Three-point Hitch Wrecker Attachment

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by

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Faculty Advisor: Prof. Ahmed Elgafy
ACKNOWLEDGEMENTS

David L Finzer, my father, who without this project could not have been completed

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ABSTRACT

There is a plethora of commercially available wrecking equipment for on road use. There are much fewer products for use in an off-road situation, and almost nothing in a price range for personal use. This paper refers to my design and build of a wrecker attachment that will mount on the three-point hitch of any tractor of sufficient size and allow a single user to move disabled vehicles.
INTRODUCTION

As of now, there is no relatively easy way for a single person to move a disabled vehicle in an off road situation. Currently there are two available methods to facilitate this endeavor. The first is a two person operation involving chaining and towing, with one person driving a tow vehicle and the other steering the other. This arrangement is not always feasible as a helper is not always readily available and there is no good way to reverse the towed vehicle. The second method is to utilize a standalone off road rated forklift (1). This has two issues; one in that it often damages the underside of the vehicle being moved and also is prohibitively expensive in most instances other than a dedicated junk yard.

Due to these limitations a true wrecker wheelift boom is a much better option. This type of equipment is readily available, but is seemingly reserved for on road applications, such as is viewable in Figure 2, and mounted to medium duty trucks (2). Once again the cost is quite large as most are hydraulically actuated and the usability anywhere off-road is severely limited. Therefore, the proposed design is for a simplified wheelift boom to be mounted to the three point hitch of a farm tractor. This design can be more cost effective as it can require no secondary actuation and the actual lift of the vehicle will be provided by the onboard lift capacity of the tractors hydraulic system.
INDUSTRY AVAILABLE ONROAD WRECKERS

Most current setups for on road use some type of auto loading feature that allows the user to hydraulically grasp the disabled vehicle. There are numerous designs for this but boil down to two basic types: Scissor or Rotating. The scissor, as shown in figure 3, uses sliding components to “pinch” the tires and thus grasp the vehicle for lifting. The main drawback of this design is the sliding surfaces are exposed to weather and dirt, requiring manual lubrication and constant maintenance for trouble free service. The main advantage of this type is the cost, since it can usually be implemented with only one hydraulic cylinder. The rotating type, as shown in figure 4, uses two fingers that move about pivots to swing around and grasp the tires. Benefits are quicker actuation and no exposed surfaces requiring lubrication, while the only drawback is higher cost.

Figure 3 – Scissor Type Autoloader (3)

Figure 4 – Rotating Type Autoloader (4)
ABOUT THE THREE POINT HITCH

The three point hitch was originally invented in the 1920s by Harry Ferguson. Ferguson held the patents until the 1960s, but other companies were already manufacturing similar hitches by changing just enough to skirt the patent laws. Three point hitches are now almost completely ubiquitous as an attaching style in the agriculture sector. As the name implies the system is a statically determinate connection that utilizes three attachment points (see figure 5). The two lower links raise and lower hydraulically and allow for attachment of different implements and to change the draft of ground engaging tools. The lower hitch points and lower point span vary based upon the drawbar power of the tractor as this is directly proportional to the total weight that the hitch can lift. Generally, one of the two lower links is adjustable to allow for uneven ground when attaching an implement (see figure 6).

Figure 5 – Diagram of Three Point Hitch Setup (5)

Figure 6 – Adjustability of Lower Links (5)
OTHER TYPES OF RECOVERY DEVICES

Most other commercially available wrecker devices are intended for use with a heavy duty pickup truck. These range from simple lifting arms that are attached to the disabled vehicle with chains, which presents a large chance to damage modern plastic bumpers (see figure 7). Tow slings (figure 8) alleviate this by using large rubber “slings” to wrap under the bumper of the vehicle. However, they still rely on chains as the main load bearing component, which allows for a greater chance for breakage.

From this we see that there is a great abundance of wrecking equipment. However, in the case of off-road the choices are more limited and all are very expensive.
CUSTOMER NEEDS

In order to determine specific details about what potential customers would like and prefer that the device contained a survey was sent out to collect data (see appendix B).

Table 1 - Survey Averages

<table>
<thead>
<tr>
<th>Customer Features</th>
<th>Averages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe</td>
<td>5</td>
</tr>
<tr>
<td>Durable</td>
<td>4</td>
</tr>
<tr>
<td>Easy to Operate</td>
<td>4</td>
</tr>
<tr>
<td>Easy to Adjust</td>
<td>4</td>
</tr>
<tr>
<td>Standardized / Compatible</td>
<td>3.5</td>
</tr>
<tr>
<td>Affordable</td>
<td>3</td>
</tr>
<tr>
<td>Easy to Manufacture</td>
<td>2.5</td>
</tr>
<tr>
<td>One Person Operation</td>
<td>2.5</td>
</tr>
</tbody>
</table>

The Quality Function Deployment (QFD) is an engineering tool that allows the user to determine what characteristics of a design are the most important to customers and thus guide the design process (see appendix C). The input from the surveys and judgment from the designer are crossed versus each other to determine the overall weight that each characteristic carries. Two criteria for this comparison are from the survey and they are; what the customer believes their happiness of a certain characteristic should be and what their satisfaction is with currently available designs. From the designers standpoint two more categories are added; a designer multiplier and a planned satisfaction. The designer’s multiplier is a method of adding more weight to certain characteristics. In this case the most emphasis was placed on safety and the ability for the device to be operated by only one person, while moderate weight was given to durability and the ease of adjustment. This is done for many reasons; some things are critical to make the design physically possible, to allow for cost constraints that may be imposed from a management or sales team, or to sway towards a safer design to meet requirements of sanctioning bodies or industry standards. Secondly, the designer has control over a planned satisfaction, which is simply the level of satisfaction that is proposed to be supplied by the new design.

With these inputs in place the power of the QFD now starts to come to life. The improvement ratio is simply the ratio of the planned satisfaction for the final product over the customer’s current satisfaction with available designs. In this case the area with the most suggested improvement is in the area of standardization, where a twofold jump is proposed. This ratio now allows us to calculate what is referred to as the modified importance; which is realized from the combination of the customer importance, the designer’s multiplier, and the improvement ratio. Basically, this is a fraction of the entire design broken down in order of that characteristics total weight. From this fraction the percentage of the total is determined and thus easily sorted and can be discussed in the project objectives.
PRODUCT OBJECTIVES

The following is a list of products objectives and how they will be obtained or measured to ensure that the goal of the project was met. The product objectives will focus on an attachment for tractor three point hitches (of the correct category) that will allow the user to move disabled automobiles. The product is intended for off road use only and will be compatible for most light vehicles excluding full size trucks and SUVs.

Safe (20%)
- The product will have no sharp edges
- Application of OSHA required signage for lifting equipment

Standardized / Compatibility (17%)
- Required tractor power will determine hitch category range for product
- All hardware will be standard sizes

Durable (15%)
- The product will be adequate construction as to meet repeated usage as described by ASTM E606 fatigue
  - All steel construction
  - Designed to limit less than 50,000psi bending stresses (100,000 cycles)

Easy to adjust (14%)
- Adjustments to the product will follow OSHA guidelines for acceptable limits on lifting and force required for operating the lift bars
  - Only four loose parts during any change or hookup

Affordable (10%)
- Material choice from cost versus required strength \( \frac{p_m}{\sigma^{1/2}} \)

Easy to Operate (10%)
- Operator have knowledge of the tractor hydraulic system

Easy to Manufacture (8%)
- Designed following DFM standards
  - Carbon and alloy steels for ease of machining, cutting, and welding

One Person Operation (7%)
- Hooking up at an Automobile
  - Alignment limits front to back and side to side will be visible from the tractor seat
ENGINEERING CHARACTERISTICS

Table 2 Engineering Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>% Relative Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Parts</td>
<td>24%</td>
</tr>
<tr>
<td>Material</td>
<td>18%</td>
</tr>
<tr>
<td>Reduced Number of Components</td>
<td>17%</td>
</tr>
<tr>
<td>Loading Setup</td>
<td>15%</td>
</tr>
<tr>
<td>Weight</td>
<td>14%</td>
</tr>
<tr>
<td>Size</td>
<td>6%</td>
</tr>
<tr>
<td>Manufacturability</td>
<td>4%</td>
</tr>
<tr>
<td>Color</td>
<td>3%</td>
</tr>
</tbody>
</table>

Engineering characteristics are determined from the correlation of the customer features in reference to the actual feature of the device that bequests said result. This shows the designer which facet of the design that results in the most prolific representation of customer needs. Determination of this relationship is somewhat subjective in terms of how the designer chooses them, but often they are very recognizable and logical. In this case Standard Parts had a relative importance of 24% which shows that both the customer and the designer will benefit greatly in terms of cost, one person operation and easy familiarity. Parallels like Reduced Number of Components and Easy to Operate have a strong association. Others that have strong links are: (Affordable, Material) (Easy to Operate, Loading Setup) (Standardization/Compatibility, Standard Parts).
CONCEPT GENERATION AND SELECTION

The concept shown in figure 9 demonstrates how two “U” shaped lift bars will be inserted into the main body of the wrecker attachment. Two pins will be used to locate the lift bars and are thus adjustable to accommodate the track widths of different vehicles. Three pins will be used to attach the assembly to the hitch of a tractor.

Figure 9 Concept Drawing
**ALTERNATIVE DESIGNS**

This design is simpler in terms of its adjustment for vehicle track width and that it only uses one main lift bar. Its main disadvantage, and reason for exclusion, is that the lift bar mounting locations are underneath the vehicle.

![Figure 10 Alternative Design 1](image)

This design allows for simpler construction of the lift bars and thus lower weight for easier handling. The reason for exclusion is that when the body is lowered for the loading of a vehicle the angle of the main body does not allow installation of the lift bars due to interference with the ground.

![Figure 11 Alternative Design 2](image)
CALCULATIONS

The design of the assembly causes most loading conditions to result in bending and or torsional stresses.

CANTILEVER SECTION

Assume 4x4x1/2 A500 Tube

\[
\sigma_A = \frac{M_c}{I} = \frac{(96000 \text{inlb}) \times (2 \text{in})}{8.22 \text{in}^4} = 23357.8 \text{ psi}
\]

\[
S_y = SF \times \sigma
\]
\[
50000 = SF \times \frac{(23357.8 \text{psi})}{2}
\]

\[
\text{Safety Factor} = 4.28
\]
U-Lift Tube

Section A

![Diagram of U-Lift Tube Section A]

\[
\sigma_A = \frac{Mc}{I} = \frac{(3600 \text{ in} \cdot \text{lb}) \times (2 \text{ in})}{8.22 \text{ in}^4} = 8759.1 \text{ psi}
\]

\[S_y = SF \times \sigma\]

\[50000 = SF \times 8759.1 \text{ psi}\]

Safety Factor = 5.7
Middle Section B

\[ \sigma_B = \frac{M_c}{I} = \frac{(44000 \text{inlb}) \times (1.5 \text{in})}{3.16 \text{in}^4} = 20886.1 \text{ psi} \]

\[ \tau_B = \frac{T_c}{J} = \frac{(36000 \text{inlb}) \times (1.5 \text{in})}{5.08 \text{in}^4} = 10629.9 \text{ psi} \]

\[ a = 0.5 \times (20,886.1) = 10433.1 \]

\[ b = 10629.9 \text{ CW} \]

\[ R = \sqrt{a^2 + b^2} = \sqrt{10433.1^2 + 1062909^2} = 14894.4 \text{ psi} \]

\[ S_y = SF \times \sigma \]

\[ 50000 = SF \times 14894.4 \text{psi} \]

\[ \text{Safety Factor} = 3.4 \]
Close Section C (Mirror Calculation to B)

\[ \sigma_c = 17088.6 \text{ psi} \]
\[ \tau_c = 12992.1 \text{ psi} \]
\[ a = 8544.3 \]
\[ b = 12992.1 \text{ CW} \]
\[ R = 15549.9 \text{ psi} \]
\[ SF = 3.2 \]


**PINS**

![Diagram of a pin](image)

Figure 16 Example Pin (8)

Bearing Stress

\[ W = 2 \times A \times 0.9S_y = (2)(0.25in^2)(0.9 \times 43200) = 19440lb \]

Shear Stress

\[ \tau = \frac{F}{A} = \frac{2000lb}{\left(\frac{\pi \times 1^2}{4}\right)} = 2546.5psi \]
SCHEDULE

The design schedule is to be completed by the final deadline date of May 12th for the first of two demonstrations, first to the project advisor and then to the entirety of the faculty. Design and qualification of components and geometries will be the first concern. The preliminary design will be completed by January 22nd and the Senior Design report and presentation are scheduled for early March. The largest part after winter reports will be fabrication and construction of the assembly which will be completed by April 14th. Final steps will be to complete the Senior Design 2 presentation by May 26th and the final report will be due on June 2nd. For a more detailed view see appendix D.

Table 3 Schedule
BUDGET PLAN

The budget for the three point hitch wrecker attachment can be separated into three main constituents; raw materials, purchased components and welding. The proposed budget for raw materials at this juncture is only estimated, as many variables are yet to be determined once loading calculations are completed. All together the forecasted total to produce the device totals to $1700 (see appendix E). In the end

Table 4 Budget

<table>
<thead>
<tr>
<th>Materials, Components or Labor</th>
<th>Forecasted Amount</th>
<th>Actual Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Material / Steel</td>
<td>$500</td>
<td>$243</td>
</tr>
<tr>
<td>Hardware</td>
<td>$350</td>
<td>$110</td>
</tr>
<tr>
<td>Welding</td>
<td>$650</td>
<td>$100</td>
</tr>
<tr>
<td>Misc.</td>
<td>$200</td>
<td>$0</td>
</tr>
<tr>
<td>Total</td>
<td>$1700</td>
<td>$453</td>
</tr>
</tbody>
</table>
REFERENCES
**APPENDIX A - RESEARCH**

<table>
<thead>
<tr>
<th>601 Series</th>
<th>Hydraulically Folds up for transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000 lb. Lift Capacity</td>
<td>Not good for rough terrain</td>
</tr>
<tr>
<td>7,500 lb. Tow Rating</td>
<td>Very Expensive</td>
</tr>
<tr>
<td>74” of Reach</td>
<td>Only mounting to specialized truck bed</td>
</tr>
</tbody>
</table>

**Standard Features:**
- 4,000 lb. Self Loading Wheelift Assembly
- Trailer Hitch Receiver
- All Steel Classic Body Construction
- Two Top Loading Oversized Tool Compartments
- Aluminum Rock Guards
- Light Pylon
- In/Out Cab Wheelift Remote Control Cord
- Two Wheelift Straps and Ratchets
- Trailer Hitch
- Wheel Grid Tire Spacer Blocks
- Grab Hooks Welded to Drawbar
- Grade 70 Secondary Attachment Chains
- Plug for Tow Lights
- FMVSS 108 Lamp Group

http://www.dynamicmfg.com/wrecker601b
9/26/11 Dynamic 601 Series Auto Load Wrecker
• Left and right side entry tool boxes
• Releasable L-arms
• FMVSS 108 lighting
• Junction box and wire harness
• Safety chain pockets
• Dual rear controls
• Rear chain anchors
• Safety chains
• Cable tensioner (with winch)
• Tow light plug
• Wheel straps
• 12 inch sills
• Rear enclosed wheel wells
• Pilot operated holding valves
• Lubrication fittings on all pivot points
• Backup alarm
• In prime
• Mud flaps

Specifications
Body width 86 inches
Boom elevation 30 degrees
Boom reach past tail board 63 inches
Underlift reach 70 inches
Power tilt range Vertical to negative 10 degrees
Control valve Sectional, 12 GPM, 1700 PSI
Oil reservoir 10 gallons
Oil filter 250 PSI, 15 GPM, 10 Microns
Direct mount pump 18 GPM @ 1200 RPM
Clutch pump 9 GPM @ 1250 RPM

Hydraulically Folds up for transport
Not good for rough terrain
Very Expensive
Only mounting to specialized truck bed

COMPLETE THREE POINT HITCH KIT:
Most 3 point hitch kit suppliers offer kits that are missing parts that you will still have to hunt for and pay more money for.
Our kits all include:
- 2 Lower Arms
- 2 Lift Arms (Both Adjustable)
- 2 Adjustable Lift Arms
- 2 Pins To Mount The Lift Arms
- 2 Sway Chains
- 4 Hitch Pins
- Comes assembled

THE STRONGER THREE POINT HITCH KIT:
Thirty years of professional steel fabrication guaranty a better made three point hitch. Instead of the usual ½" thickness of other three point hitch makes, these are 5/8" thick steel. Ours are formed on a 150 ton press. The resulting structural integrity of these 3 point hitch kits insures that they will function without warping or breaking.

THE THREE POINT HITCH KITS THAT DON'T STRIKE YOUR TIRES:
Lift arms on the competition's three point kits often strike the rear tires because they are so frequently improperly angled. Our kit lift arms operate free and clear of the rear tractor tires since they get a 45 degree bend at exactly the right location.

THE 3 POINTS HITCH KITS THAT DON'T RUST:
Our lift arms are given a zinc chromate primer coating to minimize any oxygen beneath the paint. Then they are painted electrostatically. Our rust inhibiting lift arms will outlast the tractor that wears them.
Three-Point Hitch

The three-point hitch is a standardized method of attaching implements (equipment) to tractors, first developed by Harry Ferguson in the 1920s. The hitch uses two lower connection points and one upper point which provides a rigid connection. Hydraulic cylinders operate on the lower arms to raise and lower the implement. An additional hydraulic arm may act on the upper arm to control the draft (depth) of tillage equipment. A significant advantage of the three-point hitch is that it converts the drag of the equipment into a downward force on the rear of the tractor. This means that the traction is maximized when the pulling is most difficult.

The modern three-point hitch began with experiments by Harry Ferguson in the 1920s and 1930s. During World War I, Ferguson served as a sales agent in Ireland for the Overtime tractors, which were imported Waterloo Boys. This period provided Ferguson with considerable experience at the start of mechanized farming in Ireland and England. Most early tractor plows were trailer-mounted and merely pulled behind the tractor. Often, the biggest problem was not the raw power of the tractor, but gaining enough traction to put the power to use. Early tractors were very heavy and employed steel lugs to try and achieve enough traction.

Ferguson began experimenting with mounted plows while working for the Irish Board of Agriculture. His early work with mounted plows used a modified Ford model T automobile and later a Fordson model F tractor. Ferguson’s mounting system evolved from two link arms (one top, one bottom) to three, and from spring-assisted lift to hydraulics. He met with a number of tractor manufacturers and eventually reached a deal with David Brown in 1933, resulting in the production of the Ferguson-Brown model A, with Ferguson’s three-point system. By 1937, however, poor sales and disagreements between Ferguson and Brown caused production to stop.

In the autumn of 1938, Ferguson met with Henry Ford to demonstrate his tractor and hitch system. Ferguson impressed Ford enough to enter into a production agreement (known as the “handshake agreement”, because very little of the business arrangements were formalized on paper). The result was the Ford model 9N in 1939. The N-series tractors became a great success for Ford. In 1947, Henry Ford II was in control of Ford and decided continue production without Ferguson’s involvement. Ferguson began production with another company (Ferguson Tractor, which joined with Massey-Harris in 1959). Ford eventually settled a lawsuit with Ferguson for over $9 million, but it was the beginning of the end for Ferguson's
exclusive control over his three-point system. The success of the three-point hitch on Ford N-series tractors led other manufacturers to begin building their own versions of the hitch. Most major manufacturers developed a similar hitch, each with variations to avoid violating Ferguson's patents. By 1960, Ferguson's patents had expired and a judge refused to extend them, noting their value to agriculture. The three-point hitch specifications became standardized in the industry by American Society of Agricultural Engineers (ASAE S217) and, later, the International Organization for Standardization (ISO 730-1).

### Three-point hitch specifications

<table>
<thead>
<tr>
<th>Category</th>
<th>Hitch pin size</th>
<th>Lower hitch spacing</th>
<th>Tractor drawbar power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>upper link</td>
<td>lower links</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>17 mm (5/8&quot;)</td>
<td>17 mm (5/8&quot;)</td>
<td>500 mm (20&quot;)</td>
</tr>
<tr>
<td>1</td>
<td>19 mm (3/4&quot;)</td>
<td>22.4 mm (7/8&quot;)</td>
<td>718 mm (26&quot;)</td>
</tr>
<tr>
<td>2</td>
<td>25.5 mm (1&quot;)</td>
<td>28.7 mm (1 1/8&quot;)</td>
<td>870 mm (32&quot;)</td>
</tr>
<tr>
<td>3</td>
<td>31.75 mm (1 1/4&quot;)</td>
<td>37.4 mm (1 7/16&quot;)</td>
<td>1010 mm (38&quot;)</td>
</tr>
<tr>
<td>4</td>
<td>45mm (1 3/4&quot;)</td>
<td>51 mm (2&quot;)</td>
<td>1220 mm (46&quot;)</td>
</tr>
</tbody>
</table>
Abstract
A wrecker attachment in kit form for mounting on the bed of a truck in rigid relationship with its underlying frame. The wrecker attachment includes a back post assembly for mounting a boom assembly, a floor plate assembly for bracing the back post assembly and positionally locating same on the truck bed, and mounting plate assemblies for clamping the back post and floor plate assemblies relative to the truck bed and rigidly securing same to the truck frame. The construction and method of assembling the wrecker attachment allows same to be accommodated for use with trucks having differing spacings between the channels comprising their frames and/or between such frames and the underside of their beds, as well as for inaccuracies in alignment or centering of such attachment relative to the frame of any given truck.
6450

If a 3500 lb. lift capacity isn't enough, or your old sling just can't handle it anymore, the 6450 from Diversified Products is what you need. The 6450 has a 5000 lb. lift capacity for applications where the conventional automotive sling is not enough. (Does not include chains or mount brackets)

- 5000 lb. lift capacity
- 2 1/2" X 2 1/2" holdback arms
- 1" diameter camlocks
- 3/4" lifting shackles

$800

http://zips.com/ 12/05/11
Heavy Duty Tow Sling 5000lb.

Mounts in the bed of a pickup truck
APPENDIX B - SURVEY

Wrecker attachment
For Farm Tractor Three Point Hitch

I am a senior at the University of Cincinnati studying Mechanical Engineering Technology. The purpose of my senior design project is to design and build an automotive wrecker attachment that mounts to a tractor three point hitch. Please take a few minutes to answer the following questions.

How important is each feature to you for the design of a new car moving device?
Please circle the appropriate answer.  
1 = low importance  
5 = high importance  
N/A

<table>
<thead>
<tr>
<th>Feature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>(N)</th>
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</thead>
<tbody>
<tr>
<td>Safe</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>(2)</td>
</tr>
<tr>
<td>Affordable</td>
<td>1</td>
<td>2</td>
<td>(1)</td>
<td>3</td>
<td>4(1)</td>
<td>5</td>
</tr>
<tr>
<td>Durable</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(2)</td>
<td>5</td>
<td>N/A</td>
</tr>
<tr>
<td>Easy to Manufacture</td>
<td>1</td>
<td>(1)</td>
<td>2</td>
<td>3</td>
<td>4(1)</td>
<td>5</td>
</tr>
<tr>
<td>Easy to Operate</td>
<td>1</td>
<td>2</td>
<td>3(1)</td>
<td>4</td>
<td>5(1)</td>
<td>N/A</td>
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<tr>
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How satisfied are you with current car moving devices?
Please circle the appropriate answer.  
1 = very UNSatisfied  
5 = very satisfied  
N/A

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Thank you for your time.
# APPENDIX C - QUALITY FUNCTION DEPLOYMENT

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Appendix D1
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APPENDIX F – DRAWINGS

Collection of finished drawings
Figure 17 - U-lift Bar
Figure 18 - Main Body Front View
Figure 19 - Main Body Left View
Wrecker Attachment for Three Point Hitch

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The Problem?

Available equipment is for road use, or very expensive and specialized
Background
## Customer Needs

<table>
<thead>
<tr>
<th>Customer Feature</th>
<th>% Weight</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardization / Compatibility</td>
<td>21%</td>
<td>2.5</td>
</tr>
<tr>
<td>Durable</td>
<td>20%</td>
<td>1.7</td>
</tr>
<tr>
<td>Safe</td>
<td>18%</td>
<td>1.0</td>
</tr>
<tr>
<td>Easy to Adjust</td>
<td>16%</td>
<td>1.3</td>
</tr>
<tr>
<td>Easy to Operate</td>
<td>16%</td>
<td>1.0</td>
</tr>
<tr>
<td>Affordable</td>
<td>8%</td>
<td>1.0</td>
</tr>
<tr>
<td>One Person Operation</td>
<td>7%</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>6%</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Assembly Drawings
Design Alternatives and Selection

Top Views
Loading Conditions

Cantilevered Main Beam

\[
\sigma_A = \frac{Mc}{I} = \frac{(9600 \text{ inlb}) \times (2 \text{ in})}{8.22 \text{ in}^4} = 23357.8 \text{ psi}
\]

\[S_u = 4\sigma = 4 \times (23357.8 \text{ psi}) = 93431.2 \text{ psi}\]

For 2 Beams

\[0.5 \times S_u = 46715.6 \text{ psi}\]
Loading Conditions continued

Section A – Cantilever

\[ \sigma_A = \frac{Mc}{I} = \frac{(3600 \text{inlb}) \times (2 \text{in})}{8.22 \text{in}^4} = 8759.1 \text{ psi} \]

\[ S_u = 4\sigma = 4 \times (8759.12 \text{ psi}) = 35036.5 \text{ psi} \]
Section B – Cantilever in Torsion

\[ \sigma_B = \frac{M_c}{I} = \frac{(44000 \text{ in lb}) \times (1.5 \text{ in})}{3.16 \text{ in}^4} = 20886.1 \text{ psi} \]

\[ \tau_B = \frac{T_c}{J} = \frac{(36000 \text{ in lb}) \times (1.5 \text{ in})}{5.08 \text{ in}^4} = 10629.9 \text{ psi} \]

\[ a = 0.5 \times (20886.1) = 10433.1 \]
\[ b = 10629.9 \text{ CW} \]

\[ K = \sqrt{a^2 + b^2} = \sqrt{10433.1^2 + 10629.9^2} = 14894.4 \text{ psi} \]

\[ S_{	ext{ult, 4 \sigma}} = 4 \times (14894.4 \text{ psi}) = 59577.6 \text{ psi} \]
Section C – Cantilever in Torsion

\[ \sigma_c = \frac{Mc}{I} = \frac{(36000\text{inlb}) \times (1.5\text{in})}{3.16\text{in}^4} = 17088.6 \text{ psi} \]

\[ \tau_c = \frac{Tc}{J} = \frac{(44000\text{inlb}) \times (1.5\text{in})}{5.08\text{in}^4} = 12.992.1 \text{ psi} \]

\[ a = 0.5 \times (17088.6) = 8544.3 \]
\[ b = 12992.1 \text{ CW} \]

\[ R = \sqrt{a^2 + b^2} = \sqrt{8544.3^2 + 12992.1^2} = 15549.9 \text{ psi} \]

\[ S_u = 4\sigma = 4 \times (15549.9\text{psi}) = 62199.6 \text{ psi} \]
Loading Conditions continued

• Pins in Bearing and Shear

• Bearing
  \[ W = 2 \times A \times 0.9S_y = (2)(1in^2)(0.9 \times 43200) = 86400lb \]

• Shear
  \[ \tau = \frac{F}{A} = \frac{2000lb}{(\pi \times 1^2/4)} = 2546.5psi \]
Component & Material Selection

- A500 Cold Formed Structural tubing
  - Ultimate Strength ~ 62,000 psi
  - Main section in 4x4x1/4
  - U-bend Tube in 3x3x1/4

- Safety factor of 4 was achieved
Fabrication
Assembly
Proof of Design and Testing

- Total Weights
  - Main Body 225lb
  - Lift Bars 55lb ea
  - Total 335lb
Project Deliverables

- One person operation
- Standardized Parts
- Affordability
- Steel Construction; Easy machine, fabrication, durability
Testing

- Vehicle Worst Case
  - Bonneville
  - Wide track
  - Long overhang
  - 2320 lb over front axle

- Test Tractor
  - John Deere 4440
  - Category IIIn / III hitch
<table>
<thead>
<tr>
<th>Materials, Components or Labor</th>
<th>Forecasted Amount</th>
<th>Actual Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>Worst Case $500</td>
<td>$243</td>
</tr>
<tr>
<td>Hardware &amp; Paint</td>
<td>$350</td>
<td>$110</td>
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<tr>
<td>Welding</td>
<td>$650</td>
<td>$100</td>
</tr>
<tr>
<td>Total</td>
<td>$1500</td>
<td>$453</td>
</tr>
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Questions?