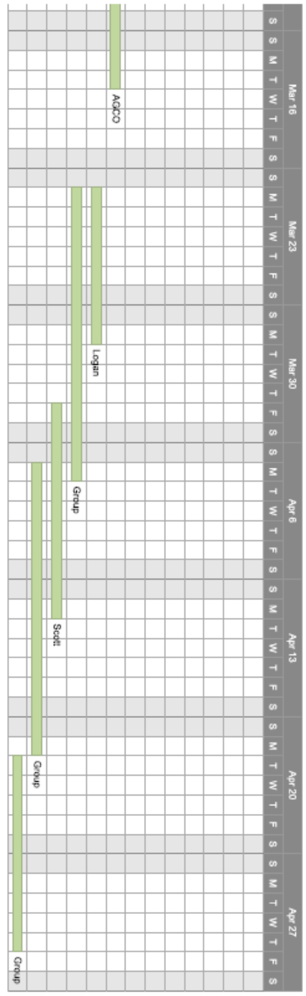
Table 2: Speed Variation Data.

Plate Removed		677 RPM			
		Even Distribution (25/25/25/25)			
		Bin	Tare Weight	Final Weight	Material Weight
	Trial 1	1	62.40	69.00	6.60
		2	62.60	71.85	9.25
		3	62.60	70.05	7.45
		4	62.60	69.05	6.45
	Trial 2	1	62.40	69.05	6.65
		2	62.60	71.60	9.00
		3	62.60	70.80	8.20
		4	62.60	68.75	6.15
	Trial 3	1	62.40	68.85	6.45
		2	62.60	71.65	9.05
		3	62.60	70.05	7.45
		4	62.60	69.15	6.55
	Average	1	Left		6.57
		2	Left Center		9.10
		3	Right Center		7.70
		4	Right		6.38
			Standard Deviation		0.08
					0.11
					0.35
					0.17

Table 3: Plate-removed Data

Appendix D: Gantt chart





Mar 16
Mar 23
Mar 30
Apr 6
Apr 13
Apr 20
Apr 27
AGCO
Logan
Group
Scott
Group
Group

Appendix E: Final Presentation

Scott Harris

Kyle Mueggenborg

Logan Nightengale

Jeremiah Pine

AGCO
Your Agriculture Company

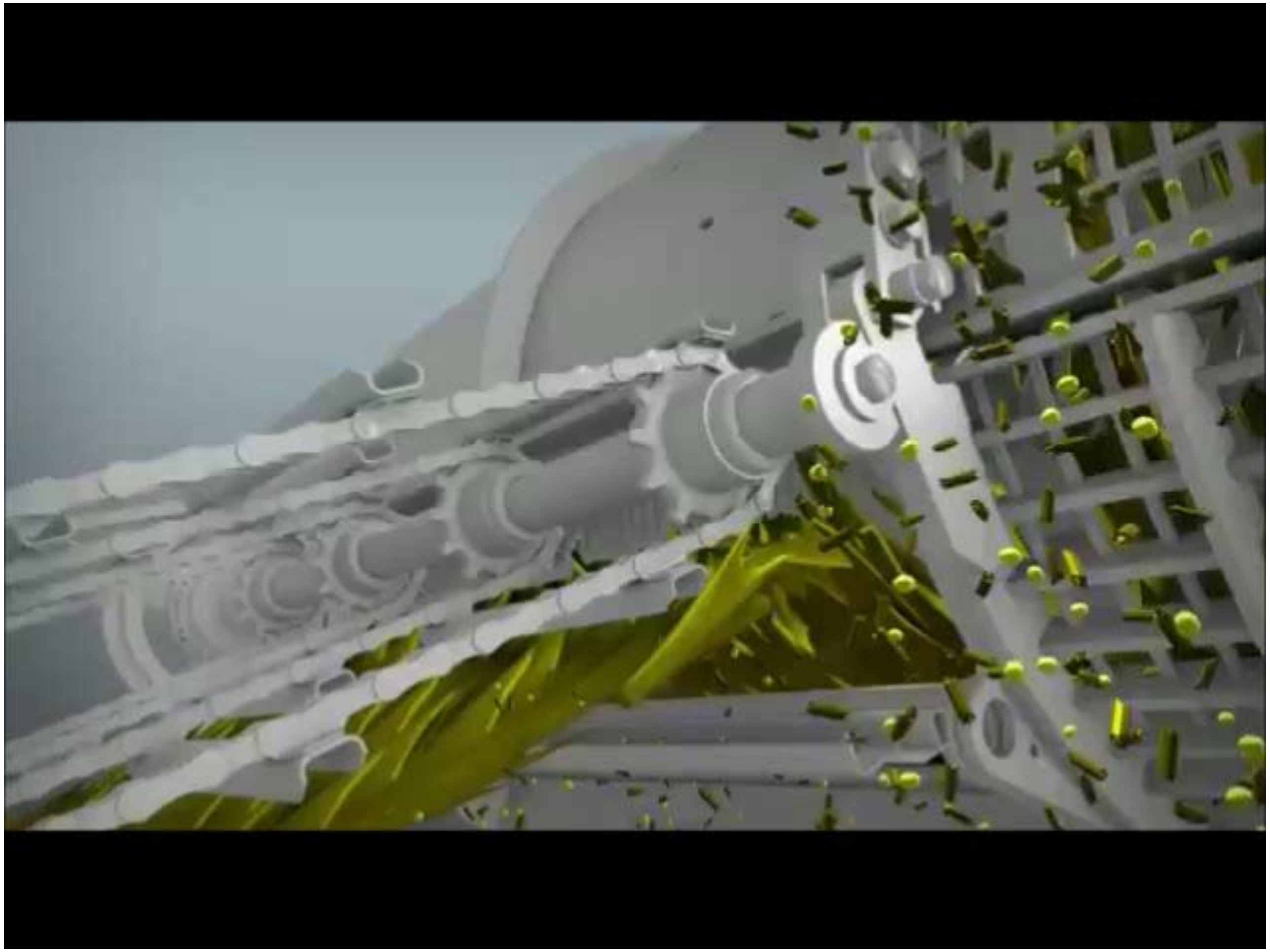
Gleaner Distribution Auger Testing System

Agenda

1	Background
2	Design
3	Testing
4	Results and Conclusions

Gleaner S77

Gleaner Transverse Combine



Project Objectives

- Develop effective testing apparatus using current Gleaner assemblies
- Determine baseline performance of production augers
- Determine alternative solutions for improving distribution
- Test alternative distribution techniques
- Analyze the performance of each alternative parameter
- Suggest the best solution based on experimental data collected

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Assumptions

- Testing apparatus accurately reflects the conditions of material entering the distribution augers found in the field
- New design shows improved distribution of material as it exits the accelerator rolls based on data collected during testing
- Alternate design is compatible with current production cleaning system
- Augers will perform the same in straw only, and grain and straw mixture
- New design cannot exceed current diameter due to space constraints

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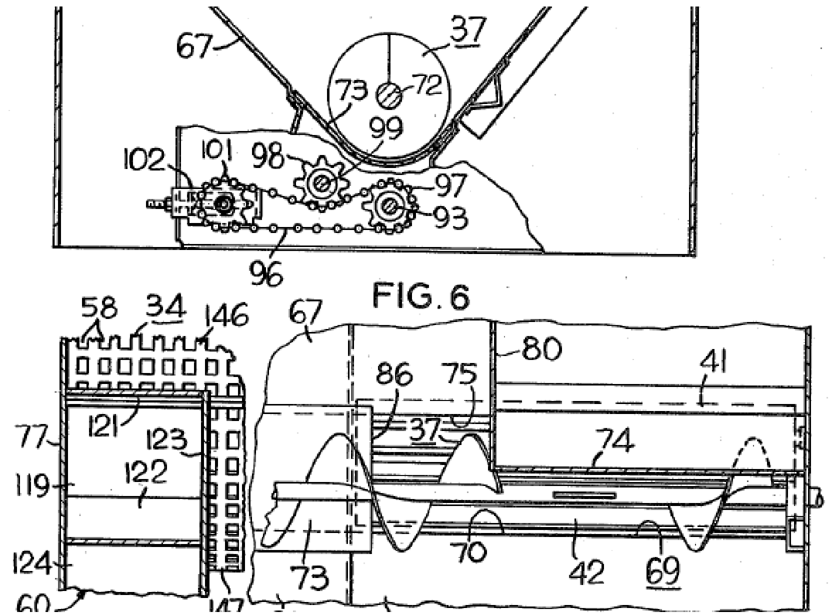
Patent Search

- We found six patents pertaining to our project dating from 1979 to 1990
  - 4180081
  - 4444208
  - 4457316
  - 4458697
  - 4716908
  - 4906218



- AGCO owns all six of the patents
- Only type of distribution system used amongst all other competitors

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Testing Apparatus

- AGCO provided the grain cleaning unit out of an S77 to use during testing
- Rotor was left out for improved observation of augers in action
- A stand for the unit was designed based on mass, size, and dynamic stresses

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Testing Apparatus

- Design Analysis Equations

Parameter	Description	Equation	Value
I	Moment of Inertia (in^4)	$I = \frac{1}{12} b_o h^3 - \frac{1}{12} b_i h^3$	1.536
σ_y	Yield Strength (psi)	Table A-20 (Shigley)	36000
σ_a	Calculated Stress (psi)	$\sigma_a = \frac{Total\ Weight}{A}$	1752.54
δ_{max}	Maximum Deflection (in)	$\delta_{max} = \frac{Fl^3}{48EI}$	0.11
F_s	Factor of Safety	$F_s = \frac{\sigma_y}{\sigma_a}$	21

Your Agriculture Company

Testing Apparatus

- Power Transmission
  - Using power and speed diagram provided, motors and speed were determined
  - 10 Hp motor for powering accelerator rolls
  - 5 Hp motor for powering front distribution auger
  - Power Take off from a tractor supplied power to rear auger
- V-Belts were used to transmit power from electric motors
- V-Belt design was performed using Shigley's Mechanical Design

Testing Apparatus

- V-Belt Design Calculations

Parameter	Description	Equation
R	Reduction	$R = \frac{d}{D}$
ω_N	DriveN Speed (RPM)	$\omega_N = R * \omega_R$
L_p	Pitch Length (in.)	$L_p = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$
H_d	design power (hp)	$H_d = H_{nom} K_s n_d$
H_a	power allowable (hp)	$H_a = K_1 K_2 H_{nom}$
V	belt speed (ft/min)	$V = \frac{\pi d \omega_R}{12}$
N_b	number of belts	$N_b = \frac{H_d}{H_a}$

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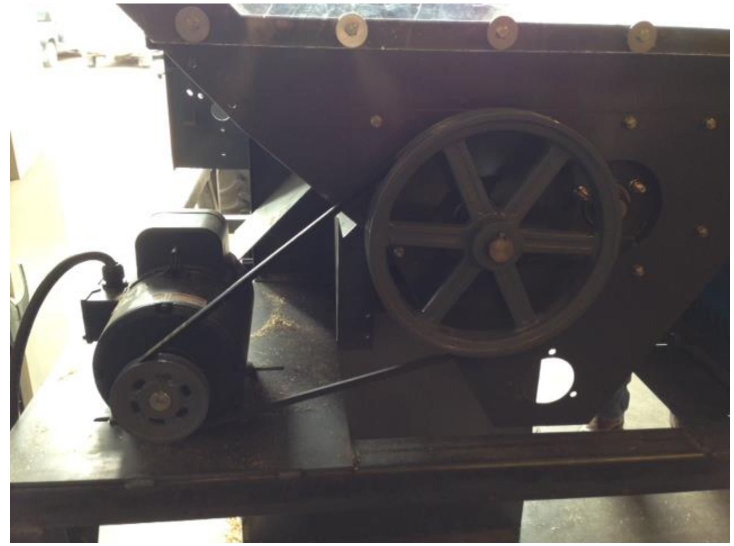
Testing Apparatus

Testing Apparatus



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Material Feeding System

- Material conveyor was based off of a design observed at AGCO
- Conveyor needed to be elevated in order to properly introduce material
- A high coefficient of friction on the tarp was required to keep material from sliding
- Lovejoy connection and hydraulic motor were used to power the conveyor
- A strengths analysis similar to the test stand was performed on the conveyor system as well

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Material Feeding System

Material introduction system used by AGCO to test feeder houses

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Material Feeding System

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Build Materials	Quantity	Estimated Cost	Total
3x3 Tubing ($/ft)	57	$7.42	$422.91
2x2 Tubing ($/ft)	160	$3.29	$527.04
1x1 Square Tubing ($/ft)	4	$1.03	$4.11
16 Gage Sheet Metal	2	$79.20	$158.40
14 Gage Sheet Metal	2	$99.00	$198.00
1 in Strap ($/ft)	10	$0.86	$8.60
Pillow Block Bearings	2	$13.95	$27.90
Ply Wood	1	$15.00	$15.00
Conveyor Drum	1	$20.00	$20.00
Labor	1	$250.00	$250.00
Power Transmission Supplies			
5 HP Motor	1	$495.95	$495.95
Motor Starter	1	$95.99	$95.99
10 HP Pulley	1	$40.95	$40.95
Accelerator Roll Pulley	1	$28.95	$28.95
5 HP Pulley	1	$20.95	$20.95
Distribution Auger Pulley	1	$52.95	$52.95
Key Stock	1	$15.00	$15.00
Drive Line	1	$199.99	$199.99
Hydraulic Hose Tip Male	2	$10.99	$21.98
Hydraulic Hoses	2	$11.99	$23.98
Miscellaneous			
Conveyor Tarp	1	$100.00	$100.00
Straw	3	$0.00	$0.00
Grain	2	$0.00	$0.00
Final Predicted Total			$2,728.65
		Final Total Spent	**$2,367.86**

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Testing Methods

- Use of supplied testing apparatus to establish baseline performance
- Material was measured and dispersed on tarp before entering the distribution augers
- Bins were placed below the accelerator rolls to collect material
- Material flow rate was determined to be 25 tonne/hour
- Flow rate of material during testing was calculated based on conveyor

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Flow Rate Calculations

Parameter	Description	Equation
Q_{mog}	Material other Grain Flowrate (tonne/hour)	$Q_{mog} = v * b * w * \frac{1}{707.12}$
Q_a	Actual Flowrate (lb/s)	$Q_a = Q_{mog} * \frac{C1}{C2}$
Q_c	Flowrate produced by conveyor (lb/s)	$Q_c = \frac{W_m}{t}$

*v = velocity of combine, b = bushels/acre, w = width of header

*C1 = conversion (2204 lb/tonne), C2 = conversion (3600 sec/hr)

*Wm = weight of material (lb), t = time to spool conveyor (sec)

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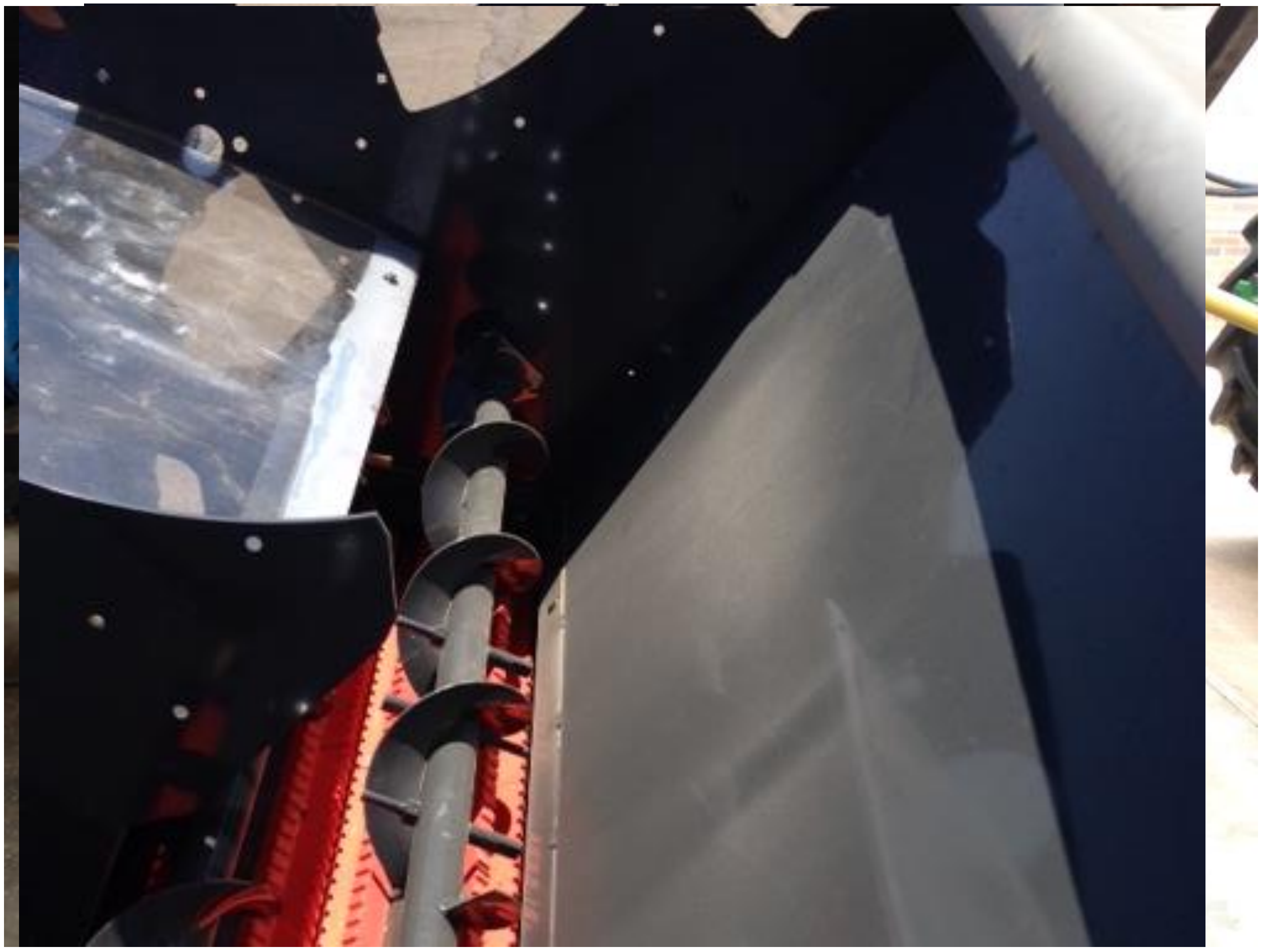
Testing Variables

- Speed of rear distribution auger was manipulated after initial tests
- Effect of speed on distribution performance was evaluated
- Plate covering right side of auger was removed in final trial
- Performance impacts with plate removed were also analyzed

Testing Methods Continued



Testing Video

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Data Collection

- Numbered bins placed below accelerator rolls to catch material
- Bins were weighed before and after each trial run
- Based on difference in weight, amount of material was calculated
- Weights were recorded into a table for evaluation

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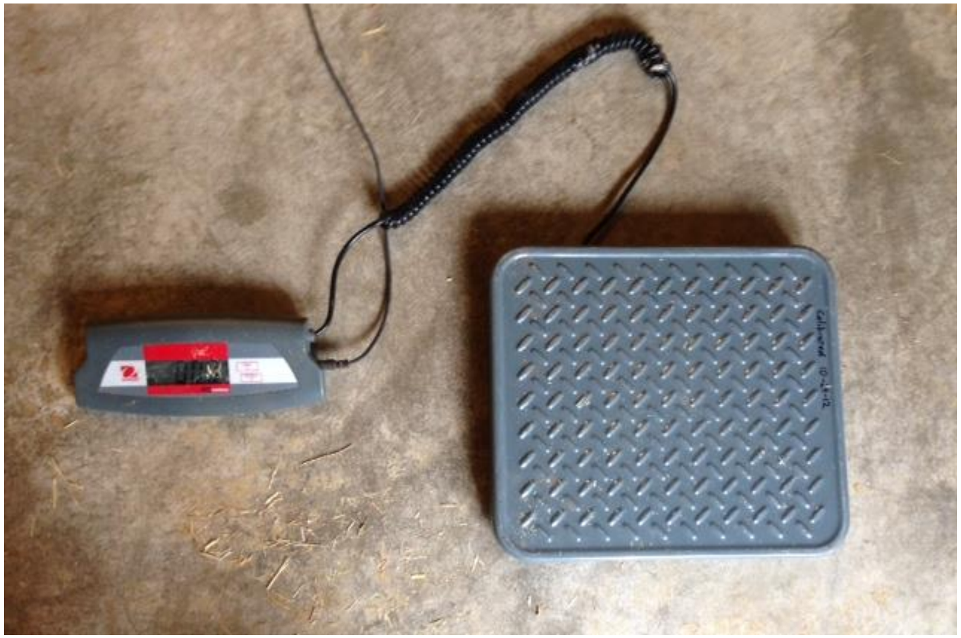
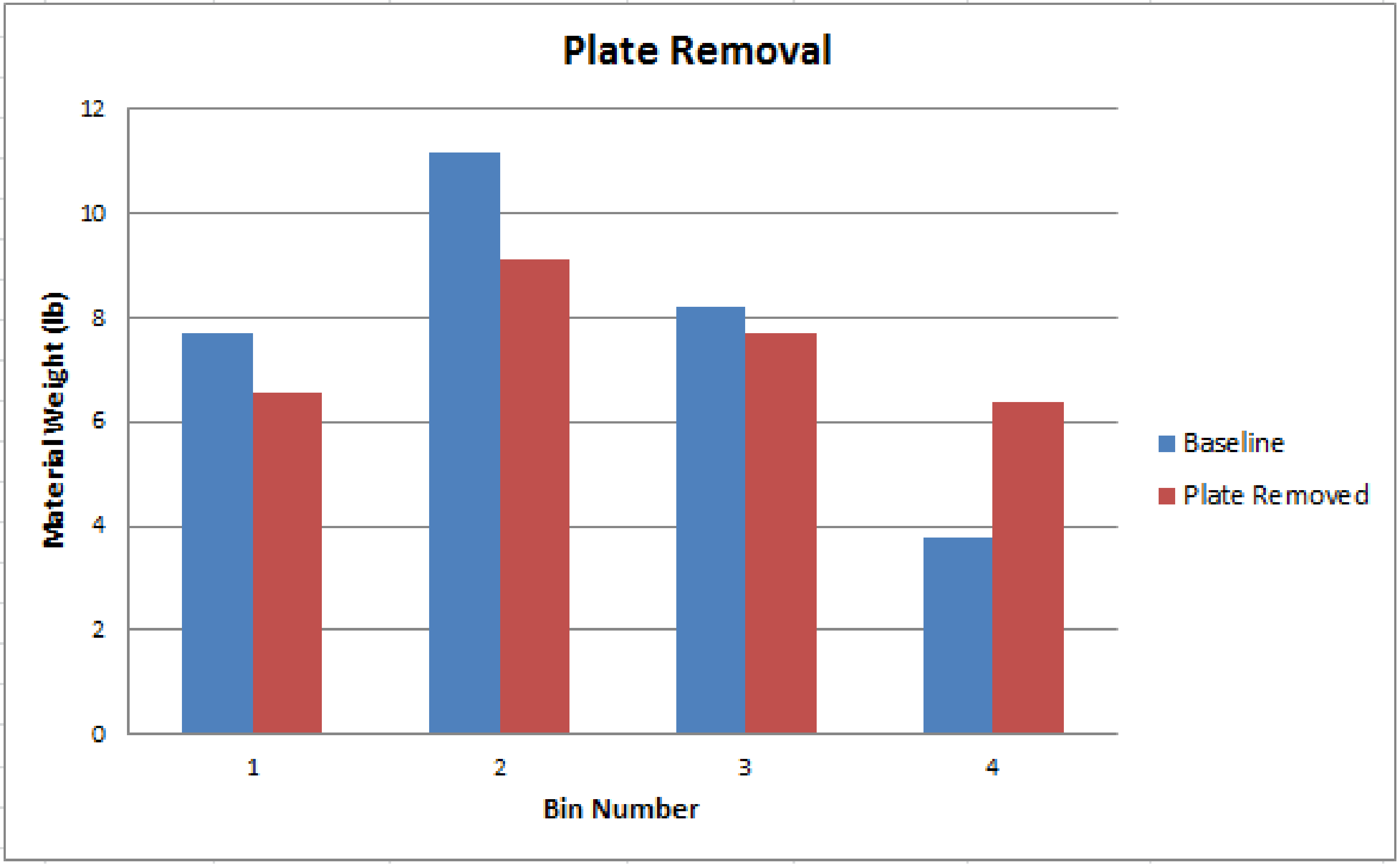
Data Collection



Data Collection

		Even Distribution (25/25/25/25)			
		Bin	Tare Weight	Final Weight	Material Weight
BASELINE	Trial 1	1	62.40	70.25	7.85
		2	62.60	72.90	10.30
		3	62.60	70.85	8.25
		4	62.60	65.90	3.30
	Trial 2	1	62.40	69.25	6.85
		2	62.60	73.65	11.05
		3	62.60	71.10	8.50
		4	62.60	67.55	4.95
	Trial 3	1	62.40	70.75	8.35
		2	62.60	74.75	12.15
		3	62.60	70.45	7.85
		4	62.60	65.65	3.05
	Average	1	Left		7.68
		2	Left Center		11.17
		3	Right Center		8.20
		4	Right		3.77
			Standard Deviation		0.62
					0.76
					0.27
					0.84

Data Analysis



Conclusions

- Objectives Achieved:
  - Designed and fabricated effective, repeatable testing method
  - Successfully evaluated performance characteristics
  - Performed testing for alternative parameters
  - Provided suggestions based on testing of alternative solutions

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Recommendations

- A change in flighting on the augers.
- Installing a canopy over part of the test stand if grain is used to test.
- Installing a more permanent way to keep the tarp out of the augers

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Acknowledgements

- Joe Biggerstaff
- Craig May
- Dr. Daniel Thomas
- Dr. Paul Weckler
- Wayne Kiner
- Dr. Randy Taylor

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Questions?

Gleaner Distribution Augers

AGCO Corporation

BAE 401: Senior Design Fall Report

Advisors: Joe Biggerstaff, Craig May, and Wayne Kiner

Prepared for: Dr. Daniel Thomas

Scott Harris

Kyle Mueggenborg

Logan Nightengale

Jeremiah Pine

Table Of Contents

Mission Statement:

To develop an accurate and consistent testing method in order to determining the performance of distribution augers currently utilized on Gleaner Combines, and to implement design improvements over current production models.

Problem Statement:

The purpose of this project is to create a testing system to determine the efficiency of distribution augers located in the grain cleaning process of Gleaner combines. Design Modifications made to distribution augers will be evaluated to determine the impact on the performance of the system.

Background:

With the world's growing demand for food and its heavy dependence on grain, today's famers are pressed to produce and harvest more grain in the shortest amount of time possible. Currently the worldwide wheat production is 700 million metric tons. In order to meet this demand, the combine harvester plays a vital role in efficiently reaping, threshing, and separating grain from material other than grain (MOG). AGCO (Allis-Gleaner Corporation) is a leading global manufacturer of agricultural equipment who produces several brands of combine harvesters. While AGCO's North American combine brands consist of Challenger, Gleaner, and Massey Ferguson, the Gleaner is the most unique and is the subject of the group's project.

In 1923, the Baldwin brothers of Nickerson, Kansas created a self-propelled combine harvester. The name "Gleaner" was used because a gleaner was considered to be someone who would collect leftover crops from fields. Thus, the name implied to a customer that a Gleaner combine would not leave grain on the field[1]. This emphasis on efficiency is still in practice today. The Gleaner's uniqueness is based on the design of the rotor (the rotor is the circular mechanism that is used to thresh the wheat). The rotor sits transversely with respect to the machine, while other competitor's machine's rotors are fixed axially within the combine. With the S7 and S8 models, Gleaner boasts a system that is leading the industry in obtaining the cleanest grain with the fewest losses from the rear of the machine. Last year, 600 S7 Gleaner units were produced at the AGCO factory in Hesston, Kansas.

The cleaning system is the target of the group's attention. In the current design of Gleaner combines, the rotor sits above a trough that houses two conveyer augers and two accelerator rollers. The augers' purpose is to feed and evenly distribute the material before it is dropped into the accelerator rollers. The accelerator rollers are present to speed up the materials descent from the auger conveyers. Without the accelerator rollers "throwing down" the material, the material leaving the augers would be falling at the speed of gravity. This does not necessarily pose a problem when the combine is on level ground, but when the machine is harvesting on a slope, a problem arises. Because the distance between the rollers and the grain pan (where the grain falls after leaving the rollers) is significant, gravity plays a major role in determining where and how the grain and MOG distributes. Thus, the accelerator rollers reduce the influence of gravity. On a slope, if the rollers were not present, the material would overload on one side. Side-overloading can cause spilling of grain from the side of the cleaning shoe. Because air from a fan is used to separate the MOG from the grain as soon as the material drops from the rollers, a constant velocity of air will not be reaching all of the material at the same time. This will result in unclean grain entering the grain tank which ultimately penalizes the producer.

For this project, the group is to submit an improved design of the current production conveyer augers. After performing a baseline test with the current Gleaner design, the team will observe and analyze the results in order to determine several possible solutions. These designs will then be tested in the same manner as the baseline trials. After analyzing the data and after discussion with AGCO's clients, the group will make a selection of the most practical design.

Project Objectives:

1. Establish an effective and repeatable testing apparatus using current production parts and assemblies found on Gleaner combines.

2. Determine the baseline performance of current production distribution augers on the Gleaner combine.

3. Design several viable alternate solutions for improving the distribution process

4. Construct alternate designs to implement into the testing apparatus

5. Analyze the performance of each alternate design to compare to the production model

6. Determine the best solution based on experimental data collected during testing.

Project Scope:

The project will include an analysis of the current distribution augers by developing a testing apparatus that can consistently reproduce the conditions seen by the Gleaner combine in the field. Design changes will then be implemented to the auger system, and the performance of the modifications will be tested under the same conditions using the same apparatus.

Testing Methods:

In order to obtain an accurate performance representation of the distribution augers; it is essential to design a testing method which will operate under conditions which can be consistently repeated. The testing system currently used by the AGCO engineering department utilizes a tarp system that is loaded with material, and is then wound around a spool to introduce material into the system. An example of this testing system can be seen in the following figures.

Figure 1: Overview of entire feeding system.

Figure 2: Tarp winding system wrapped around a powered spool.

Weighing the experience and expertise of our advisors at AGCO, our group has decided to utilize this type of testing system in our design. This apparatus will allow for variation in introduction of the material into the system as well as allowing for mechanical means of powering the system. By powering the conveyor system in this manner it eliminates the possibility of human error found in systems which require manual labor to power. The tarp will be loaded with 100 pounds of material consisting of a 70% grain and 30% straw mixture distributed evenly across the area of the tarp. This material mixture was suggested by AGCO to accurately reflect the material entering the distribution augers of combines harvesting in the field.

Following the decision to utilize this type of conveyor system to introduce material into the system, other physical requirements were then considered. One such consideration was the height of which the conveyor will need to be elevated off of the ground in order to properly insert material into the distribution augers. Through observation of the test stand provided by AGCO it was decided that the conveyor will need to be approximately 2 feet higher than the distribution augers in order for the momentum of the material to translate laterally the distance from the edge of the test stand to the center of the augers. Secondly, the strength of the stand holding the conveyor system and material was considered. A stand was designed using 3in. square tubing and cross bracing to support the conveyor system. The top of said stand will be covered with a small gauge sheet metal in order to give the tarp a smooth surface to slide on. Locking casters were then added to the stand to allow easy movement around the shop during loading and operating of the feeding system.

A test stand was constructed by the engineers at AGCO in order for us to begin testing and modifying the current design. The testing apparatus is a modified threshing system from a Gleaner combine, and was assembled using new parts in Hesston Kansas. It will not have the rotor in it, but it has the distribution augers and accelerator rolls required for testing. The absence of the rotor will allow for easier access for delivering material into the system as well as help in the observation of material flow via an overhead view. This apparatus will likely be modified further upon its arrival in Stillwater to better accommodate the material feeding system that will adjoin next to it. The power requiremtents of the system were determined using the power and speed diagram provided by AGCO Engineering. The power requirements for factory performance are 25 horsepower at 1050 revolutions per minute. The power and speed diagram can be found in Appendix A. Figure 3 presents the test stand in its current condition being currently assembled in Hesston. Figure 4 is an overhead view looking down on the accelerator rolls; however, distribution augers are not present in this picture, but can normally be seen directly above the accelerator rolls. This can be seen in figure 5 which is an old testing apparatus used by AGCO in previous tests.

Figure 3: Testing apparatus being assembled in Hesston

Figure 4: A picture of the accelerator rolls inside the threshing system.

Figure 5: Final assembled test stand

Figure 6: Entire Testing Apparatus

Performance testing will be conducted in two phases. The first phase will be to analyze the current distribution augers in the assembly. Doing so will provide the team with a base line performance characteristics of the system; as well as uncovering the flaws in the system. Anticipated performance characteristics will be one in which the material is not distributed evenly before entering the accelerator roll, but rather the material will be biased to one side of the system or the other. Upon gathering the results of the baseline testing, design modifications will be finalized. Phase two of the testing will begin at this point, consisting of analyzing the design changes made to the system. Preliminary design changes are outlined in the design considerations section. Both the original and modified designs will be tested in the same manner in which the material exiting the accelerator rolls will be collected in four bins distributed evenly across the bottom of the stand. These bins will collect the material which will subsequently be weighed to determine the distribution of the material. A minimum of ten trials per design will be conducted in order to minimize the relative error associated with conducting fewer trials.

Data Collection:

Data will be collected for each trial by measuring the tare weight of each bin prior to the trial. After the material has been processed by the distribution augers and discharged into the bins; each bin will be weighed a second time to determine the amount of material in each bin.

The tare weight, final weight, and material weight will be recorded in a data sheet and entered into the excel sheet shown in table 1. The material weight will be calculated using equation one.

Equation 1: Calculation of final weight of material

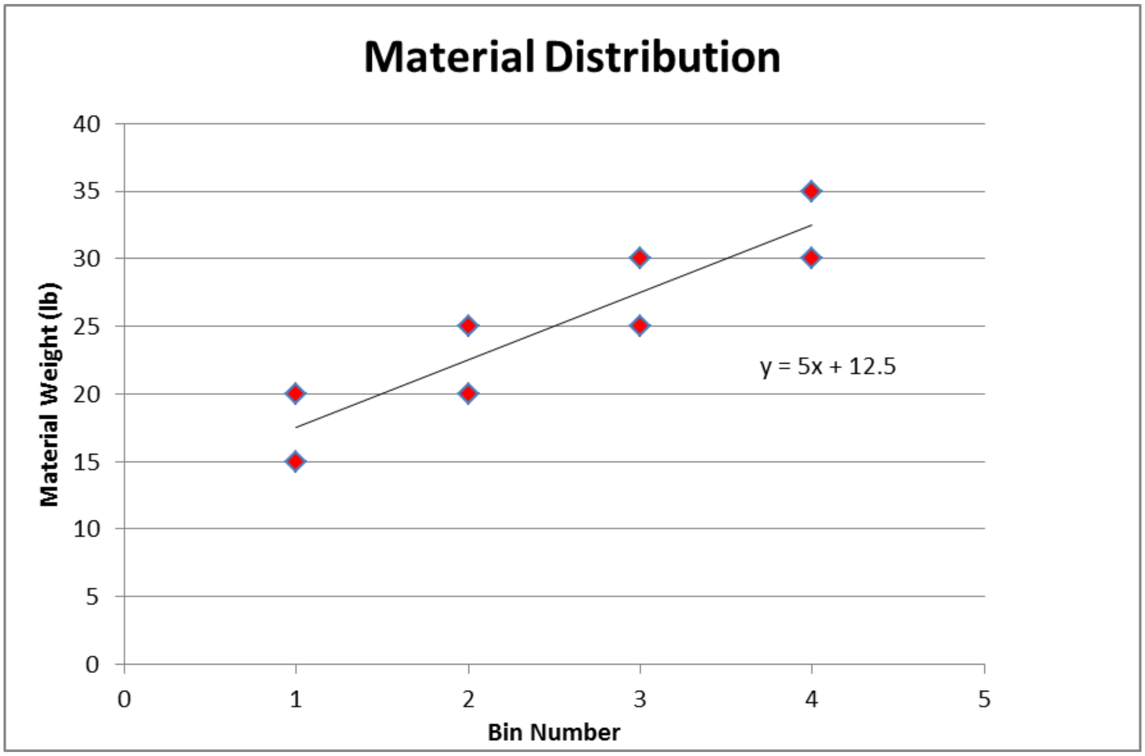
Material weight (lb) = final weight (lb) - tare weight (lb)

Table 1: Data collection and material calculation sheet

Distribution Auger Performance Evaluations								
Redesigned Flighting								
	Auger Design 1				Auger Design 2			
	Bin	Tare Weight	Final Weight	Material Weight	Bin	Tare Weight	Final Weight	Material Weight
Trial 1	1				1			
	2				2			
	3				3			
	4				4			
Trial 2	1				1			
	2				2			
	3				3			
	4				4			

Upon completion of all testing and data collection of the current production model, final design considerations will be weighed. By observing and understanding how the current design performs the team will be able to redesign the augers to even out the distribution of the material. The data collected will be graphed using excel in order to better view the distribution. After speaking with the contacts at AGCO it appears that the material is biased to on side of the machine. Figure 5 is an anticipated graph of the current performance. This figure also demonstrates the visual method in which the data will be represented.

Figure 5: Graphical representation of material distribution



The slope of the regression line fitted to the data represents how the material is unevenly distributed across the width of the apparatus. To optimize the distribution of the material the team will strive to achieve a slope of zero in the regression equation. This will only hold true for distributions in which the material is biased to one side of the test stand or the other. If the material is bunched in the material a different approach will be taken due to the fact that a linear regression line will not properly represent the performance.

Design Considerations:

A. Assumptions

1. The testing apparatus accurately reflects the conditions of material entering the distribution augers found in the field.

2. The new design shows improved distribution of material as it exits the accelerator rolls based on data collected during testing.
3. The alternate design is compatible with current production cleaning system.
4. The augers will perform the same regardless of the crop being harvested

B) Proposed Design Changes

1. Flighting

   Changing the flighting on the distribution augers can dramatically impact performance. For example, if the originally flighting is three inches and the team redesigns the flighting to six inches, a fifty percent increase in material transfer will occur. This also holds true for a decrease in the filighting of 100 percent. The final decision in the adjustments made to the flighting will be made upon the completion of baseline performance testing. This will provide the team with valuable information required to make an educated and economical decision. Knowing how the augers currently perform will lead the team in the correct direction in how to effectively modify the system.

2. Speed

   Auger speed will be manipulated and resulting performance will be measured. In order to properly test the effect of changing the speed of the augers, they will be required to be powered independently of the accelerator rolls. To accomplish this task, the accelerator rolls will remain powered by the PTO of the tractor, but distribution augers will be powered by an electric motor allowing excellent speed control of the augers. Speed manipulations showing the greatest improvement will be thoroughly analyzed using the proposed testing regimen.

Economic Analysis

Freshmen Project Contribution:

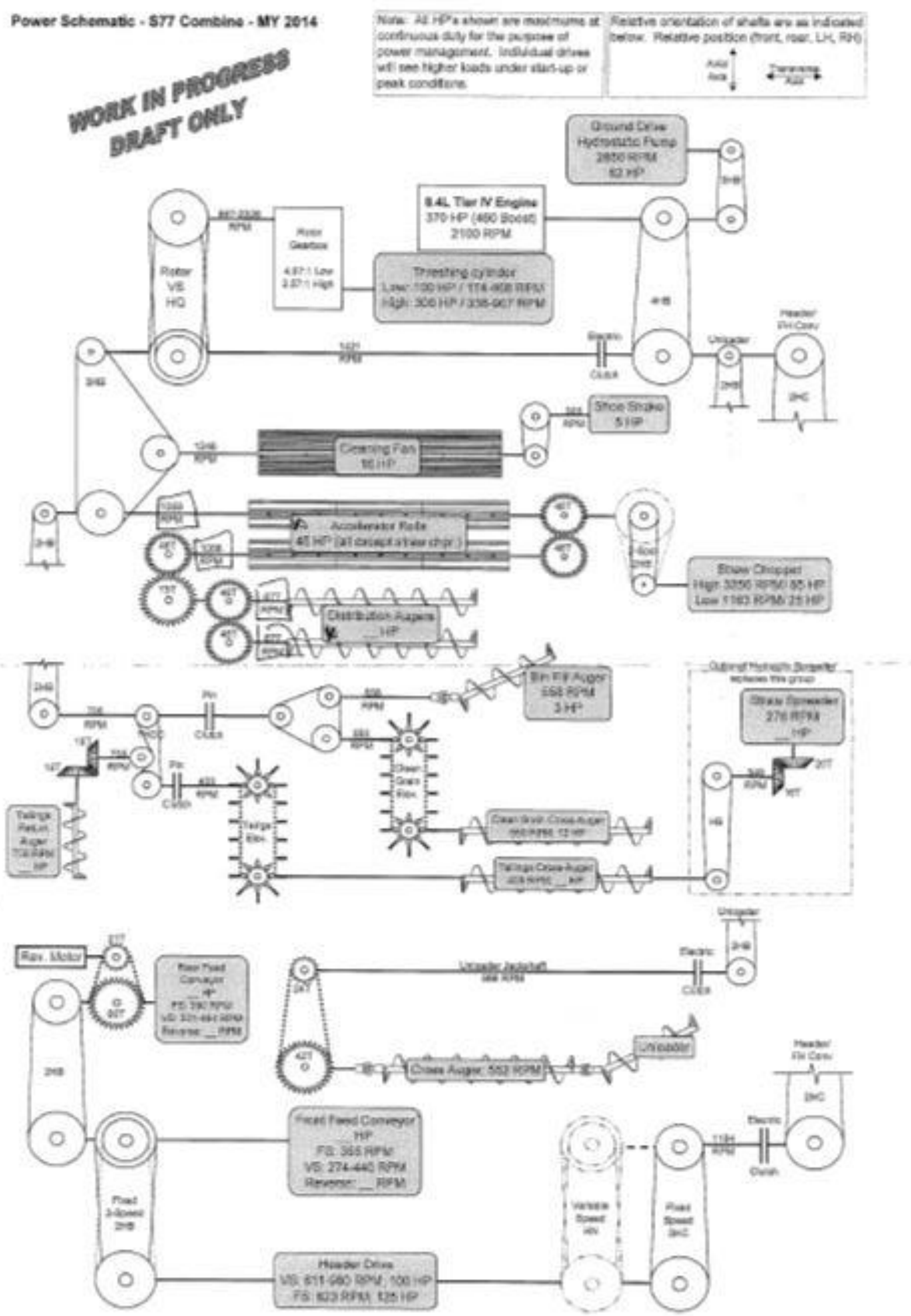
The freshmen, our colleagues, were tasked with designing a feeding system that will distribute the material into the threshing system. They designed a container that is sloped at the bottom. At the bottom end of the slope, the floor will be open to allow all of the material to fall out. They suggested that a conveyor with 1" cleats will transport the material from the hopper into the threshing system. Our colleagues suggested that we use an Elektrimax C-force Motor with 208-460 volts will be ideal for powering our conveyor.

References:

1. Buescher, Walter M. (1991), *Plow Peddler*, Macomb, Illinois, USA: Glenbridge Publishing
2. Budynas, Richard G., J. Keith. Nisbett, and Joseph Edward. Shigley. *Shigley's Mechanical Engineering Design*. New York: McGraw-Hill, 2011. Print
3. Hibbeler, R. C. *Engineering Mechanics Statics and Dynamics*. Upper Saddle River, NJ: Pearson, 2013. Print

Appendix:

Appendix A: Power and Speed Diagram



Appendix B: Material Mass Flowrate Calculations

Appendix C: Strengths of Materials Analysis of Test Stand Base

Appendix D: V-Belt Design Manual

Appendix E: SolidWorks Models and Drawings