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Multi-use Fireline Handtool

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By

Bruce Bernard

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INTRODUCTION

Motivation:

When working on a wildfire there are many tasks that require specific hand tools for different jobs. Some of these tasks are fire line construction, brushing, and mop-up. A firefighter can find themselves working on a part of the fire and require a different tool than the one they are using. This can force them to borrow someone else's or ineffectively complete the task. Many times the preferred tool is a sturdy scraping tool such as the Combi or Rhino and leaves the firefighter unable to cut into larger wood requiring a Pulaski. The Pulaski provides a hoe end that is effective in grubbing soil but not for scooping or moving it. If a tool could perform the qualities of a Rhino but also allow the firefighter to chop into wood this would improve the effectiveness of an individual firefighter on the line.

Function Statement:

A device is required that will be able dig, scoop, and scrape away soil as well as cut into woody material.

Design Requirements:

This tool must meet the following design requirements.

- The tool head must weigh less than 8.0 lbs.
- The head must fit in space no larger than 10" x 8" x 12".
- The material hardness on the axe head must be 50-60 HRC up to 1" from edge.
- The material hardness on the scraper head must be 50-60 HRC up to 1" from edge.
- The material hardness on the tool center must be 40-60 HRC.
- The scraping tool surface area must be at least 15 in^2.
- The scraping tool should scoop 15 in^3 of soil.
- Tool head must not permanently deform after experiencing 20 lbs. of impact force.
- Scraping tool must not fail in bending or shear stress when 50 lbs. of force is applied in any direction.
- The axe blade must be 3-4" long.
- The final tool head must cost less than $500.00.
- The tool life must exceed 5000 cycles of repeated impact and scraping.

Engineering Merit:

The engineering merit for this project comes from the application of engineering concepts and tools gained through the CWU MET program. This project requires research and analysis of material properties such as hardness and toughness to determine the appropriate material for the job. These concepts were used in Metallurgy. The designed tool will be required to withstand repetitive impacts. To ensure it does this, careful thought will be put into the structural shape of both tool ends using the tools gained in Statics, Strengths, and Dynamics. It will be necessary to analyze the forces the tool is expected to handle and determine the location and limits for bending stress, shear stress, and deformation. These values will also tie back into the tool material selection.

Scope of Effort:

The scope of this project is to focus on the tool head itself. This includes the material, shape, and structure of the multi-use head. It is expected that the designed tool head will be placed on standard double bit tool handle. Some analysis will be put in to calculate the failure limit of the tool handle.

Success Criteria:

The success of the project is based on the performance of the final tool. The tool should be easy to carry and swing. The scraping end of the tool should remove soil to construct fire line and perform mop up. The axe end should chop easily through branches and roots.

To ensure the success of the final project it will be compared to the performance of a standard Pulaski. Given the task of constructing 5 ft of fire line on same soil and fuel types; record a video of the new tool compared to the Pulaski. Focus attention on swings required, time to completion, and quality of completed line.

DESIGN & ANALYSIS

Approach:

The purpose of this device is to aid in required tasks on the fire line. This device will need to have a “scraping” tool that is good for digging, scooping, and scraping soil. In addition, the opposite side of the tool head will be an “axe” to perform any wood cutting needs. To ensure the listed requirements are met, important parameters are to be considered. One main parameter for this device that needs to be determined is the Impulse and the average impulse force applied on the tool during use. Another is the stress and strain throughout the tool head and location of the maximum internal moment. Lastly, the material of the tool must support the limits of these loads.

Design Description:

The visual design of this tool will be a double sided tool head on a tool handle. One end of the tool will be a 3-4” axe blade and similar to known axe heads. The second end will be the shovel like scraping tool. The scraping tool will be at least 5 in wide at the end and 2 in at the base. Length of the scraper will be 4.5 in. From the base, the tool will expand at near 30° on each side to allow for axe clearance. The thickness of the tools will be adjusted as required from the analysis of the stress and strain within the material. The completed design will be two tools that are assembled.

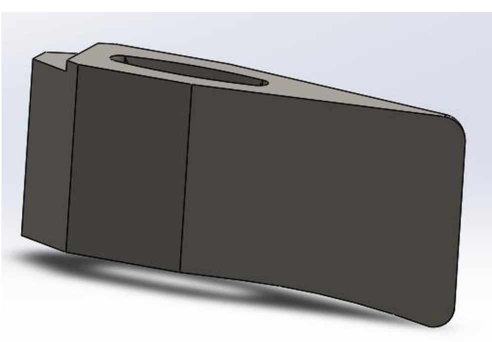


Figure 1: Axe Head

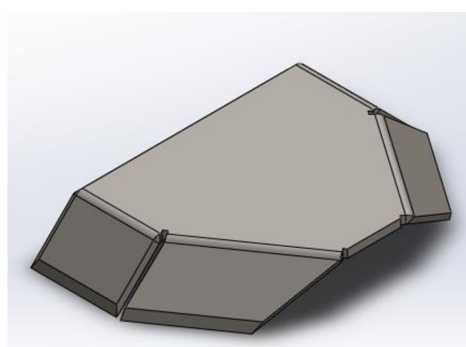


Figure 2: Scraper Head

Benchmark:

A similar solution to the need for a multi-purpose fire line tool is the Pulaski. This is a well-known and effective fire line tool. The digging done with the Pulaski differs greatly from the scooping that is required from this project's design. It is desired that the new tool will show the reliability and endurance of the Pulaski.

The Pulaski can be found at many retailers but the USFS Standard is:

GSA LineGear.com
Product Code: SKU: CT-38PE136FSS
Cost: $135.80
Info: 3.75 lbs, 36" Handle, Heat treaded to HRC 45-60

Performance Predictions:

The first prediction to be made for the tool is the weight. This will be determine after material selection and modeled design is completed. Once the weight and given swing velocity are known the prediction for the average impulse force will be calculated. The next topic of predictions is the stress and strain values. Given a normal load, determine what values for bending and shear stress the tool must endure. The last predictions are the costs of the project and time required to complete it.

Description of Analysis:

The analysis portion will be used to determine the required material, shape, and structure of the tool that meet the design requirements. As the analysis is performed the design is expected to adjust. The first parameter to be analyzed is the impulse forces applied on the tool during swinging. This will be done by making assumptions for the force applied to the tool and using Chapter 15 Kinetics of a Particle: Impulse and Momentum of Hibbeler's Dynamics text.

After analyzing the required loads, the normal stress, shear stress, and strain throughout the tool head will be analyzed. This will be done using chapters 11-13 of Hibbeler's Mechanics of Materials text. Knowing the maximum stress values and locations will result in design and shape changes along with material selection.

The last important parameter to analyze is the material selection. The material properties of the chosen material will need to consider the maximum stresses the tool may endure. The tool material will need to be tough to hold edges without chipping and able to be hand sharpened. The required material properties will be analyzed with the aid of Engineering Materials Technology by Jacobs and Kilduff and MatWeb.com.

Scope of Testing and Evaluation:

The testing of this device is going to reflect and design requirements made for the device. The first group of tests will be size and weight requirements. These will check the overall size and the detailed requirements listed. The second group of testing will be material related. The hardness and strength of the tool will be tested ensuring the required HRC, no chipping, and that the tool is able to be sharpened with a file. The last group of testing will be related to the tools ability to perform common fireline duties and give the new tool a success value when compared to the standard Pulaski.

Analysis:

Impact Forces

Approach – First step is to determine the force applied on the tool during use. The tool will be used to remove soil and it is expected the soil will not be impulsive. However, it is likely the tool will come into contact with rocks and they will be. Hibbeler's Dynamics text provides kinematic equations to help calculate the average force in a swing. In addition to the average force, the impulse exerted on the tool was calculated using the Principle of Impulse Momentum. While considering the average force on the tool the calculations for the possible deformation in the scraper tool are completed. The complete calculations are found in Appendix A.

Design – The angle at which the tool head impacts the ground will cause an internal moment in the tool head. The location of the moment will aid in the design of the scraping tool head thickness and shape.

Calculated Parameters – The calculated average force from swinging a hand tool at impact is 18 lb_f (A1). This is the average force so the scraping and axe head will be designed with a safety factor of 1.5. Therefore the design force at impact is 27 $lb_{f.}$ The possible deformation at this force is 0.0024 in (A7.1). The calculated impulse exerted from striking an impulsive rock was 11 lb_f *s (A1.1).

Stress in Tool Head

Approach – The next step is to analyze the bending stress, normal stress, and shear stress values throughout the tool head. Hibbeler's Strengths text will provide the strategies and equations for these values. The tool will reach maximum stresses in a situation where the head is stuck or impacting a solid surface. The first stress analysis is determining the failure limits and locations if the tool head was to get stuck. These complete calculations are in Appendix A. The two tools will be welded together near the failure location of the tool analysis for the weld leg requirements were performed to ensure the weld would not be the failure (A9).

Design – The overall shape of the tool is designed to meet the minimum requirements and functions as expected. The detailed dimensions of the scraper thickness and width are adjusted to ensure the tool is not fail under normal loads and the handle will fail first. The design thickness of 3/16" for the scraping tool is based on meeting the 50 lb load design requirement (A2). In general, handles are expected to be replaced at some point before the end of the tool heads life. The greatest point of interest in the tool is where the scraper and axe head mate. This is a location with the smallest cross-sectional area and just less than the maximum moment.

Calculated Parameters – The calculated maximum load on the handle before failure is 72 lbs. at the end (A3.1). At this limit, the moment within a fixed tool head is 2524 lb*in and 1747 lb*in at the location of smallest area (A3.2). The stress at this point of interest is 100 ksi (A3.3). Using the S_y for the possible material AISI 4140 shows the handle would fail before the tool head in this situation with a safety factor of 1.6 (A3.3). The required weld leg length is .5"(A9).

Material Selection

Approach – The process of selecting a material is guided by the design requirements and the strength of the material. The design requirements demand a material that can be hardened between 50-60 HRC. This requirement is to ensure the tool will have toughness for repetitive impacts and yet be able to be sharpened. An endurance strength analysis was done to verify the material will suffice normal use. To select a material, use matweb.com and compare steel materials that have the appropriate hardenability and good for impact use.

Design – The selected material's properties will aid in calculations involving stress and deformation. The dimensions of the scraper and axe will alter to ensure the tool head does not fail during the required load testing.

Calculated Parameters – The material selected is AISI 4140 Steel. This is a medium – carbon steel with high hardenability and good fatigue, abrasion and impact resistance. When oil quenched, the steel has a surface hardness 57 HRC and tensile yield strength of 161 ksi (A4). The matweb.com data is in Appendix A. The calculated actual endurance strength was 33.5 ksi (A8.1). After using the "damage accumulation method" the tool will have used 50% of its life given the expected use (A-8.2).

Device Shape:

In the device shape there are some design decisions based on functional flow more than analyzed values. The “new” scraping end of the tool will be wide at the end and narrow at the base mounting location. The reason for this design is to allow for clearance when using the axe end of the tool. If the scraper was squared off, the tool swing would likely be interrupted during use. Another design choice is to have the left and right ends of the scraping tool angled inward to give a scooping volume. This volume is a design requirement and the actual volume calculation is in Appendix A. Adding to volume of soil removal increases the functionality of the scraping tool. The minimum requirement is 15 in^3 and the actual will be greater than 20 in^3 (A6).

Device Assembly:

The primary design has the axe and scraping tool made separately and assembled after. The assembly could be done with bolts, dove tails, or welding. The selected method is welding due to its availability and strength for the tool head. The design of the final tool assembly includes the devise head mounted on a standard double bit axe handle. This allows for the handle to be readily available and replaceable. A drawing is completed for the assembly and found in Appendix B.

Tolerances, Kinematics, Ergonomics:

The end product of this project will used for digging, scraping and cutting. The tolerances will reflect this. The values for weight and size may not have to be within the thousands of an inch to perform its job but will need to be near identical to any other made and be replaceable. The function of cutting will require a sharp edge that is held to a tighter tolerance. Material hardness and strength will be tolerance to meet safety and functionality needs. The standard tolerances applied to the tool dimensions are ± .010” for three decimal places and ± .050” for two. Ergonomics are greatly considered for any human operated tool. This device will be similar to other fire line hand tools and use the standard double bit tool handle to ensure user safety and productivity.

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

Technical Risks for this project greatly lie in the material selection and manufacturing. There are several methods for producing a tool such as casting, forging, or machining. Each would have different cost and availability. The end resulting material properties must meet the requirements. The mitigation for this risk is to research common tool materials and availability.

The failure mode of this device will be when the tool is under the maximum critical load. This load could happen at impact with an impulsive surface. Hitting a harder surface with a small area would likely result in chips and deformed metal. The tool head may also become stuck where random loads could be applied to the tool. It is important that the design allows the tool to fail in a replaceable part such as the handle before failure in the head. The safety factor of 1.5 will allow the scraping tool to not bend or fracture at the area of highest stress concentration. The dimensions of all parts will at least have this safety factor of 1.5.

Normal use of this device is defined by it operational limits. This tool is to be used by hand and not assisted by machine or device. The limits of impact force will be calculated. Although the device is not for breaking rocks it will be strong enough to not catastrophically yield, or fracture when impacting them.

METHODS & CONSTRUCTION

Construction:

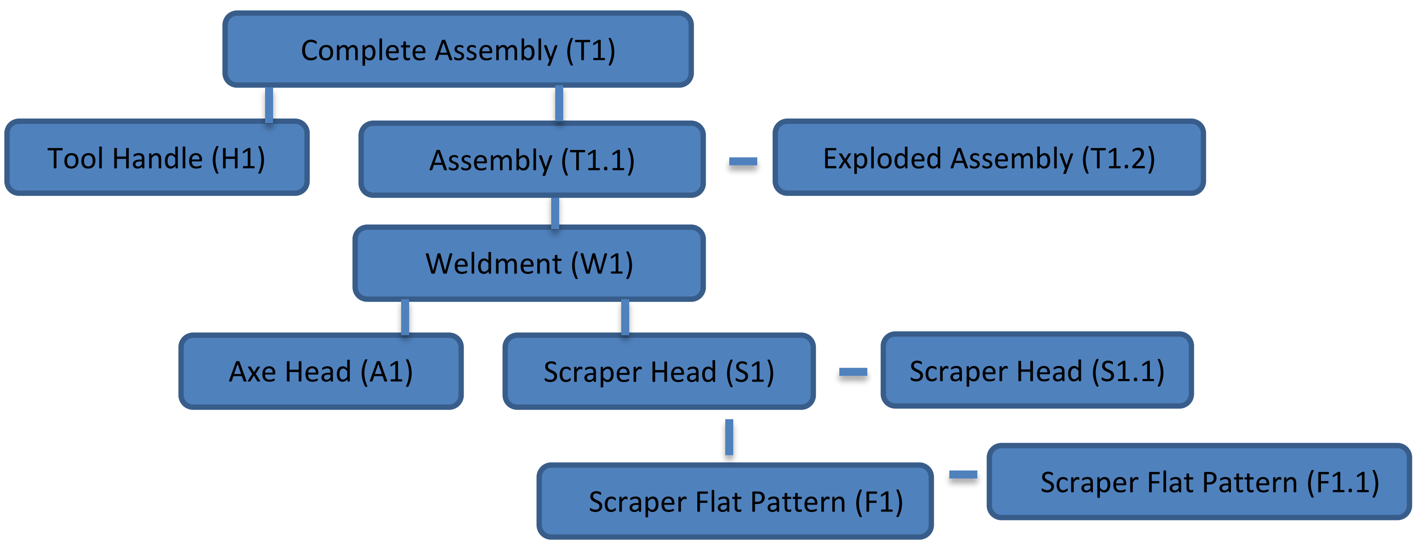
The entire tool head will be constructed. The current method is to construct the axe tool and scraping tool separately. The axe will be machined from stock material and require less setups and fixtures than if machining the entire part as one piece. The scraping tool will be cut from stock plate and flanges will be bent to the required form. The two tools will be assembled together by welding. The completed tool head then requires heat treating and will be sent out to PACMET for this service.

Description:

The device will be a double headed hand tool. The first head is an axe (A1). The axe head's features are the axe blade, tool handle mounting eye, and mounting step for the scraping tool (S1). This head can be machined from one piece of stock material. The machining will include several facing operations and a step down boring operation. The second head is the scraper. The scraper will be plasma cut from stock plate material and bent into shape. The finished form will then be welded to the axe head.

Drawing Tree, Drawing ID's:

The drawings for this device will be for the axe, scraper, scraper flat pattern, weldment, tool handle, assembly, exploded, and complete assembly. All will be found in Appendix B.



Parts List and Labels:

This device will include at most two parts that are designed and constructed. The first part is the axe head (A1). The second part is the scraping tool (S1). The end device is a double headed hand tool. The other main part of the hand tool is a handle (H1). The handle will not be constructed, only purchased and assembled to the head. The parts required for the construction of the finalized device are listed in Appendix C.

Manufacturing Issues:

During the manufacturing planning of this device it was discovered that the features of the axe would require six individual setups. This amount of set ups requires more time than expected. When the tool paths were planned, special attention was put into the feeds and speeds due to the strength of the material being cut and the length being cut with relation to tool diameter. The tooling for machining operations was mostly selected from what was readily available. Two special tools had to be ordered to complete the eye-hole feature on the axe.

Even with the above considerations for feeds and speeds the machining was more difficult then expect. The standard available HSS tooling was found inefficient and not reliable enough to complete the machining requirements. Tooling was switch to carbide tools and the tool paths were adjusted for more adaptive clearing methods. Due to time delays from this change, some designed features were removed. This removed the need for an additional setup.

During the production of the scraper there was no precision machine to bend the flanges. The flanges were however bent within an acceptable tolerance. When the device was welded, the skills from classmate Trevor Reher were required. Lastly, the tool was transported by classmate Zach Uhrich for heat treated at PACMET to meet the required material hardness. This service took four days longer than expected but was done before the due date.

Discussion of Assembly:

The axe head was machined using manual milling machines and the CNC. The shape of the axe allows for standard vise work holding setups for most of the operations. This made the production easier when running the machining programs. The machining operations and tool paths have been determined and setup with HSMworks. The axe required 4 setups. This allowed for facing on all required sides and cutting all features. The feature of greatest concern was the handle attachment eye-hole. The machining process for this feature required special tooling and two operations.

The scraping tool was cut from a 3/16” plate to reduce material waste. The use of the plasma table made this process quick. Once the flat pattern was cut, the chamfered edges were ground using the belt grinder. The flanges were then bent into place using a torch to heat along the bend line and bent to a 45 degree angle. The moment that would be required to do this for each flange cold has been calculated in Appendix A.

Once both parts were constructed, they were assembled together. The method for assembly was TIG welding the scraper to the platform on the axe head. This assembled tool head was heat treated and then put on a 36” tool handle. Finally the assembled tool was prepped and painted to protect from corrosion.

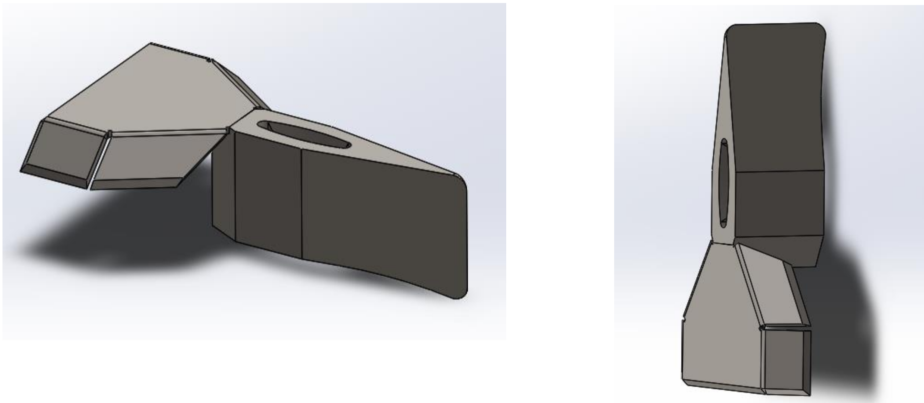


Figure 3: Assembled Tool Head

TESTING METHOD

Introduction:

The testing of the performance of the device is guided by the design requirements. If there is a requirement it will be tested to ensure the device meets it. Several of the requirements require only dimension measurements that evaluate the tool's size and weight. The second group of testing will focused on the material properties of the tool and how it deforms when forces are applied to it.

Method/ Approach:

The measurement testing will require a scale, calipers, and ruler. These tests will verify the weight and dimensions of the tool head. From the dimensions of the scraper tool, the volume and surface area will be calculated. The actual volume of soil removed will be recorded. The size measurements can be recorded at a workbench.

The next measurement to be recorded is the material hardness at different locations on the tool head. The harness will be recorded using the harness testers provided in the lab. The testing of harness will ensure that the tool meets the requirements and will maintain the required toughness and strength needed to perform.

To test the tools performance it will be placed under the designed loads and any deflection will be measured. One load will include a static application of force to determine any failure due to bending or shear stress. Another load will be impact and any deformation or fracturing will be recorded. Measuring devises for these will be the scales of the machines applying the force and calipers or gauges to record deformation.

Test Procedure:

All testing except the practical functions test should be able to be achieved in a lab on the CWU campus. Measuring devices such as calipers, micrometers, scales, strain gauges, and harness testers are available. The Following lists the tests to be performed.

The first test is to verify that the tool meets the required design dimensions. Measurements are to be recorded at workbench using scale, caliper, ruler, and micrometer. Refer to Appendix G-1.

Next, perform hardness testing in accordance with ASTM E-18. Use the hardness tester to record hardness in HRC. Test from the tool edge up the center axis of each tool. See Appendix G-3.

- Axe end 1/8”, .5 “, and 1” from end
- Scraper surface 1/8”, .5”, and 1” from end
- Tool Head center

Record strain and calculate stress under a static load. This is done by applying a strain gauge at the calculated location of greatest stress. Do the test up to 60 lbs. in 20 lb. increments. See Appendix G-4.1.

For dynamic impact, test the function of the tool with a standard practical use test. This test will be done as described in the USDA Forest Service Pulaski Specification document 5100-355E. Each end of the tool will strike a hardwood knot of any size with 10 heavy blows. After striking there shall be no evidence of chipping, dulling, turning over, or loosening of the handle. See Appendix G-4.2.

Finally evaluate the success of the tool for fire line construction when compared to the standard Pulaski. Mark two 5’ sections on typical land with the same soil conditions. Construct a section of line with the Pulaski and one with the multi-use hand tool. Record the time and swings required. Lastly rate the quality of the line and calculate the success value of each run using the success equation, SV = $\left[\frac{Rating}{100}\right]/[Time + Swings]$. See Appendix G-5.

Deliverables:

The recorded measurements and performance testing will be recorded on the prepared testing sheet found in Appendix G. These tests will be used to determine the pass or fail performance of the device. The final product will meet all design requirements and function as required.

BUDGET/SCHEDULE/PROJECT MANAGEMENT

Cost and Budget:

The primary budget concern for producing this tool is material cost. The first quote for the required 4140 greatly exceeded budget. To mitigate this cost a cheaper T-1 tool steel was used for the scraper (S1). T-1 has similar and acceptable properties for the scraper production. A more affordable supplier was found for the axe (A1) stock material. Other resources will be required but are assumed to be available in the CWU shop. These resources include the CNC mill, CNC plasma cutter, required machining tools, and required welding equipment. Only two special tools were required that were purchased within budget. Although labor cost for machining or welding are not expected to be billed, there is an estimate for the cost. The last cost is for the heat treating of the assembled tool. This heat treat service was provided by Pacific Metallurgical, Inc free of charge due to it being a school project. All expected costs are listed in Appendix D. All costs for the project will be paid out of pocket.

Schedule:

The overall schedule of this project is guided by the time requirements and due dates given in the MET 425A, B, & C syllabus. The individual schedule is organized in a Gantt chart attached in Appendix E. This chart starts in September and ends in June. Each month is broken into quarters. The task list is set in order of expected completion dates and deliverables are marked with a diamond. The deliverables on the chart include the draft proposal, analysis, documentation, CDR, MDR, TDR; The final proposal, part construction, testing evaluation, and the final report.

The Gantt chart also includes the estimated and actual hours spent on each task. At this time the estimated time for completing this project is 258 hrs.

Project Management:

This project is to be completed at the Hogue building at CWU. To complete this task, several on campus resources will be used. Some staff individuals will be required for their expertise and guidance. These staff members may include Matt Burvee and Ted Bramble. The physical resources required will include the CNC mill, CNC plasma cutter, welding equipment, and required tooling. Lastly the software need to aid in the ease of machining and plasma cutting is SolidWorks and HSMWorks.

DISCUSSION

The design of this project is motivated by the experiences and necessity wildland fire fighters have on the line. The end picture is to add a desired hand tool in the lineup of options a fire fighter could have. There are tools designed for grubbing, chopping, and scooping but none that do all these effectively. It was figured early in the design process that a tool head with a tool on both ends would be desired. This duel headed setup is found commonly in fire line hand tools.

The primary tool desired needed to be tough for grubbing soil, but also have a larger surface area and scooping volume to remove soil. These desired functions contributed to a flat edged scraping tool with flanged ends. The flat end would allow the tool to cut into soil evenly and leave a wide removed area. By flanging the end, the tool not only loosens the soil but removes it in the same swing. This is desired to increase the fire line production rate and reduce the swings required by the fire fighter. The secondary tool desired needed to chop through roots, limbs, or into stumps when the fire fighter needed. This need lead to the decision to design an axe head on the tool. The axe head is a time proven tool for these functions.

The next design decision was if the tool head should be designed as one solid piece or two separate tools that are fixed together. When considering the construction process for the final tool head it became clear that for the purpose of producing one item, two tool heads would be designed. If the head was one solid piece all tool paths and work holding setups would increase greatly in difficulty. This would require more time spend on fixture design and complex CAM processes than needed for two parts. The two designed parts; axe and scraper; will involve quicker work holding setups and simpler tool paths. In addition, theses separate construction process will better showcase skills acquired in the CWU MET program.

It is extremely important that a material that will meet all the design requirements was selected. In addition to the stated requirements this material had to be able to be machined, cut, formed, and hardened to its final state. The final tool design accounts for the strength and process ability of the material.

Once the stress analysis was under way the required dimensions were determined. The analysis used load values from swing tests, design requirements, and failure limits to ensure the designed tool would meet the desired functions. For all calculations, a minimum design factor of 1.5 was used to account for unexpected or misuses of the tool.

CONCLUSION

This final designed multi-use hand tool meets all the needs of a wild land fire fighter on the line. It will provide ease and effectiveness in line production and mop-up operations. This proposed device achieves the desired function and meets all design requirements. This device will give the desired versatility required by and individual firefighter.

Another important consideration for this proposal is the ability to complete it. This device can be produced at an affordable cost and in the time allowed in the quarter. The parameters that limit the resources at CWU do not restrict any of the required materials, tools, of construction methods proposed.

Finally, this project is of great interest to the principle designer. The designer’s skills for stress analysis and hands on CNC machining experience make them qualified to complete this project. The personal experience of the principle designer as a wild land fire fighter made the project one motivated by desired functions. Interest is increased with the combination of personal, work, and school life.

ACKNOWLEDGEMENTS

First, a special thanks to the leaders of the Central Washington University, Mechanical Engineering Technology department. These men have provided guidance, motivation, and feedback throughout this project management process.

- Dr. Craig Johnson
- Professor Charles Pringle
- Professor Roger Beardsley

Second, In addition to the gentlemen above; I would like to thank the other instructors and classmates that have provided the skills and help required to complete this project. They are all valuable resources in understanding engineering concepts and machining practices.

- Mr. Ted Bramble
- Mr. Darryl Furman
- Mr. Matt Burvee
- Trevor Reher
- Zach Uhrich

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APPENDIX A – Analyses

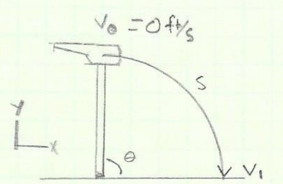
Appendix A-1: Force at Impact

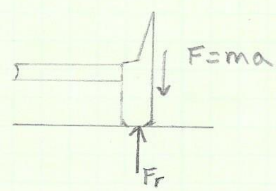
BRUCE BERNARD | MET 495A

GIVEN: A SWINGING TOOL

$r = 4.5\,ft$ $\theta = 2.666\,rad$ $W = 9\,lb$

FIND: THE AVERAGE FORCE AT IMPACT.





SOLN:

Acceleration a is uniform

$$S = V_0 t + \frac{1}{2} a t^2 \qquad S = r\theta \qquad a = \frac{2S}{t^2}$$

TIME TRIALS

0	Seconds	
1	.65	.66
2	.72	.66
3	.66	.61
4	.64	.57
5	.62	.70
6	.69	.58
7	.65	.60
8	.53	.61
9	.58	.51
10	.49	.51

AVG: 0.61 seconds

$1\,lb_f = 32.2\,lb_m \cdot ft/s^2$

MASS

$$m = \frac{W}{g} = \frac{9\,lb_f}{32.2\,ft/s^2} = 0.2795\,slug$$

$$S = 4.5\,ft\,(2.666\,rad) = 12.0\,ft$$

$$a = \frac{2\,(12.0\,ft)}{(0.61\,s)^2} = 64.5\,ft/s^2$$

$$F = \left(0.2795\,\frac{lb_f \cdot s^2}{ft}\right)\left(64.5\,ft/s^2\right) = 18.03\,lb_f$$

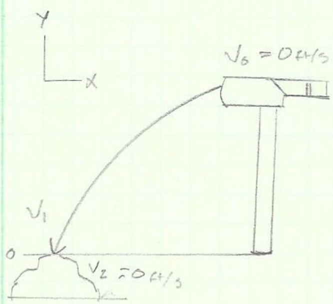
SF = 1.5

Design For

F = 27 lb

Appendix A-1.1: Impulse at Impact

BRUCE BERNARD | MET 495A | 11-22-15



IF THE HANDTOOL STRIKES A ROCK AND THE MOMENTUM CHANGES QUICKLEY THEN THERE IS A IMPULSIVE FORCE.

GIVEN: $t = 0.61$ sec
mass = 0.2745 slug
$a = 64.5$ ft/s² (constant)

FIND: THE IMPULES THE ROCK EXERTS ON THE TOOL.

SOLN:

$$V_1 = V_0^{\,0} + a_c t \qquad V_1 = 64.5\,\text{ft/s}^2\,(.61\,\text{s}) = 39.35\,\text{ft/s}$$

Principle of Impulse and Momentum

$$m_H (V_H)_1 - \int F\,dt = m_H (V_H)_2^{\,0}$$

$$0.2745\,\frac{\text{lb}_f}{\text{ft/s}^2}\,(39.35\,\text{ft/s}) = \int F\,dt$$

$$= 11.0\ \text{lb}_f\text{'s}$$

Appendix A-2: Scraper Minimum Thickness

BRUCE BERNARD | MET 495A | 11/14/15 | 1/2

RADD assesment.

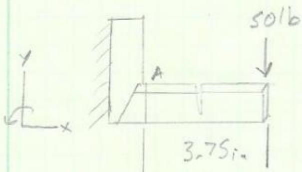
REQUIREMENT

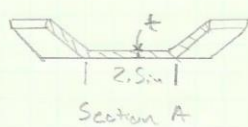
SCRAPING TOOL MUST NOT FAIL DUE TO BENDING OR SHEAR STRESS WHEN 50lb IS APPLIED IN ANY DIRECTION.

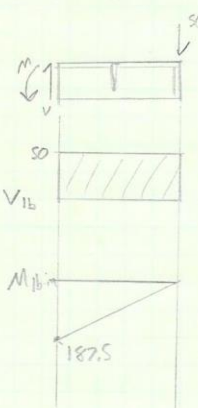
GIVEN: DIMENSIONS, MIN REQUIREMENT

FIND: Min thickness of Scraper tool

CALCULATIONS







$\circlearrowleft \Sigma M_A = 0$

$M_A = 50lb\,(3.75in) = 187.5\ lb\cdot in$

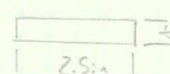
FLEXURE FORMULA

$\sigma = \frac{Mc}{I}$

AISI 4140

$\sigma_{max} = 161\ ksi$

SMALLEST AREA



$c = \frac{t}{2}$

$I = \frac{1}{12} b h^3$

$= \frac{1}{12}(2.5in)\,t^3$

$$161\ ksi = \frac{187.5\ lb\cdot in\left(\frac{t}{2}\right)}{\frac{1}{12}(2.5in)\,t^3}$$

$t = 0.0529in$ min

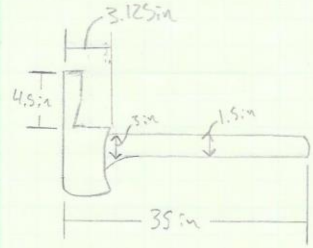
Common 1/16" MIN

SF = 3.00
USE t = 3/16"

Appendix A-3.1: Handle Failure

BRUCE BERNARD | MET 495A | 11/8/15 | 1/1

FAILURE ANALYSIS



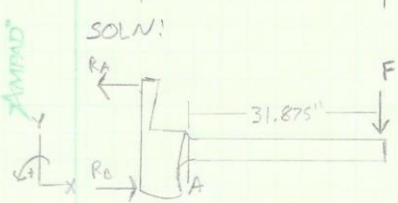
IF THE TOOL HEAD BECAME STUCK AS IF FIXED, WHAT IS THE FORCE AND LOCATION OF FAILURE?

GIVEN: Dimensions Shown
THICKNESS AT TOP IS .75in

FIND: MAX MOMENT IN HANDLE

LOCATION OF FAILURE

SOLN:



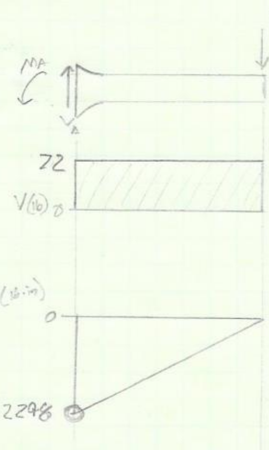
GIVEN:
HICKORY $S_y = 5.2$ ksi
AISI 4140 $S_y = 97.9$ ksi
MATWEB.COM

AREA Ellipse

$A = \pi a b$

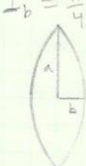
$I_b = \frac{\pi}{4} a^3 b$

$\sigma_{max} = \frac{Mc}{I}$



$5200\text{psi} = \frac{M(1.5in)}{0.663\ in^4}$

$M_A = 2298$ lb·in, Max HANDLE



a = 1.5in
b = .250in

$A = 1.77 in^2$

$I = 0.663\ in^4$ @ A

$\Sigma M_A = 0$

$2298\ lb{\cdot}in - F(31.875") = 0$

Fails at **F = 72 lb**

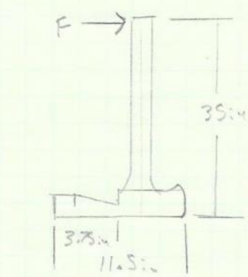
NOW THAT THE HANDLE FAILURE IS KNOWN, DETERMINE MAX MOMENT AND LOCATION IN TOOL HEAD.

Appendix A-3.2: Moment in Tool Head at Failure

BRUCE BERNARD | MET 495A | 11/9/15 | 1/2

FAILURE ANALYSIS

IF TOOL HEAD WAS FIXED, WILL THE HEAD FAIL BEFORE HANDLE?



GIVEN: F = 72 lb

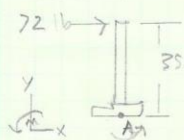
Dimensions shown

AISI 4140 $S_y = 161$ ksi

FIND: MAX MOMENT IN HEAD

Moment at smallest cross sectional area.

SOLN:

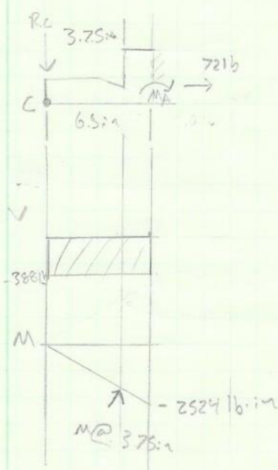


$\circlearrowleft \Sigma M_A = 0$

$M_A - 72 lb(35in) = 0$

$M_A = 2524$ lb·in

Fixed @ C



$\circlearrowleft \Sigma M_A = 0$

$R_C(6.5in) - 2524$ lb in $= 0$

$R_C = 388$ lb

$\Delta M = \int V dx$

AT SMALLEST AREA

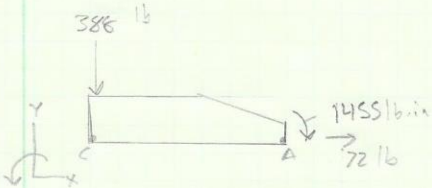
$= \int_0^{3.75} 388 \cdot dx = 1455$ lb·in

Appendix A-3.3: Tool Head Failure

BRUCE BERNARD | MET 495A | 11/10/15 | 2/2

FAILURE ANALYSIS

TOOL HEAD FIXED, WILL HEAD FAIL BEFORE HANDLE



GIVEN: $M_A = 1455 \text{ lb·in}$
$F_C = 388 \text{ lb}$
$F_{Ax} = 72 \text{ lb}$

FIND: STRESS AT A FOR .1875in thick plate X 2.5in

$A = .1875\text{in}(2.5\text{in}) = .469 \text{ in}^2$

$I = \frac{1}{12} b h^3 = \frac{1}{12}(2.5\text{in})(.1875)^3 = .00137 \text{ in}^4$

SOLN:

$$\sigma_{Total} = \frac{Mc}{I} + \frac{F}{A}$$

$$= \frac{1455 \text{ lb·in}(.094\text{in})}{.00137\text{in}^4} + \frac{72\text{lb}}{.469\text{in}^2}$$

$$= 100 \text{ ksi}$$

$\sigma_{max} = 161 \text{ ksi}$

$SF = 1.6$

HANDLE FAILS BEFORE TOOL.

Appendix A-4: AISI 4140 Steel Data

AISI 4140 Steel, oil quenched, 13 mm (0.5 in.) round [845°C (1550°F) quench, 540°C (1000°F) temper]

Categories: Metal; Ferrous Metal; Alloy Steel; AISI 4000 Series Steel; Low Alloy Steel; Carbon Steel; Medium Carbon Steel

Material Notes: As quenched hardness after oil quenching: Surface - 57 HRC, 1/2 radius - 56 HRC; Center - 55 HRC

Key Words: AFNOR 40 CD 4, AFNOR 42 CD 4 (France), ASTM A322, ASTM A331, ASTM A505, ASTM A519, ASTM A646, B.S. 708 A 42 (UK), B.S. 708 M 40 (UK), B.S. 709 M 40 (UK), JIS SCM 4 H, JIS SCM 4, JIS SCM440, SS14 2244 (Sweden), MIL SPEC MIL-S-16974, SAE J404, SAE J412, SAE J770, DIN 1.7225, UNS G41400, AMS 6381, AMS 6382, AMS 6390, AMS 6395, IS 1570 40Cr1Mo28, IS 4367 40Cr1Mo28, IS 5517 40Cr1Mo28

Vendors: No vendors are listed for this material. Please click here if you are a supplier and would like information on how to add your listing to this material.

Physical Properties	Metric	English	Comments
Density	7.85 g/cc	0.284 lb/in³	

Mechanical Properties	Metric	English	Comments
Hardness, Brinell	341	341	
Hardness, Knoop	369	369	Converted from Brinell hardness.
Hardness, Rockwell B	99	99	Converted from Brinell hardness.
Hardness, Rockwell C	37	37	Converted from Brinell hardness.
Hardness, Vickers	361	361	Converted from Brinell hardness.
Tensile Strength, Ultimate	1185 MPa	171900 psi	
Tensile Strength, Yield	1110 MPa	161000 psi	
Elongation at Break	15.4 %	15.4 %	in 50 mm
Reduction of Area	55.7 %	55.7 %	
Modulus of Elasticity	205 GPa	29700 ksi	Typical for steel
Bulk Modulus	160 GPa	23200 ksi	Typical for steel
Poissons Ratio	0.29	0.29	Calculated
Machinability	65.0 %	65.0 %	Based on AISI 1212 as 100% machinability.
Shear Modulus	80.0 GPa	11600 ksi	Typical for steel

Electrical Properties	Metric	English	Comments
Electrical Resistivity	0.0000220 ohm-cm @Temperature 20.0 °C	0.0000220 ohm-cm @Temperature 68.0 °F	specimen hardened and tempered
	0.0000263 ohm-cm @Temperature 100 °C	0.0000263 ohm-cm @Temperature 212 °F	specimen hardened and tempered
	0.0000326 ohm-cm @Temperature 200 °C	0.0000326 ohm-cm @Temperature 392 °F	specimen hardened and tempered
	0.0000475 ohm-cm @Temperature 400 °C	0.0000475 ohm-cm @Temperature 752 °F	specimen hardened and tempered
	0.0000646 ohm-cm @Temperature 600 °C	0.0000646 ohm-cm @Temperature 1110 °F	specimen hardened and tempered

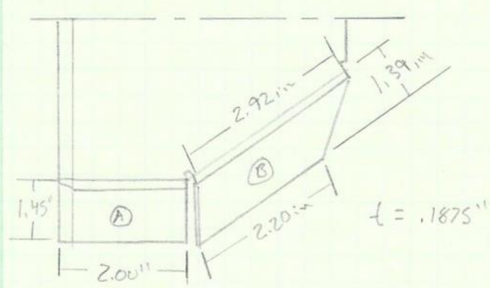
Thermal Properties	Metric	English	Comments
CTE, linear	12.2 µm/m-°C @Temperature 0.000 - 100 °C	6.78 µin/in-°F @Temperature 32.0 - 212 °F	
	13.7 µm/m-°C @Temperature 20.0 - 400 °C	7.61 µin/in-°F @Temperature 68.0 - 752 °F	
	14.6 µm/m-°C @Temperature 20.0 - 600 °C	8.11 µin/in-°F @Temperature 68.0 - 1110 °F	
Specific Heat Capacity	0.473 J/g-°C @Temperature 150 - 200 °C	0.113 BTU/lb-°F @Temperature 302 - 392 °F	
	0.519 J/g-°C @Temperature 350 - 400 °C	0.124 BTU/lb-°F @Temperature 662 - 752 °F	
	0.561 J/g-°C @Temperature 550 - 600 °C	0.134 BTU/lb-°F @Temperature 1020 - 1110 °F	
Thermal Conductivity	33.0 W/m-K @Temperature 600 °C	229 BTU-in/hr-ft²-°F @Temperature 1110 °F	
	37.7 W/m-K @Temperature 400 °C	262 BTU-in/hr-ft²-°F @Temperature 752 °F	
	42.2 W/m-K @Temperature 200 °C	293 BTU-in/hr-ft²-°F @Temperature 392 °F	
	42.6 W/m-K @Temperature 100 °C	296 BTU-in/hr-ft²-°F @Temperature 212 °F	

Component Elements Properties	Metric	English	Comments
Carbon, C	0.38 - 0.43 %	0.38 - 0.43 %	
Chromium, Cr	0.80 - 1.1 %	0.80 - 1.1 %	

Appendix A-5: Moment Required to Form Flange

BRUCE BERNARD | MET 495 A | 11-15-15 | 1/

SCRAPER FLANGE



$t = .1875''$

GIVEN: FLAT DIMENSIONS
$S_y = 97.9$ ksi
4140 Normalized

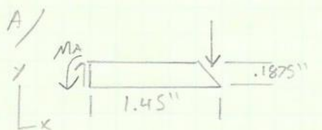
FIND: THE MOMENT REQUIRED TO FORM SCRAPER

SOLN:

$$\sigma_{max} = \frac{Mc}{I}$$

$$I = \frac{1}{12} b h^3$$

A/

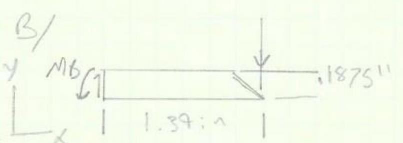


$$I_A = \frac{1}{12}(2.00'')(.1875'')^3 = .001099\ in^4$$

$$97.9\ ksi = \frac{M\,(.09375)}{.001099\ in^4}$$

$$\boxed{M_A = 1148\ lb \cdot in}$$

B/



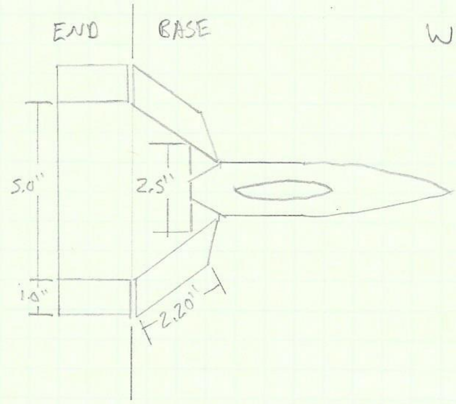
$$I_B = \frac{1}{12}(2.92\ in)(.1875\ in)^3 = .001604\ in^4$$

$$97.9\ ksi = \frac{M\,(.09375)}{.001604\ in^4}$$

$$\boxed{M_B = 1675\ lb \cdot in}$$

Appendix A-6: Calculated Scraper Volume from Design

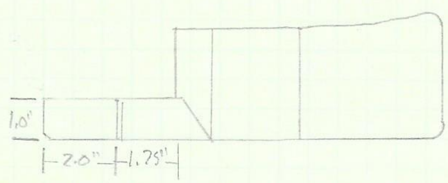
BRUCE BERNARD | MET 495A | 11/20/15

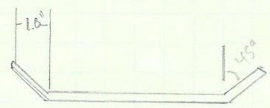


WILL THE DESIGN SCOOP THE REQUIRED 15 in³ ?

GIVEN: DIMESIONS SHOWN

FIND: ACTUAL SCRAPER SCOOP VOLUME.





SOLN:

END VOLUME $V = b \times h \times W$

$V = 5.0"(2.0")(1.0") + (1.0")(1.0")(2.0") = 12 \text{ in}^3$

BASE VOLUME Area of Trapezoid $A = \frac{1}{2} h(a+b)$

$V = \frac{1}{2}(1.75")(2.5" + 5.0")(1.0") + (1.0")(1.0")(2.2")$

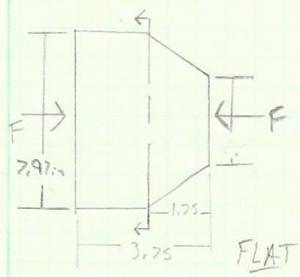
$= 8.76 \text{ in}^3$

$V_{TOTAL} = 12 \text{ in}^3 + 8.76 \text{ in}^3$

$= 20.76 \text{ in}^3$

Appendix A-7.1: Calculated Deformation

BRUCE BERNARD | MET 495A | 11-28-15 | 1/2



IF THE TOOL HAS HARD IMPACT WHAT IS THE DEFORMATION?

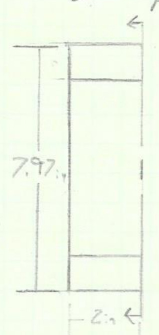
GIVEN: $F = 27\,lb$ Dimensions Shown

$E = 29.7\,msi$ $\quad t = .188\,in$

FIND: DEFORMATION OF SCRAPER

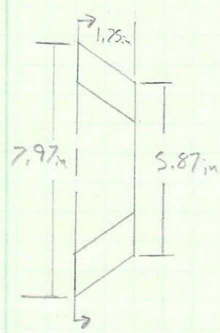
SOLN:

$$\delta = \frac{PL}{AE} \qquad \delta = \int_0^L \frac{P(x)\,dx}{A(x)\,E(x)}$$



$$\delta = \frac{27\,lb\,(2\,in)}{1.5\,in^2\,(29{,}700\,ksi)} = 1.21\times10^{-3}\,in$$

$$A = 7.97\,in\,(.188\,in) = 1.5\,in^2$$



$$\delta = \int_0^L \frac{27\,lb}{A(x)\,(29{,}700\,ksi)}\,dx$$

$$A(x) = -0.226x + 1.5\,in$$

$$\delta = \int_0^{1.75} \frac{27\,lb}{(-.226x + 1.5)(29{,}700\,ksi)}\,dx$$

USE TI-36X pro

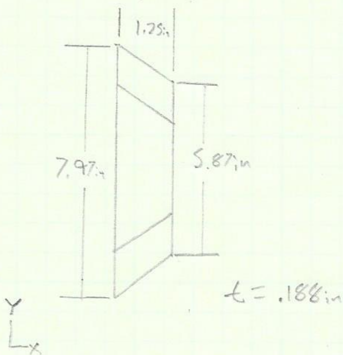
$$\delta = 1.23\times10^{-3}\,in$$

$$\delta = \Sigma\delta = 1.21\times10^{-3}\,in + 1.23\times10^{-3}\,in$$

$$\boxed{\delta = 0.0024\,in}$$

Appendix A-7.2: Calculated Scraper Area Function

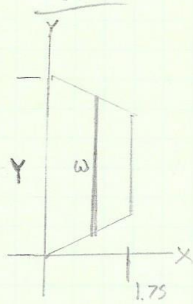
BRUCE BERNARD | MET 495A | 11-28-15 | 2/2



GIVEN: Dimensions Shown

FIND: Function of Cross-sectional Area $A_{(x)}$

SOLN



$w = mx + dy$ known

@ $x=0$ $w(0) = m(0) + Y$ $Y = 7.97in$

@ $x=1.75$ $w(1.75) = m(1.75in) + 7.97in = 5.87in$

$m = -1.2in$

$Area = w(t)$

$A_{(x)} = (-1.2in\,x + 7.97in)(.188in)$

$$\boxed{A_{(x)} = -0.226x + 1.5in}$$

Appendix A-8.1: Actual Endurance Strength

BRUCE BERNARD | MET 495 | 12-3-15 | 1/

GIVEN: AISI 4140 OQT
Cross Section 5.87 in X .188 in
Reliability 99%
Machined
Variable loading.

FIND: Actual Endurance Strength.

SOLN: $S_u = 172$ ksi Mat Web

$S'_n = S_n (C_m)(C_{st})(C_r)(C_s)$ USE MOTT TEXT

$S_n = 58{,}000$ psi Fig 5-8 pg 172

$C_m = 1.00$ pg 171

$C_{st} = 0.80$ pg 171

$C_r = 0.81$ pg 173

$C_s = (D/.3)^{-.11} = .89$ pg 174

$D_e = 0.808\sqrt{hb}$

$= .849$ in

$S'_n = 58{,}000(1.0)(.80)(.81)(.89)$

$= 33{,}450$ psi

Appendix A-8.2: Cumulative Damage

BRUCE BERNARD | MET 495 | 12-3-15 | 1/

Endurance Strength Analysis.

GIVEN: AISI 4140 OQT
Variable loading

$S_n' = 33.5$ ksi $S_u = 171$ ksi
$S_n = 58$ ksi

FIND: Cumulative damage experienced by tool.

SOLN: USE MOTT Damage Accumulation Method

$D_i = \frac{n_i}{N_i}$

Ratio of actual to standard
33.5ksi / 58ksi = .58

STRESS LEVEL KSI	# of n_i Cycles	LIFE N_i CYCLES	n_i/N_i
100	50	150	0.333
80	500	3×10^3	0.167
60	1,000	2.5×10^5	0.004
40	3,000	∞	0
20	5,000	∞	0
		TOTAL	0.504

USE Figure 5-7 @ 58%

50% of life with given loading.

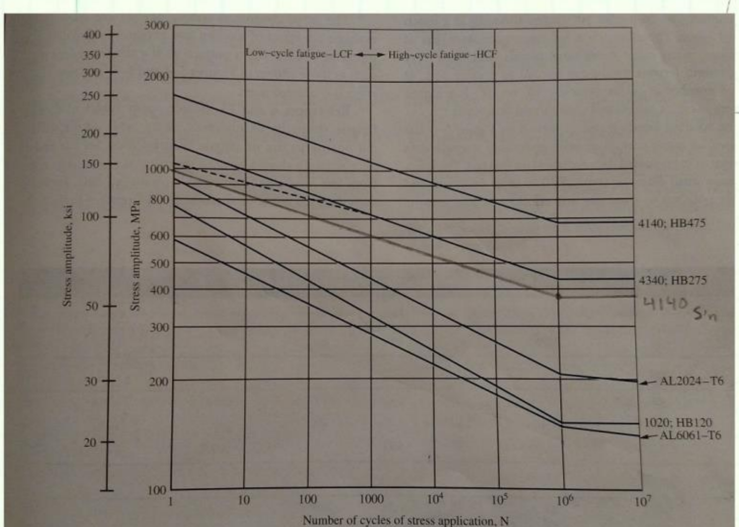
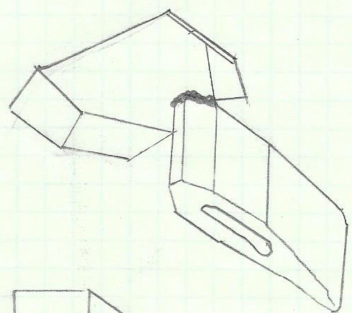


FIGURE 5–7 Representative endurance strengths

Appendix A-9: Weld Leg Length

BRUCE BERNARD | A.9 MET 495 | 12-30-15 | 1/1



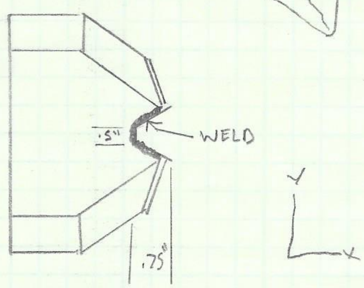
GIVEN: Scraping and Axe tool w/ Dimensions.

Electrode E70

Plate Thickness 3/16"

M @ weld = 1455 lb·in

FIND: The required weld leg size.



SOLN:

Allowable for E70 11,200 lb/in (Table 20-3)

loading

Bending $f = M/S_w$ (20-6)

Top: $S_w = \frac{2bd + d^2}{3}$ (Fig 20-8)

$b = .5\,in$

$d = .75\,in$

$S_{wT} = \frac{2(.5)(.75) + .75^2}{3}$

$S_{wT} = 0.4375\,in^2$

Bottom: $= \frac{d^2(2b+d)}{3(b+d)}$

$S_{wB} = \frac{.75^2(2(.5) + .75)}{3(.5 + .75)}$

$= 0.2625\,in^2$

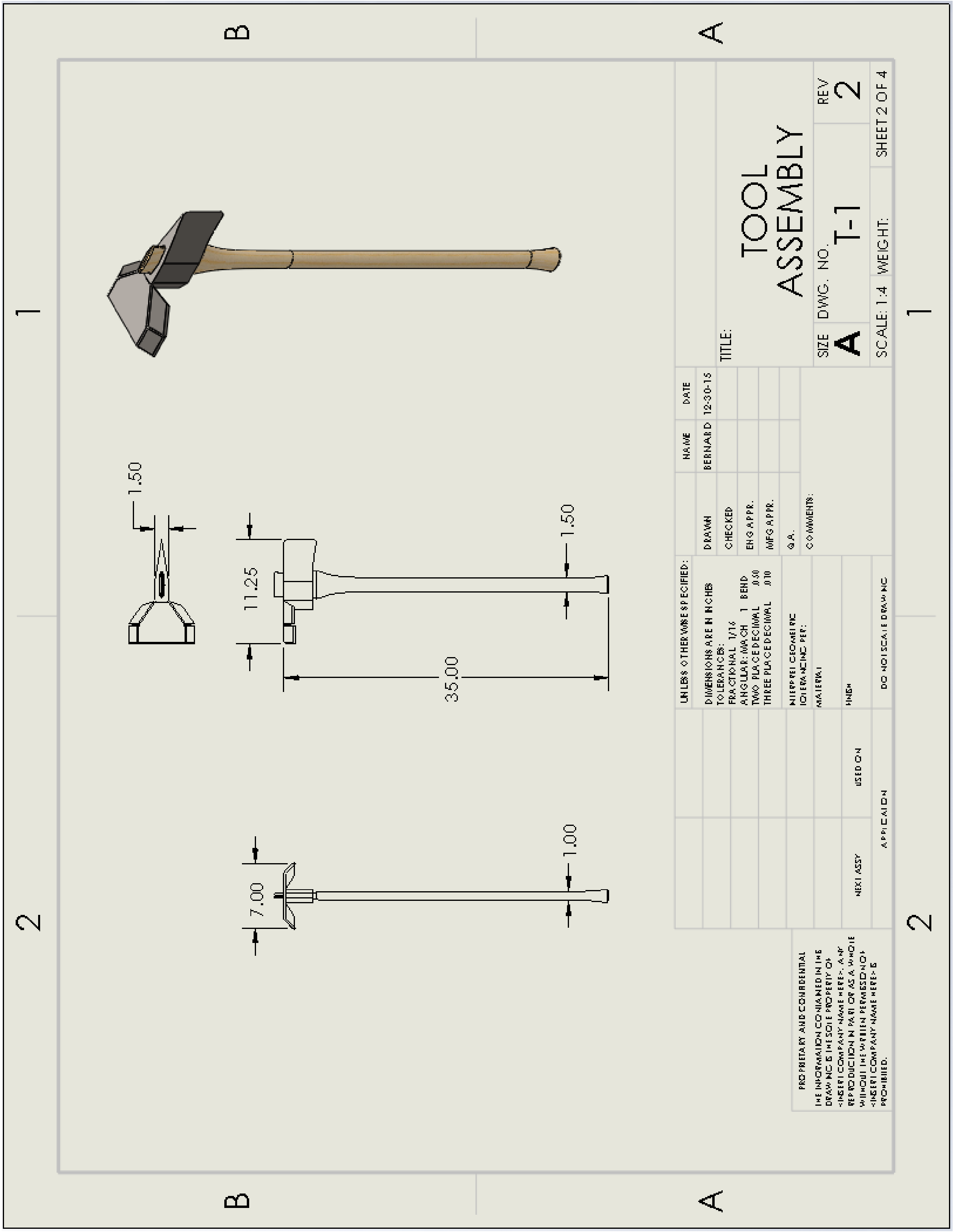
$f_b = \frac{1455\,in \cdot lb}{0.2625\,in^2} = 5543\,lb/in$

$f_b = \frac{1455\,in \cdot lb}{0.4375\,in^2} = 3326\,lb/in$

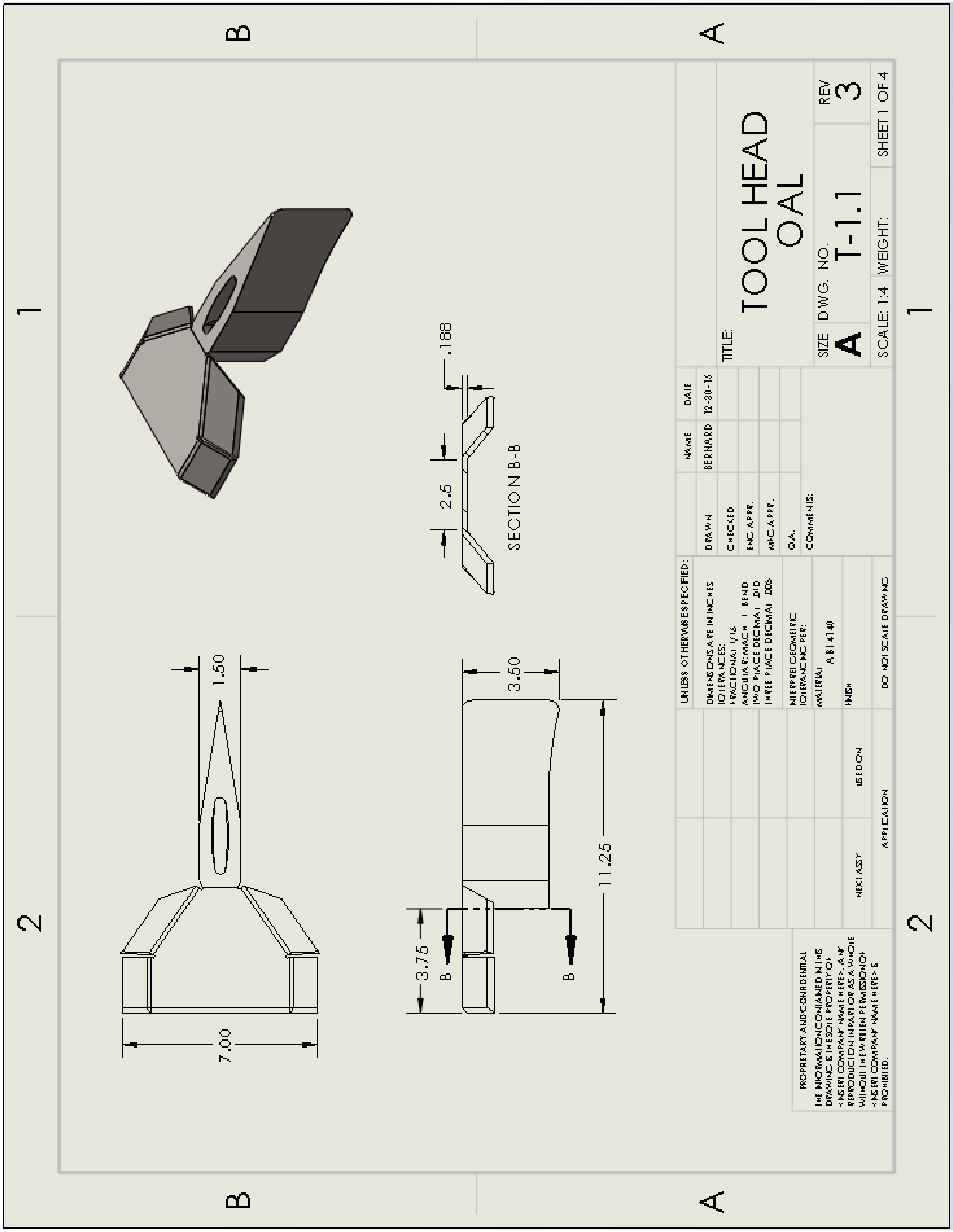
$w = \frac{5543\,lb/in}{11{,}200\,lb/in \text{ per in of leg}} =$ **0.495 in Weld LEG**

APPENDIX B - Drawings

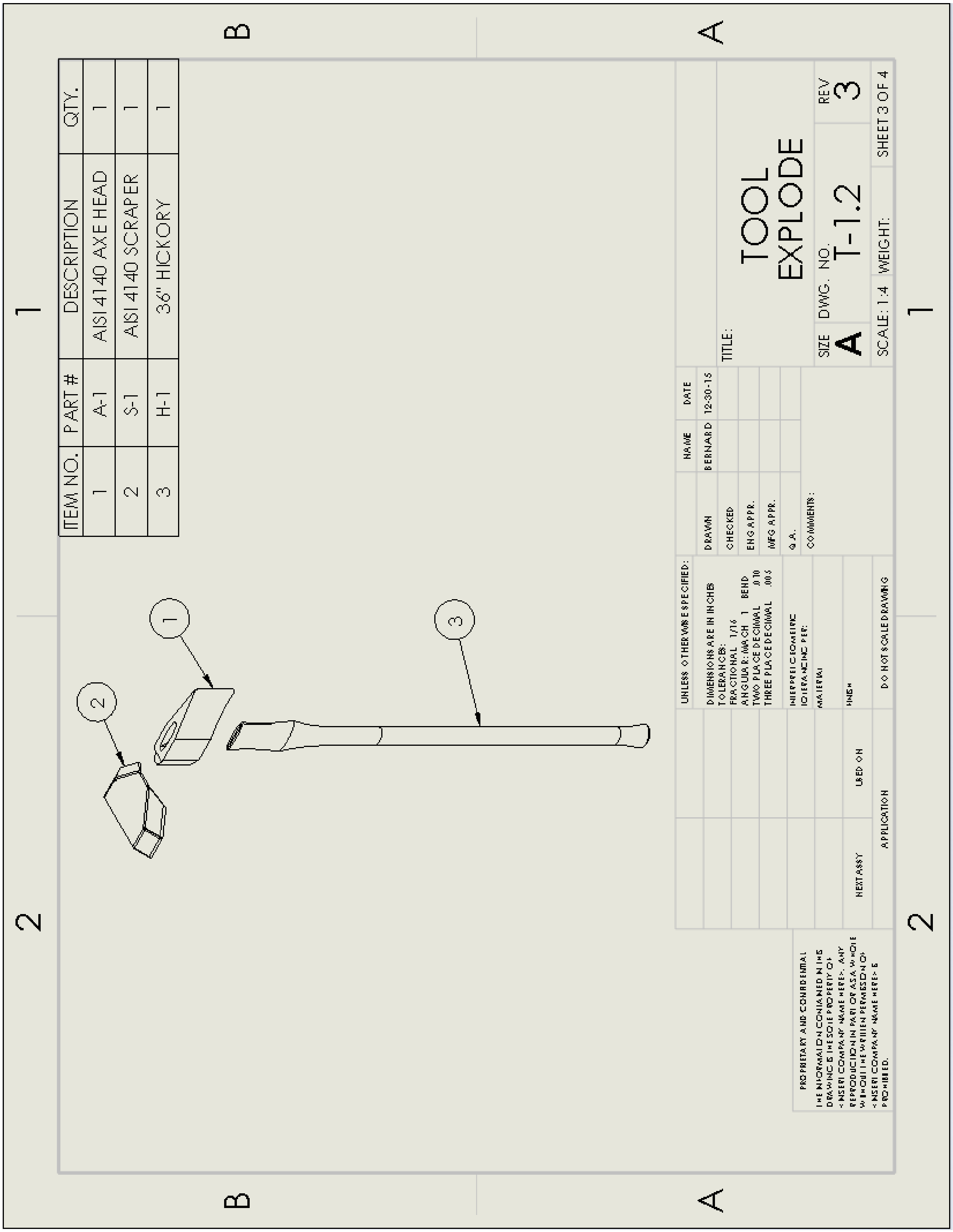
Appendix B-1: Complete Assembly (T1)



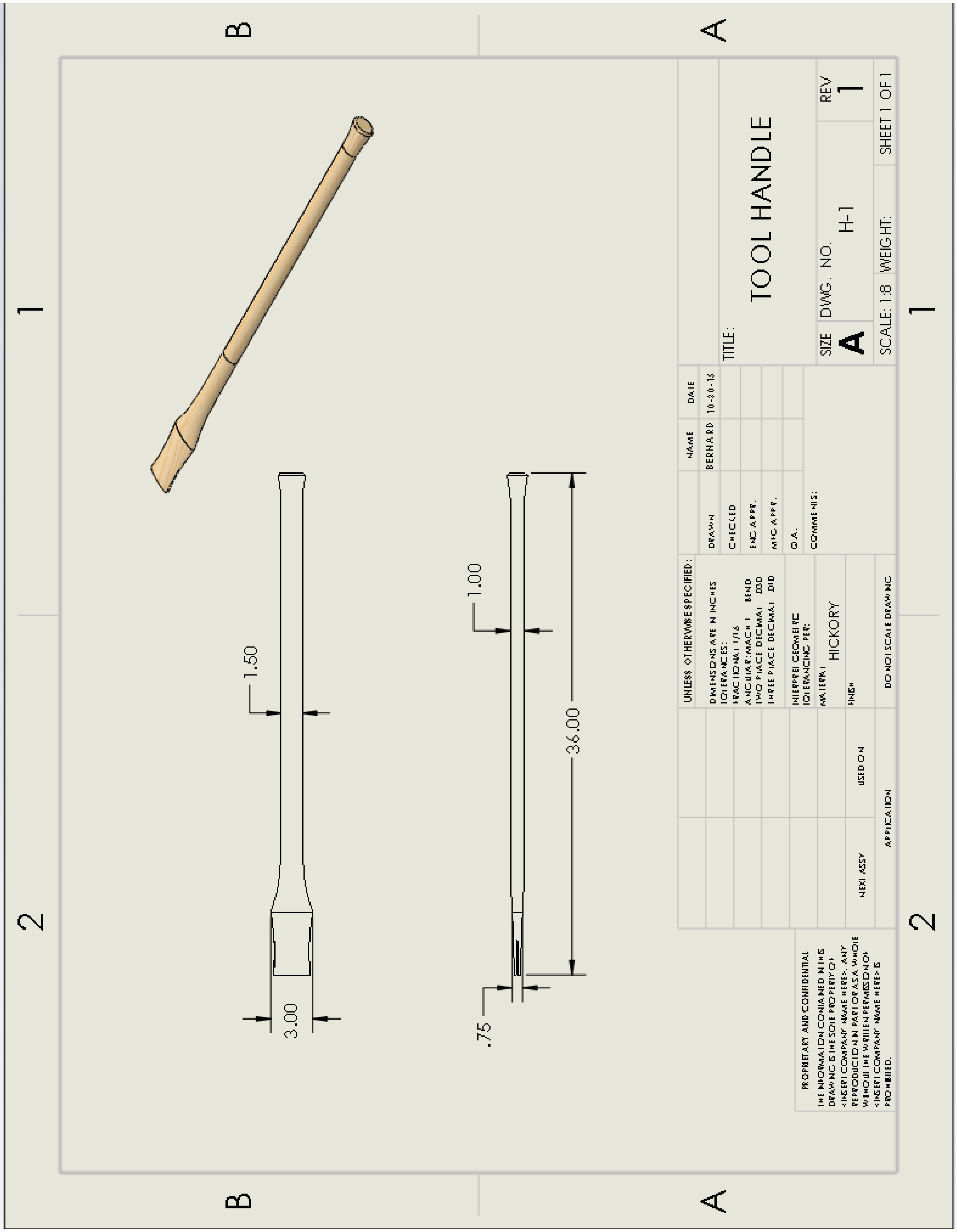
Appendix B-2: Assembly (T1.1)



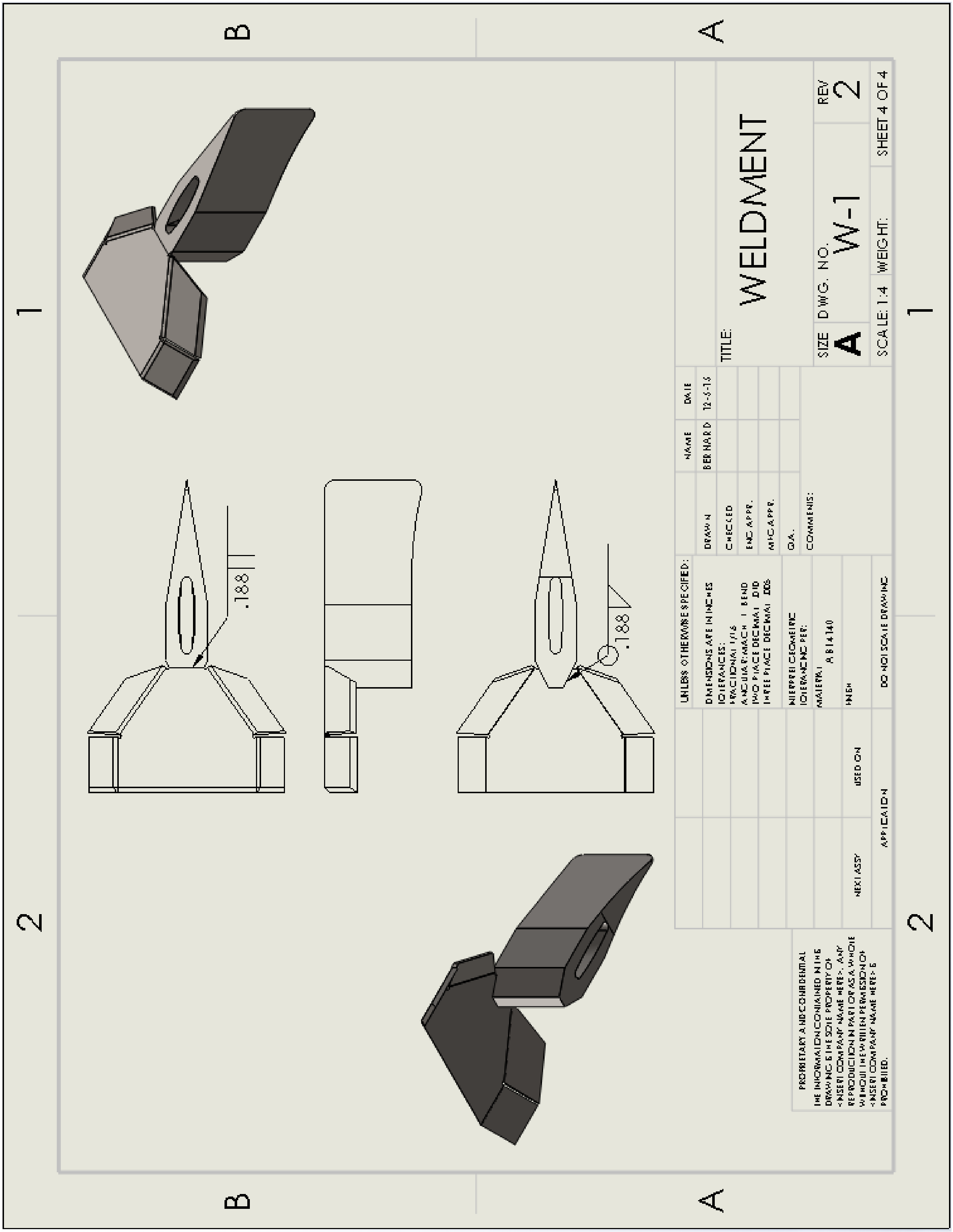
Appendix B-3: Exploded Assembly (T1.2)



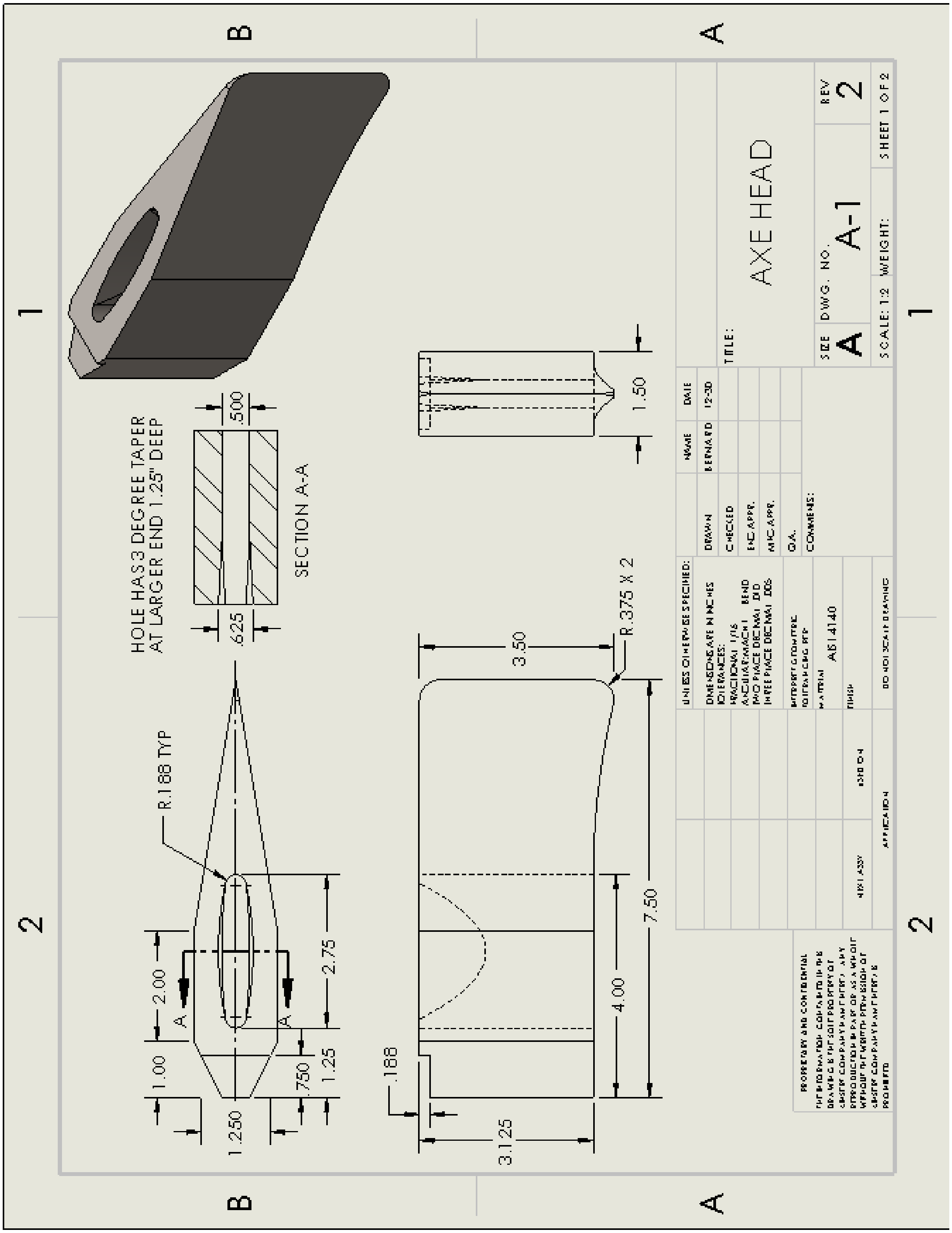
Appendix B-4: Tool Handle (H1)



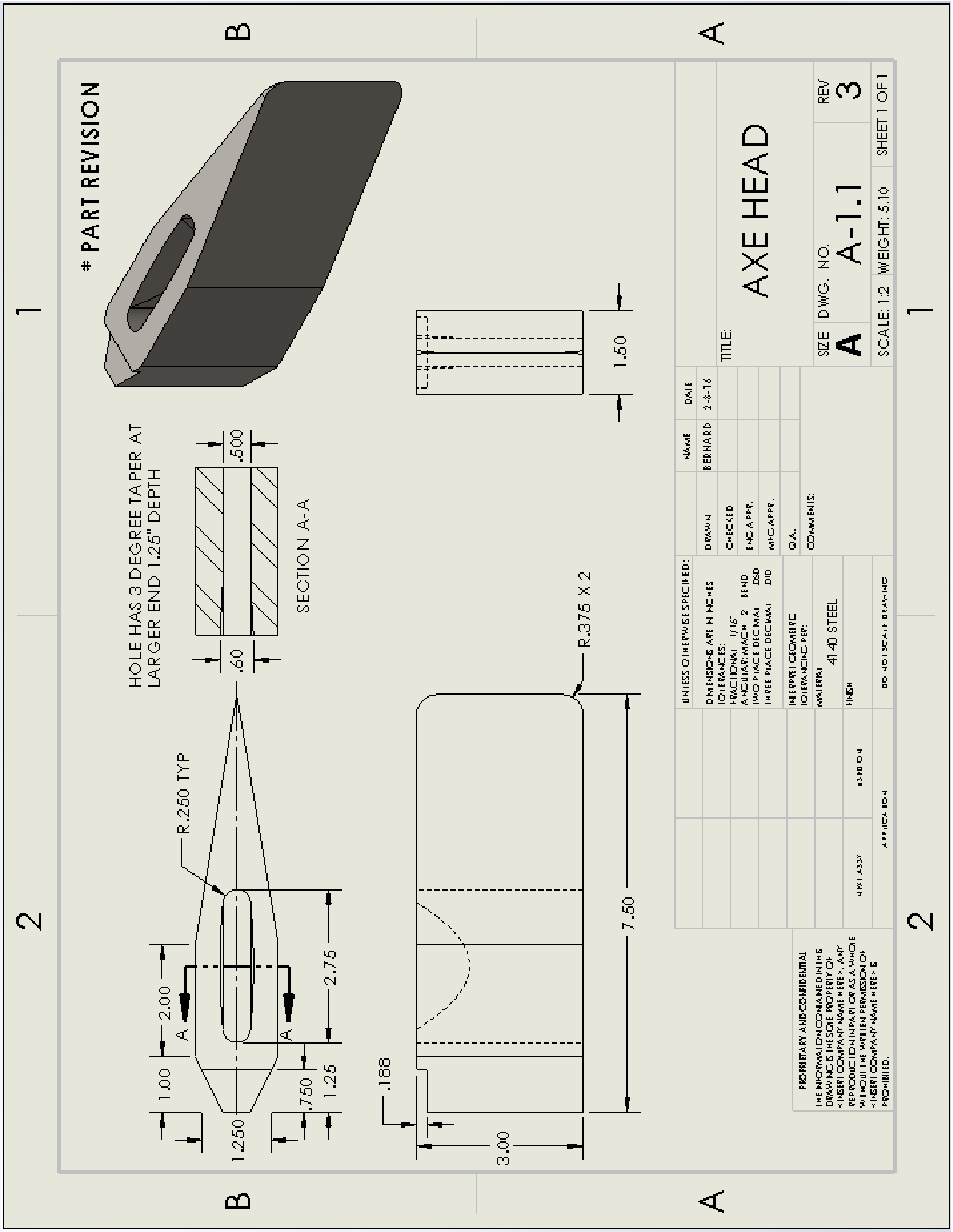
Appendix B-5: Weldment (W1)



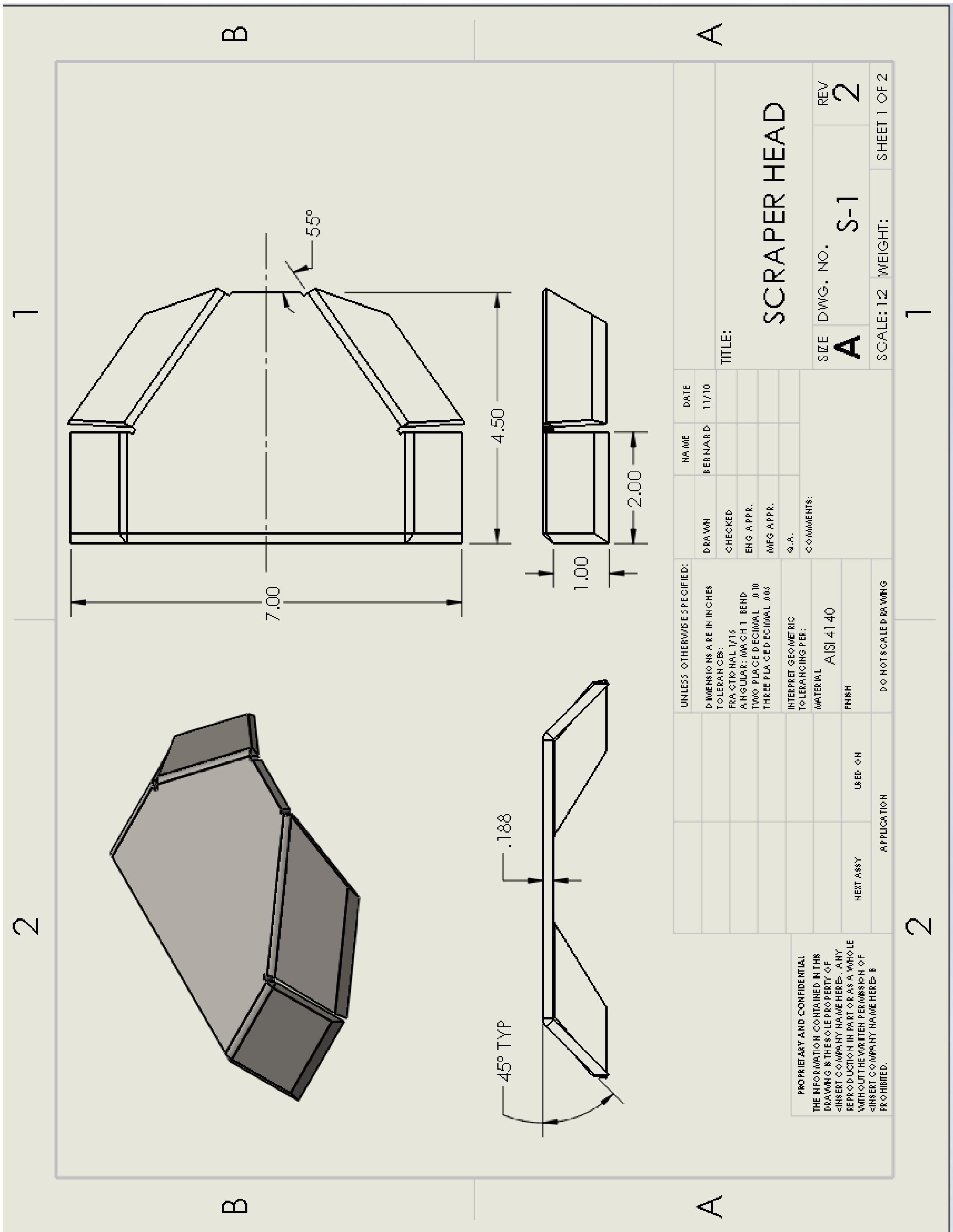
Appendix B-6: Axe Head (A1)



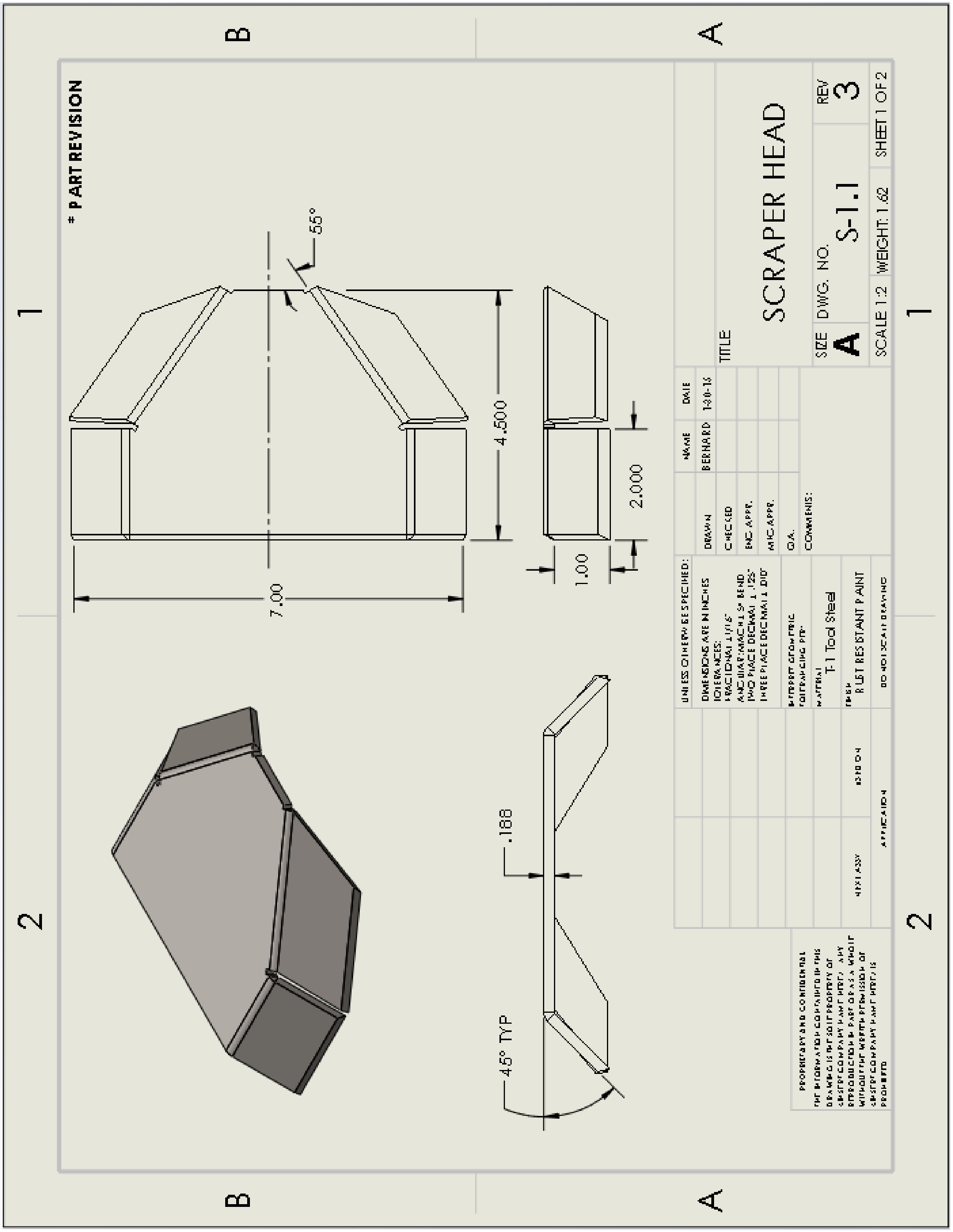
Appendix B-7: Axe Head (A1.1)



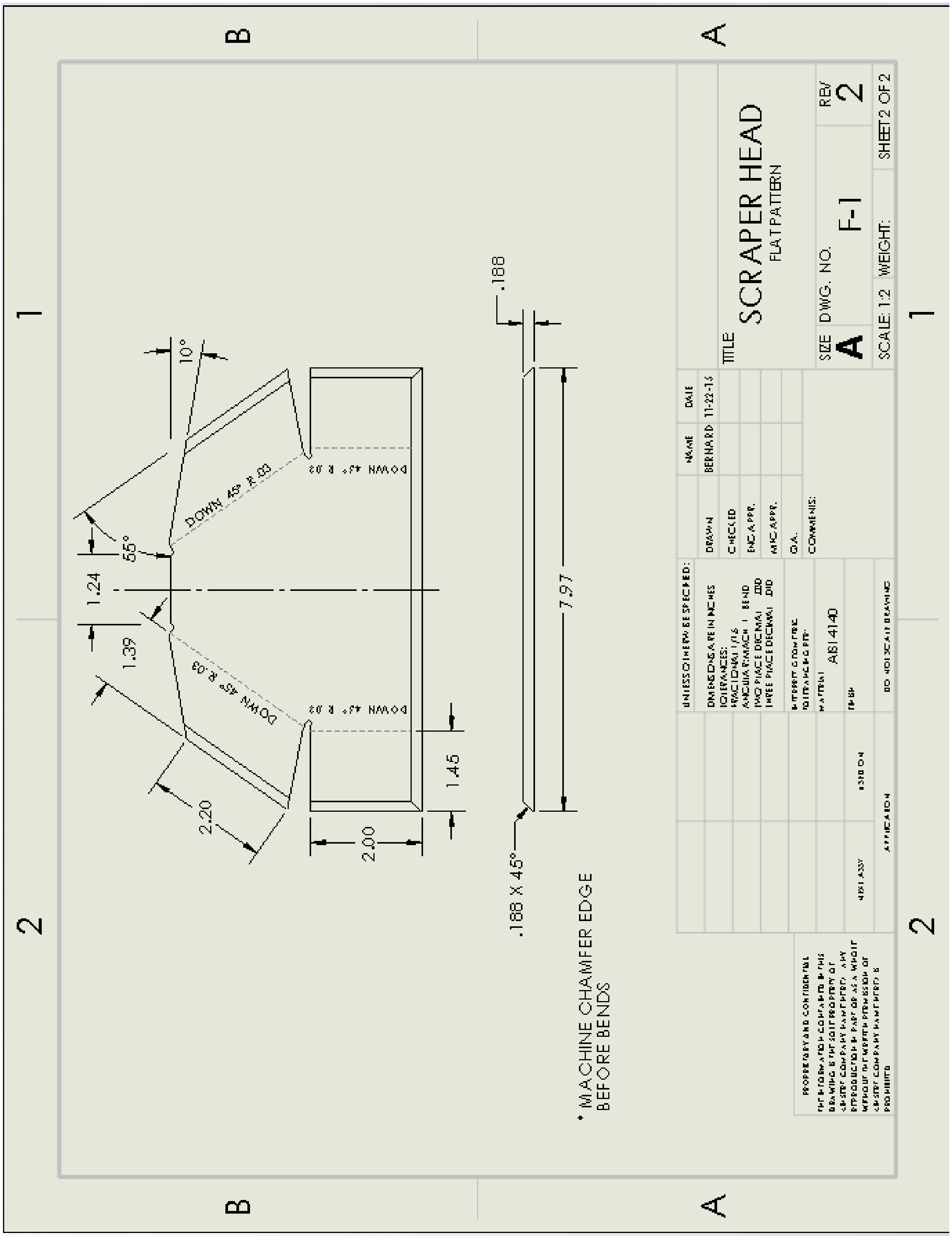
Appendix B-8: Scraper Head (S1)



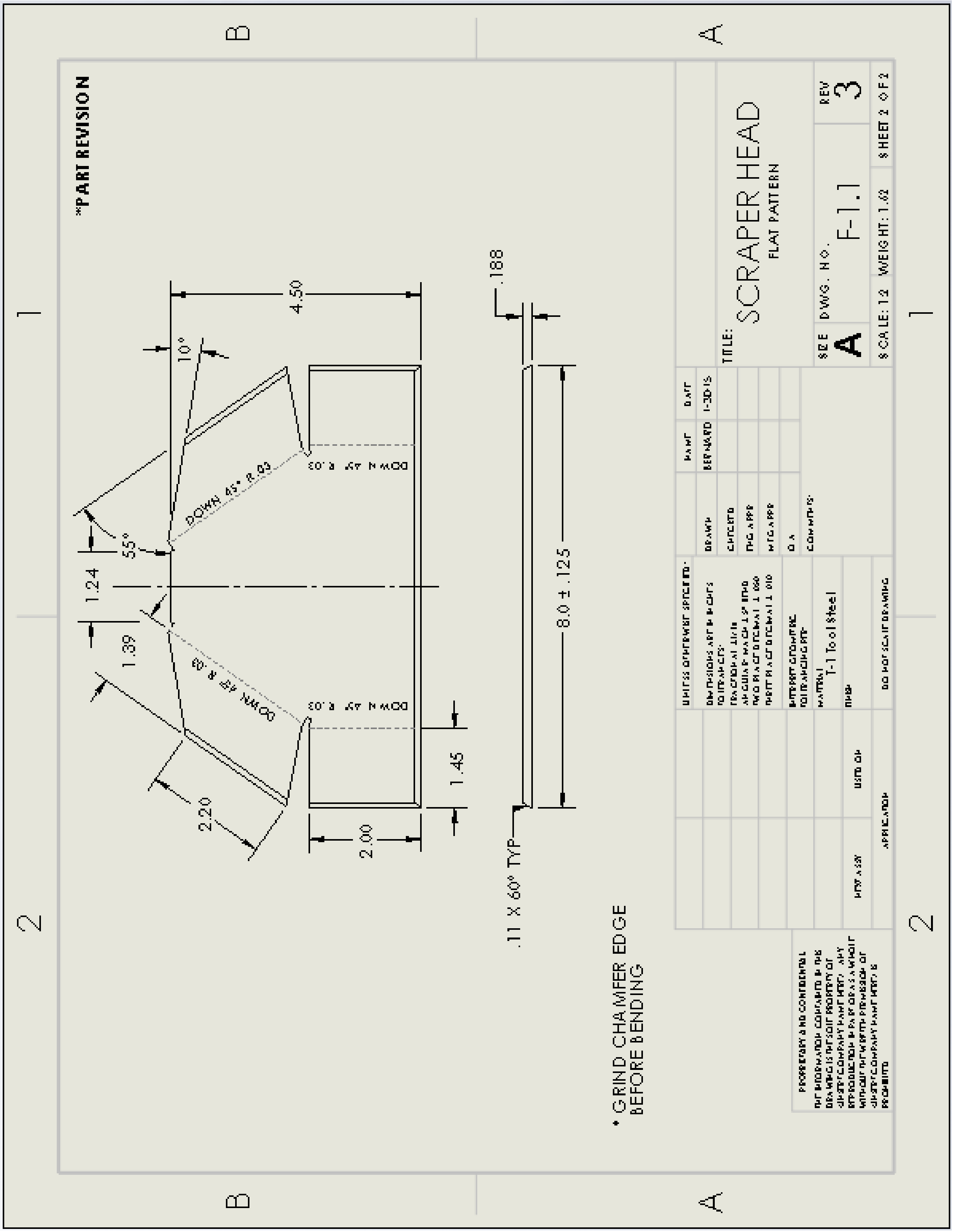
Appendix B-9: Scraper Head (S1.1)



Appendix B-10: Scraper Flat Pattern (F1)



Appendix B-11: Scraper Flat Pattern (F1.1)



APPENDIX C – Parts List

Part Name	Part Description	Source
Tool Handle	36”Hickory Double Bit Handle	Bi-Mart
Axe Head 4140 Steel	Stock for A1 1.5” x 4” x 8”	Speedy Metals
Scarper Head T-1 Steel	3/16” Plate stock for S1 6” X 12”	Haskins Steel

APPENDIX D – Budget

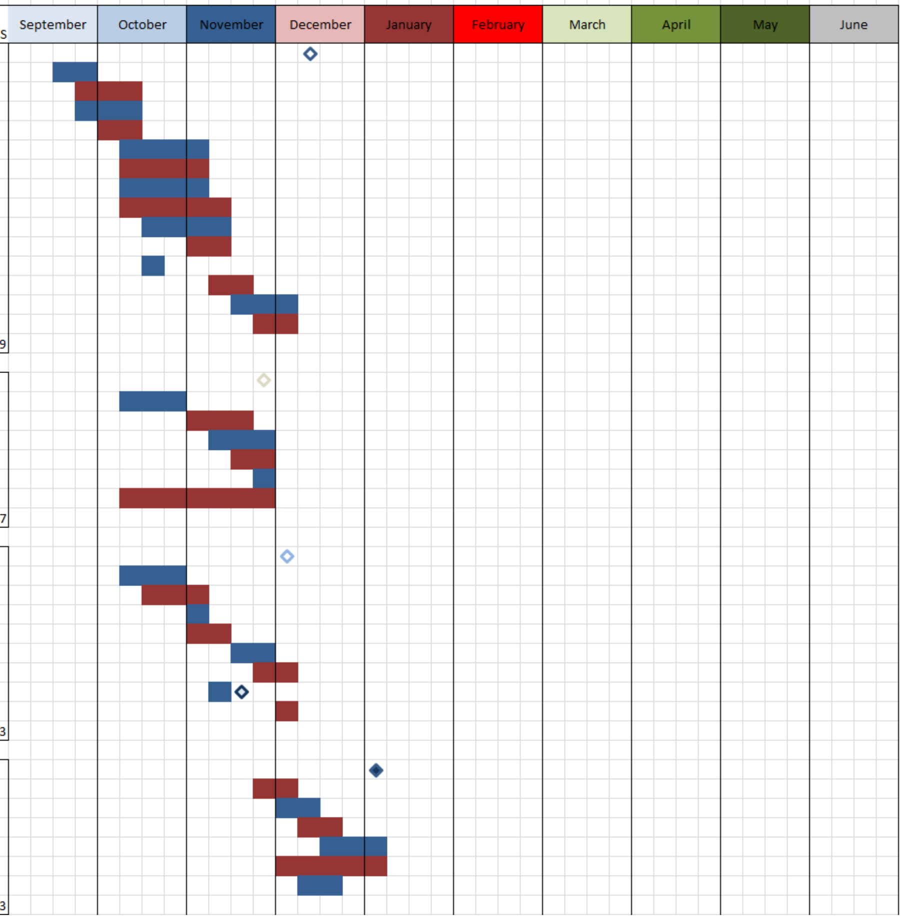
Item Name	Part Description	Source	Est. Cost	Act. Cost	Disposition
Tool Handle	36”Hickory Double Bit Handle	Bi-Mart	$20.00	$9.95	Purchased
4140 Steel	Stock for A1 2” x 4” x 8”	Speedy Metals	$75.00	$109.72	Received
T -1 Steel	Plate stock for S1 3/16” Plate 6” X 12”	Haskins Steel	$60.00	$10.83	Received
Machining Tools	1” 4-Flute 2” Cut End Mill	CWU Shop	$0.00	$0.00	Provided
Special Tools	3/8” 3-Flute Carbide 1.5” Cut End Mill	CWU Shop	$0.00	$0.00	Provided
Special Tools	3° Tapered End Mill	McMaster-Carr	$30.00	$22.62	Received
Special Tools	3/8” 2.5” Cut End Mill	McMaster-Carr	$30.00	$25.92	Received
Welding Materials	TIG Welder	CWU Shop	$0.00	$0.00	Provided
Labor	Machining, Welding	$15/hr	$60.00	$0.00	Provided
Heat Treating	Heat Treating	PACMET	$50.00	$0.00	Provided
Paint	Rust-Oleum Paint & Primmer	Bi-Mart	$15.00	$8.99	Purchased
Sand Paper	150 Grain Sand Paper	Bi-Mart	$10.00	$2.95	Purchased
					LIMIT
		Total Cost:	$350.00	$190.98	$500.00

APPENDIX E – Schedule

Appendix E-1: Schedule Gantt Chart

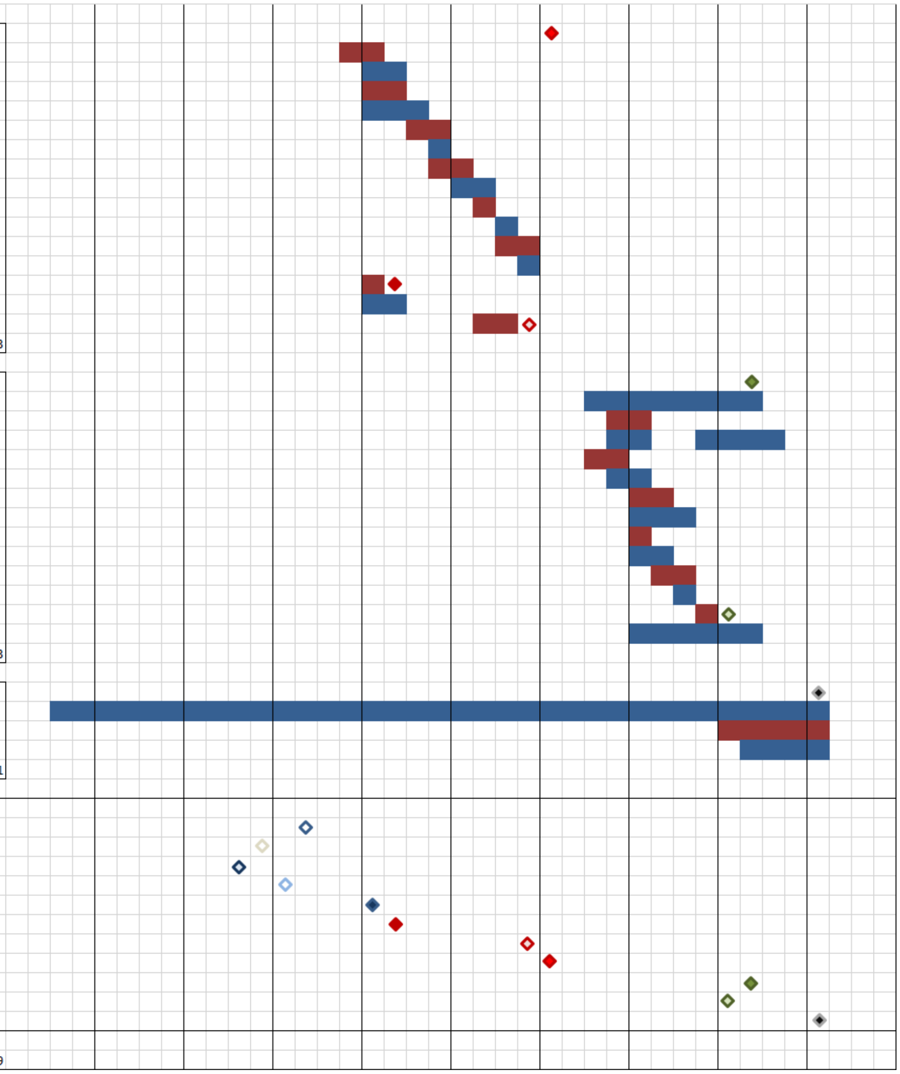
Senior Project Gantt Chart
PROJECT: Multi-use Fire Line Handtool
DESIGNER: Bruce Bernard

TASK ID:	DESCRIPTION	EST. HOURS	ACT. HOURS
1	**Proposal**		
a.	Outline	2	2
b.	Function Statement	1	2
c.	Design Requirements	2	3
d.	Intro	4	3
e.	Design	5	5
f.	Analysis	20	15
g.	Methods	5	3
h.	Drawings	10	10
i.	Testing	3	3
j.	Budget	2	2
k.	Parts List	1	1
l.	Schedule	3	4
m.	Discussion	3	3
n.	Conclusion	2	3
	Subtotal:	63	59
2	**Analysis**		
a.	Forces	2	3
b.	Stresses	3	5
c.	Material	2	2
d.	Dimensions	2	5
e.	Tolerance	2	2
f.	SolidWorks	10	10
	Subtotal:	21	27
3	**Documentation**		
a.	Axe Head	3	4
b.	Scraper Head	3	4
c.	Handle	1	1
d.	Assembly	2	3
e.	ANSI 14.5 Standards	2	2
f.	Presentation	2	1
g.	CDR	2	3
h.	Website	3	5
	Subtotal:	18	23
4	**Proposal Updates**		
a.	Design	2	3
b.	Analysis	3	3
c.	Methods	2	3
d.	Schedule	2	2
e.	Drawings	10	10
f.	Testing	5	2
	Subtotal:	24	23



Appendix E-1.1: Schedule Gantt Chart Cont.

5	**Part Construction**		
a.	Axe HSMWorks	3	5
b.	Axe Process Plan	4	6
b.1	Axe Hole	3	5
b.2	Axe Outer	2	3
c.	Axe Machining	8	30
d.	Scraper Cut Pattern	1	1
e.	Scraper Process Plan	3	3
f.	Scraper Production	5	5
f.1	Bending Flanges	2	2
g.	Welding Parts	2	3
h.	Heat Treating	2	3
i.	Assemble Handle	2	3
j.	Material Order	2	2
k.	Required Tooling	3	2
l.	MDR	3	2
	Subtotal:	45	73
6	**Testing Evaluation**		
a.	Source	10	
a.1	Abstract	2	3
b.	Website	5	3
c.	Parameters	2	3
d.	Test Design	5	4
e.	Testing Equipment	2	3
f.	Testing Sheets	3	3
g.	Dimensions	3	3
h.	Static Loads	3	2
i.	Dynamic Loads	5	2
j.	Function	2	2
k.	TDR	3	3
l.	Testing Report	8	8
	Subtotal:	36	33
7	**Final Deliverables**		
a.	Project Report	20	9
b.	Presentation	10	
c.	Website	5	2
	Subtotal:	35	11
Note:	**Deliverables***		
	Draft Proposal		
	Analysis		
	CDR		
	Document Mods		
	Final Proposal		
	Parts Arrive		
	MDR		
	Part Construction		
	Testing Evaluation		
	TDR		
	Final Report		
	TOTAL HOURS:	242	249



APPENDIX F – Expertise and Resources

Expertise

- Professor Charles Pringle, PringleC@cwu.edu
- Mr. Ted Bramble, Bramble@cwu.edu
- Mr. Matt Burvee, BurveeM@cwu.edu
- Trevor Reher, ReherT@cwu.edu

Resources

- Central Washington University LAB Equipment
  - CNC Plasma Table
  - Belt Grinder
  - CNC Milltronics Mill
  - Bridgeport Manual Mill
  - Partner CNC Mill
- Pacific Metallurgical, Inc (PACMET)
  - Heat Treating Service

APPENDIX G – Evaluation sheet (Testing)

Appendix G-1: Requirement Dimensions Test Sheet

Test / Measurement	Required	Actual		Pass / Fail
Weight	< 8.0 lb			
OAL	< 12.0 in			
Width	< 10.0 in			
Height	< 8.0 in			
Total Volume	< 960.0 in^2			
Scraper Volume	> 10.0 in^3			
Scraper Surface Area	>15.0 in^2			
Axe Blade	3.0 – 4.0”			

Appendix G-2: Soil Removal Volume

Test	Volume (oz)	Calculated Volume (in^3)		Pass / Fail Min. (15 in^3)
1				
2				
3				
4				
5				
	Average:			

Appendix G-3: Hardness Testing Sheet

Test		Required	1/8"	1/2"	1"	Pass / Fail
1	Axe	50-60 HRC				
2	Ave:					
3						
1	Scraper	50-60 HRC				
2	Ave:					
3						
			Any Test on Center Line			Ave:
	Tool Center	40-60 HRC				

Appendix G-4.1: Static Load Testing Sheet

Load	Strain (με)	Calc. Stress (σ)	Deformation (Y/N)	Pred. Stress (σ)	Pass / Fail % Error
5 lb					
20 lb					
40 lb					
60 lb					

* $\varepsilon = (\mu e)(10^{-6})$ $E = 29.7\ (10^3)$ ksi $\sigma = E\varepsilon$

Appendix G-4.2: Practical Use Dynamic Testing Sheet

After striking a hardwood knot with 10 heavy blows.	Axe Head	Scraper Head	Required	Pass / Fail
Chipping (Y/N)			N	
Dulling (Y/N)			N	
Turn Over (Y/N)			N	
Handle Loose (Y/N)			N	

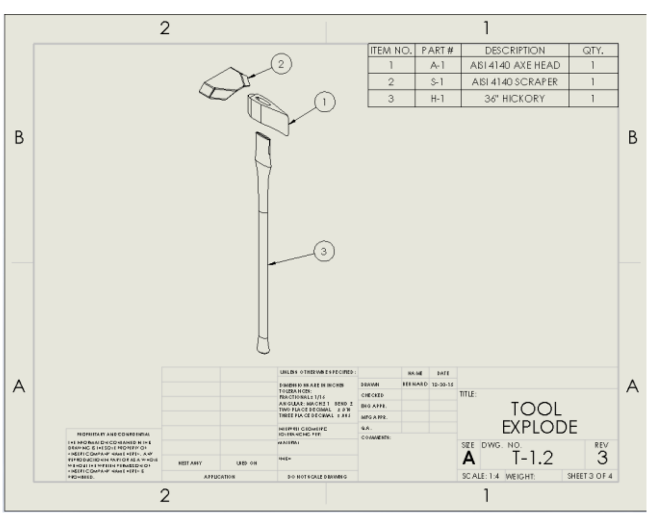
Appendix G-5: Field Line Construction Testing Sheet

Tool Used to Construct 5' of 18" Line	Time (s)		# of Swings		Rated Quality of Line (%)		Success Value	
Standard Pulaski								
Multi-Use Hand Tool								
Success Equation:								

$$SV = \left[\frac{Rating}{100}\right] / [Time + Swings]$$

APPENDIX H – Testing Report

Multi-Use Fireline Hand Tool Testing Report



Introduction: During the testing portion of this project, the constructed tool will be tested to ensure it meets all design requirements. In addition to requirements, the tool will perform typical field operations to better evaluate its success.

- Requirements:
  - The tool head must weigh less than 8.0 lbs.
  - The head must fit in space no larger than 10” x 8” x 12”.
  - The material hardness on the axe head must be 50-60 HRC up to 1” from edge.
  - The material hardness on the scraper head must be 50-60 HRC up to 1” from edge.
  - The material hardness on the tool center must be 40-60 HRC.
  - The scraping tool surface area must be at least 15 in^2.
  - The scraping tool should scoop 15 in^3 of soil.
  - Tool head must not permanently deform after experiencing 20 lbs. of impact force.
  - Scraping tool must not fail in bending or shear stress when 50 lbs. of force is applied in any direction.
  - The axe blade must be 3-4” long.
  - The final tool head must cost less than $500.00.
  - The tool life must exceed 5000 cycles of repeated impact and scraping.
- Parameters of Interest: The primary parameters to be tested in the interest of the tools success are the material’s hardness, the volume of soil removed by the scraper, and the tools condition after static and dynamic loading. The final success includes the tools performance in line construction when compared to the commonly used Pulaski.

- Predicted Performance: It is predicted that the tool head will have a material harness between 50-60 HRC, the scraper will remove at least 15 $in^3$of soil per scoop, and nether the axe or scraper will bend, chip, or fracture after static and dynamic loads.

- Data Acquisition: Hardness testing will be performed using available harness testers. The soil removal and line construction will be measured in the field and recorded as actual volume and strokes required to achieve task. For loading tests, loads will be documented along with observed results.

- Schedule: All testing will be completed by May 1. Refer to Schedule Gantt Chart (Appendix R-2).

Method/Approach:

- Resources: Main resources required to perform all testing includes materials lab hardness testing equipment, machine shop measuring tools, field environments for soil and digging tests, and hard wood knot for impact test.

- Data Documentation: Each form of testing with be recorded by the project designer and documented on individual testing sheets.

- Test Procedure Overview: The first group of testing is to verify the tools dimensions and weight meet the design requirements. In addition to the part dimensions, the volume of soil removed with the scraping tool will be recorded. The second testing is the material hardness of the tool head at given locations. This will ensure the tool is ready for tests under loads it was designed for. The third test group is to but the tool under static loads up to 50 lbs and dynamic loads to record any failures described in the testing sheet. The final test will be the tools success at fireline construction when compared to the standard Pulaski in given detailed parameters.

- Operational Limitations: Some limitations occur due to scheduling and shop/lab availability. This is mitigated by planning testing to their availability. Field testing requires demonstrations to be recorded by video and pictures.

- Precision and Accuracy: Precision of each test is given individually per test sheet. Most tests require 3-5 measurements to ensure accurate data average.

- Data Storage/Manipulation/Analysis: Data will be stored and calculations for each test will be document on each tests data form. Completed forms are located in the Report Appendix R-1.

- Data Presentation: Finalized data results are discussed and summarized in the final project report and the deliverable section of this testing report.

Test Procedure:

Dimensional Testing

- Date: April 7, 2016 Time: 0900
- Time Required: 60 min
- Location: Fluke Lab
- Required Equipment: Ruler, Caliper, Scale, Work Bench, and Data Form G-1.
- Procedure: Measure each value listed on Data Form. Determine if value meets design requirement.
- Risks/Safety: Wear safety glasses when in the machine shop.
- Discussion: Each measurement to be recorded reflects a design requirement. Volume or area measurements must be calculated.

Soil Removal Volume of Scraper

- Date: April 8, 2016 Time: 1200
- Time Required: 45 min
- Location: Home residence
- Required Equipment: Ample loose soil, Bucket, Measuring cup with units of ounces, and Data Form G-2.
- Follow these steps to perform adequate test results:
    - Step 1: Gather a bucket, a 20 oz measuring cup with 2 oz precision, and the device to be tested.
    - Step 2: While holding the tool in a normal scraping use position, scoop as much soil as possible onto the scraper tool.
    - Step 3: Vertically lift the tool smoothly with the back of the scraper oriented parallel to the ground.
    - Step 4: Allow any loose falling soil to fall.
    - Step 5: With the remaining soil stabilized, pour it into an empty bucket.
    - Step 6: Use a 20 oz measuring cup to record the amount of soil scooped to the nearest ounce.
    - Step 7: Repeat steps 2-6 four additional times.
    - Step 8: Use the conversion of [1.805 in^3/oz] to calculate the average volume of soil removed in [in^3].

- Risks/Safety: Ensure soil used is free of hazardous materials or objects.

- Discussion: The results of this test determine if the constructed tool meets the design requirement of the scraper tool scooping at least 15 in^3 of soil.

Hardness Testing

- Date: April 15, 2016 Time: 1300
- Time Required: 60 min
- Location: Materials Lab
- Required Equipment: Ruler, Hardness Tester, Calibration Block, and Data Form G-3.
- Procedure: Prepare the device's surface for hardness testing in the locations described on data form G-3. Record the hardness at each location described and repeat the test three times for each location.
- Risks/Safety: Wear safety glasses when in the lab. Ensure proper use of all equipment.
- Discussion: Of the recorded values, calculate the average hardness and determine if the tool meets the design requirement hardness.

Load Testing

- Date: April 20, 2016 Time:
- Time Required: 120 min
- Location: Materials/Machining Lab
- Required Equipment: Strain Gauge W/ recording equipment, C-clamp, 60 lbs in 20 lb increments, hard wood knot, and Data Form G-4.
- Procedure: For the static load test place a strain gauge at the base of the scraper near the weldment location. Secure the tool to a work table and connect gauge to recording equipment. Apply a C-clamp to the center edge of the scraper and record strain value for each load stated on data form G-4. For the dynamic test, set up a hard wood knot surface. Strike the wood with each end of the tool 10 times each. Ensure heavy blows and record any failures on data form G-4.
- Risks/Safety: Wear safety glasses when in the lab and when using the tool. Be aware in the event of tool failure. Stand clear of hanging weight.
- Discussion: Use the recorded strain values to calculate the stress for each load. Compare results to predicted values. Observe each tool end thoroughly to ensure no failures are found after dynamic testing.

Field Testing

- Date: April 22, 2016 Time: 1600
- Time Required: 120 min
- Location: Approved land with typical fuel and soil characteristics.

- Required Equipment: Testing Partner, Stop Watch, Counter, Pulaski, 2 marked 5ft sections of land with near identical soil conditions, and Data Form G-5.
- Procedure: Construct 5 ft of 18" fireline down to mineral soil using first the Pulaski, then the device being tested. For each run, use the same pace and record the time to complete and the swings required. Repeat test in second fuel type.
- Risks/Safety: Wear safety glasses when using the tool. Be aware in the event of tool failure. Wear PPE, i.e. gloves, long pants, and boots.
- Discussion: Record data from both runs on data form G-5. Calculate success using criteria equation and compare.

Deliverables:

- Parameter values: The axe had an average hardness of 59 HRC within tolerance while the scraper was 38 HRC. This lower hardness is not within the set tolerance, but the Pulaski's average is 35 HRC so the 38 HRC will suffice. The volume of soil removed by the scraper was averaged at 57 in^3, this is near 4x the minimum requirement. After static and dynamic loads the tool showed no indications of failure. All recorded valves are found in Appendix R-1.

- Calculated values: The most calculations were done during the static load testing. For each of the load values applied to the end of the scraper a stress value at the base was calculated. After recording actual strain values the stress was calculated and compared to the predicted. With a 60 lb load the predicted stress was 7.97 ksi and the actual was 6.62 ksi. This is an error of 20% and the larges error of the loads. All calculated values are found in Appendix R-1.

- Success criteria values: During the field testing a success criteria was established to reflect the quality of fire line constructed and the time and swings required to complete it. These values were compared to the standard Pulaski as a base value. In the end the Pulaski had a value of .015 while the multi-use tool was .023. This value shows a 1.5 time improvement.

- Conclusion: Overall the testing results showed the Multi-Use Fireline Hand Tool constructed meets the minimum design requirements. This device also provides the desired increase in soil removal and resistance to failure. Lastly, when compared to the Pulaski's field application of fire line construction, the new device improves results by 1.5 times.

Report Appendix:

- Appendix R-1: Data Forms W/ Recorded Data

G-1: Requirement Dimensions Test Sheet

Test / Measurement	Required	Actual		Pass / Fail
Weight	< 8.0 lb	7.8 lb		PASS
OAL	< 12.0 in	11.125 in		PASS
Width	< 10.0 in	7.0 in		PASS
Height	< 8.0 in	3.0 in		PASS
Total Volume	< 960.0 in^3	234 in^3		PASS
Scraper Volume	> 10.0 in^2	22.7 in^2		PASS
Scraper Surface Area	>15.0 in^2	19.188 in^2		PASS
Axe Blade	3.0 – 4.0"	3.0 in		PASS

G-2: Soil Removal Volume

Test	Volume (oz)	Calculated Volume (in^3)		Pass / Fail Min. (15 in^3)
1	30	54		PASS
2	31	56		PASS
3	34	61		PASS
4	30	54		PASS
5	33	60		PASS
	Average:	57 in^3		PASS

G-3: Hardness Testing Sheet

Test		Required	1/8"	1/2"	1"	Pass / Fail
1	Axe	50-60 HRC	62	75	42	
2	Ave:	59	70	65	45	
3			68	72	38	PASS
1	Scraper	50-60 HRC	41	31	41	
2	Ave:	38	38	33	48	
3			35	35	43	FAIL (OK)
			Any Test on Center Line			Ave: 19
	Tool Center	40-60 HRC	21	23	15	FAIL

G-4.1: Static Load Testing Sheet

Load	Strain (με)	Calc. Stress (σ)	Deformation (Y/N)	Pred. Stress (σ)	Pass / Fail % Error
5 lb	25	0.743 ksi	N	0.664 ksi	PASS 10%
20 lb	91	2.703 ksi	N	2.656 ksi	PASS 2%
40 lb	158	4.693 ksi	N	5.314 ksi	PASS 13%
60 lb	223	6.623 ksi	N	7.970 ksi	PASS 20%

* $\varepsilon = (\mu e)(10^{-6})$ $E = 29.7\,(10^{3})$ ksi $\sigma = E\varepsilon$

G-4.2: Practical Use Dynamic Testing Sheet

After striking a hardwood knot with 10 heavy blows.	Axe Head	Scraper Head	Required	Pass / Fail
Chipping (Y/N)	N	N	N	PASS
Dulling (Y/N)	N	N	N	PASS
Turn Over (Y/N)	N	N	N	PASS
Handle Loose (Y/N)	N	N	N	PASS

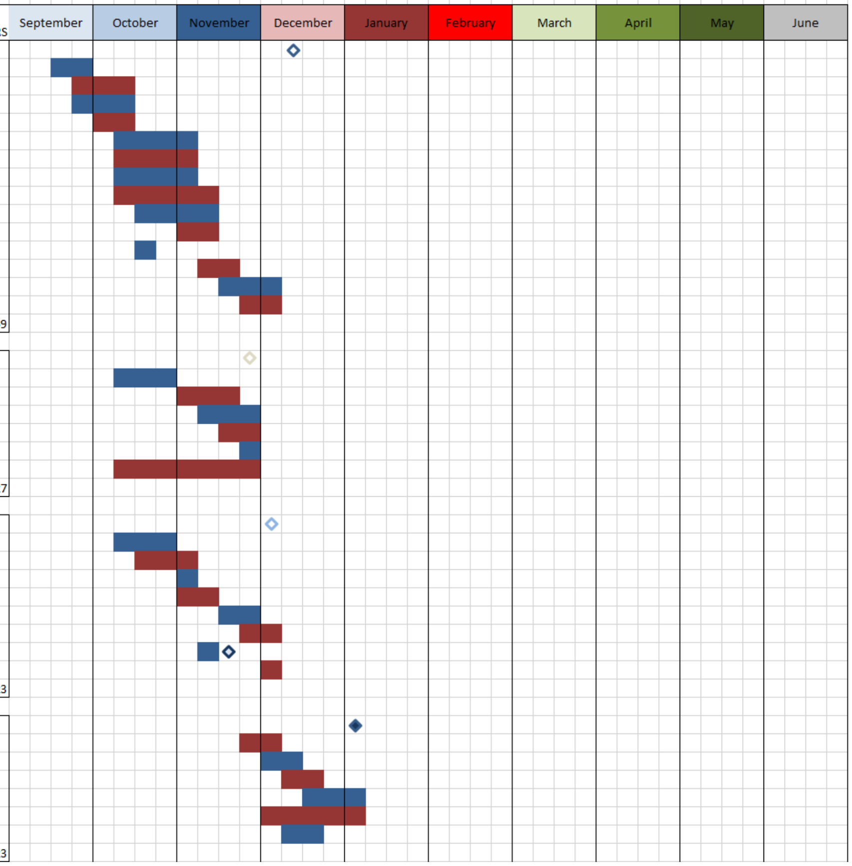
G-5: Field Line Construction Testing Sheet

Tool Used to Construct 5' of 18" Line	Time (s)		# of Swings		Rated Quality of Line (%)		Success Value	
Standard Pulaski	44	22	43	24	60	70	.007	.015
Multi-Use Hand Tool	29	20	24	19	80	90	.015	.023
Success Equation: $SV = \left[\frac{Rating}{100}\right] / [Time + Swings]$								

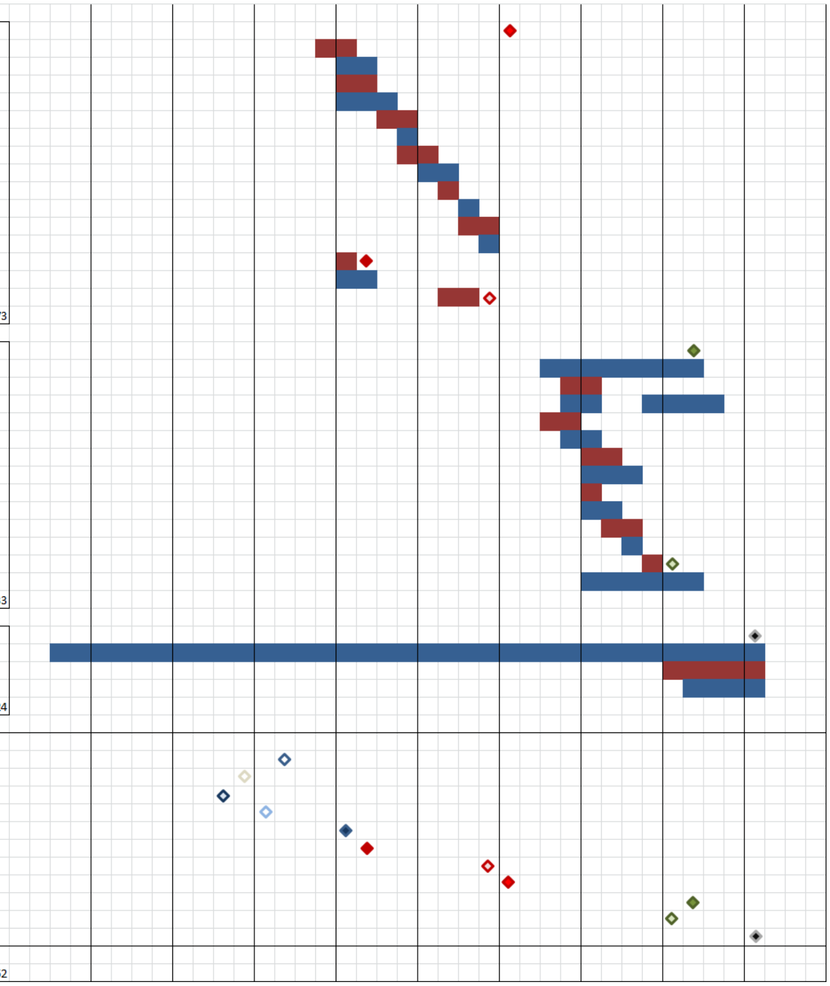
- Appendix R-2: Gantt Chart

Senior Project Gantt Chart
PROJECT: Multi-use Fire Line Handtool
DESIGNER: Bruce Bernard

TASK ID:	DESCRIPTION	EST. HOURS	ACT. HOURS
1	**Proposal**		
a.	Outline	2	2
b.	Function Statement	1	2
c.	Design Requirements	2	3
d.	Intro	4	3
e.	Design	5	5
f.	Analysis	20	15
g.	Methods	5	3
h.	Drawings	10	10
i.	Testing	3	3
j.	Budget	2	2
k.	Parts List	1	1
l.	Schedule	3	4
m.	Discussion	3	3
n.	Conclusion	2	3
	Subtotal:	63	59
2	**Analysis**		
a.	Forces	2	3
b.	Stresses	3	5
c.	Material	2	2
d.	Dimensions	2	5
e.	Tolerance	2	2
f.	SolidWorks	10	10
	Subtotal:	21	27
3	**Documentation**		
a.	Axe Head	3	4
b.	Scraper Head	3	4
c.	Handle	1	1
d.	Assembly	2	3
e.	ANSI 14.5 Standards	2	2
f.	Presentation	2	1
g.	CDR	2	3
h.	Website	3	5
	Subtotal:	18	23
4	**Proposal Updates**		
a.	Design	2	3
b.	Analysis	3	3
c.	Methods	2	3
d.	Schedule	2	2
e.	Drawings	10	10
f.	Testing	5	2
	Subtotal:	24	23



5	**Part Construction**		
a.	Axe HSMWorks	3	5
b.	Axe Process Plan	4	6
b.1	Axe Hole	3	5
b.2	Axe Outer	2	3
c.	Axe Machining	8	30
d.	Scraper Cut Pattern	1	1
e.	Scraper Process Plan	3	3
f.	Scraper Production	5	5
f.1	Bending Flanges	2	2
g.	Welding Parts	2	3
h.	Heat Treating	2	3
i.	Assemble Handle	2	3
j.	Material Order	2	2
k.	Required Tooling	3	2
l.	MDR	3	2
	Subtotal:	45	73
6	**Testing Evaluation**		
a.	Source	10	6
a.1	Abstract	2	3
b.	Website	5	6
c.	Parameters	2	3
d.	Test Design	5	4
e.	Testing Equipment	2	3
f.	Testing Sheets	3	3
g.	Dimensions	3	3
h.	Static Loads	3	2
i.	Dynamic Loads	5	2
j.	Function	2	2
k.	TDR	3	3
l.	Testing Report	8	8
	Subtotal:	36	33
7	**Final Deliverables**		
a.	Project Report	20	13
b.	Presentation	10	6
c.	Website	5	5
	Subtotal:	35	24
Note:	**Deliverables***		
	Draft Proposal		
	Analysis		
	CDR		
	Document Mods		
	Final Proposal		
	Parts Arrive		
	MDR		
	Part Construction		
	Testing Evaluation		
	TDR		
	Final Report		
	TOTAL HOURS:	242	262



APPENDIX I – Testing Data

Appendix I.1: Data G-1

SENIOR PROJECT MULTI-USE FIRELINE HAND TOOL DATA FORM G-1

Dimensional Testing

- Date: April 7, 2016 Time: 0900
- Time Required: 60 min
- Location: Fluke Lab
- Required Equipment: Ruler, Caliper, Scale, Work Bench, and Data Form G-1.
- Procedure: Measure each value listed on Data Form. Determine if value meets design requirement.
- Risks/Safety: Wear safety glasses when in the machine shop.
- Discussion: Each measurement to be recorded reflects a design requirement. Volume or area measurements must be calculated.

G-1: Requirement Dimensions Test Sheet

Test / Measurement	Required	Actual		Pass / Fail
Weight	< 8.0 lb	7.8 lb		PASS
OAL	< 12.0 in	11.125 in		PASS
Width	< 10.0 in	7.0 in		PASS
Height	< 8.0 in	3.0 in		PASS
Total Volume	< 960.0 in³	234 in³		PASS
Scraper Volume	> 10.0 in³	22.7 in³		PASS
Scraper Surface Area	>15.0 in²	19 3/16 in²		PASS
Axe Blade	3.0 – 4.0"	3.0"		PASS

Calculations:

Scraper Area

$$(4.25'' \times 2.0'') + \left(\tfrac{1}{2}(1.5'')(2'' + 4.25'')\right) + (1.5'' \times 4'')$$

$$= 19.1875 \text{ in}^2$$

Scraper Volume

$$\left[(4.25'' \times 2.0'') + \tfrac{1}{2}(1.5'')(2'' + 4.25'')\right](1.25'') + \left[1.25'' \times 1.25''\right](4)$$

$$= 22.7 \text{ in}^3$$

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Appendix I.2: Data G-2

Soil Removal Volume of Scraper

- Date: April 8, 2016 Time: 1200
- Time Required: 45 min
- Location: Home residence
- Required Equipment: Ample loose soil, Bucket, Measuring cup with units of ounces, and Data Form G-2.
- Follow these steps to perform adequate test results:
  - Step 1: Gather a bucket, a 20 oz measuring cup with 2 oz precision, and the device to be tested.
  - Step 2: While holding the tool in a normal scraping use position, scoop as much soil as possible onto the scraper tool.
  - Step 3: Vertically lift the tool smoothly with the back of the scraper oriented parallel to the ground.
  - Step 4: Allow any loose falling soil to fall.
  - Step 5: With the remaining soil stabilized, pour it into an empty bucket.
  - Step 6: Use a 20 oz measuring cup to record the amount of soil scooped to the nearest ounce.
  - Step 7: Repeat steps 2-6 four additional times.
  - Step 8: Use the conversion of [1.805 in^3/oz] to calculate the average volume of soil removed in [in^3].

- Risks/Safety: Ensure soil used is free of hazardous materials or objects.

- Discussion: The results of this test determine if the constructed tool meets the design requirement of the scraper tool scooping at least 15 in^3 of soil.

G-2: Soil Removal Volume

Test	Volume (oz)	Calculated Volume (in^3)		Pass / Fail Min. (15 in^3)
1	30	54 in^3		PASS
2	31	56 in^3		PASS
3	34	61 in^3		PASS
4	30	54 in^3		PASS
5	33	60 in^3		PASS
	Average:	57 in^3		

Calculations:

$$V_{(in^3)} = V_{(oz)} \left| \frac{1.805\ in^3}{1\ oz} \right.$$

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Appendix I.3: Data G-3

SENIOR PROJECT MULTI-USE FIRELINE HAND TOOL DATA FORM G-3

Hardness Testing

- Date: 15 APR 16 Time: 1300
- Time Required: 60 min
- Location: Materials Lab
- Required Equipment: Ruler, Hardness Tester, Calibration Block, and Data Form G-3.
- Procedure: Prepare the device's surface for hardness testing in the locations described on data form G-3. Record the hardness at each location described and repeat the test three times for each location.
- Risks/Safety: Wear safety glasses when in the lab. Ensure proper use of all equipment.
- Discussion: Of the recorded values, calculate the average hardness and determine if the tool meets the design requirement hardness.

G-3: Hardness Testing Sheet

Test		Required	~~1/16"~~ 1/8"	1/2"	1"	Pass / Fail
1	Axe	50-60 HRC	62	75	42	AVE
2			70	65	45	59 HRC
3			68	72	38	(PASS)
1	Scraper	50-60 HRC	41	31	41	AVE
2			38	33	45	38 HRC
3			35	35	43	(FAIL)
			Any Test on Center Line			AVE
	Tool Center	40-60 HRC	21	23	15	19 HRC

(FAIL)

Calculations:

STANDARD PULASKI AVG 35 HRC!

AXE AVE SCRAPER AVE
59 HRC 38 HRC

GIVEN that the standard Pulaski had an AVE of 35 HRC, Both the Axe and Scraper should be fine for field use.

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Appendix I.4: Data G-4

SENIOR PROJECT MULTI-USE FIRELINE HAND TOOL DATA FORM G-4

Load Testing

- Date: 20 April 16 Time: 1300
- Time Required: 120 min
- Location: Materials/Machining Lab

- Required Equipment: Strain Gauge W/ recording equipment, C-clamp, 60 lbs in 20 lb increments, hard wood knot, and Data Form G-4.

- Procedure: For the static load test place a strain gauge at the base of the scraper near the weldment location. Secure the tool to a work table and connect gauge to recording equipment. Apply a C-clamp to the center edge of the scraper and record strain value for each load stated on data form G-4. For the dynamic test, set up a hard wood knot surface. Strike the wood with each end of the tool 10 times each. Ensure heavy blows and record any failures on data form G-4.

- Risks/Safety: Wear safety glasses when in the lab and when using the tool. Be aware in the event of tool failure. Stand clear or free hanging weights.

- Discussion: Use the recorded strain values to calculate the stress for each load. Compare results to predicted values. Observe each tool end thoroughly to ensure no failures are found after dynamic testing.

G-4.1: Static Load Testing Sheet

Load	Strain (μe)	Calc. Stress (σ)	Deformation (Y/N)	Pred. Stress (σ)	Pass / Fail % Error
0 lb 5lb	25	.743 ksi	N	0.664 ksi	Pass 10%
20 lb	91	2.703 ksi	N	2.656 "	2%
40 lb	158	4.693 ksi	N	5.314 "	13%
60 lb	223	6.623 ksi	N	7.970 "	20%

* $\varepsilon = (\mu e)(10^{-6})$ $E = 29.7\ (10^3)$ ksi $\sigma = E\varepsilon$

Calculations:

Calc (σ)

$= 29{,}700 \text{ ksi}\ (.000025) = .743 \text{ ksi}$

Cont.

Pred. (σ)

$\sigma = \frac{Mc}{I}$

$M = \text{load}\ (3.5\text{in})$

$C = .09375\text{in}$

$I = \frac{1}{12}\ 4.5\text{in}\ (3/16)^3$

$= .00247\text{in}^4$

$\sigma_0 = \frac{5\text{lb}(3.5\text{in})(.09375\text{in})}{.00247\text{in}^4}$

$= .664 \text{ ksi}$

G-4.2: Practical Use Dynamic Testing Sheet

After striking a hardwood knot with 10 heavy blows.	Axe Head	Scraper Head	Required	Pass / Fail
Chipping (Y/N)	N	N	N	PASS
Dulling (Y/N)	N	N	N	PASS
Turn Over (Y/N)	N	N	N	PASS
Handle Loose (Y/N)	N	N	N	PASS

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Appendix I.5: Data G-5

SENIOR PROJECT — MULTI-USE FIRELINE HAND TOOL — DATA FORM G-5

Field Testing

- Date: 22 APRIL Time: 1600
- Time Required: 120 min
- Location: Approved land with typical fuel and soil characteristics.
- Required Equipment: Testing Partner, Stop Watch, Counter, Pulaski, 2 marked 5ft sections of land with near identical soil conditions, and Data Form G-5.
- Procedure: Construct 5 ft of 18" fireline down to mineral soil using first the Pulaski, then the device being tested. For each run, use the same pace and record the time to complete and the swings required.
- Risks/Safety: Wear safety glasses when using the tool. Be aware in the event of tool failure. Wear PPE, i.e. gloves, long pants, and boots.
- Discussion: Record data from both runs on data form G-5. Calculate success using criteria equation and compare.

G-5: Field Line Construction Testing Sheet

Tool Used to Construct 5' of 18" Line	Time (s) 1	Time (s) 2	# of Swings 1	# of Swings 2	Rated Quality of Line (%) 1	Rated Quality of Line (%) 2	Success Value 1	Success Value 2
Standard Pulaski	44	22	43	24	60%	70%	.007	.015
Multi-Use Hand Tool	29	20	24	19	80%	90%	.015	.023

Success Equation:

$$SV = \left[\frac{Rating}{100}\right] / [Time + Swings]$$

Calculations:

Success

Test 1

$$\frac{\text{Multi}}{\text{Pulaski}} \rightarrow \frac{\left(\frac{80}{100}\right) / (29+24) = .015}{\left(\frac{60}{100}\right) / (44+43) = .007} = 2.1 \times \text{ Improve}$$

Test 2

$$\frac{\frac{90}{100} / (19+20) = .023}{\frac{70}{100} / (22+24) = .015} = 1.5 \times \text{ Improve}$$

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APPENDIX J – Resume

Bruce Wayne Bernard Jr
10 Mary Way A
Yakima, WA 98908
Phone: 509-480-2487
Email: bernardb@cwu.edu

OBJECTIVE	Mechanical Engineering position with opportunity for training and experience
EDUCATION 2012-2015	Central Washington University Current senior; B.S. Mechanical Engineering Technologies GPA: 3.9/4.0 Quarterly Honor Roll; 6 Quarters
2008-2012	Pierce College Associate of Arts – August 2012 GPA: 3.7/4.0 Honors Graduate
EMPLOYMENT 2010-2015	U.S. Forest Service, Naches, WA Wildland Firefighter Type 1 6 total seasons as a Type 3 Engine Operator 3 seasons as a Type 1 Firefighter/Squad Boss
2007-2010	U.S. Army, Ft. Campbell, KY 5th Special Forces (Airborne) Weapons Specialist, Rank: Specialist E-4
PERSONAL	CERTIFICATES SolidWorks Associate – Mechanical Design – March 2015 S-211 Pumps and Water Use – July 2011 Class B CDL w/ Tank – June 2012
	SKILLS/ EXPERIENCE • Applied Skills Courses; Advanced Machining and CAD/CAM. Use of CNC Mill, CNC Lath, and HSM Works • Firefighting experience with tools, chainsaws, pumps, and tactical/ scientific understanding of hose lays • Technical understanding of military weapons. Use of precision tools and gauges to perform weapons maintenance and repairs
REFERENCES	Beau Clark; Capt. U.S. Forest Service beauclark@fs.fed.us; 509-833-5095 Ted Bramble; Instructor CWU Bramble@cwu.edu; 509-963-1191