Design of the HLPR Chair

Home Lift Position and Rehabilitation Chair

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June 19, 2007
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Introduction

Reference [1] says “today, approximately 10 percent of the world’s population is over 60; by 2050 this proportion will have more than doubled” and “the greatest rate of increase is amongst the oldest old, people aged 85 and older.” She follows by adding that this group is subject to both physical and cognitive impairments more than younger people. These facts have a profound impact on how the world will maintain the elderly independent as long as possible from caregivers. Both physical and cognitive diminishing abilities address the body and the mental process of knowing, including aspects such as awareness, perception, reasoning, intuition and judgment. Assistive technology for the mobility impaired includes the wheelchair, lift aids and other devices, all of which have been around for decades. However, the patient typically or eventually requires assistance to use the device; whether it’s someone to push them in a wheelchair, to lift them from the bed to a chair or to the toilet or for guiding them through cluttered areas. With fewer caregivers and more elderly, there is a need for improving these devices to provide them independent assistance.

Wheelchairs

There has been an increasing need for wheelchairs over time. L.H.V. van der Woude [2] states that mobility is fundamental to health, social integration and individual well-being of the humans. Henceforth, mobility must be viewed as being essential to the outcome of the rehabilitation process of wheelchair dependent persons and to their successful (re-)integration into society and to a productive and active life. Thrun [3] said that, if possible, rehabilitation to relieve the dependence on the wheelchair is ideal for this type of patient to live a longer, healthier life. Van der Woude continues stating that many lower limb disabled subjects depend upon a wheelchair for their mobility. Estimated numbers for Europe and USA are respectively 2.5 million and 1.25 million. The quality of the wheelchair, the individual work capacity, the functionality of the wheelchair/user combination, and the effectiveness of the rehabilitation program do indeed determine the freedom of mobility.

Patient Lift

Just as important as wheelchairs are the lift devices and people who lift patients into wheelchairs and other seats, beds, automobiles, etc. The need for patient lift devices will also increase as generations get older. When considering if there is a need for patient lift devices, several references state the positive, for example:

- “The question is, what does it cost not to buy this equipment? A back injury can cost as much as $50,000, and that’s not even including all the indirect costs. If a nursing home can buy these lifting devices for $1,000 to $2,000, and eliminate a back injury that costs tens of thousands of dollars, that’s a good deal,” [4]
- 1 in every 3 nurses become injured from the physical exertion put forth while moving non-ambulatory patients; costing their employers $35,000 per injured nurse. [5]
- 1 in 2 non-ambulatory patients fall to the floor and become injured when being transferred from a bed to a wheelchair. - [6]
- "Nursing and personal care facilities are a growing industry where hazards are known
Design of the HLPR Chair

and effective controls are available,” said OSHA Administrator John Henshaw. "The industry also ranks among the highest in terms of injuries and illnesses, with rates about 2 1/2 times that of all other general industries..." [7]

- “Already today there are over 400,000 unfilled nursing positions causing healthcare providers across the country to close wings or risk negative outcomes. Over the coming years, the declining ratio of working age adults to elderly will further exacerbate the shortage. In 1950 there were 8 adults available to support each elder 65+, today the ratio is 5:1 and by 2020 the ratio will drop to 3 working age adults per elder person.” [8]

In 2005, NIST ISD began the Healthcare Mobility Project to target this staggering healthcare issue of patient lift and mobility. ISD researchers looked at currently available technology through a survey of patient lift and mobility devices [9]. That report showed that there is need for technology that includes mobility devices that can lift and maneuver patients to other seats and technology that can provide for rehabilitation to help the patient become independent of the wheelchair.

An additional area investigated in the survey was intelligent wheelchairs. NIST has been studying intelligent mobility for the military, transportation, and the manufacturing industry for nearly 30 years through the Intelligent Control of Mobility Systems (ICMS) Program. [10] Toward a standard control system architecture and advanced 3D imaging technologies, as being researched within the ICMS Program, and applying them to intelligent wheelchairs, NIST has begun outfitting the HLPR Chair with computer controls. Although throughout the world there are or have been many research efforts in intelligent wheelchairs, including: [11, 12, 13, 14] and many others, the authors could find no sources applying standard control methods nor application of the most advanced 3D imagers prototyped today to intelligent wheelchairs. Therefore, NIST began developing the HLPR Chair [15] to investigate these specific areas of mobility, lift and rehabilitation, as well as advanced autonomous control.

This paper includes mechanical and electrical designs for the HLPR Chair in its prototype stage with designs dating back to December 2005. An initial prototype HLPR Chair concept, called RoboChair, was completed in July 2004.

Introduction References

Design of the HLPR Chair

Design of the HLPR Chair

Concept

HLPR Chair is shown in the powered chair configuration with controls that the patient can use to drive the chair or a nurse/caregiver can use the controls from behind the chair to mobilize the patient.

Top view of the HLPR Chair rear steering and drive wheel and fixed front casters configuration.

PLACEMENT ON CHAIR, TOILET, BED

Place on seat and stay for support...
Design of the HLPR Chair

(a) HLPR Chair can be used to carry a patient to a chair or toilet, rotate the patient ready to place them on the seat, remove the footrest, raise the torso lifts and patient above the HLPR Chair seat, remove the HLPR Chair seat from beneath the patient, and place the patient on the target chair or toilet. (b) HLPR Chair can be used for patient placement on a comfortable chair. Additionally, controls can be designed to allow the patient to command using voice or remote interface to control the HLPR Chair go away until or come when needed.

Top view showing HLPR Chair accessing a toilet in a bathroom. The red arc shows the maximum radius of seat frame rotation needed.
Design of the HLPR Chair

HLPR Chair allows lift, currently up to 0.9 m (36 in) above mobility configuration height.

HLPR Chair can be used for patient rehabilitation and incorporate future legs load control.
Design of the HLPR Chair

Prototype

Photograph 1 of the HLPR Chair prototype.

Photograph 2 (left) of the HLPR Chair in the mobility configuration showing the side view and Photograph 3 (right) front view relative to a typical doorway.
Design of the HLPR Chair

Graphic showing the concept of placing a patient onto a toilet or chair with the HLPR Chair. The patient drives to the target seat (left), manually rotates near or over the seat (middle) while the torso lifts support the patient and the seat retracts, and then is lowered onto the seat - toilet, chair or bed (right)

Photographs 4, 5, and 6 (lt. to rt.) of the HLPR Chair prototype in the same configurations as in the graphic above placing a patient on a toilet.

Photograph 7 of the HLPR Chair prototype shown in the patient lift position.
Design of the HLPR Chair

Photograph 8 of the HLPR Chair with recently added front wheel encoders, development computer and interface electronics.

Photograph 9 of the HLPR Chair prototype in the rehabilitation/walking configuration. Summer Interns (Alex Page and Robert Vlacich) demonstrate the patient and nurse configuration as part of their official duties.
## Specifications

| Size:            | Mobility Configuration | 145 cm long x 58 cm wide x 178 cm high (57” long x 23” wide x 70” high) with 57 cm (22 ½”) seat ht. above floor |
|                 | Full Lifted Configuration | 145 cm long x 58 cm wide x 241 cm high (57” long x 23” wide x 95” high) with 125 cm (49”) seat ht. above floor – currently can be adjusted to lift 91 cm (36”) |
| Weight (unloaded) | 136 kg (300 Lbs.) |
| Payload:        | 136 kg (300 Lbs.) (designed) |
|                 | 91 kg (200 Lbs.) (tested to date) |
| Tilt            | 0.06 rad (10 deg) |
| Max. Speed      | 0.7 mps (28 ips) |
| Turning Radius  | 86 cm (34”) centered about the rider |
| Chair Rotate Angle | 0.5 rad (90 deg) CCW to 1 rad (180 deg) CW |
| Wheels:         | Rear Drive/Steer | 10” diameter pneumatic |
|                 | Front Caster     | 5” diameter solid |
| Ground Clearance | 4.4 cm (1 ¼”) |
| Battery         | 2-12Vdc dry cells (series 24V) |
| Per-Charge Range | unknown to date |
| Battery weight  | 11.6 kg (26 Lbs) each |
| Drive Train     | 1 motor chain drive, 1 gearmotor direct steer |
| Battery Chargers | two (one per battery), off-board |
Design of the HLPR Chair

**Mechanical Design**

Manual Fork Lift Base Frame

Hydraulic Lift

- Foot operated hydraulic pump makes raising the load a simple task.
- Foot pedal release results in controlled lowering to reduce the risk of accidents.
- Wheels are on swivel casters and lock into position for load lifting and lowering.
- Two forks lower to 10.8 cm (4.3 in) above the floor and raise loads up to 137 cm (54 in) to get your machinery or heavy objects at an accessible level.
- 227 kg (500 Lbs) capacity.

For the HLPR Chair Design, the hydraulic piston was replaced with an electric ball screw actuator with 454 kg (1000 Lbs) lift capacity and 0.45 m (18 in) stroke. The fork lift chain design allows a 2:1 lift height for 0.9 m (36 in) fork (chair) lift with half the payload or 227 kg (500 Lbs).

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1 NIST does not endorse products or organizations.
Design of the HLPR Chair

Left (side) view shows 0.9 m (36 in) base and seat frame travel and maximum system height. Center side view shows 37.4 cm (95 25/32 in). Center (side) and right (back) views show only the base frame with the forklift frame components with the seat frame removed and the rotation (top) joint view.

Side and front views of the HLPR Chair with minimal dimensions for length, height, and width while in the mobility configuration.
Design of the HLPR Chair

HLPR Chair side view without the rear drive system and suggested front wheel extension to allow the seat rotation point to be within the wheelbase. This modification was not added to the prototype and is not necessary with appropriate counterweight (e.g., drive and battery system) added to the rear.
Design of the HLPR Chair

Top views of the HLPR Chair showing (a) Maximum length and width, (b) minimum HLPR Chair rotation about the front casters axle center 76 cm (30 in) and (c) top view of the HLPR Chair.
**HLPR Chair Component Labels**

These labels refer to drawings that follow.

- Frames pivot
- Seat frame assembly
- Base frame assembly
- Torso lifts
- Joystick
- Seat (rotated to standing position)
- Seat support
- Lift plate
- Forklift frame
- Upper motor support plate
- Battery
- Lower motor support plate
- Axel plates
- Wheel assembly
Notes:
- Make 1 part, 5061 aluminum, 3/8" thick
- Bearing is supplied

Upper Motor Support Plate
for: RoboChair Phase 2
Roger Bostelman
Jim Albus
NIST 823 2/8/06
Design of the HLPR Chair

Notes:
- Make 1 part, 6061 aluminum, 3/8" thick
- Bearing is supplied

Lower Motor Support Plate
for RoboChair Phase 2
Roger Bostelman
Jim Albus
NIST 823 2/8/06
Design of the HLPR Chair

Front view of wheel assembly
(component drawings for this assembly follow)
Design of the HLPR Chair

Notes:
Make 2 MIRRORed parts out of 6061 aluminum, 3/8" thick 1 cm
Bearings are supplied, press into part.

Axel Plates
for: RoboChair 2
Roger Bostelman x3426
NIST 823.11 2/7/06
Design of the HLPR Chair

Top Axel Plate
for: RoboChair 2
Roger Bostelman x3426
NIST 823.11 2/7/06

Notes:
Make 1 part, 6061 aluminum, 3/8" th. 1 cm

22 of 88
Notes:
Make 1 part, 6061 aluminum, 3/8" th.
1 cm

Top Axel Plate-Cutouts
for HLPR Chair
Roger Eostelman x3426
NIST 823.11 3/26/06
Design of the HLPR Chair

Notes:
drill 4 holes as shown on drawing

Wheel Drive Sprocket
for: RoboChair 2
Roger Bostelman x3426
NIST 823.11 2/7/06, 2/22/06
Design of the HLPR Chair

1) Drill and tap 5/16" - 18 holes 1/2" dp into both ends.
   1.3 cm dp
   1.6 cm
   Ø5/8"

   14.6 cm
   5-3/4"

   13.3 cm
   5-15/64" to left side of ring

   9/16" 1.27 cm to left side of ring

   groove for 1/32" thick rings (please supply rings)

NOTES:
Steel rod, 5/8" dia. 1.6 cm dia.
make 1

2) Also, cut down to 1 1/2" long, the 4 steel nuts supplied.
   3.8 cm

   Coupling nut

Wheel Axle, nuts
for HLPR Chair
Roger Bostelman x3426
NIST 823.11 5/15/07
Design of the HLPR Chair

Replaced steering motor with 93 W (1/8th Hp) gearmotor.

SPEED
= 3600 rpm x 1/20 reducer x 3 (sprockets)
= 65 rpm on a 10" da. = 10" x PI x 65/80 sec
= 34 in/sec (86 cm/sec)

TORQUE
= 6.2 in-Lbs. x 20 reducer x 3 (sprockets)
/ 6" wheel radius
= 74 in-Lbs. drawbar at the floor

3" dia x 1/8" th. teflon
3-13/32"
1-13/32"
15/16"

3/4" chain holes
3-9/16"

slots for chain adjust
Speed reducer mount (following drawing)

Drive Steering Motor Design
for: RoboChair Phase 2
Roger Bostelman
Jim Albus
NIST 823 2/6/06, 3/7/06
Design of the HLPR Chair

Notes:
Steel angle, 6 x 6" x 3/8" thick, NIST # 53205
Make 1

Speed Reducer Mount
for: RoboChair 2
Roger Bostelman x 3426
March 13, 2006, nsd 3/22
Design of the HLPR Chair

Battery Compartment
for: RooChair Phase 2
Roger Bostelman
NIST 823 2/6/06, 3/7/06

2 x 1" spacer and mount to frame
else wheel will rotate against frame base.
Could have notched base frame to allow
for wheel rotation but, assembly was built.

Odyssey Drycell PC 925 Batteries
Design of the HLPR Chair

Top view of battery compartment.
Design of the HLPR Chair

10-32 tapped holes, 90 degrees apart, for set screws, 2 each (please supply them!)

Drill 1/4" dia. thru holes, 4 places as shown.

Weld coupling to center, then drill 5/8" thru hole so it is centered.

Note:
- Steel plate and rod
- Make one.
- Weld center coupling, then drill so hole is ensured part center.

Motor-End, Adapter Plate
for: HLFR
Roger Bostelman x3426
NaST 823.11 5/17/07
Design of the HLPR Chair
Design of the HLPR Chair

Notes:
- Make 1 part, 5061 aluminum, 3/8" thick
- Bearing is supplied
Design of the HLPR Chair

See Modifications to Existing Design section for new version of the seat frame assembly.
See Modifications to Existing Design section for new version of the base frame assembly.
Design of the HLPR Chair

See Modifications to Existing Design section for new version of the frames pivot.
Design of the HLPR Chair

- Seat support
- 1/2" rad.
- 1-1/2"
- 18-1/2"
- 7-1/4"
- 29-1/4"
Design of the HLPR Chair
Design of the HLPR Chair
Design of the HLPR Chair
Design of the HLPR Chair
Design of the HLPR Chair

McMaster
6530K100
Electromechanical Actuator 12 VDC Motor W/ Limit Switch,
250# Force, 12" Stroke
In stock at $234.74 Each

side view
Design of the HLPR Chair
Design of the HLPR Chair

Seat Retraction Actuator Design - top
for: RoboChair 2
Roger Bostelman
NIST 823.11 2/14/06
Design of the HLPR Chair

Note:
All parts are aluminum, weldable
Make 1.

Lift Plate
for: RoboChair Ph2
Roger Bostelman
NIST 12/1/05
Design of the HLPR Chair

2 x 2" sq. alum. to be mounted on each side as shown. If back plate is thickened to 1/2", increase sides to flush mount 2 x 2" sq.

Note:
Weld two aluminum angles 2 1/2" x 2 1/2" x 1/4" th. x 14" long, NIST # 50448 to back as shown.

Lift Plate back angles
for: RoboChair Ph2
Roger Bostelman
NIST 12/1/05
Notes:
Make one part, weld to lift plate (supplied)
Aluminum, 6061 bar stock.

Lift Bar
for RoboChair 2
Roger Bostelman 2/10/06
NIST 823.11
Design of the HLPR Chair

Notes:
- Make 2 each
- Weld to outside of seat frame sides.
  Weld along inside and outside of plate frame. 1" tack welds spaced at 2' intervals will suffice or full weld.
- Use 6061 3/16" th. plate # 50568

Seat Frame Stiffeners
for RoboChair 2
Roger Bostelman x3426
NIST 823.11  1/11/06
Design of the HLPR Chair

Notes:
- Make 2 each
- Weld to outside of base frame sides. Weld along inside and outside of plate frame. 1" tack welds spaced at 2" intervals will suffice or full weld.
- Use 6061 3/16" th. plate # 50558

Base Frame Stiffeners
for RoboChair 2
Roger Bostelman x3426
NiST 823.11 1/12/06
Design of the HLPR Chair

1. Drill 1 bolt (supplied), clearance thru-hole in both the Seat and Base Frames as shown.

2. Drill 2 bearing inserts (as shown) in the Seat Frame (bearings supplied). Allow Bearing to seat flush or just out of hole as shown (i.e., not recessed).
Design of the HLPR Chair

Make one part
Use Alum. 6081 material

Actuator to Pulley Coupling
for: HLPR Chair
Robert Vlatich
NIST 6/7/07
Modifications to Original Designs

Design of the HLPR Chair

Materials: Electrical conduit 1 3/4 in OD.

Base-Frame
for: HLPR Chair
Roger Bostelman, x3426
NIST 823.11 2/20/87
Design of the HLPR Chair

Note:
Weld two steel angles 1 1/2" x 1 1/2" x 1/8" th. x 14" long, NIST #53168t to back as shown.

Lift Plate back angles
for: RoboChair Ph2
Roger Bostelman
NIST 2/22/07
Design of the HLPR Chair

Notes:
Make one part, weld it to lift plate (supplied)
Aluminum, 6061 bar stock.

Lift Bar
for: HLPR Chair
Roger Bostelman 2/10/06
NIST 923.11 rpsd 6/7/06
Design of the HLPR Chair

NOTES: material - 1 3/4" dia. x 1/16" wall steel conduit
- make the two, mirrored halves then weld together as shown.

Actual Measurements:
- front width: 24 1/8"
- back width: 23 3/4"
- top to back: 21 1/2"
- arm length: 25 7/8"
- height: 34"

Seat Frame
for HLPR Chair
Roger Bostelman, x3426
NIST 823.11 2/25/07
NOTES:
- Pipe flange screws on pipe threads to compress:
- Seat frame with welded seat plate against:
- Bottom lazy susan against:
- Bottom plate (welded to bottom of base frame) against:
- Top plate (welded to top of base frame) against:
- Top lazy susan against:
- Pipe-plate (welded to pipe top),
- Allowing seat frame to rotate with respect to base frame.

Rotary Joint Design
for HLPR Chair
Roger Bostelman
NIST 6/7/07
This drawing provided courtesy of McMaster-Carr. Other manufactured turntables could also be used.
Design of the HLPR Chair

Pipe
6-5/8"

4-1/4"

threads

Pipe Flange

3/4"

Pipe and Pipe Flange

- Cut down 12" pipe as shown to 4 1/4" long.
- Mill 1 1/2" thick pipe flange to 3/4" thick as shown.

for: HLPR Chair Rotary Joint
Roger Bostelman
NIST 6/13/07
Design of the HLPR Chair

NOTES:
- Make 1 steel plate, 1/4" thick

Pipe-Plate (welded to pipe)
for: HLPR Chair Rotary Joint
Roger Bostelman
NIST 6/13/07
Design of the HLPR Chair

NOTES:
- Weld Top Plate to Pipe top as shown.
- Leave 3/16" pipe above plate.
- Weld all around pipe top only.

Pipe to Pipe-Plate Weld
for: HLPR Chair
Roger Bostelman
NIST 6/13/07
Design of the HLPR Chair

Note: Make 2 plates as shown out of steel plate, 1/8" thick
Design of the HLPR Chair

Top View

Top Plate

Weld along all contact edges.

Flange is up

(Noted: bottom plate also has flange in the same direction as the top; i.e., in top view, point bottom plate flange up also.)

Base Frame Plates Weld Design
for: HLPR Chair
Roger Bostelman
NIST 6/13/07
Design of the HLPR Chair

Note: Make 1 plate as shown out of steel plate, 1/8" thick
Design of the HLPR Chair

Top view

Weld along entire edge

Align along pipe centerline

Flange up
Design of the HLPR Chair

assembly side view

stainless steel tubing

stainless steel tubes
- press flat 1” from both ends and drill 1/4” through holes as shown
- radius ends 7/16” and sand smooth to touch.

make 2 each

Footrest Assembly, Tubes
for HLPR Chair 2
Roger Boselman
NIST 823.11 3/14/07
Design of the HLPR Chair

Footrest and Sides Design for: HLPR Chair 2
Roger Bostelman
NIST 823.11 3/14/07
spring compresses from 6" to 3.5" with 40 Lbs.
so 2 will compress from 12" to 7" = 2 springs on each side = 80 Lbs. - F

Seat, Footrest Retract Design
for: HLPR Chair 2
Roger Bostelman
NIST 823.11 3/14/07
Design of the HLPR Chair

Notes:
- Make 1 part, 5061 aluminum, 3/8" thick
- Bearing is supplied

Upper Motor Support Plate
for: RoboChair Phase 2
Roger Bostelman x3426
Jim Albus
NIST 823 3/26/07
Design of the HLPR Chair

Notes:
- Make 1 part, 5061 aluminum, 3/8" thick
- Bearing is supplied

Lower Motor Support Plate
for: RoboChair Phase 2
Roger Bostelman x3426
Jim Albus
NIST 823  3/26/07
Design of the HLPR Chair

Electrical Design
Design of the HLPR Chair

Steering Circuit
for: RoboChair 2
Roger Bostelman
NIST 823.11 6/6/06
Design of the HLPR Chair
Design of the HLPR Chair
Design of the HLPR Chair

Steer and Drive Circuit
for: HLPR Chair
Roger Bostelman
Jim Albus
NIST 823.11 11/29/06
Design of the HLPR Chair
Design of the HLPR Chair
Design of the HLPR Chair

Connector Wiring
for RoboChair
Roger Bostelman
NIST 823.11 6/2/06
Towards Autonomous Control
Refer to Photograph 8 for the following design drawings in this section.
Design of the HLPR Chair

Encoder Circuit for HLPR Chair
Peter Russo
Roger Bostelman
NIST 823 Y 1/22/07
Design of the HLPR Chair

Notes:
- Make 2 parts
- Alum. 6061 C-Channel: 3x1.596x 356 in #80456

Encoder Casing
for HLPR Chair
Roger Boettcher, #0426
NIST 823.11 11/13/06

A view

front

drill wall to allow for allen cap

drill and tap for M3 screws, 4 places as shown, 1/2" dp.

3/16" 3/16"

1/2" 1/4"

1/4"

mirror hole measurements across part center line (A).

1-3/8" 1-3/8"

drill 1/4" through holes, 4 places as shown

cut down to: 1-9/32"

1" dia through hole centered on part

1" dia through hole centered on part

mill and press in bearing, 1 3/8" OD x 5/8" ID x 11/32" th. (2 supplied)

Leave 1/8" material so that bearing does not push through and is flush with part base.
Design of the HLPR Chair

Notes:
- make 2 parts
- use alum. 5061 material, 1/4" th. x 2" wide S&F #50574

Encoder Mount/Cover
for HLPR Chair
Roger Buskiman, x3428
NIST 023:11 11/1396
Design of the HLPR Chair

Notes:
- Make 2 parts
- Steel rod, 4" dia. #52813

Front Wheel Axle for Encoder for HLPR Chair
Roger Bostelman x3426
NIST 823.11 11/11/308
Design of the HLPR Chair

Stability Testing

- approximate CG of HLPR = 300 Lbs.
- approximate CG of rider = 250 Lbs.

Resultant CG is within wheelbase when on level floor and seat is rotated Pi rad (180 deg) from mobility position.

Resultant CG is near the front wheel when tilted 0.17 rad (10 deg) and seat is rotated Pi rad (180 deg).

Tipped CG of HLPR and rider is well within front wheelbase.

Approximate CG of HLPR and rider = 250 kg (550 Lbs).

Estimated Max. Tilt

For HLPR Chair
Roger Bestelman
NIST 823.11 10/12/06
## Prototype Cost Estimate

<table>
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<th>Manufacturer/Vendor</th>
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<td>80.00</td>
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<tr>
<td>Torso Lift Actuator, 3&quot;</td>
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<tr>
<td>Arm pads - foam, vinyl</td>
<td>JoAnn Fabrics</td>
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<tr>
<td>Seat, Backrest</td>
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<td>Wheel, tire</td>
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<tr>
<td>chain (unit = per foot)</td>
<td>McMaster Carr</td>
<td>3</td>
<td>3.47</td>
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<tr>
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<tr>
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<td>Batteries, 12V, PC925</td>
<td>Odyssey</td>
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<tr>
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<td>Shops work**</td>
<td>NIST</td>
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<td><strong>total:</strong></td>
<td></td>
<td></td>
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<td>$ 10,332.97</td>
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</table>

** Shop work for this prototype was dramatically reduced incorporating a redesigned seat and base frame through the use of bent tubing (see Modifications to Original Design section). The base frame was made from 5 cm (2 in) OD steel electrical conduit with a welded support bead and the seat frame was designed at NIST and procured from a pipe bending manufacturer. A 30 cm (12 in) diameter turntable bearing ring was used as the rotation device. The total for these components was approximately $400.00 verses $5,000.00.