The Design of a Device to Aid in the Loading of a Canoe

Worcester Polytechnic Institute

John C. Mallers Jr.
Advisor: Eben Cobb
5/1/2014
Abstract

The primary goal is to design an assistive device to aid the user and help transfer their canoe from the ground to the roof of their vehicle. After selecting the original design, a four-bar linkage, some changes were made to suit the application and allow it to simplify the process of loading a canoe. The system includes a six bar mechanisms with a driver dyad and a four-bar mechanism; they are attached to either end of the canoe. The mechanism is powered by a crank attached to the driver dyad and it will load the boat on top of the car.
Acknowledgements

Throughout this process, I had the pleasure of working with Professor Eben Cobb. He greatly helped throughout the entire project. It is with only his guidance that I was able to complete this project.
# Table of Contents

Abstract..................................................................................................................................................1
Acknowledgements .................................................................................................................................2
List of Figures ..........................................................................................................................................4
List of Tables ............................................................................................................................................4
Introduction ...........................................................................................................................................5
  Background Research..............................................................................................................................5
  Goal Statement .....................................................................................................................................10
  Approach ...............................................................................................................................................10
  General Results ...................................................................................................................................11
Methodology ..........................................................................................................................................11
  Design ..................................................................................................................................................11
  Qualitative Analysis ...............................................................................................................................14
  Quantitative Analysis .............................................................................................................................22
  Recommendations .................................................................................................................................25
Conclusion .............................................................................................................................................28
References ..............................................................................................................................................30
Appendix A: Three Position Synthesis ..................................................................................................32
Appendix B: Buckling Calculations .........................................................................................................35
List of Figures

Figure 1: Kayak Lifter .............................................................................................................................................. 7
Figure 2: Backpack Portage Device .................................................................................................................. 7
Figure 3: Example of Spring in Car Hood ........................................................................................................... 9
Figure 4: Example of Spherical Four-Bar Linkage ........................................................................................... 9
Figure 5: Classification and Dyads .................................................................................................................. 10
Figure 6: Two Pictures of Collapsible Cradles ............................................................................................... 17
Figure 7: Dimensions and Isometric View of 80/20 Type 1010 Aluminum Bar ................................................... 18
Figure 8: Link with Spring Attachment ........................................................................................................... 20
Figure 9: 3D Link ................................................................................................................................................. 20
Figure 10: Attachment of Dyad, Driver Link, and Crank .................................................................................. 22
Figure 11: Back View of Six-Bar Mechanism .................................................................................................. 23
Figure 12: Various End Conditions for Columns and Their Resultant Deflection Curves .............................. 25

List of Tables

Table 1: Design Selection .................................................................................................................................... 15
**Introduction**

The primary function of any tool is to satisfy the needs of the people. The current problem is that canoes are heavy and the large weight can be difficult to move across long distances over land or lift them to a height that may be out of reach. Although, it only takes a single person to row a canoe through a body of water, they require two people to lift up. People need assistance lifting these heavy objects great distances. The only consumer device that is close to the proposed design, guides the canoe on top of the car while the user lifts up an end of the canoe and pushes it on to the roof. The primary purpose of that device is for the transport of a canoe to and from their home to a body of water. The device shall relieve a heavy burden off of the user. The primary objective is to design a device that can assist people with lifting a boat on top of a car.

**Background Research**

Research is a tool that is used to investigate and find whether or not there are similar devices for the application. Also, research helps provide inspiration for the design and could help to incorporate desirable characteristics of current gadgets into a new. The new qualities are found, modified, and combined into a single useful application. The new application is adapted to complete a specific function.

It is important to examine current devices on the market to improve and possibly take inspiration for future designs. The current loading device requires that a single end of the canoe lay on top the car while the other is hoisted on top of the roof. Figure 1 (boathoist.com) displays a device currently on sale that demonstrates this process. Some modifications have made the device collapsible, they have also changed the aesthetics of the device, and the mechanism has been made to support different sized canoes (Sautter, Kemery, Edler). It is useful that collapsible
fit in a small space without changing the size of the object. The knowledge of previous devices helped define certain desirable qualities and incorporate them into the design.

Figure 1: Kayak Lifter

Portage devices are used to transport the boat from place to place. The original portage devices were used to transfer a boat from one body of water to another. The original device was used via horseback and later adapted to attach to cars. There were some backpacks that were outfitted to be able to carry the canoe under a single man power an image is displayed in figure 2 (Zwagerman). These have been made to support different sized canoes and they also collapse for easy storage.

Figure 2: Backpack Portage Device
A vital piece of information is the characteristics of canoes. The device must be able to support the weight of the canoe and the shape of the device. The maximum weight of a canoe is 200lbs and the length is 18 ft. (wcha.org). The size of the car is important information when loading a canoe; height of 76.8 in, length of 222.4 in, and width 79.1 in (chevrolet.com). An SUV was assumed for the dimensions because the height of the vehicle make it the most difficult to load a canoe. The dimensions of an SUV and the canoe limit the dimensions of the mechanism.

A four-bar linkage is the simplest possible pin-jointed mechanism that is versatile because it can generate different types of motion (Norton pg. 100). Simplicity is important in design, the less parts used signify a cheaper and more reliable model. One limitation of this type of linkage can be caught in a toggle position which limits the direction of movement. Additional assistance is required to move the linkage to the desired position.

Applications of springs are used in certain devices and help the movement. Cars utilize a spring in two places; a truck tailgate and the hood of car. The hood of a car connects to the body via either a four or six bar linkage. An example of this application is in Figure 3 (Nagy). The spring connects to the links in order to keep the hood open and under this situation the system has zero degrees of freedom (Norton, pg.65). An applied force to the hood can overcome the force of the spring, the system has a single degree of freedom, and the hood closes. The force provided by a spring is utilized in any different mechanisms and in these applications provide a force that keeps the objects open.
Four-bar linkages are simple and they can complete a variety of movements. Any point of a planar mechanism is restricted to moving in the single plane and all the planes are parallel to each other. The same thing can be said about spherical mechanisms in which any point in a moving body is restricted to move within a spherical surface (Chiang, pg. 2). Each of these bodies is confined to three degrees of freedom. A mechanism moving in spherical motion rotates about three axes that are perpendicular and pass through the center of the sphere. The basic form of all spherical mechanisms is a spherical four-bar linkage and an example is in Figure 4 (Chiang, pg. 6).
The simplest fundamental kinematic chain is a binary group which is composed of two links and three joints. The binary group is known as a dyad. Dyads are categorized into different groups and figure 5 (Popescu and Marghitu) shows examples of the general categories. A single dyad can be connected to a driver link in order to generate a mechanism with a single degree of freedom. The movement of the dyad can be considered to have either rotational or translational motion. There are 38 possibilities with one driver link and a dyad. Adding a single dyad constructs a mechanism with different kinematic possibilities. Increasing the number dyads generates more possibilities for motion. A new classification of dyads generates new planar mechanisms with one, two, and even three dyads.

Figure 5: Classifications of Dyads

Many aspects of a design come from the inspiration of previous work and adapted to apply to the given situation. Canoes have been carried on many different devices in the past and they have been adapted to attach to vehicles. There are varying shapes and sizes of canoes, they help in determining the strength and shape of the final design. The simplicity of four-bar linkages gives them the ability to have varying movements and they can be utilized for many applications. The force of a spring can function in mechanisms to keep them open or to move them in the desired direction. Another useful tool to modify a linkage, altering the shape of a specific link
does not change the kinematics of the device, but can reduce the interference between the links. Research allows for a greater understanding of the problem and provides motivation for a design.

Goal Statement

Background research provides context, the problem can now be condensed further into a more specific goal statement. The general concept set forth was to design a device that can assist people with lifting a boat on top of a car. The origin of this concept came to be upon several excursions while watching people load their boat onto their car. Generally, it is a two person task to lift a canoe on top of a vehicle. Canoes are heavy to lift and can be difficult to place them on top of taller vehicles. A mechanism shall be designed to minimize human interaction and make the process of loading a canoe easier. As well as reduce the need for a second person to assist in the process. The system will replace the second person and shall require the user to exert significantly less energy to complete this task. The primary goal is to design an assistive instrument to aid the user and help transfer their canoe from the ground to the roof of their vehicle.

Approach

The design process was devised to assist in the completion of various problems. Many definitions exist for engineering design and one has defined it as “…the process of applying the various techniques and scientific principles for the purpose of defining a device, a process or a system in sufficient detail to permit its realization. Design may be simple or enormously complex, easy or difficult, mathematical or nonmathematical; it may involve a trivial problem or one of great importance (Norton, pg. 7).” The design process is practiced by many and they utilized it to solve any given problem, whether they are simple tasks or very complex ones. The procedure taken to solve different problems is always the same. The steps in the design process are well thought out and the order is important to achieve a satisfied result.
General Results

The final proposed design is a mechanism consisting of a four-bar and six bar mechanism working in tandem to lift the canoe and place it on top of a vehicle. The device is driven by a driver dyad that is part of the six bar mechanism. Attached to the driver dyad is a crank that is used to power the entire system.

Methodology

The proposed design began by defining what tasks it must complete. Brainstorming of several solutions compiles ideas to identify desirable characteristics of the design. Once the designs are examined, a single solution to the problem is selected based on the individual proposed tasks. The chosen design is then undergoes many changes that improve the design so it can complete the initial problem. An analysis of the design can help further guide any changes to the design, understand if it measures up to expectations, and can provide future ideas. The design of a device is never complete and the design can always evolve and more effectively complete the dilemma.

Design

The performance specifications are laid out to define what the system must do and how it will accomplish the task. There use is to help further define the problem, serve as a way to choose the final design, and further alter that design. The device can lift a boat that weighs up to 200 pounds. In order to fulfill this requirement a safety factor of 1.25 will be applied in order to leave a cushion for the device to function properly even under the maximum applied load, 240 lbs. It will be able to function with different sized loads. The consumer could have a canoe and they are of varying lengths and weights. A boat could be lifted from either side of the car. It shall not limit the operation of the device to one side of the car because that is not always possible.
The primary power source of the device shall be hand operated and not rely on another power source. In some remote locations, there is not always the possibility of electricity. Also, it should not require more than a single operator to maneuver. The operator should be able to use the device unassisted because they might be alone. The device shall have a way of connecting to the car while it completes the task and can be detached upon completion. It is important that the boat attaches to the vehicle so the operation should be able to make attaching it to the car easier. The cost shall be less than that of similar competitors’ products. Boat Hoist sells their Strong Arm Kayak Loader for $395 (boathoist.com). Also, they can only support kayaks up to 65 kg. In order for anything to be competitive in the market, the idea is to produce a quality product that is cheaper and more efficient than the competitors. In order to transport the mechanism, it must be able to fit in the vehicle. Since it shall be in use outdoors, it should be waterproof and corrosion resistant. The mechanism will be used outside and in contact with a boat so it shall not be degraded by water. All of the proposed designs shall fulfill all of these requirements. Though, the creative process allows for designs to fulfill these requirements in varying degrees.

The performance specifications outline criteria that the device must fulfill. There are numerous solutions to any single problem and the specifications begin to narrow the search for a single solution. Then, ideas for a probable solution are collected as long as they meet the performance specs.

A simple solution to the problem would be to use a ramp. The canoe would sit on a cart with wheels and the cart would just be pushed up the ramp onto the top of the car. The idea for this came from the canoe lifters currently on the market. The canoe would be attached to the cart with straps so that it would not fall off. Instead of pushing the cart up the ramp, a pulley system could be utilized to pull the cart up the ramp.
- Advantages: Simplicity, Quick Assembly
- Disadvantages: User exerts lots of force to pull or push

A claw could be attached to the top of the car and have an arm long enough to lift up the canoe from the ground and place it on top of the car. The claw would be able to maneuver in all directions so that it can maximize the degrees of freedom. The inspiration for this idea came from any claw game that lifts up a stuffed animal.

- Advantages: Good attachment to canoe
- Disadvantages: Not manually powered

The canoe can be set on a platform and be lifted by a large jack. A crank is used to raise the jack to the height of the car. The canoe is then pushed off the platform on to the roof of the car. This is a simple solution and does not require the user to exert lots of energy.

- Advantages: Manually Powered, Strong Base, Simplicity
- Disadvantages: User exerts force to push

A track in the shape of a garage door track will lift and flip the canoe on to the top of the car. The canoe will be attached to the track by a grip.

- Advantages: Trajectory of the canoe
- Disadvantages: Difficult to be manually powered, Complexity
A mechanical arm would be attached to the roof of the car and lift the canoe. The arm will be able to bend at several joints and flip the canoe on top of the car.

- **Advantages:** Similar to linkage system
- **Disadvantages:** Difficult to be manually powered

The final proposed design combines some of the previously mentioned design. The design would be a four-bar mechanism that mimics the projected path based on the mechanical arm design as well as the garage door design.

- **Advantages:** Trajectory of canoe, Strong Base, Manually Operated
- **Disadvantages:** Complex Assembly

**Qualitative Analysis**

The selection process weights the performance specifications against each of the possible solutions. A single design is then chosen that best satisfies criteria. Table 1 identifies the design best suited to complete the task. The categories were broken down except for cost. Safety looked at the amount of force required for the user to move the canoe. Performance looked at the motion the canoe would take and that the device was manually powered. Reliability was based on the simplicity of the design because simplicity corresponds to smaller size and less assembly time.

<table>
<thead>
<tr>
<th>Weighting Factor</th>
<th>Cost</th>
<th>Safety</th>
<th>Performance</th>
<th>Reliability</th>
<th>RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ramp/ Pulley</strong></td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>3.5/5</td>
</tr>
<tr>
<td><strong>Claw</strong></td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2.95/5</td>
</tr>
<tr>
<td><strong>Jack</strong></td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3.2/5</td>
</tr>
<tr>
<td><strong>Garage Door</strong></td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2.7/5</td>
</tr>
<tr>
<td><strong>Mechanical Arm</strong></td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2.95/5</td>
</tr>
<tr>
<td><strong>Combination</strong></td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>3.7/5</td>
</tr>
</tbody>
</table>

*Table 1: Design Selection*
The pros and cons of each of the devices were weighed and based on the performance specifications a single design was chosen. The Claw, Mechanical Arm, and Garage Door designs were penalized for being complex. The ramp and jack offered the simplest solutions, but require the user to apply a greater force to transfer the canoe. Each of the designs ranked close to each other, but there was one that stood above the rest. The design with the combined attributes was chosen because it fulfilled all the categories, never received a score below a 3, and ranked the highest at 3.7/5.

Once the design was selected, it becomes modified before the final design. The design took inspiration from previous devices, combined attributes from the selection process, and acquired characteristics from the background research.

While researching previous devices, certain traits were identified that were desired and incorporated into the device. Some previous devices collapsed in on themselves for easy storage. An example of a collapsible cradle is in figure 6 (Sautter, Kemery, Elder). This device needs to be portable because it needs to function in two separate locations: at one’s home and in a remote environment. It needs to function properly in these locations because this is where the device is to assist the user loading the canoe. Since the size of the device meant that it had to nearly completely disassemble to fit within a vehicle. So the device must be collapsible and must have the ability to be assembled easily. Attaching the links would simply be a bolt that screws into each link and secured with a washer. The research also found another desirable quality.
A feature that makes it adaptable to many situations is allowing the device to alter the lengths of specific parts. Altering the lengths of canes and tents adjust depending on the height of the user. Adjusting the length of the base can allow the device to work on cars of different sizes. The bolts will have different slots to be placed in different slots so that the canoe could be lifted to different heights. The distance between the mechanisms could be adjusted by using the same concept on the base. Allowing the handle to change length makes the device easier to maneuver for the consumer. Background research can provide characteristics that will help guide the design.

The selection process helped the iterative process by combining features from separate potential designs. The combined attributes of several designs proposed the best design. The jack design had a good support system and proposed the idea of using a crank to power the device. The idea of the strong base to support the mechanism came from the jack design. The proposed trajectory of several designs showed that would be an ideal motion for the mechanism to make. The idea of a linkage system came from the mechanical arm design. It would be attached to the
roof a curl like an arm. Examining the different designs combined different concepts into a single one.

The concept of the base came from selection process. There is some base necessary to ground the device because it the center of gravity may be shifted and cause the device to topple. A strong base is required to keep the device upright and an easily assembled base makes it easier to assemble and transport. The material of the base was chosen while searching for parts. The 80/20 website provided a strong aluminum bar with a strange cross-sectional area and the design and dimensions of the bar are shown in figure 7 (80/20.net). The cross sectional area made it an ideal selection as the material for the links as well. The material was chosen because as well as being the cheapest solution, the aluminum is strong enough to support the weight of the canoe.

![Figure 7: Dimensions and Isometric View of 80/20 Type 1010 Aluminum Bar](image)

The market has produced consumer products that attach to the canoe and the car and keep the canoe safe during transport. The device must be attached to the canoe and be able to easily transfer the canoe from the device to the car. By utilizing the strap from the cradle, the canoe is secured to the cradle. Pins will be driven through one of the linkages than through the cradle to keep the canoe steady during motion. The pins will also be used to attach the cradle to the car.
The initial design was a simple four-bar mechanism. Initially the path of the linkage was not ideal so it underwent a change so the motion of the device left the canoe on top of the car. The original trajectory of the device was through the car. Three position synthesis (Norton, pg. 109) was applied by defining three positions of a line in the plane and will produce a four-bar linkage mechanism that moves through each of the defined positions. The entire process can be seen in Appendix A. The process began by identifying three positions with specified pivots. Since the original design sent the device through the car, the selection of the fixed pivot prevented the car from moving through the car and allowed to have a more desirable trajectory. Next, the position of the ground relative to the second coupler point was identified. The second ground plane position was then transferred to a reference location at the first position. The second step is then repeated relative to the third coupler position. The third ground plane position was then transferred to a reference location at the first position. Finally, the three inverted positions of the ground plane correspond to the original coupler position were found. The desired motion of the device was reached.

While a four-bar mechanism is in motion, it gets stuck in a toggle position. A four-bar linkage is restricted to a certain motion in which the device cannot reach all desired positions. It is stuck in that position a spring is attached to one of the bars so it can pull the mechanism out of the toggle position. The spring provides enough force to allow for a more fluid motion in which the speed slows down until the spring pulls the mechanism in the desired direction. Figure 8 displays the link with the spring attachment.
There is another dilemma that halted the motion of the four-bar mechanism. Attaching a canoe to the machine alters the motion of the mechanism and prevents it from completing its path. The problem was solved by changing the shape of one of the linkages. By altering the shape of the link avoids obstructing the path of the canoe. An image of the 3D link is in figure 9. The inspiration of altering the shape of the link came from viewing spherical linkages. A mechanism moving in spherical motion rotates about axes perpendicular passing through the center of the sphere. The general shape of spherical links resembles arcs. They incorporate a different coordinate system in order to avoid obstructions and create a different motion. The change in shape does not alter the kinematic properties of the device as long as the distance between the two pins remains the same.
A four-bar linkage is one of the simplest mechanisms to create, however there is functions that are difficult for it to complete. Adding a dyad and a driver link to the mechanism makes it a six bar mechanism. Creating a six bar mechanism does not alter the path of the four-bar mechanism. The dyad and driver link were attached to the mechanism to create an easy way of powering the device and it was attached with a transmission angle of 90 degrees. The transmission angle is defined as the angle between the output link and the coupler (Norton, pg. 109). The ideal transmission angle is 90 degrees because the link is under only tension or a compressive force. That radial component amplifies the pivot friction and does not affect to the output torque. The ideal transmission angle requires the user to apply a smaller force to drive the mechanism. A crank was then attached to the dyad to drive the mechanism.

The device will not be restricted to a single location; the primary source of power would be via under man power. The choice is limited when dealing with hand powered devices. The inspiration of using a crank came from a jack that utilizes a crank to raise it up. The crank is attached to a driver dyad that drives the mechanism. Figure 10 below displays how the driver link and the dyad are attached to the mechanism. A smaller engine was considered, but ideally the device needs to take up as little space as possible. Also, a small engine is more difficult to transport and can it has to be maintained by the user. Using an engine requires a greater threat to the environment.
The design is finalized when the modifications to the initial selected design cease. The proposed final design has two similar linkages attached to base. The first mechanism is a four-bar linkage that is a triple rocker. The second is an identical four-bar linkage with the addition of a driver link and a dyad making it a six bar mechanism. The distance between the two mechanisms is restricted by the length of the canoe, 16 ft.

Both mechanisms are reinforced by two supports. The short supporting leg is closest to the car at a distance of 56 in. and has a height 22 in. The longer leg is 66 in. away from the car and is 46 in high. The two supports are connected to a base. Beneath the base are four wheels that help maneuver the device. These wheels lock when the device is stationary to prevent undesired movement.

Both mechanisms are composed of the oddly shaped link, a ground link, the canoe link, and an additional link. The link lengths determined by the three position synthesis are 66 in, 21 in, 36 in, and 34 in. The corresponding link lengths are from pin to pin and there a few additional inches added to each end of the link. A spring is attached to the canoe link to make the motion of the mechanism fluid and continuous. There are pins at each ending of the link that connect the
links together. These links are made of aluminum and there cross-sectional area is 0.0422 square inches.

In the six-bar mechanism, the dyad and a driver link are attached to the 3D link near the ground link. There is a handle that is attached to the driver dyad that powers the motion of the mechanisms. An image of the six bar mechanism is shown below in Figure 11.

![Diagram of Six-Bar Mechanism]

**Figure 11: Back View of Six-Bar Mechanism**

The canoe is strapped to a cradle that is attached to the mechanisms. There are pins driven through part of the cradle as well as the link of the mechanism. Once the canoe is in mid-air and directly above the roof of the car, the pins are removed from the mechanism and the cradle lies on top of the car. Those pins are then reinserted into the cradle, but this time connects it to the roof rack.

**Quantitative Analysis**

A quantitative analysis of the mechanism examines the kinematics of the mechanism and determines if it can support the weight of the canoe. Kinematics studies the motion of mechanisms without examining the cause of the movement. An analysis of the proposed material was done to see if the weight of the device could be supported by the device.
Determining the Grashof Condition, the classification of the four-bar linkage and the degrees of freedom provide an understanding of the kinematics of both the four and six bar linkages. The Grashof Condition predicts the rotation behavior of a four-bar linkage based on the link lengths (Norton, pg. 55).

\[
\text{short + long vs. the sum length of other two links}
\]

\[
6.6 + 2.1 > 3.4 + 3.6
\]

The linkage is non-Grashof signifying that none of the links are able to fully rotate. The Gashof condition helps determine the classification of four-bar (Norton, pg. 66). The classification of four-bar provides an understanding of the motion of the four-bar linkage. The four-bar mechanism is a triple rocker.

The degrees of freedom determine the mobility of a mechanism. The following equation totals the number of parameters that define the configuration of a set of rigid bodies that are limited by joints that connect the links (Norton, pg. 39). Both the four and six bar mechanisms have a single degree of freedom. They both rotate along a single axis.

\[
DOF = 3L - 2J - 3G
\]

4bar: \( DOF = 3(4) - 2(4) - 3(1) = 1 \)

6bar: \( DOF = 3(6) - 2(7) - 3(1) = 1 \)

The links are under compression while moving the canoe. In mid-air the entire weight of the canoe is supported by the device. The links could buckle or yield under the weight of the canoe. In order to support the canoe, the material was specifically chosen to support the weight of the canoe.
canoe. In order to prevent buckling, the cross-sectional area of the material is increased or a different material is chosen that can withstand the load. Though, changing the material of the design can increase the cost of the device. The difficulty is choosing a material that is cheap and can support the weight of the canoe. Balancing cost and material part was an integral part of the design.

An analysis of the proposed material was done to see if the weight of the device could be supported by the device. Some assumptions were made to ensure that the completed design could support the canoe under the worst conditions. The longest link has the best chance of buckling because the middle of the longest link requires the least amount of force to buckle. The calculations assumed that the longest link was supporting the full weight of the canoe. An observation made to calculate the force that made the link buckle was that the link is pinned at both ends. 4-41(Norton, 203) (Figure 12 below) and Table 4-3 (Norton, 204) displays the end conditions of a column and there resulting deflection curves says that the given scenario is pinned/pinned and the equivalent length is equal to the actual length. The critical load is calculated to understand under what weight the device will buckle and a safety factor is applied to calculate the maximum allowable weigh to ensure that device will not fail and does not reach the critical load. The entirety of the calculations can be seen in Appendix B.

![Figure 12: Various End Conditions for Columns and Their Resultant Deflection Curves](image)
\[
\text{Critical Load} = P_{cr} = A \left[ S_y - \frac{1}{E} \left( \frac{S_y S_i}{2\pi} \right)^2 \right] = 1019 \text{ lbs}
\]

\[
\text{Allowable Load} = P_{allow} = \frac{P_{cr}}{SF} = 765 \text{ lbs}
\]

The 1010 model can support up to a critical load of 1000 lbs, which means the cheapest material and the longest link can support the weight of the canoe when it is under compression in mid-air. Though the critical load is more than a weight of the canoe, a safety factor is applied to ensure that the device will not buckle under a force close to the critical load. Since, a single link can support the canoe under the worst conditions than the proposed design allows the two mechanisms that share the weight of the canoe will not buckle.

Another important material property is the yield strength. The yield strength happens at the stress at which the material begins to permanently deform and the yield strength of the 1010 aluminum is 35,000 pounds per square in. Multiplying the yield strength by the area determines the force at which the material will yield.

\[
35,000 \frac{\text{lbs.}}{\text{in}^2} \times 0.4379 \text{ in}^2 = 15,327 \text{ lbs}
\]

Again, the force required to buckle is much less than the force required to yield. Meaning that the 1010 aluminum will not yield or buckle under the weight of the canoe.

**Recommendations**

The design and analysis are complete. The design is never officially finalized; there are always ideas to improve upon a design. Modifying the design is way to keep up with the ever changing market. Changes to the original design are always occurring and a product can always be altered to make it better. Recommendations allow the mechanism to evolve and some are to provide an additional power source, to adjust dimensions to fit different vehicle sizes, and to
make the device more maneuverable. There are additional recommendations to improve the device.

The most useful recommendation would be to modify the device so it can work on different car sizes. The initial design works on one extreme in which the scenario is most difficult for the operator. Ideally an adjustable design would allow the consumer to use the device on multiple sized vehicles. It also appeals to the market because it more desirable to consumers than a one-dimensional mechanism.

In order to make the more mobile and easier to maneuver, the mechanism can have some modifications. The application wheels make the mechanism mobile and easier to align with the car. A handle in conjunction with the wheels makes the device extremely mobile. Though, these make the device larger and more pieces to assemble and transport. They also do not help when the mechanism is being utilized in uneven terrain. Though, the increased mobility could reduce the amount of force exerted by the user.

An additional power source may be desirable to make the device easier to operate. Instead of requiring the user to expend energy to power the device, a small engine or electrical component could later be added to power the device. However, it is ideal that one of the power sources be by hand because the device cannot rely on any form of technology that cannot function in any remote environment. It is not important that the primary source be hand powered, but it is required of the device needed to function properly in an environment where electricity is not readily available.

In order to prevent movement while the device is transferring the canoe, a brace would connect the mechanism to the car. The process of lifting the canoe may cause the mechanism to
shift and that would not allow the canoe to be placed in the proper position. Even a slight movement of the device would affect the final position of the canoe. The brace would stabilize the device and prevent the base from moving while the device is operating.

Recommendations to modify this design include increased mobility, more adjustable parts, and provide a second power source. Increasing the mobility of the base allows the user to apply less force when moving the device. Adjustable parts allow the system to be used on larger as well as smaller cars. A secondary power source gives two options to power the device and a backup in case one of them fails. Also, a brace would prevent the base of the mechanism from shifting while lifting the canoe. Even with the additional recommendations, the device is never finished and can further evolve.
Conclusion

The primary goal was to design a mechanism that was operated by a single person and could transfer a canoe from the ground to the roof of their vehicle. It takes one person to row a canoe, but an additional person is required to lift a canoe on top of a vehicle.

A four-bar linkage is the simplest pin-jointed mechanism that is versatile because it can produce a variety of motions. Simple designs are desired because they utilize fewer parts signifying a cheaper and more reliable design.

Previous devices require that the person do most of the heavy lifting. One end of the canoe has to be lifted so that it rests on top of the car. The devices only guide the device on top of the car and require the user to lift up the other end and push it on top of the car. This is the most cost efficient solution to the problem, but still forces the user exert a significant amount of energy to lift the canoe. They also can only support the weight of a kayak and they are not designed to support the weight of a canoe.

The performance specifications define conditions that the device must accomplish. The selection of the design compared each of the plausible solutions with the performance. The final design was chosen because it best met all of the performance specifications. The final combined system is composed of a six bar mechanism with a driver dyad and a four-bar mechanism that are attached to either end of the canoe and powered by a crank attached to the driver dyad. The combined system will transfer the boat from the ground on top of the car.
An analysis of the mechanism evaluated the motion of the mechanism and determined it will support the weight of the canoe. The results showed that the four-bar mechanism is non-Grashof and that it is a triple rocker. Further analysis of the motion shows that both the four and six-bar mechanisms have a single degree of freedom. A second analysis was done to determine if the mechanism would either buckle or yield under the weight of the canoe. The force required to permanently deform the mechanism is larger than 15,000 lbs. which is significantly greater than a 200 lb. canoe. The maximum allowable load was calculated to be 765 lbs. showing that the single longest link will not buckle under the weight of the canoe. The analysis shows that the system will neither yield or buckle under the weight of the canoe.

Designs are never complete and there are always improvements that can be made to a design. Modifications to the original design are always occurring and a product can always be altered to improve. Recommendations allow the mechanism to evolve and some are to include a secondary power source, to have adjustable dimensions to fit different vehicle sizes, and to make the device more maneuverable. An additional alteration is a brace to stabilize the device and prevent it from moving and altering the projected path of the canoe. Design is a never ending process and the solutions to the problem can be changed to more efficiently complete the task.
References


Appendix A: Three Position Synthesis*

Scale: 1 cm=10 inches

Step 1: Draw Link LR in its three desired positions L1R1, L2R2, and L3R3

Step 2: Draw the ground link O2O4 in its desired position in the plane with respect to the first couple position L1R1

Step 3: Draw construction arcs from point L2 to O2 and point R2 to O2 whose radii define the sides of triangle L2O2R2. This defines the relationship of the fixed pivot O2 to the coupler line LR in the second coupler position.
Step 4: Draw construction arcs from point L2 to O4 and point R2 to O4 whose radii define the sides of triangle L2O4R2. This defines the relationship of the fixed pivot O4 to the coupler line LR in the second coupler position.

Step 5: Now transfer the relationship back to the first coupler position L1R1 so that the ground plane position O2’ O4’ bears the same relationship to L1R1 as O2O4 bore to the second coupler position L2R2. L2 is sliding along the line L2-L1 and R2 along the line R2-R1. The ground link is now pretending to move from O2O4 to O2’ O4’ instead of the coupler moving from L1R1 to L2R2. The problem is now inverted.
Step 6: Repeat the process for the third coupler position and transfer the third relative ground link position to the first, or reference, position.

Step 7: The three inverted positions of the ground plane that correspond to the three desired coupler positions labeled O2O4, O2'O4', and O2''O4''. The three original lines L1R1, L2R2, and L3R3 are now needed for the linkage system.

* All references are from Machine Design: An Introduction to the Synthesis and Analysis of Mechanisms and Machines by Norton.
Appendix B: Buckling Calculations**

**Step 1:** Calculate Area (in^2), Area Second Moment of Inertia (in^4), and find the Modulus of Elasticity for the given material (E) (psi) (A, I, and E are all given by 80/20.net)

\[
E = 102000 \\
A = 0.4379 \text{ in}^2 \\
I = 0.0442 \text{ in}^4
\]

**Step 2:** Calculate the radius of gyration (k) (in) (equation 4.34)

\[
k = \sqrt{\frac{I}{A}} = \sqrt{\frac{0.0442}{0.4379}} = 0.3177
\]

**Step 3:** Assume the link is in the pinned/pinned condition (Figure 4.41) and that the effective length is equal to the actual length (Table 4-3)

**Step 4:** Calculate the slenderness ratio (Sr) (unit less) (equation 4.33) and substitute the effective length by applying (equation 4.41). This value determines if a column is short or long

\[
Sr = \frac{L_{eff}}{k} = \frac{60}{0.3177} = 189.16
\]

**Step 5:** Calculate the compressive yield Stress (Sy) (psi).

\[
Sy = \frac{2\pi^2 E}{Sr^2} = \frac{2\pi^2 \cdot 102000}{189.16^2} \approx 1019.11
\]

**Step 6:** Calculate the critical unit load (Pcr) (lbs.) (equation 4.43)

\[
Pcr = \frac{A}{2} \left[ \frac{Sy}{L_{eff}} - \frac{1}{E} \left( \frac{Sy}{Sr} \right)^2 \right] = 0.4379 \left[ \frac{1019.11 - \frac{1}{102000} \left( \frac{1019.11}{189.16} \right)^2}{60} \right]
\]

\[
Pcr = 0.4379 \left[ \frac{1019.11 - 2.358}{60} \right] = 1019.11
\]
Step 7: Calculate the allowable desired load ($P_{allow}$) (lbs) by applying the safety factor (SF) (unitless) to $P_{cr}$

The safety factor is a margin of error used to prevent any values close to $P_{allow}$ to buckle the beam because there are other factors that can cause the beam to buckle.

$$Allowable\ Load = P_{allow} = \frac{P_{cr}}{SF} = 765\ lbs$$

Since 765 lbs. is greater than 240 lbs., the longest link will not buckle under the weight of the canoe.

**All references are from Machine Design: An Integrated Approach by Norton**