Spring 2016

JME 4110 Senior Design Project - C.H.E.T.

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JME 4110
C.H.E.T.

Children's Hydraulic Excavator Toy
# TABLE OF CONTENTS

List of Figures ....................................................................................... 3  
List of Tables ......................................................................................... 3  
1 Introduction ....................................................................................... 4  
1.1 C.H.E.T. Value Proposition ............................................................... 4  
1.2 List of Team Members ....................................................................... 4  
2 Background Information Study ........................................................... 4  
2.1 Design Brief ..................................................................................... 4  
2.2 Summary of Relevant Background Information .................................. 5  
3 Concept Design and Specification ....................................................... 8  
3.1 User Needs, Metrics, and Quantified Needs Equations ....................... 8  
3.1.1 Record of The User Needs Interview ............................................. 8  
3.1.2 List of Identified Metrics ............................................................... 9  
3.1.3 Quantified Needs Equations ......................................................... 10  
3.2 Concept Drawings .......................................................................... 11  
3.3 Concept Selection Process ............................................................... 12  
3.3.1 Concept Scoring .......................................................................... 12  
3.3.2 Preliminary Analysis of Each Concept’s Physical Feasibility .......... 13  
3.3.3 Final Summary Statement ............................................................ 13  
4 Embodiment and Fabrication Plan ....................................................... 14  
4.1 Embodiment/Assembly Drawing/Parts List ......................................... 14  
5 Engineering Analysis .......................................................................... 17  
5.1 Engineering Analysis Proposal .......................................................... 17  
5.1.1 Signed Engineering Analysis Contract .......................................... 17  
5.2 Engineering Analysis Results ........................................................... 17  
5.2.1 Results ....................................................................................... 17  
5.2.2 Conclusion ................................................................................ 25  
6 Risk Assessment ................................................................................ 26  
6.1 Risk Identification ........................................................................... 26  
6.2 Risk Analysis .................................................................................. 26  
6.3 Risk Prioritization ............................................................................ 28  
7 Codes and Standards ......................................................................... 29  
7.1 Identification ................................................................................. 29  
7.2 Justification ..................................................................................... 29
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3</td>
<td>Design Constraints</td>
<td>30</td>
</tr>
<tr>
<td>7.4</td>
<td>Significance</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>Working Prototype</td>
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<td>C.H.E.T. Prototype</td>
<td>30</td>
</tr>
<tr>
<td>8.2</td>
<td>Final Prototype Performing</td>
<td>31</td>
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<tr>
<td>8.3</td>
<td>C.H.E.T. Prototype – Additional Photos</td>
<td>31</td>
</tr>
<tr>
<td>9</td>
<td>Design documentation</td>
<td>33</td>
</tr>
<tr>
<td>9.1</td>
<td>Final Drawings and Documentation</td>
<td>33</td>
</tr>
<tr>
<td>9.1.1</td>
<td>Engineering Drawings see Appendix C</td>
<td>33</td>
</tr>
<tr>
<td>9.2</td>
<td>Final Presentation</td>
<td>33</td>
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<tr>
<td>9.2.1</td>
<td>C.H.E.T. Video Presentation</td>
<td>33</td>
</tr>
<tr>
<td>10</td>
<td>Teardown</td>
<td>34</td>
</tr>
<tr>
<td>11</td>
<td>Appendix A - Parts List</td>
<td>35</td>
</tr>
<tr>
<td>12</td>
<td>Appendix B - Bill of Materials</td>
<td>35</td>
</tr>
<tr>
<td>13</td>
<td>Annotated Bibliography</td>
<td>36</td>
</tr>
<tr>
<td>14</td>
<td>Appendix C – Engineering Drawings</td>
<td>36</td>
</tr>
</tbody>
</table>
LIST OF FIGURES
Figure 4.1: CHET ASSEMBLY ................................................................. 14
Figure 4.2: CONTROL BOX ASSEMBLY .................................................. 14
Figure 4.3: EXCAVATOR ARM ASSEMBLY .............................................. 15
Figure 4.4: LOCKING MECHANISM ASSEMBLY ....................................... 15
Figure 4.5: CYLINDER ASSEMBLY ....................................................... 16
Figure 4.6: FABRICATED CYLINDER ASSEMBLY ..................................... 16
Figure 8.1: CHET ASSEMBLY ................................................................. 30
Figure 8.2: CHET ASSEMBLY ................................................................. 31
Figure 8.3: CONTROL BOX ASSEMBLY ............................................... 31
Figure 8.4: PIVOT CYLINDER ASSEMBLY ............................................ 32
Figure 8.5: CONTROL LEVER ............................................................... 32
Figure 8.6: PIVOT RACK & TUBING ..................................................... 32

LIST OF TABLES
Table 5.1: Information used to calculate spring constants.............................. 18
1 INTRODUCTION

1.1 C.H.E.T. VALUE PROPOSITION

- For parents with a decent salary wanting to buy their children a fun and educational toy introducing the use of hydraulics.
- Parents are dissatisfied with the basic current toy tractors that lack an educational attention-grabbing feature like hydraulics.
- Our product is a multi-adjustable water-hydraulic kids excavator tractor.
- This provides a more educational toy tractor to children rather than what currently is available on the market.
- Unlike current toy tractors (brands like Tonka) our toy tractor provides children with a hands-on learning experience with simple safe hydraulics while still maintaining the toy’s fun factor.

1.2 LIST OF TEAM MEMBERS

- Jared Sanneman
- Patrick Sherman
- Christian Cody
- JT Reiser

2 BACKGROUND INFORMATION STUDY

2.1 DESIGN BRIEF

- For parents with a decent salary wanting to buy their children of ages 6-12 a fun and educational toy introducing the use of hydraulic systems.
- Parents of children ages 6-12 are dissatisfied with the basic current toy tractors that lack an educational attention-grabbing feature like hydraulics.
- Our product is a 4-motion-adjustable water-hydraulic kids excavator tractor. Boxed up the product will be roughly 10”x 15”x 20”. The excavator is equipped with aluminum hydraulic cylinders along with 1/8” black nylon line to transfer the fluid between the cylinders.
- This provides a more educational toy tractor to children rather than what currently is available on the market.
- Unlike current toy tractors (brands like Tonka) our toy tractor provides children with a hands-on learning experience with simple safe hydraulics while still maintaining the toy’s fun factor.

A few changes needed to be made to further enhance the design proposition. Age was specified to aim our design towards a more specific audience. Our excavator will have four levers each controlling a different movable feature, hence 4-motion. To make the fabrication, design, and quality for the current budget as professional as possible and affordable to the consumer at the same time, the size of the excavator will be roughly 10”x 15”x 20” when in its dormant position. The 1/8” nylon black tubing was chosen due to its high-pressure capability (100psi) and the color helps the appearance look more realistic. Testing and many calculations will need to be done before the cylinder size can be determined. All in all, this hydraulic excavator tractor will be a fun project this summer.
2.2 SUMMARY OF RELEVANT BACKGROUND INFORMATION

- US 3862697 A  - Front Loading Hydraulic Excavator
  There is disclosed a hydraulic excavator having linkage providing for a front loading arrangement whereby the bucket opens away from the vehicle. The linkage is arranged to maintain a substantially fixed preselected attitude of the bucket with respect to the boom upon movement of the stick about its pivotal connection to the boom. Further control means are provided to maintain a preselected attitude of the bucket with respect to a fixed plane upon movement of the boom.
• US 2911111 A - Mobile Hydraulic Crane
This is a hydraulic crane design that uses a hydraulic cylinder to raise and lower a telescoping boom arm. The telescoping operation is achieved by a hydraulic cylinder within the telescoping structure. On the end of the boom arm is a pulley for the wire rope and hook leading to the winch. This entire assembly is mounted on a rotating base that is actuated by two hydraulic cylinders.
## CONCEPT DESIGN AND SPECIFICATION

### 3.1 USER NEEDS, METRICS, AND QUANTIFIED NEEDS EQUATIONS

#### 3.1.1 Record of the user needs interview

<table>
<thead>
<tr>
<th>Question</th>
<th>Customer Statement</th>
<th>Interpreted Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>How important is it that CHET is easy to use? (Think age ranges)</td>
<td>Well, since it is an educational toy, not THAT important. If a learning curve (that can be managed) is necessary, then that is fine.</td>
<td>CHET is an educational toy</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHET has easy to use controls</td>
<td>4</td>
</tr>
<tr>
<td>How important is safety when using CHET?</td>
<td>CRITICAL. If on the learning curve, and mistakes are made, then there should ideally be no dangers that result. Identify pinch and shear points and try to eliminate.</td>
<td>CHET is a safe toy for children</td>
<td>5</td>
</tr>
<tr>
<td>How important is the arm/bucket’s weight bearing property?</td>
<td>I guess the key idea here is that it should not be able hold more than it should: the kid user should not be able to overload. Perhaps the bucket has false sides that limit its capacity. There are a number of factors that will contribute to a choice of capacity, including tipping, dropping, etc.</td>
<td>CHET should not allow the able to be overloaded</td>
<td>5</td>
</tr>
<tr>
<td>How important is it that CHET is portable?</td>
<td>This is a tough question. If this device is a “step up” in terms of performance, then maybe it can be less portable. Tempted to say that it should fit in the trunk of average sedan and weigh &lt;= 60 lbs. But, is it on wheels? Can the kid move it around? I would say yes if possible, but not a deal killer if it isn’t easy.</td>
<td>CHET weighs less than or equal to 60 lbs</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHET must be portable</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHET must fit in the trunk of an average sedan</td>
<td>4</td>
</tr>
<tr>
<td>How important is it for CHET to have interchangeable arm tools?</td>
<td>From an educational standpoint, I think this is pretty important. Look at the Toro Dingo, and any of the Kubota</td>
<td>CHET must have interchangeable arm tools</td>
<td>5</td>
</tr>
</tbody>
</table>
systems. The idea of modular snap-in hydraulics is pretty widespread. You should have this also.

How many directions should CHET be able to move through the use of levers?
Have it do everything that a backhoe can do in the plane. In addition to this, if the kid can swivel around, so much the better.

CHET is able to move in the same manner as a backhoe

What environment setting should CHET be built for as far as should it be indoor/outdoor friendly, pool friendly, …etc.
You guys might have differing opinions, but I see this thing outdoors in the dirt (talk up the fact that it is not computer gaming). I think it should actually be able to move dirt and make a trench. Can it bust through sod? I dunno. I know that you were thinking a little tamer, but I am always after publicity. No, keep it out of the swimming pool. Your big problem is going to be making it real and making it safe.

CHET is made for outdoor use
CHET is strong enough to dig and move dirt around

Roughly what dimensions/size should CHET be?
I see something roughly the size of a (small perhaps) minibike that the kid can actually sit on. A bucket-load should be approximately 5 cm cube.

CHET will have a bucket load of 5 cubic centimeters

### 3.1.2 List of identified metrics

<table>
<thead>
<tr>
<th>Metric Number</th>
<th>Associated Needs</th>
<th>Metric</th>
<th>Units</th>
<th>Min Value</th>
<th>Max Value</th>
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<td>1</td>
<td>5,6</td>
<td>Weight</td>
<td>Pounds</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>6,7</td>
<td>Length</td>
<td>Inches</td>
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<td>24</td>
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<tr>
<td>3</td>
<td>6,7</td>
<td>Width</td>
<td>Inches</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>6,7</td>
<td>Height</td>
<td>Inches</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>2,9</td>
<td>Number of Controls</td>
<td>Integer</td>
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<td>5</td>
</tr>
<tr>
<td>6</td>
<td>4,11</td>
<td>Lifting Strength</td>
<td>Pounds</td>
<td>1</td>
<td>15</td>
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<tr>
<td>7</td>
<td>1,3</td>
<td>Youngest age to use toy</td>
<td>Years</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>Number of interchangeable arm tools</td>
<td>Integer</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>12</td>
<td>Volume</td>
<td>Cm³</td>
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<td>5</td>
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### 3.1.3 Quantified Needs Equations

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<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
<th>Unit 5</th>
<th>Unit 6</th>
<th>Unit 7</th>
<th>Unit 8</th>
<th>Unit 9</th>
<th>Importance Weight</th>
<th>Total Happiness</th>
<th>Overall Placement</th>
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<tr>
<td>1</td>
<td>CHET is an educational toy</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>0</td>
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<td>0.105625</td>
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<td>2</td>
<td>CHET has easy to use controls</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>1</td>
<td>0.17</td>
<td>0.18</td>
<td>1st Place</td>
</tr>
<tr>
<td>3</td>
<td>CHET is a safe toy for children</td>
<td>0.1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0</td>
<td>0.05</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
<td>0.2</td>
<td>0.075</td>
<td>1st Place</td>
</tr>
<tr>
<td>4</td>
<td>CHET should not allow the able to be overloaded</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
<td>0</td>
<td>0.9</td>
<td>0.0</td>
<td>0.0475</td>
<td>1st Place</td>
</tr>
<tr>
<td>5</td>
<td>CHET weighs less than or equal to 60 lbs</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0.2</td>
<td>0.3</td>
<td>0.95</td>
<td>0.0475</td>
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</tr>
<tr>
<td>6</td>
<td>CHET must be portable</td>
<td>0.7</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0.97333</td>
<td>0.135</td>
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<td>7</td>
<td>CHET must fit in the trunk of an average sedan</td>
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<td>0.055</td>
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<td>CHET must have interchangeable arm tools</td>
<td>0</td>
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<td>9</td>
<td>CHET is able to move in the same manner as a backhoe</td>
<td>0.1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>10</td>
<td>CHET is made for outdoor use</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0.5</td>
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<td>0.1375</td>
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<td>1st Place</td>
</tr>
<tr>
<td>11</td>
<td>CHET is strong enough to dig and move dirt around</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<td>0.055</td>
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<td>12</td>
<td>CHET will have a bucket load of 5 cubic centimeters</td>
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<td>0.2</td>
<td>0.2</td>
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<td>0</td>
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<td>0.94667</td>
<td>0.075</td>
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**Units**

- **Basic Value**
- **Worst Value**
- **Actual Value**
- **Normalized Metric Happiness**
3.2 CONCEPT DRAWINGS
### 3.3 CONCEPT SELECTION PROCESS

#### 3.3.1 Concept Scoring

<table>
<thead>
<tr>
<th>Concept 1</th>
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<th>Concept 3</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<th>Concept 4</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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</table>
3.3.2 Preliminary analysis of each concept’s physical feasibility

Concept #1 was our winner. It had the highest happiness. It looks and acts like an actual excavator. It can rotate its base as well as dig with its bucket. With this design we can build for a specific area that the bucket can dig and load for the arm to handle. With several pistons it would be able to dig, lift, and drop items within a certain radius.

Concept #2 was similar to #1 with the exception that it can only move laterally instead of swiveling about its base. It can also dig with its bucket which made it a close second choice for our final design but the inability to rotate poses a lot of problems for practical use. With the majority of the base being horizontal, it puts the excavator at risk of falling forward if the load is too high.

Concept #3 used a different bucket design. The claw design can pick things up but can’t manually release them. The claw can’t dig and therefore isn’t very practical. Other than the drawback of the claw, it closely resembled concept 1 which gave it a higher happiness.

Concept #4 looks like a crane. Its base can swivel and uses the same claw concept as #3. It can’t dig and would require much bigger and longer cylinders in order to fully extend the arms. The claw can only go as low as the cylinder, which would be long, and wouldn’t be able to reach the ground. Since its design looks more like a crane it functions poorly as an excavator.

3.3.3 Final summary statement

The specifications didn’t change much with the choice of a final concept. We want a machine that will function as an excavator. Concept 1 looks very similar to an actual excavator. With this design we want multiple attachments such as a different toothed buckets or designs to better dig with or carry more dirt. With this design we are aiming to be able to lift 10 lbs of force at the end of the arm. This design also has an extendable arm which we are hoping to make longer, compared to concept design 4 which has a fixed length of its arm. The overall performance measure of CHET is for it to be able to hold and lift 10 lbs with the arm fully extended.
4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT/ASSEMBLY DRAWING/PARTS LIST

FIGURE 4.1: CHET ASSEMBLY

FIGURE 4.2: CONTROL BOX ASSEMBLY
FIGURE 4.3: EXCAVATOR ARM ASSEMBLY

FIGURE 4.4: LOCKING MECHANISM ASSEMBLY
FIGURE 4.5: CYLINDER ASSEMBLY

FIGURE 4.6: FABRICATED CYLINDER ASSEMBLY
5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 Signed engineering analysis contract

MEMS 411 / JME 4110
MECHANICAL ENGINEERING DESIGN PROJECT
ASSIGNMENT 5: Engineering analysis task agreement (2%)

ANALYSIS TASKS AGREEMENT

PROJECT: CHET       NAMES: Christian Cody CC  INSTRUCTOR: Professor Jakiela
                Jared Sanneman JS
                JT Reiser JR
                Patrick Sherman PS

The following engineering analysis tasks will be performed:

Pre-prototype analysis:

- Attempt finite element analysis of the excavator arm linkages (CC)
- Attempt finite element analysis of excavator arm base attachment (JS)
- Free body diagrams for arm linkages (JT)
- Determine safety disengaging magnets based on FBD (JT)
- Pressure testing custom in-house made hydraulic cylinders (PS)
- Leakage test hydraulic cylinders (PS)

Post prototype analysis:

- Testing hydraulic cylinders operation (PS)
- Leakage test hydraulic cylinders and bleeding each of the four hydraulic
closed systems (PS)
- Testing operation safety specifications (CC)

Instructor signature: [signature]  Print instructor name: Mark Jakiela

(Group members should initial near their name above.)

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Results

One of our goals for CHET was for it to be strong enough to lift and hold ten pounds with the arms
fully extended. To analyze how ten pounds of weight hanging from the end of the arm would affect
our design we used statics equations to model the forces throughout the system when such a load was
applied. We chose three different positions that all seemed like “worse case” scenarios where the
reaction to the weight applied would be the most difficult for CHET to handle. The three positions were: 1) all cylinders on the arms were fully closed, or at their shortest length, which caused the arms to reach out almost as far and low as they could go, 2) the cylinder controlling the arm attached to the bucket is fully closed and the two at the base attached to the boom are open enough so that they are perpendicular to the ground. This position allows for the arms to be outstretched as far as they can making it an ideal position to analyze and 3) the cylinder controlling the extension of the arm attached to the bucket is fully closed as it was in position one and two, but this time the two cylinders at the base are fully open or fully extended. This causes CHET to reach up as high and far out that it can. Examples of these positions can be seen in the figures below.

One thing to note before we get started with the analysis is that since CHET uses single acting hydraulic cylinders it needed the help of some springs to return each cylinder to its fully closed position. Nylon washers were used between every surface where two different moving pieces came together to cut down on any possible friction. The springs used on our design will be included in the calculations, but from the calculations we can find out how much force is required of these springs in these “worst case” scenarios. To determine the spring constants for the springs used in the design we first measured the resting spring length. Once that was recorded one end of the spring was fixed to something sturdy and from the other end a known weight was hung. The spring’s displacement due to the weight hanging from it was recorded and the following spring constants were recorded. Spring 1 is the spring used to aid the two cylinders at the base, Spring 2 was used to aid the cylinder attached between the two arms and Spring 3 was used to aid the cylinder that moved the bucket.

<table>
<thead>
<tr>
<th>Spring</th>
<th>Resting length (in.)</th>
<th>Stretched Length (in.)</th>
<th>Weight (lbs)</th>
<th>Spring Constants (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 1</td>
<td>3.875</td>
<td>6.689</td>
<td>2.5</td>
<td>10.67</td>
</tr>
<tr>
<td>Spring 2</td>
<td>3.75</td>
<td>6.25</td>
<td>13.2</td>
<td>63.53</td>
</tr>
<tr>
<td>Spring 3</td>
<td>4.625</td>
<td>8.75</td>
<td>4.4</td>
<td>12.83</td>
</tr>
</tbody>
</table>

Table 5.1: Information used to calculate spring constants

Now, on to the analysis starting with position one. It should be noted that in these calculations the weight is applied to the furthest pin attached to the bucket at the end of the second arm. All dimensions and angles were recorded from the Solidworks model of CHET in each of the three different positions and the weight of the arms themselves are neglected in the calculations due to their weight being sufficiently less than the ten pound load being applied. Counter-clockwise is considered positive for all moment equations.
Position 1

FBD of Arm 2:

\[ \sum F_X = 0: \quad F_C \cos(6.13^\circ) - F_{BX} = 0 \]

\[ \sum F_Y = 0: \quad -F_C \sin(6.13^\circ) + F_{BY} - 10 \text{ lbs} = 0 \]

\[ \rightarrow F_{BX} = 27.12 \text{ lbs} \]

\[ \rightarrow F_{BY} = 12.91 \text{ lbs} \]

\[ \sum M_B = 0: \]

\[ -F_C \cos(6.13^\circ)(2.83 \text{ in}) + F_C \sin(6.13^\circ)(0.33 \text{ in}) + (10 \text{ lbs})(7.58 \text{ in}) = 0 \]

\[ \rightarrow F_C = 27.28 \text{ lbs} \]
The forces at B are distributed between two parallel arms so the actual force each arm experiences
there in position 1 is $F_{BX} = 13.56$ lbs and $F_{BY} = 6.46$ lbs. This means that the pin used to secure
the two arms together there will need to be able to handle the shear force generated by a resultant force of
15.02 lbs on both ends in order to hold the ten pound load in this position. $F_c$ represents the minimum
force that will be required of the spring to hold the system in equilibrium with the given load in this
position. Using a spring constant of 63.53 lbs/ft we have for the spring in that position we see that
this particular spring would need to be stretched a total of 0.43 feet or 5.16 inches in order to achieve
this force.

**FBD of Arm 1:**

\[
\begin{align*}
\sum F_X &= 0: \\
27.12 \text{ lbs} - 27.28 \text{ lbs} \cos(6.13^\circ) - F_c \sin(22.43^\circ) + 3 \text{ lbs} \sin(22.43^\circ) + F_{DX} &= 0 \\
1.14 \text{ lbs} - F_c \sin(22.43^\circ) + F_{DX} &= 0 \quad \rightarrow F_{DX} = 23.92 \text{ lbs}
\end{align*}
\]

\[
\begin{align*}
\sum F_Y &= 0: \\
-12.91 \text{ lbs} + 27.28 \text{ lbs} \sin(6.13^\circ) + F_c \cos(22.43^\circ) - 3 \text{ lbs} \cos(22.43^\circ) - F_{DY} &= 0 \\
-12.05 \text{ lbs} + F_c \cos(22.43^\circ) - F_{DY} &= 0 \quad \rightarrow F_{DY} = 48.67 \text{ lbs}
\end{align*}
\]

\[
\begin{align*}
\sum M_D &= 0: \\
(12.91 \text{ lbs})(15.57 \text{ in}) - (27.12 \text{ lbs})(4.20 \text{ in}) + 27.28 \text{ lbs} \cos(6.13^\circ)(6.26 \text{ in}) - 27.28 \\
\text{lbs} \sin(6.13^\circ)(8.74 \text{ in}) - F_c \cos(22.43^\circ)(6.12 \text{ in}) + F_c \sin(22.43^\circ)(5.15 \text{ in}) + 3 \\
\text{lbs} \cos(22.43^\circ)(6.12 \text{ in}) - 3 \text{ lbs} \sin(22.43^\circ)(5.15 \text{ in}) &= 0 \\
\rightarrow 242.52 \text{ lbs} - F_c \cos(22.43^\circ)(6.12 \text{ in}) + F_c \sin(22.43^\circ)(5.15 \text{ in}) &= 0 \\
\rightarrow F_c = 65.69 \text{ lbs}
\end{align*}
\]

Since the forces found at D are distributed between the two parallel arms the actual force that each
arm sees there is $F_{DX} = 11.96$ lbs and $F_{DY} = 24.34$ lbs. This means that the pin used to secure both
arms to the base will need to be able to withstand the shear force generated by a resultant force of
27.12 lbs on both sides. The 3 pound force in the force body diagram acting exactly opposite that of
$F_c$ is the spring force. Using the spring data found earlier a simple measurement of the springs
displacement in position 1 was all that was needed to calculate the total force that it was exerting on
the system. In these equations, $F_c$ represents the force that is needed to be generated by the cylinders
in order to keep the system in equilibrium in this position. Since the number found above is shared
between the two cylinders at the base each cylinder is responsible for exerting 32.85 lbs of force. Looking at the cylinders themselves we can use this force to calculate how much internal pressure is built up in position 1. The inner diameter of the cylinder is 0.5 inches so that means that the cross-sectional area of the cylinder is 0.196 in². By dividing the force acting on the cylinder by the cross-sectional area of that cylinder we get an inner pressure of 167.6 PSI.

**Position 2**

### FBD of Arm 2:

\[
\sum F_x = 0: \quad -F_{BX} + F_C \cos(31.06^\circ) = 0
\]

\[
\rightarrow F_{BX} = 33.2 \text{ lbs}
\]

\[
\sum F_y = 0: \quad -10 \text{ lbs} + F_{BY} - F_C \sin(31.06^\circ) = 0
\]

\[
\rightarrow F_{BY} = 30 \text{ lbs}
\]

\[
\sum M_B = 0: \quad (10 \text{ lbs}) \times (10.81 \text{ in}) - F_C \cos(31.06^\circ) \times (2.69 \text{ in}) - F_C \sin(31.06^\circ) \times (0.94 \text{ in}) = 0
\]

\[
\rightarrow F_C = 38.76 \text{ lbs}
\]
Starting off in position two we start to see the forces getting larger as we begin to go through the lifting motion. At position B we find that the forces felt by each arm is $F_{BX} = 16.6$ lbs and $F_{BY} = 15$ lbs. This means that, in this position, the pin used to secure the two arms together will need to be strong enough to withstand the shear force generated by a resultant force of 22.37 lbs acting on each end of the pin. Looking again at $F_C$ we see that the force required of the spring to keep the system in equilibrium is 38.76 lbs. Using the 63.53 lbs/ft spring constant of the spring used in this position we calculated that this spring would need to stretch a distance of 0.61 feet or 7.32 inches in order to make the 38.76 lbs of force needed.

FBD of Arm 1:

\[
\begin{align*}
\sum F_X &= 0: \\
33.2 \text{ lbs} - 38.76 \text{ lbs} \times \cos(31.06^\circ) + F_{DX} &= 0 \\
\rightarrow F_{DX} &= 0.0029 \text{ lbs} \\
\sum F_Y &= 0: \\
-30 \text{ lbs} + 38.76 \text{ lbs} \times \sin(31.06^\circ) + F_C - 4.59 - F_{DY} &= 0 \\
\rightarrow F_{DY} &= 58.52 \text{ lbs} \\
\sum M_D &= 0: \\
30 \text{ lbs} \times (12.37 \text{ in}) - 33.2 \text{ lbs} \times (10.35 \text{ in}) + 38.76 \text{ lbs} \times \cos(31.06^\circ) \times (9.36 \text{ in}) - 38.76 \text{ lbs} \times \sin(31.06^\circ) \times (5.3 \text{ in}) + 4.59 \text{ lbs} \times (3.39 \text{ in}) - F_C \times (3.39 \text{ in}) &= 0 \\
\rightarrow F_C &= 73.11 \text{ lbs}
\end{align*}
\]

Because the force from the spring and cylinder are acting perpendicular to the ground in this position we see that little to no force in the x direction is felt by the pin holding the arms together at point D. Since that force is so small we will neglect it and say that the force the pin experiences in this position on both ends is 29.26 lbs and it will need to withstand the shear force that occurs as a result of that force. The 4.59 lbs force seen in the force body diagram above represents the force from spring on the system. This was found by measuring the spring’s displacement while the system was in this position and using the spring constant found for that spring. Now onto the force from the two cylinders at the base. From the equations above we see that both of the cylinders will need to create a combined force of 73.11 lbs or 36.56 lbs per cylinder. Using the same information as before, but using the newly found force we can calculate the pressure built up in the system while it is in position 2. The internal pressure of each cylinder come out to be 186.53 PSI.
Position 3

FBD of Arm 2:

\[ \sum F_X = 0: \]
\[ -F_{BX} + F_C \cos(69.44^\circ) = 0 \]
\[ \rightarrow F_{BX} = 14.5 \text{ lbs} \]

\[ \sum F_Y = 0: \]
\[ -10 \text{ lbs} + F_{BY} - F_C \sin(69.44^\circ) = 0 \]
\[ \rightarrow F_{BY} = 48.64 \text{ lbs} \]

\[ \sum M_B = 0: \]
\[ 10 \text{ lbs} \times (11.53 \text{ in}) - F_C \cos(69.44^\circ) \times (1.53 \text{ in}) - F_C \sin(69.44^\circ) \times (2.41 \text{ in}) = 0 \]
\[ \rightarrow F_C = 41.27 \text{ lbs} \]
In position 3, the forces seem to follow the same trend as before and now that we are at our highest point in our lifting motion we see the greatest forces acting on the system as a result. The forces at point B are distributed between both the arms so in this position each arm will see a force of $F_{Bx} = 7.25$ lbs and $F_{By} = 24.32$ lbs. This means that the pin in that position will need to be strong enough to withstand the shear force generated by a resultant force of 25.38 lbs on both ends of the pin. Looking at $F_C$ we see that the spring in this location will need to pull with a force of 41.27 lbs in order to keep the system in equilibrium. To create that much force with the spring we used it would have to stretch 0.65 feet or 7.8 inches.

**FBD of Arm 1:**

![Diagram of Arm 1](image)

$\Sigma F_X = 0:$

$$14.5 \text{ lbs} - 41.27 \text{ lbs} \cdot \cos(69.44^\circ) - 6.51 \text{ lbs} \cdot \cos(60.67^\circ) + F_C \cdot \cos(60.67^\circ) - F_{DX} = 0$$

$\rightarrow F_{DX} = 32.77 \text{ lbs}$

$\Sigma F_Y = 0:$

$$-48.64 \text{ lbs} + 41.27 \text{ lbs} \cdot \sin(69.44^\circ) - 6.51 \text{ lbs} \cdot \sin(60.67^\circ) + F_C \cdot \sin(60.67^\circ) - F_{DY} = 0$$

$\rightarrow F_{DY} = 48.32 \text{ lbs}$
\[ \Sigma M_D = 0: \]

\[ 48.67 \text{ lbs} \times (3.27 \text{ in}) - 14.5 \text{ lbs} \times (15.79 \text{ in}) + 41.27 \text{ lbs} \times \cos(69.44^\circ) \times (10.63 \text{ in}) + 41.27 \text{ lbs} \times \sin(69.44^\circ) \times (1.65 \text{ in}) + 6.51 \text{ lbs} \times \cos(60.67^\circ) \times (7.79 \text{ in}) - 6.51 \text{ lbs} \times \sin(60.67^\circ) \times (1.84 \text{ in}) - FC \times \cos(60.67^\circ) \times (7.79 \text{ in}) + FC \times \sin(60.67^\circ) \times (1.84 \text{ in}) = 0 \]

\[ \rightarrow 162.32 \text{ lbs} - FC \times \cos(60.67^\circ) \times (7.79 \text{ in}) + FC \times \sin(60.67^\circ) \times (1.84 \text{ in}) = 0 \]

\[ \rightarrow FC = 73.4 \text{ lbs} \]

From the equations above we see that quite a lot of forces are starting to build up now that we have reached the upper limit of our lifting motion. The forces exerted on the pin by the two arms at point D are \( F_{DX} = 16.39 \text{ lbs} \) and \( F_{DY} = 24.18 \text{ lbs} \). This means that the pin at point D will need to be able to withstand the shear force generated by a resultant force of 29.21 lbs acting on both ends. The 6.51 pound force acting in the opposite direction at \( FC \) in the force body diagram above is the force from the spring. This was found by measuring its displacement while the system was in this position and multiplying it by the spring constant found earlier. Moving onto \( FC \) we see that the two cylinders at the base will have to provide 73.4 lbs of combined force or 36.7 lbs of force per cylinder. Again, using the same information as before we can divide the force exerted by the cylinder by the cross-sectional area of the cylinder to find the pressure needed to make this force. The internal pressure found was 187.3 PSI.

\[ \text{5.2.2 Conclusion} \]

After running through the calculations it is clear to see that though ten pounds may not sound like that much weight, when suspended from the end of the lifting arm of CHET it takes considerably more force to lift and causes quite a lot of stress on the entire system. Looking specifically at the amount of pressure in the cylinders at the base when holding such a load we can see that this may be a safety risk. We do believe that the cylinders we’ve made will hold that amount of pressure, but the force required by the operator to simple lift that would be far too much for a child to do. On top of that, the locking mechanism we used in our design would not hold that much weight on its own so as soon as you would let go of the controls the system would drop the weight. A solution to this problem would be to use a longer set of levers for the controls to give the operator a better mechanical advantage when attempting to lift that much weight along with a different type of locking mechanism that would hold the force when the controls were let go of. A possible option for the locking mechanism would be one that required the user to push a button before moving the lever. This button press would release a pin that would be in place to support the force. To cut down on the amount of pressure built up in the cylinders when lifting this much weight we could have used a larger diameter cylinder. This would increase the cross-sectional area of the piston and require a much smaller amount of pressure to lift the same amount of weight.

Another problem that became apparent after completing the analysis was the force required from the spring to hold the target weight of ten pounds. Relying on the springs alone to hold the weight would have caused us to use really strong springs that would make normal operating loads much more difficult to control because the movement of the cylinder would be constantly fighting the heavy force from the spring no matter how much weight was being lifted. On top of that, these heavy springs would keep the whole system in a state of constant stress even when no weight was being lifted. This constant stress on the locking mechanism would slowly degrade it over time until it reached a point where it no longer functioned correctly. A solution to this problem, which was probably one of the biggest lessons we learned during this project, would be to use double acting hydraulic cylinders.
instead of the single acting ones we used. The difference between the two different types of cylinders is that double acting hydraulic cylinders have ports on either end of the cylinder so that the working fluid can be injected in both ends giving the cylinders the necessary strength it needs in both directions whereas single acting hydraulic cylinders only use one port which gives it strong force in only one direction. All in all the materials we used and the tolerances we were able to hold on the machining of the cylinders were more than enough to reach our target goal of lifting ten pounds, but the design on the locking mechanism and length of the levers would need some redesigning along with the type of cylinders we used.

6 RISK ASSESSMENT

6.1 RISK IDENTIFICATION

- **BUDGET**
  - USE ALL OF BUDGET BEFORE PROJECT COMPLETION
  - REQUEST FOR MORE FUNDING
  - REQUESTED MONEY DOES NOT COME IN FULL OR ON TIME
  - FUNDING IS DENIED
  - INFLATION OF LABOR/MATERIALS

- **SAFETY**
  - PINCH POINTS
  - SHEARING POINTS
  - CYLINDER RUPTURE UNDER HIGH PRESSURE
  - LEAKING HYDRAULIC SYSTEM
  - PART MALFUNCTION
  - EXPOSED SHARP EDGES

- **SCHEDULE**
  - PARTS REQUIRED ARE NOT ORDERED
  - PARTS ORDERED ARE NOT RECEIVED OR LATE
  - DOES NOT MEET PERFORMANCE LEVEL ON COMPLETION DATE
  - LABORERS TAKE LONGER TO FABRICATE PROJECT THAN EXPECTED

- **PERFORMANCE**
  - CANNOT LIFT TARGET LOAD
  - RACK AND PINION SYSTEM
  - CYLINDER PRESSURE
  - LOCKING MECHANISM
  - EXCAVATOR BUCKET

6.2 RISK ANALYSIS

- **BUDGET**
  - USE ALL OF BUDGET BEFORE PROJECT COMPLETION – If this happens then the project would stop or request more funding.
  - REQUEST FOR MORE FUNDING – The amount of time to obtain more funds could push the completion date beyond the due date and could risk the relationship with the investor.
  - REQUESTED MONEY DOES NOT COME IN FULL OR ON TIME – The amount of time to obtain more funds could push the completion date beyond the due date.
- FUNDING IS DENIED – Project production cannot be completed or alternate funding must be acquired.
- INFLATION OF LABOR/MATERIALS – The project could go over budget.

**SAFETY**
- PINCH POINTS – Could cause minor or severe injury to operator or bystander.
- SHEARING POINTS – Could cause minor or severe injury to operator or bystander.
- CYLINDER RUPTURE UNDER HIGH PRESSURE – Could cause minor or severe injury to operator or bystander.
- LEAKING HYDRAULIC SYSTEM – Could cause slippery walking surface and/or mold within or around the leaking hydraulic system.
- PART MALFUNCTION – Could cause minor or severe injury to operator or bystander.
- EXPOSED SHARP EDGES – Could cause minor or severe injury to operator or bystander.

**SCHEDULE**
- PARTS REQUIRED ARE NOT ORDERED – Project production cannot be completed on time.
- PARTS ORDERED ARE NOT RECEIVED OR LATE – Project production cannot be completed on time.
- DOES NOT MEET PERFORMANCE LEVEL ON COMPLETION DATE – Product could be returned by unsatisfied customer. Product would need additional development to meet performance spec.
- LABORERS TAKE LONGER TO FABRICATE PROJECT THAN EXPECTED – Project production cannot be completed on time.

**PERFORMANCE**
- CANNOT LIFT TARGET LOAD – Product would need additional development to meet performance spec. There could be a failure in the hydraulic system that could cause minor or severe injury to operator or bystander.
- RACK AND PINION SYSTEM – Gear teeth could fail and the arm assembly would not be able to rotate. Customer will return product.
- CYLINDER PRESSURE – If cylinder pressure is too high then the cylinder could burst causing minor or severe injury to operator or bystander. This will be covered under the warranty if the operator was using C.H.E.T. under the correct max load limit. Warranty will be void if max load limit was exceeded.
- LOCKING MECHANISM – Locking mechanism can only hold a load up to the max load limit before releasing. Exceeding the max load limit could result in minor or severe injury to operator or bystander.
- EXCAVATOR BUCKET – Bucket can fracture if max load limit if exceeded, leaving the product essentially useless.
6.3 RISK PRIORITIZATION

**High Risk** – High probability and high impact. Require explicit management to keep these risks under control.

**Medium Risk** – Medium probability and medium impact. These risks are delegated to lower levels in the organization but under the supervision of explicit management.

**Low Risk** – Low probability and low impact. These risks are delegated to lower levels in the organization.

- **BUDGET**
  - Use all of budget before project completion – **Medium Risk**
  - Request for more funding – **Medium Risk**
  - Requested money does not come in full or on time – **Low Risk**
  - Funding is denied – **High Risk**
  - Inflation of labor/materials – **Low Risk**

- **SAFETY**
  - Pinch points – **High Risk**
  - Shearing points – **High Risk**
  - Cylinder rupture under high pressure – **High Risk**
  - Leaking hydraulic system – **Medium Risk**
  - Part malfunction – **Medium Risk**
  - Exposed sharp edges – **Medium Risk**

- **SCHEDULE**
  - Parts required are not ordered – **High Risk**
  - Parts ordered are not received or late – **Medium Risk**
  - Does not meet performance level on completion date – **High Risk**
  - Laborers take longer to fabricate project than expected – **Medium Risk**

- **PERFORMANCE**
  - Cannot lift target load – **High Risk**
  - Rack and pinion system – **Medium Risk**
  - Cylinder pressure – **High Risk**
  - Locking mechanism – **Medium Risk**
  - Excavator bucket – **Medium Risk**
7 CODES AND STANDARDS

7.1 IDENTIFICATION

Toy Safety:

USA Standards

ASTM F963-11

1. Section 4.3.5.1, Surface Coating Materials - Soluble Test for Metals
2. Section 4.7, Accessible Edges (except labeling and/or instructional literature requirements)
3. Section 4.11, Nails and Fasteners
4. Section 4.13, Folding Mechanisms and Hinges
5. Section 4.38, Magnets (except labeling and/or instructional literature requirements)

International Standards:

6. ISO 8124-1
   Safety of Toys—Part 1: Safety Aspects
   Related to Mechanical and Physical Properties
7. ISO/TR 8124-8
   Age determination guidelines

7.2 JUSTIFICATION

1. In an industrial setting CHET with have anodized aluminum parts that will need to be non-toxic according to ASTM F963-11 Section 4.3.5.1 standards
2. CHET has multiple edges that can’t be sharp according to ASTM F963-11 Section 4.7 standards
3. Multiple fasteners are used for the assembly of CHET and therefore must abide by ASTM F963-11 Section 4.11 standards
4. CHET contains multiple hinges and therefore must abide by ASTM F963-11 Section 4.13 standards
5. Magnets are used in the lever box of CHET and therefore must abide by ASTM F963-38 Section 4.13 standards
6. For CHET to be marketed abroad as a children’s toy CHET must abide by ISO 8124-1 international safety standard
7. For CHET to be marketed towards a specific age group CHET must abide by ISO/TR 8124-8 international age determination guidelines
7.3 DESIGN CONSTRAINTS

1. Anodizing coating, powder coat, and/or paint for the aluminum needs to be non-toxic post-process
2. Edges of all metal parts will need to be smoothed out
3. Fasteners that protrude will need to be capped or coated to prevent possible injury
4. Hinges will need to have a warning to inform about possible pinching/injury area
5. Magnets need to have a warning to inform users of possible pinching area and magnets also will need to be fixed to prevent any possibility of ingestion

7.4 SIGNIFICANCE

1. With the anodized coating all aluminum parts will have a cleaner, scratch resistant surface, and non-toxic surface
2. Edged surfaces will be filleted and/or chamfered
3. Rubber caps will be incorporated into the hardware assembly
4. Warning labels will be used to warn users of any pinch points
5. Magnets will be completely hidden and glued in place to prevent any chance of possible injury

8 WORKING PROTOTYPE

8.1 C.H.E.T. prototype

FIGURE 8.1: CHET ASSEMBLY
8.2  FINAL PROTOTYPE PERFORMING
https://www.youtube.com/watch?v=9xFGGcakNC4

8.3  C.H.E.T. PROTOTYPE – ADDITIONAL PHOTOS

Figure 8.3 shows the internals of the control box assembly. This contains five independent hydraulic systems with the control levers and locking mechanism. Each control set controls one of the four degrees of motion for C.H.E.T.’s excavator arm. From left to right; the dual cylinder control set controls the lifting arm articulation, the next control set controls the boom arm articulation, the next control set controls the bucket articulation and the last control set controls the rotation of the entire excavator arm assembly.
FIGURE 8.4: PIVOT CYLINDER ASSEMBLY

Figure 8.4 shows the pivot cylinder assembly which includes one cylinder without a pressure relief valve. The pressure relief valves are shown in Figure 8.3 as the gold valve stems that each cylinder contains. Each cylinder not inside the control box contains a spring with a certain diameter and spring constant that was chosen carefully to help aid and not take control of the individual hydraulic system that it is placed on. The reason springs were used in this design is to help aid the cylinder when in retraction because a vacuum is created within the system and it cannot create a force to retract.

FIGURE 8.5: CONTROL LEVER

Rapid Prototyping – 3D Printing using black ABS plastic was used for the control lever grips and the excavator bucket in the production stage.

FIGURE 8.6: PIVOT RACK & TUBING

Additional structure was required to support the plastic rack and pinion rotational operation design.
9 DESIGN DOCUMENTATION

9.1 FINAL DRAWINGS AND DOCUMENTATION

9.1.1 Engineering Drawings see Appendix C.

9.2 FINAL PRESENTATION

9.2.1 C.H.E.T. Video Presentation
https://www.youtube.com/watch?v=9xFGGcakNC4
10 TEARDOWN
The following teardown/clean up tasks will be performed:

- No hazardous materials/chemicals were used in the fabrication of C.H.E.T.
- C.H.E.T. will not be disassembled during the teardown phase.
- Machine shop on Washington University, Danforth Campus has been cleaned after C.H.E.T. fabrication.
- JT Reiser will be receiving C.H.E.T. to take home after all assignments pertaining to the project are completed.
- Extra wood material purchased for C.H.E.T. was stored in wood cabinet in machine shop.
- Extra metal material purchased for C.H.E.T. was stored in corresponding metal type cabinet in the machine shop.
- Extra springs purchased by fabricators were donated to WUSTL FSAE.

Re: CHET Assignment 10 Teardown Contract

Jakiela, Mark
Sat 8/6/2016 7:51 PM
To: Sanneman, Jared <jared.sanneman@go.wustl.edu>

Jared Sanneman:

Please consider this email reply to be equivalent to my signature.

I approve of your teardown plan.

My only comment would be to suggest that you find a way to show your completed prototype to Dean O'Sullivan.

Mark Jakiela

From: Sanneman, Jared
Sent: Friday, August 5, 2016 4:51:59 PM
To: Jakiela, Mark
Subject: CHET Assignment 10 Teardown Contract

Hello Mark,

Here is our assignment 10 teardown contract for you to sign and send back to us.

Thank you,
Jared Sanneman
636-692-3006

From: Jared Sanneman <jaredsann@gmail.com>
11 APPENDIX A - PARTS LIST

*See Figure 4.1, Figure 4.2, Figure 4.3, Figure 4.4 and Figure 4.5.

12 APPENDIX B - BILL OF MATERIALS
13 ANNOTATED BIBLIOGRAPHY


This website was used to locate standards and codes for our project. Only useful as a topic guide as they wanted almost $200 for access to the standards.


Initial findings of similar products that are already on the market. Useful to see what works and is currently being used.


After initial testing of the prototype, this website proved useful in helping us understand why our design wasn’t working. Single action hydraulic cylinders need a spring return in order to provide movement in two directions.


This document provided o-ring information on sealing that was used in the design of the pistons and tubular walls of the hydraulic cylinders.

14 APPENDIX C – ENGINEERING DRAWINGS

- CHET-G01-SD, REV 1
GENERAL NOTES

1. ALL MATERIAL, WORKMANSHIP AND TESTING WILL BE OF THE HIGHEST INDUSTRIAL STANDARD.
2. ALL WELDING IS TO BE CONTINUOUS AND IN ACCORDANCE WITH ANSI/AWS D1.2, GMAW OR G Tay PROCESS. ALL WELDS TO BE 1/8" FILLET WELDS UNLESS OTHERWISE NOTED.
3. AFTER FABRICATION ALL MATERIAL WILL BE THOROUGHLY CLEANED TO REMOVE ALL DIRT, DEBRIS, WELD SPATTER, ETC.
4. ASSEMBLY SUBJECT TO TESTING AS DIRECTED BY THE GROUP MEMBERS DESIGNING AND FABRICATING CHET.

GROUP MEMBERS:  JARED SANNEMAN, PATRICK SHERMAN, CHRISTIAN CODY, JT REISER

REV: 1  
ADDED SUPPORT STRUCTURE AND STOP FOR RACK AND PINION ROTATIONAL SYSTEM. ADDED SPACERS TO DUAL CYLINDER SYSTEM. REVISED CYLINDER BORE AND CAP DESIGN TO BE A PRESS FIT.

DATE: 8/3/2016  
APPROVED: J. SANNEMAN

THIS DRAWING IS CONFIDENTIAL AND PROPRIETARY IN DESIGN AND DETAIL AND IS THE SOLE PROPERTY OF JARED SANNEMAN. NEITHER RECEIPT NOR POSSESSION CONFER ANY RIGHT IN, OR LICENSE TO USE THE SUBJECT MATTER OF THE DRAWING OR ANY DESIGN OR TECHNICAL INFORMATION SHOWN THEREON. IF ANY COPYING OF THIS DRAWING IS NOT TO BE RECURRENT WITHOUT THE EXPRESS WRITTEN CONSENT OF JARED SANNEMAN.

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GROUP MEMBERS:  JARED SANNEMAN, PATRICK SHERMAN, CHRISTIAN CODY, JT REISER

REV: 1  
ADDED SUPPORT STRUCTURE AND STOP FOR RACK AND PINION ROTATIONAL SYSTEM. ADDED SPACERS TO DUAL CYLINDER SYSTEM. REVISED CYLINDER BORE AND CAP DESIGN TO BE A PRESS FIT.

DATE: 8/3/2016  
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GROUP MEMBERS:  JARED SANNEMAN, PATRICK SHERMAN, CHRISTIAN CODY, JT REISER

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DATE: 8/3/2016  
APPROVED: J. SANNEMAN

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ELEVATION VIEW

EXCAVATOR ARM SUBASSEMBLY, DETAIL 7, SEE SHT 9

CONTROL BOX SUBASSEMBLY, DETAIL 5, SEE SHT 7

STAND SUBASSEMBLY, DETAIL 4, SEE SHT 6

PLAN VIEW

- Dimensions: 24" x 16" x 12"
- Tolerances:
  - Fractional: 1/16, 1/8, 1/4
  - Angular: 1/2, .01, .005
- Break all sharp edges
- Surface finish 125 or better

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INSERT ITEM 13, LOCKING PLATE INTO THE SLOT AND GLUE. [TOP AND BOTTOM] (4 PLCS)

DRILL THRU HOLE INTO BOTTOM OF CONTROL BOX AND BOLT CYLINDER BRACKETS WITH 1/2" (16 PLCS)

NOTE: ASSEMBLE CONTROL BOX SUBASSEMBLY ONTO STAND SUBASSEMBLY THE APPROPRIATE LENGTH DRY WALL SCREWS. (4 PLCS)
DRILL THRU HOLE INTO CYLINDER BRACKET AND BOTTOM OF STAND AND BOLT CYLINDER BRACKETS WITH (4 PLCS) 52 53 54 47 2X

EXCAVATOR ARM SUBASSEMBLY, DETAIL 7, SEE SHT 9

STAND SUBASSEMBLY, DETAIL 4, SEE SHT 6

BOLT DETAIL 7 TO DETAIL 4 USING ITEMS 58 61

ST. LOUIS, MO 636-692-3006
J. SANNEMAN JUNE 26, 2016
JUNE 26, 2016

C.H.E.T.
STRUCTURAL DETAIL

JME 4110 SUMMER 2016

CHET-G01-SD

SCALE: 1:3
SHEET 5 OF 23
NOTE: ASSEMBLE STAND SUBASSEMBLY WITH WOOD GLUE AND THE APPROPRIATE LENGTH DRY WALL SCREWS.

STAND WOOD PANEL - 1, ITEM 5, SEE SHT 13 (3 PLCS)

STAND WOOD PANEL - 2, ITEM 6, SEE SHT 13

STAND WOOD PANEL - 3, ITEM 7, SEE SHT 13

STAND WOOD PANEL - 4, ITEM 8, SEE SHT 14

WOOD FRAME - 1, ITEM 1, SEE SHT 13 (2 PLCS)

WOOD FRAME - 2, ITEM 2, SEE SHT 13 (4 PLCS)

WOOD FRAME - 3, ITEM 3, SEE SHT 13 (2 PLCS)

WOOD FRAME - 4, ITEM 4, SEE SHT 13 (2 PLCS)

QUANTITY REQUIRED = ONE [1]

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BREAK ALL SHARP EDGES

SURFACE FINISH 125 OR BETTER

ST. LOUIS, MO

636-692-3006

J. SANNEMAN

JUNE 26, 2016

J. SANNEMAN JUNE 26, 2016

C.H.E.T.

STRUCTURAL DETAIL

JME 4110 SUMMER 2016

CHET-G01-SD
CONTROL BOX WOOD PANEL - 1, ITEM 9, SEE SHT 14 (4 PLCS)

ENSURE SLOT ALIGNMENT (4 PLCS)

CONTROL BOX WOOD PANEL - 3, ITEM 11, SEE SHT 14

CONTROL BOX WOOD PANEL - 2, ITEM 10, SEE SHT 14

SECTION A-A

CONTROL BOX WOOD PANEL - 1, ITEM 9, SEE SHT 14 (4 PLCS)

NOTE: ASSEMBLE CONTROL BOX SUBASSEMBLY WITH WOOD GLUE THE APPROPRIATE LENGTH DRY WALL SCREWS.
CYLINDER SUBASSEMBLY, DETAIL 8, SEE SHT 11

LOCKING PLATE, ITEM 13, SEE SHT 15

CONTROL LEVER, ITEM 12, SEE SHT 15

CONTROL LEVER GRIP, ITEM 35, SEE SHT 20

DUAL CYLINDER SPACER - 2, ITEM 65, SEE SHT 23

NOTE: APPLY GLUE TO INSIDE OF GRIP, IF LOOSE FIT.

DUAL CYLINDER SPACER - 1, ITEM 64, SEE SHT 23

CYLINDER BRACKET - 1, ITEM 14, SEE SHT 15

CYLINDER BRACKET - 2, ITEM 15, SEE SHT 15

SINGLE CYLINDER QUANTITY REQUIRED = THREE[3]

DUAL CYLINDER QUANTITY REQUIRED = ONE[1]

DUAL CYLINDER SPACER - 1, ITEM 64, SEE SHT 23

NOTE: APPLY GLUE TO INSIDE OF GRIP, IF LOOSE FIT.

DUAL CYLINDER SPACER - 1, ITEM 64, SEE SHT 23

CYLINDER BRACKET - 1, ITEM 14, SEE SHT 15

CYLINDER BRACKET - 2, ITEM 15, SEE SHT 15

SINGLE CYLINDER QUANTITY REQUIRED = THREE[3]

DUAL CYLINDER QUANTITY REQUIRED = ONE[1]
EXCAVATOR ARM BASE SUBASSEMBLY, DETAIL 9, SEE SHT 12

CYLINDER SUBASSEMBLY, DETAIL 8, SEE SHT 11 (5 PLCS)

BUCKET LINKAGE, ITEM 21, SEE SHT 16 (4 PLCS)

BUCKET, ITEM 34, SEE SHT 20

BOOM ARM, ITEM 23, SEE SHT 17 (2 PLCS)

LIFT ARM, ITEM 22, SEE SHT 17 (2 PLCS)

EXCAVATOR ARM SUBASSEMBLY QUANTITY REQUIRED = ONE

CALLOUT IN DETAIL 3, SEE SHT 5
SECTION B-B

PIVOT PIN,
ITEM 30, SEE SHT 19

PIVOT RACK SUPPORT - 2,
ITEM 67, SEE SHT 23 (3 PLCS)

BOOM ARM CYLINDER SPACER,
ITEM 26, SEE SHT 18 (4 PLCS)

LIFT ARM SPACER,
ITEM 24, SEE SHT 18 (2 PLCS)

PIVOT RACK SUPPORT - 1,
ITEM 66, SEE SHT 23 (2 PLCS)

BOOM ARM SPACER,
ITEM 25, SEE SHT 18

SECTION C-C

PIVOT RACK,
ITEM 33, SEE SHT 19

PIVOT GEAR,
ITEM 32, SEE SHT 19

PIVOT RACK SLIDE,
ITEM 31, SEE SHT 19

NOTE: APPLY THIN LAYER OF ADHESIVE BETWEEN ITEM 31 AND DETAIL 4.

NOTE: APPLY THIN LAYER OF ADHESIVE BETWEEN ITEMS 31, 32 AND DETAIL 9.

PIVOT RACK CATCH,
ITEM 63, SEE SHT 23

Cylinder Bracket - 3,
ITEM 16, SEE SHT 15

Cylinder Bracket - 2,
ITEM 15, SEE SHT 15

Cylinder Bracket - 1,
ITEM 14, SEE SHT 15

NOTE: APPLY THIN LAYER OF ADHESIVE BETWEEN DETAIL 4.

NOTE: QTY = FIVE[5] DO NOT HAVE SECONDARY 1/8" NPT HOLE IN ITEM 39 FOR THE PRESSURE RELIEF VALVE.
EXCAVATOR ARM BASE TUBE, ITEM 19, SEE SHT 16

EXCAVATOR ARM BASE PIN, ITEM 20, SEE SHT 16

EXCAVATOR ARM BRACKET, ITEM 17, SEE SHT 15 (2 PLCS)

CYLINDER BRACKET - 3, ITEM 16, SEE SHT 15 (4 PLCS)

PRESS FIT ITEM 20 INTO ITEM 18

INSIDE ONLY

1/16

EXCAVATOR ARM BASE PLATE, ITEM 18, SEE SHT 16

SECTION E-E

ALL BRACKETS THREE SIDES

1/8" (2 PLCS)

1" (2 PLCS)

1/8"

1/3"

3"

1/8"

EXCAVATOR ARM BRACKET, ITEM 17, SEE SHT 15 (2 PLCS)

CYLINDER BRACKET - 3, ITEM 16, SEE SHT 15 (4 PLCS)

1/16 INSIDE ONLY

DETAIL 9

EXCAVATOR ARM BASE SUBASSEMBLY

QUANTITY REQUIRED = ONE(1)
ITEM 1
WOOD FRAME - 1
QUANTITY REQUIRED = TWO [2]

ITEM 2
WOOD FRAME - 2
QUANTITY REQUIRED = FOUR [4]

ITEM 3
WOOD FRAME - 3
QUANTITY REQUIRED = TWO [2]

ITEM 4
WOOD FRAME - 4
QUANTITY REQUIRED = TWO [2]

ITEM 5
STAND WOOD PANEL - 1
QUANTITY REQUIRED = THREE [3]

ITEM 6
STAND WOOD PANEL - 2
QUANTITY REQUIRED = ONE [1]

ITEM 7
STAND WOOD PANEL - 3
QUANTITY REQUIRED = ONE [1]
ITEM 12
CONTROL LEVER
QUANTITY REQUIRED = FOUR[4]

ITEM 13
LOCKING PLATE
QUANTITY REQUIRED = FOUR[4]

ITEM 14
CYLINDER BRACKET - 1
QUANTITY REQUIRED = FOUR[4]

ITEM 15
CYLINDER BRACKET - 2
QUANTITY REQUIRED = FOUR[4]

ITEM 16
CYLINDER BRACKET - 3
QUANTITY REQUIRED = SIX[6]

ITEM 17
EXCAVATOR ARM BRACKET
QUANTITY REQUIRED = TWO[2]
ITEM 18
EXCAVATOR ARM BASE PLATE
QUANTITY REQUIRED = ONE[1]

ITEM 19
EXCAVATOR ARM BASE TUBE
QUANTITY REQUIRED = ONE[1]

ITEM 20
EXCAVATOR ARM BASE PIN
QUANTITY REQUIRED = ONE[1]

ITEM 21
BUCKET LINKAGE
QUANTITY REQUIRED = FOUR[4]

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UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES, TOLERANCES: FRACTIONAL ± 1/16 ANGLES ± 1/2.

BREAK ALL SHARP EDGES, SURFACE FINISH 125 OR BETTER.
ITEM 22
LIFT ARM
QUANTITY REQUIRED = TWO(2)

ITEM 23
BOOM ARM
QUANTITY REQUIRED = TWO(2)
ITEM 24  LIFT ARM SPACER  QUANTITY REQUIRED = TWO[2]

ITEM 25  BOOM ARM SPACER  QUANTITY REQUIRED = ONE[1]

ITEM 26  BOOM ARM CYLINDER SPACER  QUANTITY REQUIRED = FOUR[4]

ITEM 27  BUCKET SPACER - 1  QUANTITY REQUIRED = ONE[1]

ITEM 28  BUCKET SPACER - 2  QUANTITY REQUIRED = ONE[1]

ITEM 29  BUCKET LINKAGE SPACER  QUANTITY REQUIRED = ONE[1]

ALL SPACERS ON THIS SHEET FOLLOW THIS CONCENTRIC PROFILE  SCALE 2:1
ITEM 30
PIVOT PIN
QUANTITY REQUIRED = ONE

ITEM 31
PIVOT RACK SLIDE
QUANTITY REQUIRED = ONE

ITEM 32
PIVOT GEAR
QUANTITY REQUIRED = ONE

ITEM 33
PIVOT RACK
QUANTITY REQUIRED = ONE
ITEM 34
BUCKET
QUANTITY REQUIRED = ONE[1]

ITEM 35
CONTROL LEVER GRIP
QUANTITY REQUIRED = FOUR[4]
ITEM 36
CYLINDER PISTON
QUANTITY REQUIRED = TEN [10]

ITEM 37
CYLINDER BORE
QUANTITY REQUIRED = TEN [10]
ITEM 38
CYLINDER BORE CAP
QUANTITY REQUIRED = TEN[10]

(2 PLCS) R.250

SECTION I-I

NOTE: QTY = FIVE[5] DO NOT HAVE SECONDARY 1/8" NPT HOLE FOR THE PRESSURE RELIEF VALVE.

ITEM 39
CYLINDER BASE
QUANTITY REQUIRED = TEN[10]

(2 PLCS) R.250

SECTION J-J

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UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES, TOLERANCES:
FRACTIONAL ± .016
ANGULAR ± 1/2
XX = ± 25
XXX = ± .005
BREAK ALL SHARP EDGES SURFACE FINISH 125 OR BETTER

DRAWN BY: J. SANNEMAN
APPROVED BY: J. SANNEMAN
ST. LOUIS, MO 636-692-3006
JUNE 26, 2016
JUNE 26, 2016

C.H.E.T.
STRUCTURAL DETAIL

JME 4110 SUMMER 2016
CHET-G01-SD

SCALE: 3:2
SHEET 22 OF 23

J. SANNEMAN
JUNE 26, 2016

REV C.H.E.T.
ITEM 63
PIVOT RACK CATCH
QUANTITY REQUIRED = ONE[1]

ITEM 64
DUAL CYLINDER SPACER - 1
QUANTITY REQUIRED = ONE[1]

ITEM 65
DUAL CYLINDER SPACER - 2
QUANTITY REQUIRED = ONE[1]

ITEM 66
PIVOT RACK SUPPORT - 1
QUANTITY REQUIRED = TWO[2]

ITEM 67
PIVOT RACK SUPPORT - 2
QUANTITY REQUIRED = THREE[3]