Spring 2018

H.F. Hauff Pruner Cutting Blades

Wyley Stewart
Central Washington University, stewartw@cwu.edu

HAUFF ELECTRIC PRUNER: CUTTING BLADES

By

Wyley Stewart

Partners:

Grady Graff-Drive System
Brian Woolery-Housing and Ergonomics

Table of Contents

INTRODUCTION

Abstract:

Apple orchards are a critical component of agriculture in the United States, and keeping the apple trees in the best shape for optimum growth and production is hard work. Neil Hauff, an agriculture industry expert, challenged students at CWU to engineer a power assisted tree pruner. Across the country, apple orchards need pruned every season. The pruning of the trees is strenuous manual labor that requires many man hours. The proposed solution is to create a power assisted tree pruner that would minimize the amount of work needed to trim each tree branch. This project has been separated into three main components; power drive system, housing and ergonomics, and the cutting blades. The main focus of this report was the optimization of the pruners cutting blades and their ability to cut branches quickly and repeatedly. The entire device was created by utilizing an electric impact driver and converting the rotational motion into linear motion that would actuate the cutting blades. The cutting blades were designed to open large enough to cut a 1.50” diameter branch, and use a linear pulling force of 1000 lbs, supplied by the impact driver. Testing showed that the cutting blade assembly was capable of withstanding the 1000 lb force applied by the drive system. This report describes the motivation, engineering analysis, and results of testing the cutting blades within the device.

Description:

Workers in the agriculture industry are in need of a power assisted branch cutting device that is capable of being used an entire working day without overheating or causing extreme fatigue to the user.

Motivation:

The motivation for this project originated from the potential market for workers in the agriculture industry and their need of a tree pruning device that could be used for an entire day without excessive fatigue to the user.

Function Statement (Entire Pruner):

This power assisted cutting device will be able to cut small branches for an entire working day without overheating.

Function Statement (Cutting Blades):

This set of pruner cutting blades will connect to a power drive system and be capable of severing tree branches.

Design Requirements (Entire Pruner):

- Capable of producing 500 in-lbs of torque.
- Cutting blade must be at least 36” away from trigger.
- Must weigh less than 10lbs.
- All components must cost less $500.

Design Requirements (Cutting Blades):

- Open at least 1.5” in middle of blades.

- Weigh less than 1lb.
- Each blade must be less than ¼” thick.
- Capable of cutting 5,000 branches without need for maintenance/sharpening.

Engineering Merit:

The ergonomics of the pruner system will be one of the most important engineering challenges. It will be extremely important for the pruner to be lightweight and comfortable to use and hold for long periods of time.

The important engineering challenges that will be faced with creating the cutting blade system are the geometry of the blade and anvil system. The anvil will need to be able to hold the tree limb in place and the blade will need to have an optimized cutting shape, angle, and size. It will also be important to create the geometry of the blade in a way that the power system will be able to translate the maximum amount of force to the branch as possible.

Scope of Effort:

The scope of effort for this project is quite reasonable for three people to accomplish. While the entire pruning system would be unrealistic for one person to design and create, separating the work among three partners should work out nicely. Separating the project into three categories (drive system, housing, and cutting system) will allow the completion of each portion of the project in a timely and professional manner.

By only completing the cutting blade system, there will be much more time to optimize the design of the cutting blade and anvil. If one person were to do all three components, then the design and function of the blades would not be nearly as effective.

Success Criteria:

The entire pruner system will be considered successful if it meets all of the design requirements stated above. It will also be considered a success if all of the components are produced and assembled within the given time period.

The success of the cutting blades will be determined by their ability to severe tree branches and the cohesiveness to the rest of the pruner system. If the cutting blades meet all of the listed design requirements, then it will be considered successful.

DESIGN & ANALYSIS

Approach:

The solution that has been proposed is to use an impact drill to actuate a ball screw that will move a rod in an out. The linear movement of the rod will rotate the cutting blade head with a large amount of force, allowing it to cut through tree limbs. The cutting blade will consist of a leverage arm that attaches to the actuating arm via an intermediate linkage. The anvil will hold the branch in place, ensuring that it does not slip out of the cut.

Many parameters within the cutting blade assembly will need to be analyzed in depth to ensure that the design meets the requirements. A few of the things that will be analyzed include the dimensions of the connecting pins, the angle of the cutting blade, the max cutting force, etc.

Design Description:

The initial sketch of the design can be seen below in Figure 1. This design was going to utilize a chain and sprocket approach, similar to the Fiskars design seen in Figure 5 below. While this design may have been an easier way to convert rotational into linear movement, the ball screw design should be much more effective and efficient. The design of the blade and anvil will require very specific design and dimensions. Reference Appendix B to see the first drawing of the Anvil.

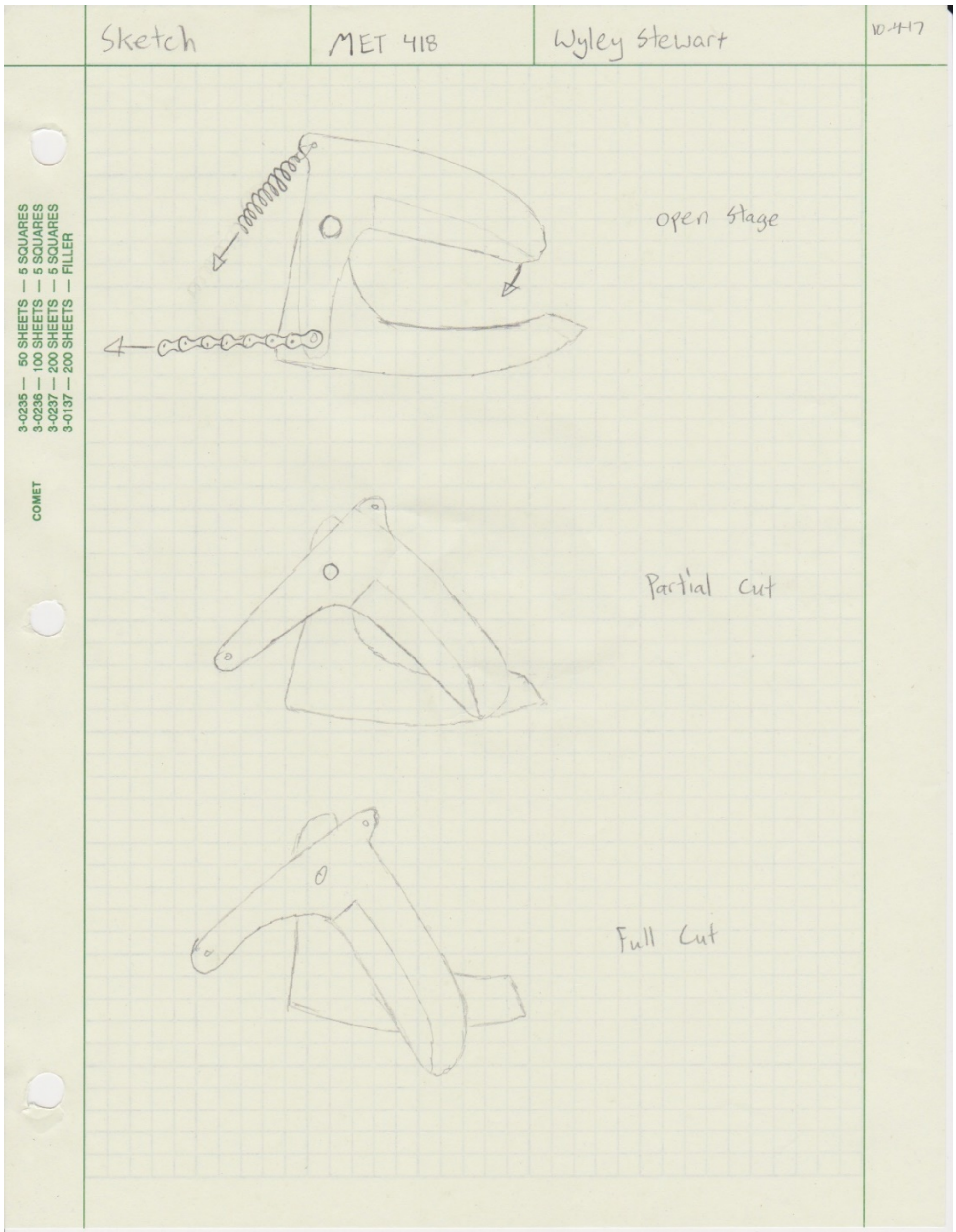


Figure 1

The design of the cutting blade assembly changed significantly with the change in the drive system. Once it was determined that the drive system would use a ball screw, the design of the blade assembly changed as well. Seen below in figure 2 is a rendering of the new design.

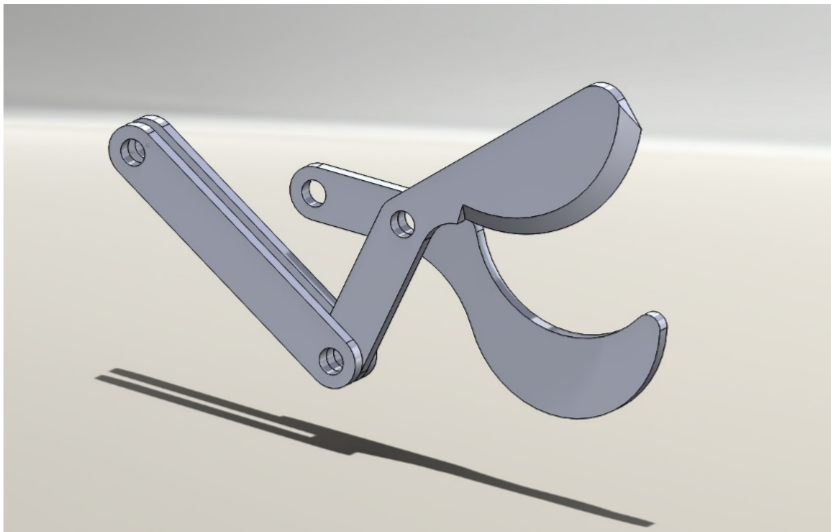


Figure 2

Benchmark:

Currently in the agriculture market is an electric hand pruner made by Pellenc Group, a French company that specializes in high quality agriculture equipment. The model that they produce is called the Treelion D45-900. Greek orchardist Emmanuel Maniadakis approached Neil Hauff with this piece of equipment with a few complaints and suggestions on how to improve it. This Treelion D45-900 will serve as the benchmark for our project. The Treelion D45-900 can be seen in figure 3 below.

Figure 3

Figure 4

The design benchmark for the cutting blade assembly will stem from tree loppers that are currently in production. Current productions cutting blade assemblies all have very similar shapes and designs, however they are not specific to our project. The cutting blades in our project will be designed to optimize the amount of input power from the motor assembly. A benchmark for the blade and anvil cutting shape design can be seen above in figure 4. Figure 4 shows the benchmark that will be used for the shape of the anvil and the basic shape used for the blade and the leverage arm.

Figure 5

Performance Predictions:

Our tree pruner should be able to cut apple tree branches up to 1.5” in diameter. The pruner should be able to cut over 5000 branches of varying size before needing servicing or sharpening of the blades. The cutting blade, anvil, and two linkages should collectively weigh no more than .70 pounds after completely machined.

Description of Analyses:

As seen in Appendix A-1 through A-11, the analyses performed were utilized to optimize the design of the cutting blade assembly. Seen in Appendix B-1 through B-3 are the drawings as an outcome of the analyses performed. The analyses will be discussed in further detail below.

The analyses started by using a generic design created in Solidworks. These generic designs helped give basic angles and measurements that would allow for the requirements that were set beforehand. By using these designs and by keeping standard sizing in mind, analyzing the different components of the assembly (blade, anvil and linkages) was possible.

The analysis began with the amount of linear force that would be applied from the drive system (A-1). This allowed a calculation of the force that could be applied to a 1.5” diameter branch (692.5lb). Solving for this force also showed the forces that would be applied to the connecting pins. By using these forces and the type of shear the pins would endure, diameters were able to be solved for in each location (A-3). The thickness of the intermediate linkages was also solved for using a direct axial loading method (A-2).

Given the maximum force that could be applied to an object between the cutting blade and the anvil, the reaction forces at the other two pinned locations on the anvil were solved for (A-4). These forces allowed for two pins to be sized, a shear pin (A-6) and a structural pin (A-5). The shear pin size was determined so if a solid object resists the maximum cutting force, then a cheap and easy to replace pin will break instead of one of the drive components.

Using the maximum force applied to the point of impact with a branch, an optimal cutting blade angle was determined (A-7). While the linkages will usually experience large tensile forces, it is possible that they experience compression force as well. In the case that the blade got stuck closed, a critical buckling load was solved for (A-8). Although the primary forces applied to the blade linkages will be tensile and compressive, some cases would allow for an extreme torsional force. In the case that the linkages experience torsion, the maximum torsional shear stress was solved for (A-9).

One of the design requirements is weight. In attempt to reduce the weight of the cutting blade assembly, a lightening cut within the blade was proposed. After analysis, the benefits of the weight reduction were not great enough (A-10). Because the blades will be used in all sorts of weather conditions, thermal expansion is a legitimate factor to take into consideration. After analysis, the thermal expansion of the 304 stainless steel blade and anvil would not be great enough to alter the performance of the cutter (A-11). The intermediate linkage will experience great tensile force, in which deformation will occur. At maximum 1000 lb tensile force, only 0.0015 in of deformation will occur in the linkage (A-12).

Due to cost, machinability, material availability and other reasons, the material for the cutting blade, the anvil and the linkages were all changed to mild steel during the manufacturing process. As you can see in appendix A-13, there were recalculations using the new yield stress data for the new material. In this appendix, the stress of the linkages is recalculated. Since the linkages experience the most force out of the all of the parts within the assembly, it was only necessary to determine that the linkages will withstand the forces and still maintain an appropriate safety factor. As described in the appendices, the yield strength for the material increased from 31,200 psi with 304 stainless steel to 50,800 psi with 1020 cold rolled steel plate. It is obvious that the new material will withstand the same forces that the stainless-steel material will withstand, which makes the recalculation redundant, however, it is important to recalculate using the new values for the purpose of optimizing the design.

Scope of Testing and Evaluation:

The scope of testing and evaluation is very realistic with the resources available here at CWU. Available to us is everything needed for this project to be successful. The only testing and evaluation equipment that will be needed that is not immediately available here at CWU will be actual tree branches. Those can be gathered elsewhere.

While not all of the requirements are as important as others, all should be able to be tested. Whether it is weight, cutting force, or durability, we will be able to complete it here with the resources that are already at our disposal.

Analyses:

RADD 1:

Requirements:

This example of R.A.D.D is of two intermediate linkages that must be able to transmit 1000 lbs force to the cutting blade arm. The linkages will be constructed of 304 Stainless Steel and will have a height of 0.500". Using a safety factor of 1.5, the thickness of the linkages will be determined.

Analysis:

The analysis of the linkage thickness can be seen Appendix A-2. The parameters used include the equation Stress=Force/Area. Also used was the yield strength of 304 Stainless Steel (31,200 psi), the area calculation for a rectangle (thickness x height), and a safety factor of 1.5. By manipulating the equation and substituting yield strength for stress, thickness can be solved for.

Design Parameters:

The design parameters for the linkages are briefly mentioned above. The height of the linkages are 0.500", they will be made of 304 Stainless Steel, and they will hold a safety factor of at least 1.5. After completing analysis using the given design parameters, it was determined that the minimum thickness for the linkages would be .048". To keep consistent with the rest of the cutting blade design, choosing a standard thickness of 0.125" will prove to be effective. By using 0.125" thickness the actual safety factor will increase to 3.9. It will be more cost efficient to produce out of same stock material as the cutting blade and anvil, rather than have to order another portion of raw stock that has a different thickness.

Documentation:

This analysis is documented in Appendix A-2.

RADD 2:

Requirements:

This example of R.A.D.D is of two intermediate linkages that must be able to resist 185 lb-in of torque without deforming. In normal situations the linkages would not need to resist a torsional force, however, if the ball screw got stuck and all of the rotational movement from the drive system was translated to the linkages, they would need to overcome that torsion.

Analysis:

The analysis utilized the dimensions of drawing B-3, as well as the equation (Max torsional shear stress = T / Q). This equation is used for non-circular cross sections that experience a torsional force. By solving for Q and using 185 lb-in as the torque value, the maximum torsional shear stress was 40848 psi. This value exceeded the value for yield strength in 304 stainless steel.

Design Parameters:

The design parameters for the linkages are briefly mentioned above. The height of the linkages are 0.500", the thickness will be 0.125”, and they will be made of 304 Stainless Steel. As a result of the analysis, it is likely that the thickness of the linkages will need to be increased. However, additional design of a torque resisting tab being added to the drive shaft has been considered.

Documentation:

This analysis is documented in Appendix A-9.

Device: Parts, Shapes, and Conformation:

Some parts of the design for the blade and anvil were not analyzed, rather were designed to utilize standard industry sizing. In fact, in the drawing of the anvil (B-2) it is clear that standard radius’ are used. The benefit of doing this is to ensure that the part is produced to specification. Without the use of a CMM, it would be very difficult for us to measure and design parts with very complex geometries and features.

Device Assembly and Attachments:

The cutting blade assembly will be made up of three components; the blade, anvil, and two identical intermediate linkages. Although these pieces were primarily designed to be cohesive with one another, they were part of a bigger design. Once assembled to each other, the cutting blade assembly pieces will be attached to the housing and drive system of the entire pruner. An assembly drawing of the cutting blade assembly can be seen in Appendix B-4.

Tolerances, Kinematics, Ergonomics, etc.:

Tolerances were not initially expected to be a huge factor in the design of the cutting blade assembly. The most important tolerance for the design is in the thickness of the blade and anvil. This tolerance could affect the pin length, which could result in a gap between the blade and anvil allowing pieces of tree branch to get lodged in between them. To reduce this risk, tight tolerance (±0.002 in) raw stock will be purchased. By using a tight-tolerance stock, an accurate pin length can be determined.

After construction, it was determined that hole location was another tolerance that was critical to the overall fit of the parts within the assembly.

Ergonomics and kinematics did not have a large effect in the design of the cutting blade assembly. The ergonomics of the device are largely effected by the housing.

Technical Risk Analysis, Failure Mode Analysis, Safety Factors, Operation Limits:

Every project has risks, however the risks of this project are minimal. The cost is low, the schedule is reasonable, the technicality is not unrealistic, and the necessary resources are at our disposal. Any risk that is associated with this project is not foreseen to be an issue.

A standard safety factor of 1.5 was used throughout the analysis of this device. The components that were most likely to break were the connecting pins, so a safety factor was necessary for their design.

The operational limits for this device include a 1.75" diameter apple tree branch. This pruner was entirely designed around pruning apple trees, not another type of wood. Although the pruner would be capable of cutting other wood types, it is recommended to only be used on apple tree branches. It is not to be used to cut any other material than wood.

METHODS & CONSTRUCTION

Construction:

This project was initially conceived by Neil Hauff, CEO of H.F. Hauff Inc. Neil reached out to the MET department at CWU in hopes of a solution to the project. The solution for this project will be designed, analyzed, and constructed at CWU using the materials, equipment, and knowledge available within the MET department. While there are many resources available at CWU, there are also more resources available at H.F. Hauff Inc. Neil has offered the use of materials as well as laser cutting machinery to produce the blade assembly. Although his offer is very generous, the plan is to produce as much of the project as possible here at CWU.

To pursue a greater hands-on experience and learning opportunity, the construction of the device was created entirely at CWU using the machine shop equipment. After a long discussion with mentor Ted Bramble, it was determined that it would be too difficult to CNC mill the 2-dimensional geometries described by the assembly's drawings. Instead, the idea of changing the material and utilizing the CNC plasma cutter was adopted. Although unable to use the stainless steel that was used for the original design calculations, the use of the plasma cutter proved to be very successful.

Description:

Each component of the electric pruner will be produced separately, including the blade assembly. The three main components of the blade assembly are the blade, the anvil, and two identical linkages. There will also be fasteners to secure the pieces together, but those will be purchased externally. The blade, anvil and linkage were originally going to be machined at CWU using a CNC mill, but were actually produced using the CNC plasma cutter instead. The stock material was a piece of “scrap” that was generously supplied by CWU.

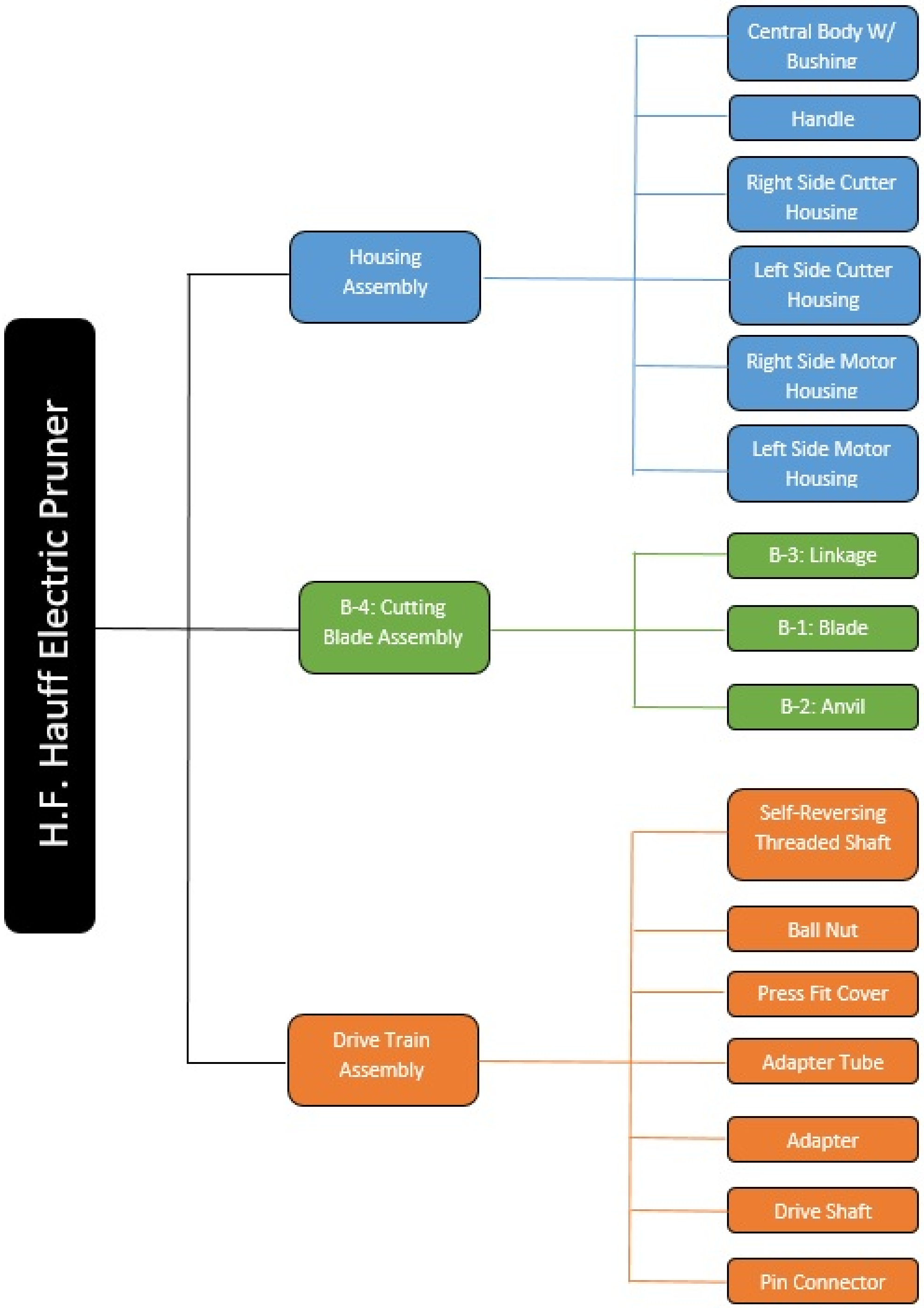
The anvil is a very key component to the design. The anvil will be secured to the housing with two pins. These two pins will help the anvil resist all rotational movement caused by the blade forcing the branch down into the anvil. The anvil will be directly connected to the housing with the rear pin and to the housing and the blade with the front pin. The anvil drawing is in Appendix B-2.

The blade is the most important component of the assembly. The blade has to be capable of withstanding the tensile force from the drive system, as well as the force needed to cut through the branches. The shape of the blade will be extremely important in order to withstand these forces, however the curvature and cutting angle on the actual blade face will be extremely important as well. As you can see in Appendix B-1, the blade will have a curved edge with a radius of 1.50” and have a rake angle of 35 degrees. It is important to note that the blade will have a single bevel cutting angle, allowing for closer interaction with the anvil and easier sharpening and maintenance.

The linkages are a fairly basic but necessary component for the entire design. The linkages allow the appropriate movement of the cutting arm. They also have to endure 500 pounds of tensile force each. The drawing of the linkage can be seen in Appendix B-3.

The photos of the completed parts can be seen in Appendix B-5 through B-10.

Drawing Tree:



Parts List:

The parts originally needed for this project include 1/8" thick steel plate as well as a few fasteners. All of the material used for the cutting blade assembly will be made of 300 series stainless steel. The plate steel will be 304 stainless, while the connecting pins may be 304 or 316 stainless depending on the sizing and availability. While maintaining the design by using stainless-steel pins, the material for the blade, anvil, and linkages changed to 1020 cold rolled steel plate instead.

A complete parts list is shown in Appendix C-1. A summary with the cost of the parts is in the budget table seen in Appendix D-1.

Manufacturing Issues:

There is a possibility of a few issues associated with manufacturing that will be prepared for. The issue that is most prevalent is the actual machining of the cutting angle on the blade. While we do have the equipment available to produce this complex geometry, it is going to be difficult to get a smooth surface finish and a very sharp edge on the end of the cutting blade. A proposed solution to this potential problem is to use a grinder to produce a very smooth surface and a precise edge. A similar process will need to be repeated throughout the blades life as repeated cutting will dull the blade edge.

Another potential problem that could occur is securing either the blade or the anvil into the vise of the CNC mill. While this shouldn't be a problem, the proposed solution would be to create a custom tooling plate.

The above mentioned "potential manufacturing issues" turned out to be legitimate problems with the production of all pieces. As discussed earlier in the "Methods and Construction" section, the material was changed to mild steel in order to utilize the plasma cutter. This eliminated the large issue of work-holding while trying to CNC mill the parts. It was determined that creating a custom tooling plate or a custom work-holding device would not be nearly as efficient as plasma cutting the parts. Because the blade was produced with the plasma cutter, the issue of trying to mill the complex cutting angle geometry was not faced. Instead, the entire blade angle and contour was created using a wheel grinder and polishing wheel. An example of this process can be seen in the production video. No modifications were made to the parts initial design.

Assembly:

The order of production is not entirely critical for the assembly of the project as a whole. The first logical part to machine will be the anvil. It will be important to produce the anvil first in order to assure proper fit with the housing. The other parts (blade and linkages) will be produced later because their fit to the other components is not nearly as critical as the fit of the anvil to the housing.

All three parts (anvil, blade and linkages) would be produced using the CNC plasma cutter here at CWU. As mentioned above, the blade needed additional grinding and polishing to ensure a smooth cutting surface and sharp blade edge. Because of the small size and relatively simple geometry of the parts, the run-time on the machines should not be very long. The most time-consuming part of the manufacturing process was the meticulous grinding of the blade edge.

Once the parts were manufactured, they were assembled together. First the blade and the linkages were connected, then the blade and the anvil, then the anvil and the housing, and finally the linkage and the drive shaft were connected. The assembling of the parts counted for approximately 13.0 hours of work. No one part was entirely difficult during this process, other than slight fitment issues. For example, the holes in the anvil and housing did not align perfectly. To fix this fitment issue, the hole was re-drilled in the anvil, resulting in a slot shape. This shape did not compromise the integrity of the part or design, as it still holds tight in the housing without moving. The rest of the parts went together very smoothly. All other pieces fit together as designed and the entire assembly moved as it is supposed to.

TESTING METHOD

Introduction:

Testing the blades of the pruning device will be an interesting portion of the project. There are a few different ways the cutting portion of the device can be tested.

1. The first "test" will be the quality of manufacturing. The blade, anvil, and linkages will be visually inspected as well as measured to match the design drawings.
2. The next test will be the actual fit of the cutting system to the rest of the pruner. The blade, anvil, and linkages will all be judged on a go/no-go test basis, go if it fits, no-go if it does not fit the other components properly.
3. After the entire pruner assembly is constructed, the device will be able to be tested to its full potential. The first test for the blade system will be the fit of larger branches inside the cutting mouth. The test will consist of fitting incrementally larger branches in the cutting mouth until a maximum branch size is reached. The expected maximum branch size will be approximately 1.70".
4. The next test that will be completed will be cycle operation. Before the pruner is able to be tested on cutting branches, we will need to know that it can open and close repeatedly as we have designed it to.
5. Once the pruner is operating as expected without resistance we will begin to test the pruner on actually cutting branches. The first branch cutting test will be to determine if the pruner can actually cut the large sized branches like it was designed for. To complete this test we will start with small branches (about .50") and incrementally increase the size of the branches cut (up to the max size we previously tested for).

6. Following the max cutting size test, the pruner blades will be tested for durability. For this test the pruner will cut 1000 branches ranging in size from .50” to 1.5”, like it would in a real life situation. This will test for durability of the blades.
7. An optional test of ultimate strength can also be performed to determine the first component that would break if the pruner attempted to cut something like metal.

Method/Approach:

1. Test 1 would be scored by the actual dimensions of the measured parts in respect to the design drawings as described in Appendix B. As long as the parts were to spec and within the design tolerances, then they would pass this test. Tools needed would include calipers and other precision measuring devices that are available in the CWU machine shop.
2. Test 2 will go as described above. The actual assembling of the product will determine whether it passes or not. As long as each part fits accordingly, it will be deemed successful. No tools will be needed for this test other than those required to assemble the pruner pieces.
3. Test 3 will be scored by the pruners’ ability to fit large branches within the cutting mouth. The materials needed for this test will be calipers and either circular raw stock of sizes ranging from 1.25” to 1.75” or tree branches in the same size range.
4. Test 4 will also be scored on a go/no-go basis. As long as the pruner is capable of cycling correctly, it will pass the test. No materials will be necessary to perform this test.
5. Test 5 will be scored on a pass/fail basis. The pruner will receive a pass or fail score for cutting through branches ranging from .50” to the maximum size branch found in test 3. Materials needed for this test will be apple tree branches of varying size, as well as calipers to measure them.
6. Test 6 will be scored by visual inspection as well as precise measurement. If the blade and anvil show absolutely zero variation from the original condition, then they will score 100%. As the deterioration and dulling occur, the score will decrease accordingly. Supplies needed to complete this test include measurement devices (CWU machine shop) and a large supply of apple tree branches from my house.
7. Test 7 is optional but would be helpful to ensure the design was correct. By placing attempting to cut a very strong object like a 1.00” diameter steel rod, we will be able to see which piece of the assembly breaks first. This test would prove the safety factor and sizing we used for each part was correct. Materials needed for this test would include measuring devices as well as 1.00” thick steel rod.

Test Procedure Description:

Test 1:

1. Machine Parts.
2. Measure Parts.
3. Reference measurements to drawings.

Test 2:

1. Assemble drive system, housing, and cutting system together.
2. Determine if fitment is proper and to spec of drawings/3-d model.

Test 3:

1. Gather and measure materials.
2. Open cutting blade to fit largest branch possible.

Test 4:

1. As a complete assembly and using the power drive system, operate the blades to ensure they cycle correctly. (Open and close completely)
2. Score on pass/fail basis.

Test 5:

1. Gather materials including apple tree branches ranging from .50” to maximum mouth size determined in test 3.
2. Attempt to cut branches from small to large size.

Test 6:

1. Gather measuring devices, i.e. calipers, micrometers, protractor, surface finish gauges, etc.
2. Gather apple tree branches ranging from 0.50” to 1.50”.
3. Perform cuts on 1000 branches.
4. Inspect components for visual wear and damage.
5. Measure all dimensions and reference to initial measurements.

Test 7:

1. Attempt to cut through 1.00” thick steel rod.
2. Inspect device and determine where it failed first.

Deliverables:

Deliverables for the tests that will be completed will include measurement sheets that compare drawing specs to actual dimensions, as well as measurements taken after cutting 1000 branches. More deliverables will include sheets showing the outcome of each of the go/no-go and pass/fail tests.

BUDGET/SCHEDULE/PROJECT MANAGEMENT

Proposed Budget:

A table of the itemized budget can be seen in Appendix D-1.

The main parts supplier that will be used will be McMaster-Carr. McMaster-Carr currently stocks all of the components and raw material needed to machine and assemble the cutting blade system. The blade, anvil, and linkages will all use 1/8” thick 304 stainless steel plate as raw stock. Each of the components will be machined from this raw stock. The size plate that needs to be purchased is 4”x8” 1/8” thick. A plate of tight-tolerance stainless steel in this size will cost about $107. The fasteners will be 300 series stainless steel clevis pins, also purchased from McMaster-Carr. The clevis pins will be purchased in packs of 5 at a cost of $7. It will be necessary to purchase at least 2 packs to ensure there are plenty of replacements.

The above paragraph was the initial project proposal budget description. As discussed earlier in the report, the actual stock material for the anvil, blade, and linkages were supplied by CWU, resulting in $0 cost. The pins used to assemble the parts were supplied by Brian Woolery and Grady Graff, as they ordered more than needed for their sections of the project. The pins they supplied were modified to be the correct length, however they were already the correct diameter for the cutting blade assembly. These pins also resulted in a cost of $0 for the project. Currently the project sits with an outstanding expenditure of $0.00 for materials. The only cost incurred to this point is the cost of operating CWU machinery, the labor from CWU staff, and personal time spent on the project. All of those items are provided free of cost to the project.

Labor and outsourcing are two factors that will not effect this project. The only labor that will be involved is to machine and assemble the parts. All of this will be completed at CWU, mostly in the machine shop. All machine time and assistance from CWU staff will be considered “donated” from CWU. However, if an estimated cost of labor would be attributed to the work being completed, the CWU staff could be $40/hr and my time spent on the project could be $15/hr. No outsourcing will be necessary, as all of the machine processes will be able to be completed at the CWU machine shop.

The estimated total cost of designing, analyzing, and producing the cutting blade assembly for the electric tree pruner is under $200. As mentioned above, the exact total and itemized budget is in Appendix D-1.

While funding for this project will not be entirely necessary, both Neil Hauff and Nether Industries have offered materials, money, and other resources to help complete the project. The main component that will be donated by Neill Hauff is the impact drill for the power drive system.

Proposed Schedule:

The scheduling for this project is outlined in Appendix E-1 with a detailed Gantt chart. This Gantt chart includes each step of the project process with estimated and actual hours to complete each task. The chart also has highlights for the week in which the task shall be completed. Some tasks will be worked on for multiple weeks, while others may just take a couple of days. The entirety of the project will be completed at least one week before the end of spring quarter of 2018 and is projected to take 268.0 hours.

All tasks and milestones were reached before their projected completion date. A tool that was utilized in order to keep the project on track was the weekly project status reports. These status reports documented hours spent on each specific task, as well as described them.

The first milestone that was met during the Winter Quarter was finishing the final proposal. This milestone was set to be completed by the fourth week in January, however, it was completed on January 12th. This component of the project was extremely important in order to have the project planned completely. Having this task completed made the following tasks much easier to accomplish.

The next major milestone that was met was the "part construction" milestone. This milestone was set to be completed by the third week in February, in which it was. This task consisted of actually producing each part of the cutting blade assembly. While this seems like a fairly straightforward task, it was much more daunting than expected. Within this milestone were 8 different tasks; order stock material, make setup sheets, gather materials and tools, setup machine, machine parts, grind/sharpen blade edge, take part pictures, and update website. All of these subtasks took anywhere from 1.0 to 9.5 hours to complete, totaling in approximately 51.7 hours spent total.

The last milestone defined for winter quarter was device construction. This task consisted of assembling the linkage and blade, assembling the blade and anvil, assembling the anvil and housing, assembling the linkage and drive, taking device pictures, and finally updating the website. This milestone took less time, about 13.0 hours total. The subtask that took the longest was updating the website.

The total number of hours spent working on this project to date is 162.0. All tasks and milestones will be referenced in the Gantt chart in Appendix E-1.

Project Management:

This project will succeed due to the close and careful attention taken by Wyley Stewart, Grady Graff, and Brian Woolery. Contributors to the success of the project will also include Neil Hauff, Dr. Johnson, Professor Pringle, Professor Beardsley, Ted Bramble and Matt Burvee.

The principle engineer, Wyley Stewart, will provide his expertise in designing and producing the cutting blade system. His resume can be seen in Appendix J.

The project sponsor, Neil Hauff, will supply materials and components for the project.

DISCUSSION

This project has already progressed quite a bit, just during this first quarter. Like mentioned above, this project began with a very different design in mind. When the quarter started our first design was to use a chain and sprocket to turn the rotational motion of the impact driver into linear motion to actuate the cutting blades. Since then, the design has change significantly. The new design for the drive system is to utilize a ball screw in order to turn that rotational movement from the impact driver into linear movement to drive the cutting blades. This change resulted in significant changes for all three parts of the pruner. The change in the drive system required changes in the cutting blade assembly as well.

The changes to the cutting assembly included a smaller leverage arm angle, additional linkages, and a shorter mounting arm on the anvil. The leverage arm angle was reduced from 280 degrees to 210 degrees because of the nature of the drive system. This reduced angle also allowed the cutting blade assembly to take up a smaller amount of space. The change in angle and drive type also developed the need for intermediate linkages to translate the movement from the drive shaft to the cutting blade arm.

As the development of the project progresses, it is expected that changes will be made. They will be documented here in the discussion section of the report.

The next phase of this project will include completing the tests that are described above. The results of those tests will determine whether the project was successful or not, as well as identify any changes that could be made to the design.

CONCLUSION

Fall Quarter Conclusion:

In conclusion, the analysis and design of the H.F. Hauff electric pruner cutting blades meet all of the senior project requirements. This project has both creativity and engineering merit and deserves to move forward. All of the necessary resources are available to make this project a success. Not only is this project entirely practical, but it is of interest to the principle investigator.

If given the opportunity to move forward with the project, the principle investigator will make best use of the time and resources that are available. The principle investigator will also do everything possible to ensure that the project is a success and meets all of the design requirements outlined in this proposal.

Winter Quarter Conclusion:

It has been determined that the use of Winter Quarter 2018 has been a success for the H.F. Hauff pruner cutting blade project. The project progressed as expected from the start to the end of the quarter, resulting in a working device that is ready to be tested.

The three key factors that will determine whether this project will be a success from winter quarter forward are as follows:

1. Meet expectations defined by the testing methods.
2. Not require any additional re-design.
3. Work cohesively with the other group members parts.

Spring Quarter/Final Project Conclusion:

After the completion of spring quarter and the entire year, the project has been considered successful. Although the device failed to pass a few key requirements, it was still an improvement on previous attempts on this same project. The pruner cutting blades were a success because of the following reasons:

1. The cutting blades did not require additional re-design after they were produced.
2. The cutting blades were easily assembled and worked smoothly and cohesively with the other components of the pruner.
3. The cutting blades passed two of the outlined tests. Although more tests should have been performed, and the pruner failed to complete them due to malfunctions and break-downs, it was still successful in the tests it was able to perform.

In conclusion, if this project was to be re-done, it would benefit from taking on a bulkier design. Although this pruner was lightweight and ergonomic, a more robust pruner would be more effective and produce better cutting results.

ACKNOWLEDGEMENT

Thank you to H.F. Hauff Company for the financial support and the use of resources.

Thank you to Neil Hauff for the mentorship and fruition of the project. Without the idea of an electric tree pruner, this project would not exist today.

Thank you to the CWU professors for the guidance, support, and necessary tools that have helped the development of this project.

Thank you to Matt Burvee and Ted Bramble for helping manufacture the parts and provide manufacturing guidance throughout.

REFERENCES

Mott, R. L. (n.d.). Machine Elements in Mechanical Design (5th ed.). Upper Saddle River, NJ: Pearson.

18-8 Stainless Steel Clevis Pins with Retaining Ring Groove. (n.d.). Retrieved December 5, 2017, from https://www.mcmaster.com/#clevis-pins/=1ak057t

304 Stainless Steel. (n.d.). Retrieved December 5, 2017, from http://www.matweb.com/search/DataSheet.aspx?MatGUID=abc4415b0f8b490387e3c922237098da&ckck=1

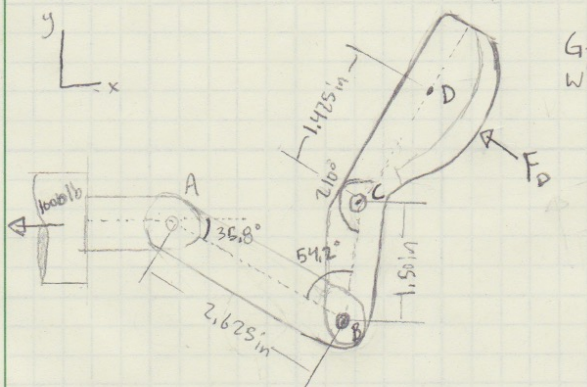
APPENDIX A

A-1.1:

A-1	Cutting Blade		Wyley Stewart	1/2

Given: A rod pulls on the cutting blade via an intermediate linkage with 1000 lbs force.

Geometry at first impact with 1.50" diameter branch.



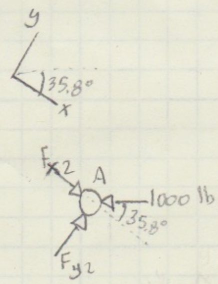
Find: Force Applied to Branch.

Solution:

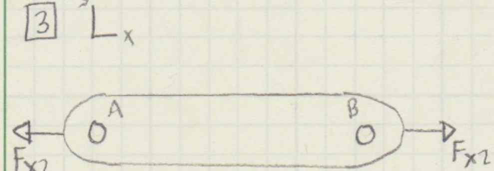
FBD's

1

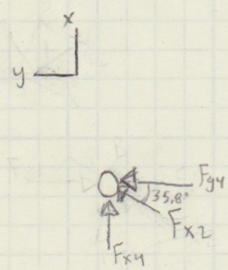
2



3



4



From 2: $\Sigma F_x = 0$: $\overset{+}{\rightarrow}$

$F_{x2} - (1000\,lb)(\cos(35.8°)) = 0$

$F_{x2} = 811.0638\ lb \rightarrow$

$\Sigma F_y = 0$: $+\uparrow$

$F_{y2} - (1000\,lb)(\sin(35.8°)) = 0$

$F_{y2} = 584.9576\ lb \uparrow$

From 4: $\Sigma F_x = 0$: $+\rightarrow$

$F_{x4} - (811.0638\,lb)(\sin(35.8°)) = 0$

$F_{x4} = 474.438\ lb \rightarrow$

$\Sigma F_y = 0$: $+\uparrow$

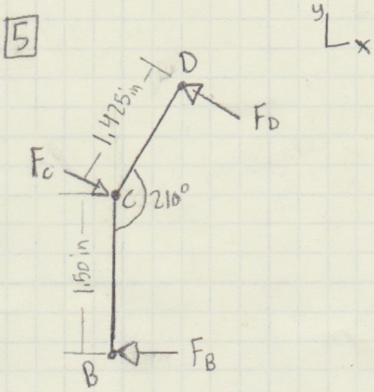
$F_{y4} - (811.0638\,lb)(\cos(35.8°)) = 0$

$F_{y4} = 657.8245\ lb \uparrow$

A-1.2:

A-1	Cutting Blade		Wyley Stewart	2/2

5



$$\circlearrowleft + \ \Sigma M_C = 0:$$

$$-F_B(1.50\,in) + F_D(1.425\,in) = 0$$

$$F_D = \frac{F_B(1.50\,in)}{1.425\,in}$$

$$F_D = \frac{(657.824516\,lb)(1.50\,in)}{1.425\,in}$$

$$\boxed{F_D = 692.447\,lb}$$

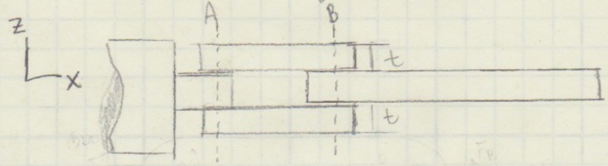
A-2:

A-2	FBD Linkage		Wyley Stewart	

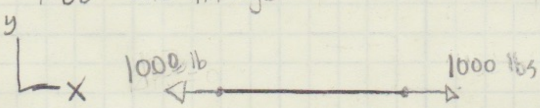
Given: Rod will pull on Linkage with 1000lbs maximum force in horizontal direction. Maximum force will be applied when linkage is at horizontal. Use 304 Stainless steel.
Height = 0.500 in

Find: Thickness of Linkage

Solution:



FBD one linkage:



Safety Factor = 1.5

Use yield strength (S_y) for Analysis.

$$\sigma = \frac{F}{A}$$

$\sigma = S_y$ $\quad$ S_y 304 Stainless Steel = 31,200 psi

$$S_y = \frac{(SF)F}{th} \Rightarrow t = \frac{(SF)F}{S_y h}$$

Force is distributed over 2 linkages therefore, $F = \frac{1000}{2} = 500\text{ lbs}$

$$t = \frac{(1.5)(500\text{ lb})}{(31200\text{ psi})(0.50\text{ in})} = \boxed{0.048\text{ in}}$$

Use Standard thickness of 0.125 in

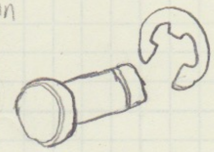
Actual Safety factor = 3.9

A-3.1:

A-3	Pin dimensions		Wyley Stewart	1/2

Given: Use 18-8 Stainless Steel Headed Clevis Pin with Retaining Ring Groove

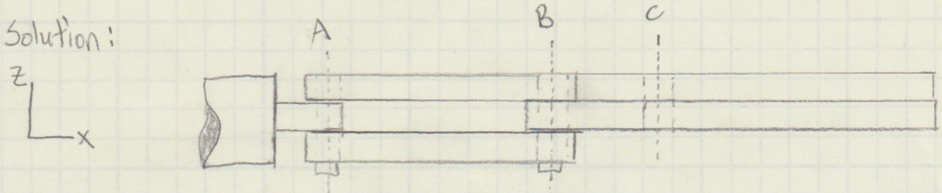
- Yield Strength = 31,200 psi
- Safety Factor = 1.5

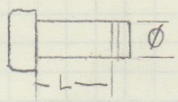


Find: Pin diameters

Assume Max Shear Occurs at end of cut when all components are at horizontal

Solution:



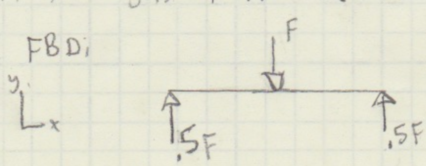


Usable Lengths:

Pin A	3/8''
Pin B	3/8''
Pin C	1/4''
Pin D	3/8''

Pin Ø Analysis A & B: (Double Shear)

FBD:



Pin A:

$\tau = \frac{F}{2A}$ $F = (1.5)(1000lb)$

$S_y = \frac{F}{2\left(\frac{\pi}{4}d^2\right)}$

$d_A = \sqrt{\frac{2(1.5)(1000)}{\pi(31{,}200\,psi)}}$

$\boxed{d_A = 0.1749\,in}$

Pin B:

$d_B = \sqrt{\frac{2(1.5)(1000lb)}{\pi(31{,}200\,psi)}}$

$\boxed{d_B = 0.1575\,in}$

A-3.2:

A-3	Pin Dimensions		Wyley Stewart	2/2

Pin C (Single Shear)

$$\tau = \frac{F}{A} \Rightarrow S_y = \frac{F}{A} \Rightarrow S_y = \frac{F}{\frac{\pi}{4}d^2}$$

$$d_c = \sqrt{\frac{4(F)SF}{\pi(S_y)}}$$

$$d_c = \sqrt{\frac{4(1.5)(1000\ lb)}{\pi(31{,}200psi)}}$$

$$\boxed{d_c = 0.247\ in}$$

Use standard size 0.250 in ⌀.

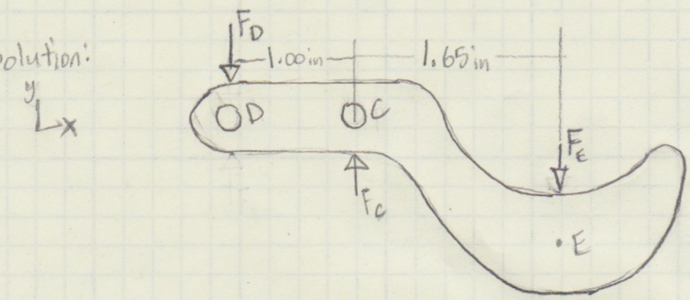
A-4:

A-4 | Anvil | Wyley Stewart

Given: • Anvil will be fixed by pins at points A & B.
• Maximum force will be applied at center of Anvil hook.
• Max Force = 692.5 lb

Find: Force at point C & D

Solution:



$\circlearrowleft + \; \Sigma M_C = 0$:

$$F_D(1.00in) - F_E(1.65in) = 0$$

$$F_D = \frac{(692.5lb)(1.65in)}{(1.00in)}$$

$$\boxed{F_D = 1142.625\text{ lb} \downarrow}$$

$+\uparrow \; \Sigma F_C = 0$:

$$F_C - F_D - F_E = 0$$

$$F_C = F_D + F_E$$

$$F_C = 1142.625\text{ lb} + 692.5\text{ lb}$$

$$\boxed{F_C = 1835.125\text{ lb} \uparrow}$$

A-5:

A-5	Anvil Pin Dimension		Wyley Stewart

Given: 18-8 Stainless Steel Pin

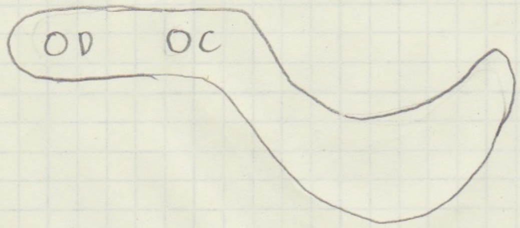
Yield Strength = 31,200 psi

Safety factor = 1.5

Force Acting on Pin D = 1142.625 lb Per A-4.

Find: Pin D Diameter

Solution:



$$\tau = \frac{F}{A} \Rightarrow S_y = \frac{F}{A} \Rightarrow S_y = \frac{F}{\frac{\pi}{4} d^2} \quad \text{(Single Shear)}$$

$$d_D = \sqrt{\frac{4(F)SF}{\pi(S_y)}} \Rightarrow d_D = \sqrt{\frac{4(1142.625\,\text{lb})(1.5)}{\pi(31{,}200\,\text{psi})}}$$

$$\boxed{d_D = 0.264\ \text{in}}$$

A-6:

A-6	Anvil Shear Pin		Wyley Stewart

Given: 18-8 Stainless Steel Pin

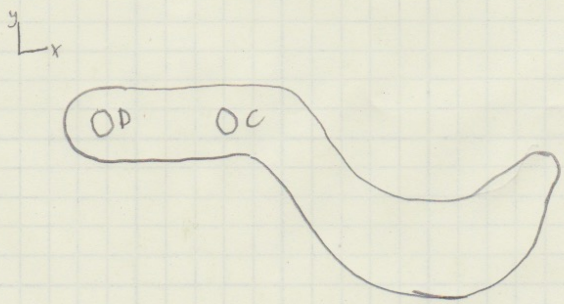
Ultimate Strength = 73,200 psi

Safety factor = 0 ← This pin should break if max cutting force is achieved.

Double Shear   Max. force = 1835 lb ← from A-4

Find: Dimension of Pin C.

Solution:



$$\tau = \frac{F}{2A} \Rightarrow S_u = \frac{F}{2\left(\frac{\pi}{4}d^2\right)} \Rightarrow d_c = \sqrt{\frac{2F}{\pi S_u}}$$

$$d_c = \sqrt{\frac{2(1835\text{ lb})}{\pi(73{,}200\text{ psi})}} \Rightarrow \boxed{d_c = 0.126\text{ in}}$$

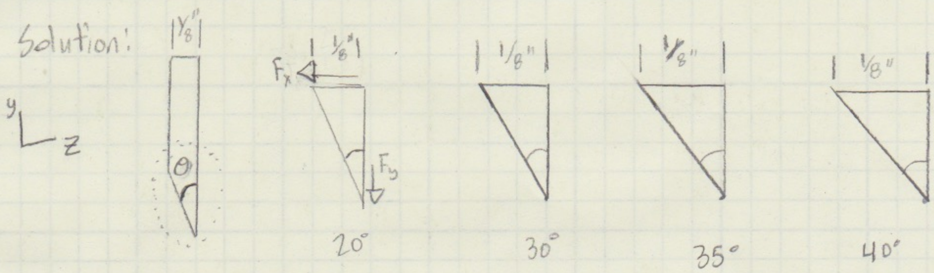
A-7:

A-7	Blade Angle		Wyley Stewart	

Given: Max Force @ Cutting Center = 692.5 lb
Larger angle = More Durability
Smaller angle = less force to cut
Single Bevel Blade angle

Find: Optimal cutting angle

Solution:



★ Drawings not to Scale.

Angle	Vertical Force	Lateral Force
20°	$F_y = 692.5 \cos(20°)$ $F_y = 650.73$ lb	$F_x = 692.5 \sin(20°)$ $F_x = 236.85$ lb
30°	$F_y = 692.5 \cos(30°)$ $F_y = 599.72$ lb	$F_x = 692.5 \sin(30°)$ $F_x = 346.25$ lb ☆
35°	$F_y = 692.5 \cos(35°)$ $F_y = 567.26$ lb	$F_x = 692.5 \sin(35°)$ $F_x = 397.20$ lb
40°	$F_y = 692.5 \cos(40°)$ $F_y = 530.48$ lb	$F_x = 692.5 \sin(40°)$ $F_x = 445.13$ lb

Chose to use 30° Blade angle. Sufficient lateral & Vertical force, large enough angle to maintain durability.

A-8:

A-8 | Linkage Buckling | Wyley Stewart

Given: 304 Stainless Steel

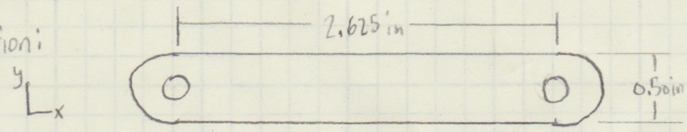
$\ell = 2.265$ in

Cross Section $= 0.50\text{ in} \times 0.125\text{ in}$

Both ends pinned

Find: Critical Load, P_{cr}

Solution:



$$r_{min} = \sqrt{\frac{I}{A}} \Rightarrow r_{min} = \sqrt{\frac{\left(\frac{BH^3}{12}\right)}{B \cdot H}} \Rightarrow r_{min} = \sqrt{\frac{\left(\frac{(0.5)(0.125)^3}{12}\right)}{(0.5 \times 0.125)}} = 0.036\text{ in}$$

$$I = \frac{BH^3}{12}$$

$$A = B \cdot H$$

effective length:

$$L_e = K \cdot L = (1)(2.625\text{ in})$$

Slenderness ratio: $\frac{L_e}{r_{min}} \Rightarrow \frac{2.625\text{ in}}{0.036\text{ in}} = 72.92$

$$C_c = \sqrt{\frac{2\pi^2 E}{S_y}} \Rightarrow \sqrt{\frac{2\pi^2 (28 \times 10^6\text{ psi})}{31{,}200\text{ psi}}} \Rightarrow C_c = 133.1$$

$$\frac{L_e}{r_{min}} < C_c \Rightarrow \underline{\text{Column is Short}}$$

Use J.B. Johnson formula for short columns

$$P_{cr} = A \cdot S_y \left[1 - \frac{S_y \left(\frac{L_e}{r_{min}}\right)^2}{4\pi^2 E}\right] = (0.5\text{ in} \times 0.125\text{ in})(31{,}200\text{ psi})\left[1 - \frac{31{,}200\,(72.92)^2}{4\pi^2 (28 \times 10^6)}\right]$$

$$\boxed{P_{cr} = 1657.34\text{ lb}}$$

A-9:

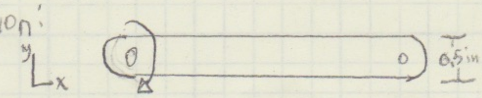
A-9 | Torque in Linkages | Wyley Stewart

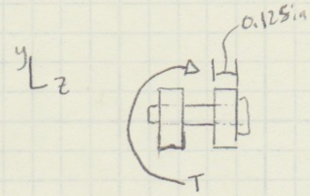
Given: 304 Stainless Steel

185 lb·in torque from drive System

Find: Torsional Shear Stress

Solution:





$$\tau_{max} = \frac{T}{Q} \quad \text{eq. (3-12) Mott}$$

Distributed among 2 linkages:

$$\tau_{max} = \frac{T}{2Q}$$

$$Q = \frac{bh^2}{\left[3 + 1.8\left(\frac{h}{b}\right)\right]} \Rightarrow \frac{0.5(0.125)^2}{\left[3 + 1.8\left(\frac{0.125}{0.5}\right)\right]} \Rightarrow Q = 0.00226 \text{ in}^3$$

$$\tau_{max} = \frac{185 \text{ lb·in}}{2(0.00226 \text{ in}^3)} \Rightarrow \boxed{\tau_{max} = 40848 \text{ psi}}$$

40848 psi > S_y of 304 Stainless Steel.

★ Consider using thicker linkages or add a torque resisting guide to the drive shaft.

A-10:

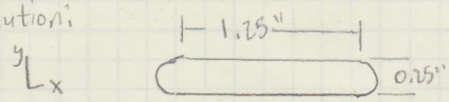
A-10	Blade Weight Red.		Wyley Stewart

Given: Drawing B-1
304 Stainless Steel

Slot: 1.25" ℓ
0.125 R each end

Find: Weight saved by machining slot in blade

Solution:



density = 0.289 lb/in³
↳ per Matweb

Area: $A = 1.25'' \times 0.25'' + \pi (0.125'')^2$

$A = 0.36158\ in^2$

Volume: $V = A \cdot t$

$V = 0.36158\ in^2 \cdot 0.125\ in$

$V = 0.04519\ in^3$

Weight: $W = V \cdot density$

$W = 0.04519\ in^3 \times 0.289\ lb/in^3$

$\boxed{W = 0.13\ lb}$

0.13 lbs is miniscule compared to the benefit saving that much weight would serve. Chose to leave blade solid with no weight reduction slots.

A-11:

A-11	Thermal Expansion		Wyley Stewart

Given: 304 Stainless Steel

Coefficient of thermal expansion (32°F - 212°F) = 9.61×10^{-6} in/in/°F

Minimum Temp = 32°F
Maximum Temp = 110°F

$\Delta T = 78°F$

Find: Thermal expansion (Thickness)

Solution: TE = (CTE)(ΔT)(t)

$$TE = \left(9.61 \times 10^{-6} \ \text{in/in/°F}\right)(78°F)(0.125 \ \text{in})$$

Thermal Expansion = 0.000093 in

This is well below the geometric tolerance of ±0.010", therefore temperature should not affect usability.

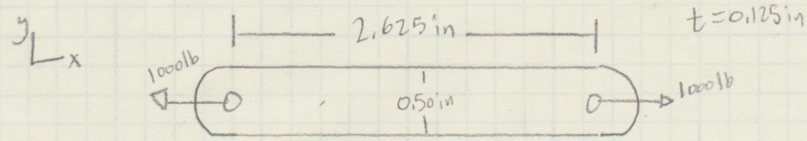
A-12:

A-12	Linkage Deformation		Wyley Stewart	

Given: Drawing B-3
304 Stainless Steel

Find: Total deformation due to Axial loading

Solution:



$$\delta = \frac{FL}{EA} \Rightarrow \delta = \frac{(1000\ lb)(2.625\ in)}{(28\times10^6\ psi)(0.50 \times 0.125\ in^2)}$$

$$\boxed{\delta = 0.0015\ in}$$

A-13:

A-13	Linkage Re-Calc		Wyley Stewart	2-10-18

Given: 1020 Cold Rolled Steel
↳ $S_y = 50800$ psi
Appendix A-2

Safety Factor = 1.5
F = 500 lb

Find: New Thickness

Solution:

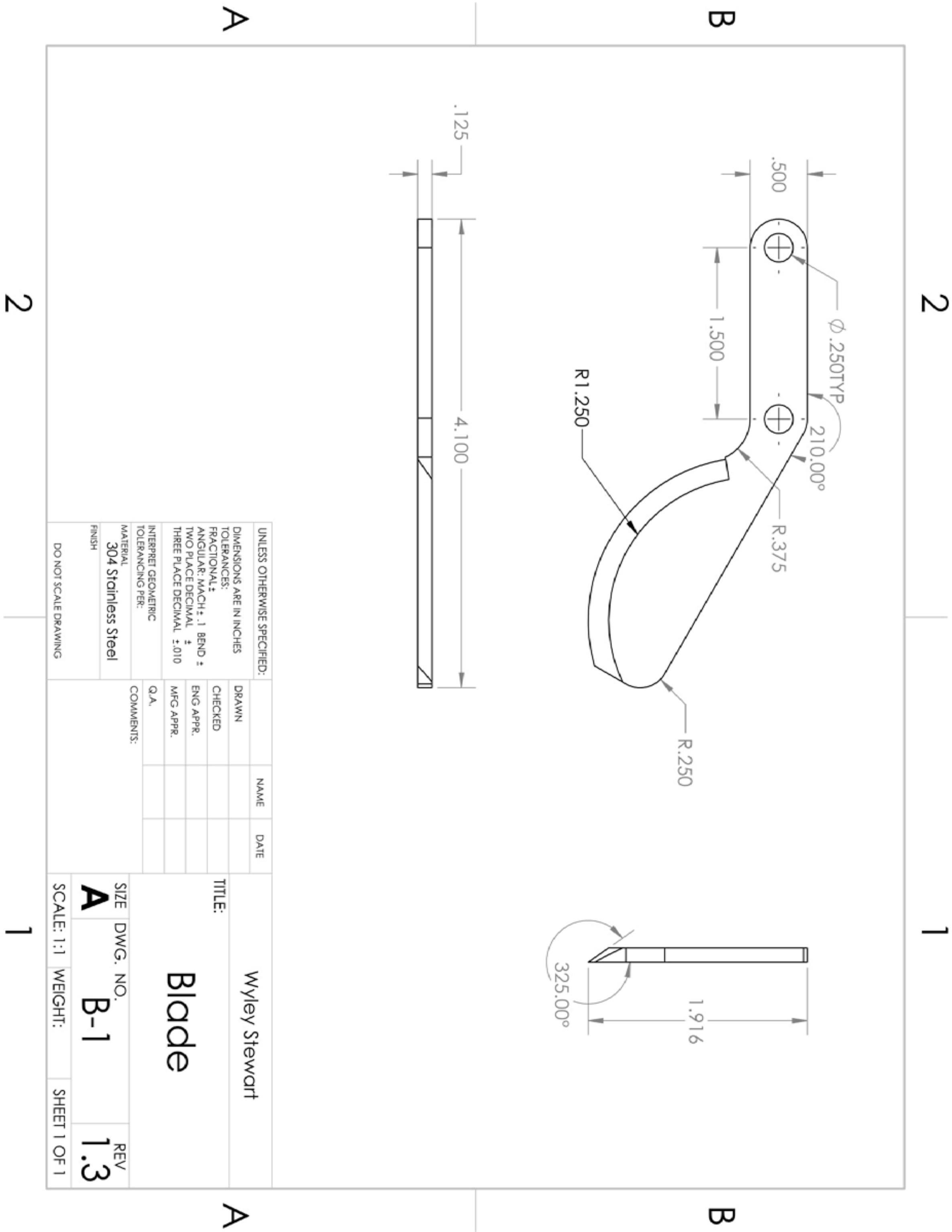
$$\sigma = \frac{F}{A} \Rightarrow A = \frac{F}{\sigma} \Rightarrow th = \frac{F}{\sigma} \Rightarrow t = \frac{(SF)(F)}{(h)(S_y)}$$

$$t = \frac{(1.5)(500\text{ lb})}{(0.5\text{in})(50800\text{ psi})} = \boxed{0.029\text{ in}}$$

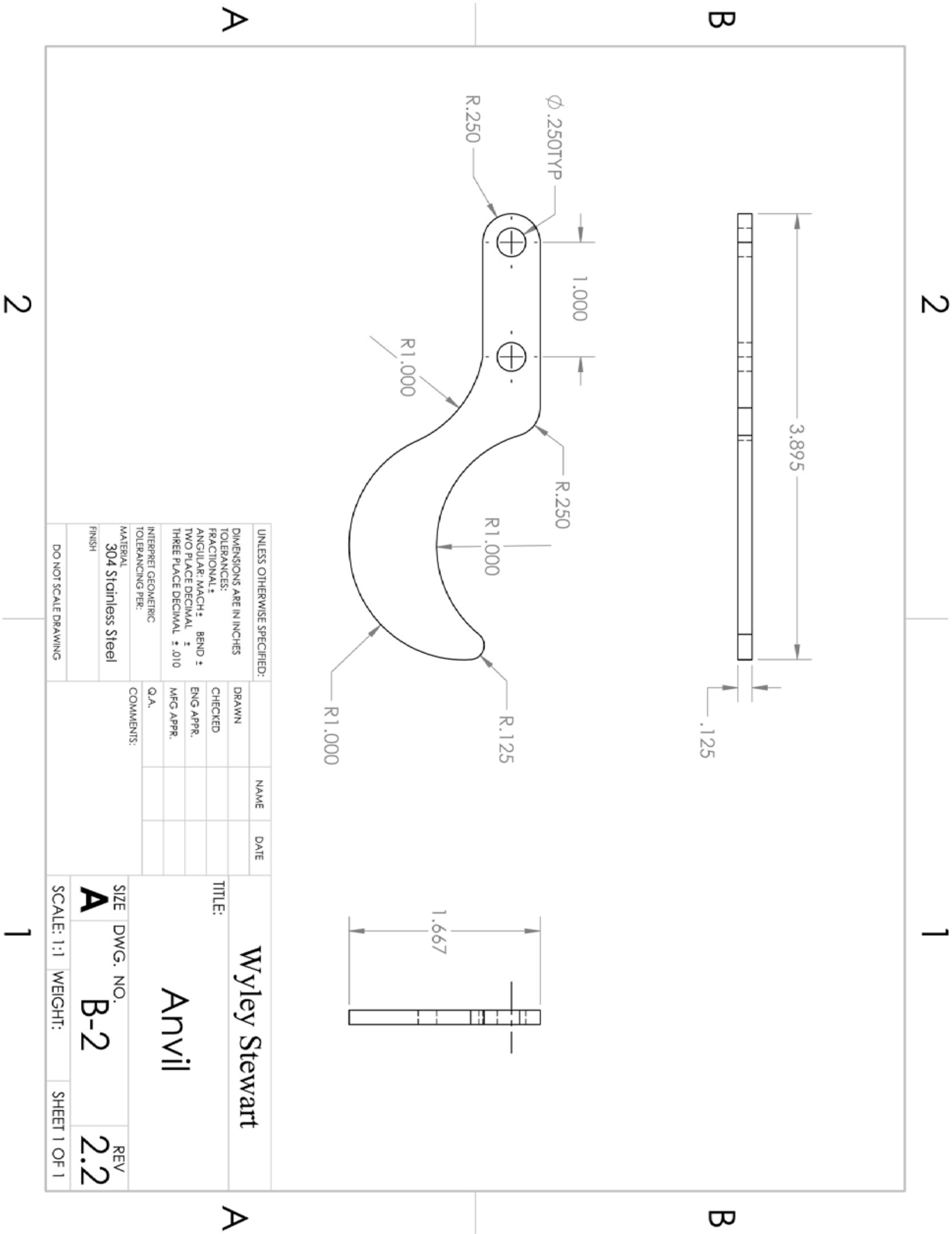
Still Choose to use 0.125" thickness

APPENDIX B

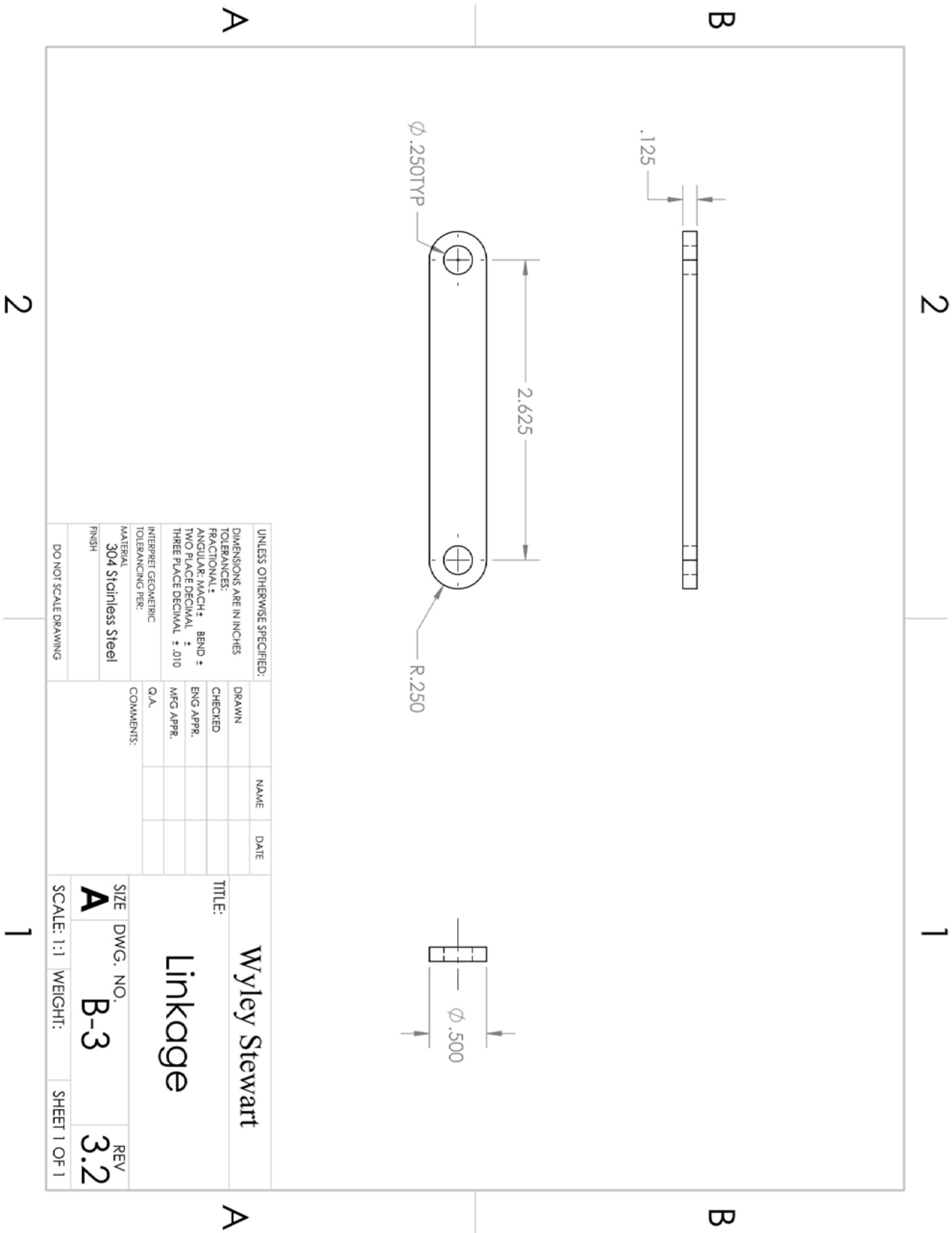
B-1:



B-2:

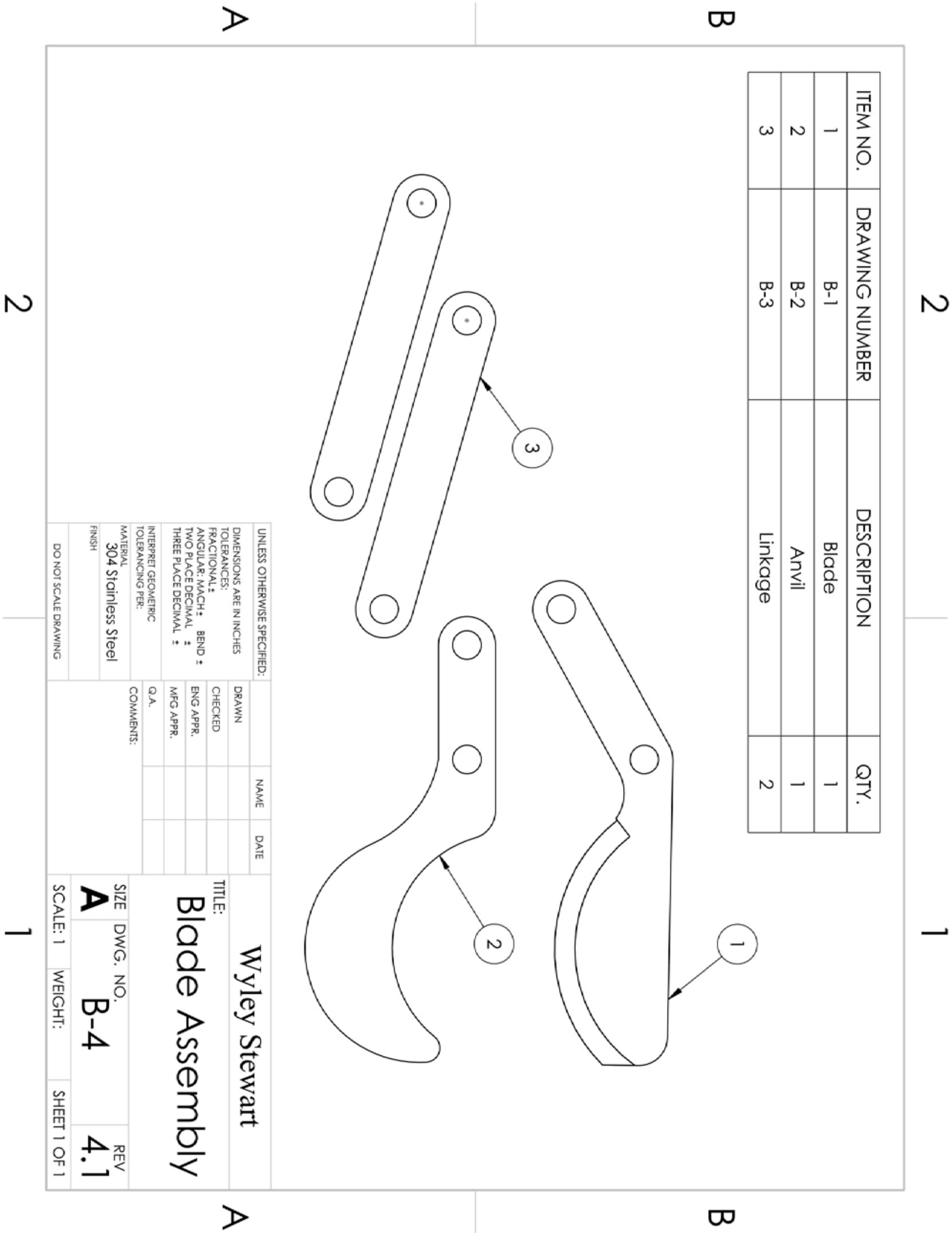

A
B
2
1
⌀.250TYP
R.250
1.000
R1.000
3.895
R.250
R1.000
R.125
R1.000
.125
1.667
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±.010
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
304 Stainless Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Wyley Stewart
TITLE:
Anvil
SIZE
A
DWG. NO.
B-2
REV
2.2
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

B-3:



.125
Ø.250TYP
2.625
R.250
Ø.500
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±.010
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
304 Stainless Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Wyley Stewart
TITLE:
Linkage
SIZE
A
DWG. NO.
B-3
REV
3.2
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

B-4:


ITEM NO. | DRAWING NUMBER | DESCRIPTION | QTY.
1 | B-1 | Blade | 1
2 | B-2 | Anvil | 1
3 | B-3 | Linkage | 2
1
2
3
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
304 Stainless Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Wyley Stewart
TITLE:
Blade Assembly
SIZE
A
DWG. NO.
B-4
REV
4.1
SCALE: 1
WEIGHT:
SHEET 1 OF 1

B-5:

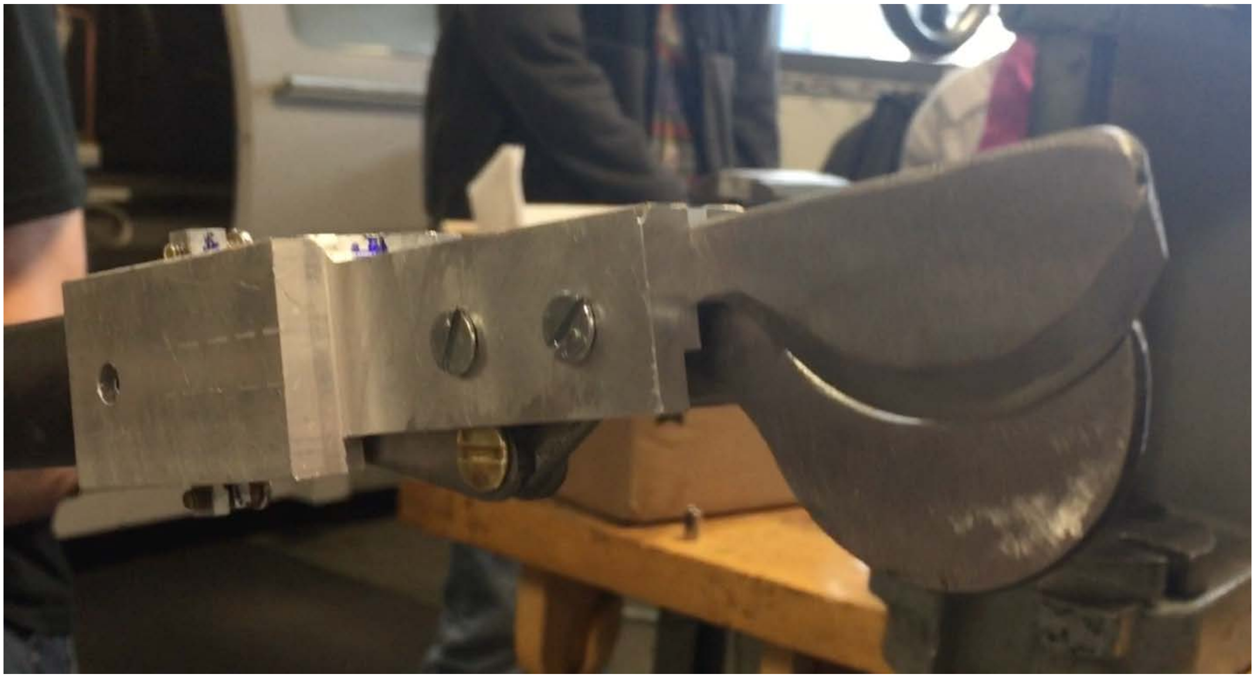
B-6:

B-7:

B-8:

B-9:

B-10:



APPENDIX C

C-1:

Parts List					
Part	**Size**	**Supplier**	**Price**	**Quantity**	**Subtotal**
304 Stainless Steel Plate	4”x8” (1/8” Thick)	McMaster-Carr	$107.24	1	$107.24
18-8 Stainless Steel Grooved Clevis Pin	3/8” Long ¼” Diameter	McMaster-Carr	$6.99	1	$6.99
18-8 Stainless Steel Grooved Clevis Pin	1/2” Long ¼” Diameter	McMaster-Carr	$6.99	1	$6.99
				Total	$121.22

APPENDIX D

D-1:

Project Budget		
A.	Salaries and Wages	
	1. Undergraduate Student Hours (268 @ $15/hr)	$4,020
Total Salaries and Wages		**$4,020**
B.	Parts and Supplies	
	1. 304 Stainless Steel Plate	$107.24
	2. 18-8 Stainless Steel Clevis Pins (Pack of 5) 3/8"	$6.99
	3. 18-8 Stainless Steel Clevis Pins (Pack of 5) 1/2"	$6.99
Total Parts and Supplies		**$121.22**
C.	Travel for Testing Materials	
	1. 2 Trips @ $200/trip	$400
Total Project Costs		**$4,541.22**

APPENDIX E

E-1:

Note: March x Finals
Note: June x Presentation
Note: June y-z Spr Finals

PROJECT TITLE: Hauff Electric Pruner Blades
Principal Investigator: Wyley Stewart

TASK ID	Description	Duration Est. (hrs)	Actual (hrs)	November	Dec	January	February	March	April	May	June
1	Proposal*										
1a	Outline	6	8								
1b	Intro	4	3								
1c	Methods	4	5								
1d	Analysis	12	15								
1e	Discussion	6	5								
1f	Parts and Budget	4	4								
1g	Drawings	10	12								
1h	Schedule	6	4								
1i	Summary & Appx	4	6								
	subtotal:	56	62								
2	Analyses										
2a	Blade Force Calc.	4	6								
2b	Linkage Dimension Calc.	1	1								
2c	Pin Dimension/Material Cal	1	0.5								
2d	Anvil Force Calc.	3	4.5								
2e	Anvil Pin D	1	1.5								
2f	Anvil Pin C	1	2								
2g	Blade Angle Calc.	2	3								
2h	Linkage Buckling	0.5	1								
2i	Torque in Linkages	1	1								
2j	Blade Weight Reduction	0.5	0.5								
2k	Thermal Expansion	1	1.5								
2l	Linkage Axial Deformation	1	1								
	subtotal:	17	23.5								
3	Documentation										
3a	Anvil Drawing	1	1.5								
3b	Blade Drawing	1	1.5								
3c	Linkage Drawing	1	0.5								
3e	Assembly Drawing	2	2.5								
	subtotal:	5	6								
4	Proposal Mods										
4a	Project Robot Schedule	1	0.5								
4b	Project Robot Part Inv.	1	1.5								
4c	Crit Des Review*	6	4								
	subtotal:	8	6								

Note: March x Finals
Note: June x Presentation
Note: June y-z Spr Finals

PROJECT TITLE: Hauff Electric Pruner Blades
Principal Investigator: Wyley Stewart

TASK ID	Description	Duration Est. (hrs)	Actual (hrs)	November	Dec	January	February	March	April	May	June
7	Part Construction										
7a	Order Stock Material	4	6.7								
7b	Make Setup Sheets	6	9.5								
7c	Gather Materials and Tools	3	9.5								
7d	Setup Machine	6	6.5								
7e	Machine Part	8	9.5								
7f	Grind/Sharpen Blade Edge	1	5								
7g	Take Part Pictures	2	1								
7h	Update Website	6	4								
	subtotal:	36	51.7								
9	Device Construct										
9a	Assemble Linkage & Blade	1	1.5								
9b	Assemble Blade & Anvil	1	0.5								
9c	Assemble Anvil & Housing	3	3.5								
9d	Assemble Linkage & Drive	3	2								
9e	Take Device Pictures	2	1.5								
9f	Update Website	6	4								
	subtotal:	16	13								
10	Device Evaluation										
10a	List Parameters	6	0								
10b	Design Test&Scope	4	0								
10c	Obtain resources	6	0								
10d	Make test sheets	10	0								
10e	Plan analyses	8	0								
10f	Instrument Device	2	0								
10g	Test Plan*	12	0								
10h	Perform Evaluation	11	0								
10i	Take Testing Pics	4	0								
10h	Update Website	8	0								
	subtotal:	71	0								

Note: March x Finals
Note: June x Presentation
Note: June y-z Spr Finals

PROJECT TITLE: Hauff Electric Pruner Blades
Principal Investigator: Wyley Stewart

TASK ID	Description	Duration Est. (hrs)	Actual (hrs)	November	Dec	January	February	March	April	May	June
11	495 Deliverables										
11a	Get Report Guide	1	0								
11b	Make Rep Outline	5	0								
11c	Write Report	20	0								
11d	Make Slide Outline	4	0								
11e	Create Presentation	12	0								
11f	Make CD Deliv. List	2	0								
11e	Write 495 CD parts	4	0								
11f	Update Website	8	0								
11g	Project CD*	3	0								
	subtotal:	59	0								
	Total Est. Hours=	268	162								
Labor	15	4020									
Note:	Deliverables*										
	Draft Proposal										
	Analyses Mod										
	Document Mods										
	Final Proposal										
	Part Construction										
	Device Construct			=Total Actual Hrs							
	Device Evaluation										
	495 Deliverables										

APPENDIX G

G-1:

Test 1 Results Table		
Trial #	Branch Size	Result (Go/No-Go)
1	0.75”	Go
2	1.00”	Go
3	1.25”	Go
4	1.50”	Go
5	2.00”	No-Go
6	1.90”	Go

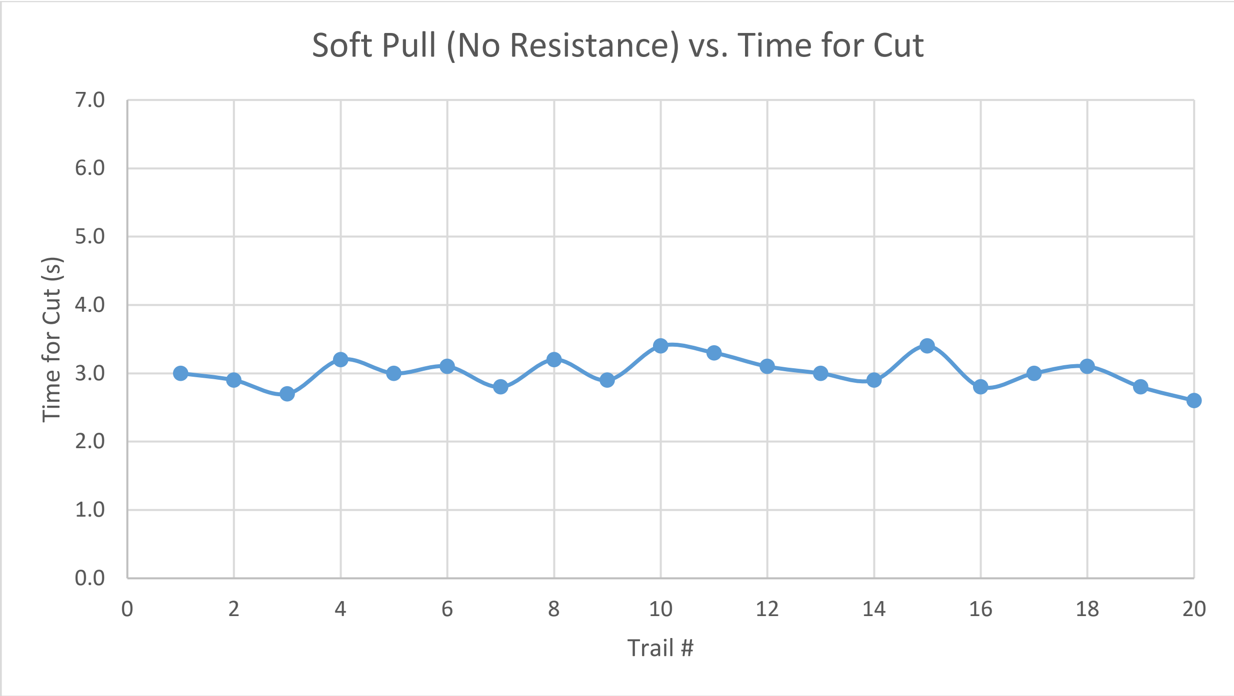
G-2:

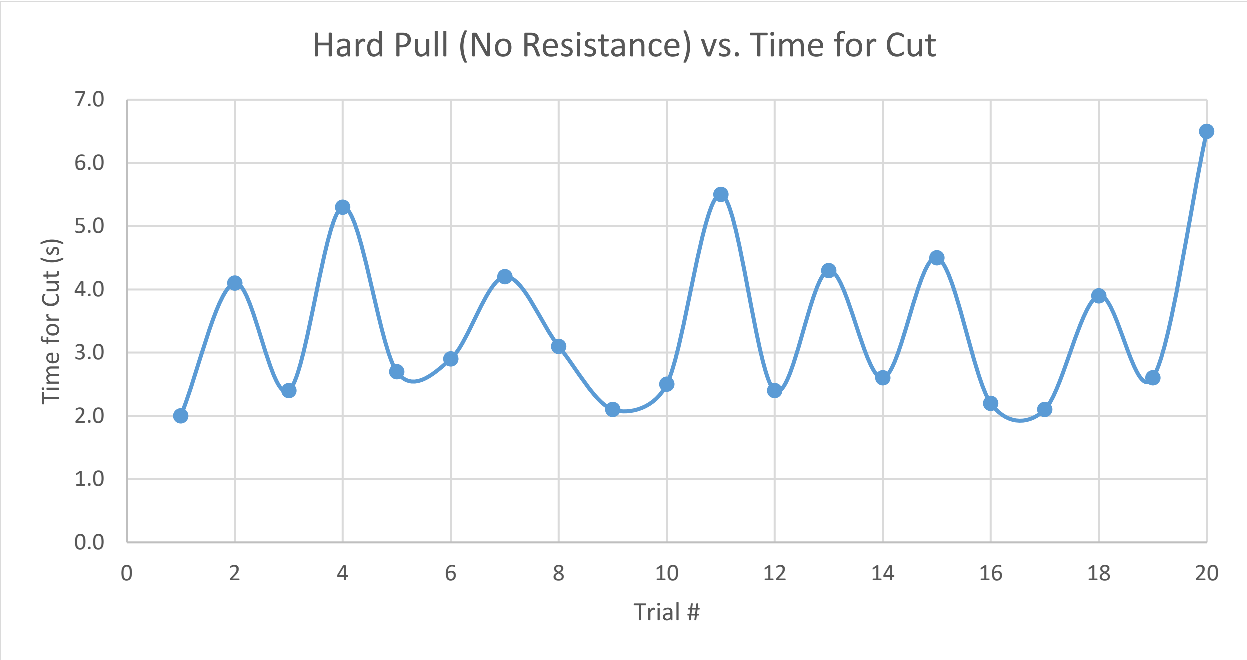
Test 2 Results Table			
Hard Trigger Pull (No Resistance)		Soft Trigger Pull (No Resistance)	
Trial #	Time for Cut (s)	Trial #	Time for Cut (s)
1	2.0	1	3.0
2	4.1	2	2.9
3	2.4	3	2.7
4	5.3	4	3.2
5	2.7	5	3.0
6	2.9	6	3.1
7	4.2	7	2.8
8	3.1	8	3.2
9	2.1	9	2.9
10	2.5	10	3.4
11	5.5	11	3.3
12	2.4	12	3.1
13	4.3	13	3.0
14	2.6	14	2.9
15	4.5	15	3.4
16	2.2	16	2.8
17	2.1	17	3.0
18	3.9	18	3.1
19	2.6	19	2.8
20	6.5	20	2.6
AVG	3.4	AVG	3.0

APPENDIX H

H-1:

Data Evaluation of Test 2





H-2:

Test 2 Raw Data Table

Test 2 Raw Data			
Trial #	Time for Cut (s)	Trial #	Time for Cut (s)
1	2	1	3
2	4.1	2	2.9
3	2.4	3	2.7
4	5.3	4	3.2
5	2.7	5	3
6	2.9	6	3.1
7	4.2	7	2.8
8	3.1	8	3.2
9	2.1	9	2.9
10	2.5	10	3.4
11	5.5	11	3.3
12	2.4	12	3.1
13	4.3	13	3
14	2.6	14	2.9
15	4.5	15	3.4
16	2.2	16	2.8
17	2.1	17	3
18	3.9	18	3.1
19	2.6	19	2.8
20	6.5	20	2.6
AVG	3.4	AVG	3

APPENDIX I

I-1:

TESTING REPORT

Introduction:

Testing the blades of the pruning device was an interesting portion of the project. There are a few different ways the cutting portion of the device was tested. Some of the tests required the blades to be assembled to the rest of the pruner, and some of the tests did not. Below is a list of the design requirements as outlined in the project proposal and project report:

- Open at least 1.5” in middle of blades.
- Weigh less than 1lb.
- Each blade must be less than ¼” thick.
- Capable of cutting 5,000 branches without need for maintenance/sharpening.

The parameters that were of greatest interest were the fit of the cutting system into the rest of the pruner, how large the cutting mouth could open once assembled, and how quickly the blades could complete a cutting motion. Other parameters of interest included the weight of the cutting components, as well as their thickness and durability.

The predicted performance was as outlined below:

- Weigh 0.65 lbs.
- Thickness be ¼”.
- Fit 1.70” diameter branch in cutting mouth.
- Complete cutting motion in 3.50 seconds with no resistance.
- Complete cutting motion in 5.00 seconds with resistance.

Data to compare to the predicted performance was acquired through various means. Most of the data was collected through testing the device, while other data was taken via direct measurement. Some data was collected using instruments like a scale, while other data was collected by timing the actuation of the cutting blades.

As seen in the Gantt Chart in the appendix, all testing should be completed by the third week in April.

The following will describe the Introduction, Method/Approach, Test Procedure, and Deliverables for each test individually:

Test 1: Cutting mouth opening

Introduction: After the entire pruner assembly is constructed, the device will be able to be tested to determine its full cutting potential. The first test for the blade system will be the fit of different sized branches inside the cutting mouth. The test will consist of fitting incrementally larger

I-2:
branches in the cutting mouth until a maximum branch size is reached. Increments of 0.25” will be used. Once a branch is too big for the cutting mouth, the size of branch tested will decrease in size by an increment of 0.10”. The calculated maximum branch size that will fit in the cutting mouth with appropriate clearance is 1.70”. The process for this test includes steps 10a-10g on the Gantt chart.

Method/Approach: This test will be scored by the pruners’ ability to fit large branches within the cutting mouth. The materials needed for this test will be calipers and tree branches of sizes ranging from 1.25” to 2.00”. There will only need to be one person present to test and record data. The resources needed for this test include the pruning device, varying sizes of apple tree branches, and calipers. The data will be recorded by hand. The precision and accuracy will be dependent on the calipers used. Calipers typically have a precision of .001”, which is much more precise than needed for this test.

Test Procedure: The test procedure includes the following:

3. Gather apple tree branches.
4. Measure materials.
5. Open cutting blade.
6. Insert branch. Determine fit. If extra space, proceed to step 5.
7. Insert branch 0.25” larger in diameter and determine fit.
8. Repeat step 5 as needed until there is no extra space between branch and the blade.
9. Once a size of branch is reached that will not fit in the cutting mouth, reduce the diameter by 0.10” and check fit again.
10. Record the maximum size branch that will fit in cutting mouth without being forced into place. The “maximum” size branch should be easily placed in and taken out of the cutting mouth.

The entire test procedure will take less than one hour and can be completed at CWU. There are no safety precautions that will need to be followed.

Deliverables: The deliverables for this test will include a table with the different sizes of branches tested, as well as the result with each size. This test will be considered a “go/no go” test. If the branch fits it will score “go”, and if the branch doesn’t fit it will score a “no go”.

I-3:

Table 1

Test 1 Results Table		
Trial #	Branch Size	Result (Go/No-Go)
1	0.75”	Go
2	1.00”	Go
3	1.25”	Go
4	1.50”	Go
5	2.00”	No-Go
6	1.90”	Go

Conclusion: In conclusion, this test was successful. This test was successful because the cutting mouth was able to fit a 1.90”, when the calculated maximum was 1.70”. The reason for this increase in size was due to using a lead screw for driving the drive shaft instead of using the self-reversing ball screw. By using the lead screw, the cutting blades full motion was only restricted by the room they had to move within the housing, instead of being restricted by the stroke of the ball screw.

Test 2: Time to complete cutting motion

Introduction: The time to complete the cutting motion is an integral aspect of this project. If the pruner took an absurd amount of time to complete a cut, it would be nearly useless. As discussed in the initial design of the project, the pruner should only take a few seconds to complete an entire cutting cycle. The complete cutting cycle includes closing the blade until the cut is complete, and re-opening it to the “fully open” position where a new branch can be positioned inside the cutting mouth. It was calculated that a full cutting motion with no resistance would take 3.50 seconds to complete. The calculated time for the full cutting motion with the resistance of a branch was 5.00 seconds. The process for this test includes steps 10a-10g on the Gantt chart.

Method/Approach: This test will be scored by the pruners ability to complete a full cutting motion as quickly and efficiently as possible. The resources required to complete this test are two test personnel, the pruner, 1.0” diameter branches, and a stopwatch. Data will be captured by using a stopwatch to time the cutting cycle. This test should be performed with a fully charged battery in the impact drill. The precision and accuracy of this test is determined by the instruments used to collect data. For example, the calipers have a tolerance of ± 0.001”, and the stopwatch is only going to be as accurate as the user, so I would say it has an accuracy of ± 0.25 seconds. The data for this test will be compiled into a table and then converted into a graph to show the results more visually. This test will be completed 4 times, each with 20 trials. The first

I-4:
of the four trials will be with a soft trigger pull on the impact drill and no resistance to the blades. The second will be with a hard trigger pull on the impact drill and no resistance to the blades. The last two will be the same as the first two, but with a 1.0” diameter branch to represent a real-life use situation.

Test Procedure: The test procedure includes the following:

1. For the first round of tests (soft pull, no resistance):
    a. Gather apple tree branches, pruner and a stopwatch.
    b. Begin with cutting blades in open position.
    c. With a soft pull on the impact drill trigger, complete a full cutting motion. The second tester will time the cycle by starting the timer when the blade begins to move, and stop the timer once it reaches the fully-open position.
    d. Record time for cutting cycle and repeat 19 more times.
2. For the second round of tests (hard pull, no resistance):
    a. Gather apple tree branches, pruner and a stopwatch.
    b. Begin with cutting blades in open position.
    c. With a harder pull on the impact drill trigger, complete a full cutting motion. The second tester will time the cycle by starting the timer when the blade begins to move, and stop the timer once it reaches the fully-open position.
    d. Record time for cutting cycle and repeat 19 more times.
3. For the third round of tests (soft pull, branch resistance):
    a. Gather apple tree branches, pruner and a stopwatch.
    b. Begin with cutting blades in open position.
    c. Place 1.0” diameter branch into the cutting mouth.
    d. With a soft pull on the impact drill trigger, complete a full cutting motion. The second tester will time the cycle by starting the timer when the blade begins to move, and stop the timer once it reaches the fully-open position.
    e. Record time for cutting cycle and repeat 19 more times.
4. For the fourth round of tests (hard pull, branch resistance):
    a. Gather apple tree branches, pruner and a stopwatch.
    b. Begin with cutting blades in open position.
    c. Place 1.0” diameter branch into the cutting mouth.
    d. With a harder pull on the impact drill trigger, complete a full cutting motion. The second tester will time the cycle by starting the timer when the blade begins to move, and stop the timer once it reaches the fully-open position.
    e. Record time for cutting cycle and repeat 19 more times.

The entire test procedure should take approximately two hours and can be completed at

I-5:
CWU. The only safety precaution to be aware of is the dangerousness of the cutting mouth. Do not put fingers or anything other than a tree branch inside the cutting mouth.

Deliverables: The deliverables for this test will include a table with the results for each trial, as well as graphs of the times in order to better compare the efficiency of the cutting cycle. The test will be a success if the pruner completes the entire cutting cycle in less than 3.50 seconds without resistance and 5.0 seconds with the resistance of a 1.0” branch.

Table 2

Hard Trigger Pull (No Resistance)		Soft Trigger Pull (No Resistance)	
Trial #	Time for Cut (s)	Trial #	Time for Cut (s)
1	2.0	1	3.0
2	4.1	2	2.9
3	2.4	3	2.7
4	5.3	4	3.2
5	2.7	5	3.0
6	2.9	6	3.1
7	4.2	7	2.8
8	3.1	8	3.2
9	2.1	9	2.9
10	2.5	10	3.4
11	5.5	11	3.3
12	2.4	12	3.1
13	4.3	13	3.0
14	2.6	14	2.9
15	4.5	15	3.4
16	2.2	16	2.8
17	2.1	17	3.0
18	3.9	18	3.1
19	2.6	19	2.8
20	6.5	20	2.6
AVG	3.4	AVG	3.0

I-6:

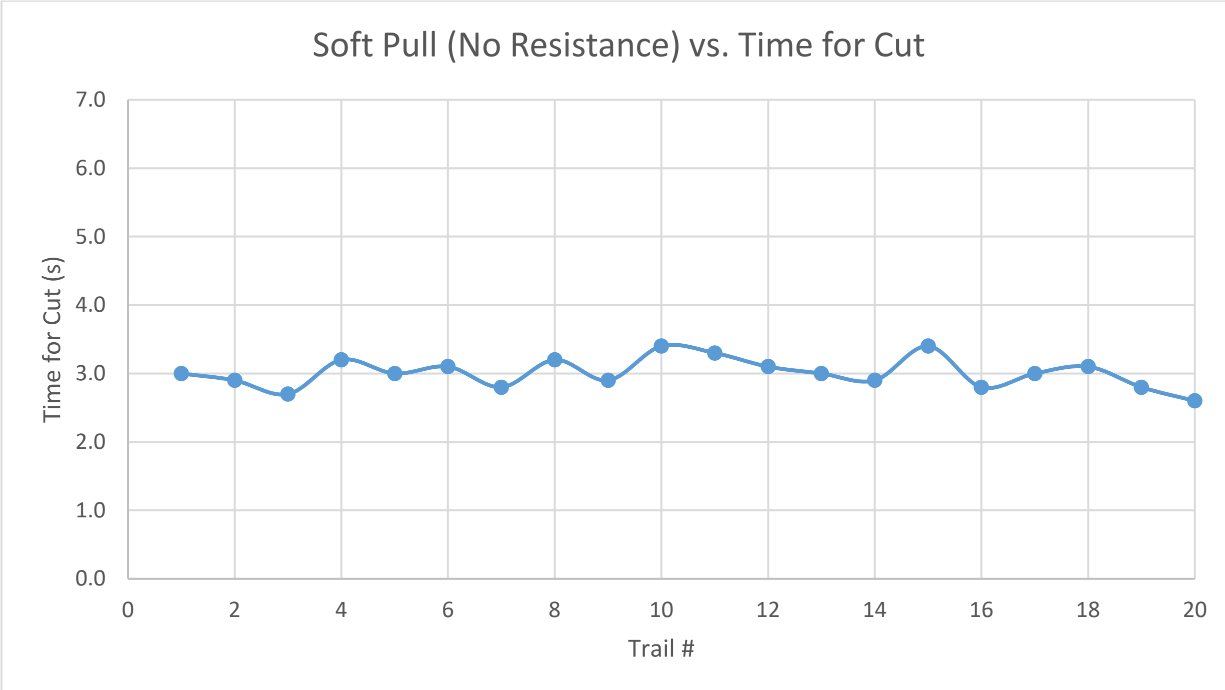


Figure 3

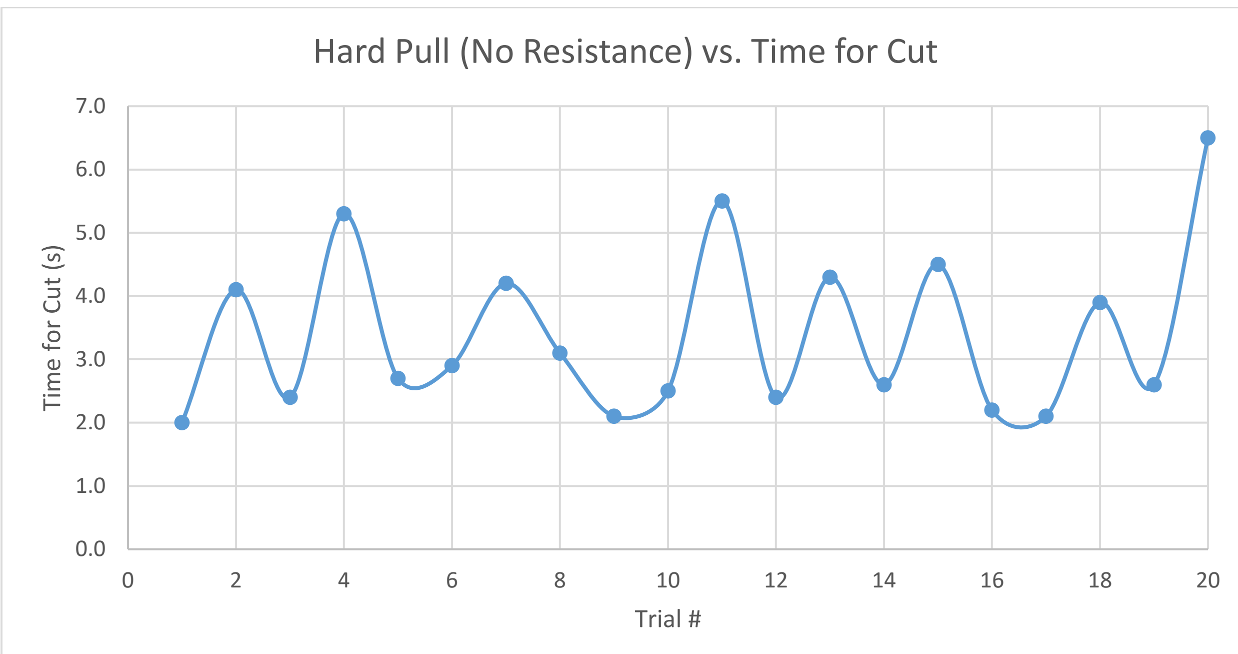


Figure 4

Conclusion: In conclusion, this test was very successful with no resistance. However, when the portion of the test where the pruner needed to cut through branches, the housing pieces of the pruner failed, leaving that part of the test as a failure. As seen below in figure 3 and figure 4, the test was unable to continue due to the failed parts of the pruner. Without resistance, the pruner performed very well. With a soft trigger pull the pruner was much more consistent for each time

I-7:

to complete the cycle, whereas with a hard trigger pull the pruner was very inconsistent. With the hard trigger pull it would either complete the cycle very quickly (as low as 2.0 seconds), or very slowly (as high as 6.5 seconds). This inconsistency was due to the drive components not being perfectly concentric, causing hang-ups in the linear actuation of the drive shaft. However, when the trigger on the impact drill was pulled softly, resulting in a slower rotation of the lead screw, the cutting motion was much more consistent and still achieved a lower than calculated time of 3.0 seconds (average).

Figure 5

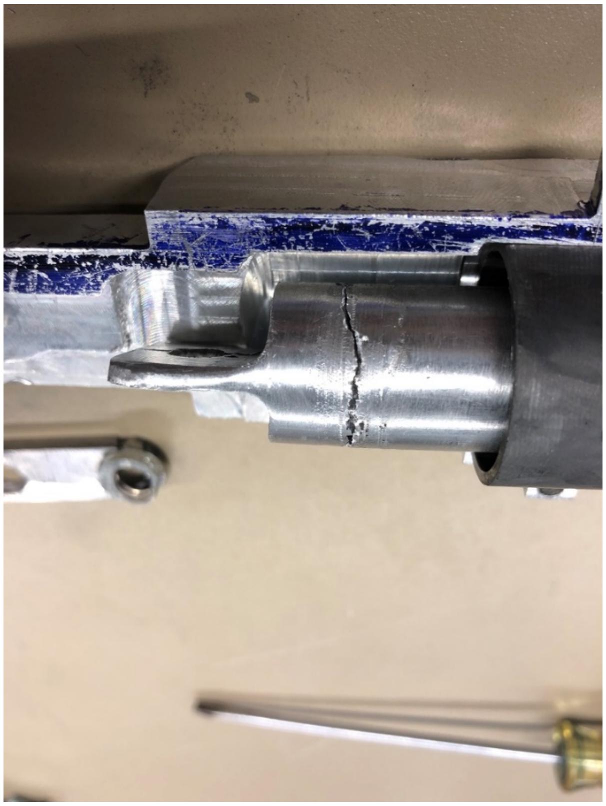


Figure 6

APPENDIX J

J-1:

Wyley Stewart

Address: 24424 SE 437th Pl
Enumclaw, WA 98022
Phone: 360-367-1885
Email: stewartw@cwu.edu

Objective: As an employee in the Mechanical Engineering field, my vision is to utilize my knowledge and intuition to achieve a high level of productivity and contribute to a great level of success in a professional work environment.

Qualifications:
Exceptional technical skills
Friendly, personable and outgoing
Substantial knowledge and experience with mechanical equipment/software
Able to manage peers in a friendly but productive manner

Technical/Computer Skills:
Computer Aided Drafting (AutoCAD)
3-Dimensional Modeling (SolidWorks)
Associate Level Certificate
Machining Equipment (Engine Lathe, Mill, CNC)
Operating Systems (Microsoft Windows, Mac OS)
Word Processing (Microsoft Word)
Spreadsheets/ Presentations (Microsoft Excel, Microsoft Powerpoint)
Email (Microsoft Outlook, Gmail)

Recent Employment:
Big J's Outdoor Store Orting, WA (April 2011-Present)
Managed Employees
Produced store website
Managed social media
Provided superb customer service
Merchandised/sold sporting goods

Education:
Central Washington University (2015-Present)
Bachelor of Science
Mechanical Engineering Technology Major
3.57 GPA
Green River Community College (2012-2015)
Participated in Running Start
Graduated with Associates in Arts

References: Available Upon Request