**Clarkson University’s**

**Root Vegetable Cultivator Analysis and Enhancement**



**ROOT VEGETABLE CULTIVATOR**

Clarkson University

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**EXECUTIVE SUMMARY**

Organic farming provides carefully grown produce that ensures quality.  The demand for organically grown foods is growing; however a lot of these farms are expensive to start and to maintain.  There are many tools that can ease the laborious, back bending work of farming.  These tools are hard for organic farmers to obtain because they are very expensive and the farmers do not have much capital.  This is why many farmers resort to building their own tools and equipment.

The client for this project is Dan Kent, an organic vegetable farmer in Lisbon, NY. Utilizing the engineering skill of the Engineering and Management department at Clarkson University, Kent hopes to optimize the design of a Root Vegetable Cultivator that he fabricated on his own. This cultivator is a Bed-Lifter, meaning it utilizes a blade pulled behind a tractor to loosen up the soil surrounding root vegetables ready to harvest. This minimizes the manual labor involved for the workers, and saves money for the owner of the farm. The Bed-lifter is attached to the tractor by a three point hitch, with the angle of the top bar determining the angle that the blade is used at. The issue with this bed lifter was the problem of the blade snapping during use. Every time the blade broke, this created down time during harvest season due to the time needed to fix it. The owner believes that this has to do with the angle of the blade. Using CAD software, the team determined the angle that would prove most efficient at loosening soil without breaking the blade. The team also determined possible additions to the design to minimize manual labor, such as metal fingers to collect vegetables. The team also looked into the feasibility of making the blade spring loaded to remove the blade from soil that would otherwise add too much resistance.

**INTRODUCTION**

Kent Family Growers is a small organic agriculture farm located in Lisbon, New York. They offer a wide range of fruit and vegetables year round. Kent Family Growers participate in a community supported agriculture program. A community supported agriculture program allows farmers to directly supply customers with vegetables with customers pledging support to various small farms. Customers pay for vegetables at the onset of the growing season, and then receive shares of the vegetables periodically, as they become ready. This increases the farmer’s profit, as they are not selling through a market that acts as a middle-man for their product.

There are many costs and barriers to entry for small organic farms. The capital expenditure needed to get an organic farm started is extremely large. This is due to the permitting, inspections and costs associated with creating organic certified fields. Because of this, small farms have trouble turning over a large profit, especially in their earlier years. Creating their own equipment, or custom modifying existing equipment, are ways that farmers are able to try and cut costs.

One of the pieces of equipment used in the cultivation of vegetables, specifically root vegetables, is called a bed lifter. The purpose of a bed lifter is to dig underneath the soil of the vegetables to loosen it up, making it easier to extract the vegetables by hand. Dan Kent has created his own bed-lifter with scrap metal that he was able to find. The whole design was created for roughly $100. After several iterations of the design, he believes that the design is well optimized, as it does not break as frequently as it did before and has a greater efficiency.

**INDUSTRY ANALYSIS**

Interest in organic farming has surged as a result of increased attention to the food process, worries about environmental issues and more focus on health. The use of conventional farming practices like herbicide, pesticide use, mono-cropping, and the application of synthetic fertilizer has been designed to maximize yields while reducing manual labor. Organic farms abandon most of these with the goal of reducing the pollution associated with runoff and avoiding any pesticide/herbicide residue on the food. Organic products command a heavy market premium because the massive increase in necessary labor and increased variability that comes along with avoiding conventional practices. However, according to a study by the University of Minnesota, the higher prices offset the lower yields to the point that most organic farms are equally as profitable as their conventional counterparts. But the use of the term “profitable” is questionable, as the median farm income in 2014 was $-1,626.

The organic farm industry has been steadily growing over the past decade. New York state ranks 3rd highest in the United States in the number of organic farms, with just under 1,000 registered organic farms registered with the USDA. That makes up a very small percentage of total farms in New York State. Despite industry growth, many farmers are skeptical about the transition to organic as it requires a farm use organic practices without the market premium for three years.

Manufacturing farm equipment is a large industry with a heavy focus on large scale agriculture. As farms keep increasing in size, they demand larger and more complicated equipment. This gives major brands a very small incentive to make small scale equipment. This forces small farms to source older, used equipment or to manufacture the necessary equipment on their own.

**PROBLEM STATEMENT**

The local farmer has designed his root cultivator from experimentation.  This is a very expensive process because every time he breaks a blade, he has to find and weld on a new one.  Dan will also need his laborers to pick the root vegetables by hand while the equipment is being repaired.  While Dan believes he has a near optimal design, our team needs to dig deeper. How can our team increase the efficiency of the design process? What is the optimal design for the root cultivator using the local farmer’s materials? Are there any simple designs that the farmer might be able to use in the future to increase productivity?

**DESIGN OBJECTIVE**

The bed lifter fabricated by Dan Kent is a relatively simple design that utilizes a recycled snow plow blade attached to the bottom of a rectangular frame. The bed lifter is towed behind a tractor, attached to the three point hitch. Although effective, the bed-lifter blade consistently snapped, which then created a considerable amount of downtime during critical harvest time. After much trial and error, the client believes the angle in which the bed lifter is attached, is crucial for reducing the amount of force on the blade. Using CAD, the client wants the optimal angle determined so that the plow blade will break the least. He also wants the bed lifter to be put into a digital form so that the designs may be disseminated to other vegetable farms looking to fabricate their own.

**Measurements**

Measurements were taken of the specific dimensions of the bed lifter at the client’s farm in Lisbon, New York. We began with the initial measurements because the client had gone through other designs with minimal success but this one had outlasted the others. The detailed measurements were used in the recreation of the design in Solid Edge. These measurements were used in providing accurate data in modeling the forces that act upon the bed lifter when it is in use. It also gave a base system to use for optimization and material analysis.

**Material Analysis**

After the initial measurements were taken at the Kent Family Farm, material properties were needed to start the analysis. The original design used recycled snow plow blades donated by local municipalities. Commercial snow plow blades are commonly made of Standard High Carbon 1084 Finished Steel. 1084 Steel is what will be used for the cutting blade in our design. The material properties of the 1084 Steel are shown in Table 1. The remainder of the bed lifter was constructed using recycled steel found on the farm. Material testing on the steel was not possible, so assumptions were made. Steel was chosen by availability, price, and maximum strength. After research and collaborative thinking by the team, AISI 1018 grade steel was chosen for the rest of the bed lifter, its materials properties are also shown in Table 1.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Density (Lbs/in^3) | % Elongation | Modulus of Elasticity (ksi) | Yield Stress (ksi) | Ultimate Stress (ksi) |
| High Carbon 1084 Finished Steel | .284 | 10 | 29,000 | 53.7 | 119 |
| AISI 1018 Steel | .284 | 15 | 29,000 | 25.5 | 63.8 |

Table 1: Material Properties for Steel Used in Analysis

**Financial Analysis**

There are several scenarios that need to be considered when analyzing how much this design would cost to produce. One very important part of the design is the equipment Dan has to fabricate the bed lifter. Another aspect that needs to be considered is whether or not the materials can be gathered for free. Looking at Table 2, there are several scenarios that break down the total cost of producing the bed lifter. These are based on if its created by the farmer or by a fabrication shop, as well as what materials the farmer is able to get at a reduced cost or free from scrap metal. It will be assumed that the fabrication of the design will take approximately 10 hours and the fabricator receives an hourly wage of $30/hour. Material prices were gathered from websites to get a reference to the general cost of the materials.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Material and fabrication cost | Material cost with no fabrication | Fabrication with no materials cost |
| High Carbon 1084 Finished Steel | $58.39 | $58.39 | 0 |
| AISI 1018 Steel | $211.49 | $211.49 | 0 |
| Fabrication Cost | $300 | 0 | $300 |
| Total Cost | $569.88 | $269.88 | $300 |

Table 2: Production Costs

**Initial Designs**

Dan Kent’s current design was a byproduct of trial and error. His knowledge of metal fabrication allowed him to repair and adjust the bed lifter into its current design. Dan said he had problems with the center support arm breaking and the blade breaking near the connections. He also had to find the proper angle to run the bed lifter at. Dan accomplished this by adjusting the centered connection arm from the tractor. Our analysis will be to discover why these problems happened and find optimal solutions to prevent them.

**Analysis Method**

An analysis was performed with the material properties chosen and the measurements taken from the original design. To perform the force analysis on the bed lifter our team used Solid Edge software. Solid Edge is a 3D CAD history based parametric feature and synchronous technology solid modeling software. To input the design model each individual section of the bed lifter had to be designed, assigned material properties, and then assembled. While assembling the bed lifter an assumption was made that the welds were done correctly and will have more strength than the materials themselves. The final design in Solid Edge is shown in Figure 1.

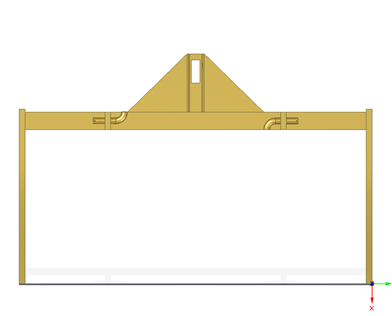
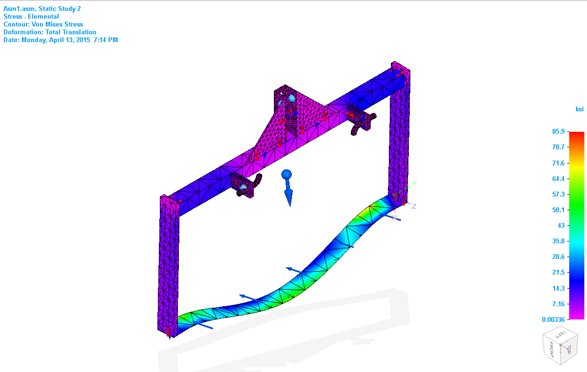
****The next process of the analysis was to input all forces acting on the bed lifter. Our team had limited information to find forces and conditions when the bed lifter was in use. In an ideal situation forces would have been tested while in use, soil properties would have discovered, and angle of operation would have been measured. None of these things were possible due to the Potsdam weather and available time for optimization. Due to the lack of information many assumptions had to be made and research had to be done. The forces acting on the blade are a combination of weight, gravity, pulling forces from the tractor, and draft resistance from the soil. Weight and gravity came from the material properties of the steel and gravity constant respectively. Web soil surveys were used to discover the resulting drag forces produced by the soil. Taking a 40 square mile grid around Lisbon NY, assuming the hardest soil type for analysis,

Figure 1: Solid Edge Final Assembled Design

soil properties were discovered. With these soil properties we were able estimate the forces acting on the blade of the harvester. With all three of these forces combined our team could now figure out what force the tractor pulls at an estimated speed of 2.5 miles per hour.

The forces were then applied to the model in Solid Edge using the solver platform. The points connected to the tractor were the fixed points for the analysis. Since data on proper angles of the bed lifter were not available, the force analysis was done at multiple angles. Angles chosen were 10°, 12°, 15°, 17°, and 20° from the fixed reference frame. From the analysis it can be concluded that 12° is optimal angle for the bed lifter. Additionally, any angle greater than 20° will break the blade, and any angle less than 10° will break the top supports. The report ran for 12° is shown in Figure 2. When looking at Figure 2 we notice that the highest stress points are located on the blade near the joints, and in the center. The highest stress force at 12° is 75 (ksi), this stress is less than high carbon 1084 steel ultimate stress of 119 (ksi).



**Figure 2: Force analysis at 12**°

The upper arm of the original design was breaking because it was too long. Its length was causing a large moment force. The moment equation is defined as force multiplied by the distance from a fixed point on a lever. With the current length of the connection arm, there is no longer an issue.

**Design Improvement**

There are many ways the root vegetable cultivator can be improved. To determine what was parts of the bed lifter need improvement, problems have to be discovered. The first problem is that the blade of the cultivator has been breaking as we noted in the previous sections analysis. This leads into our second problem. As the tractor is pulling the bed lifter rocks make contact with the bed lifter and stop the tractor. Therefor we need a way to go under or over these rocks. Of course, going under these rocks is not feasible because of the possibility of large rocks or other ground formations and you the possibility that you could ruin the vegetables with the top of the cultivator. Therefore we need to go over these rocks.

One of our initial ideas was to put a hydraulic lift on the top of the cultivator. This would allow Dan to move over the rocks and proceed with cultivation. In this situation Dan would reverse slightly and then raise the root cultivator using a control module wired right next to the steering wheel. The design was too complicated because of the wiring that we would need to configure through the tractor. The combination of the hydraulic and the control panel cost also seemed out of range for Dan.

The concept of lifting the root cultivator after it hits a rock did not make much sense to our team. First of all you would need to reverse to make sure the blade did not scrape or bend on the rock as it is being pulled up. This could also possibly lead to failure and is not worth the expense and effort. Therefore our team needed to think of another strategy

**Design Description**

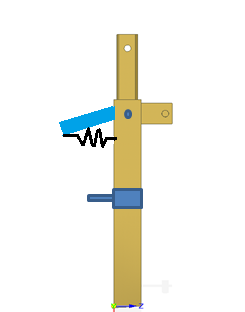
The design needed to involve a way for the tractor to keep moving after the cultivator hit a rock. This would also require there to be no extra wiring to simplify the design. Using a spring system is the best way our team thought of to keep the tractor and the cultivator moving over the rocks. The next question our team had to answer was how to incorporate the springs into the cultivator. Our initial design had the springs on the bottom of the cultivator which would mean that the springs also have to move through the ground. This is not an ideal design because it would increase drag in the cultivator. It would also increase the likelihood that the design would fail. Therefor our team moved the springs above ground. This would allow for an optimal design between fail rate, efficiency, and cost.

With the optimal design, the cultivator would act like a swinging gate with springs. The hinges of the gate will be located near the top of the cultivator. When the cultivator hits a rock, the force of impact will allow the springs to compress as the tractor moves forward. This will in turn reduce the depth of the cultivator temporarily allowing for it to move over the rock then continue on at its normal depth after.

Also, we are adding a finger blade to the middle of the frame. These fingers will be across the frame facing towards the tractor, from vertical bar to vertical bar, approximately half-way down. They will also be free floating on the top half of the frame so they do not dig into the dirt too much and ruin the vegetables. These fingers will “float” on the dirt and grab the vegetation as the fingers pass by. They will not collect the vegetation but they will pick it out the ground so it is visible and no one has to dig them up.

*Design Specifications*

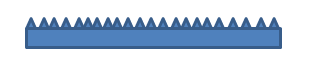
Our spring system involves a few modifications as well as 6 pieces of equipment. First there needs to be two 14” pieces of steel, two 12” springs, and two 1” diameter by 8” pieces of steel. Start by removing the bottom frame of the bed-lifter including the sides and bottom but only take off 1 side bar. Next, the two 1” diameter pieces of steel will welded on each side on the top horizontal bar on the bed-lifter facing sideways. A hole will be made on each side of the frame that was removed. These holes will be centered and large enough so that the bottom frame can swing along the horizontal bar. On the top horizontal bar of the bed-lifter, there will be two 16” pieces of 1x1 steel welded extending back in the reverse direction. They will be slightly angled out and down to allow the springs to attach with the vertical bars of the bed-lifter perpendicularly. The springs will be attached 6 inches from the top of the vertical bars.



**Figure 3: Side Spring Bedlifter View**

This will allow for a gate system to swing the bed-lifter back when the bed-lifter is hitting a rock at a force just under failure. The gate will swing open when the force on the bed-lifter reaches 2000lb. This design will need a spring that really starts to bend when the force exerted on it is 9900lb.

A piece of 1”x 60” x 4” steel will have teeth welded every 3”. These teeth will be 3” wide and 5” long. This finger blade will be welded to two hollow pieces of steel just slightly larger than 1”x4” so that it can fit over. Two pins will be welded on the back side halfway down (15”) so that the finger blade does not ruin vegetation and dig into the dirt.



**Figure 3: Finger Blade Concept**

**SUSTAINABILITY**

There are many sustainable practices that can be utilized on an organic farm. Organic farms are not necessarily sustainable by any means. Sustainable practices can help reduce the overall costs that a farm incurs. It can also greatly reduce the environmental impact the farm has on its surroundings, which is critical for organic farms due to the regulations and restrictions that

The bed lifter was fabricated using mostly scrap material. The blade was given to him from a local municipality because they did not have a use for it anymore, as it went through its useful service life. This greatly reduces the cost of creating the bed lifter. If the client were to find ways to reuse more materials around his farm, or receive more materials from other locations or businesses, it would make the farm more sustainable economically.

One method that would be a reasonable sustainable method for an organic farmer would be the use of drip irrigation on crops where it would be appropriate. This would allow for an efficient use of water on the farm. Although water shortages are not a problem in New York State, sustainable practices benefit more than just the farmer using them. Having small trenches along the length of the fields in between rows would allow for some of the water to be reclaimed to be reused on the fields, reducing the overall amount of water being consumed for each field. This would help save money on the costs of water and make the whole process more efficient.

Another way the farm can have sustainable practices is through the use of cover crops on their fields. Cover crops are crops whose purpose is to replenish the soil with nutrients when the field is not in use, as well as reducing the amount of soil erosion on a particular field. This greatly reduces the amount of fertilizer that will be used on the fields, which greatly reduces the pollution from the water runoff for a given field.

Practices such as these will greatly benefit a farming operation looking to move towards sustainability. Using sustainable practices has benefits for the farm, the environment, and the neighboring towns. It can greatly reduce the impact that farms have on the environment by reducing the amount of fertilizers that make it into the water table, as well as reducing the amount of soil erosion on a field.

**Community**

Organic farmers are a strong community and while small, they are a pivotal part of our culture. This is why we have decided to share our design with organic farm communities online. This will allow other farmers looking to increase their productivity have access to a cultivator design. Our team is going to post our results to farmhack.org and websites of the like. Our team hopes that this plays a part in growing the organic farming industry through encouraging farmers to think creatively and reach out to more universities.

**CONCLUSION**

Using CAD software, the optimal angle for the Bed-lifter was determined to be 12 degrees. The blade would break on initial use at 17 degrees, but the stress caused by anything in between 12 and 15 degrees would lead to the blade breaking within a few uses. If a greater angle than 12 is to be used, the arms need to be shorter to reduce the moment on the top pin. Using the maximum stress determined on the blade, a spring could be added to the frame to allow the blade to swing out of the way before it snaps. These calculations and additions can be used to limit the amount of damage to the Bed-Lifter and will save the client time and money during harvest. Digitized designs of the Bed-Lifter have also been created in order to make the design readily available to other vegetable farmers who wish to fabricate their own design.

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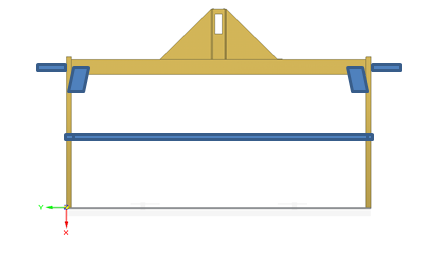
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**Appendix**

Figure 4: Spring Bedlifter Top View





**Figure 5: Spring Bedlifter Back View**

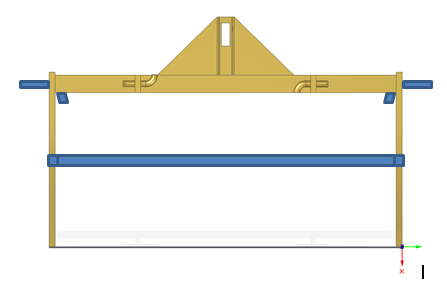


Figure 6: Bedlifter Front View

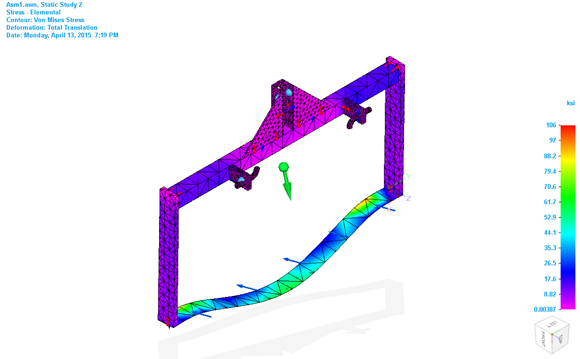
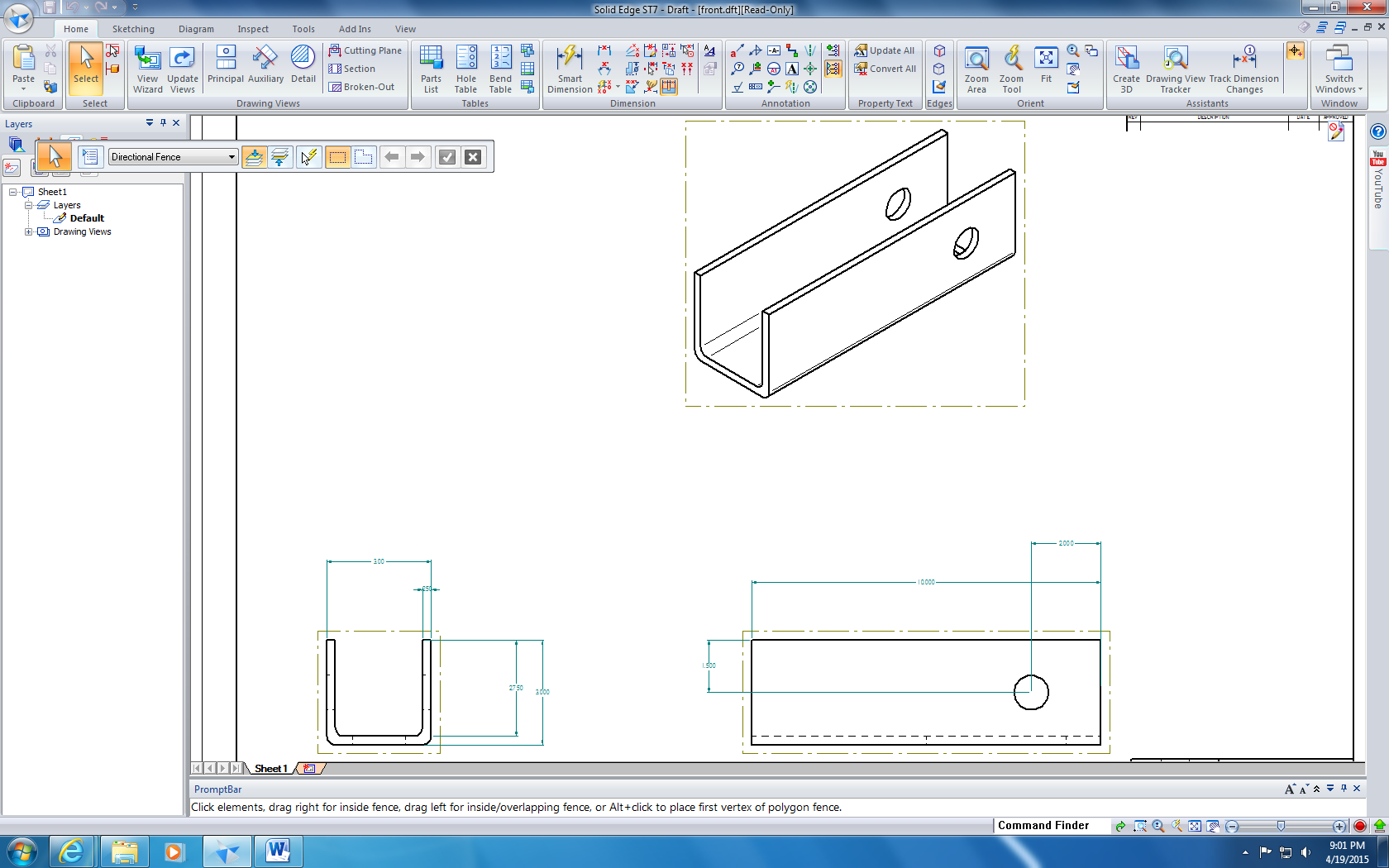


Figure 7: Force analysis at 12°

**Dimensions**

