TEAM GREEN

DESIGN OF AN AUTOMATED ASPARAGUS PICKER

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EXECUTIVE SUMMARY
The people of Oceana County, Michigan are struggling to harvest their asparagus crops, due to low prices and high labor costs. An automated picking device is highly desirable to combat this economic problem. Previous attempts to design such a device have not succeeded due to the complexity and uniqueness of the asparagus cultivation process. When stalks reach a mature height of five to six inches, they release an enzyme that spurs the production of more stalks. If young stalks are damaged before maturity, they will not produce the enzyme and the plant will die. Harvesting mature stalks without damaging surrounding shorter plants is difficult because asparagus stalks tend to cluster and the tenderness of the stalk makes it susceptible to breaking. Also, wind and weather conditions will cause the stalk to bend requiring a device with additional degrees of freedom.

Any harvesting mechanism must be able to compete with labor costs, have precise movements, work efficiently in any weather conditions, separate stalks very near to the ground, retrieve stalks once they are separated, and transport stalks to a storage device. The design of the picker has been separated into four main functions via a functional decomposition. These functions are converting energy, moving the end effecter, holding the stalk, and separating the stalk. For each of these functions, multiple concepts were developed and organized into a morphological chart to determine how each function would be achieved. To create unique designs, one concept from each function was selected and combined to create a mechanism. Once there were five unique concepts that drew from a wide range of the team's ideas, they were evaluated against objective design criteria to determine the most advantageous design. The design criteria were a combination of customer requirements and manufacturing or robustness concerns. After this preliminary evaluation was complete, a second evaluation was conducted using variations on the top two designs from the preliminary evaluation. From this second evaluation an alpha design was selected. Some of the anticipated difficulties of the alpha design have been discussed, and detailed dimensioning and component selection has been completed for the final design.

Engineering analyses have been conducted on all major components of the design to ensure that they will meet their corresponding engineering specifications. The materials chosen for the design are low in weight and appropriate measures have been taken to ensure that the design is weatherproof. The horizontal arm of the picker has been modeled as a cantilever beam, and appropriate beam bending stress and deflection calculations have been conducted to verify that proper materials were selected for the application. The peak torque required to move the vertical arm was calculated in order to select a proper motor. A solenoid was selected to actuate the harvesting cone because solenoids are fast, lightweight, and easy to control. Additionally, it provides the amount of force called for in the engineering specifications to cut an asparagus stalk. The gears used to drive the rack fixed to each arm were sized to meet the engineering specification of precise path movements while still moving as large a distance possible with each motor step to operate at high speed.

A prototype was developed which validated our design by displaying the salient features in a scaled down and limited fashion. The motors were able to drive the arms and position the cone, and the actuator was able to cut through and harvest an asparagus stalk. Based on the prototype, recommendations have been made for further iterations of the asparagus picker.

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1 INTRODUCTION

Oceana County is feeling the negative impacts of the poor Michigan economy, including scarce labor and low prices which lead to leaving up to 25% of asparagus crops unpicked. An automated robotic picker will help to harvest the entire asparagus crop. The picker will work in unison with a vision system that will identify the asparagus stalks that are ready for harvest. The ME 450 project will focus on the design and fabrication of the robotic picking mechanism which must be able to navigate through the asparagus clusters, as well as cut and retrieve the asparagus.

The sponsors of this project are Frode Maaseidvaag, Carl Fuehring, Norm Myers, John Bakker, Jerry Malburg, and David Roseman. The sponsors have a diverse collection of experiences that led them to collaborate on the planning of this project. Mr. Bakker is an asparagus researcher at Michigan State University. Each of the other gentlemen is either an asparagus farmer or a citizen of Oceana County who is interested in developing an automated asparagus picker. Oceana Country is the third largest asparagus producer in the nation. Asparagus is an important and valuable crop to farmers and a typical asparagus field in Oceana County can bring in $250,000 of revenue during harvesting season.

However, due to government regulations, there are difficulties in securing a large enough labor force to harvest the crop. This problem is exacerbated by the rapid rate of growth of asparagus. If it is not harvested in a specific time frame when the stalks are between six and eight inches, it is not acceptable for the marketplace. Furthermore, clear cutting of the fields is not acceptable for several reasons. Most importantly, if the stalks are cut beneath a height of five inches, a crucial enzyme will not be released by the stalk, and the plant will not produce more stalks and eventually die. Additionally, stalks that are harvested below five inches cannot be sold. Therefore, younger stalks that are not ready to be harvested cannot be damaged in any way without losing the entire plant. The adult stalks that are meant to be harvested must be cut as close to the ground as possible to reduce stubble and make harvesting easier in later years. As fields grow older, harvestable stalks may grow as far as one foot from the center of the crop row. These issues create a need for an intelligent, electromechanical harvesting system that would allow asparagus farmers to eliminate their dependency on seasonal labor and allow them to harvest crop that would otherwise be left in the field.

The ME 450 project team is made up of individuals who have experience in manufacturing processes, computer simulations, static dynamics and material and component selection. All these fields will be utilized and incorporated into the design so the background of the individuals that comprise the group will be useful.

2 PROBLEM STATEMENT

The project objective is to develop a mechanism to precisely grasp, cut, and retrieve asparagus stalks. This includes a mechanism to precisely move an end effecter to a stalk and also to transport the harvested stalk to a storage system. There are two main outcomes for the project, the first being a test bed for evaluating possible picking mechanism designs. This should consist of a stationary board to hold multiple asparagus in fixed locations to demonstrate asparagus as they grow in the fields. Second, a prototype of the picking mechanism should be delivered. The prototype will demonstrate that it is capable of moving through the required ranges of motion to pick asparagus in any situation. During this demonstration, it will be controlled by signals fed from a personal computer operated by a member of the team. The picking mechanism should solve all the consumer problems mentioned above, and provide a means for replacing human labor in the picking workforce in a cost effective fashion.

The team is not responsible for construction and detailed design of the asparagus storage system, development of vision recognition and control system, or integrating the interface between image analysis and mechanism prototype.

3 INFORMATION SOURCES

There are several models of asparagus pickers that are patented, being researched and used. The models use varying forms of picking mechanisms in their designs. One model uses a plow to remove the entire plant where the plant and soil are moved to a conveyer belt where the plants are hand sorted [1]. Another design developed at Washington State University has a plate that is at the minimum desired asparagus height. When a plant hits the plate compressed air is used to cut the stalks and pneumatic cylinders quickly vacuum the severed plant into a holding area [2]. An image of this harvesting mechanism is shown in Appendix A. The main difference between existing devices and our product concept is that our concept will be able to harvest mature asparagus without damaging either the harvested stalk or the surrounding immature asparagus. Also, the models that are available now involve large capital investments without fully solving the problem. These factors combined, create an opportunity for a relatively low cost device to be created that satisfies all the customer needs.

There are several patents of asparagus harvesters using different methods of picking. One design involves a sensing device, a set of tines for guiding the stalk and grasping once it has been cut. A series of conveyer belts moves the plant once it is severed [3]. A vertical guide is used to secure the stalk while a severing mechanism then cuts the stalk near the base in another design. The vertical guide is then used to hold and place the stalk on a series of conveyer belts where it eventually reaches the storage unit [4]. In another design, when a stalk interrupts an optical beam, a pair of soft rollers move to hold the stalk while applying force upwards and outwards. A cutting tool severs the stalk and the rollers place the plant on conveyors to send it to the storage unit [5]. The condition dealing with a field that has more than a couple years growth of asparagus is not sufficiently dealt with and not answered in any of the patent descriptions. Due to the relatively new nature of developing automated devices that harvest asparagus and the select market it applies to, reviews on these patents are not very detailed or many.

4 DESIGN SPECIFICATION DEVELOPMENT

In order to determine the engineering specifications and requirements for this project, a Quality Function Deployment (QFD) was formed. The first step in creating a QFD is to develop a list of customer requirements and engineering specifications were developed from this. The completed QFD is shown in Figure 1 on page 6.

4.1 Customer Requirements

Certain requirements and specifications must be met in order for the asparagus picker to be practical. The first necessary customer requirement is that the device needs to be able to withstand and operate in most weather conditions. Asparagus fields have a lot of dirt and sand, and the combination of this with wind and rain conditions can be detrimental to any exposed mechanical or electrical components. In order to satisfy this requirement, the number of exposed elements must be kept to a minimum. Next, the device needs to be able to remove the asparagus stalk from the ground and then retrieve it for storage. This translates to a necessity of some form of grasping mechanism, as well as a mechanism for cutting the stalk. A storage method must also be developed to meet these requirements. The mechanical arm of the picker needs to be able to move precisely enough as to not damage other stalks. Asparagus stalks do not grow back if they are broken below a certain length, so the arm must be able to take out single stalks with minimal interference with the surrounding stalks. To achieve this, the mechanical parts of the arm must be capable of accurate movements, and the system controlling these movements must be precise. This corresponds to the need for multiple degrees of freedom of the arm in order to navigate effectively. Another requirement is that the grasping mechanism used to take the stalk out and place it into storage needs to be gentle enough to not damage the asparagus that is being picked. The stalk is very tender, so the force used in grasping must be low enough to protect the crop. The grasping mechanism must also be versatile enough to deal with stalks of various growth orientations, since the stalk does not always grow straight out of the ground. The arm must also be able to operate continuously in order to be efficient enough for use. This is because the mechanism will most likely have a slower process time than a human, and will not be able to grasp multiple stalks in the way a human might.

Other requirements would be desirable to include in the design but are not crucial for implementation. The entire harvesting process time should be minimized for a single stalk of asparagus. Since the automated picker can run continuously it is not required to match the speed of a human. Also, since the cart can run at slow speeds the picker is not required to have a large area of operation. The arm should be versatile enough to reach mature stalks in a cluster, but if this cannot be achieved with a single arm, multiple arms could be added.

4.2 Engineering Specifications

The following engineering specifications are critical to our design and are listed in order of relative importance. The mechanism must be capable of or have the following:

- Precise path movements that are accurate within 1/8 inch
- A maximum grasping force of less than 10 Newtons (2.25 lbs force)
- A grasping mechanism size measured in the plane of the field that is less than 1 ft^2
- A force for removal of 10 Newtons (2.25 lbs force)
- More than 2 degrees of freedom
- Materials that are lightweight and non-corrosive

- A weight that is less than 100 lbs
- A lifetime of 10 years
- A process time of 10 seconds
- An 85% picking efficiency while the cart is in motion
- No exposed elements that could be damaged by outdoor conditions
- An operational area that covers long rows of asparagus that are 3 feet wide

The customer requirements were converted into engineering targets that our mechanism is looking to achieve by first outlining how the mechanism will accomplish what the customer wants. The QFD diagram, Figure 1 on page 6, shows these requirements in the order of importance determined by the customer. Then, engineering specifications were developed listing how the mechanism would accomplish the requirements specified by the customer. These specifications need to be detailed so that a guideline for a prototype can be generated.

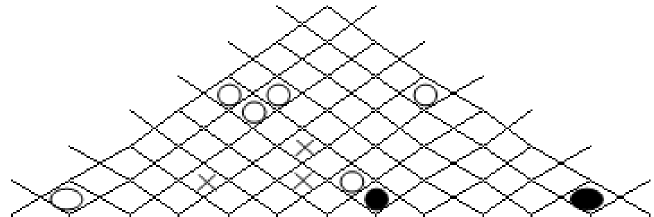
Path movements that are accurate within 1/8 inch were determined from the fact that most asparagus are 3/8 inch diameter and movement precision with resolution greater than 1/8 inch may cause stalks to be damaged or missed. A grasping force of less than 10 Newtons was determined by experimentally measuring the force needed to crush an asparagus. This test was conducted by applying pressure with a force gauge and calibrated masses until noticeable damage was done to the asparagus stalk, and is intended to prevent the mechanism from damaging the stalk during holding. A cutting force of 10 Newtons was also determined by experimentally measuring the force needed to cut a stalk. A similar test to the crush test was performed, but pressure was applied to a blade rather than a flat surface to give an estimate of cutting force. A grasping mechanism with a projected area of less than 1 ft^2 is the size needed in order to prevent any damage to surrounding non-harvestable stalks. A mechanism with more than 2 degrees of freedom is needed so that the grasping and separating device can move along at least a plane and if needed rotate or move along a third axis.

Materials that are lightweight and non-corrosive are important because during operation the mechanism will be subjected to harsh outdoor elements and must be able to continue working. A weight of less than 100 lbs is required because the device is intended to replace a currently-used worker while being mounted on the currently used cart for transportation; having a weight less than 100 lbs will ensure that no problems arise when the mechanism is mounted to the cart. In order to make use of an automated picking mechanism feasible and economical a lifetime of 10 years is needed. A process time of 10 seconds would allow for the replacement of human workers economical for farmers when deciding between human and machine labor. As stated by the customer, a picking efficiency of 85% would be acceptable as human labor could harvest the missed stalks. Having no exposed elements of the device is important to protect the device's working components and ensure that the lifetime is as long as possible. Lastly, an operational area that covers long rows of asparagus that are 3 feet wide is the target because this is the condition which will be encountered in the fields when in use.

The relative importance of the customer requirements was determined during meetings with the customer. The most important requirements of the mechanism are its retrieving and removal ability. Next in importance was the protection of surrounding stalks that aren't being harvested at the time. The requirements that the mechanism must withstand weather conditions and exude gentle handling after retrieval were both third in relative importance. Fourth were the requirements that the mechanism have a transportation of the crop to storage and be versatile for different asparagus growth orientations. The requirements of continuous operation and good range of motion were the fifth most-important requirements. The lowest in relative importance was the requirement that the mechanism meet specified operational speed requirements.

The engineering specifications and engineering targets are coupled because the engineering targets give numerical values to the engineering specifications. Without engineering targets, the specifications would be open for interpretation, unclear and would not aid in the design of a useful mechanism. The numerical values for the engineering targets were determined by experiment, through meetings with the customer regarding mechanism life, weight and role in harvesting, field properties associated with plant harvesting and concept generations.

Correlation	
●	Strong Positive
○	Positive
×	Negative
⋇	Strong Negative



Engineering specifications (HOWs) / Customer requirements (WHATs)	**Importance**	Force required for removal	Maximum force for grasping	Operational area	# of exposed elements	Process time	Machine lifetime	Weight	Material selection	Size of grasping mechanism	Use of arm while cart is in motion	Degrees of freedom	Precise path movements
Retrieving ability	10	1	9	1		1		3		3	3	3	3
Removal ability	10	9	1	1		1		3	1		1	1	3
Protection of other stalks	9	3	1	1						9		3	9
Withstand weather conditions	8				9		9	1	9				
Gentle handling after retrieval	8	1	9						1	3			1
Transport to storage method	7					3		3				1	1
Versatile for different growth orientations	7	1	3							3		1	3
Continuous operation	6			1			3		1		3		
Good range of motion	6			3							1	9	3
Operation speed requirements	5			1		9		1			3		3
HOW Importance		142	202	58	72	86	90	94	96	156	79	135	210
Customer Satisfaction Targets (HOW Much)		10 N	< 10 N	3ft wide, long rows	None	2 s	10 years	<100 lbs	Light, non-corrosive	1 ft^2	85% picked	> 2	< 1/8"

Figure 1: QFD diagram showing customer requirements, engineering specifications, targets and importance qualities.

5 CONCEPT GENERATION

In order to generate a multitude of concepts that satisfy the engineering requirements, a functional decomposition and morphological chart were used. Concepts were generated to provide a method for performing each function of the functional decomposition.

5.1 Functional Decomposition

To determine the necessary functions needed for picking asparagus, the inputs and outputs need to be well defined. The inputs will consist of electrical energy provided by the motorized cart, a location signal for the zero point and for a single stalk of asparagus which consists of Cartesian coordinates given by the vision control system, and the asparagus in the ground. The significant outputs of the system are the separated stalks of asparagus and the dirt and debris. A set of functions is then defined which transform the inputs into outputs. One function will convert the inputted energy into some usable form. Then a series of functions will move the apparatus to the selected asparagus stalk followed by grasping, separating, and moving the stalk to storage. The stalk is then released and returned to a zero point so that the process can restart. The functional decomposition diagram shows how the functions interact with each other and the inputs to give the determined outputs. The diagram is presented below in Figure 2 for the asparagus picker.

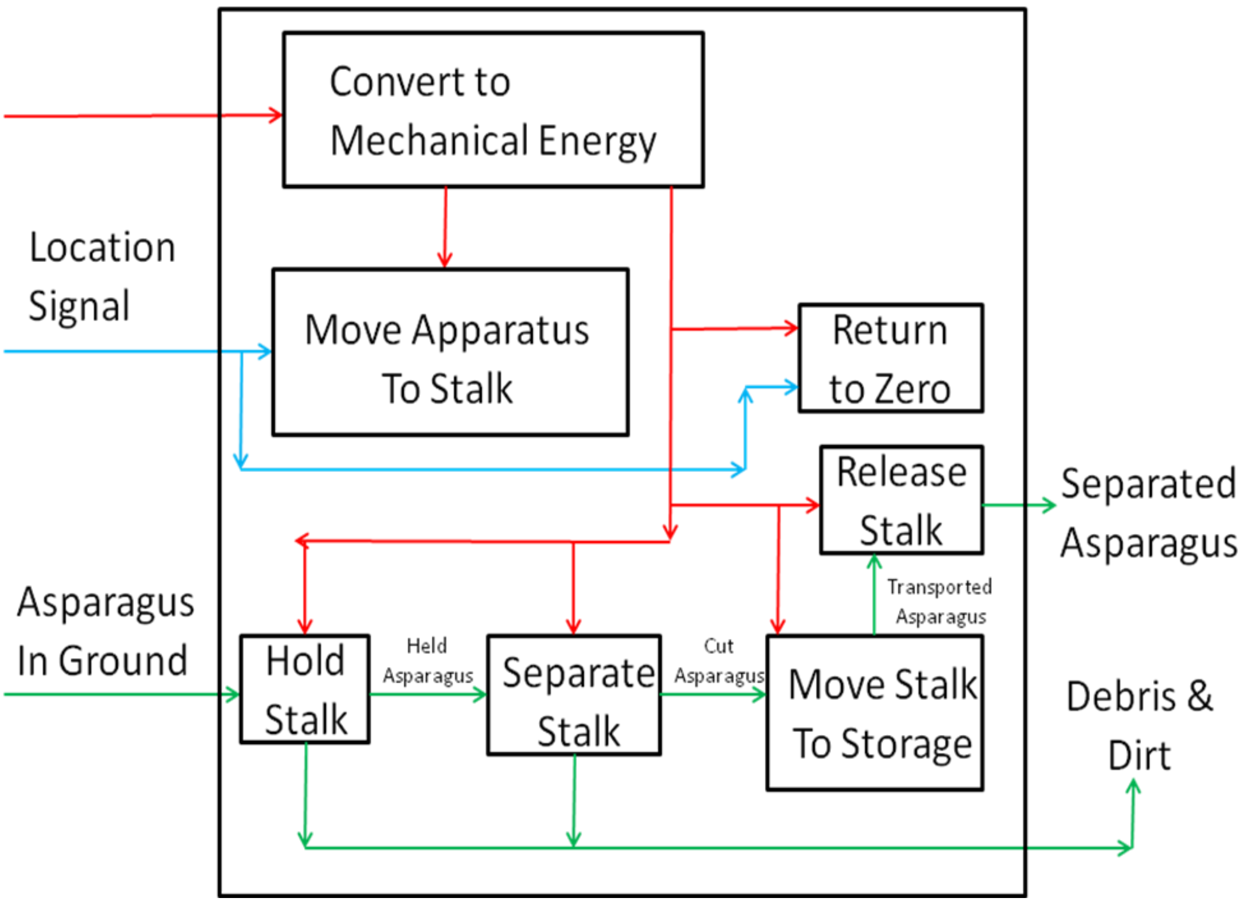


Figure 2: Functional decompostion diagram for the asparagus picker.

Using the decomposition diagram the functions can be coupled together. The 'move apparatus to stalk' , 'move stalk to storage', and 'return to zero' functions can all be coupled into a single function of movement. The 'hold stalk' and 'release stalk' are combined into a holding function. By coupling the similar functions together and using the other functions shown in the diagram, there are four main functions used to convert the inputs into outputs. Each of the four functions are then given a type of form to determine how they will work, and this is organized in the form of a morphological chart.

5.2 Function Specific Concept Development

The functions below have many different methods that can be implemented to carry out their function. The different techniques which can be used for each function are organized in a morphological chart below in Figure 3.

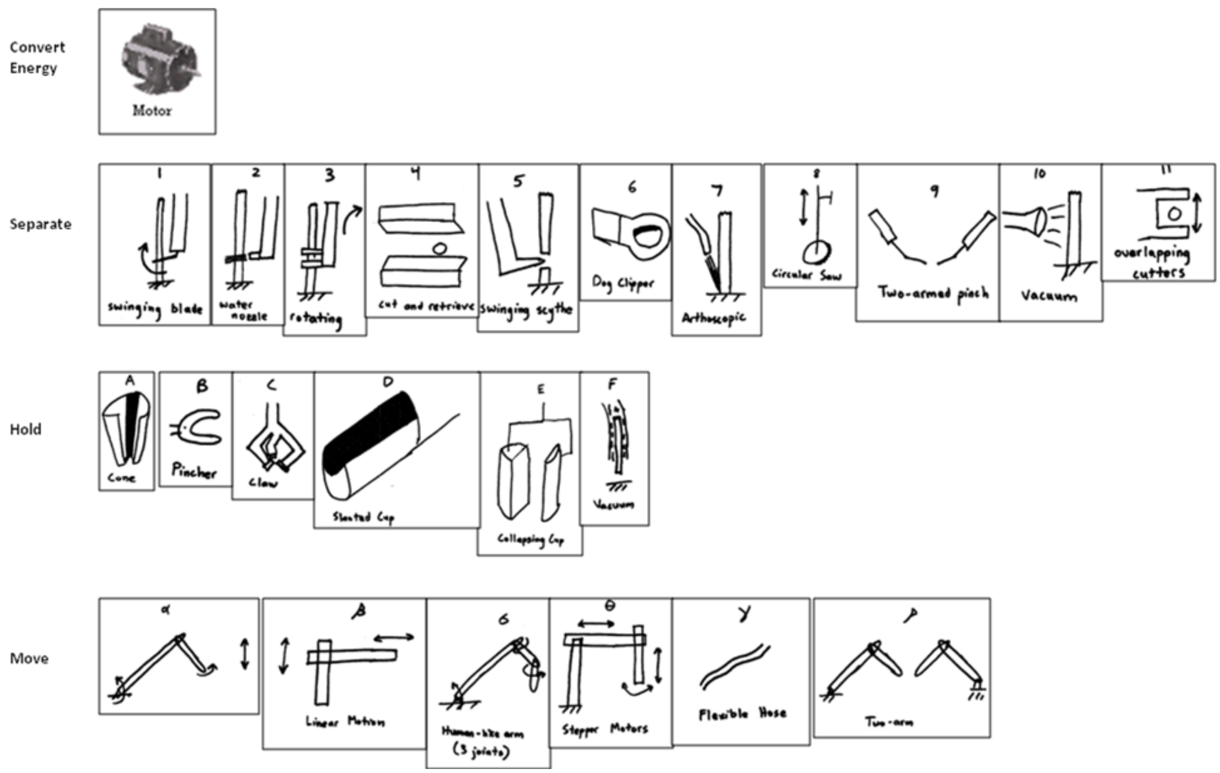


Figure 3: Morphological chart of the four distinct functions of the asparagus picker.

After discussions with the project sponsor, the team learned that the main form of energy being provided will be electrical energy from a generator connected to the internal combustion engine that is driving the picking cart. Since only electrical energy will be supplied, this somewhat limits the type of energy conversion devices available to the team. Therefore, the decision was made to focus on electric powered motors of varying types to provide movement to the mechanism. While this form of energy conversion is not as power dense as some alternatives such as hydraulics, it does provide excellent precision to the movements of the apparatus, which is far more important to the design.

The team developed eleven ways of separating the stalks so that they could be harvested. Most of these involved cutting the stalks but two of the concepts involved rotational motion to break the stalk similar to the type of rotation that a human wrist would provide. These concepts, however, were deemed less feasible because they would involve the addition of a joint and degree of freedom to the design. According to the engineering specifications, the degrees of freedom were to be minimized.

The remaining designs all aimed to cut the stalk in some fashion. Each was feasible, but also had advantages and disadvantages. The water nozzle design would require that water be carried onboard the cart, adding to the system's weight. It would provide a clean cut and do it in a very short amount of time. Any of the swinging blade or saw designs would require that the blade was kept sharp and require an additional mechanism to hold the stalk while the blade cuts it. This is a simple method though that is the most analogous to the way humans harvest the crop in places other than Michigan. The third type of design, the overlapping cutters, solves many of the problems of the above two design. It is most robust because there is no way for the stalk to bend away from the blade; the two blades come together and lock the asparagus from moving. The blades do not need to be as sharp due to this factor, because the force of the two flanges coming together should be enough to pinch the stalk into two pieces. Although the design may be slower than a swinging blade, it is also very precise and extremely versatile for different orientations.

The team devised six methods for holding the separated asparagus stalks. Vacuuming the stalks would be an extremely fast method, but would also be damaging to the asparagus. Since gentle handling is an extremely important customer requirement, this method would need significant work to be feasible. The other methods can be split into two categories, those that grasp and hold the asparagus and those that form a container or cup for it. The grasping methods are deemed more precise, because they physically grasp a single stalk and hold it. This is also their drawback, because the grasping force must be carefully limited to below 10 N (engineering requirements) to avoid damaging the asparagus. Again, because gentle handling is one of the team's top priorities, the cone and cylinder designs that allow the stalk to sit softly inside them were deemed the most appropriate. The cone and cylinder designs have an additional advantage of being less complex from a mechanical standpoint, and the cone's flared top opening is more versatile for holding asparagus that has bent into the wind at various orientations.

The team created six methods for moving the apparatus to the asparagus stalks. The most feasible concepts used linear motion to translate the end effecter. Linear motion is advantageous because it simplifies the coordinate system used to guide the mechanism. In addition, the three dimensional design was chosen over the two dimensional design because although it is more complex and heavier, it will be far more robust for picking stalks anywhere in the range of motion and avoiding immature stalks. A flexible hose design was also considered, but precise control of this mechanism would be a daunting task in the constraints of ME 450. Rotational designs were also included as a basis of comparison for the linear motion designs.

5.3 Unique Concepts

The following are different concepts that can be created by picking out different components from the morphological chart. The concepts that are generated can be very diverse; however all concepts will use a motor to convert energy since that is the only means that is examined for use on the asparagus picker. Then each design will consist of a number which corresponds to the means for separating the stalks, a letter for the molding technique, and a Greek symbol for the movement function. Below are a variety of concepts which can be used for the asparagus picker. More concepts are provided in brief detail in Appendix B.

5.3.1 Gentle Touch Cone

Motor-11-A-θ

This design has a cutting and grasping functions combined. As the cone closes around the stalk, the bottom of it will cut through the asparagus stalk because of the overlapping blades. Additionally, the shape of the cone will allow it to hold asparagus regardless of its growing orientation and because the asparagus will sit in the cone, it will be gentle and there is no concern about the apparatus crushing the stalk. Furthermore, the arm design is very simple and eliminates the need for many degrees of freedom. The cart will move in one direction and the arm will move perpendicular to that, this will allow it to access all stalks of asparagus.

5.3.2 Swing Blade

Motor-1-B-β

The Swing Blade design is quite robust since the blade should have little difficulty cutting through an stalk of asparagus. Also, this design takes advantage of using pincers to grab the stalk which helps it spread the holding force around the entire stalk. This design also uses a simple set of arms where one moves in the direction of the cart and the other moves perpendicular; however the arms cannot move up and down and it may have difficulty getting to the stalks determined for picking without damaging the surrounding stalks.

5.3.3 Water Claw

Motor-2-C-α

The Water Claw uses high pressured water out of a nozzle to cut the asparagus. The water is desirable for use because it is inexpensive, clean, and renewable. The holding mechanism is a claw which will grab the stalk of asparagus from overhead which enables it to compensate for all different growing orientations. The movement device is a simple set of arms which will allow it to move in all directions so that it can easily reach any stalk determined ready for harvesting.

5.3.4 Grasping Saw

Motor-8-B-σ

The saw blade used for this cutting is very robust because it should be able to cut through any stalk of asparagus even if it is covered in dirt or debris.   Similar to the Swing Blade, this design takes advantage of using pincers to grab the stalk which helps it spread the holding force around the entire stalk. The movement is achieved through a mechanism which is similar to a human arm since it has three joints. This mechanism allows the concept to be very versatile in approaching a stalk of asparagus.

5.3.5 Swinging Blade Vacuum

Motor-1-F- θ

This design utilizes the swinging blade to cut through a stalk of asparagus with ease. Then it uses a vacuum to hold the asparagus stalk. The vacuum is desired because it could be used to force the asparagus to stand upright, thus no concern for the growth orientation. Also the use of a vacuum reduces the number of moving parts. Lastly, this design uses the movement apparatus described in the Gentle Touch Cone. This arm allows the apparatus to reach the asparagus from overhead which negates the need for the apparatus to navigate through the field.

6 CONCEPT SELECTION

In order to select the alpha concept, comparison tables called Pugh charts were used in conjunction with logical reasoning to combine the best aspects of all the designs. Two levels of Pugh Charts were considered during the design process, one for unique concepts and one for variations of the most promising concepts.

6.1 Unique Concept Comparison

In order to select the most suitable concept for our design problem from the many concepts that were generated, the team utilized a Pugh chart. To populate the Pugh chart, concepts from each function of the morphological chart were combined to obtain five highly unique concepts. The sketches of each of these concepts are shown in Appendix C. The Swing Blade design was chosen as the datum, because it was considered an average design early in the process. The Pugh chart used for concept selection is shown as Table 1 below.

		Design #1	**Design #2**	**Design #3**	**Design #4**	**Design #5**
	Name	Gentle Touch Cone	Swing Blade	Water Claw	Grasping Saw	Swinging Blade Vacuum
	Code	11-A-θ	1-B-β	2-C-α	8-B-σ	1-F-θ
Design Criteria	**Weight**					
Maintenance	5	1	**DATUM**	1	0	0
Robustness	5	-1		-1	0	-1
Speed	1	0		0	1	1
Weight	1	-1		1	0	-1
Range of Motion	9	1		1	1	1
Gentle Handling	9	1		-1	0	-1
Versatile for Different Orientations	9	1		1	1	1
Precision	9	1		1	1	1
Total Points		**35**	**0**	**10**	**20**	**5**

Table 1: Pugh chart of five unique concepts.

The rationale for each category of the Pugh chart is as follows:

Maintenance: The designs with a moving blade score low in this category, because they would require frequent replacement or sharpening. The Water Claw design does slightly better because it has less moving parts, but it would still need a steady supply of water to perform its cutting. The Gentle Touch Cone could continue working even when its blade is dull because it pinches the stalks rather than cutting them unsupported.

Robustness: The swinging blade design was considered the most robust because it would cut through debris and dirt and not pick it up with the stalk. The Grasping Saw is similar in this fashion. The Water Claw could run into complications if it was attempting to pick a particularly tall stalk because the claw design may contact the top of a tall piece of asparagus. The Swinging Blade Vacuum and Gentle Touch Cone would both pick up dirt with the stalk.

Speed: The vacuum design rates highest here because it does not need to actually move the end effecter back to the storage area; instead, the stalks travel down the vacuum hose to storage. The Grasping Saw is also fairly quick with its three jointed arm.

Weight: The Gentle Touch Cone rates below average here, because its three dimensional linear motion design and larger end effecter will add mass. The vacuum is the heaviest design, because it will require a compressor and hose in addition to a movement device in order to operate. The other designs have fewer parts and will therefore be lighter.

Range of Motion: The range of motion of the Swing Blade is limited because it utilizes two dimensional linear motion, so it is always in the field and cannot avoid immature stalks.

Gentle Handling: The cone design rates highest here because it does not physically grasp the stalks, unlike the Swing Blade, Water Claw, and Grasping Saw designs. As stated before, the vacuum design may be hard on the stalks because it forcefully pulls them through a hose, unless the hose system is carefully designed.

Versatile for Different Orientations: The Swing Blade would not be able to grasp stalks if they were bent severely away from the direction the pincer is approaching from. The Gentle Touch Cone works well here because its cone is designed to accommodate asparagus that is leaning in a variety of orientations.

Precision: The Swing Blade is not precise because it could damage surrounding immature stalks when the blade is swinging to cut. Each of the other designs avoids damaging immature stalks.

6.2 Lead Concept Comparison

After this chart of five unique concepts was analyzed, the most promising designs were selected and variations on those designs were considered. Another Pugh chart was created studying variations of the Grasping Saw and gentle touch cone. Since the Gentle Touch Cone was the best design from the original five unique designs, it was chosen as the datum for the second Pugh Chart. This gave the team a chance to compare it against four other designs for each design criteria. This Pugh chart is shown on page 13 as Table 2.

The rationale for the Pugh chart is as follows:

Maintenance: The double clip cone scores low here because it has two arms, and therefore twice the maintenance work. The two saw designs also score low because their blades must be replaced often to stay sharp.

Robustness: The saws are considered more robust because they can slice through all debris with ease. The Gentle Touch Cone and overlapping cup designs are less robust because a stray stick could prevent them from shutting on the desired stalk. The double clip cone would require a very precise control system to be able to fit over a stalk and would be insensitive to varying stalk diameters.

		Design #1	Design #2	Design #3	Design #4	Design #5
	Name	Gentle Touch Cone	Double Clip Cone	Overlapping Cup	Grasping Saw	Saw Claw
	Code	11-A-θ	6-A-ρ	11-E-σ	8-B-σ	8-C-θ
Design Criteria	**Weight**					
Maintenance	5	**DATUM**	-1	0	-1	-1
Robustness	5		-1	0	1	1
Speed	1		1	0	1	1
Weight	1		-1	0	0	0
Range of Motion	9		1	0	0	0
Gentle Handling	9		-1	0	-1	-1
Versatile for Different Orientations	9		-1	-1	0	0
Precision	9		0	0	0	0
Total Points		**0**	**-19**	**-9**	**-8**	**-8**

Table 2: Pugh chart of five similar concepts based off the Gentle Touch Cone and Grasping Saw.

Speed: The double clip cone scores high here because it has two arms and would therefore harvest quickly. The saw designs are also fast because their cutting action would be very quick.

Weight: Most designs have similar movement apparatuses which cause them to have similar weights. The double clip cone, however, has two arms and would weigh more than the other designs.

Range of Motion: The double clip cone has a large range of motion owing to its two arm design. The other designs have approximately the same range of motion because they have similar movement apparatuses.

Gentle Handling: The Gentle Touch Cone and overlapping cup designs score the highest here because they do not have any parts that grasp the stalk. The stalk simply rests inside of them.

The double clip cone has this advantage as well, but also must feed over the stalk to cut so it may damage the stalk in this phase of operation.

Versatile for Different Orientations: The grasping claw, saw claw, and Gentle Touch Cone all approach from above the stalk and move downward. Due to the nature of how they grasp, the orientation should not affect their success. When an asparagus is leaning at an angle, the cup could sever the top of a stalk accidentally when it closes. The flared design of the cones solves this problem.

Precision: All the designs are fairly precise. Since they all use similar methods, there is no clear advantage to any one design in this category.

While the Gentle Touch Cone design did not rate the highest in all the categories, it did rate highest in the most important ones. It did so even when compared as a datum to four similar designs in a secondary round of evaluations. Therefore, the team chose this as its alpha design and moved forward with detailed design work. During meetings with the sponsors of the project, however, the design will need to evolve as the design process continues.

7 CONCEPT DESCRIPTION

Based on the concept selection methods discussed previously, the concept selected for the initial design steps was the Gentle Touch Cone. This device utilizes arms with linear motion in the horizontal and vertical directions. It will move over the asparagus stalk that is to be picked with the two pieced, cone shaped end effecter in an open position. The arms will move the cone around the stalk and a device will be used to close the cone quickly when the position of the cone is correct. Figure 4 below shows two general views of the apparatus, in closed (4a) and in open (4b) form.

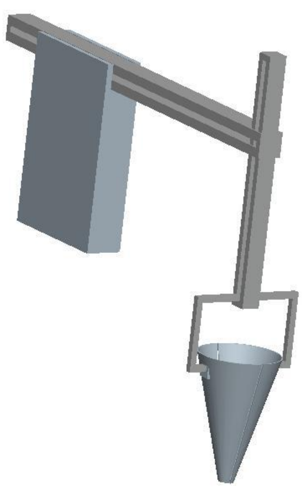


Figure 4a: Cone closed position.

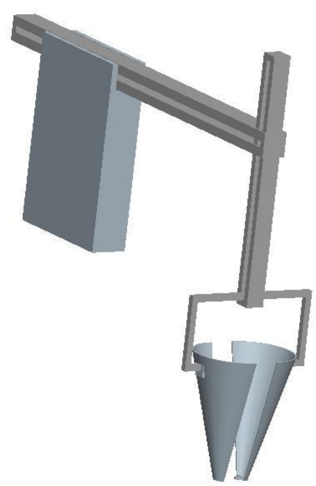


Figure 4b: Cone open position.

The bottom of the cone is formed so that it will perform the separation of the stalk upon closing. There are two sharp corners coming out from the bottom, at slightly different heights. When the cone closes, these ends will close in on the stalk and sever it. The overlapping cutters are shown more closely in Figure 5 below. The cut stalk will then rest inside the cone, and will stay there as it is brought to the storage method.

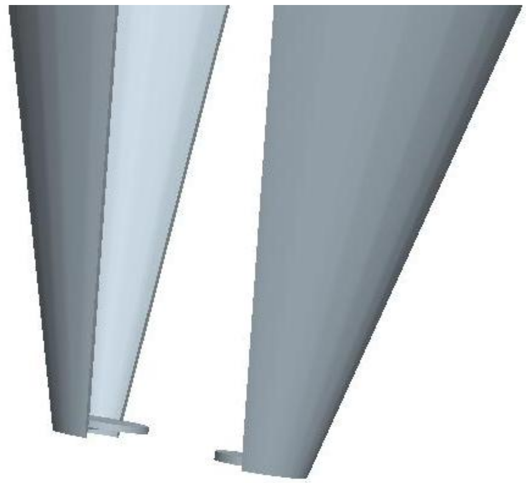
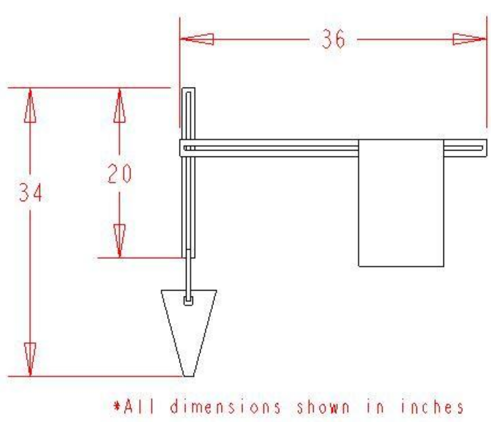


Figure 5: Close-up view of the separating device on the cone end effecter.

As shown in the previous section, the Gentle Touch Cone has some major advantages. It is a versatile design, able to handle stalks of various growth orientations. Its handling of the picked asparagus stalk is very gentle because it is not grasping the stalk directly, only holding it within the cone. Also, since all of the movement of the arms is linear with no rotational joints, it is a simple design that will not require a lot of maintenance.

The initial direction for the design concept was to use stepper motors to control the arms, with some sort of pneumatic device to open and close the cone around the asparagus stalk. Rough initial dimensions for the arms and for the cone are shown in Figure 6 below. The length of the horizontal arm was determined by the width of the field that will be picked, which is around three feet. The vertical dimensions are based on the need to move above the tops of the crop when traveling to the asparagus, then lower down on top of it. The cone angle of 15 degrees was determined by the maximum expected angle of lean for asparagus growth. This angle prevents the cone from severing the tops of asparagus that are leaning when it closes.



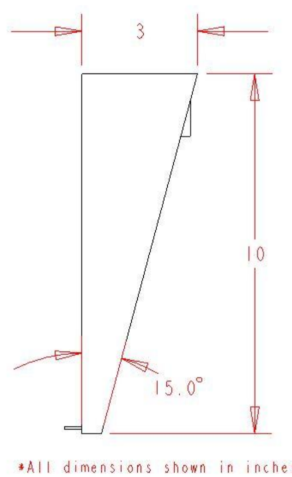


Figure 6a. Dimensions of full mechanism.

Figure 6b. Cone dimensions.

8 CONCEPT EMBODIMENT

This section provides the detailed dimensions of the final design and the engineering analyses used to support them. It also details prototype fabrication and differences between the prototype and final design.

8.1 Parameter Analysis

In this section, the final design is analyzed using engineering judgment and analyses to guide all the major design decisions. The parameter analysis is divided into five sections describing the engineering reasoning behind the material selection, arm bending strength, arm bending stiffness, selection of actuators, and pinion gear sizing.

8.1.1 Arm Material and Section Selection

The engineering specifications for the asparagus picker state that any materials used to build it must be non-corrosive and lightweight. This applies to the arms as well. An additional concern that arose during the design process was that the surfaces on the arms must be flat to allow for the installation of a rack and pinion system, and also to allow for easy mounting of the motor to drive the vertical arm. Although carbon fiber was initially considered for the arm design, it was ruled out for two important reasons. First, there are more readily available and inexpensive materials that satisfy the requirements with little penalty as far as weight or strength. It is easier to buy aluminum in bulk because the stock sizes for this project are more readily available. Second, carbon fiber is a black material that would become hot during extended operation in direct sunlight. Painting it would make the manufacturing process more complex. The team decided that the most feasible option for constructing the arms would use hollow aluminum tubing. Aluminum can be anodized to protect it from corrosion, and is a more lightweight option than steel while still providing excellent strength. The material selection process is overviewed in Appendix L1.

The cross section used on the arms needs to have flat surfaces to mount racks on, in order to actuate the arms. Thus, this effectively eliminates circular sections from consideration. A listing of area moments of inertia for various sections can be found in Appendix D. Since stress for a beam in bending is inversely proportional to the area moment of inertia, a larger area moment of inertia gives a more robust beam. As the data show, the largest area moment of inertias exist for the square or rectangular sections. Therefore, to ease manufacturing concerns and use readily available materials, a square shape of one inch sides was chosen for the design.

8.1.2 Arm Bending Strength Analysis

Due to the nature of the picker's operation, the robotic arms may often be operating while extended far from the base. In addition, there is a significant load on the end of the horizontal beam, because it must support the vertical arm, the cone, and any racks, linkages, and motors needed for movement. The horizontal arm was modeled as a cantilever beam and a bending strength analysis was conducted to ensure that the arm does not yield during full extension. A diagram of the forces acting on the arm during operation is shown on the next page in figure 7 where W is the weight of the arm and F_{arm} is the external load of the vertical arm and associated hardware.

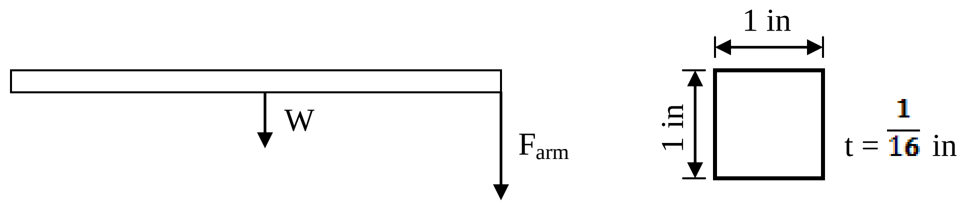


Figure 7: Forces acting on the arm during operation and arm cross section dimensions.

In order to determine the bending stress for the above situation, the relationship between maximum bending stress and maximum moment was used. Also, F_{arm} was conservatively assumed to be equal to 10 lbs by using a safety factor of two times the expected weight and *W*, calculated using the density of aluminum, is equal to 0.88 lbs. Thus, the main source of stress on the arm comes from the load of the vertical arm acting on the end of the beam. The maximum bending stress for the arm is calculated in Appendix E, after converting the dimensions and loads to SI units.

As shown in Appendix E, the maximum bending stress acting on the arm for the above assumptions is equal to 65 MPa. Using aluminum to construct the arms, there should be no worry that the arms will yield. Additionally, because the ratio of section width to wall thickness is much less than 50, the buckling stress is much greater than the yield stress. Therefore, the arms should not buckle under load either.

8.1.3 Arm Bending Stiffness Analysis

In addition to ensuring that the arm will not yield during full extension in operation, the amount of deflection should be acceptable to where it does not affect the accuracy of the picking. This is calculated using the relationship between load and deflection for a cantilevered beam as shown in Appendix F. In these calculations, the weight force was neglected for simplicity and because the moment it produces is less than five percent of the moment due to F_{arm}.

From the Appendix F calculations, the deflection of the tip of the arm during full extension is less than one inch. This should be acceptable for the design because the variation in ground height of an asparagus field is greater than this amount anyway and the actuators used for arm movement are robust enough to account for this difference and adjust accordingly.

8.1.4 Motor Sizing

In order to accurately select a motor to translate the arms of the asparagus picker, the team first had to analytically calculate the torque that would be required from the motor. The torque required was calculated based on figure 8 below.

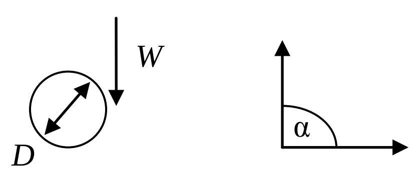


Figure 8: Motor torque and direction of motion schematic.

In the above diagram, D is the diameter in inches of the gear being used, W is the total weight of the object to be moved, and α is the angle between the horizontal and the direction of motion. The weight force W is equal to the weight of the vertical arm, the cone, and any hardware that may be attached to the vertical arm because this is the total weight that the motor will be required to move. To calculate the torque requirements, torque was summed around the center of the motor. The values pertinent to the team's design were inserted into the equations shown in Appendix G, assuming a safety factor of two for the weight of the object to be moved.

The torque calculated, 352 oz-in, is equal to the peak torque that the motor would be required to produce. The most lightweight, compact motor that was capable of easily exceeding this torque requirement was selected for use in the final design.

8.1.5 Gear Sizing

When sizing the gear that will drive the arms via a rigidly connected rack, there are two conflicting concerns. These concerns are speed and precision. In order to attain high precision, a small gear radius should be used so that the 1.8 degree step angle of the stepper motors translates into a precise movement. In order to attain high speeds of operation however, the gear should be large so that 1.8 degree steps translate into a large horizontal or vertical motion. For this project the team determined that 1/8" steps would be precise enough to harvest most asparagus stalks, as they have a stalk diameter of 3/8". Using this goal with a safety factor of 2 because it was treated as a maximum that should not be exceeded, the relationship between rotation angle and horizontal translation was used to solve for the gear that best met both speed and precision requirements. These calculations are shown in Appendix H.

According to the calculations, the maximum gear diameter to achieve a precision of 1/16" is 4 inches. This is, however, a maximum and smaller gears could be used in its place depending on availability or packaging constraints if one was willing to sacrifice speed. The gears selected are aluminum which is lightweight and can withstand the torque of the system according to the manufacturer's specifications.

8.2 Final Design Description

This section provides a full description of the final design after refining the alpha concept. It provides full detailed dimensions of all subcomponents. A summary of all materials and components for the design is provided in Appendix I. In addition this section provides a listing of all materials and off-the-shelf components that are needed to construct the final design. Figure 9 on the next page shows an isometric view of the CAD model for the final design. Appendix M contains added detailed drawings for some key components of the system as well.

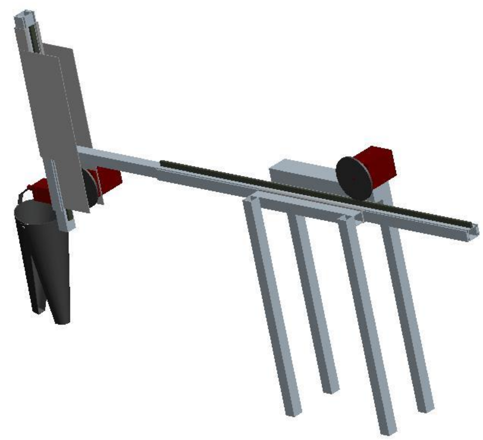


Figure 9: CAD Model for Final Design

8.2.1 Arm Design

The final design was formed based on the results of the analysis shown in section 8.1. The arm dimensions, shown below in figure 10, were chosen based on the required range of motion of the device. The mechanism will be attached to the edge of the cart, which will be located approximately 2.5 feet away from the center of a row of asparagus. Thus, the horizontal arm will be 4 feet long including a foot long section that is supported by the base; this will give the system the range of motion to move the cone past the center of the row, allowing for overlapping coverage on the row by multiple arms on opposite sides. The vertical arm will be 20 inches long. This was chosen because there needs to be at least 12 inches of possible vertical motion in order to ensure the bottom of the cone can move freely above any asparagus stalks in the field while also being able to move to the ground. The material selected for both arms was square aluminum tubing with 1 inch cross section.

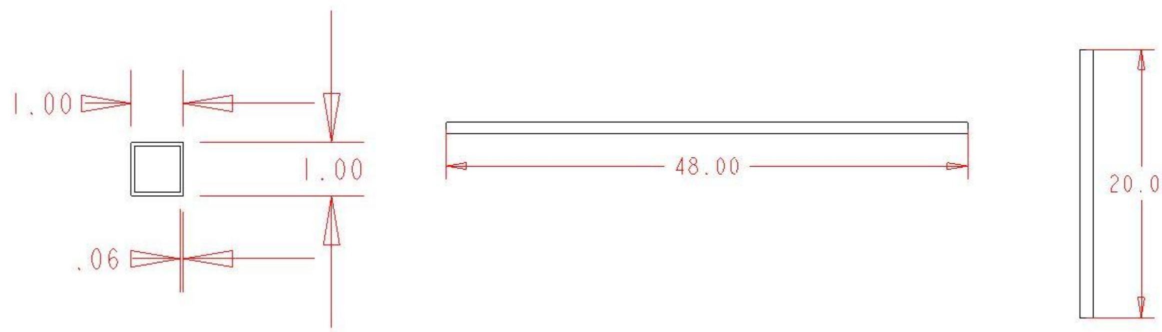


Figure 10: (a) Cross-section dimensions, (b) Horizontal arm dimensions, (c) Vertical arm dimensions

Attached to both the horizontal and the vertical arm will be sliders similar to those used for drawer slides. This will guide the arms to move correctly, as well as provide the arm with more support. Also attached to each arm will be a rack, which will be used in combination with a gear and motor to move the arms.

8.2.2 Cone Design

The cone was chosen to have a height of 10 inches in order to be able to fully enclose even the largest stalks that are to be picked. The angle on the side of the cone was determined to be 15 degrees in order to provide the system with the versatility to pick stalks of growth orientations of up to 15 degrees from the vertical. It was designed for a 0.5 inch overlap in order to ensure that the blades fixed to the bottom of the cone completely pass through the stalk. This resulted in a total diameter of 4.8 inches at the top, with a 0.5 inch, flat overlap. A close up of the cone as well as a dimensioned drawing is shown in the figure 11 below. The cone will be made of carbon fiber, in order to ensure it will stand up to the stresses of being in the field for extended periods of time. It is also lightweight, easy to clean, and easy to form on a mold. The material selection process for the cone is shown in Appendix L1.

Figure 11a: Isometric view of Cone

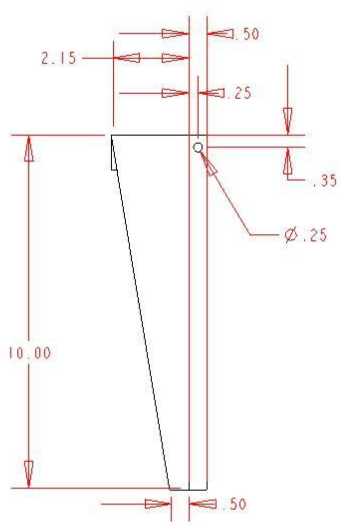


Figure 11b: Dimensioned Drawing of cone

8.2.3 Motor and Actuator Selection

To move the vertical arm, the 24Y404S-LW8 stepper motor from Anaheim Automation was selected because it is able to provide the required torque calculated in the Parameter Analysis section. It minimizes weight and packaging constraints and can be controlled by simply commanding the motor the number of steps to move. To move the horizontal arm, the 23Y104S-LW8 stepper motor from Anaheim Automation was selected. To open and close the cone, the actuator chosen was a linear intermittent pull solenoid, part number 70155K43 from McMaster-Carr. It gives the range of motion required and is lightweight, which is important due to its location on the vertical arm. It also has a continuous force output of 22.2 N which gives a safety factor of 2 times the 10 N force that was determined to cut an asparagus.

8.2.4 Gear Selection

The gear selected for both the horizontal and vertical arm applications was part number S1086Z-064A256 from Stock Drive Products. It has a diameter of four inches and a diametral pitch of 64. It is constructed from 2024 aluminum alloy. The rack that this gear will drive is Stock Drive Products part number S1811Y-RB-4P constructed from 416 stainless steel. It is important that both these components have the same pressure angle, which in this case is equal to twenty degrees for both items, and also the same diametral pitch. Additionally, these materials should offer excellent resistance to the weather changes that are common in Michigan.

8.2.5 Fasteners and Brackets

An important component to the system is the bracket connecting the vertical arm to the horizontal arm. This bracket is required to hold the motor controlling the vertical arm motion in place, along with the sliders that guide the vertical arm. An isometric view of the role of this bracket is shown below in Figure 12a, and a dimensioned drawing of this bracket is shown in Figure 12b. The lower dimensions were determined by the required space for the motor with gear to operate without interference from the horizontal arm. It also was required to position the motor shaft correctly to allow for the gear to contact the rack on the vertical arm. The upper dimensions were set to hold the sliders for the vertical arm securely to support the motion. The width was set to allow enough of the bracket to be connected to the horizontal arm to allow the vertical components to be held securely.

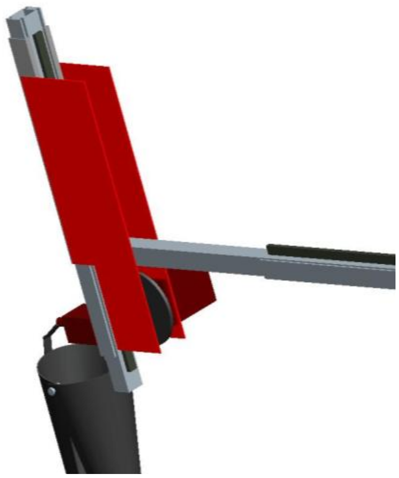


Figure 12a: Isometric view of bracket.

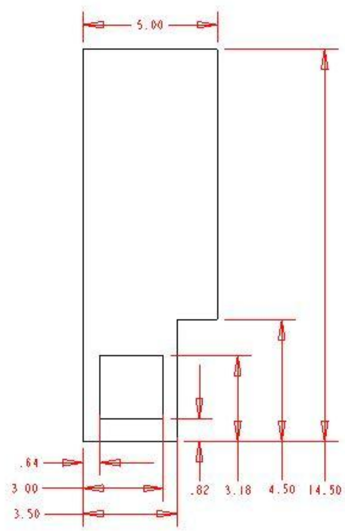


Figure 12b: Dimensioned drawing of bracket

The mount for the motor controlling the horizontal arm motion is also a key aspect. This mount was designed to position the motor shaft correctly above the rack in order to allow for good contact between the rack and the gear.

8.2.6 Base Design

The dimensions of the base were determined based on the movement requirements of the end effecter. The bottom edge of the cone needs to be held at least 12 inches above the ground in order to clear any stalks while moving into position to pick one. Thus, the horizontal arm needs to be at a set distance above the field, and the base is responsible for positioning this. The 20” was determined to be adequate for this requirement because the cart is already 7 inches above the ground. An isometric view and dimensioned drawing of the base is shown in figure 13 on page 22. We used aluminum tubing for the base due to low cost, high strength, and ease of availability of the material.

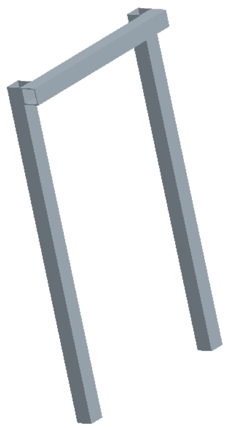


Figure 13a: Isometric view of half of the base.

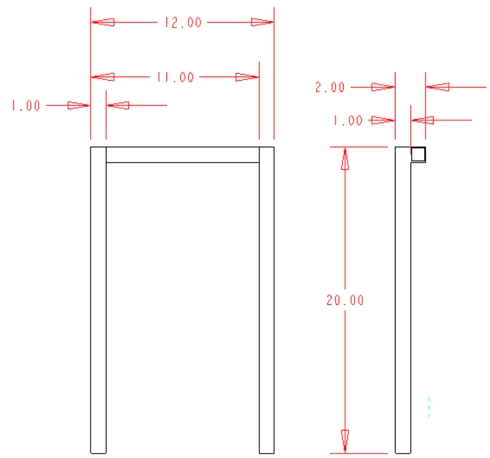


Figure 13b: Dimensioned drawing of the base.

8.3 Prototype Description

One of the features that will be demonstrated by the prototype is the use of linear arms to achieve the range of motion for the picking device. Another is the use of a cone-shaped end effecter to show that it is able to be used for the separation, holding and moving processes of asparagus harvesting while not damaging any surrounding stalks or the harvested stalk during the process. These will be demonstrated because these are the most important aspects in the design and were important customer requirements.

There will be several differences between the final design and the prototype. First, in the final design the cone end effecter will most likely be made out of a stiffer and stronger material, possibly carbon fiber, instead of the fiberglass that is used in the prototype. Apart from being lighter and enabling the use of smaller actuating devices for faster movement, carbon fiber will ensure that the effecter will have a long lifecycle without failing from fatigue. It was not used in the prototype due to cost and availability issues. In addition, the horizontal arm used in the final design will be a foot longer than the horizontal arm used in the prototype. The shorter arm was used in the prototype because of the lack of availability of longer arms without going outside the budget. Additionally, the full extension of the arm is not required to demonstrate how the design will work. A more robust set of slides that assist in the translational motion will also be needed in a final design that is going to be used in a higher number of cycles.

The prototype proves the most important areas of design because it shows that linear arms and a cone-shaped end effecter can be used for the successful picking of asparagus. The feasibility of the final design will be evaluated during the fabrication process of the prototype and the difficulties that were encountered. Also, the decision about whether the components of the prototype would be able to be mass produced will factor into whether the prototype is feasible. The performance of the final design will be assessed by comparing the performance of the prototype against the engineering specifications that were developed and are shown in the QFD diagram, figure 1 on page 6.

8.4 Initial Fabrication Plan

To create a design that will provide all the salient features described in section 8.3, a variety of fabrication techniques will be used. These techniques will be limited due to the budget constraints, available resources provided by the ME 450 machine shop, and the team's machining experience. Originally the cone was going to be created using rapid prototyping but the high cost prevented the pursuit of this option. Instead a form will be created which will have the overall desired dimensions of the cone. The form can be designed on a lathe since it has rotational symmetry. Then the form will be covered in fiberglass to create the shell. Once the fiberglass dries it will be pulled off of the form and then cut in half using a band saw. The upper rim of the cone will be covered by a strip of 3/4 inch wide 1/16 inch thick aluminum to strengthen and give rigidity to the cone since the fiberglass is not as strong as the material desired for the final design. The strip can be cut using a band saw; then using a hand drill holes can be made in the cone and the metal strip. The strip can then be attached to the cone using a set of rivets. The blades on the cone will be cut to size using a pair of side cuts and attached to the cone using a strong two part epoxy. The base will be made using 24 feet of 2 by 4 inch wood. The wood will be cut using a circular saw and then attached using wood screws. The arms will be cut to size using the band saw. The bracket will be made from a piece of 1/16 inch aluminum or steel and will be cut on the band saw. The holes needed for all of the parts will be drilled with a drill press but if the geometry does not allow a drill press's setup then a hand drill will be used. The linkage to connect the actuator to the cone will be made from the 1 X 1/16 inch strip of aluminum, it will be cut with a band saw and the joint will be made by passing a bolt through a hole that will be drilled. The test bed will consist of a polystyrene sheet that is 3 square feet by 1 inch thick. The holes for the asparagus will be made using a hand drill.

8.4.1 Tolerances

Tolerances are very important for producing the prototype. Some parts have small tolerances because they are essential to produce the salient features and some have higher tolerances since they have little effect on the features that the prototype will display. The cone for the prototype has the smallest tolerances. The cone must be able to open and close smoothly and this can only be achieved with proper precision. Also, the spacers used to combine the two halves of the base are critical. The spacers have to be the correct size so that when the sliders and the horizontal arm are placed in between the halves, it is not too tight for the arm to move. At the same time they cannot be too loose because the arm will not be held in place properly and could fall out. Similarly the bracket that attaches the vertical arm to the horizontal arm needs small tolerances to be spaced properly to allow the arm to move freely. Additionally, the bracket will hold the motor that controls the motion for the vertical arm. The mounting holes will need to be designed with precision so the motor is held tightly against the rack on the vertical arm. This way, it can drive the arm properly. The base's dimensions have higher tolerances. These dimensions are not critical because they do not add to the prototype's ability to display its desired features. The location for the linkage which opens and closes the cone also has larger tolerances. It is acceptable for the cone to open slightly more or less then what was designed since it will still show that the prototype is able to control this feature.

8.4.2 Critical Surfaces

Surfaces are also critical for producing the salient features of the design. The base and the horizontal arm must be perpendicular so the arm will move in the proper direction. Similarly the vertical arm needs to be perpendicular to the horizontal arm to ensure that the vertical arm will be orthogonal to the field and will be able to harvest the asparagus from directly overhead. Also, the cone must be attached vertically to the vertical arm so its overlapping cutters will be cutting the asparagus properly; if the cone was tilted sideways then the walls of the cone would be cutting the asparagus, not the blades.

8.4.3 Assembly

The assembly for the prototype will be straightforward once the subcomponents are fabricated. Since the design is relatively simple, the parts will be attached easily using either bolts or welds. The sliders will be attached to the base, bracket, and arms using the screws provided in their packaging. The horizontal arm will simply rest in the horizontal sliders mounted on the base. The motor will then be attached to the top of the base using a bracket; thus it will need bolts. The vertical arm will rest in the sliders on the bracket. The motor for the vertical arm will be bolted to the bracket connecting the horizontal and vertical arms. The cone can be attached to the vertical arm by welding together the aluminum cone rim and arm. The racks will be mounted on the arms either using a weld, weld epoxy, or bolts. The casing included with the pull solenoid actuator will be welded to the vertical arm.

8.5 Final Fabrication Plan

The fabrication plan for the prototype and final design are very similar. The parts are listed in Appendix I. Pictures of the finished design are also provided in Appendix N.

8.5.1 Prototype

- Tighten set screw provided with gear onto each motor
- Base – Cut two 12 foot 2x4” pieces of wood using a circular saw.
  4 @ 27”
  2 @ 12”
  2 @ 36”
- The pieces are then assembled together using 2” wood screws
- Arms – Cut to size (36” and 24”) using a band saw set to 275 ft/min
- Using industrial strength glue, attach the racks to the arms
- Screw sliders onto arms with screws provided with the sliders with hand drill
- Bracket – Cut to size (fig. 12b on page 21) on bandsaw set to 275 ft/min
- Screw slider tracks onto bracket and base using the provided screws with hand drill
- Place motor on top of vertical piece of wood on the base and secure it with the strap and screws
- Drill ¼” holes through bracket and horizontal arm using a hand drill
- Place vertical arm inside bracket and then using 2” long ¼” bolts, secure bracket to the arm
- Cut 1” angle bracket to 2” long on the band saw at 275 ft/min
- Drill ¼” hole through the vertical arm and two holes on angle bracket then secure with ¼” bolt
- Place the solenoid on the bracket and secure it with ¼” bolt
- Cut 1/16”thick aluminum strip to 8” on the band saw at 275 ft/min
- Bend the linkage strip by hand at 2”
- Drill a ¼” hole into both ends of the strip with a hand drill
- Make cone’s form by cutting a 6” and 2” circle out of quarter inch plywood, cut on bandsaw 165 ft/min

- Place a 9.5” long dowel rod in between two pieces, secure with wood screws
- Wrap with heavy cardboard then place tape to hold it in shape
- Wrap form in saran wrap followed by layering it with fiberglass
- Once fiberglass dries remove from form and cut in half using a hack saw
- Drill a series of 1/8” holes around rim
- Take a piece of aluminum strip and cut it on the band saw at 275 ft/min so it fits around the top of both cone halves.
- Using a centerpunch line up the strip with the cone then mark where the 1/8” holes are
- Using a hand drill, make 1/8” holes in the aluminum strips
- Use a rivet gun with 1/8” rivets with 1/8” grab and attach the strip to the cone.
- Place a nail through the cone halves to attach them together
- Glue razor blades to the bottom of the cone
- Using a ¼” bolts attach the bent strip to the cone and to the solenoid.
- Use a hack saw to cut a cavity in the bracket to place the vertical motor
- Hold the vertical motor in place by bolting an angle bracket below it

8.5.2 Final Design

The asparagus picker will only be made on a small scale so the fabrication process will be very similar. The parts are listed in Appendix I.

- Tighten set screw provided with gear onto each motor
- Weld the ¼” tubing together to create the base
- Bracket will be milled by a water cutter to produce accurate dimension
- Screw sliders to arms, base, and bracket using sheet metal screws
- Drill 1/8” holes into the rack and arms, thread hole with a 4-40 tap and then attach together with a 4-40 bolt
- Using the same cone form from the prototype, cover in carbon fiber
- Drill ¼” holes into the top of the cone and use a shoulder bolt to make the hinge using a hand drill
- Weld solenoid on to the vertical arm
- Weld motors to the base and bracket
- Drill ¼” hole into cone and vertical arm and attach with a ¼” bolt
- Place bolts through bracket to attach it to the base
- Glue razor blades to the bottom of the cone

The estimated cost of the final design is $600, based on similarities between the prototype and the final design. Since the final design is has a lot of custom detail, the assembly time will take longer and be more difficult. The approximate time for assembly is 4-5 minutes; however, to manufacture the parts the total time would be close to 2 hours. Estimating labor at $30 an hour we can approximate labor costs as $60 per picker. Equipment costs would be $4,000 for the drills, bandsaws, and welder; however the cost would exclude the water jet cutter. The cutter would be very expensive so the bracket could be purchased separately.

8.6 Description of Validation Approach

The following is a list of which engineering specifications will be tested and how these tests will be done. The engineering specifications are taken from figure 1 on page 6.

Engineering Specification	Method of Testing
Precise path movements that are accurate within 1/8 inch	Using motor controls to place end effecter in position to completely grasp stalk. Stalk will be positioned in a fabricated board to simulate a natural growing environment.
A grasping mechanism size measured in the plane of the field that is less than 1 ft^2	When the cone is fully opened the area that is in the plane of the field will be measured.
A force for removal of 10 Newtons (2.25 lbs force)	By using the fabricated board with positioned stalks, the device will be operated and the force will be tested by noting whether the stalks are separated.
Greater than or equal to 2 degrees of freedom	Using motors and controls the end effecter will be moved along 2 axes, the horizontal and vertical.
Picker weighs less than 100 lbs	The device, excluding base, would be placed on a scale to measure its weight.
A process time of 2 seconds	The time required to harvest one asparagus stalk will be recorded. This includes the time from beginning of device movement from the zero position to the return to the zero position.
No exposed elements that could be damaged by outdoor conditions	The prototype will be examined to determine areas that might be affected by outdoor conditions.

Table 3: Engineering specifications and methods of testing.

There are several engineering specifications that are not outlined above and no methods are given for how they would be tested. These specifications and reasons are shown in the table below.

Engineering Specification	Reason for No Method of Testing
An operational area that covers long rows of asparagus that are 3 feet wide	The prototype has shorter horizontal arms than what will be used in the final design. Shorter arms were used because of lack of availability of longer arms while staying within budget constraints.
Materials that are lightweight and non-corrosive	A method to test exactly this specification is difficult to devise. By meeting other specifications like 'process time under 2 seconds' and 'weight under 100 lbs' this specification will be met indirectly.

A lifetime of 10 years	This specification is outside of reasonable time frame of project. The only way to test is to determine life time through actual use. Robust materials were chosen.
An 85% picking efficiency while the cart is in motion	A moving cart is outside the scope of project and available only in actual harvesting applications. The measure of efficiency would be determined during actual asparagus harvesting seasons by measuring the number of harvestable stalks picked by device and the total number of harvestable stalks in the field.
A maximum grasping force of less than 10 Newtons (2.25 lbs force)	No testing is needed, as the cone shaped end effecter eliminates a force-exerting grasping device, thus satisfying the specification.

Table 4: Engineering specifications and reasons that testing cannot be carried out.

As mentioned in the table above, there are specifications that don't have experiments that directly measure them. However, several specifications are ones that can only be determined during the devices real world use while harvesting asparagus. Others require an extended period of time, or involve resources that could not be used in our prototype due to cost and availability concerns. However, if the specifications that can experimentally tested are met, then those are substantial enough to ensure that sound engineering judgment was used during the design and fabrication process.

8.7 Validation

The design of the automated asparagus picker was validated by how it performed during simulated picker operation. It was determined that the design does indeed work, drawn from the results of several tests which are outlined below. First, the horizontal and vertical arms were independently moved using motor controls to various positions of harvesting. This displayed the device's ability to achieve the required two degrees of freedom. Next, the cone end effecter was able to be placed within 1/8" of a known asparagus stalk by using the motors and motor control software. This test was carried out using the prototype and a simulated asparagus field made up of asparagus stalks that were placed in a Styrofoam test bed. The cone effecter was actuated to separate the stalks thus displaying its ability to be used for this application, and achieving the necessary 10 N of force. By simply measuring the area of the end effecter in the plane of the field, the requirement that the grasping mechanism have an area in the field plane of less than 1 ft^2 was met. This was also the case for the requirement that the device be less than 100 lbs. By placing the mechanism on a scale, it was determined that this requirement was met. Therefore, the conclusion is that our design is able to be used for asparagus harvesting based upon the positive results obtained using real stalks in a simulated field environment and by also achieving the desired engineering specifications.

8.8 Discussion

If additional iterations were done on the picker device, there are some things that could be done differently. First, the motor used for the vertical arm's motion should be resized for an increased torque output, based on the calculations shown in the Recommendations section of this report.

Also, a ‘push/pull’ solenoid should be used in place of the ‘pull’ solenoid for the actuation of the end effecter in order to have the ability to open the cone as well as close it.

The strength of the initial prototype design was the end effecter design. It embodied several engineering specifications, grasping, separating and moving, in one component. It also allows for the harvesting of stalks with various growth orientations without harming surrounding stalks. Additionally, it does not harm the harvested stalk after it is separated. The weakness of the prototype is the speed of operation. The motors were sized to achieve the specifications while being the most cost effective. Therefore, the initial prototype operation speed was not fast enough to achieve the specification of a process time of 2 seconds. However, by choosing larger motors capable of higher speeds in combination with multiple pickers, the process time can be decreased until the specification can be met.

The specifications that weren’t explicitly met in the design prototype were that the device should have a process time of 2 seconds and that it shouldn’t have any exposed elements that could be damaged by outdoor conditions. The reason the process time of 2 seconds could not be validated was due to the fact that the prototype was not able to be run from a ‘zero’ position and be returned back to this ‘zero’ position. There were several reasons for this. First, the motor used for the vertical motion was the second choice of motors after delivery time issues associated with the first choice. Therefore, the vertical arm wasn’t able to move upward after being moved downward to the level of the stalks. Also, the solenoid used for the end effecter actuation was only a ‘pull’ type device. Due to this, the effecter wasn’t able to be opened after being closed to separate the stalks. The reason for not choosing a ‘push/pull’ solenoid that would have been ideal for this application was cost issues and budget constraints.

9 RECOMMENDATIONS

Based upon the experiences of the design project from generating concepts to prototype fabrication, there are several recommendations to be made for the next iterations of the design. The operation of the prototype showed that sizing the vertical arm stepper motor by calculating the peak torque required was insufficient because it did not take into account that stepper motors pulse on and off during operation. The motors are redesigned below using steps from [6] specifically designed for sizing stepper motors:

$$operating\ pulses = \frac{l}{l_{rev}}\frac{360}{\theta_s} = \frac{10''}{4\pi''}\frac{360}{1.8} = 160$$

$$operating\ pulse\ speed = \frac{pulses}{time} = \frac{160}{8\ s} = 20\ Hz$$

$$operating\ speed = 20\ Hz\frac{1.8}{360}(60) = 6\ rpm$$

$$Load\ Torque = \frac{FD}{2\eta i} = \frac{10\ lbs(4\ in)}{2(0.9)(1)} = 355\ oz \cdot in$$

$$acceleration\,torque = (160\;oz)(2)^2\frac{\pi(1.8)20}{180(2)} = \;201\;oz \cdot in$$

$$total\;torque = load\;torque + acc.torque = 355 + 201 = 556\;oz \cdot in$$

Thus, the total torque is approximately 56% higher than just the load torque alone. This would have been acceptable had the team been able to acquire the geared motor that was originally planned for, but it could not be used due to time constraints. An additional recommendation when choosing the higher torque motor is to examine methods of moving the arms that may be faster. Although the speed of motion could be increased by choosing higher torque motors than those used on the prototype, they still may not be fast enough for full time, efficient use in an asparagus field. Thus, alternative methods of motion should be examined.

Another important recommendation the team discovered was the need to remove the blades of the cone to facilitate maintenance. The blades dull fairly quickly when cutting asparagus, and simple replacement of the blades would be much easier and less expensive than replacing the entire cone. This is an area that could be focused on in future designs.

A final recommendation is to find a solenoid or other end effecter with a longer range of motion. This would enable the connection point on the cone linkage to be placed further away from the actual rotation point, which would allow for more force at the actual cutting point of the end effecter.

10 SUMMARY

Economic conditions in Oceana County are the driving force behind the design of an automated asparagus picker. Critical elements have been identified for implementation in a practical design using concept generation methods that include a functional decomposition, a morphological chart and Pugh charts. An alpha design has been developed which includes a cone shaped end effecter which incorporates overlapping cutters to both separate and hold a selected asparagus stalk. A set of arms move in two axes of motion in a linear fashion to achieve a full range of motion. From the alpha design, a final design was developed by examining the alpha design using sound engineering reasoning. Materials were selected based on engineering specifications such as corrosion resistance and low weight. Other engineering specifications were designed for by calculating the gear sizing needed for precise movements and actuator force to sever an asparagus stalk. From these analyses, detailed dimensioning for the final design was completed. In addition to the dimensioned drawings, a list of all materials needed to manufacture the final design has been developed. In addition, the design dimensions were modified slightly for ease of fabrication for a concept demonstration. The prototype was manufactured and used to demonstrate the salient features of the design. Based on the prototype's performance, some recommendations for future iterations were made, including looking at faster motors and finding a way to easily remove the blades for fast maintenance.

11 SPONSOR FEEDBACK

Through many meetings the team was able to come up with a design that was able to meet as many customer requirements as possible. The sponsors were pleased with the progress that was made in such a short amount of time to solve the open-ended problem of developing an asparagus picker. Both the team and the sponsors were excited about the use of a cone as an end effecter. The cone is a very elegant design which cuts and gentle holds the asparagus with one simple motion. After the expo, the sponsor informed us that they will continue to pursue the idea of an automated asparagus picker with an emphasis on the use of the cone.

12 TEAM BIOGRAPHIES

My name is Chris Leitzsch and I am a senior mechanical engineering student in my last semester at the University of Michigan. I am originally from northern New Jersey and I still go back there for the holidays and the summer. I have an interest in mechanical engineering because I like learning how devices function and how to try to improve them. I have some experience working in an engineering environment. I had an internship at Picatinny Arsenal in New Jersey the past two summers with the warhead design group. I gained experience running CAD modeling software and finite element analysis software among other things at this internship. For the future, I plan on finding a job in a mechanical engineering field, but I am undecided on what industry I would like to work in.

My name is James (Jim) Marcicki, and I am a 4^{th} year student of Mechanical Engineering at the University of Michigan. My hometown is Livonia, Michigan, which is about 25 miles east of Ann Arbor. I will be graduating this April and will most likely be continuing at U of M for graduate school. I have had summer internships with Ford Motor Company the past two summers, and greatly enjoyed my time there. My career interests lie in alternative fuels and advanced powertrains for automobile use, including hybrid and fuel cell technologies. I have found mechanical engineering to be a rewarding and challenging field, because it deals with issues that are very tangible and relevant to society on the whole. For instance, the automotive industry builds products that touch nearly every member of society's lives. For fun, I enjoy playing basketball and football, and staying active. I also build and fly remote control sailplanes and electric powered aerobatic airplanes. I take particular pride in producing my own scratch built designs from carbon, fiberglass, Kevlar, and foam composites, and have been active in this hobby for 10 years. Another hobby I enjoy is training my two year old Papillon, Lexi, for dog agility competitions.

My name is Kyle Rademacher and I'm in my final semester in the mechanical engineering program at the University of Michigan. I am originally from DeWitt, Michigan, located just a few miles north of Lansing. My interests include traveling, playing sports and being outdoors with family and friends. Initially, my interest in physics, math and the intricacies of how things worked drew me to mechanical engineering. I am now focusing on energy applications, efficiency and conservation as I near the end of my undergraduate studies. A lasting experience includes the summer I spent abroad living and studying in

Stuttgart, Germany during the 2006 World Cup and the traveling with friends throughout Europe I did afterwards. This past summer I worked with the Industrial Assessment Center at the University of Michigan to help large energy consuming manufacturing plants streamline their operations and use energy more efficiently. This experience led directly into the full time position I will begin after graduation with Schneider Electric in Raleigh, North Carolina. I hope to continue further education a few years down the road when I find something that truly intrigues me.

My name is Michael Weessies and I am a senior in mechanical engineering at the University of Michigan. I was born in Farminigton Hills Michigan and spent half of my life there before moving to Portage Michigan which is on the outskirts of Kalamazoo. So yes Kalamazoo truly does exist. My interests include playing sports especially hockey although I am prone to injury. From a young age I displayed a strong interest in math, science, and mischief. The mischief included taking random household appliances apart and attempting to put them back into working conditions without being caught by my parents. These interests led me to pursue a degree in mechanical engineering which focuses heavily on the application of math and science for the purpose of solving relevant real world problems. Upon graduation I hope to find a job working in product and process engineering with the intent of going to graduate school soon after.

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Jim Otten
Lalit Patil
David Roseman
Steven J. Skerlos

14 REFERENCES

[1] Mechanical Harvester of Asparagus RGA-type. Retrieved January 21, 2008. Website: http://www.kirpy.com/en/materiel/recoltes/recoltaspe.html

[2] Asparagus Research Selective Harvester 2003. Retrieved January 21, 2008. Website:http://www.agribusiness-mgmt.wsu.edu/AgbusResearch/asp_selective_harvester03.htm

[3] Green Asparagus Harvester. Retrieved January 21, 2008. Website: http://www.freepatentsonline.com/4918909.html

[4] USTPO Patent Database, Asparagus Harvesting Devices. Retrieved January 21,2008. Website: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=33&f=G&l=50&d=PTXT&S1=asparagus.TI.&OS=ttl/(asparagus)&RS=TTL/asparagus

[5] USPTO Patent Database, Asparagus Harvesting Devices. Retrieved January 21, 2008. Website: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=40&f=G&l=50&d=PTXT&S1=asparagus.TI.&OS=ttl/(asparagus)&RS=TTL/asparagus

[6] Stepping Motor Selection Guide. Retrieved April 12, 2008. Website: http://www.orientalmotor.com/support/mtr_sizing_stp.htm

APPENDIX A: BENCHMARKED DESIGNS

Kirby Plow Design

Human Handpicking

APPENDIX B: CONCEPTS

Motor-4-B-β
This design uses the pincers as blades, so the cutting and grasping are combined. When cut, the asparagus will lie in the pincers and will be transported through a linear motion which will help the asparagus will able to lie in the pincers without falling out.

Motor-10-F-γ
A vacuum will hold the asparagus and through a rotation, the stalk will become separated. The flexible hose will allow the movement to be extremely robust and can virtually move wherever it needs to.

Motor-6-A-ρ
The cone will slide over the stalk and the bottom will have a blade which can cut the stalk. The movement will be achieved through an arm with two joints. There will be two arms though which will allows it to cover more of the field quicker.

Motor-5-D-θ
I scythe blade will cut the stalk which will then fall into a cup that is on an angle. The motion will be achieved through arms that will be above the field, thus enabling it to reach any desired stalk.

Motor-9-C-ρ
This design uses multiple pinchers to cut the stalk, which increases its robustness because it can cut the asparagus easier even if it is covered in dirt. The use of two arms increases the speed of the picking process.

Motor-1-E-σ
In this design two halves of a cup comes together as a blade cuts it. This design enables gentle handling of the stalk because the stalk will rest inside of the cup. Lastly, the movement occurs through a a human like arm which increases the versatile motion of the apparatus.

Motor-7-F-α
A vacuum will hold the stalk as an arthroscopic appendage is able to move to a determined cutting point and it can use a high pressure stream of water to cut the stalk. A two jointed arm will allow the apparatus to reach the stalks.

Motor-8-C- θ
The saw will cut the stalk which is grasped by a claw. The stepper motors will move the arms through motion which is perpendicular to the travel of the cart.

Motor-11-E-θ
Two halves of a cup closes around a stalk and as they close, the stalk is cut. The stalk then rests inside the cup as is moves by way of linear motion above the field.

Motor-1-C-σ
A claw evenly grasps the stalk as a blade cuts it. A human like arm is used to easily move to and from the desired stalk while navigating the field.

Motor-5-F-ρ
A large scythe cuts the stalk that is being held by the vacuum. Two arms are implemented to achieve the desired movement while increasing the rate at which the asparagus can be harvested.

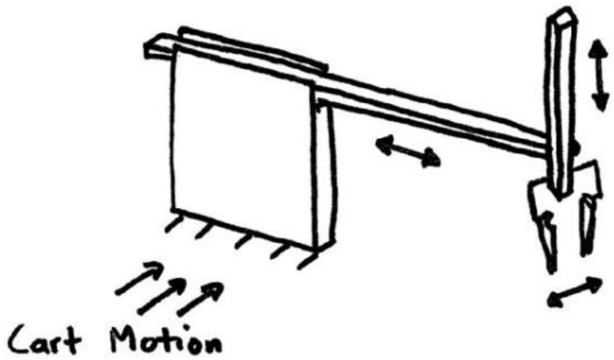
Motor-10-F-α
A vacuum will hold the asparagus and through a rotation, the stalk will become separated. A two jointed arm will be used to navigate the field.

Motor-4-D- σ
The cup will be slanted and part of it will have blades which cut the stalk, then gravity will cause the stalk to fall into the cup. A human like arm achieves the versatile motion.

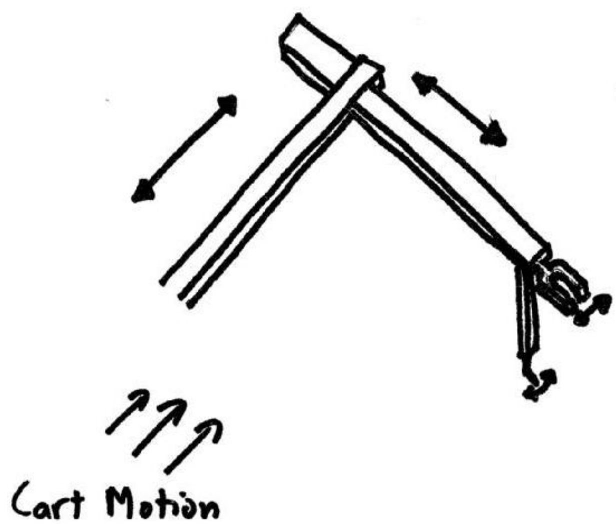
Motor-3-B- α
The pincer will hold the stalk and then rotate which will cause the stalk to separate. A two jointed arm will allow the pincer to rotate and also a move the apparatus through the field.

Motor-10-A-θ
A cone will guide the asparagus into a vacuum which will apply an upward force causing the stalk to break. The stepper motors will move the arms through motion which is perpendicular to the travel of the cart.

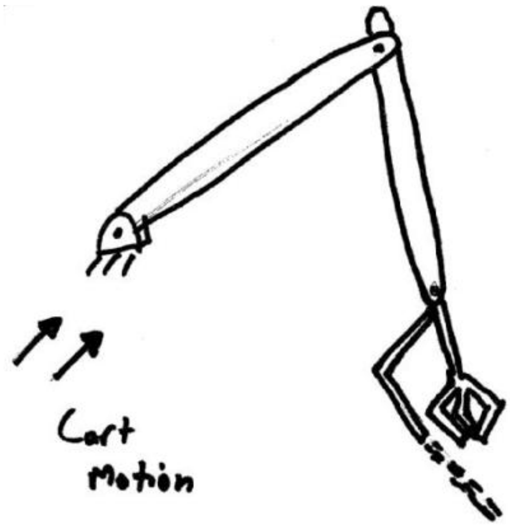
APPENDIX C: UNIQUE CONCEPTS



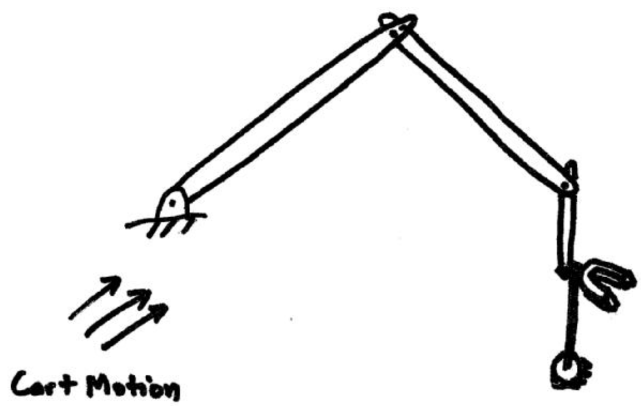
Gentle Touch Cone



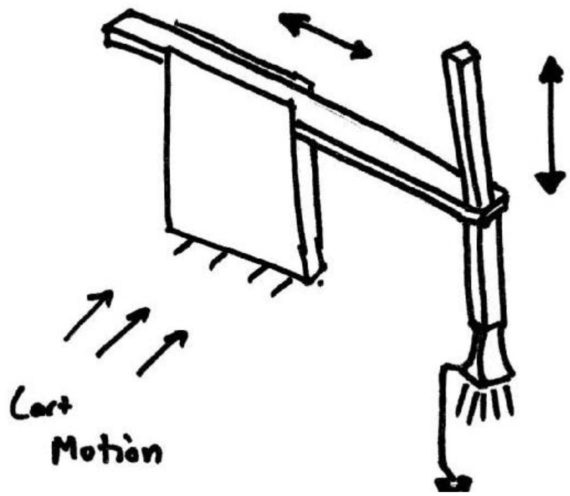
Swing Blade



Water Claw

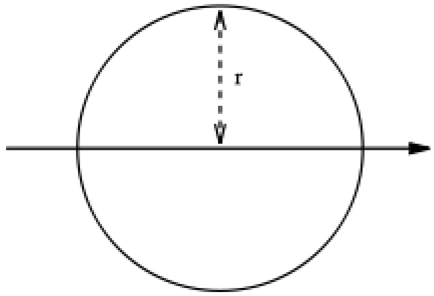


Grasping Saw

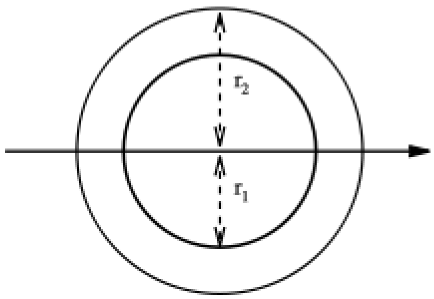


Swinging Blade Vacuum

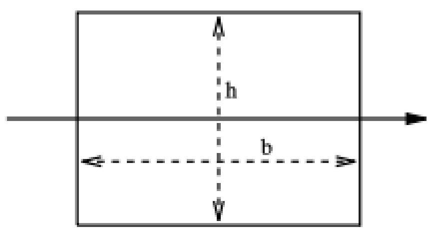
APPENDIX D: ARM SECTION SELECTION



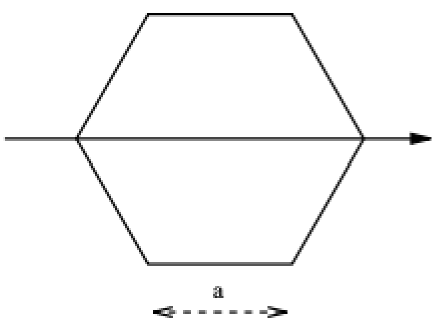
$$I_0 = \frac{\pi r^4}{4}$$



$$I_0 = \frac{\pi}{4}\left({r_2}^4 - {r_1}^4\right)$$



$$I_0 = \frac{bh^3}{12}$$



$$I_0 = \frac{5\sqrt{3}}{16}a^4$$

(Images taken from Wikipedia)

APPENDIX E: ARM BENDING STRENGTH CALCULATIONS

$$\sigma_{max} = \frac{M\boldsymbol{h}}{\mathbf{2}I} = \frac{FL\boldsymbol{h}}{\mathbf{2}I}$$

$$I = \frac{b\boldsymbol{h}^{\mathbf{3}}}{\mathbf{12}}_{outer} - \frac{b\boldsymbol{h}^{\mathbf{3}}}{\mathbf{12}}_{inner}$$

$$I = \frac{0.025\mathbf{4}^{\mathbf{4}}}{\mathbf{12}}_{outer} - \frac{0.023\mathbf{8}^{\mathbf{4}}}{\mathbf{12}}_{inner} = 7.95 \times \mathbf{10^{-9}}\ m^{\mathbf{4}}$$

$$\sigma_{max} = \frac{FL\boldsymbol{h}}{\mathbf{2}I} = \frac{44.5\ N\,(0.914\,m)(0.0127\,m)}{7.95 \times \mathbf{10^{-9}}\ m^{\mathbf{4}}} = 6.49 \times \mathbf{10^{7}}Pa \approx 65\ MPa$$

APPENDIX F: ARM DEFLECTION CALCULATIONS

$$\frac{F}{\delta} = \frac{\mathbf{3}EI}{L^{\mathbf{3}}}$$

$$\delta = \frac{FL^{\mathbf{3}}}{\mathbf{3}EI}$$

$$\delta = \frac{44.5\ N\ (0.914\ m)^{\mathbf{3}}}{\mathbf{3}(70 \times 10^{\mathbf{9}}\ Pa)(\mathbf{7.95}\ \times 10^{-\mathbf{9}})}$$

$$\delta = 0.020\ m$$

APPENDIX G: MOTOR TORQUE CALCULATIONS

$$T = \frac{F}{2\pi\varepsilon}\frac{\pi D}{i} = \frac{FD}{2\varepsilon i}$$

$$F = F_E + W(sin\alpha + \mu cos\alpha)$$

In the above equations, F_E is any external forces acting on the load (assumed equal to zero for this application), i is the gear ratio (assumed equal to one for this application), and ε is the system efficiency (assumed equal to 0.9).

$$F = 0 + 2(5lb)(\sin(90) + \mu\cos(90)) = \mathbf{10}\ lb$$

$$T = \frac{10lb(4in)}{2(0.9)(1)} = 22\ lb \cdot in = 352\ oz \cdot in$$

APPENDIX H: GEAR SIZING CALCULATIONS

$$x = \pi D \frac{\theta}{360}$$

$$\frac{\mathbf{1}}{\mathbf{16}} = \pi D \frac{1.\mathbf{8}}{36\mathbf{0}}$$

$$\frac{36\mathbf{0}}{\mathbf{16(1.8)(\pi)}} = D \approx 4\ inc\boldsymbol{he}s$$

APPENDIX I: BILL OF MATERIALS

Prototype BOM

Part #	Part Name	Qty	Source	Material	Color/Finish	Size (inches)	Mass	Manuf. Process	Function
216099	Horizontal Arm	1	Lowe's Hardware	Aluminum	Gray/Unfinshed	1"x1"x48" long	0.88 lbs	Cutting/Drilling	Method of moving end effecter
216099	Vertical Arm	1	Lowe's Hardware	Aluminum	Gray/Unfinshed	1"x1"x20" long	0.45 lbs	Cutting/Drilling	Method of moving end effecter
3000016	Cone	1	Lowe's Hardware	Carbon Fiber	Unfinished	10" high x 4" top diameter	0.5 lbs	Cutting/Drilling	Seperation, holding, transporting of stalk
79644	Sliders	4	Lowe's Hardware	Steel	White/Painted	1.2"x1.2"x18" long	0.5 lbs	Cutting/Drilling	Method of moving end effecter
70155K43	Solenoid	1	McMaster-Carr	Steel/Magnet	Gray/Unfinshed	1.6"1.4"2" long	0.62 lbs	Fastening	Actuation device for end effecter
23Y104S-LW8	Horizontal Motor	1	McMaster-Carr	Various Materials	Gray/Unfinshed	2.25"x2.25"x2.21" long	1.55 lbs	Fastening	Power source for device movement
24Y404S-LW8	Vertical Motor	1	McMaster-Carr	Various Materials	Gray/Unfinshed	2.36"x2.36" x 3.03" long	2.6 lbs	Fastening	Power source for device movement
GFS24X36	Linkage	1	X50 Lab	Sheet Steel	Gray/Unfinshed	1"x6" long	0.2 lbs	Cutting/Drilling	Utilize mechanical advantage between solenoid and end effecter
S1086Z-064A256	Horizontal Gear	1	McMaster-Carr	2024 Aluminum Alloy	Gray/Unfinshed	4" diameter 0.1875" width 0.25" bore size	0.5 lbs	Fastening	Convert rotational motor motion to linear motion
S1086Z-064A256	Vertical Gear	1	McMaster-Carr	2024 Aluminum Alloy	Gray/Unfinshed	4" diameter 0.1875" width 0.25" bore size	0.5 lbs	Fastening	Convert rotational motor motion to linear motion
S1811Y-RB-4P	Horizontal Rack	1	McMaster-Carr	Brass	Gray/Unfinshed	0.48" x 0.23" x 24"long	0.8 lbs	Cutting/Fastening	Convert rotational motor motion to linear motion
S1811Y-RB-4P	Vertical Rack	1	McMaster-Carr	Brass	Gray/Unfinshed	0.48" x 0.23" x 24"long	0.5 lbs	Cutting/Fastening	Convert rotational motor motion to linear motion
GFS24X36	Bracket	1	X50 Lab	Sheet Steel	Gray/Unfinshed	5"x15"long	0.5 lbs	Cutting/Drilling	Interphase horizontal and vertical arms
GFS24X36	Support Bracket	2	X50 Lab	Sheet Steel	Gray/Unfinshed	L-shaped, 5"x2"	0.2 lbs	Cutting/Drilling	Supports Motor for Vertical Motion on
79644	Slider Screws	12	Lowe's Hardware	Steel	Gray/Unfinshed	1/8" diameter	0.05 lbs	Drilling	Attaches slider to vertical and horizontal arms
PP23518-10	Shoulder Bolts	12	X50 Lab	Steel	Gray/Unfinshed	1/4" dianeter	0.1 lbs	Drilling	Serves to attach components
A303/PB61	Nuts	15	X50 Lab	Steel	Gray/Unfinshed	1/4" dianeter	0.1 lbs	N/A	Attaches to bolts, ensures bolt placement

Final Design BOM

Part #	Part Name	Qty	Material	Color/Finish	Size (inches)	Mass	Manuf. Process	Function
216099	Horizontal Arm	1	Aluminum	Gray/Unfinshed	1"x1"x48" long	0.88 lbs	Cutting/Drilling	Method of moving end effecter
216099	Vertical Arm	1	Aluminum	Gray/Unfinshed	1"x1"x20" long	0.45 lbs	Cutting/Drilling	Method of moving end effecter
3000016	Cone	1	Carbon Fiber	Unfinished	10" high x 4" top diameter	0.5 lbs	Cutting/Drilling	Seperation, holding, transporting of stalk
79644	Sliders	2	Steel	White/Painted	1.2"x1.2"x18" long	0.5 lbs	Cutting/Drilling	Method of moving end effecter
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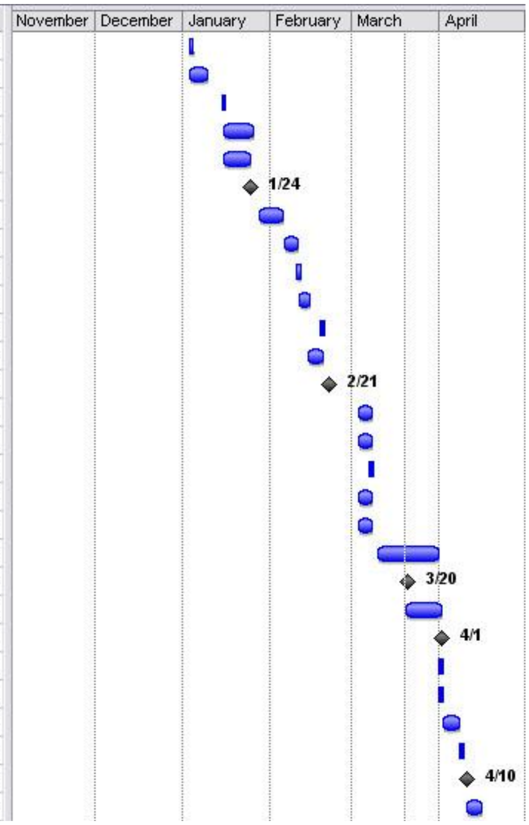
23Y104S-LW8	Horizontal Motor	1	Various Materials	Gray/Unfinshed	2.25"x2.25"x2.21" long	1.55 lbs	Fastening	Power source for device movement
24Y404S-LW8	Vertical Motor	1	Various Materials	Gray/Unfinshed	2.36"x2.36" x 3.03" long	2.6 lbs	Fastening	Power source for device movement
GFS24X36	Linkage	1	Sheet Steel	Gray/Unfinshed	TBD	0.2 lbs	Cutting/Drilling	Utilize mechanical advantage between solenoid and end effecter
1086Z-064A25	Horizontal Gear	1	2024 Aluminum Alloy	Gray/Unfinshed	4" diameter 0.1875" width 0.25" bore size	0.5 lbs	Fastening	Convert rotational motor motion to linear motion
1086Z-064A25	Vertical Gear	1	2024 Aluminum Alloy	Gray/Unfinshed	4" diameter 0.1875" width 0.25" bore size	0.5 lbs	Fastening	Convert rotational motor motion to linear motion
61811Y-RB-4F	Horizontal Rack	3	416 Stainless Steel	Gray/Unfinshed	0.48" x 0.23" x 11"long	0.8 lbs	Cutting/Fastening	Convert rotational motor motion to linear motion
61811Y-RB-4F	Vertical Rack	2	416 Stainless Steel	Gray/Unfinshed	0.48" x 0.23" x 11"long	0.5 lbs	Cutting/Fastening	Convert rotational motor motion to linear motion
GFS24X36	Bracket	1	Sheet Steel	Gray/Unfinshed	5"x15"long	0.5 lbs	Cutting/Drilling	Interphase horizontal and vertical arms
GFS24X36	Support Bracket	2	Sheet Steel	Gray/Unfinshed	L-shaped, 5"x2"	0.2 lbs	Cutting/Drilling	Supports Motor for Vertical Motion on
216099	Base	2	Aluminum	Gray/Unfinshed	1"x1"20" + 1"x1"x12"	0.7 lbs	Cutting/Drilling	Method of moving end effecter

APPENDIX J: GANTT CHART

		Task Name	Duration	Start	Finish
1		Team formation	2 days	Thu 1/3/08	Fri 1/4/08
2		Project selection	5 days	Thu 1/3/08	Wed 1/9/08
3		Meet with sponsors	1 day	Tue 1/15/08	Tue 1/15/08
4		Problem definition	9 days	Tue 1/15/08	Fri 1/25/08
5		Creation of engineering specifications	8 days	Tue 1/15/08	Thu 1/24/08
6		Design review #1	1 day	Thu 1/24/08	Thu 1/24/08
7		Develop funcitonal decomposition	7 days	Mon 1/28/08	Tue 2/5/08
8		Develop morphological chart	4 days	Wed 2/6/08	Sun 2/10/08
9		Construct Pugh chart	2 days	Sun 2/10/08	Mon 2/11/08
10		Concept selection	4 days	Mon 2/11/08	Thu 2/14/08
11		Customer meeting	1 day	Tue 2/19/08	Tue 2/19/08
12		Develop CAD model	4 days	Thu 2/14/08	Tue 2/19/08
13		Design review #2	3 days	Tue 2/19/08	Thu 2/21/08
14		Static mechanics determination	5 days	Mon 3/3/08	Fri 3/7/08
15		Material dynamics and selection	5 days	Mon 3/3/08	Fri 3/7/08
16		Order Parts	1 day?	Fri 3/7/08	Fri 3/7/08
17		Motion simulation	5 days	Mon 3/3/08	Fri 3/7/08
18		Integration of power	5 days	Mon 3/3/08	Fri 3/7/08
19		Prototype fabrication	16 days	Mon 3/10/08	Mon 3/31/08
20		Design review #3	3 days	Tue 3/18/08	Thu 3/20/08
21		Completion of preliminary prototype	9 days	Thu 3/20/08	Tue 4/1/08
22		Design review #4	1 day	Tue 4/1/08	Tue 4/1/08
23		Final prototype review	1 day	Tue 4/1/08	Tue 4/1/08
24		Final prototype review	1 day	Tue 4/1/08	Tue 4/1/08
25		Design LabView interface	4 days?	Wed 4/2/08	Mon 4/7/08
26		Test interface with design	1 day?	Tue 4/8/08	Tue 4/8/08
27		Design expo and presentation	1 day	Thu 4/10/08	Thu 4/10/08
28		Final report completition	4 days	Thu 4/10/08	Tue 4/15/08

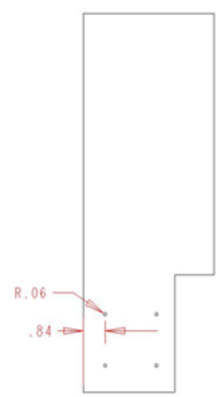


APPENDIX K: DESCRIPTION OF CHANGES SINCE DR3

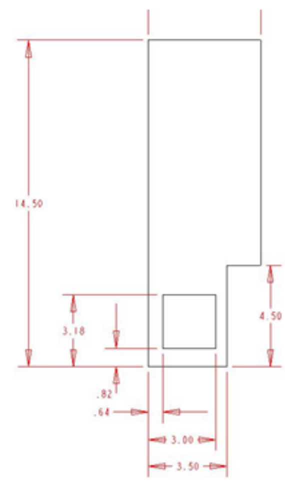
The following changes were made to the prototype and final design:

Engineering Change Notice

WAS:



IS:



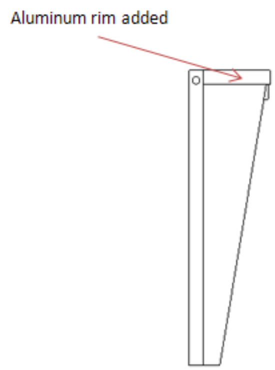
Notes: Bracket was originally designed so the motor could be bolted directly into the material. Needed to move motor through bracket in order for gear to reach rack.

TEAM 34
PROJECT: Automated Asparagus Picker
REF. DRAWING: Bracket
CHANGES MADE BY: Team 34

Engineering Change Notice

WAS:

IS:



Notes: An aluminum rim was added to the top of the cone for the prototype. This was placed there in order to add support for the closing mechanism.

TEAM 34
PROJECT: Automated Asparagus Picker
REF. DRAWING: Cone
CHANGES MADE BY: Team 34

APPENDIX L: DESIGN ANALYSIS ASSIGNMENT FROM LECTURE

Appendix L1: Material Selection Assignment

Appendix L1.1: Cone End Effecter

Function: Separate stalk when the cone comes together, hold stalk after stalk is harvested from the ground.

Objective: Minimize mass without sacrificing rigidity.

Material Index – $M = \frac{E^{1/2}}{\rho}$

Constraint	Value
Young's Modulus, E	> 20 GPa
Yield Stress, σ_{max}	> 70 MPa
Density, ρ	< 1.75 g/cm^3
Cost	< 30 $/kg
Water resistance	Good

Top Five Material Choices:

- Epoxy SMC (Carbon Fiber)
- Epoxy SMC (Glass Fiber)
- Oak
- Phenol Formaldehyde
- Phenolic/E-glass Fiber

Final Material Chosen: Epoxy SMC (Carbon Fiber)

Reasoning: Carbon Fiber is chosen for the cone material because it is the stiffest of all the materials examined, and also has the lowest density. Furthermore, it will be easily cleaned, which is an important factor because the cutting of asparagus will be a messy process and the fields are very dusty. Carbon fiber also offers impressive resistance to weather conditions.

Appendix L1.2: Arms

Function: Move end effecter, hold end effecter rigidly without yielding or deflecting excessively under operating loads.

Objective: Minimize mass without sacrificing rigidity.

Material Index – $M = \frac{E^{1/2}}{\rho}$

Constraint	Value
Young's Modulus, E	> 70 GPa
Yield Stress, σ_{max}	> 70 MPa
Density, ρ	> 2.8 g/cm^3
Cost	< 7 $/kg
Water resistance	Good
Length, L	1.22 m

Top Five Material Choices:

- 7075 T6 Wrought Aluminum Alloy
- Silica (Fused)
- 6061 T4 Wrought Aluminum Alloy
- Glass Ceramic 9608
- A201 T7 Cast Aluminum Alloy

Final Material Chosen: 6061 T4 Wrought Aluminum Alloy

Reasoning: This aluminum alloy provides the best combination of low price, high strength, high rigidity, and low weight. In addition, it is very resistant to fresh water, acids, and UV radiation which will give it good wear properties during in-field use. Aluminum is also very accessible and machines well. It can be welded and as shown during the prototype construction it is easy to work with. This analysis was performed using Cambridge Engineering Software. Screenshots from the program are shown below.

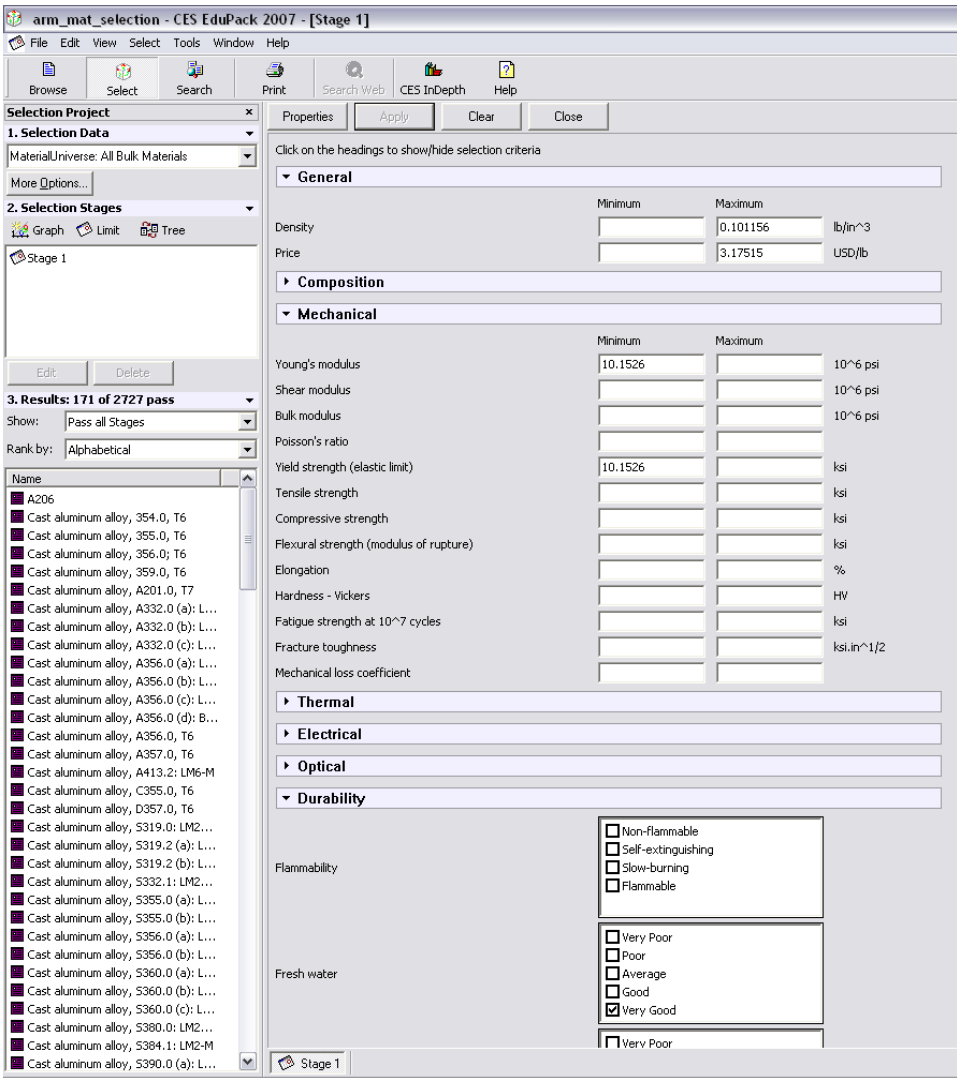


Figure L1.1: Arm material selection CES data entering.

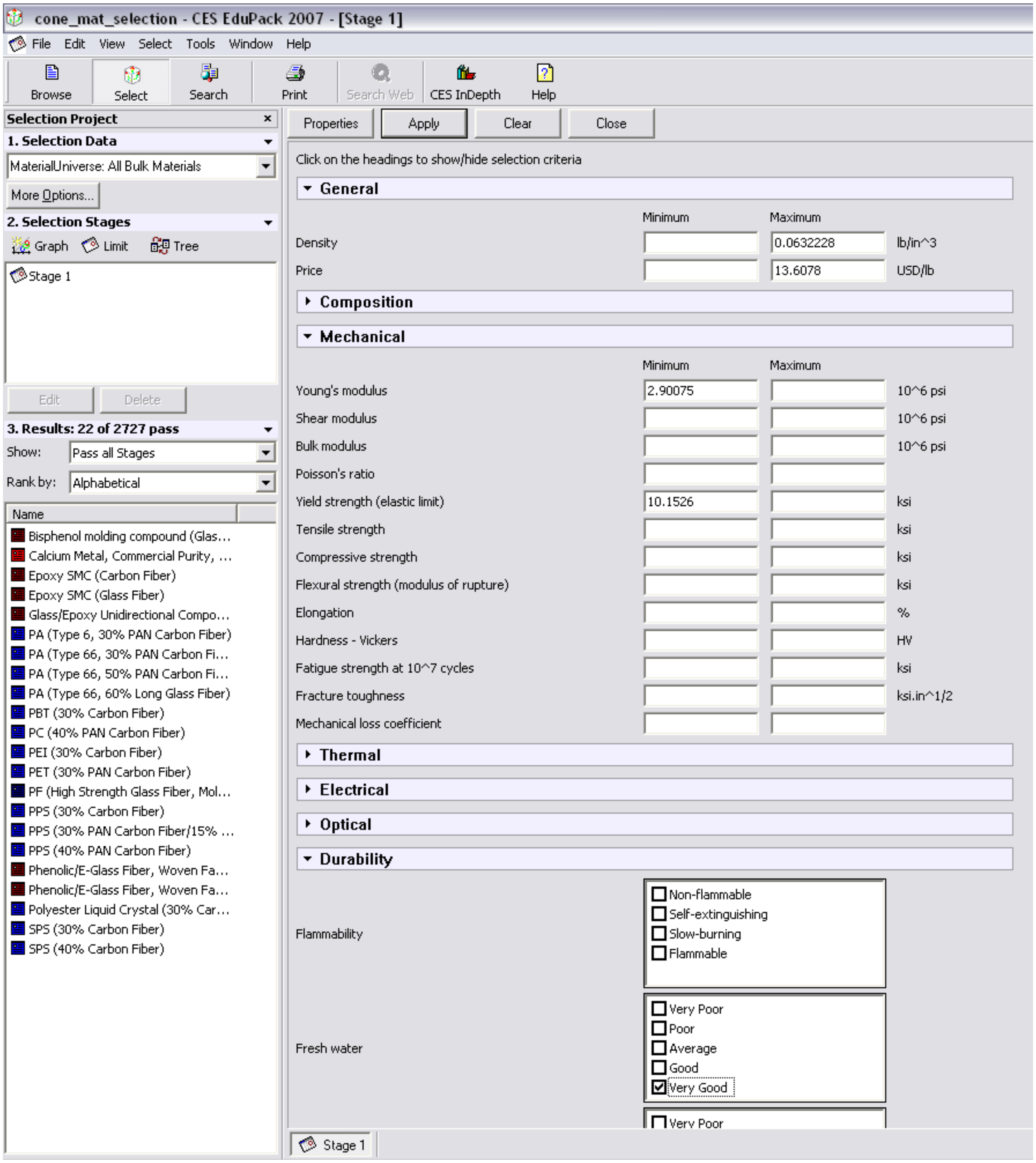
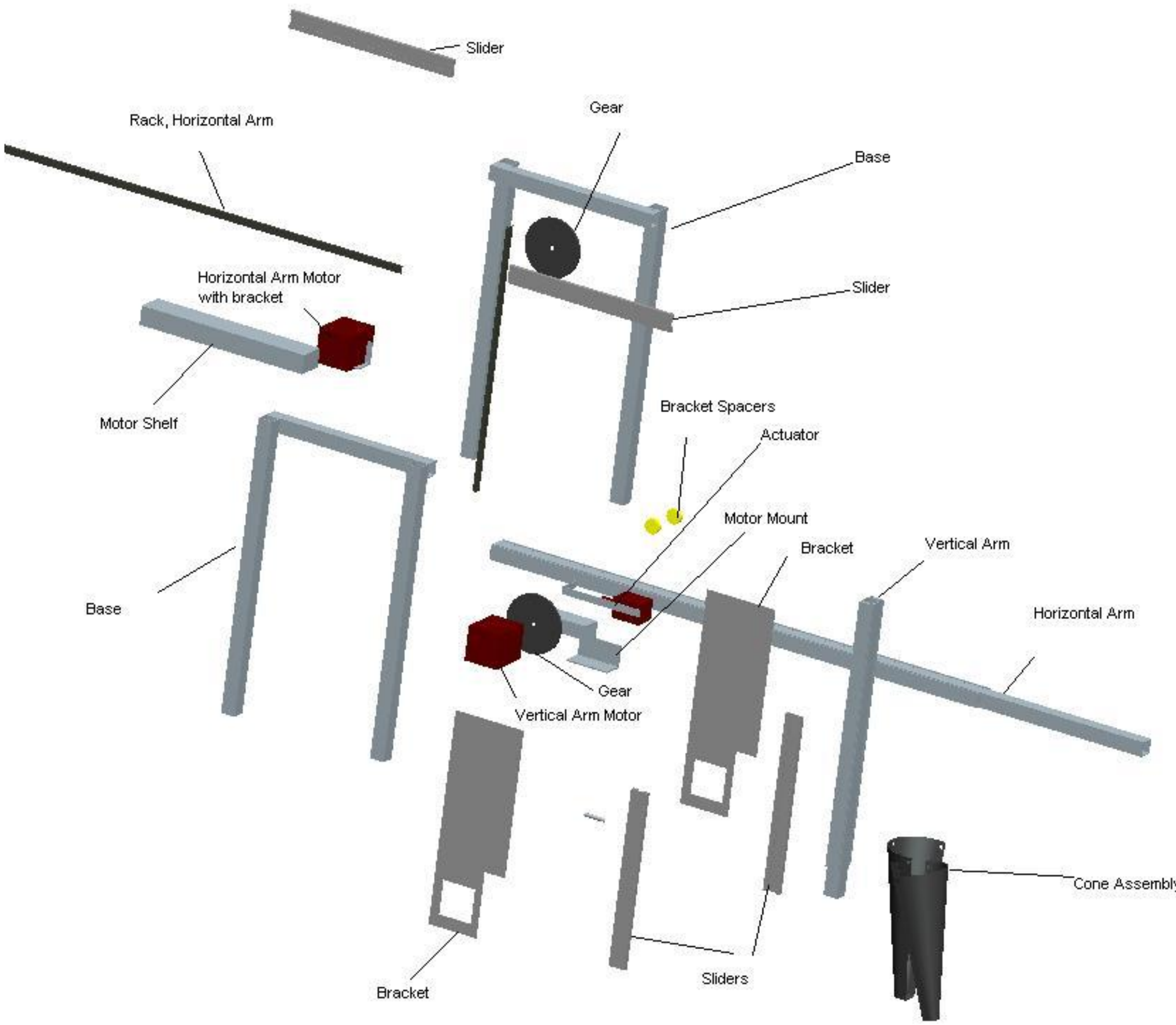
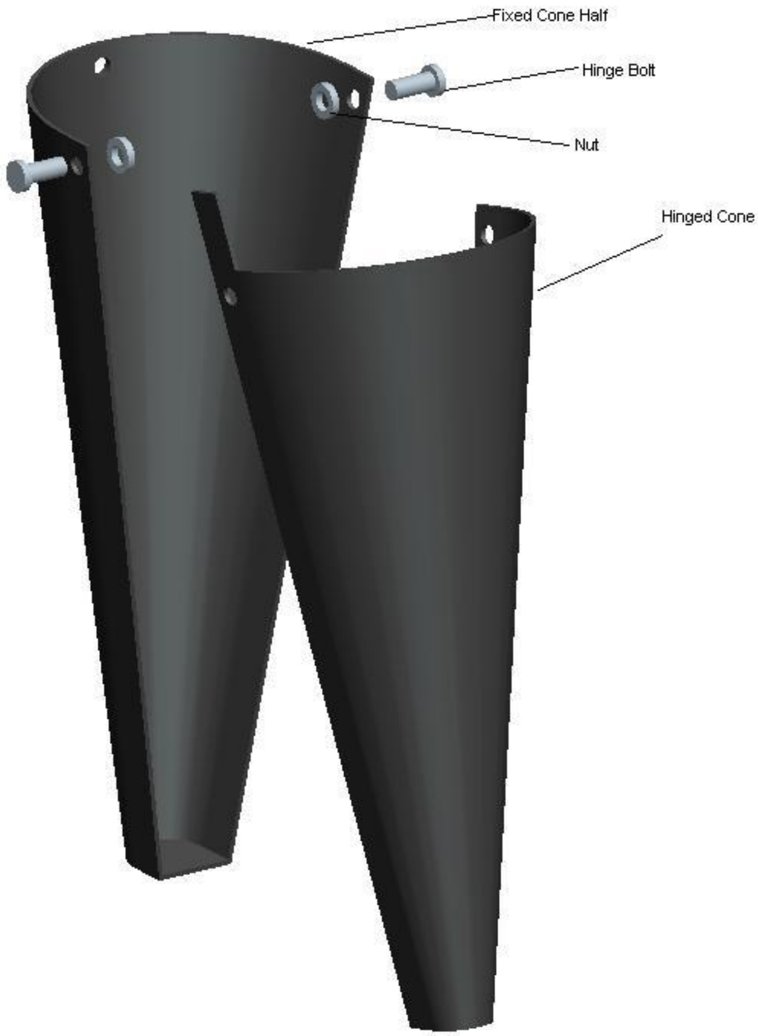


Figure L1.2: Cone material selection CES data entering.

Appendix L2: Design for Assembly

The design for assembly (DFA) has been performed for the automated asparagus picker. The original efficiency is 35% and after utilizing DFA techniques, the newly re-designed efficiency is 46%. The efficiencies are based upon the number of parts that go into the assembly along with estimated times for handling and insertion. The times are standardized for use in industry. Furthermore, parts were examined to determine if they could either be combined or eliminated from the assembly in order to increase the efficiency. The major improvements that helped contribute to the efficiency increase include combining the two legs on each side of the horizontal arm into one piece along with including motor1's mount. Also, the bolts which hold motor2 will now completely pass through the bracket, thus allowing easier access for insertion. Welding is now more frequently used to decrease the number of bolts and steps required for assembly. However, the automated picker is a very complex system so the number of parts cannot be drastically decreased, thus it still has a low efficiency.




Fixed Cone Half
Hinge Bolt
Nut
Hinged Cone

1	2	3	4	5	6	7	8	Name of Assembly
Number of times the operation is carried out consecutively	2 digit manual handling code	Manual handling time per part	2 digit manual insertion code	Manual insertion time per part	Operation time (seconds) (2) * [(4)*(6)]	Operation costs (cents) 0.4 * (7)	Figures for estimation of theoretical minimum parts	**Original Asparagus picker**
2	00	1.13	03	3.50	9.26	3.704	2	Gear
4	20	1.88	00	1.50	13.52	5.408	2	Legs of base
2	20	1.88	00	1.50	6.76	2.704	0	Horizontal bar
1	20	1.88	00	1.50	3.38	1.352	1	Horizontal arm
2	00	1.13	02	2.50	7.26	2.904	2	Rack
1	20	1.88	00	1.50	3.38	1.352	0	Horizontal motor mount
1	20	1.88	02	2.50	4.38	1.752	1	Motor1
4	11	1.80	48	8.50	41.2	16.48	4	Bolt
1	20	1.88	00	1.50	3.38	1.352	1	Vetical Arm
2	33	2.51	18	9.00	23.02	9.208	2	Bracket
1	23	2.36	18	9.00	11.36	4.544	0	Motor Support
1	20	1.88	18	9.00	10.88	4.352	1	Motor2
4	11	1.80	48	8.50	41.2	16.48	4	Bolt
4	30	1.95	12	5.00	27.8	11.12	4	Sliders
1	23	2.36	18	9.00	11.36	4.544	1	Solenoid Support
1	11	1.80	38	6.00	7.8	3.12	0	Bolt
1	20	1.88	00	1.50	3.38	1.352	1	Solenoid
1	11	1.80	38	6.00	7.8	3.12	0	Bolt
2	23	2.36	02	2.50	9.72	3.888	2	Linkage
1	30	1.95	00	1.50	3.45	1.38	1	Cone
3	11	1.80	38	6.00	23.4	9.36	3	Bolt

TM	CM	NM	Design Efficiency = 3*NM/TM	
273.69	109.476	32		0.350762

1	2	3	4	5	6	7	8	Name of Assembly	
Number of times the operation is carried out consecutively	2 digit manual handling code	Manual handling time per part	2 digit manual insertion code	Manual insertion time per part	Operation time (seconds) (2) * [(4)*(6)]	Operation costs (cents) 0.4 * (7)	Figures for estimation of theoretical minimum parts	**Redesigned Asparagus picker**	
2	00	1.13	03	3.50	9.26	3.704	2	Gear	
2	20	1.88	00	1.50	6.76	2.704	2	Legs of base	
1	20	1.88	00	1.50	3.38	1.352	1	Horizontal arm	
2	00	1.13	02	2.50	7.26	2.904	2	Rack	
1	20	1.88	02	2.50	4.38	1.752	1	Motor1	
4	11	1.80	38	6.00	31.2	12.48	4	Bolt	
1	20	1.88	00	1.50	3.38	1.352	1	Vertical arm	
2	03	1.69	18	9.00	21.38	8.552	2	Bracket	
1	20	1.88	18	9.00	10.88	4.352	1	Motor2	
4	11	1.80	38	6.00	31.2	12.48	4	Bolt	
4	30	1.95	12	5.00	27.8	11.12	4	Sliders	
1	23	2.36	18	9.00	11.36	4.544	1	Solenoid Support	
1	20	1.88	00	1.50	3.38	1.352	1	Solenoid	
2	23	2.36	02	2.50	9.72	3.888	2	Linkage	
1	30	1.95	00	1.50	3.45	1.38	1	Cone	
3	11	1.80	38	6.00	23.4	9.36	3	Bolt	
					208.19	83.276	32	Design Efficiency = 3*NM/TM	0.461117
					TM	CM	NM		

Appendix L3: Design for Environmental Sustainability

Volume of material used to make the cone:

$$\frac{1}{3}\pi r_o^2 h - \frac{1}{3}\pi r_i^2 h = \frac{1}{3}\pi(0.0564)^2(0.255) - \frac{1}{3}\pi(0.0548)^2(0.255)$$

$$V_{cone} = 1.51 \times 10^{-5}\ m^3$$

Mass of cone:

$$M_{cone} = \rho_{cf} V_{cone} = \left(1750\ \frac{kg}{m^3}\right)(1.51 \times 10^{-5}\ m^3)$$

$$M_{cone} = 0.0265\ kg$$

Volume of material used to make the arms using a thin walled approximation:

$$(2bt + 2ht)L = \big(2(0.0255)(0.0016) + 2(0.0255)(0.0016)\big)(1.73)$$

$$V_{arms} = 2.82 \times 10^{-4}\ m^3$$

Mass of arms:

$$M_{arms} = \rho_{al} V_{arms} = \left(2700\ \frac{kg}{m^3}\right)(2.82 \times 10^{-4}\ m^3)$$

$$M_{arms} = 0.761\ kg$$

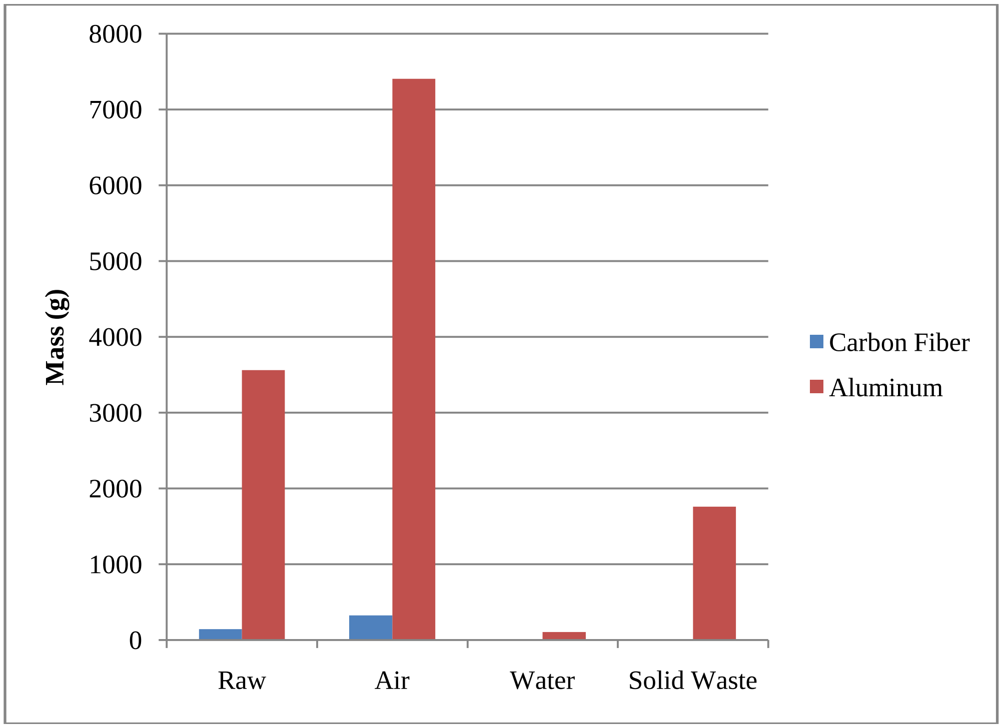


Figure L3.1: Plot of total emissions for the amounts of carbon fiber and 6061 aluminum used in the final asparagus picker design.

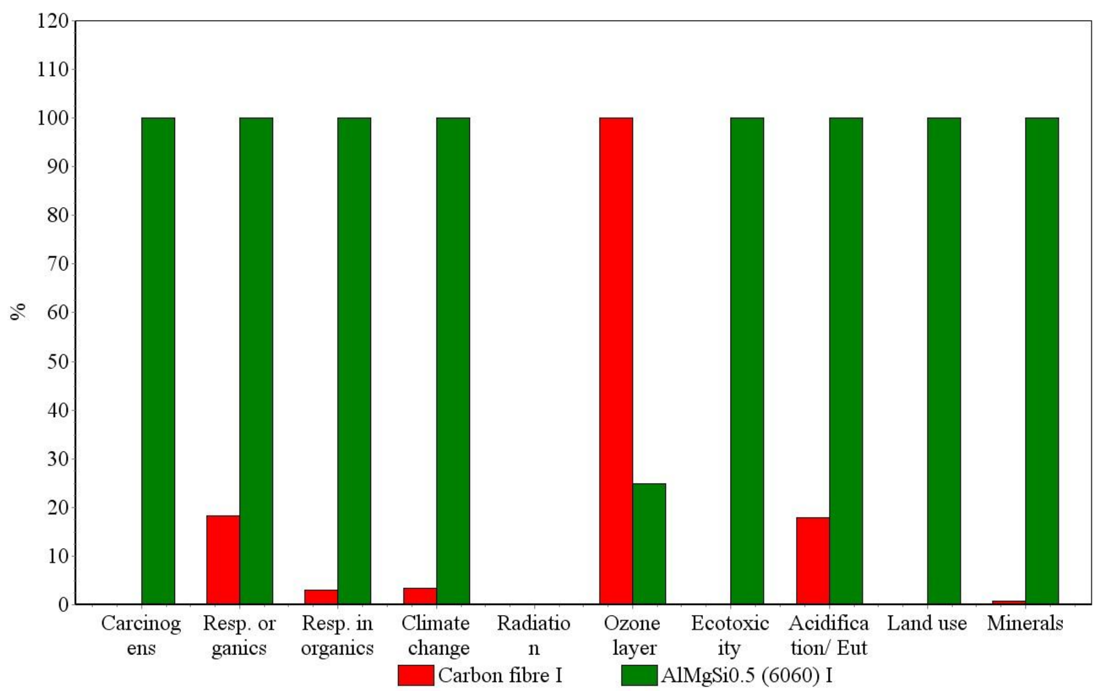


Figure L3.2: Plot of disaggregated damage categories for the amounts of carbon fiber and 6061 aluminum used in the final asparagus picker design.

Aluminum has the bigger impact on the environment for all of the EI99 damage classifications except for the ozone layer. In most cases, the impact of aluminum is far greater than that of carbon fiber because much more aluminum is used in the design.

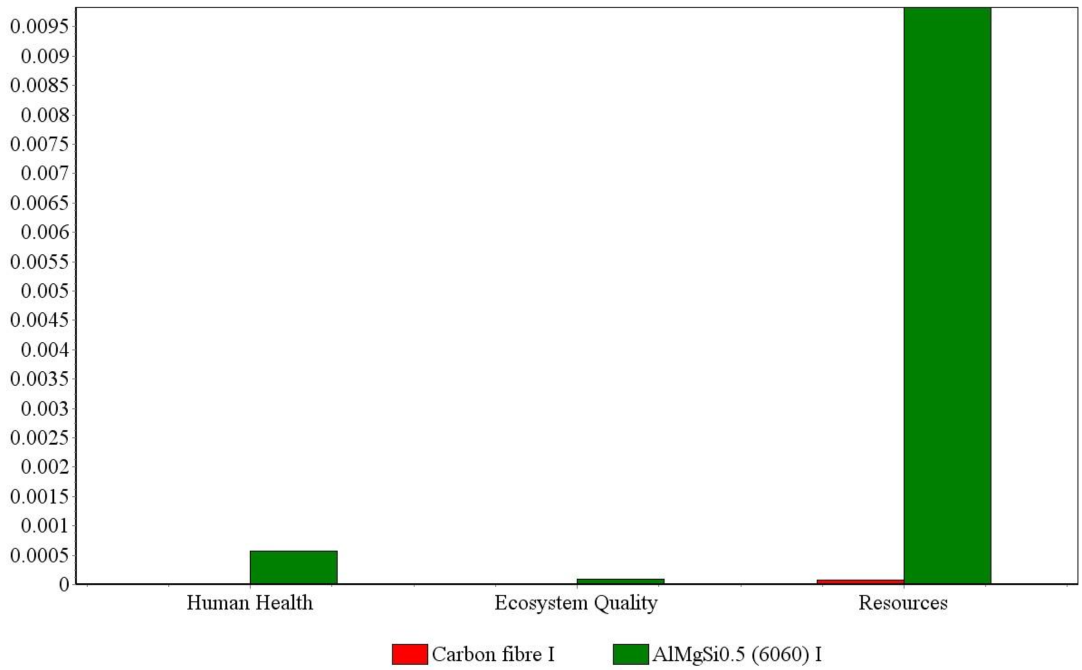


Figure L3.3: Plot of the normalized scores in human health, eco-toxicity, and resource categories.

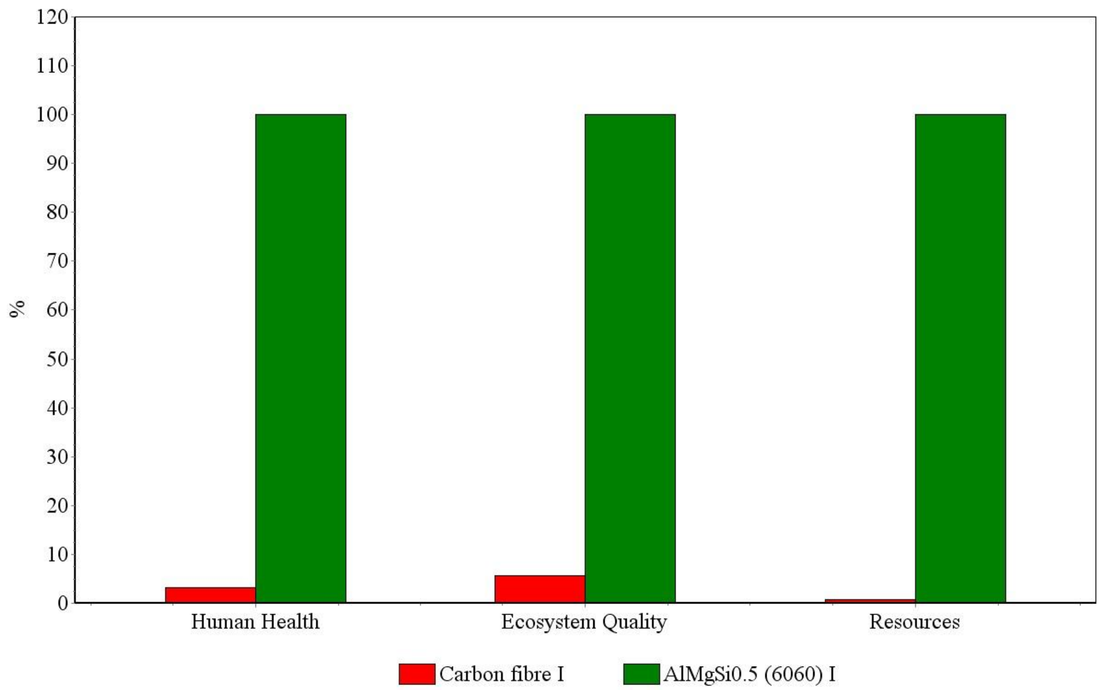


Figure L3.3: Plot of the normalized scores in human health, eco-toxicity, and resource categories.

Based on the EI99 point values, the damage meta-category that is most likely to be the most important is the ‘Resources’ category. This is far and away the area of greatest impact for aluminum. Carbon fiber has its greatest impact in the ‘Ecosystem Quality’ but this impact is still far less than the impact of aluminum in the ‘Resources’ category.

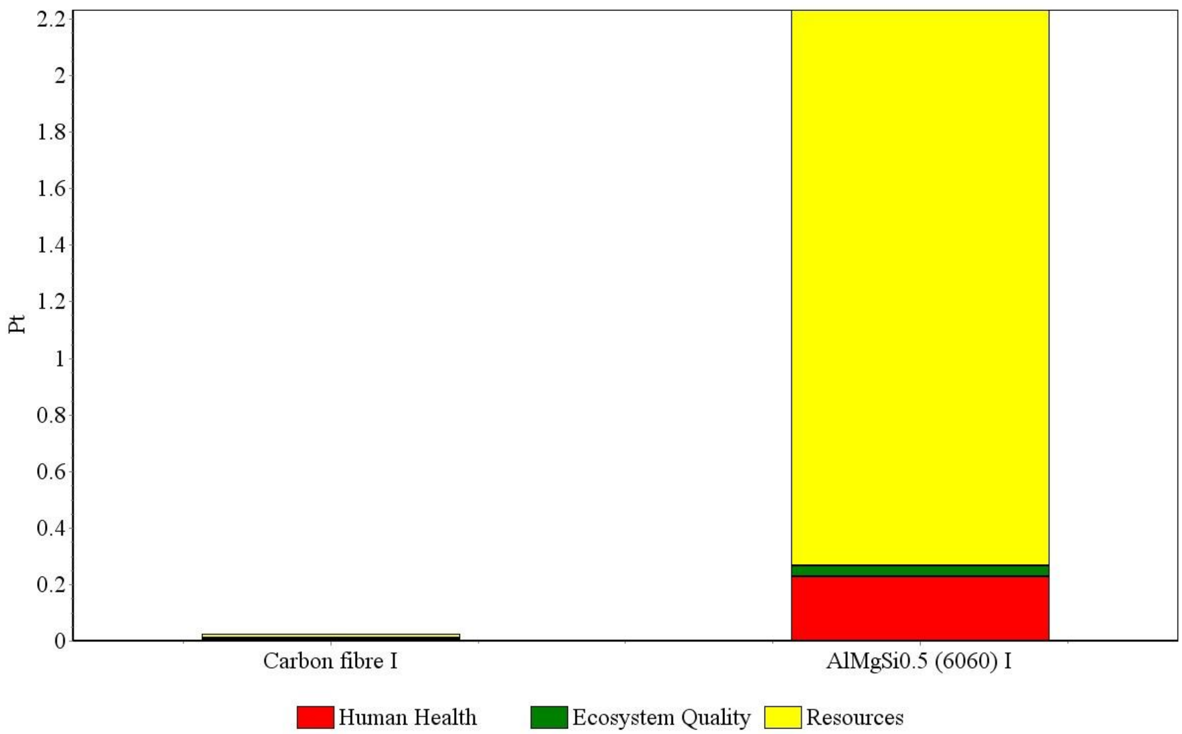


Figure L3.4: Plot of the single score point values using EcoIndicator 99 metric for the amounts of carbon fiber and 6061 aluminum used for the final design of the asparagus picker.

The Aluminum has a far greater EcoIndicator99 point value. This is mostly because it far outweighs the carbon fiber in the ‘Resources’ category, but the ‘Human Health’ category also contributes significantly.

Overall, the Aluminum appears to have a far greater environmental impact. It far exceeds the carbon fiber in every category except the ozone category, where carbon fiber dominates. If the full life cycle of the product is considered this may change, because aluminum is more easily recycled than carbon fiber. Therefore, this would partially offset the environmental impact of aluminum.

Based on this analysis, other materials could be considered for the design. One of the other top candidates was fused silica. Using this material, however, would require significant changes in the manufacturing process plan because welds are used heavily. Using silica, these welds would have to be replaced with another method of fastening. Still, because the environmental impact of silica is so heavy, it is worth considering.

Appendix L4: Design for Safety

The main risks associated with this device are presented during maintenance of the system. The system is meant to be run without a human user, as it is automated, and thus there should be no human interaction with it during operation. These risks are outlined below in the results table from the DesignSafe analysis.

designsafe Report

Application:	Asparagus Picker	Analyst Name(s):	Team 34
Description:		Company:	
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : cutting / severing The sharp cutting edges of the cone could cut a person's finger	Slight Occasional Unlikely	Moderate	gloves	Slight Occasional Unlikely	Moderate	
All Users All Tasks	mechanical : pinch point The closing of the cone presents a pinch point which could pinch a person's finger	Slight Occasional Negligible	Low	Power cutoff button for when manitenance is performed	Slight None Negligible	Low	
All Users All Tasks	mechanical : stabbing / puncture The closing motion of the cone could stab a person's finger with the sharp edges	Serious Remote Unlikely	Moderate	Power cutoff button for when maintenance is performed	Serious None Negligible	Low	
All Users All Tasks	electrical / electronic : energized equipment / live parts If the battery is exposed to a person, electrical shock is possible.	Slight Remote Negligible	Low	other devices	Slight Remote Negligible	Low	
All Users All Tasks	electrical / electronic : improper wiring If the motors are wired incorrectly to the battery or the wires are exposed, electrical shock is possible.	Slight Remote Negligible	Low	instruction manuals	Slight Remote Negligible	Low	

Figure L4.1: DesignSafe results

Risk assessment is a process that is performed to analyze the device in terms of user safety and determine ways to prevent harm to the people using it. Failure Modes and Effects Analysis is performed to determine and prevent the possible methods by which the mechanical parts of the device will fail.

Zero risk is something that is impossible to go wrong, that has no chance of failing. This does not exist in the real world. Acceptable risks are risks that can be overlooked because either the chances of something going wrong are acceptably small or the severity of the possible injury is acceptably low. The distinction shows up in this project in the risks mentioned in the table above. None of these are zero risk, but they are all acceptable risks.

Appendix L5: Manufacturing Process Selection

In the immediate time frame, the volume of production of an automated aspragus device relates specifically to growers here in the United States. This is because growers here are having difficulty keeping costs of their crop low when labor costs are rising. In other countries, the cost of labor is only a fraction of what it is in the United States, so until labor wages increase, it is assumed that prospective customers are only here in the United States.

It was calculated that the number of individual asparagus farmers in the United States is about 370. From data, there are roughly two million farmers in the US [L1]. Also from data, about 52,000 acres of land in the US is used for asparagus farming [L2] and roughly 282.2 million acres are used for farming overall [L3]. Therefore, by using the percentage of farming land used for asparagus to the overall farming land usage and multiplying it by the number of people who farm in the US, the number of asparagus farmers was found. However, the size of these farms vary greatly as they are located all over the country and have different operations regarding picking schedule, picking equipment and labor requirements so the number of devices needed is difficult to exactly calculate. Nevertheless, assuming that the average farm uses 10 carts and each cart has a pair of support arms that will allow for an average of two pickers to operate at once, the number of picking devices demanded in the US can be determined to be roughly 15,000.

The material selected for the cone end effecter is epoxy SMC which is also known as carbon fiber. The shape structure that most closely resembles the cone end effecter is the hollow 3-D shape. For the actual manufacturing process, investment casting is a very good option. It allows for the hollow 3-D to be produced, the epoxy SMC to be used, for the tight tolerances needed, the required thickness, estimated volume, high production rate, above average material utilization rate and an fair capital cost. This makes investment casting a very attractive manufacturing process.

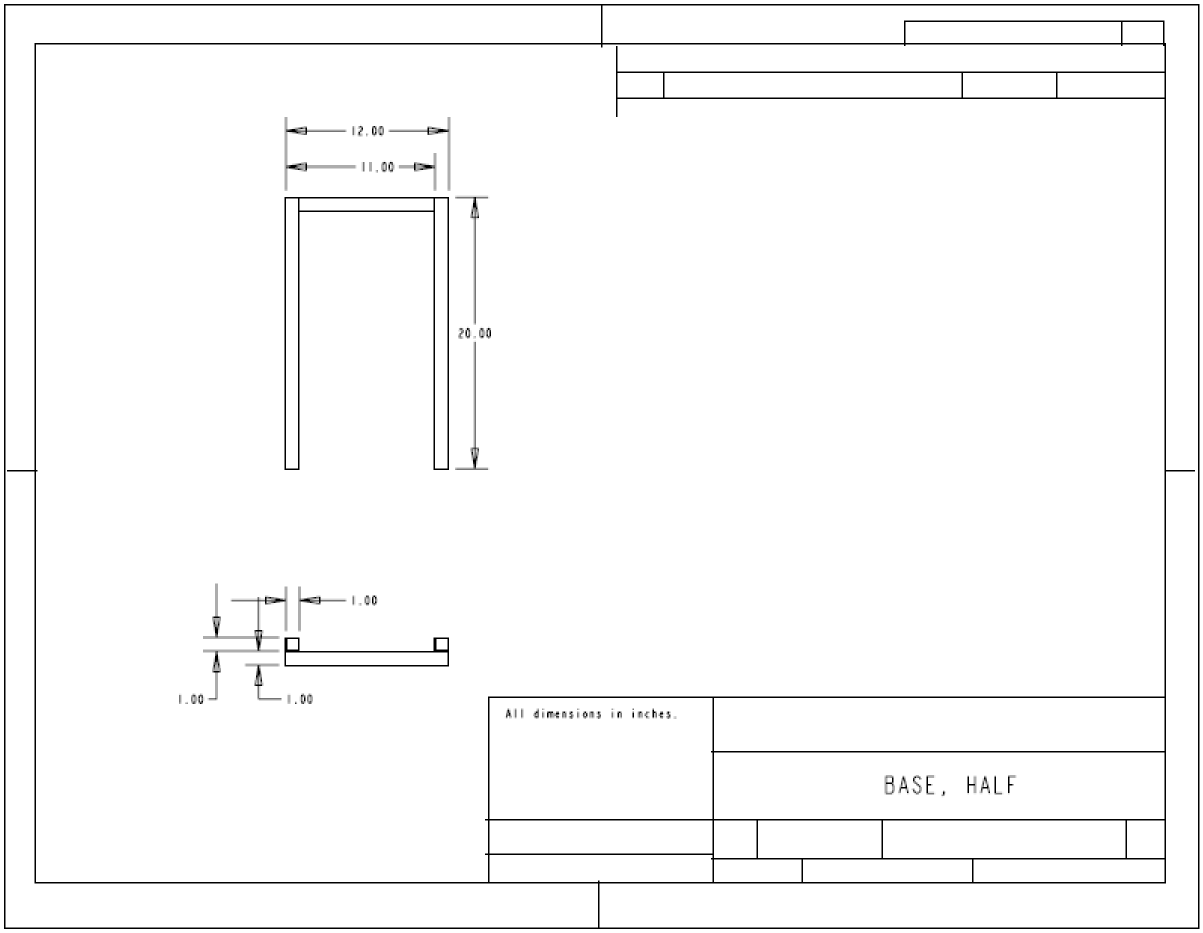
The material selected for the horizontal and vertical arms is 6061 T4 Wrought Aluminum Alloy. The shape function that most applies to the picking device is the hollow non-circular prismatic. The manufacturing process that works very well for this shape is sand and mold casting. It allows for tight tolerances, the required mass of the arms, a small capital cost, a potential for high material utilization and an adequate production rate. The small capital cost is especially pleasing due to the relatively small volume of production.

The processes analyzed in this section were found from using Cambridge Engineering Software.

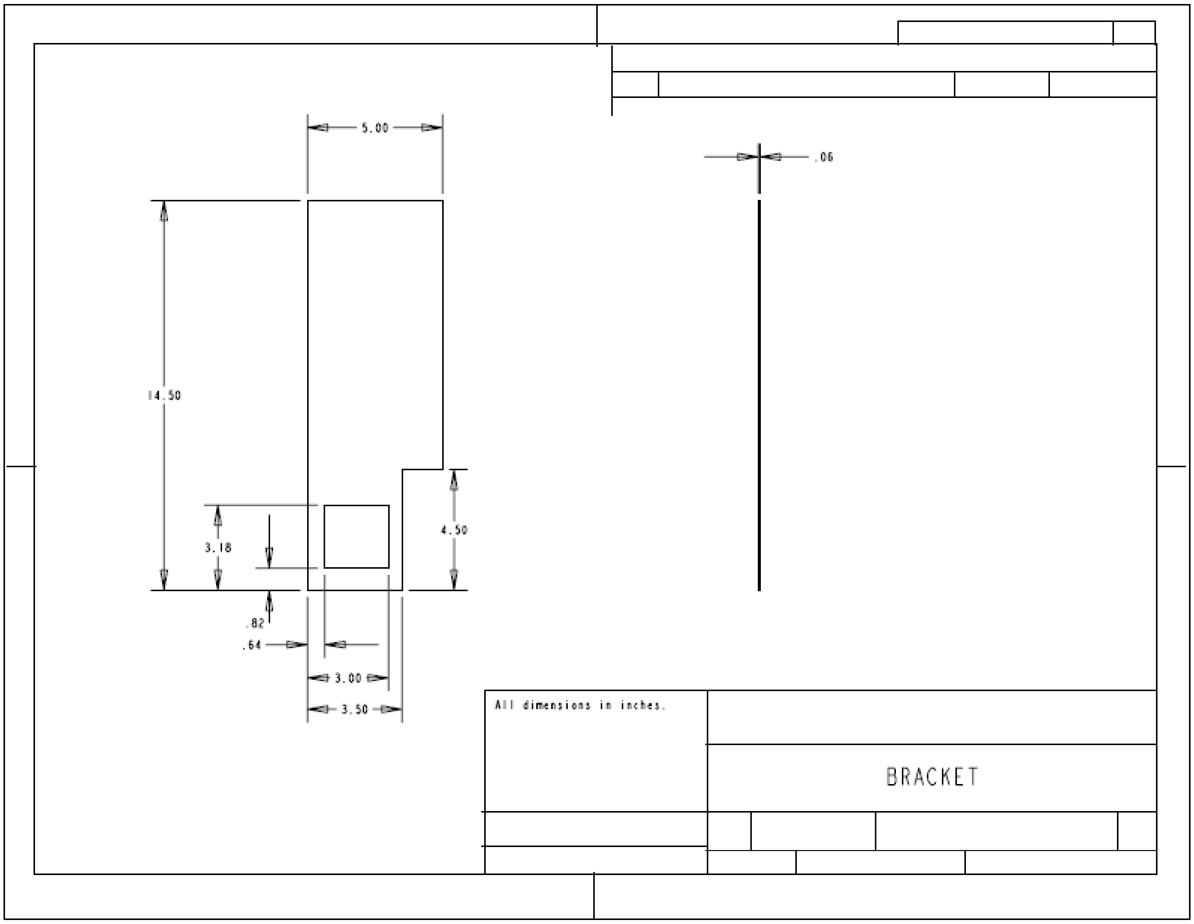
[L1] http://www.epa.gov/oecaagct/ag101/demographics.html
[L2] http://aic.ucdavis.edu/profiles/Asparagus-2006.pdf
[L3] http://www.epa.gov/oecaagct/ag101/cropmajor.html

APPENDIX M: DETAILED DRAWINGS

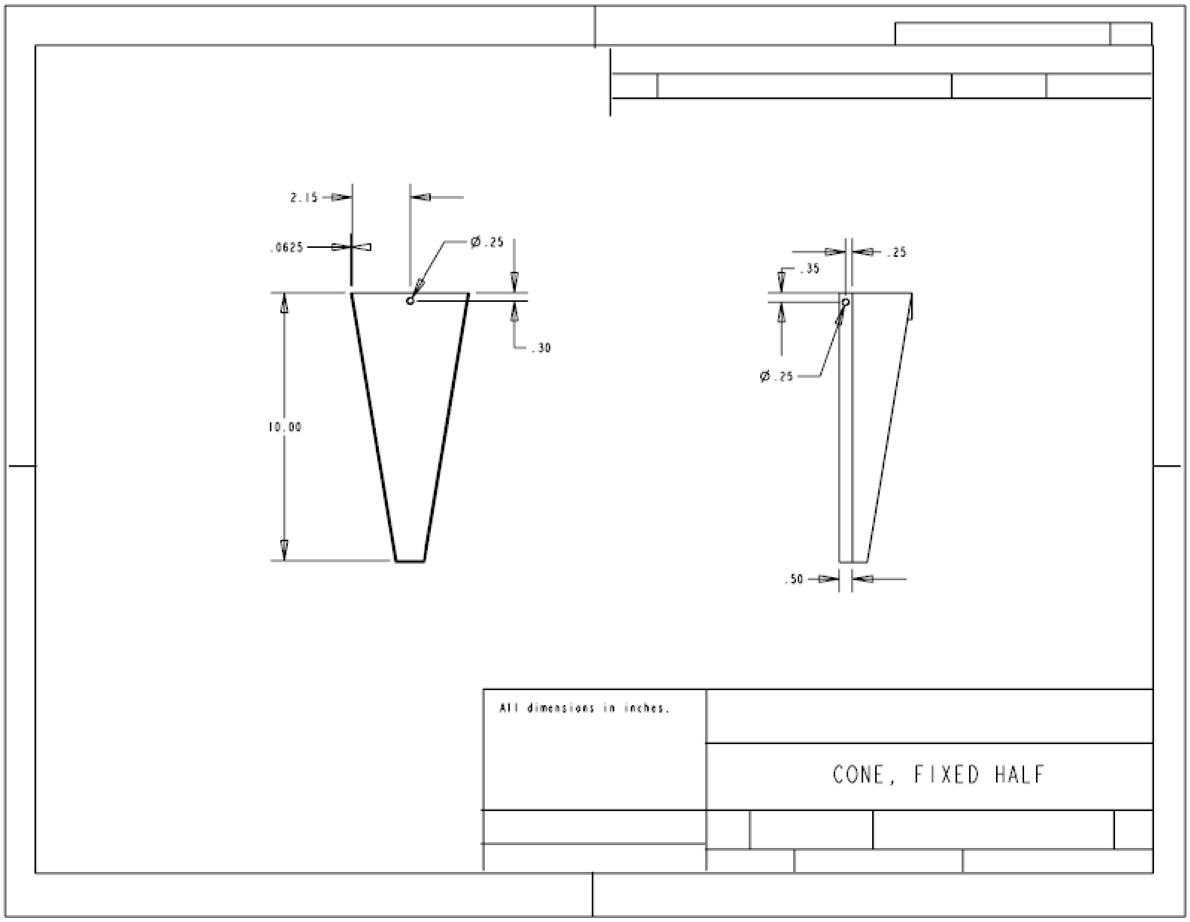
Appendix M1: Base



Appendix M2: Bracket



Appendix M3: Cone



APPENDIX N: FINAL PROTOTYPE PICTURE