Spring 2017

Adjustable Shelving Unit for Home Beer Brewing

Andrew L. Kastning
kastninga@cwu.edu

Follow this and additional works at: http://digitalcommons.cwu.edu/undergradproj

Part of the Mechanical Engineering Commons

Recommended Citation
http://digitalcommons.cwu.edu/undergradproj/40

This Undergraduate Project is brought to you for free and open access by the Undergraduate Student Projects at ScholarWorks@CWU. It has been accepted for inclusion in All Undergraduate Projects by an authorized administrator of ScholarWorks@CWU. For more information, please contact pingfu@cwu.edu.
ADJUSTABLE SHELVING UNIT FOR HOME BEER BREWING

By: Andrew Kastning
**Table of Contents**

INTRODUCTION .................................................................................................................. 3  
  Motivation ......................................................................................................................... 3  
  Function Statement ........................................................................................................... 3  
  Requirements ..................................................................................................................... 3  
  Success Criteria ................................................................................................................. 3  
  Scope ................................................................................................................................. 3  
  Success of the project ....................................................................................................... 4  

DESIGN & ANALYSIS ........................................................................................................ 5  
  Approach .......................................................................................................................... 5  
  Description ....................................................................................................................... 5  
  Benchmark ........................................................................................................................ 6  
  Performance Predictions ................................................................................................. 6  
  Description of Analysis ..................................................................................................... 6  
  Scope of Testing and Evaluation ....................................................................................... 7  
  Analysis ............................................................................................................................. 8  

METHODS AND CONSTRUCTION ..................................................................................... 9  
  Description ....................................................................................................................... 9  
  Drawing Tree and Drawing Identification ....................................................................... 9  
  Parts List and Labels ....................................................................................................... 10  
  Manufacturing Issues ....................................................................................................... 10  
  Discussion ......................................................................................................................... 10  

TESTING METHOD ............................................................................................................ 12  
  Introduction ...................................................................................................................... 12  
  Method and Approach ...................................................................................................... 12  
  Test Procedure .................................................................................................................. 12  
  Deliverables ....................................................................................................................... 12  

BUDGET/SCHEDULE/PROJECT MANAGEMENT ............................................................ 13  
  Budget ............................................................................................................................... 13  
  Schedule ............................................................................................................................ 13  
  Task Flow and Timing ...................................................................................................... 14  
  Task Dates and Deadlines ............................................................................................... 14  
  Estimated Total Project Time ........................................................................................... 14  
  Project Management ......................................................................................................... 14
DISCUSSION ................................................................................................................... 16
CONCLUSION .................................................................................................................. 17
ACKNOWLEDGEMENTS ................................................................................................. 17
REFERENCES ................................................................................................................... 17
APPENDIX A – Calculations .......................................................................................... 18
APPENDIX B – Sketches ............................................................................................... 34
APPENDIX C – Parts List .............................................................................................. 51
APPENDIX D – Budget .................................................................................................. 52
APPENDIX E – Schedule .............................................................................................. 53
APPENDIX F – Resources ............................................................................................. 56
APPENDIX G – Evaluation Sheet .................................................................................. 57
APPENDIX H – Testing Report ..................................................................................... 58
   Introduction .................................................................................................................. 58
   Method/Approach ........................................................................................................ 58
   Test Procedure ........................................................................................................... 59
   Safety .......................................................................................................................... 60
   Discussion .................................................................................................................... 60
   Deliverables ............................................................................................................... 60
Appendix ......................................................................................................................... 62
Testing Gantt Chart ....................................................................................................... 62
Test 1 .................................................................................................................................. 62
Test 2 .................................................................................................................................. 62
Test Procedure ................................................................................................................ 63
   Procedure for Center Tree Strain ............................................................................... 63
   Procedure for Center Tree Angle of Deflection ....................................................... 63
   Safety ......................................................................................................................... 63
Strain Data ...................................................................................................................... 64
Angle of Deflection Data ............................................................................................... 66
APPENDIX I – Testing Data ......................................................................................... 67
   Strain Data .................................................................................................................. 67
   Angle of Deflection Data ......................................................................................... 69
APPENDIX J – Resume .................................................................................................. 70
INTRODUCTION

This project was created to fill a gap in the market of home beer brewing station systems. Currently, there are no adjustable racks to hold all of the necessary equipment for the home brewing of beer. Customers are required to purchase a rack based off their needs at the time, which often do not include options for small setups. The new system will allow customers to easily scale up (or down) as their needs grow and change. The new system will be the only do-all system in the market for small to medium home brewing stations.

Motivation

To create a storage rack for home brewing systems that is lightweight and collapsible while being adjustable and adaptable to an individual’s needs. A system of this design would allow customers to choose what types of components they use without worry of fitment or compatibility issues.

Function Statement

To create a compact beer brewing rack that will hold all the basic beer brewing necessities.

Requirements

The requirements to be met to achieve a successful rack are as follows:

- It must weigh less than 150lbs total.
- It must take up less than 2.5ft x 2.5ft x 6ft when collapsed.
- The tree will not flex more than 2° when under a 200lb load.
- Each rack must be individually adjustable for height in 2” increments.
- Each rack must be capable of holding 200lbs each.
- Each rack must be able to be mounted to any of the four sides of the tree.
- Each rack will be a minimum of 8 inches diameter.
- All weight requirements will include a 1.2 safety factor.

Success Criteria

The center tree should hold the racks in any configuration necessary. It should be easily assembled and disassembled with one user. The rack should use standard size components.

Scope

The scope of this project is to create the complete rack that will hold all of the necessary beer brewing equipment. The project will include the base, main tree, and shelves and other mounting surfaces to hold heaters, tanks, and other brewing necessities. This project will include the selection of materials for the base, tree, and mounting systems, it will include the design and analysis of all components, and it will include the assembly of the components into a finished system. This project is only the rack; it will not include any brewing or brewing components.
Success of the project
This project will be successful if: the center support tree can withstand the weight of the brewing equipment without bending or deforming; the stand is able to lock in the open position and support the weight of the brewing equipment without bending or deforming; and if the racks are fully supported by the collars and pins without excess play in the shelves or shearing the pins.
DESIGN & ANALYSIS

Approach
Design and manufacture a simple system to facilitate adjusting needs of home beer brewing.

There is currently nothing on the market for home beer brewers that is adjustable and scalable to the users’ needs. A new design is needed that could be adapted to an individual’s current needs, and later be up- or down-scaled on a piece-by-piece basis.

Home beer brewers often use spare space in a garage or a storage shed to make their creations. This creates a need for a unit that can be used against a wall, in a corner, around other storage devices (bike racks, shelving units, large items such as kayaks or project vehicles), or in other similarly tight/non-uniform spaces.

Description
The system will have a center tree that is capable of securely mounting attachments from the bottom to the top in small increments. The center tree will need to withstand all forces and moments placed upon it by the weight of the brewing equipment. The tree should have a built in feature for the safe management of cables, hoses, and other hazards needed by each piece of brewing equipment.

The base will be a simple set of feet that are minimally long enough to support the entire structure from tipping over. The entire base, or the individual feet, must be able to be folded or detached from the tree for storage when the tree is not in use. The hinges on the feet must be able to lock into place while supporting the moment forces exerted upon them by the brewing equipment.

The shelves will use a simple collar or sleeve that fits over the center tree. The collars will lock into place using pins that will have to support the weight of the brewing equipment on the shelf. The shelves will be designed to fit to specific brewing equipment as shown in Appendix A. All pins will be strong enough to support the heaviest shelf, to prevent the wrong pins being used on a shelf.

The engineering merit of this project comes from the analysis and design of the center tree, the hinges, and the pins:

The design of the center tree will be determined using the forces and moments exerted on the tree by all shelves and other components supported by the tree. The calculations for bending stresses will need to be determined for square tubing with holes drilled on all sides the length of the tube. Wall thickness, outside length and width, and material will need to be determined.

The design of the hinges will require a design that allows all four feet to lie flat on the floor when open. The locking mechanism will need to support the moment forces caused by the weight of the brewing equipment without bending or shearing.
The design of the pins will require the determination of the largest forces on the pins to determine the shearing forces on the pins.

**Benchmark**

Compared to the “OG All Grain Brewing System” (shown in Figure 2.1) this project will produce a rack that is capable of holding the same components at the same or different heights on multiple sides. The new system will weigh less, cost less, and be entirely user adjustable.


**Performance Predictions**

The center tree will be able to hold both shelves with brewing kettles as well as the instant hot water heater using 2”x2” square tubing or smaller.

This will require the pins in the base hinges to be precision fit and the legs to be extremely well aligned during the welding of the hinges. The base and the center tree will also need to be square to the ground surface as well as each other to prevent wobble or wobble of the unit.

**Description of Analysis**

The following is a list of each calculation found in Appendix A:

1. The volumes and weights of each component are found to use in subsequent calculation sheets. The weights of the brew kettles are calculated using commonly available sizes at full weight. A safety factor of 1.2 was used due to the high level of accuracy in the brew kettle weights, the fixed volume, and the calculations being static. (Figure A.1)

2. The forces acting on the center tree due to fully loaded brew kettles. This calculation determined the forces to which the center tree would be subject. The moment on the center tree due to a shelf is 3420 lb*in (Figure A.2)

3. The selection of the center tree size. This calculation was paramount to selecting sizes of material for the remainder of the project. Mc/I was used in place of M/S due to insufficient data in the textbooks available. A system solver quickly determined the necessary outside width. At .25” thick, the minimum square tubing needed is only .984” x .984” (Figure A.3-4)

4. The forces on the center tree using eccentric loading formulas. This calculation not only confirmed the size of the center tree to be adequate, but also showed less than 1 degree in flexure when under load using the tubing size previously selected. The center tree will only flex .4 degrees due to one shelf. (Figure A.5-6)
5. The forces on the base hinge pins were calculated using statics. These forces were necessary to know in order to select the correct size pins and hinges. Each pin receives 757.1 lbs force. (Figure A.7)

6. The base hinge pin selection used a double shear formula to ensure the correct diameter hinge pins could be ordered. The pins will need to be .1209” diameter or larger. (Figure A.8)

7. The forces on the shelf locking pins were calculated using statics. These forces were necessary to know in order to select the correct size pins. Each pin receives 1714.1 lbs force. (Figure A.9)

8. The shelf locking pin selection used a double shear formula to ensure the correct diameter hinge pins could be ordered. The pins will need to be .182” diameter or larger. (Figure A.10)

9. The shelf hinge pins were more complicated to calculate as shown below. The pins being offset from one another, as well as the load, made solving them more involved. Unlike previous pins, these pins do not have the same forces acting on them. The hinge pin receives 1569.4 lbs force and the locking pin receives 1410.2 lbs force. (Figure A.11-12)

10. Once the shelf hinge pin forces were found, the proper selection using double shear could be made. The hinge pins will need to be .174” diameter or larger and the locking pins .165” (Figure A.13)

11. The weight of the center stand and its center of gravity were needed to find the total system weight and center of gravity. The center tree weighs 20.35 lbs. (Figure A.14)

12. The weight of the base and legs their centers of gravity were needed to find the total system weight and center of gravity. The base weighs 33.24 lbs. (Figure A.15)

13. The system center of gravity was found based off the direction it is most likely to fall. Using the sum of the moments to locate the center of gravity when under a full use load. The force required to tip over the system at the most extreme point was found as well. This was assuming the brew kettles would stay in place while falling, which is unlikely, however it would be the worst case scenario. The total weight of the rack is 96.74 lbs, and 523.99 lbs when loaded. (Figure A.16)

**Scope of Testing and Evaluation**

For the testing phase of this project, the entire system will be completely assembled and disassembled as well as assembled from a “collapsed” version. This is done to ensure that the end user will be able to easily assemble the product out of the box and continue to collapse and expand the product as it is used. The assembly of the system will confirm function. After the basic function of the system is determined. The system will be used in multiple applications of brew kettle heating, rapid water heating, and full beer brewing to ensure complete usability.
Analysis

Design Issues
The first issue to overcome was the size of tubing required for the center stand. Since the center stand would be subject to multiple moments and compression forces, the proper selection was critical. The failure of this part would be a catastrophic failure.

The next design issue was the length of the base feet required to support the system. The base needed to be wide enough to support the brew kettles and shelves but also short enough to not be in the way or become subject to excessive moment forces. The base also had to support the center stand and shelves when in the folded position.

The final design issue was the hinges and locking pins for the base. Multiple iterations of hinge designs were used to find the currently successful design (Figure B.14, B.15, and B.17). The design had to hold the legs in place under a large static load including a safety factor as well as be commercially available and cost efficient. The current design will allow cost to be reduced without sacrificing safety.

Calculated Parameters
Appendix A shows the calculations required to ensure a successful brewing stand. The calculations determined to solve the above design issues are shown below:

- 1.5 inch by 1.5 inch by .24 inch thick square tubing to support shelves and kettles (Figure A.3-A.6)
- 50 inch by 50 inch total base width when extended
- 28 inch by 28 inch base width when collapsed
- Heavy duty hinges with .125 inch diameter pins to support base legs (Figure A.8)
- Steel locking pins to secure base legs of .125 inch or greater (Figure A.8)
- Total rack weight of 96.79 lbs (Figure A.16)
- The tree will not flex more than 1 degree for each shelf (Figure A.5-6)
- The system was designed using the required 1.2 Safety Factor and then the next largest available size was selected (Figure A.1)
METHODS AND CONSTRUCTION

Description
The intent of this project is to make the setup, operation, and take down of typical home brewing systems more efficient. The construction of this device will mainly consist of welding, drilling, and fastening of square tube structural steel. The welding and cutting of material will be conducted in the Central Washington University Foundry. Any machining and fastening of material will take place in the University’s machine shop. The square tubing will be ordered through a local materials supplier. The fasteners and hinges will be purchased through a supplier (McMaster Carr has been recommended). Choice of the supplier will depend on part cost and availability. This device is a very rigid device and therefore will not incur much maintenance or repair costs.

Drawing Tree and Drawing Identification
Parts List and Labels
The final parts list contains everything needed to assemble the main tree as well as the shelves. All of the parts selected are commonly available parts to consumers. This was done to ensure end users could build the system from scratch using only design plans, or be able to buy replacement parts from several common outlets. The list includes all of the minor parts like locking tabs, hinges, pins, and gussets; nothing was left off. The complete parts list and budget are in Appendices C and D respectively.

Manufacturing Issues
Anticipated
The most complicated issue anticipated during the construction of this device is going to be mounting the burners to the shelf arms. Since the shelf arm will be constructed from square steel tubing and the burners being used in this design have a circular support frame. This is going to require a mounting collar to be fabricated.

The center tree is going to have holes drilled through it to allow the shelf height to be adjusted to accommodate the end user. While the drilling of the holes is not a complicated process, it requires precision to ensure the spacing and centering of the holes are where they should be in order to prevent undesired stress concentrations during equipment operation.

The base hinges will be welded or bolted on after testing of each design to determine the most efficient method of ensuring a consistently square attachment. The legs must be parallel to the mating section of the base as well as flat on the supporting surface to prevent wobble of the system.

Build Issues
The largest issues was the alignment of the pin holes and hinges for the base legs and for the shelf arms. The holes had were drilled after the tabs were welded in place due to the heat from welding moving the tabs. This method required transfer punches and step drilling, which did not allow perfect alignment of the holes. This was overcome with a tapered reamer, but it would not be ideal for mass production.

The center tree holes were done using multiple vises on the CNC mill. The collars were also done on a mill with a DRO. This method allowed for precision placement of the holes. Once all the holes were drilled, a .501 inch straight reamer was used to make sure all of the holes were perfectly aligned. The process took less time than anticipated.

The mounting of the shelf rings to the shelf arms was the easiest. Using a piece of flat bar for the rings was the cheapest option found. Due to the use of a 3-bar roller, each end of the rings, once bent, had a 2 inch flat section. This flat section mounted perfectly to the face of the shelf arms. Welding these was easily done with a simple c-clamp and vise.

Discussion
The entire premise of this design is to allow the rack to be assembled in a way to minimize the effort required from the end user to set up the system during brewing and collapse the system.
after brewing is complete. The shelving system is going to consist of the shelving arm mounted to the burner and burner arm via a hinge. The shelving arm is going to be welded to a mounting collar which will in turn slide onto the shelving backbone. The shelving backbone is going to slide into the base. The base is going to consist of four legs. Each leg will be hinged which will allow the system to further collapse.
TESTING METHOD

Introduction
The primary means for testing this device is to, after the device is fully constructed, place brew kettles on the rack, fill them with water, and verify the structural integrity of the system. Also, the ease of setup and take down will be assessed. While there is not going to be quantitative data associated with most of the testing, if the device is capable of withstanding the applied stresses and can be setup and collapsed quickly, then the device will be deemed successful.

Method and Approach
The intent of this testing procedure is to test the device in the actual operating scenario. Using gauges and assumed weights may be able to determine theoretical success however, it is not possible to account for all scenarios without actually using the device in the brewing process. This will require that the device is manipulated multiple times throughout the operation.

UPDATE:
The actual testing done determined real stresses in the system compared with theoretical. Testing also determined flexure of the system when under a load, and when heated. Testing required a full brew process as well as testing for quantitative data. The updated testing report, procedure, and data can be found in Appendix H. The below test procedure was done in addition to the extensive testing in the appendix.

Test Procedure
1. Brew a batch of beer using existing brew rack system (record time of set up, operation, and clean-up/breakdown)
2. Brew a batch of beer using collapsible beer rack system (record time of set up, operation, and clean-up/breakdown)
3. Compare the times and issues encountered between the two tests to determine success of new device
4. Document findings and suggestions in a formal report.

Deliverables
Once the testing has been completed, the deliverables will be a formal report containing quantitative data (before and after times), improvement suggestions, etc. Since the testing requires the brewing of beer, another deliverable will be approximately 20 gallons of beer.
BUDGET/SCHEDULE/PROJECT MANAGEMENT

Budget
Parts suppliers, substantive costs, and buying issues:
Appendix C shows the complete budget table to include estimates and totals. Shipping cannot be included until parts are purchased. All parts will be purchased as soon as all calculations are complete to ensure delivery and prevent price increase issues. The total length of tubing shows a larger amount that the calculated sum in the parts drawings (Appendix B) due to suppliers offering sections in standardized lengths at a reduction in cost. In most cases, it will be cheaper to order an even length of feet in tubing than a fraction of feet. This is similar with small items available in bulk, eg. packages of 5 hinges, a box of locking pins, or a bag of screws.

The updated budget in Appendix D shows a savings of approximately 50%. This discount was due to ordering parts in bulk with other projects and the school’s regular parts order. This savings would closely reflect the cost of parts if they were purchased in bulk as in a manufacturing situation.

Labor rates, outsourcing rates, and estimated costs:
Welding costs and shop time will be calculated for estimates only as the project is designed using procedures already known and available to the design team. Parts costs and totals can be seen in Appendix C

Labor:
An itemized list of labor intensive jobs can be found in Appendix E

Estimated total project cost:
The estimated total cost of this project is $350 with tax/shipping. This includes all raw material, delivery fees, additional hardware, and testing. The raw steel tubing is cheaper in longer sections; this will require more time to cut to size. The difference in price for cut-to-length sections is more expensive than the labor to cut them down in Hogue. Items listed as available under MSC or McMaster Carr will be price checked through other distributors again before purchasing for possible savings.

Funding sources:
This project is independently funded since the product is intended to be patented and sold after its completion. Any donations or other funding from outside sources could create issues with the ownership rights.

Schedule
The proposed schedule can be found in Appendix E. This timeline includes mildly conservative time estimates to account for error but currently does not allow for major issues to include parts not arriving within a week of ordering, winter school closures, or part failure and rebuild.
Task Flow and Timing
The order of the tasks in Appendix E is designed to assist the project flow and in most cases cannot be done out of order. Shop time and parts ordering will be planned to assist the chart as shown.

Task Dates and Deadlines
The dates and deadlines in Appendix E are in place to ensure adequate progress is met each week and that there is time at the end of the quarter for testing set up, part modifications, and to allow for possible unforeseen issues. The major milestones in the construction of this project are the center tree, the base, and the racks. These are the three section headings seen in the Gantt chart in Appendix E.

The updated Gantt chart shows the anticipated time for completion and actual completed dates for each task and subtask. The overall time to complete was close to what was anticipated, but was not close for most individual tasks, (ie. some were longer and others were shorter than anticipated). The order of tasks was changed to do similar work like drilling or cutting all at the same time rather than do each part together. This reduced much of the anticipated time for sections that would have made the total project run long.

Estimated Total Project Time
Most of the time associated with this project is going to be in the physical construction of the device. The estimated total project time can be found at the end of Appendix E. A conservative estimate of 51 hours has been assumed to accommodate minor issues and will be used to estimate future projects.

Project Management
Human Resources:
The three stages of this project (Design, Build, and Test) will require many specific individuals. Professors Johnson, Pringle, and Beardsley will be utilized during the design stage of this project for calculation and estimation of the overall design. Matt Burvee and Ted Bramble will be utilized the most during the build stage of this project. They will assist mostly in the set-up of the build and in welding. Professors Johnson, Pringle, and Beardsley and Matt Burvee will again be used during the testing stage. Jason Warenksi will be used during the duration of the project for assistance in building and testing.

Physical Resources:
A large area will be required for layup and construction of the brew system. The welding shop and power technology room in Hogue will be utilized for a majority of the build. The machine shop and associated equipment will be used for the construction of parts of the system. The welding equipment in the welding shop will be needed for construction of the base and center stand.
Financial Resources:
This project will be solely funded by Jason Warenoki to ensure all parts belong to him as well as design rights. All discounts or deals used to obtain parts and materials will be used under the knowledge of this fact.
DISCUSSION

To date, this project has seen a number of redesigns. This is not out of the ordinary for a project that begins in someone’s head and is then described to another engineer to be designed before being put on paper. Many issues were only discovered once drawings or sketches were made.

The first issue encountered was the hinges used on the base and shelves. The design worked, as seen in Appendix B.14 and B.17, however it was changed and eventually replaced due to lack of machinability. The mating faces under the curved section would be very difficult to machine in the Hogue machine shop. The mating hinge “knuckles” had similar issues in the original design. The redesign moved several mating faces apart to allow larger tolerances and radii; however it meant a large increase in raw materials for larger hinges and more weight. This issue was mitigated with the inclusion of heavy duty steel hinges and locking “tabs” as seen in Appendix B.12.

One of the more successful things on this project was the center tree size. It was estimated at the start of the project that it would require 2” x 2” steel tubing or larger. After calculating the bending stresses at max weight, it was determined that a much smaller and lighter version would suffice. The current version is still one standard size tube larger than necessary due to costs and availability. This also allowed for a tighter fit of the rack sleeves as 2” x 2” tubing is the smallest size available with .25” thick wall. The inside dimensions of the sleeves will be 1.5” x 1.5”.

Another issue encountered during this project was the shelves. Now referred to as racks, the original shelves were designed to be 24” x 36” rectangular steel shelves (Appendix B.16). This would have been much less useful for round kegs. Having extra space on each shelf could have easily invited users to store items on the shelves, only inches away from a gas burner. The new racks will not have extra room to place flammable or metal equipment that could become extremely hot or ablaze.

As a whole, this project has seen a number of stalls and setbacks due to the lead engineer taking time off for an addition to his family. This was a known issue at the beginning of the project; however, its impact was severely under estimated. The project has been adjusted for this issue, and no further setbacks are anticipated. As much of the rest of the project as possible will be completed as soon as safely possible to provide a “buffer” in case of future personal issues.

Upon completion of the build, final design approval from the customer was required before testing could commence. After approval, the first and main test was checking the strain on the center tree. If everything (racks, hinges, pins, welds, etc.) could withstand the testing of the center tree, and if nothing approached the elastic limit, the design would ultimately be a success. After testing the center tree for acceptable strains, flexure of the center tree was also tested. These two tests ensured that overall, the system would hold up to use. The remaining tests were simply pass/fail type standards. Testing was completed rather quickly and was successful in all criteria. This was, by far, the easiest section of the project. Final approval from the customer on the design, build process, and testing was received. The system has since been sold to independent brewers to build/modify for their personal use.
CONCLUSION

This project is expected to be completed on time, accounting for possible setbacks and redesigns. The timeline has been created with the above average number of federal holidays during the period in mind. The budget is far under that of the competition while still allowing for some error. The assistance needed to complete the project has been confirmed to be available during the entire build period. All parts needed are currently in stock from multiple suppliers. The space required to build the project has been confirmed available and the construction team has the means to unlock the area.

Everything necessary to complete this project has been checked. Extra time, space, and money has been built into the plans for this project. This project is a solid endeavor and should be approved immediately.

This project was designed, built, and tested on time. The final design can be found in Appendix B. Future modifications may be performed by the customer/manufacturing facilities, but this design is a success.

ACKNOWLEDGEMENTS

A big thank you is due to the following people:

- Jason Warenksi, for the design help, motivation, document assistance, and patience.
- Roger Beardsley, for assistance in the direction of calculations and design parameters.
- Charles Pringle, for project guidance, support, and critiques.
- Craig Johnson, for design ideas and patience with the project.
- Matt Burvee, for conceptualizing needs based on bad whiteboard drawings and looking ahead for build and assembly issues.
- Ted Bramble, for pointing out a bad design when he sees one.

Without their help, this project would not be where/what it is.

REFERENCES


APPENDIX A – Calculations

Figure A.1 Shelving Weights

<table>
<thead>
<tr>
<th>Given:</th>
<th>Standard Brew Kettle size = 20 gal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard Brew Kettle weight = 34 lb</td>
</tr>
<tr>
<td></td>
<td>Standard 20gal brew uses 15gal beer</td>
</tr>
<tr>
<td>Find:</td>
<td>Determine Total shelf weights</td>
</tr>
</tbody>
</table>

**Solution:**

- **20 gal brewing** → **15 gal brew**
  - Weight of standard kettle = 34 lb
  - Safety factor 1.2 
    - Known weights
    - No unexpected loads
    - Steel system
  - **Kettle contents:** 5 lb grain/1 gallon batch size max
    - 15 gal batch → 75 lb wet grain
    - 75 lb x 1.2 = 90 lb
  - 15 gal batch → 25 gal water
    - 18 gal water (8.5 lb/gal water) = 144 lb
    - 144 lb x 1.2 = 172.8 lb
  - **Shelf Brackets:**
    - From computer estimate:
      - Mount = 8 lb
      - Shelf = 10 lb
      - Total = 18 lb
  - **Total weight of full shelf:**
    - 34 lb
    - 172.8 lb
    - 18 lb
    - Total = 235.2 lb
Figure A.2 Center Stand Applied Forces

Given:
- Shelf distance from stand = D
- Brew kettle weight = W
- Square hollow tubing

Find:
- Determine the forces on the center stand

Solution:

\[
D = 2.5; D = 2 \quad \text{in} \quad 15 \quad \text{in} \\
S = \text{shelf weight} \quad \text{center of gravity} \\
L = \text{load weight} \quad \text{center of gravity} \\
\]

\[
\begin{align*}
D & = 2.5; \quad D = 2 \quad \text{in} \quad 15 \quad \text{in} \\
S & = \text{shelf weight} \\
L & = \text{load weight} \\
\end{align*}
\]

\[
F_x = 0; \quad B_x = W_x = 0 \\
B_x = W_x = 0 \\
\]

\[
F_y = 0; \quad F_{Ay} + F_{By} = S - L = 0 \\
F_{Ay} = F_{By} = S - L = 0 \\
\]

\[
L = \text{water + kettle} = (14.4 + 3.4)1.2 \quad \text{lb} = 21.8 \quad \text{lb} \\
S = \text{shelf} = (1.8)1.2 \quad \text{lb} = 21.6 \quad \text{lb} \\
\]

\[
\begin{align*}
E_{F_y} & = 2F_{Ay} + 2.5F_{By} \quad F_{Ay} + F_{By} = W_x = 17.6 \quad \text{lb} \\
\end{align*}
\]

\[
E_{M_x} = B_x = 21.6 \quad \text{lb} - 21.6 \quad \text{lb} \quad 2 \quad \text{in} \\
B_x = 17.6 \quad \text{lb} \\
B_x = 17.6 \quad \text{lb} \\
\]

\[
A_x = 17.6 \quad \text{lb} \\
A_x = 17.6 \quad \text{lb} \\
\]
Figure A.3 Center Stand Forces

Given:
Weight and Moment Forces
Space steel tubing as solid

Find:

Solution:
\[ S = \text{Shef} = 21.6 \text{ lb} \]
\[ L = \text{Load} = 213.6 \text{ lb} \]

Total weight = 235.2 lb (compression)

Moment about Center Line
\[ S \left( D_2 \right) = L \left( D_1 \right) \]
\[ 21.6 \text{ lb} \left( 10 \text{ in} \right) = 213.6 \text{ lb} \left( 13 \text{ in} \right) \]

\[ 342.0 \text{ in} \cdot \text{lb} = 285 \text{ lb} \cdot 13 \text{ in} \]

Shear

\[ S = 342 \text{ in} \cdot \text{lb} \]

\[ t = 0.15 \text{ in} \]
\[ d = D - 0.5 \]
\[ D_1 = D - 0.35 \]

Moment

\[ M = \frac{\Delta V}{I} \]
\[ M = 3420 \text{ in} \cdot \text{lb} \]
\[ C = \frac{L}{2} \]
\[ I = \frac{D^4 - d^4}{12} \]
Figure A.4 Center Stand Forces (Continued)

\[ J = \frac{Mc}{I} \]

\[ 15,700 \text{ psi} = \frac{(3,420 \text{ lb-in})(4\frac{1}{2})}{D^4 - d^4} \]

\[ \frac{D^4 - d^4}{D(12)} = \frac{3,420 \text{ lb-in}}{2(15,700 \text{ psi})} \]

\[ \frac{D^4 - (D-2\frac{1}{2})^4}{D} = \frac{(3,420 \text{ lb-in}) \cdot 6}{15,700 \frac{1}{4}} \]

For both shelves at max height & weight on same side (Extrem)

System Solver ⇒

\[ t = 1.2'' \quad D_{\text{min}} = 1.136'' \]

\[ t = 1.875'' \quad D_{\text{min}} = 1.023'' \]

\[ t = 2.5'' \quad D_{\text{min}} = 0.984'' \]
Figure A.5 Center Stand Forces (Eccentric Column Preparation)

**Given:**
- Weight and location of kettle: 213,616 lb @ 15”
- Height of tallest shelf setting: 53”
- Flexibility of 2.1 (fixed at one end)
- 1.5” x 1.5” x .25” steel tubing

**Find:**
- Determine max deflection and verify required yield strength using Eccentric Column Analysis

**Solution:**

\[
A = D^2 - d^2 = 1.5\text{in}^2 - 1\text{in}^2 = 1.25\text{in}^2
\]

\[
I = \frac{3}{12} \cdot \frac{d^4}{12} = \frac{1.5 \times 1.5^3}{12} = \frac{1.5^4}{12}
\]

\[
I = 0.3385\text{in}^4
\]

\[
\sigma = \frac{N \cdot L}{I \cdot r}
\]

\[
r = \frac{D^2 + d^2}{12} = \frac{1.5^2 + 1.5^2}{12} = 0.5204\text{in}
\]

A501 Structural Steel (matweb.com)

\[S_y = 45700\text{ksi}\]

\[E = 11600\text{ksi}\]

From Eccentric Column Design Sheet

Max Deflection = 0.300 in \(\Rightarrow 0.49\text{°}\)

Required Yield Strength = 15138 PSI
### ECCENTRIC COLUMN ANALYSIS

Solves Equation 6-13 for design stress and Equation 6-14 for maximum deflection.

**Data To Be Entered:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length and End Fixity:</strong></td>
<td></td>
</tr>
<tr>
<td>Column length, ( L ) =</td>
<td>53 in</td>
</tr>
<tr>
<td>End fixity, ( K ) =</td>
<td>2.1</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material Properties:</strong></td>
<td></td>
</tr>
<tr>
<td>Yield strength, ( s_y ) =</td>
<td>45700 psi</td>
</tr>
<tr>
<td>Modulus of Elasticity, ( E ) =</td>
<td>1.16E+07 psi</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cross Section Properties:</strong></td>
<td></td>
</tr>
<tr>
<td>Area, ( A ) =</td>
<td>1.250 in(^2)</td>
</tr>
<tr>
<td>Moment of Inertia, ( I ) =</td>
<td>0.38854 in(^4)</td>
</tr>
<tr>
<td>Radius of Gyration, ( r ) =</td>
<td>0.520 in</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Values for Eqns. 6-13 and 6-14:</strong></td>
<td></td>
</tr>
<tr>
<td>Eccentricity = ( e ) =</td>
<td>15 in</td>
</tr>
<tr>
<td>Neutral axis to outside = ( c ) =</td>
<td>0.75 in</td>
</tr>
<tr>
<td>Allowable load = ( P_a ) =</td>
<td>213.6 lb</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Factor</strong></td>
<td></td>
</tr>
<tr>
<td>Design factor on load, ( N ) =</td>
<td>2</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Computed Values:</strong></td>
<td></td>
</tr>
<tr>
<td>Eq. Length, ( L_e = KL ) =</td>
<td>111.3 in</td>
</tr>
<tr>
<td>Column constant, ( C_c ) =</td>
<td>70.8</td>
</tr>
<tr>
<td>Argument for secant =</td>
<td>0.280 for strength</td>
</tr>
<tr>
<td>Value of secant =</td>
<td>1.0406</td>
</tr>
<tr>
<td>Argument for secant =</td>
<td>0.198 for deflection</td>
</tr>
<tr>
<td>Value of secant =</td>
<td>1.0200</td>
</tr>
<tr>
<td>Slenderness ratio, ( KL/r ) =</td>
<td>103.3</td>
</tr>
<tr>
<td>Column is:</td>
<td><strong>Long</strong></td>
</tr>
<tr>
<td>Req'd yield strength =</td>
<td>15,138 psi</td>
</tr>
<tr>
<td>Must be less than actual yield strength:</td>
<td></td>
</tr>
<tr>
<td>( s_y ) =</td>
<td>45,700 psi</td>
</tr>
<tr>
<td>Max. deflection, ( y_{max} ) =</td>
<td>0.300 in</td>
</tr>
</tbody>
</table>
Figure A.7 Base Hinge Forces

**Given:**
- Moment forces from center stand
- Distance of stand to hinges

**Find:**
- Determine shear force on base hinge pins

**Solution:**

\[ \begin{align*}
2F_c &= 0; \\
B &= A = \phi \\
D &= A
\end{align*} \]

\[ \begin{align*}
2M_B &= \phi; \\
1.1''(A) + 1''(F_b) - 1''(F_c) &= 0 \\
A &= \frac{1''(21.6 lb) - 1''(21.6 lb)}{1.1''} \\
A &= 757.11 lb \\
B &= 757.11 lb
\end{align*} \]
Figure A.8 Base Hinge Pin Selection

Given:
- Forces on base pins from load
  - \( F = 757.1 \text{ lb} \) force
  - 2 pins

Find:
- Determine minimum diameter

Solution:

Hinge pin in double shear

\[
A = \frac{1}{4} \pi b^2
\]

\[
T = \frac{F}{2A} = \frac{757.1 \text{ lb}}{2 \pi b^2 / 4}
\]

Steel Shear Strength = 0.60 (Tensile Strength)

\[
= 0.60 (55 \text{ ksi}) = 33,000 \text{ psi}
\]

Steel Shear Strength = 1020 mild Steel

\[
T = \frac{4}{\pi} (757.1 \text{ lb})
\]

\[
D_2 = \frac{2(757.1 \text{ lb})}{1020 \text{ psi}}
\]

\[
D_2 = \frac{2(757.1 \text{ lb})}{1020 (33,000 \text{ psi})}
\]

\[
D_2 = 0.0146 \text{ in}^2
\]

\[
D = 0.1209 \text{ in}
\]
Figure A.9 Shelf Height Pin Forces

Given: Brew kettle weight & distance
Shelf weight & distance

Find: Determine shear force on shelf pins

\[
\begin{align*}
F_S &= 21.6 \text{ lb} \\
F_X &= 21.6 \text{ lb}
\end{align*}
\]

\[
\begin{align*}
F_x &= 0 \\
F_y &= 0
\end{align*}
\]

\[
\begin{align*}
\Sigma F_x &= 0; \quad B_x = A_x = 0 \\
\Sigma F_y &= 0; \quad F_y = F_x + A_y + B_y = 0
\end{align*}
\]

\[
A_y B_y = F_y = F_x
\]

\[
\begin{align*}
2 A_y B_y &= (2.16 \text{ lb})(10^3) - F_x(15^3) = 0 \\
A_y B_y &= 2.35 \text{ lb}
\end{align*}
\]

\[
\begin{align*}
B_x &= \frac{F_x(15^3) + F_y(15^3)}{2^3} \\
B_x &= \frac{(21.6 \text{ lb})(10^3) + (2.35 \text{ lb})(15^3)}{2^3}
\end{align*}
\]

\[
\begin{align*}
B_x &= 1710 \text{ lb} \\
A_x &= 1710 \text{ lb}
\end{align*}
\]

\[
F_{B_x} = \sqrt{B_x^2 + B_y^2}
\]

\[
F_{B_x} = \sqrt{1710^2 + 117.6^2}
\]

\[
F_B = 1714.1 \text{ lb}
\]

\[
F_A = 1714.1 \text{ lb}
\]
Figure A.10 Shelf Height Pin Selection

Given:
Forces on shelf pins from load:
\[ F = 1714.1 \text{ lb} \text{ force} \]
Pin material: 1020 mild steel
Shear strength: 33 ksi

Find:
Determine minimum pin diameter

Solution:
Pins in double shear

\[ D = \sqrt{\frac{2F}{\tau A}} \]
\[ A = \pi D^2 \frac{t^2}{4} \]

\[ \frac{1020 \text{ lb}}{2(33000 \text{ psi})} \Rightarrow D = \sqrt{\frac{2(1714.1 \text{ lb})}{2 \pi (33000 \text{ psi})}} \]
\[ D = 0.182 \text{ in} \]
Figure A.11 Shelf Hinge Pin Forces

Given: Beam Kettle weight & Distance
213.6 lb @ 10"

Find: Shelf length & hinge location

Solution:

\[ F_k = 213.6 \text{ lb} \]

- \( E_f = 0 \), \( B_x - A_x = 0 \)
- \( E_f = 0 \), \( B_y + A_y - F_k = 0 \)

- \( E_m = \phi \), \( A_y (1\text{"}) + A_x (1.1\text{"}) - F_k (10\text{"}) = 0 \)
  \[ A_y = \frac{F_k (10\text{"}) - A_x (1.1\text{"})}{1\text{"}} = 213.6 \text{ lb} - 1.1A_x \]

- \( E_m = \phi \), \( B_x (1\text{"}) - B_y (1\text{"}) - F_k (4\text{"}) = 0 \)
  \[ B_y = \frac{B_x (1\text{"}) + F_k (4\text{"})}{1\text{"}} = A_x \]
  \[ A_y = 213.6 \text{ lb} - 1.1 \left( \frac{B_y (1\text{"}) + F_k (4\text{"})}{1\text{"}} \right) \]

- \( -B_y + 213.6 \text{ lb} + \sqrt{ \left( B_y (1\text{"}) + F_k (4\text{"}) \right)^2 - 1\text{"}} = F_k \)
- \( -B_y + 313.6 \text{ lb} = 213.6 \text{ lb} = 213.6 \text{ lb} \)
- \( 2B_y = 213.6 \text{ lb} - 213.6 \text{ lb} = 213.6 \text{ lb} \)
- \( 2B_y = -2007.8 \text{ lb} \)
- \( B_y = 1003.9 \text{ lb} \)
Figure A.12 Shelf Hinge Pin Forces (Continued)

Continued:

\[-B_y + A_y = F_h\]
\[A_y = 1003.9 \text{ lb} + 213.6 \text{ lb}\]
\[A_y = 1217.5 \text{ lb}\]

\[B_y = \frac{B_y (6.5') + F_h (6.5')}{1.1''}\]
\[B_x = \frac{1003.9 \text{ lb} + 213.6 \text{ lb}(6.5'')}{1.1''}\]
\[B = 990.5 \text{ lb}\]
\[A = 990.5 \text{ lb}\]

\[A = \sqrt{B_x^2 + B_y^2} = \sqrt{990.5 \text{ lb}^2 + 1003.9 \text{ lb}^2}\]
\[A = 1569.4 \text{ lb}\]
Figure A.13 Shelf Hinge Pins Selection

Shelf Hinge Pin Selection

Given:  Forces on shelf pins from load
   Hinge pin = 1569.4 lb
   Locking Pin = 1410.5 lb

Find:  Determine minimum pin diameter

Solution:  "Heavy Duty" Hinge ⇒ Pins are in double shear

\[
\tau = \frac{F}{2A} \quad A = \frac{\pi D^2}{4}
\]

Hinge:  \( \frac{\pi D^2}{4} = \frac{1569.4 \text{ lb}}{2 \times (33 \text{ ksi})} \)

\[
D = \sqrt{\frac{2 \times 1569.4 \text{ lb}}{1^\prime \times 33 \text{ksi}}} \approx 0.174''
\]

Locking:  \( \frac{2 \times (1410.5 \text{ lb})}{\sqrt{\pi} \times 33 \text{ksi}} \) \( \approx 0.168'' \)

1020 Mild Steel
Shear Strength = 33 ksi
Figure A.14 Center Stand Weight and Center of Gravity

Given:
- Commerically available tubing size
- Stand height = 60"
- Base width/length = 20" x 20"

Find:
- Determine the weight and center of gravity

Solution:

\[
\text{60" tall } \left( \frac{1 \text{ ft}}{12"} \right) = 5 \text{ ft}
\]

Weight of 1.5" x 1.5" hollow square tubing = 4.07 lb/ft

\[
5 \text{ ft} \left( \frac{4.07 \text{ lb}}{1 \text{ ft}} \right) = 20.35 \text{ lb}
\]

Center of gravity:
- Assume symmetrical shape throughout

\[
\text{CG} = (1, 50"
\]

For center stand
Figure A.15 Base Weight and Center of Gravity

Given: Commercially available tubing size
Base width/length = 24" x 24"

Task: Determine the weight and center of gravity

Solution:

\[
\text{Weight of } 1.5" \times 1.5" \text{ hollow tubing} = 1.07 \text{ lb/ft} \\
8.167 \text{ ft} \times (1.07 \text{ lb/ft}) = 8.67 \text{ lb}
\]

Center of Gravity: Assume symmetrical shape

\[ CG = \frac{25" + 25"}{2} = 25" \text{ for base} \]

.75" from floor
Figure A.16 System Center of Gravity

Given: Distances & weights of all components

Find: Determine system center of gravity from 45° with 2 kettles

Solution:

\[
\begin{align*}
\text{CG}_{\text{Cham}} &= (17.68'', 1'') \quad 33.24\text{lb} \\
\text{CG}_{\text{Top}} &= (17.68'', 50'') \quad 20.55\text{lb}
\end{align*}
\]

\[
\begin{align*}
\text{CG}_{\text{Swt1}} &= (-10.61'', 53'') \quad 21.6\text{lb} \\
\text{CG}_{\text{Kettle1}} &= (-7.07'', 64'') \quad 21.6\text{lb} \\
\text{CG}_{\text{Swt2}} &= (-10.61'', 31'') \quad 21.6\text{lb} \\
\text{CG}_{\text{Kettle2}} &= (-7.07'', 42'') \quad 21.6\text{lb}
\end{align*}
\]

\[
\begin{align*}
\text{CG}_{x} &= \frac{\sum \text{Moments}}{\text{Total Weight}} = -8.45'' \\
\text{CG}_{y} &= \frac{\sum \text{Moments}}{\text{Total Weight}} = 41.7''
\end{align*}
\]

\[
\begin{align*}
\text{CG} &= (-8.45'', 41.7'') \quad 523.99\text{lb}
\end{align*}
\]

8.45'' (523.99lb) = 60'' (615)

73.81lb at top to knock over
APPENDIX B – Sketches

Figure B.1 Completed Stand Rendering
### Brew Stand Assembly and Sub Assembly List

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Center_Tree_V2</td>
<td>Center Tree</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Base_Leg_V2</td>
<td>Leg with Tabs</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>15195A16</td>
<td>Hinge</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Shelf_Ass</td>
<td>Shelf Assembly</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>92384AD96</td>
<td>Quick Release Pin</td>
<td>4</td>
</tr>
</tbody>
</table>

**Figure B.2** Brew Stand Assembly and Sub Assembly List
Figure B.3 Center Tree Post
Figure B.4 Center Tree Base A
Figure B.5 Center Tree Base B
Figure B.6 Base Legs
Figure B.7 Base Leg Tabs
Figure B.8 Shelf Collar
Figure B.9 Shelf Ring

1.25 inch flat bar curved on three roller machine. 9 inch diameter ideal.

ø9.0 ±.50
Figure B.10 Shelf Mount Assembly
Figure B.11 Shelf Ring Assembly
Figure B.12 Base Leg Assembly

Holes in tabs to be drilled after welded on to leg. Tabs to be centered on leg height.
Figure B.13 Center Tree Assembly
Figure B.15 Starting Sketches Showing Friction Lock Hinges
Figure B.16 Original Rectangular Shelves
Figure B.17 Original Hinge Design Sketch
# APPENDIX C – Parts List

<table>
<thead>
<tr>
<th>Item #</th>
<th>Quantity</th>
<th>Supplier</th>
<th>Description</th>
<th>Drawing #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Online Metals</td>
<td>Center Tree Post</td>
<td>B.3</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Online Metals</td>
<td>Legs</td>
<td>B.6</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Online Metals</td>
<td>Rack Arms</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>MSC/McMaster</td>
<td>Hinge Set</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Online Metals</td>
<td>Leg Base</td>
<td>B.4-5</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>MSC/McMaster</td>
<td>Pins</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>12</td>
<td>MSC/McMaster</td>
<td>Leg Tabs</td>
<td>B.7</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>Online Metals</td>
<td>Rack Steel Ring</td>
<td>B.9</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>MSC/McMaster</td>
<td>Gussets</td>
<td>N/A</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>Online Metals</td>
<td>Rack Steel Collar</td>
<td>B.8</td>
</tr>
</tbody>
</table>
## APPENDIX D – Budget

### Parts List

<table>
<thead>
<tr>
<th>Item #</th>
<th>Quantity</th>
<th>Drawing #</th>
<th>Description</th>
<th>Vendor</th>
<th>Cost Each</th>
<th>Estimated Cost</th>
<th>Actual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 ft</td>
<td>B.3-6</td>
<td>1.5&quot;x1.5&quot;x.25&quot; Tubing (8ft)</td>
<td>Online Metals</td>
<td>$42.50</td>
<td>$85.00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3 ft</td>
<td>B.8</td>
<td>2&quot;x2&quot;x.25&quot; Tubing (2ft)</td>
<td>Online Metals</td>
<td>$14.30</td>
<td>$21.45</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>20 in</td>
<td>B.9</td>
<td>1.25&quot; by .25&quot; Flat Bar (2ft)</td>
<td>Online Metals</td>
<td>$4.18</td>
<td>$4.18</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>B.7</td>
<td>Gussets</td>
<td>MSC/McMaster</td>
<td>$0.00</td>
<td>$0.00</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>N/A</td>
<td>Burners</td>
<td>Beer Site</td>
<td>$0</td>
<td>$0.00</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>N/A</td>
<td>Pins</td>
<td>MSC/McMaster</td>
<td>$5</td>
<td>$20.00</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>N/A</td>
<td>Hinges</td>
<td>MSC/McMaster</td>
<td>$6.57</td>
<td>$13.14</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>N/A</td>
<td>Small Hinges</td>
<td>MSC/McMaster</td>
<td>0.54</td>
<td>$2.16</td>
<td></td>
</tr>
</tbody>
</table>

**Tax & Shipping**

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>$145.93</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amount Budgeted</strong></td>
<td>$300.00</td>
<td></td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>$154.07</td>
<td></td>
</tr>
</tbody>
</table>
# APPENDIX E – Schedule

## Fall Quarter

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Task Description</th>
<th>Estimated Time (hr)</th>
<th>Actual Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Proposal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.A</td>
<td>Project Idea</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>1.B</td>
<td>Introduction</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>1.C</td>
<td>Design &amp; Analysis</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td>1.D</td>
<td>Methods &amp; Construction</td>
<td>5</td>
<td>4.5</td>
</tr>
<tr>
<td>1.E</td>
<td>Testing Methods</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>1.F</td>
<td>Budget &amp; Schedule</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>1.G</td>
<td>Discussion</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>1.H</td>
<td>Conclusion</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>1.I</td>
<td>Documentation</td>
<td>16</td>
<td>17.5</td>
</tr>
<tr>
<td>1.J</td>
<td>Appendix</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td><strong>Subtotal</strong></td>
<td><strong>92</strong></td>
<td><strong>84</strong></td>
</tr>
<tr>
<td>2</td>
<td>Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.A</td>
<td>Analysis of Center Tree</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>2.B</td>
<td>Analysis of Hinges</td>
<td>10</td>
<td>8.5</td>
</tr>
<tr>
<td>2.C</td>
<td>Analysis of Pins</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2.D</td>
<td>Analysis of Rack</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>2.E</td>
<td>Analysis of Feet</td>
<td>4</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td><strong>Subtotal</strong></td>
<td><strong>32</strong></td>
<td><strong>30</strong></td>
</tr>
<tr>
<td>3</td>
<td>Documentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.A</td>
<td>Drawing of Center Tree</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>3.B</td>
<td>Drawing of Hinges</td>
<td>4</td>
<td>5.5</td>
</tr>
<tr>
<td>3.C</td>
<td>Drawing of Pins</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3.D</td>
<td>Drawing of Rack</td>
<td>4</td>
<td>3.5</td>
</tr>
<tr>
<td>3.E</td>
<td>Drawing of Feet</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>3.F</td>
<td>Assembly Drawing</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td><strong>Subtotal</strong></td>
<td><strong>16</strong></td>
<td><strong>17.5</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>140</strong></td>
<td><strong>131.5</strong></td>
</tr>
</tbody>
</table>
# Beer Brewing Rack

## Winter Quarter

### Task Number 1: Build

<table>
<thead>
<tr>
<th>Task</th>
<th>Estimated Time (hr)</th>
<th>Actual Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Build: Center Tree Assembly</td>
<td>13.9</td>
</tr>
<tr>
<td>i</td>
<td>Cut Part: Center Tree Post</td>
<td>2</td>
</tr>
<tr>
<td>ii</td>
<td>Drill holes</td>
<td>4</td>
</tr>
<tr>
<td>iii</td>
<td>Cut Part: Center Tree Base A</td>
<td>1</td>
</tr>
<tr>
<td>iv</td>
<td>Cut Part: Center Tree Base B</td>
<td>0.4</td>
</tr>
<tr>
<td>v</td>
<td>Weld Part: 1.A.i,iii,iv</td>
<td>3</td>
</tr>
<tr>
<td>vi</td>
<td>Cut Part: Gussets</td>
<td>1.5</td>
</tr>
<tr>
<td>vii</td>
<td>Weld Part: Gussets</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>Build: Base Leg Version 2</td>
<td>15.7</td>
</tr>
<tr>
<td>i</td>
<td>Cut Part: Base Leg</td>
<td>2</td>
</tr>
<tr>
<td>ii</td>
<td>Square and Tack Hinges</td>
<td>4</td>
</tr>
<tr>
<td>iii</td>
<td>Cut Part: Base Leg Tab</td>
<td>2.5</td>
</tr>
<tr>
<td>iv</td>
<td>Weld Part: 1.B.i,iii</td>
<td>2.4</td>
</tr>
<tr>
<td>v</td>
<td>Weld Part: Hinges</td>
<td>1.8</td>
</tr>
<tr>
<td>vi</td>
<td>Drill Pin Holes</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>Build: Shelf Mount Assembly</td>
<td>10.6</td>
</tr>
<tr>
<td>i</td>
<td>Cut Part: Collar</td>
<td>1.4</td>
</tr>
<tr>
<td>ii</td>
<td>Drill Pin Holes</td>
<td>4</td>
</tr>
<tr>
<td>iii</td>
<td>Cut Part: Collar Arm</td>
<td>0.4</td>
</tr>
<tr>
<td>iv</td>
<td>Grind inside Collar</td>
<td>2.3</td>
</tr>
<tr>
<td>v</td>
<td>Weld Part: 1.C.i,iii</td>
<td>2.5</td>
</tr>
<tr>
<td>D</td>
<td>Build: Shelf Assembly</td>
<td>11.3</td>
</tr>
<tr>
<td>i</td>
<td>Cut Part: Ring</td>
<td>3</td>
</tr>
<tr>
<td>ii</td>
<td>Cut Part: Ring Arm</td>
<td>1.4</td>
</tr>
<tr>
<td>iii</td>
<td>Weld Part: 1.D.i,ii</td>
<td>5.5</td>
</tr>
<tr>
<td>iv</td>
<td>Weld Part: Hinges</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Total** | 51.5 | 49.5 |
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Task</th>
<th>Estimated Time (hr)</th>
<th>Actual Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>List parameters</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>B</td>
<td>Design test &amp; scope</td>
<td>8</td>
<td>2.8</td>
</tr>
<tr>
<td>C</td>
<td>Obtain resources</td>
<td>3</td>
<td>1.3</td>
</tr>
<tr>
<td>D</td>
<td>Make test sheets</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>Plan analyses</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>F</td>
<td>Instrument device</td>
<td>8</td>
<td>2.8</td>
</tr>
<tr>
<td>G</td>
<td>Test plan</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>H</td>
<td>Perform evaluation</td>
<td>25</td>
<td>8.4</td>
</tr>
<tr>
<td>I</td>
<td>Take testing pictures</td>
<td>2</td>
<td>2.2</td>
</tr>
<tr>
<td>J</td>
<td>Update report</td>
<td>6</td>
<td>10.25</td>
</tr>
<tr>
<td>K</td>
<td>Website</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>74</strong></td>
<td><strong>45.22</strong></td>
</tr>
</tbody>
</table>

Beer Brewing Rack
Spring Quarter
Andrew Kastning

Task Number| Task                        | Estimated Time (hr) | Actual Time (hr) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>8</td>
<td>2.8</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>3</td>
<td>1.3</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>E</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>8</td>
<td>2.8</td>
</tr>
<tr>
<td>8</td>
<td>G</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>H</td>
<td>25</td>
<td>8.4</td>
</tr>
<tr>
<td>10</td>
<td>I</td>
<td>2</td>
<td>2.2</td>
</tr>
<tr>
<td>11</td>
<td>J</td>
<td>6</td>
<td>10.25</td>
</tr>
<tr>
<td>12</td>
<td>K</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>74</strong></td>
<td><strong>45.22</strong></td>
</tr>
</tbody>
</table>
APPENDIX F – Resources


APPENDIX G – Evaluation Sheet

Print off this page to assist in testing deliverables: 1, 2, 4, 6, 7, and 8 (Appendix H).

Deliverables 3 and 5 have their own testing procedures and pages in Appendix H.

- Total weight is 72lbs (less than 150 for passing).
  ___________lbs

- The rack is approximately 24” x 24” x 60” (less than 30” x 30” x 72” for passing).
  ___________inches x ___________inches x ___________inches

- Each rack is adjustable for height in 2” increments (as required).
  □ (check if passed)

- Each rack can be mounted to any of the four sides of the tree (as required).
  □ (check if passed)

- Each rack is 11.5” diameter (greater than 8” for passing, still held brew kettles).
  ___________inches

- The 1.2 Safety Factor was included in weights (as required).
  □ (check if passed)
APPENDIX H – Testing Report

Introduction
The testing of the Beer Brewing Rack System was completed to show success or failure for every design requirement originally listed. The testing was documented for each step to ensure repeatability for each requirement. The testing was done with the 1.2 Safety Factor for all weight requirements. All testing was done in Hogue Hall (The Fluke Lab).

The following items were listed as design requirements and were all tested.

- It must weigh less than 150lbs total.
- It must take up less than 2.5ft x 2.5ft x 6ft when collapsed.
- The tree will not flex more than 2° when under a 200lb load.
- Each rack must be individually adjustable for height in 2” increments.
- Each rack must be capable of holding 200lbs each.
- Each rack must be able to be mounted to any of the four sides of the tree.
- Each rack will be a minimum of 8 inches diameter.
- All weight requirements will include a 1.2 safety factor.

Of the eight design requirements, seven items needed to be tested to ensure success (the eighth item being the safety factor, applied to the first seven). Four of these requirements applied directly to the center tree of the rack (requirement #3, 4, 5, and 6). Requirements 3 and 5 required the most testing to ensure not only success, but safety.

Based on initial calculations and information received from the CAD designs, the following are the predicted values for the above requirements.

1. Total weight is predicted to be 89lbs based on CAD software.
2. The rack is approximately 24” x 24” x 60”.
3. The tree will flex approximately 2°.
4. Each rack is adjustable for height in 2” increments.
5. Each rack will hold over 280lbs without yielding.
6. Each rack can be mounted to any of the four sides of the tree.
7. Each rack is a minimum of 8 inches diameter.
8. The 1.2 Safety Factor will be included.

Method/Approach
The testing of the center tree required a number of resources. The measurements and weight data were gathered through the use of shop measuring devices (tape measure, calipers, and bathroom scale). Other items required were strain gauges, Wheatstone bridge circuits, computer and strain gauge software, and calibrated weights. All of these items were available for student use at CWU. The instruction for use of the strain gauges and software was available from faculty and
student lab technicians. The data from the strain gauges was able to be exported into Microsoft Excel, which was used for the angle of deflection tests as well. All graphs and other visualizations of data were completed using Excel.

The testing was all able to be accomplished in the Fluke lab without limitations. To prevent damaging the floor in case of failure, pieces of medium-density fiberboard were placed under the weights/racks.

The precision of data received for strain and angle of deflection was determined to be within 2% with the number of trials performed (3 for each test). Based on the procedures used and recommendations by industry suppliers of strain gauges, the accuracy is within 1%. No tests were within 3% of the failure envelope, therefore, all tests were given a pass without conditions. Measurement and weight data was performed 3 times each (Requirement #1, 2, 4, and 7) and averaged out. Data and graphical representations can be found in Appendix H.

Test Procedure
The tests for center tree stain and angle of deflection followed specific steps to ensure repeatability of each respective test. The tests for length or weight of a specific item was simply measured and recorded, these items did not need a list of steps for the simplicity of the tasks. For schedule and timing of each test, refer to the Gantt charts in Appendix H.

Procedure for Center Tree Strain
1. Apply strain gauges to center tree per supplied literature. Let fully cure before testing (at least 24 hours).
2. Prepare computer/notebook for separating and recording data. Mark which strain gauge is axial and which is transverse.
3. Measure and record each weight. Number each weight using masking tape. (The use of calibrated weights eliminates the need for this step).
4. Set up system in first position and ensure all locking pins are fully in place. Note the position of all components.
5. Place a single weight (20.0 lbs) on hot water heater to simulate water inside the pipe and heating element.
6. Zero strain gauge at the strain gauge factor number.
7. Place a single weight (20.0 lbs) on each burner shelf.
8. Record strain gauge values.
9. Repeat steps 7-8 until a minimum of 200lbs has been applied to each shelf (400 lbs total, 10 weights on each shelf).
10. Remove weights and repeat steps 6-8 two more times for a total of 3 sets of data.
11. Repeat steps 4-8 for each additional position (both racks on front, back, and with one rack on each side).

Procedure for Center Tree Angle of Deflection
1. Prepare computer/notebook for recording data.
2. Measure and record each weight. Number each weight using masking tape. (The use of calibrated weights eliminates the need for this step).
3. Set up system with both racks/burner on single side ensure all locking pins are fully in place. This will determine the MAXIMUM deflection the rack could experience.
4. Place a single weight (20.0 lbs) on hot water heater to simulate water inside the pipe and heating element.
5. Place a single weight (20.0 lbs) on each burner shelf.
6. Record angle of deflection.
7. Repeat steps 5-6 until a minimum of 200lbs has been applied to each shelf (400 lbs total, 10 weights on each shelf).
8. Remove weights and repeat steps 5-7 two more times for a total of 3 sets of data.

Safety
These tests used heavy objects and high stressed steel. Closed toed shoes and eye protection were used. The devise being tested does have the risk of burns during normal operation. The removal of hot water and burning gas during testing mitigated the risk of burns.

Discussion
The testing for strain in the center tree used three different configurations to gather maximum, minimum, and most-likely stresses. With both shelves and the burner on one side (strain gauge side), the axial and bending compressive stresses were at a maximum. With all components opposite the strain gauge, the bending stress was in tension while the axial stress was in compression. With the racks and burners all on different sides, the bending stresses were counteracting one another. This configuration is the most likely to be seen during brewing, as it is the only configuration that allows a full-size brew kettle to fit on each shelf.

The testing for angle of deflection only used the maximum strain configuration to find the maximum angle of deflection. Even with both of the shelves and burner on a single side (an unusable position), the center tree only deflected a maximum of one degree.

Deliverables
All of the testing indicated the design and construction of the Beer Brewing Rack System was a success in each requirement. The rack not only passed all requirements, but during testing of brewing, there were no unforeseen issues with the rack. The successful brewing tests indicate this is a useable system. The following is a list of the design requirements and the tested results:

1. Total weight is 72lbs (less than 150 for passing).
2. The rack is approximately 24” x 24” x 60” (less than 30” x 30” x 72” for passing).
3. The tree flexed 1° maximum (less than 2° for passing).
4. Each rack is adjustable for height in 2” increments (as required).
5. Each rack held 200 lbs without yielding; maximum strain was .05% (at least 200lbs required for passing; .2% maximum for A500 steel).
6. Each rack can be mounted to any of the four sides of the tree (as required).
7. Each rack is 11.5” diameter (greater than 8” for passing, still held brew kettles).
8. The 1.2 Safety Factor was included in weights (as required).
The system passed in each requirement and was capable of brewing successfully. The system has also been appreciated by multiple people within the brewing program at CWU and by hobbyists within the local area. The system, while having room for future improvement, is completely modular and has been requested to be manufactured by hobbyists. This system is a success and is predicted to be a commercial success as well.
### Appendix

#### Testing Gantt Chart

**Spring Quarter**

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Task</th>
<th>Estimated Time (hrs)</th>
<th>Actual Time (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Test</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>List parameters</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>Design test &amp; scope</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>Obtain resources</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>Make test sheets</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>E</td>
<td>Plan analyses</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>Instrument device</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>G</td>
<td>Test plan</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>H</td>
<td>Perform evaluation</td>
<td>25</td>
</tr>
<tr>
<td>10</td>
<td>I</td>
<td>Take testing pictures</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>J</td>
<td>Update report</td>
<td>6</td>
</tr>
</tbody>
</table>

**Total** 69 21.77

---

#### Test 1

**Spring Quarter**

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Task</th>
<th>Estimated Time (min)</th>
<th>Actual Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Test</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>Set up strain gauge</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>Prepare Tablet</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>Measure each weight</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>Set up system</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>E</td>
<td>Place weight on heater</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>Zero strain gauge</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>G</td>
<td>Test/record weight 5x</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>H</td>
<td>Record 3x</td>
<td>24</td>
</tr>
<tr>
<td>10</td>
<td>I</td>
<td>Change setup</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>J</td>
<td>Repeat Test</td>
<td>48</td>
</tr>
</tbody>
</table>

**Total** 110 429

---

#### Test 2

**Spring Quarter**

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Task</th>
<th>Estimated Time (min)</th>
<th>Actual Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Test</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>Prepare Recording Device</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>Measure each weight</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>Set up system</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>Place weight on heater</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>G</td>
<td>Test/record weight 5x</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>H</td>
<td>Record 3x</td>
<td>20</td>
</tr>
</tbody>
</table>

**Total** 40 73
Test Procedure
This page can be printed separate from the report for a testing guide.

Procedure for Center Tree Strain
- Apply strain gauges to center tree per supplied literature. Let fully cure before testing (at least 24 hours).
- Prepare computer/notebook for separating and recording data. Mark which strain gauge is axial and which is transverse.
- Measure and record each weight. Number each weight using masking tape. (The use of calibrated weights eliminates the need for this step).
- Set up system in first position and ensure all locking pins are fully in place. Note the position of all components.
- Place a single weight (20.0 lbs) on hot water heater to simulate water inside the pipe and heating element.
- Zero strain gauge at the strain gauge factor number.
- Place a single weight (20.0 lbs) on each burner shelf.
- Record strain gauge values.
- Repeat steps 7-8 until a minimum of 200lbs has been applied to each shelf (400 lbs total, 10 weights on each shelf).
- Remove weights and repeat steps 6-8 two more times for a total of 3 sets of data.
- Repeat steps 4-8 for each additional position (both racks on front, back, and with one rack on each side).

Procedure for Center Tree Angle of Deflection
- Prepare computer/notebook for recording data.
- Measure and record each weight. Number each weight using masking tape. (The use of calibrated weights eliminates the need for this step).
- Set up system with both racks/burner on single side ensure all locking pins are fully in place. This will determine the MAXIMUM deflection the rack could experience.
- Place a single weight (20.0 lbs) on hot water heater to simulate water inside the pipe and heating element.
- Place a single weight (20.0 lbs) on each burner shelf.
- Record angle of deflection.
- Repeat steps 5-6 until a minimum of 200lbs has been applied to each shelf (400 lbs total, 10 weights on each shelf).
- Remove weights and repeat steps 5-7 two more times for a total of 3 sets of data.

Safety
This test has exposure to heavy objects and high stressed steel. Closed toed shoes and eye protection are required at a minimum. The devise being tested does have the risk of burns during normal operation. The removal of hot water and burning gas during testing mitigates the risk of burns.
### Strain Data

<table>
<thead>
<tr>
<th></th>
<th>Front Strain (UE)</th>
<th>Back Strain (UE)</th>
<th>Sides Strain (UE)</th>
<th>Weight</th>
<th>Axial Strain</th>
<th>Radial Strain</th>
<th>Weight</th>
<th>Axial Strain</th>
<th>Radial Strain</th>
<th>Weight</th>
<th>Axial Strain</th>
<th>Radial Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rack</td>
<td>0</td>
<td>0</td>
<td>(Shelf)</td>
<td>0</td>
<td>89</td>
<td>19</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>-1</td>
</tr>
<tr>
<td>(Shelf)</td>
<td>0</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>33</td>
<td>37</td>
<td></td>
<td>20</td>
<td>23</td>
<td>-9</td>
<td>20</td>
<td>22</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>-2</td>
<td>47</td>
<td></td>
<td>40</td>
<td>68</td>
<td>-24</td>
<td>40</td>
<td>23</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>-53</td>
<td>62</td>
<td></td>
<td>60</td>
<td>96</td>
<td>-32</td>
<td>60</td>
<td>28</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>-84</td>
<td>72</td>
<td></td>
<td>80</td>
<td>140</td>
<td>-47</td>
<td>80</td>
<td>26</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>-144</td>
<td>89</td>
<td></td>
<td>100</td>
<td>175</td>
<td>-59</td>
<td>100</td>
<td>36</td>
<td>-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>-176</td>
<td>99</td>
<td></td>
<td>120</td>
<td>211</td>
<td>-71</td>
<td>120</td>
<td>33</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>-229</td>
<td>116</td>
<td></td>
<td>140</td>
<td>244</td>
<td>-80</td>
<td>140</td>
<td>34</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>-273</td>
<td>131</td>
<td></td>
<td>160</td>
<td>280</td>
<td>-90</td>
<td>160</td>
<td>35</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>-323</td>
<td>145</td>
<td></td>
<td>180</td>
<td>330</td>
<td>-105</td>
<td>180</td>
<td>38</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>-366</td>
<td>161</td>
<td></td>
<td>200</td>
<td>396</td>
<td>-118</td>
<td>200</td>
<td>38</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Test 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rack</td>
<td>0</td>
<td>0</td>
<td>(Shelf)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(Shelf)</td>
<td>0</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>-33</td>
<td>9</td>
<td></td>
<td>20</td>
<td>26</td>
<td>-5</td>
<td>20</td>
<td>12</td>
<td>-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>-72</td>
<td>24</td>
<td></td>
<td>40</td>
<td>71</td>
<td>-15</td>
<td>40</td>
<td>21</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>-104</td>
<td>34</td>
<td></td>
<td>60</td>
<td>101</td>
<td>-25</td>
<td>60</td>
<td>28</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>-152</td>
<td>48</td>
<td></td>
<td>80</td>
<td>146</td>
<td>-39</td>
<td>80</td>
<td>31</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>-199</td>
<td>58</td>
<td></td>
<td>100</td>
<td>180</td>
<td>-53</td>
<td>100</td>
<td>34</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>-245</td>
<td>74</td>
<td></td>
<td>120</td>
<td>219</td>
<td>-64</td>
<td>120</td>
<td>32</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>-280</td>
<td>85</td>
<td></td>
<td>140</td>
<td>249</td>
<td>-77</td>
<td>140</td>
<td>34</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>-317</td>
<td>102</td>
<td></td>
<td>160</td>
<td>293</td>
<td>-87</td>
<td>160</td>
<td>35</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>-401</td>
<td>128</td>
<td></td>
<td>180</td>
<td>338</td>
<td>-103</td>
<td>180</td>
<td>39</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>-474</td>
<td>152</td>
<td></td>
<td>200</td>
<td>402</td>
<td>-112</td>
<td>200</td>
<td>42</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Test 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rack</td>
<td>0</td>
<td>0</td>
<td>(Shelf)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(Shelf)</td>
<td>0</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>-28</td>
<td>11</td>
<td></td>
<td>20</td>
<td>29</td>
<td>-12</td>
<td>20</td>
<td>19</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>-71</td>
<td>26</td>
<td></td>
<td>40</td>
<td>72</td>
<td>-29</td>
<td>40</td>
<td>26</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>-100</td>
<td>36</td>
<td></td>
<td>60</td>
<td>103</td>
<td>-36</td>
<td>60</td>
<td>27</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>-151</td>
<td>51</td>
<td></td>
<td>80</td>
<td>150</td>
<td>-55</td>
<td>80</td>
<td>32</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>-202</td>
<td>60</td>
<td></td>
<td>100</td>
<td>183</td>
<td>-69</td>
<td>100</td>
<td>36</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>-251</td>
<td>75</td>
<td></td>
<td>120</td>
<td>227</td>
<td>-80</td>
<td>120</td>
<td>37</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>-278</td>
<td>88</td>
<td></td>
<td>140</td>
<td>255</td>
<td>-93</td>
<td>140</td>
<td>42</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>-329</td>
<td>107</td>
<td></td>
<td>160</td>
<td>297</td>
<td>-104</td>
<td>160</td>
<td>40</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>-400</td>
<td>139</td>
<td></td>
<td>180</td>
<td>340</td>
<td>-117</td>
<td>180</td>
<td>43</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>-481</td>
<td>166</td>
<td></td>
<td>200</td>
<td>404</td>
<td>-135</td>
<td>200</td>
<td>44</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

![Load vs. Strain](chart.png)
Angle of Deflection Data

<table>
<thead>
<tr>
<th>Load</th>
<th>Deflection</th>
<th>Corrected</th>
<th>Deflection</th>
<th>Corrected</th>
<th>Deflection</th>
<th>Corrected</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-0.5</td>
<td>0</td>
<td>-0.25</td>
<td>0</td>
<td>-0.25</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>-0.25</td>
<td>0.25</td>
<td>-0.25</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>0.5</td>
<td>-0.25</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>120</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0.25</td>
<td>0.25</td>
<td>0.5</td>
</tr>
<tr>
<td>160</td>
<td>0.5</td>
<td>1</td>
<td>0.25</td>
<td>0.5</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>200</td>
<td>0.25</td>
<td>0.75</td>
<td>0.25</td>
<td>0.5</td>
<td>0.25</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Beer Rack
Load vs. Deflection

![Graph showing load vs. deflection for different tests.
Test 1 (blue), Test 2 (orange), Test 3 (gray).]
## APPENDIX I – Testing Data

### Strain Data

<table>
<thead>
<tr>
<th>Front</th>
<th>Strain (UE)</th>
<th>Back</th>
<th>Strain (UE)</th>
<th>Sides</th>
<th>Strain (UE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight</td>
<td>Axial Strain</td>
<td>Radial Strain</td>
<td>Weight</td>
<td>Axial Strain</td>
</tr>
<tr>
<td>Test 1</td>
<td>Rack 0</td>
<td>0</td>
<td>0</td>
<td>Test 1</td>
<td>Rack 2</td>
</tr>
<tr>
<td>(Shelf)</td>
<td>0</td>
<td>89</td>
<td>19</td>
<td>(Shelf)</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>33</td>
<td>37</td>
<td>20</td>
<td>23</td>
<td>-9</td>
</tr>
<tr>
<td>40</td>
<td>-2</td>
<td>47</td>
<td>40</td>
<td>68</td>
<td>-24</td>
</tr>
<tr>
<td>60</td>
<td>-53</td>
<td>62</td>
<td>60</td>
<td>96</td>
<td>-32</td>
</tr>
<tr>
<td>80</td>
<td>-84</td>
<td>72</td>
<td>80</td>
<td>140</td>
<td>-47</td>
</tr>
<tr>
<td>100</td>
<td>-144</td>
<td>89</td>
<td>100</td>
<td>175</td>
<td>-59</td>
</tr>
<tr>
<td>120</td>
<td>-176</td>
<td>99</td>
<td>120</td>
<td>211</td>
<td>-71</td>
</tr>
<tr>
<td>140</td>
<td>-229</td>
<td>116</td>
<td>140</td>
<td>244</td>
<td>-80</td>
</tr>
<tr>
<td>160</td>
<td>-273</td>
<td>131</td>
<td>160</td>
<td>280</td>
<td>-90</td>
</tr>
<tr>
<td>180</td>
<td>-323</td>
<td>145</td>
<td>180</td>
<td>330</td>
<td>-105</td>
</tr>
<tr>
<td>200</td>
<td>-366</td>
<td>161</td>
<td>200</td>
<td>396</td>
<td>-118</td>
</tr>
<tr>
<td>Test 2</td>
<td>Rack 0</td>
<td>0</td>
<td>0</td>
<td>Test 2</td>
<td>Rack 1</td>
</tr>
<tr>
<td>(Shelf)</td>
<td>0</td>
<td>89</td>
<td>19</td>
<td>(Shelf)</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>-33</td>
<td>9</td>
<td>20</td>
<td>26</td>
<td>-5</td>
</tr>
<tr>
<td>40</td>
<td>-72</td>
<td>24</td>
<td>40</td>
<td>71</td>
<td>-15</td>
</tr>
<tr>
<td>60</td>
<td>-104</td>
<td>34</td>
<td>60</td>
<td>101</td>
<td>-25</td>
</tr>
<tr>
<td>80</td>
<td>-152</td>
<td>48</td>
<td>80</td>
<td>146</td>
<td>-39</td>
</tr>
<tr>
<td>100</td>
<td>-199</td>
<td>58</td>
<td>100</td>
<td>180</td>
<td>-53</td>
</tr>
<tr>
<td>120</td>
<td>-245</td>
<td>74</td>
<td>120</td>
<td>219</td>
<td>-64</td>
</tr>
<tr>
<td>140</td>
<td>-280</td>
<td>85</td>
<td>140</td>
<td>249</td>
<td>-77</td>
</tr>
<tr>
<td>160</td>
<td>-317</td>
<td>102</td>
<td>160</td>
<td>293</td>
<td>-87</td>
</tr>
<tr>
<td>180</td>
<td>-401</td>
<td>128</td>
<td>180</td>
<td>338</td>
<td>-103</td>
</tr>
<tr>
<td>200</td>
<td>-474</td>
<td>152</td>
<td>200</td>
<td>402</td>
<td>-112</td>
</tr>
<tr>
<td>Test 3</td>
<td>Rack 0</td>
<td>0</td>
<td>0</td>
<td>Test 3</td>
<td>Rack 1</td>
</tr>
<tr>
<td>(Shelf)</td>
<td>0</td>
<td>89</td>
<td>19</td>
<td>(Shelf)</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>-28</td>
<td>11</td>
<td>20</td>
<td>29</td>
<td>-12</td>
</tr>
<tr>
<td>40</td>
<td>-71</td>
<td>26</td>
<td>40</td>
<td>72</td>
<td>-29</td>
</tr>
<tr>
<td>60</td>
<td>-100</td>
<td>36</td>
<td>60</td>
<td>103</td>
<td>-36</td>
</tr>
<tr>
<td>80</td>
<td>-151</td>
<td>51</td>
<td>80</td>
<td>150</td>
<td>-55</td>
</tr>
<tr>
<td>100</td>
<td>-202</td>
<td>60</td>
<td>100</td>
<td>183</td>
<td>-69</td>
</tr>
<tr>
<td>120</td>
<td>-251</td>
<td>75</td>
<td>120</td>
<td>227</td>
<td>-80</td>
</tr>
<tr>
<td>140</td>
<td>-278</td>
<td>88</td>
<td>140</td>
<td>255</td>
<td>-93</td>
</tr>
<tr>
<td>160</td>
<td>-329</td>
<td>107</td>
<td>160</td>
<td>297</td>
<td>-104</td>
</tr>
<tr>
<td>180</td>
<td>-400</td>
<td>139</td>
<td>180</td>
<td>340</td>
<td>-117</td>
</tr>
<tr>
<td>200</td>
<td>-481</td>
<td>166</td>
<td>200</td>
<td>404</td>
<td>-135</td>
</tr>
</tbody>
</table>

### Load vs. Strain

#### Front

![Load vs. Strain Graph](image_url)
## Angle of Deflection Data

<table>
<thead>
<tr>
<th>Load</th>
<th>Deflection</th>
<th>Corrected</th>
<th>Deflection</th>
<th>Corrected</th>
<th>Deflection</th>
<th>Corrected</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-0.5</td>
<td>0</td>
<td>-0.25</td>
<td>0</td>
<td>-0.25</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>-0.25</td>
<td>0.25</td>
<td>-0.25</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>0.5</td>
<td>-0.25</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>120</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0.25</td>
<td>0.25</td>
<td>0.5</td>
</tr>
<tr>
<td>160</td>
<td>0.5</td>
<td>1</td>
<td>0.25</td>
<td>0.5</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>200</td>
<td>0.25</td>
<td>0.75</td>
<td>0.25</td>
<td>0.5</td>
<td>0.25</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Beer Rack

#### Load vs. Deflection

- **Test 1**
- **Test 2**
- **Test 3**

![Graph showing Load vs. Deflection for different tests](image_url)
APPENDIX J – Resume

Andrew Kastning
403 S. Pine St. • Ellensburg, WA 98926

509.899.3465 • kastninga@cwu.edu

EDUCATION

Major: Mechanical Engineering Technology
Minor: Mathematics
Anticipated June 2017
Completed June 2015

Related Coursework
- SolidWorks CSWA Exam certified
- Static Systems Analysis
- CNC Mill and Lathe Operations
- Programmable Logic Controllers
- Machine Shop Safety Operations
- Metal and Materials Composition

EXPERIENCE

Lab Technician
ETSC Department, Central Washington University
June 2015 – Present
- Responsible for design, construction, and implementation of lab equipment for various purposes and classrooms throughout department
- Maintain and prioritize requests for machine/tool maintenance and repairs based on part cost, life of service, and availability
- Assist support staff, maintenance personnel, and department chair with daily operations as well as special tasks
- Research and investigate unknown processes and skills required to accomplish new tasks and assist instructors
- Provide professional opinion to superiors on machine use and operation at lowest level

Salesperson
Wildcat Shop, Central Washington University
April 2014 – Sept 2015
- Set up, operated, and conducted maintenance and repairs on the Wildcat Shop’s first 3D printer
- Maintained “Apple Product Professional” certification by continuing education of technical specifications and compatibility of products
- Worked without assistance on weekends and evenings as junior-level employee without incident or complaints
- Assisted in overhauling online catalog of electronic devices to include descriptions, product photos, sale eligibility, and recommendations of similar merchandise

Clerk/Janitor
AM/PM, Thorp, WA
June 2013 – July 2014
- Obtained food handler’s permit and pump operator safety instruction prior to first shift to ensure safety on the job from the start
- Responsible for incoming morning delivery/retuned items, checking quantities and ensuring storage of perishables
- Worked unaccompanied night shift while maintaining all sections of convenience store/gas pumps without issue
**Squad Leader**

988th Military Police Co., US Army  
Feb 2012 – May 2013  
- Shift supervisor for detainee holding facility, included overseeing transportation/transfer of detainees, daily meals, medical exams, prayer times, and overall proper treatment  
- Coordinated and completed turn in/exchange of retired and damaged property to surplus  
- Provided personnel and equipment in support of multiple squad-level redeployments as well as company level redeployment, maintaining arms and equipment security during transportation  
- Directed squad of 9-15 Soldiers including Military Police, medical, and other support personnel  
- Company level Key Control Non-Commissioned Officer, responsible for bringing company up to regulation and passing inspection for first time in two years  
- Maintained training and personal health records for company

**Team Leader**

988th Military Police Co., US Army  
Sept 2009 – Feb 2012  
- Responsible for direct training and leadership of 2-4 Soldiers while providing law enforcement services and preparing for deployment  
- Selected as only individual from company to attend Secret-level electronics course for troubleshooting and maintaining equipment while deployed in Iraq  
- Assisted squad leader as alpha team leader during two certification training exercises at US Army training and evaluation centers

**Military Police Enlisted**

988th Military Police Co., US Army  
Aug 2006 – Sept 2009  
- Received Army Achievement Medal as top Soldier in platoon during pre-deployment field certification exercise  
- Selected above peers to attend advanced radioman’s course to become subject matter expert  
- Member of top team in company and was responsible for personal security of company commander  
- Selected first to attend Interview & Interrogation training by Law Enforcement Training Institute  
- Attended Warrior Leader Course and graduated above 96% overall score

**ACCOMPLISHMENTS**

- CWU Dean’s List member (10 consecutive quarters)  
- US Army Pistol and Rifle Expert Qualifications  
- Field Promotion to Sergeant  
- Eagle Scout Award recipient  
- Boy Scout’s Order of the Arrow member, Brotherhood

**MILITARY HONORS**

- Two consecutive Good Conduct Medals (2009, 2012)  
- German Armed Forces Badge for Military Proficiency (GOLD)  
- Army Commendation Medal  
- NCO Professional Development Ribbon