Universal Patient Transfer Device

by

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Mechanical Engineering Technology
Universal Patient Transfer Device:
The Frame and Mobility Systems
ABSTRACT

Medical professionals encounter several problems while transferring patients into and out of resting positions. The results of interviews with medical professionals explained that transferring patients is physically demanding, and that there is normally more than one nurse needed when assisting patients. Based on the survey results, the most important features in a chosen by medical professionals were safety, stability, ease of operation, transportability, and comfort. Medical professionals were least satisfied with features in current transfer devices such as appearance, cost, size, and comfort. The House of Quality was then used as a tool to compare and assign a ranking system for each feature. The important features in design from the House of Quality were the following: easy to operate, transportability, and low cost. Also, the weight, payload, and limited controls were determined to be important criteria in the design. A weighted decision matrix was made to determine the top overall concept choices of each system i.e. power, frame, mobility, and comfort. Loading conditions were needed for drawings and calculations. The individual responsibilities for this report include the frame and mobility design. The adjacent report covered by Mr. Wooddell includes the power and motion design. The frame material 8020 was chosen based on its ability to handle repeated loads and bending stresses of 3174psi. A bill of materials was made to organize and initiate the ordering of parts. There were 86 purchased components and 79 manufactured components. Overall, the fabrication and assembly was time consuming, but efficient because all frames and parts could be assembled by hand or with bolts. The testing and proof of design was done by medical professionals who simulated using the device. The original engineering features were successfully met in the completed device i.e. minimal controls, payload of 300lbs, light weight, aesthetically pleasing, less than 20ft², comfort, cost competitive, minimal maintenance, and the compatibility with nitrogen tanks or a compressed air supply. The actual combined budget was 6.5% of the proposed amount of $1150. There were several delays in the schedule due to the redesign of the scissor members and scissor clevis. However, the goal of having a tested and functional device by the end of April 2007 was successfully completed.
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INTRODUCTION

Currently there are no available user-friendly systems or devices for transferring a medical patient into and out-of resting positions. Medical professionals would rather manually assist patients than use transfer devices because they require a considerable setup and retrieval time. Also, the inability of to perform more than one purpose does not warrant a need to use the existing devices. This decision results in using more than two assistants to transfer a patient which proves to be inefficient. Manually assisting patients also presents a liability to both the medical professional and the patient.

As seen below in the Figures 1-4, medical professionals transfer patients in a variety of ways. The positions of the assistants appear to be awkward and strenuous on their bodies. In particular, Figure – 1 illustrates individuals actually straining their body in order to assist a patient to a standing position. Figure – 2 also illustrates that it takes more than one individual to aid a patient in any situation. There are many scenarios of transferring patients in-to and out-of resting positions:

- From one bed to another
- From one chair to another
- From a bed to a chair
- From a bed to a standing position
- From a chair to a standing position

Figure 1 – Medical professionals trying to assist patients to a standing position
There needs to be a multi-purpose patient transfer device to make life simpler for medical professionals in aiding patients in-to and out-of resting positions. This device also needs to include a sufficient comfort system and safety features to complement the patients and nurses. In addition, the amount of assistance needed to transfer a patient with this device should be minimal. Therefore, the ability of such a device to perform multiple tasks safely while being easy to operate will change the way medical professionals assist patients in the future.

The individual responsibilities for this report include the frame and mobility design. The adjacent report covered by Mr. Wooddell includes the power and motion design.

A variety of products exist on the market which transfer patients in and out of resting positions. Some of the current products offer a wide range of motorized and non-motorized options. The devices seen in Figure – 3 represent non-motorized multi-purpose chairs. They can assume multiple positions and are light enough to move without much assistance. Figure – 4 represents devices that transfer patients from one room to another or lift a patient to a standing position. They are both controlled by hydraulics and seem to be very cumbersome and difficult to set-up. The devices shown in Figure – 5 illustrate smaller individual devices that can be used from time to time. Seen in Figure – 6 are the ideal features that should be designed into any patient transfer device i.e. simplicity, size, and aesthetics.
Figure 4 – Existing pneumatic/hydraulic products that present ways to assist patients

Figure 5 – Existing products that present ways to assist patients without help
PRODUCT/ENGINEERING FEATURES AND OBJECTIVES

The product/engineering features were incorporated into the design to establish attributes and a criterion for the finished product. These were needed to ensure a proof of design for the finished device. They were gathered in response to customer feedback and surveys. The Universal Patient Transfer Device’s product/engineering features were as follows:

- Minimal controls
- Maximum payload of 300 pounds
- Light weight
- Aesthetically pleasing
- Take up less than 20 ft²
- Comfort level equivalent to current hospital beds
• Costs competitive with the current market
• Minimal maintenance
• Compatible with nitrogen tanks or a compressed air supply

SUMMARY OF CUSTOMER INTERVIEWS

Customer interviews, which can be seen in Appendix - B, were conducted with the following interviewees detailing the most important features in any system which aids patients:

• Katie Wooddell, RN, Bethesda North Hospital, Rehab unit, Montgomery, Ohio [14]
• Kim Ransdell, Nurse Manager, Ohio Cancer Specialists, Mansfield, Ohio [15]
• Marje Filcox, RN, Med Central Hospice, Mansfield, Ohio [16]
• Sindy Dowds, RN, Med Central Hospital, Oncology Unit, Mansfield, Ohio [17]

All of the interviewees mentioned that transferring patients is a physically demanding job. They also stated that the availability of a patient transfer device is normally irrelevant because it takes too much time to find. Even though some transfer devices do exist, they are not easy-to-use. They would rather transfer patients themselves with or without assistance.

CUSTOMER SURVEY RESULTS

A total of 39 surveys, as seen in Appendix - C, were filled out by medical professionals around Ohio. The customer feedback from the surveys established standards for a patient transfer device in the medical field. Medical professionals concluded that the most important features to have in a patient transfer device were the following:

1. Safety
2. Stability
3. Easy to Operate
4. Transportable

They also concluded that they were least satisfied with the following features in existing devices:

1. Appearance
2. Cost
3. Size
4. Comfort
HOUSE OF QUALITY

After developing the House of Quality with the results from the survey, as seen in Appendix – D, certain criteria was determined to be more influential for the design than others. The features that were more influential in improving upon existing patient transfer devices included the following:

- Easy to Operate
- Transportable
- Low Cost

Also, a study was conducted that compared the absolute/relative importance of product objectives to the features of a device which aids patients. The highest features of importance in a patient transfer device included the following:

- Limited Controls
- Payload
- Weight

These product objectives are directly related with features that include: being easy to operate, having sufficient stability, and being able to be transportable. The weight factors and importance values from the QFD were taken under consideration when developing the design of the universal patient transfer system.

DESIGN

The design process entailed many challenging tasks from startup. The first task was to evaluate the type of capabilities and functions that were desired in the end product. The patient transfer device needed to be aesthetically pleasing to the customer and consumer. Next, a 2-D frame layout was designed based from human parameters and the ideal area of occupation. A mockup was made to determine the appropriate angle to aid patients from a chair to a standing position. Cylinders were then placed at different positions within the frame to account for the motion needed to assist patients at different angles and lengths. The loading conditions of the human body led to the positioning of forces applied per frame. With the type of vertical lift chosen, a stress analysis was conducted throughout each frame member. Material selection was chosen based from the results of the stress analysis. Drawings of the component and material selections were created via Solid Works in 3-D. A complete bill of materials was created to start the process of ordering parts.

Design Alternatives and Selection

Table - 1 lists the three design alternatives chosen for each system in design. Individual weighted decision matrices were conducted i.e. lift position, frame, mobility, and comfort. The highest graded design for each system was included into the design choices. The results incorporate the top overall choice for each system.
Table - 1

<table>
<thead>
<tr>
<th>Design Choice</th>
<th>Lift-Position</th>
<th>Frame</th>
<th>Mobility</th>
<th>Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>4-6 pneumatic cylinders controlled by a central valve station. Hand lever to actuate cylinders. Nitrogen/Compressed Air</td>
<td>8020 style extruded aluminum utilizing a bolt together design minimizing fabrication</td>
<td>Castor wheels with total locking mechanism</td>
<td>Upholstered cushions</td>
</tr>
<tr>
<td>#2</td>
<td>1 hydraulic cylinder under butt, gas struts used to assist in lifting head and feet</td>
<td>Aluminum welded frame</td>
<td>Ball bearings used as wheels with individual locks or combined locking system</td>
<td>Conventional spring mattress</td>
</tr>
<tr>
<td>#3</td>
<td>1 hydraulic cylinder under butt, manual positioning of head and feet</td>
<td>Steel welded frame</td>
<td>Non-mobile</td>
<td>Woven nylon net</td>
</tr>
</tbody>
</table>

For the lift-position system in the top overall design choice, six pneumatic cylinders were indeed chosen. Two cylinders were needed for the vertical lift and four other cylinders were needed for the individual body frames. In order to minimize fabrication, an 8020 style extruded aluminum was used which incorporated bolts and fasteners. In order to transfer patients comfortably to different destinations, industrial castor wheels with simple locking mechanisms were chosen. Due to the prototype design, individual upholstered cushions were made instead of a one-piece memory foam mattress.

**Drawings**

The drawings, as seen in Appendix - I and in Figures 7-9 below, represent different positions that the patient transfer device can maintain. The minimum vertical distance from the seat cushion to the floor is approximately 16in. The maximum vertical distance the device can maintain from the seat cushion to the floor is approximately 48in. The overall length of the patient transfer device in the bed position is designed for 78in. The arm assemblies can assume different positions in accordance to an individual’s need.
Figure 7 – Side view and trimetric view in chair position

Figure 8 – Side view and trimetric view with seat tilt at 45°

Figure 9 – Side view and trimetric view of bed extreme position
Loading Conditions

The loading conditions used for the patient transfer device were based from the parameters of the 99th percentile man. The parameters i.e. heights, centers of gravity, and body part thicknesses set up a guideline for the overall concept design. The illustrations in Figures 9-10 below are represented by dimensions and body weights. The maximum loading condition used for the design was approximately 300lbs. Worst case loading conditions occur at the lowest vertical position.

Figure 10 – Illustrations of human body parameters used in design

Figure 11 – Illustrations of loading conditions used in design
Design Analysis

The overall goal of the frame design was to be lightweight, easy to assemble, aesthetically pleasing, durable, and multi-functional. A bottom and top frame was designed independently to account for the scissor lift. Individual body frame assemblies were also designed to accommodate for each body segment area of the upper and lower limbs. The idea of using a scissor lift provides the medical professional the ability to attain a minimum seat level of 16in. and a maximum bed level of 48in. The sacrifice with the scissor lift design included a longer top and bottom frame design of 63in. respectively. The length of the top and bottom frames is directly proportional to the vertical height of the device; a longer frame results in a higher vertical lift.

As seen in Appendix-H, calculations were based from worst case conditions. With the force required to lift the patient transfer device at 2224 lbs per cylinder, a force analysis was conducted to determine the forces acting upon the top and bottom frames as well as the scissor 3-force members. With the results of the static forces on the top frame, bottom frame, and scissor members, a stress analysis with shear and moment diagrams were conducted. Using the Flexure Formula, the maximum design bending stress occurring on the top frame was 2694.63 psi. Also, using the General Shear Formula, the maximum shear in bending stress was 699.00psi. The maximum beam deflection on the top frame was -0.108 in.

For the scissor members, the maximum bending stress occurs at the pin connecting the two scissor members. For accurate shear and moment diagrams, perpendicular forces were needed. Using the Flexure Formula, the maximum bending stress was 3174.33 psi/member. Since C-Channel members were used for the scissor lift, some type of minimal twisting occurs. However, due to an 8 factor of safety used in design, it was assumed irrelevant because the majority of the stress occurs at the pin. Twisting and shearing were assumed to be minimal for this particular design.

The top frame was also designed to accommodate all of the individual frame assemblies i.e. seat, torso, hammy, and the calf and feet. The worst case loading condition occurred on the seat frame at the lowest vertical position with 300lbs. The maximum bending occurring on the seat frame is 2186.09 psi/member. A suitable material was needed to not allow failure.

Material Selection

To account for a lightweight frame design, the material selection was entirely made up of Aluminum 6105-T5 from 8020 Inc. 8020 Inc. provides simple assembly fasteners and joints that require minimal fabrication and machining. For the top and bottom frame, the 8020_1530_T-Slotted_Profile was used for simplicity. It is a 1.5in. x 3in. profile with high tensile and yield strengths of 38000psi and 35000psi respectively. With a factor of safety at 8, the design bending stress for this type of material was 4375psi. Since the actual bending stress (2694.63psi) occurring on the frame was less than the design bending stress (4375psi), the material chosen was more than suitable for this particular design.

The material chosen for all individual frame assemblies was Aluminum 6105-T5 from 8020 Inc. However, because the individual frame assemblies acquire less bending stress, an 8020_1515_T-Slotted Profile was used. It is a 1.5in. x 1.5in. profile that incorporates the same tensile and yield strengths as the 1530 profile. The moment of Inertia was 0.2524 in\(^4\), almost less than half than the 1530 profile.
Bill of Material

The Bill of Materials, as seen in Appendix – G, included a total of 84 purchased components and 79 manufactured components. The entire patient transfer device cost was $2588.00. The frame design cost was $1186.18. Overall, the ratio of purchased and manufactured components was acceptable because the entire design required minimal fabrication and machining.

FABRICATION AND ASSEMBLY

As previously mentioned in the Bill of Materials section, there was a total of 79 manufactured components used for the Universal Patient Transfer Device. The total amount of manufactured components included:

- Scissor members (4)
- Fixed scissor mounts (4)
- Seat pivot blocks (2)
- Clevis for scissor lifts (1)
- Cylinder clevis (4)
- Arm rest mounts (4)
- Cylinder mounting plates (8)
- Frames
  - Top (8)
  - Bottom (5)
  - Torso (11)
  - Seat (13)
  - Hamstring (9)
  - Feet (6)

All frame members were cut-to-length within 1/64 in. Also, all frame members needed to have through holes and counter bores for bolt assembly. Some individual frame members needed to be rounded off on the ends to ensure an angle of rotation. For the fixed scissor mounts, a vertical end mill was used to mill 0.25in spacing for the placement of the scissor members. They were original aluminum blocks that were horizontally milled to exact specifications. Using the drill press, through holes and counter bores were needed for bolt assembly to the top and bottom frames. The arm rest mounts needed the same fabrication as the fixed scissor mounts. The individual fabricated parts and scissor members were primed and painted white to replicate a sanitary, aesthetically pleasing patient transfer device. All assembly was done by hand by using allen-head wrenches for bolts and fasteners.

The Figures 12-14 listed below illustrate the different kinds of fabrication done on the device. Typical machines or equipment used in fabrication included a vertical end mill, horizontal mill, vertical band saw, horizontal band saw, chop saw, drill press, compound miter saw, bench grinder, and an angle grinder.
Figure 12 – Top and bottom frame with scissor members

Figure 13 – Fixed scissor mount

Figure 14 – Fixed scissor mounts with the overall finished frame
TESTING AND PROOF OF DESIGN

Testing was conducted in order to prove that the design worked. Several nurses controlled the device in order to replicate a real life experience. All of the results listed below were successful in terms of meeting the goals of the design. The maximum and minimum height tested were 6 ft. 4 in. and 5 ft. respectively. The maximum and minimum weight tested were 300 lbs and 0 lbs respectively. The five positions listed below provide the lengths and angle of rotation the device was able to maintain during testing trials.

- Vertical lift (16 to 48 in.)
- Seat tilt (+45°)
- Torso tilt (+90°), (-10°)
- Hamstring tilt (+30°), (-90°)
- Feet tilt (-90°)

The results of the product/engineering features also include:

- Minimal Controls (5)
- Maximum payload of 300 lbs (success)
- Lightweight (285 lbs)
- Aesthetically pleasing (success)
- Takes up less than 20 ft² (16.25 ft²)
- Comfort equivalent to current hospital beds (success)
- Minimal maintenance (yearly)
- Compatible with nitrogen tanks or a compressed air supply (success)

Some observations during testing included the following:

- Cylinder speeds were inconsistent
- “The vertical lift takes a minute to lift a person” (Katie RN)
- Leak in feet cylinder resulted with cushion not being stable for a long period of time
- Minimal twisting in frame occurred during seat cylinder actuation
- Minimal deformation in C-channel

Figures 15-16 below illustrate some examples of the proof of design for the device. The pictures were both taken at the 2007 Tech Expo.
Figure 15 – Front view illustration of the seat tilt at 45 degrees

Figure 16 – Illustration of Prof. Dong in a raised seated position
RECOMMENDATIONS

Certain attributes of the device were evaluated after it was completed. The goal in the future is to make the necessary improvements to commercialize the device to the appropriate industry or field. Unfortunately, the majority of the material for this device is non-recyclable. The only materials under consideration would be the upholstered cushions, but that is not sufficient enough to warrant a change in design. However, with the recommendations listed below, the opportunities to market a universal patient transfer device seem plausible. The recommendations and improvements for the prototype include the following:

- Use standard 8020 extruded aluminum instead of the LITE version for members experiencing torque
- Reduce maximum height of vertical lift to 40 in.
- Reduce amount of material needed for frame design
- Eliminate pneumatic cylinders and replace with electric linear actuators
- Replace pneumatic power supply with a rechargeable battery adaptable with a 110V outlet
- Make entire system controlled by one electric remote
- Eliminate loose fit between the fixed scissor mounts and scissor members
- Create a side-to-side transfer system
- Design for a wider comfort system
- Design user-friendly areas to push/transfer device
- Design a side-tilt
- Use accordion skirting for safety

SCHEDULE

A master schedule and individual schedule were created, as seen in Appendix – E, to be used as preliminary timelines for the product development of the patient transfer device. Since system responsibilities were divided, individual responsibilities needed to meet every deadline. All time constraints were subject to change. The list for the key deadline dates were as followed:

- Design Freeze Feb. 19th
- Design Report March 5th
- Oral Design Presentation March 12th
- Demonstration May 1st
- Tech Expo June 16th
- Project Report June 4th

There were several delays in our original schedule which included:

- Scissor member redesign (5 days)
- Framing reinforcements (2 days)
- Pneumatic leaks (2 days)
- Upholstery (1 day)
- Scissor clevis redesign (4 days)
- Assembly (2 days)

Due to the fabrication on the end of the scissor members, one side failed from bending. Fabricated blocks were made and bolted to each end in order to support the structure of the scissor members.
Some framing reinforcements were needed on the top frame to prevent some minimal twisting and bending from occurring while assisting an individual to a standing position. Assembly took longer than expected because each frame assembly needed to be taken apart and squared perfectly in order for the proper angles of rotation. Since we did start earlier than expected and did account for some delays in our schedule, there was minimal cause for concern in completing the project for the 2007 Tech Expo deadline.

BUDGET

A master budget and individual budget, as seen in Appendix – F, were created to be used as a forecasted cost estimate for materials and labor. Since system responsibilities were divided in a group, an individual budget was also created. The combined actual cost of the device was 12.5% over the proposed amount. This was due from the unforeseen expenses directed towards additional nuts and bolts and some redesign. The actual budget for this portion of the project was 6.4% over the proposed budget. Overall, the budget was more than satisfactory for this type of patient transfer device.

<table>
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<th>Actual</th>
<th>% Error</th>
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<td>Combined</td>
<td>$2,300</td>
<td>$2,588</td>
<td>12.5%</td>
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<tr>
<td>Riggenbach</td>
<td>$1,150</td>
<td>$1,224</td>
<td>6.4%</td>
</tr>
<tr>
<td>Wooddell</td>
<td>$1,150</td>
<td>$1,364</td>
<td>18.6%</td>
</tr>
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CONCLUSION

Overall, the Universal Patient Transfer Device was completed and deemed successful for the 2007 Tech Expo. For a prototype, the features and objectives were met efficiently enough to portray the overall concept. The difficulties with this concept initially were to design multiple capabilities and produce a finished product in a limited amount of time. Since a lot of time was spent in research and design via Solid Works, the process of machining and producing a finished product went smoothly. The logistics also played an important role because this project required a lot of individual responsibilities to meet a final deadline. Improvements still need to be made to enhance the product/engineering features. However, the goal to create a functional, professional looking device that could perform multiple tasks efficiently and easily was completed.
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16 Marje Filcox, RN, Med Central Hospice, Mansfield, Ohio (phone conversation) August 25, 2006

17 Sindy Dowds, RN, Med Central Hospital, Mansfield, Ohio (phone conversation) August 25, 2006


APPENDIX A – EXISTING PRODUCTS


- Complete stainless steel framework
- Waterproof & wearable cloth
- High dense sponge
- Size: 690 X 610 X 1000mm
- Extensible length : 1900mm

FEATURES:
- transportable
- versatile
- color
- size
- simple
- non-motorized
- no adjustments
- no assistance provided
- stainless steel


- Both sitting and laying positions
- Rexine material
- High dense sponge
- Device:1pc oddment basket
- Size: 1100×690×1200mm
- Extensible length : 1700mm

FEATURES:
- versatile
- color
- size
- simple
- non-motorized
- no adjustments
- no assistance provided
- seat cushions
- aesthetics
- storage rack
- sturdy
- comfortable
- non transportable
- not stainless steel
**FEATURES:**
- transportable
- versatile
- color
- size
- simple
- non-motorized
- no adjustments
- no assistance provided

- Powder spray painting steel framework
- Waterproof & wearable cloth
- High dense sponge
- Expanding length: 1900mm
- Size: 690×610×1000mm
**FEATURES:**
- transportable
- versatile
- size
- simple
- no power assist
- lightweight
- low cost
- one person use
- non-mobile

- Bed rail helps assist and guard the user in getting in and out of bed
- Adjustable to fit most beds with box spring and mattress
- Bed rail handle height adjusts independently of mattress height
- Legs extend to floor for added stability
- Rail length (width) is 12"
- Constructed of 1" steel tubing
- No bed attachment required
- No tools required
- Soft vinyl hand grip
- Warranty: 3 year limited
- Cost $72.95
• Low cost
• Easy patient lifting and lowering
• Versatile - can be used in multiple rooms
• No installation required
• Easily performs room to room transfers
• Can lift directly from the floor anywhere in the home
• Can lift to and from lying position
• Any patient can be lifted regardless of physical/mental condition
• Can be stored out of sight
• Does not perform well on thickly carpeted floors
• Requires storage space
• Does not function as a bath lift in a standard tub
• Requires under bed clearance
• Will not perform well in confined spaces or very small rooms
• Cost $1885

FEATURES:
• heavy duty
• high cost
• motorized
• requires recharging of battery
• assistance needed
• setup time
• storage
• bulky
400 lb safe working load
Compact design allows for easy lifting from floor
Six point spreader bar offers additional safety and comfort
Unique foot pedal base opening for wheelchair/commode access
Hydraulic pump pivots to both sides for caregiver convenience
Rubber coated base protects furniture
Low base height provides maximum stability and fits under lower beds
Large easy to grip handles allow for easy maneuvering
Choice of four colors, matches most decors (white, beige, blue, green)
Optional digital scale available
Cost $826
<table>
<thead>
<tr>
<th>FEATURES:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• high cost</td>
</tr>
<tr>
<td>• incompatibility</td>
</tr>
<tr>
<td>• versatile</td>
</tr>
<tr>
<td>• requires strength from patient</td>
</tr>
<tr>
<td>• only works for sitting position</td>
</tr>
<tr>
<td>• design</td>
</tr>
<tr>
<td>• color</td>
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</table>

- Excellent physical/psychological benefits for the patient
- Versatile - can be used in multiple rooms
- More dignified, less intimidating to the patient
- Excellent for toileting, perineal care, changing incontinent briefs
- Faster and easier for care giver
- Can perform room to room transfers
- Patient must be cognitive to use lift
- Patient must have some muscle tone in at least one leg and trunk
- Lift may become incompatible with patient if mental/physical conditions deteriorate
- Will not perform well on thickly carpeted surfaces
- Cost $2668
UpEasy Seat Assist are self-powered and require no batteries or electricity. A hydro-pneumatic piston slowly and automatically activates as you begin to stand up, lifting you gently up and out of your seat. *Not designed to work in a recliner chair that has padded cushions.*

- As you sit down on the Uplift Seat Assist, it eases you gently into a seated position.
- To get up, simply shift forward and begin to stand. The lifting piston activates automatically.
- This provides a gentle and stable lift up from the chair or sofa.
- 2 sizes available.
- Works with any chair that has arms.
- 1 year warranty.
- Lift up to 80% of your weight, but only as needed.
- Easily adjustable for various weights.

**MSRP: $204.00**

**Your Price: $119.00**

<table>
<thead>
<tr>
<th>Model No</th>
<th>Description</th>
<th>Weight Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP 1</td>
<td>Standard Uplift</td>
<td>95-220 lb</td>
</tr>
<tr>
<td>UP 3</td>
<td>Uplift PLUS</td>
<td>200-340 lb</td>
</tr>
</tbody>
</table>

**FEATURES:**
- design
- low cost
- reduces strength requirements
- single person operation
- comfortable
- reduces assistance for in and out of seat
- non motorized
- hydraulic / spring driven
# United States Patent

## Ellwanger et al.

**3,724,003**

**Apr. 3, 1973**

<table>
<thead>
<tr>
<th>FEATURES:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• options</td>
</tr>
<tr>
<td>• design</td>
</tr>
<tr>
<td>• sturdy</td>
</tr>
<tr>
<td>• cost</td>
</tr>
<tr>
<td>• non transportable</td>
</tr>
<tr>
<td>• unable to transfer positions</td>
</tr>
</tbody>
</table>

---

**HYDRAULIC ADJUSTING APPARATUS FOR HOSPITAL BEDS OR THE LIKE**

Inventors: Hans Ellwanger, Stuttgart; August Kraade, Bittenfeld; Walter Krauss, Maglingen; Wilhelm Zapf, Hemmingen, all of Germany

Assignee: Robert Bosch GmbH, Stuttgart, Germany

Filed: Jan. 3, 1972

Appl. No.: 214,949

Foreign Application Priority Data

July 8, 1971 Germany............P 21 34 0614

U.S. Cl. 5/48, 5/56, 5/58, 60/DIG. 2, 60/97 P

Int. Cl. F16b 21/08, F16b 21/08, A61g 7/00

Field of Search


References Cited

UNITED STATES PATENTS

2,703,505 2/1955 Patterson..................5/83 X
2,957,784 11/1960 Patterson..................5/83 X

Primary Examiner—Caspar A. Nussberg

Attorney—Michael S. Striker

15 Claims, 3 Drawing Figures
US6955366: Heavy bed transporting device

A heavy bed transporting device having a pair of dolly devices for moving collapsible hospital beds. Each dolly device has a horizontal base member with a pair of wheels attached to the lower surface thereof and a connecting structure formed on the surface of said base member configured to operatively engage and secure the hospital bed thereto. The front dolly device is equipped with swivel-mounted wheels, while the rear dolly device has fixed unidirectional wheels and a manual braking system. The connecting structures are adaptively formed to engage and secure different configurations of hospital bed frames, including both manual and electric hospital bed frames.
Patient Transfer Method.

http://www.cornmed.com/images/wrong_way.jpg

Patient Transfer Method.


Patient Transfer Method.

Patient Transfer Method.


Patient Transfer Method.
APPENDIX B – CUSTOMER INTERVIEWS SUMMARY

Interviewees:
1. Katie Wooddell, RN, Bethesda North Hospital, Rehab unit, Montgomery, Ohio
2. Kim Ransdell, Nurse Practitioner, Ohio Cancer Specialists, Mansfield, Ohio
3. Marje Filcox, RN, Med Central Hospice, Mansfield, Ohio
4. Sindy Dowds, RN, Med Central Hospital, Oncology Unit, Mansfield, Ohio

Questions and Answers
1. What is the most physically demanding part about your job?
   1. Lifting patients out of bed
   2. Lifting patients out of a chair
   3. Helping patients to get on their feet
   4. Helping patients out of wheelchairs

2. Is transferring patients physically demanding?
   1. Yes
   2. Yes
   3. Yes
   4. Yes

3. How many nurses are used when transferring patients to different positions?
   1. I usually do it myself
   2. It normally takes 2 nurses to lift a patient by their arms
   3. Two for the most part
   4. Just one

4. Does your employer currently have patient transfer devices, if so do you use them? Why or why not?
   1. We just got one, but I don’t use it because I don’t have time
   2. No
   3. No
   4. I think so, but I don’t know where they are

5. Is there a need for a user friendly patient transfer device?
   1. I think so
   2. Well, It would depend on what it could do
   3. No
   4. Yes, I think it would be beneficial to have one
APPENDIX C – CUSTOMER SURVEY RESULTS

Patient Transfer Device Customer Survey Results

As students attending the University of Cincinnati in the field of Mechanical Engineering Technology, we are interested in improving upon the current methods of transferring medical patients. Please take a few minutes to provide your professional opinion.

Please rank the need for an easy to use device to assist in the following patient transfer scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1 = not needed</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Very Needed %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transferring a patient from one bed to another</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>194</td>
</tr>
<tr>
<td>Transferring a patient from one chair to another</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>179</td>
</tr>
<tr>
<td>Transferring a patient from a bed to a chair</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Transferring a patient from a bed to a standing position</td>
<td>1 1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>136</td>
</tr>
<tr>
<td>Transferring a patient from a chair to a standing position</td>
<td>1 1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>142</td>
</tr>
</tbody>
</table>

Please rate how important it is for a patient transfer device to contain the following features.

<table>
<thead>
<tr>
<th>Feature</th>
<th>1 = low importance</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Very Important %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>194</td>
</tr>
<tr>
<td>Easy to operate</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>179</td>
</tr>
<tr>
<td>Appearance</td>
<td>1 1 2 3 4</td>
<td>5</td>
<td>24</td>
<td>N/A</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Low cost</td>
<td>1 2 3 4 5</td>
<td>11</td>
<td>24</td>
<td>N/A</td>
<td>136</td>
<td></td>
</tr>
<tr>
<td>Minimal size</td>
<td>1 2 3 4 5</td>
<td>7</td>
<td>10</td>
<td>N/A</td>
<td>142</td>
<td></td>
</tr>
<tr>
<td>Low maintenance</td>
<td>1 2 3 4 5</td>
<td>10</td>
<td>17</td>
<td>N/A</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td>1 2 3 4 5</td>
<td>36</td>
<td>N/A</td>
<td>192</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportable</td>
<td>1 2 3 4 5</td>
<td>10</td>
<td>26</td>
<td>N/A</td>
<td>178</td>
<td></td>
</tr>
<tr>
<td>Comfortable</td>
<td>1 2 3 4 5</td>
<td>13</td>
<td>22</td>
<td>N/A</td>
<td>173</td>
<td></td>
</tr>
</tbody>
</table>

Are you satisfied with current patient transfer devices? Please circle the appropriate answer.

<table>
<thead>
<tr>
<th>Feature</th>
<th>1 = very unsatisfied</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Very Satisfied %</th>
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</thead>
<tbody>
<tr>
<td>Safety</td>
<td>1 2 3 4 5</td>
<td>10</td>
<td>10</td>
<td>N/A</td>
<td>1 55</td>
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</tr>
<tr>
<td>Easy to operate</td>
<td>1 2 3 4 5</td>
<td>14 5 9</td>
<td>N/A</td>
<td>1 144</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appearance</td>
<td>1 2 3 4 5</td>
<td>16</td>
<td>5 5</td>
<td>N/A</td>
<td>2 123</td>
<td></td>
</tr>
<tr>
<td>Low cost</td>
<td>1 2 3 4 5</td>
<td>10</td>
<td>3 5</td>
<td>N/A</td>
<td>10 85</td>
<td></td>
</tr>
<tr>
<td>Minimal size</td>
<td>1 2 3 4 5</td>
<td>14</td>
<td>5 5</td>
<td>N/A</td>
<td>3 111</td>
<td></td>
</tr>
<tr>
<td>Low maintenance</td>
<td>1 2 3 4 5</td>
<td>10</td>
<td>14 5 10</td>
<td>N/A</td>
<td>3 137</td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td>1 2 3 4 5</td>
<td>14 5 14 5 14</td>
<td>N/A</td>
<td>1 153</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportable</td>
<td>1 2 3 4 5</td>
<td>16</td>
<td>5 9</td>
<td>N/A</td>
<td>1 140</td>
<td></td>
</tr>
<tr>
<td>Comfortable</td>
<td>1 2 3 4 5</td>
<td>14 5 7</td>
<td>N/A</td>
<td>1 132</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thank you for your time. Your opinions are appreciated.

If you have any additional feedback or questions, please contact us.

Sean Riggenbach (419) 295-2476 riggensd@email.uc.edu
Brian Wooddell (937) 216-3135 wooddebm@email.uc.edu

Appendix C1
## APPENDIX D – HOUSE OF QUALITY

9 = Strong  
3 = Moderate  
1 = Weak  
no relation = blank

| Operation          | Conform to hospital safety regulations | Limited controls | Payload | Weight | Surface finish | Floor space | Bedding material | material/component cost | Service warranty duration | Customer importance | Satisfaction | Planned design | Improvement ratio | Improvement (Absolute weight) ratio | Relative weight |
|--------------------|----------------------------------------|------------------|---------|--------|----------------|-------------|------------------|-------------------------|------------------------|---------------------|--------------|----------------|------------------|-------------------------------------|-----------------|----------------|
| 1. safety          | 9                                      | 1                |         |        |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 0.38 5.00 0.13 |
| 2. easy to operate | 9                                      |                  |         |        |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 0.42 5.00 0.13 |
| 3. stability       | 1                                      | 9                | 3       |        |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 0.42 5.00 0.13 |
| 4. transportable   |                                        | 9                |         | 1      |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 1.11 1.00 0.10 |

| Features           | Conform to hospital safety regulations | Limited controls | Payload | Weight | Surface finish | Floor space | Bedding material | material/component cost | Service warranty duration | Customer importance | Satisfaction | Planned design | Improvement ratio | Improvement (Absolute weight) ratio | Relative weight |
|--------------------|----------------------------------------|------------------|---------|--------|----------------|-------------|------------------|-------------------------|------------------------|---------------------|--------------|----------------|------------------|-------------------------------------|-----------------|----------------|
| 5. appearance      |                                        | 1                | 9       | 1      |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 0.30 2.10 0.06 |
| 6. minimal size    |                                        | 9                |         |        |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 0.33 3.33 0.09 |
| 7. comfort         |                                        |                 |         |        |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 0.36 4.36 0.12 |

| Cost               | Conform to hospital safety regulations | Limited controls | Payload | Weight | Surface finish | Floor space | Bedding material | material/component cost | Service warranty duration | Customer importance | Satisfaction | Planned design | Improvement ratio | Improvement (Absolute weight) ratio | Relative weight |
|--------------------|----------------------------------------|------------------|---------|--------|----------------|-------------|------------------|-------------------------|------------------------|---------------------|--------------|----------------|------------------|-------------------------------------|-----------------|----------------|
| 8. low cost        |                                        | 1                |         |        |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 0.43 3.86 0.10 |
| 9. low maintenance |                                        |                  |         |        |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 0.33 3.67 0.10 |

| Absolute Importance| Conform to hospital safety regulations | Limited controls | Payload | Weight | Surface finish | Floor space | Bedding material | material/component cost | Service warranty duration | Customer importance | Satisfaction | Planned design | Improvement ratio | Improvement (Absolute weight) ratio | Relative weight |
|--------------------|----------------------------------------|------------------|---------|--------|----------------|-------------|------------------|-------------------------|------------------------|---------------------|--------------|----------------|------------------|-------------------------------------|-----------------|----------------|
|                    |                                        | 1.3              | 1.38    | 1.37   |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 10.12 37.3 1.00 |

| Relative importance| Conform to hospital safety regulations | Limited controls | Payload | Weight | Surface finish | Floor space | Bedding material | material/component cost | Service warranty duration | Customer importance | Satisfaction | Planned design | Improvement ratio | Improvement (Absolute weight) ratio | Relative weight |
|--------------------|----------------------------------------|------------------|---------|--------|----------------|-------------|------------------|-------------------------|------------------------|---------------------|--------------|----------------|------------------|-------------------------------------|-----------------|----------------|
|                    |                                        | 0.13             | 0.13    | 0.13   |                |             |                  |                         |                        |                     |              |                |                  |                       |                 | 0.11 1.06 0.99 |

| Units              | Conform to hospital safety regulations | Limited controls | Payload | Weight | Surface finish | Floor space | Bedding material | material/component cost | Service warranty duration | Customer importance | Satisfaction | Planned design | Improvement ratio | Improvement (Absolute weight) ratio | Relative weight |
|--------------------|----------------------------------------|------------------|---------|--------|----------------|-------------|------------------|-------------------------|------------------------|---------------------|--------------|----------------|------------------|-------------------------------------|-----------------|----------------|
|                    |                                        | #                | lbs     | lbs    | (in)           | ft²         | ($)              | $                       | Wks                     |                     |              |                |                  |                       |                 | 0.08 0.05 0.01 |

Appendix D1
APPENDIX E – MASTER SCHEDULE

Sean Riggenbach & Brian Wooddell
Wooddell Master Schedule
Patient Transfer Device

Dates

Tasks

Proof of design
Weighted Objective Method
Design of Power System
Design of Base Frame System
Design Tracking System
Design of Motion system
Design of Comfort System
Design Mobility System
Design Freeze
Oral Design Presentation
Touch up design
Order Parts
Design Report
Build Power System
Build Base Frame System
Build Tracking System
Build Motion System
Build Comfort System
Build Mobility System
Demonstration
Correct problems
Tech EXPO
Start Oral Presentation
Project Report

* Deadline
APPENDIX E-1 – RIGGENBACH’S SCHEDULE

Sean Riggenbach Schedule

<table>
<thead>
<tr>
<th>Dates</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1-1/7</td>
<td>Proof of design Jan. 12th</td>
</tr>
<tr>
<td>1/8-1/14</td>
<td>Weighted Objective Method</td>
</tr>
<tr>
<td>1/15-1/21</td>
<td>Design of Base Frame System</td>
</tr>
<tr>
<td>1/22-1/28</td>
<td>Design Mobility System</td>
</tr>
<tr>
<td>1/29-2/4</td>
<td>Design Freeze</td>
</tr>
<tr>
<td>2/5-2/11</td>
<td>Oral Design Presentation</td>
</tr>
<tr>
<td>2/12-2/18</td>
<td>Touch up design</td>
</tr>
<tr>
<td>2/19-2/25</td>
<td>Order Parts</td>
</tr>
<tr>
<td>2/26-3/4</td>
<td>Design Report March 5th</td>
</tr>
<tr>
<td>3/5-3/11</td>
<td>Build Base Frame System</td>
</tr>
<tr>
<td>3/12-3/18</td>
<td>Build Tracking System</td>
</tr>
<tr>
<td>3/19-3/25</td>
<td>Build Comfort System</td>
</tr>
<tr>
<td>3/26-4/1</td>
<td>Build Mobility System</td>
</tr>
<tr>
<td>4/2-4/8</td>
<td>Demonstration</td>
</tr>
<tr>
<td>4/9-4/15</td>
<td>Correct problems May 1st</td>
</tr>
<tr>
<td>4/16-4/22</td>
<td>Tech EXPO Thurs. 17th</td>
</tr>
<tr>
<td>4/23-4/29</td>
<td>Start Oral Presentation</td>
</tr>
<tr>
<td>4/30-5/6</td>
<td>Project Report June 4th</td>
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<tr>
<td>5/7-5/13</td>
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<tr>
<td>5/14-5/20</td>
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<td>5/21-5/27</td>
<td></td>
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<tr>
<td>5/28-6/3</td>
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</tr>
<tr>
<td>6/4-6/10</td>
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</table>

* Deadline
# APPENDIX F – MASTER BUDGET AND INDIVIDUAL BUDGET

## Master Budget for Sean Riggenbach & Brian Wooddell

<table>
<thead>
<tr>
<th>Systems</th>
<th>Forcasted Amounts</th>
<th>Actual Amounts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power</td>
<td>Motion</td>
</tr>
<tr>
<td>Power (actuators)</td>
<td>$300</td>
<td>$300</td>
</tr>
<tr>
<td>Motion</td>
<td>$100</td>
<td>$100</td>
</tr>
<tr>
<td>Frame</td>
<td>$300</td>
<td>$300</td>
</tr>
<tr>
<td>Mobility</td>
<td>$100</td>
<td>$100</td>
</tr>
<tr>
<td>Tracking</td>
<td>$600</td>
<td>$600</td>
</tr>
<tr>
<td>Comfort</td>
<td>$400</td>
<td>$400</td>
</tr>
<tr>
<td>Plumbing</td>
<td>$200</td>
<td>$200</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>$200</td>
<td>$200</td>
</tr>
<tr>
<td>Misc. Hardware</td>
<td>$100</td>
<td>$100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>$2,300</td>
</tr>
</tbody>
</table>

## Riggenbach Budget

<table>
<thead>
<tr>
<th>Systems</th>
<th>Forcasted Amounts</th>
<th>Actual Amounts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power</td>
<td>Motion</td>
</tr>
<tr>
<td>Power (actuators)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Motion</td>
<td>N/A</td>
<td>$100</td>
</tr>
<tr>
<td>Frame</td>
<td>$300</td>
<td>$200</td>
</tr>
<tr>
<td>Mobility</td>
<td>$100</td>
<td>$100</td>
</tr>
<tr>
<td>Tracking</td>
<td>$50</td>
<td>$50</td>
</tr>
<tr>
<td>Comfort</td>
<td>$100</td>
<td>$100</td>
</tr>
<tr>
<td>Plumbing</td>
<td>$200</td>
<td>$200</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>$100</td>
<td>$100</td>
</tr>
<tr>
<td>Misc. Hardware</td>
<td>$50</td>
<td>$50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$1,150</td>
<td>$1,150</td>
</tr>
</tbody>
</table>
# Patient Transfer Device Bill of Materials

<table>
<thead>
<tr>
<th>Level</th>
<th># Part #</th>
<th>Sup. Description</th>
<th>Qty</th>
<th>Price Ea</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Mfg. Top Frame Assembly</td>
<td>1</td>
<td>$117.18</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1 8020_1530_63</td>
<td>8020 1530 x 63 inches</td>
<td>126</td>
<td>$0.93</td>
<td>$117.18</td>
</tr>
<tr>
<td>2</td>
<td>2 8020_1515_24</td>
<td>8020 1515 x 24 inches</td>
<td>48</td>
<td>$0.53</td>
<td>$25.44</td>
</tr>
<tr>
<td>2</td>
<td>3 8020_1515_3</td>
<td>8020 1515 x 3.0 inches</td>
<td>6</td>
<td>$0.53</td>
<td>$3.18</td>
</tr>
<tr>
<td>2</td>
<td>4 8020_1515_6.5</td>
<td>8020 1515 x 6.5 inches</td>
<td>13</td>
<td>$0.53</td>
<td>$6.89</td>
</tr>
<tr>
<td>2</td>
<td>5 Seat Raise Pivot Block</td>
<td>Mfg. Seat Raise Pivot Block</td>
<td>2</td>
<td>$25.00</td>
<td>$50.00</td>
</tr>
<tr>
<td>2</td>
<td>6 5/16-18 x 1.50 SHCS</td>
<td>Hard Socket Head Cap Screw</td>
<td>4</td>
<td>$0.38</td>
<td>$1.52</td>
</tr>
<tr>
<td>2</td>
<td>7 5/16-18 x 5.00 SHCS</td>
<td>Hard Socket Head Cap Screw Grade 8</td>
<td>2</td>
<td>$2.25</td>
<td>$4.50</td>
</tr>
<tr>
<td>2</td>
<td>8 3x3 Scissor Safety Plate</td>
<td>Mfg. Scissor Safety Plate 3x3x.25</td>
<td>2</td>
<td>$6.00</td>
<td>$12.00</td>
</tr>
<tr>
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APPENDIX H – CALCULATIONS

Scissor Members

FBD Scissor Member

FBD of Entire System

\[
\begin{align*}
\text{V (lbs)} & \quad 109.0 \text{ lbs} \\
\text{M (in-lbs)} & \quad -3370.28 \text{ in-lbs}
\end{align*}
\]
Calculations

Force Required from Cylinder for Scissor Lift:

\[
Force = F = \left(\frac{b}{h}\right)W
\]

\[
Force = F = \left(\frac{61.5}{6.5}\right)235 = 2224\text{lbs}
\]

Static Forces on Scissor Members:

\[
\sum F_y = 0 = P_y + C_y - 150 - 85
\]

\[
\sum F_x = 0 = P_x - 2224
\]

\[
\sum M_p = 0 = (-150)(33.7) - (85)(30.75) + C_y(61.5)
\]

\[
P_y = 110.31\text{ lbs}
\]
\[
P_x = 2224\text{ lbs}
\]
\[
C_y = 124.7\text{ lbs}
\]

\[
\sum F_y = 0 = 110.31 - 124.7 + D_y
\]

\[
\sum F_x = 0 = 2224 - D_x
\]

\[
\sum M_d = 0 = (-110.31)(30.75) + 2224(3.25) - (124.7)(30.75) + B_x(3.25)
\]

\[
D_y = 14.4\text{ lbs}
\]
\[
D_x = 2224\text{ lbs}
\]
\[
B_x = 0\text{ lbs}
\]

Bending Stress:

Material Selection: Aluminum C-Channel 6105-T5:

\[
S_y = 35000\text{ psi}
\]

\[
\sigma_{design} = \frac{S_y}{8} = 35000/8 = 4375\text{ psi}
\]

Max Moment = M = \((110.3\text{ lbs})*(30.75\text{ in.}) + (25.3\text{ lbs})*(2.95) = 3466.37\text{ in-lbs}

\[
\sigma_{actual} = \frac{M(c)}{(I)} = \frac{(3466.37)(1)}{(546)} = 6348.66\text{ psi}/2\text{ (# of members)} = 3174.33\text{ psi/member}
\]

OK. \(\sigma_{design} > \sigma_{actual}\)
Pin Sizing for Scissor Lift:

\[ F_c = \sqrt{(2224)^2 + (124.7)^2} = 2228\text{lbs} \]

Double Shear
Use Grade 8 Bolt
\( S_y = 130000\text{psi} \)

\( P = 2228 \text{ lbs for 2 bolts} \)
\( F_c = 2228/2 = 1114 \text{ lbs} \)

Repeated Load = \( \frac{S_y}{8} = \frac{130000}{8} = 16250 \text{ psi} \)

\[ Dia = \sqrt{\frac{4F}{\pi\tau}} = \sqrt{\frac{4(1114)}{\pi(16250)}} = 0.295\text{in} \]

Therefore use 5/16”- 18 bolts for pin C.
Since solved for worst case at C, same bolts are used for pins B, A, and P.

Sizing for Pin D
Use Grade 8 Bolt
\( S_y = 130000\text{psi} \)

\( P = 4448 \text{ lbs for 2 bolts} \)
\( F_d = 4448/2 = 2224 \text{ lbs} \)

Repeated Load = \( \frac{S_y}{8} = \frac{130000}{8} = 16250 \text{ psi} \)

\[ Dia = \sqrt{\frac{4F}{\pi\tau}} = \sqrt{\frac{4(2224)}{\pi(16250)}} = 0.417\text{in} \]

Therefore use 1/2”- 18 bolts for pin D.
Calculations:

\[ \sum M_A = 0 = -B(2.22) + 2224(5.11) \]
\[ \sum M_B = 0 = -A(2.22) + 2224(2.89) \]

A = 2895 lbs
B = 5119 lbs

Material Selection: 1040 Hot Rolled Steel
Repeated Load:

\[ \sigma_{design} = \frac{S_y}{8} = \frac{60000}{8} = 7500 \text{ psi} \]

\[ \sigma_{actual} = \frac{(M)(c)}{(I)} = \frac{(6427)(.875)}{(.7816)} = 7195.24 \text{ psi} \]

OK. \( \sigma_{design} > \sigma_{actual} \)
Calculations

Bending Stress:
Aluminum 8020_1530_T-Profile:

\[ S_y = 35000 \text{ psi} \]
\[ \sigma_{design} = \frac{S_y}{8} = \frac{35000}{8} = 4375 \text{ psi} \]

Max Moment = \( M = (110.3 \text{ lbs}) \times (30.75 \text{ in.}) + (25.3 \text{ lbs}) \times (2.95) = 3466.37 \text{ in-lbs} \)

\[ \sigma_{actual} = \frac{(M)(c)}{(I)} = \frac{(3466.37)(.75)}{(.4824)} = 5389.26 \frac{\text{psi}}{2 \text{ (# of members)}} = 2694.63 \text{ psi/member} \]

OK. \( \sigma_{design} > \sigma_{actual} \)

Beam Deflection in Top Frame

1.) 8020_1530_3”x1.5”

Formula:

\[ y_{max} = \frac{(-P)(a)(b)(L+b)\left(\sqrt{3}(a)(L+b)\right)}{(27)(E)(I)(L)} \]

Where:
\[ P = \text{Load (lbs)} \]
\[ L = \text{Overall Length (in)} \]
\[ a = \text{length (in)} \]
\[ b = \text{length (in)} \]
\[ E = \text{Modulus of Elasticity (10E6 psi)} \]
\[ I = \text{Moment of Inertia (in}^4) \]

1.) \[ y_{max} = \frac{(-300)(27.8)(33.7)(61.5+33.7)\left(\sqrt{3}(27.8)(61.5+33.7)\right)}{(27)(10^9)(.4824)(61.5)} = -.0108 \text{in} \]
Calculations:

Static Forces:
\[ \sum F_x = 0 = P_x - C_x \]
\[ \sum F_y = 0 = P_y - 98.4 - 201.6 + C_y - 25 - 35 \]
\[ \sum M_p = 0 = (-98.4)(4.24) - (201.6)(14.14) + C_y(9.5) - 25(10.5) - 35(24.1) \]
\[ \sum M_c = 0 = P_y(9.5) + (98.4)(5.26) - 201.6(4.64) - 25(1) - 35(14.6) \]

\[ C_y = 460.4 \text{ lbs} \]
\[ C_x = 518.0 \text{ lbs} \]
\[ C = 693 \text{ lbs} \]
\[ P_y = 100.4 \text{ lbs} \]
\[ P_x = 518.0 \text{ lbs} \]
\[ P = 527.6 \text{ lbs} \]

Cylinder Bore Size:
\[ Dia = \sqrt[4]{4F \over \pi P} = \sqrt[4]{4(693lb)} \over \pi(84 \text{ psi}) = 3.24 \text{in} \]

Therefore use 3.25” Bore Diameter

Pivot Pin:

Use Grade 8 Bolt
\[ S_y = 130000 \text{ psi} \]

Repeated Load = \[ \left( \frac{S_y}{8} \right) = \frac{130000}{8} = 16250 \psi i \]

\[ P = 894 \text{ lbs for 2 bolts} \]
\[ F_p = 894/2 = 447 \text{ lbs} \]

\[ Dia = \sqrt[4]{4F \over \pi \tau} = \sqrt[4]{4(447)} \over \pi(16250) = 0.187 \text{in} \]

Therefore use 5/16” bolt to match 8020_1515

Cylinder Pin Sizing:

Single Shear
Use Grade 8 Bolt
\[ S_y = 130000 \text{ psi} \]

\[ P = 693 \text{ lbs for 2 bolts} \]
\[ F_p = 693/2 = 346.5 \text{ lbs} \]
Repeated Load = \( \frac{130000}{8} = 16250 \text{ psi} \)

\[ \text{Dia} = \sqrt{\frac{4F}{\pi\tau}} = \sqrt{\frac{4(346.5)}{\pi(16250)}} = 0.165 \text{ in} \]

Therefore use 0.25”-20 bolt

Bending Stress:
Aluminum 8020_1515_T-Profile
\( S_y = 35000 \text{ psi} \)

\[ \sigma_{design} = \frac{S_y}{8} = \frac{35000}{8} = 4375 \text{ psi} \]

Max Moment = \( M = (-100.4 \text{ lbs}) \cdot (4.24 \text{ in.}) + (-198.8 \text{ lbs}) \cdot (5.26 \text{ in.}) = -1471.4 \text{ in-lbs} \)

\[ \sigma_{actual} = \frac{(M)(c)}{(I)} = \frac{(1471.4)(.75)}{(2524)} = 4372.18 \text{ psi / 2 (number of members) = 2186.09 psi/member} \]

OK. \( \sigma_{design} > \sigma_{actual} \)
Calculations:

Static Forces:
\[ \sum M_p = 0 = 14C_y + 2C_x - 13.84 \times 201.6 \\
= 14(c(\sin \theta)) + 2(c(\cos \theta)) = 2790.14 \\
= 5.2(c) + 1.9(c) = 2790.14 \\
c_y = 146.85 \\
c_x = 367.15 \\
c = 400\,\text{lbs} \\
\]

\[ \sum F_y = 201.6 = P_y + C_y \\
P_y = 54.75\,\text{lbs} \\
P_x = 367.15\,\text{lbs} \\
\]

Cylinder Bore Size:

\[ Dia = \sqrt{\frac{4C}{\pi P}} = \sqrt{\frac{4(400\,\text{lb})}{\pi(84\,\text{psi})}} = 2.46\,\text{in} \]

Therefore used 2.5” Bore Diameter

Pivot Pin:

Use Grade 8 Bolt
\[ S_y = 130000\,\text{psi} \]

Repeated Load = \[ \frac{S_y}{8} = \frac{130000}{8} = 16250\,\text{psi} \]

P = 393 lbs for 2 bolts
\[ F_p = 393/2 = 196.5\,\text{lbs} \]

\[ Dia = \sqrt{\frac{4F}{\pi \tau}} = \sqrt{\frac{4(196.5)}{\pi(16250)}} = 0.124\,\text{in} \]

Therefore use 5/16” bolt to match 8020_1515

Cylinder Pin Sizing:

Double Shear
Use Grade 8 Bolt
\[ S_y = 130000\,\text{psi} \]

P = 400 lbs for 2 bolts
\[ F_p = 400/2 = 200\,\text{lbs} \]
Repeated Load = $\frac{S_y}{8} = \frac{130000}{8} = 16250$ psi

$$Dia = \sqrt[\pi]{\frac{4F}{\pi \tau}} = \sqrt[\pi]{\frac{4(200)}{\pi(16250)}} = 0.125\text{in}$$

Therefore use 0.25”-20 bolt

Bending Stress:
Aluminum 8020_1515_T-Profile
$S_y = 35000$ psi

$$\sigma_{design} = \frac{S_y}{8} = \frac{35000}{8} = 4375 \text{ psi}$$

Max Moment = $M = (54.75 \text{ lbs})*(13.84 \text{ in.}) = 757.74 \text{ in-lbs}$

$$\sigma_{actual} = \frac{(M)(c)}{(I)} = \frac{(757.74)(.75)}{(2524)} = 2251.6 \text{ psi} / 2 \text{ (# of members)} = 1125.8 \text{ psi/member}$$

OK. $\sigma_{design} > \sigma_{actual}$
Hammy @ 180°
Calculations

Static Forces:
\[ \sum F_x = 0 = P_x - C_x \]
\[ \sum F_y = 0 = C_y + P_y - 37.5 \]
\[ \sum M_p = 0 = (- C_y)(4.5) + 37.5(12.26) \]

\[ C_x = \frac{C_y}{\tan \theta} = \frac{15.78}{\tan(34.695)} = 147.6 \text{ lbs} \]
\[ C_y = 15.78 \text{ lbs} \]
\[ C = \frac{C_y}{\sin \theta} = \frac{102.2}{\sin(34.695)} = 179.55 \approx 180 \text{ lbs} \]
\[ P_x = 147.6 \text{ lbs} \]
\[ P_y = 21.72 \text{ lbs} \]
\[ P = 96 \text{ lbs} \]

Bending Stress:
Aluminum 8020_1515_T-Profile
\[ S_y = 35000 \text{ psi} \]
\[ \sigma_{\text{design}} = \frac{S_y}{8} = 35000/8 = 4375 \text{ psi} \]

Max Moment = \[ M = (-37.5)(7.76) = -291.00 \text{ in-lbs} \]
\[ \sigma_{\text{actual}} = \frac{(M)(c)}{(I)} = \frac{(291.00)(.75)}{(2524)} = 864.7 \text{ psi} / 2 \text{ (# of members)} = 432.35 \text{ psi/member} \]

OK. \( \sigma_{\text{design}} > \sigma_{\text{actual}} \)

Cylinder Bore Sizing:
\[ \text{Dia} = \sqrt{\frac{4C}{\pi P}} = \sqrt{\frac{4(180lb)}{\pi(84 \text{ psi})}} = 1.65 \text{ in} \]
Therefore used 2” bore diameter.

Cylinder Pin Sizing:
Use Standard Grade 8 0.25”-20 bolts based from the worst case cylinder sizing of the butt.

Pivot Pin:
Use Standard Grade 8 5/16” bolts to match 8020_1515. This is based from the worst case pivot pin sizing of the seat.
Calf and Feet @ 180°

Calf & Feet

\[ C_x = 37.5 \text{ lb} \]
\[ C_y = 93.7 \text{ lb} \]
\[ P_x = 93.7 \text{ lb} \]
\[ P_y = 21.72 \text{ lb} \]

\[ 5.865 \quad 4.26 \]

\[ 15.78 \quad -21.72 \quad 92.5 \]

\[ M(\text{in.} \cdot \text{lb}) \]
Calculations

Static Forces:
\[ \sum F_x = 0 = P_x - C_x \]
\[ \sum F_y = 0 = C_y + P_y - 37.5 \]
\[ \sum M_p = 0 = (C_y)(10.125) + 37.5(4.26) \]

\[ P_x = 93.7 \text{ lbs} \]
\[ P_y = 21.72 \text{ lbs} \]
\[ P = 96 \text{ lbs} \]
\[ C_x = 93.7 \text{ lbs} \]
\[ C_y = 15.78 \text{ lbs} \]
\[ C = \frac{C_y}{\sin \theta} = \frac{15.78}{\sin(9.56)} = 95.01 \approx 100 \text{ lbs} \]

Bending Stress:
Aluminum 8020\_1515\_T-Profile

\[ S_y = 35000 \text{ psi} \]
\[ \sigma_{design} = S_y / 8 = 35000/8 = 4375 \text{ psi} \]

Max Moment = \( M = (15.78 \text{ lbs})*(5.87 \text{ in.}) = 92.55 \text{ in-lbs} \)

\[ \sigma_{actual} = \frac{M c}{I} = \frac{92.55(75)}{2524} = 275.01 \text{ psi} / 2 (\text{# of members}) = 137.51 \text{ psi/member} \]

OK. \( \sigma_{design} > \sigma_{actual} \)

Cylinder Bore Sizing:
\[ Dia = \sqrt{\frac{4C}{\pi P}} = \sqrt{\frac{4(100lb)}{\pi(84 psi)}} = 1.23 \text{ in} \]

Therefore use 1/2” bore diameter.

Cylinder Pin Sizing:

Use Standard Grade 8 0.25”-20 bolts based from the worst case cylinder sizing of the seat.

Pivot Pin:

Use Standard Grade 8 5/16” bolts to match 8020\_1515. This is based from the worst case pivot pin sizing of the butt.
Shearing Stresses in Beams

1.) 8020_1515_1.5”x1.5”  
2.) 8020_1530_3”x1.5”  
3.) C-Channel Beam (Scissor Member)

Formulas:
Shear Stress = \( \tau = \frac{V \cdot Q}{I \cdot t} \)

First Moment of Area = \( Q = (A_p)\cdot(y) \)

1.) \( Q = (A_p)\cdot(y) = \left(\frac{1.514}{2}\right)(.375) = 0.216in^3 \)
   \( \tau = \frac{V \cdot Q}{I \cdot t} = \frac{(300lbs)(216in^3)}{(2524in^4)(16in)} = 1604.6psi \)

Design Shear Stress = (0.4) \((S_y) = (0.4)(35000psi) = 14000 psi \)
OK. 14000psi > 1604.6psi

2.) \( Q = (A_p)\cdot(y) = \left(\frac{16}\cdot(3)\right)(.75) = 0.18in^3 \)
   \( \tau = \frac{V \cdot Q}{I \cdot t} = \frac{(300lbs)(18in^3)}{(4824in^4)(16in)} = 699 psi \)

Design Shear Stress = 14000 psi
OK. 14000psi > 699.0psi

3.) \( Q = (A_p)\cdot(y) = \left(\frac{911}{2}\right)(1) = 0.4555in^3 \)
   \( \tau = \frac{V \cdot Q}{I \cdot t} = \frac{(300lbs)(4555in^3)}{(546in^4)(205in)} = 1220.85 psi \)

Design Shear Stress = 14000 psi
OK. 14000psi > 1220.85psi

Appendix H
Volume Displacement for 1 Bed Cycle per Cylinder

Total Displacement Volume per Cycle = 664 in$^3$
Volume displacement calculations include:

1.) Feet and Calf
Bore Diameter = 1.5”
Bore Area = $\frac{(\pi D)^2}{4} = \frac{(\pi)(1.5)^2}{4} = 1.77$ in$^2$
Volume Displaced = $V = (1.77)(4) = 7.08$ in$^3$

2.) Hammy
Bore Diameter = 1.8” ~ 2.00”
Bore Area = $\frac{(\pi D)^2}{4} = \frac{(\pi)(2)^2}{4} = 3.14$ in$^2$
Volume Displaced = $V = (3.14)(6.6) = 20.73$ in$^3$

3.) Back
Bore Diameter = 2.52” ~ 2.5”
Bore Area = $\frac{(\pi D)^2}{4} = \frac{(\pi)(2.5)^2}{4} = 4.91$ in$^2$
Volume Displaced = $V = (4.91)(8.5) = 41.74$ in$^3$

4.) Butt
Bore Diameter = 3.25”
Bore Area = $\frac{(\pi D)^2}{4} = \frac{(\pi)(3.25)^2}{4} = 8.30$ in$^2$
Volume Displaced = $V = (8.3)(7) = 58.10$ in$^3$

5.) Bed
Using 2 – 6” cylinders
Bore Diameter = 6”
Bore Area = $\frac{(\pi D)^2}{4} = \frac{\text{rod} \ _{area}}{4} = \frac{(\pi)(6)^2}{4} - \frac{(\pi)(1.375)^2}{4} = 26.79$ in$^2$
Volume Displaced = $V = (2)(26.79)(10) = 535.80$ in$^3$
Nitrogen Tank Sizing:

Total Displacement Volume of All Cylinders = 664 $in^3$

Output Volume:

\[
\frac{P_2}{P_1} = \left( \frac{V_1}{V_2} \right)^k \quad \text{(Polytropic)}
\]

\[
V_1 = \left( \frac{(P_2)(V_2)}{(P_1)^{\frac{1}{k}}} \right)^{\frac{1}{4}}
\]

Where:
- $P_2$ = Pressure of Tank = 14.7 psi
- $P_1$ = System Operating Press = 84 psi
- $V_2$ = Tank Volume = 40 ft$^3$ = 69120 $in^3$
- $V_1$ = Operating Volume = 520 $in^3$
- $K = \frac{C_p}{C_v} = 1.4$

\[
V_1 = \left( \frac{(14.7)(69120)^{1.4}}{(84)} \right)^{\frac{1}{4}} = 19903\text{ in}^3
\]

Life Cycles:

# of Cycles = Output Volume/Cycle Volume
# of Cycles = 19903 $in^3$/664 $in^3 = 30$ cycles