

HLPR Chair – A Novel Patient Transfer Device

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ABSTRACT

In this paper, we briefly describe the design of the Home Lift, Position and Rehabilitation (HLPR) Chair, invented at the National Institute of Standards and Technology (NIST), Manufacturing Engineering Laboratory (MEL) under the Healthcare Mobility Project. The HLPR Chair was designed to provide independent patient mobility for indoor tasks, such as moving to and placing a person on a toilet or bed, and lift assistance for tasks, such as accessing kitchen or other tall shelves. These functionalities are currently out of reach of most wheelchair users. One of the design motivations of the HLPR Chair is to reduce back injury, typically an important issue in the care of this group. Static and dynamic stability tests of the HLPR Chair prototype were also recently completed and are also described here. The tests followed the appropriate and current wheelchair standards and provide suggestions for improvement to these standards. While the Healthcare Mobility Project has recently ended, stability test methods of a lift wheelchair, such as the HLPR Chair, potentially overlap into forklift standard stability test methods and could be useful to the manufacturing industry.

General Terms

Design, Performance, Experimentation, Standardization.

Keywords

HLPR Chair, wheelchair standards, stability, forklift, static, dynamic.

1. 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.

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 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 2.5 million and 1.25 million, respectively. 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.

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 becomes 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 falls to the floor and becomes injured when being transferred from a bed to a wheelchair. [6]
- “Nursing and personal care facilities are a growing industry where hazards are known 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]

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- “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]

Wheelchairs and patient lift devices have been built and are commercially available today. What has not been built, prior to the HLPR Chair, is a combined: intelligent, powered, lift-wheelchair, geared towards home use that can provide independent or dependent patient transfer to beds, chairs, and/or toilets while also providing a support structure for rehabilitation. Similarly, there are no standards for such devices. [9] Therefore, NIST MEL developed the HLPR Chair to investigate this type of patient transfer device while advancing standards in this area. Of particular concern for safe operation of a device like HLPR Chair is its stability. The question here is: can the device meet current wheelchair standards and are there new standards that can be suggested for these devices as they become commercialized?

This paper includes the HLPR Chair: design, specifications and recent static stability test descriptions and results. Conclusions and references close the paper. References [10, 11, 12, and 13] provide in-depth discussion of the HLPR Chair design and capabilities.

2. HLPR CHAIR DESIGN

The HLPR Chair [10, 11, 12, 13] prototype, shown in Figure 1, is based on a manual, steel, inexpensive, off-the-shelf, and sturdy forklift. The forklift includes a U-frame base with casters in the front and rear and a rectangular vertical frame. The lift and chair frame measures 58 cm (23 in) wide by 109 cm (43 in) long by 193 cm (76 in) high (when not in the lift position) making it small enough to pass through even the smallest, typically 61 cm (24 in) wide x 203 cm (80 in) high, residential bathroom doors. The HLPR Chair frame could be made lighter with aluminum instead of steel.

The patient seat structure is a double, nested and inverted L-shape where the outer L is a seat base frame that provides a lift and rotation point for the inner L seat frame. The L frames are made of square aluminum tubing welded as shown in the photograph. The outer L is bolted to the lift device while the inner L rotates with respect to the seat base frame at the end of the L as shown in Figure 1. The frame's rotation point is above the casters at the very front of the HLPR Chair frame to allow for outside wheelbase access when the seat is rotated 180° and is the main reason access to other seats is available. Drive and steering motors, batteries and control electronics along with their aluminum support frame provide counterweight for the patient to rotate beyond the wheelbase. When not rotated, the center of gravity remains near the middle of the HLPR Chair. When rotated to 180° with a 136 kg (300 lb) patient on board, the center of gravity remains within the wheelbase for safe seat access. Heavier patients would require additional counterweight.

The HLPR Chair is powered similarly to typical powered chairs on the market. Powered chairs include battery powered, drive and steer motors. However, the HLPR Chair has a tricycle design to simplify the need to provide steering and drive linkages and provide for a more vertical and compact drive system design. The drive motor is mounted perpendicular to the floor and above the

drive wheel with chain drive to it with maximum speed set to 0.7 m/s (27 in/s). The steering motor is coupled to an end cap on the drive motor and provides approximately 180° rotation of the drive wheel to steer the HLPR Chair. The front of the robot has two casters mounted to a U-shaped frame.

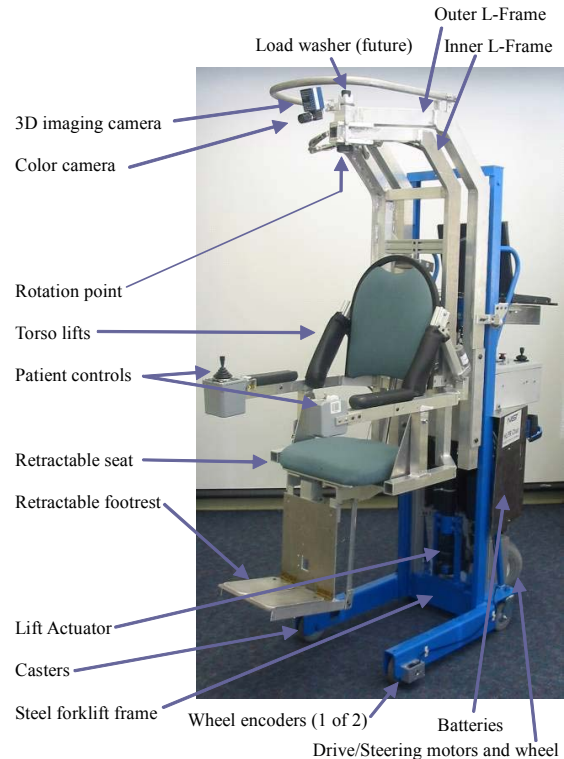


Figure 1: HLPR Chair Prototype

Steering is a novel single wheel design hard stopping the wheel at just beyond 180° for safety of the steering system. Steering is reverse Ackerman controlled as joystick left rotates the drive wheel counterclockwise and joystick right rotates the drive wheel clockwise. The steering rotation amount can be limited by the amount of drive speed so as not to roll the frame during excessive speed with large steering rotation.

Access to and from the HLPR Chair, lift, and rehabilitation configurations, as well as autonomous control efforts and designs are described in detail in [10, 11, 12, 13]. Two prototypes of the HLPR Chair have been built where the first version is used to study stability and autonomous control. The second was built to study ergonomics and manufacturability of the seat and sling designs.

3. HLPR CHAIR SPECIFICATIONS

Current specifications for the HLPR Chair are listed in Table 1. Weight was measured unloaded using a spring scale. Maximum payload was designed into the seat and frame structures. The manufacturer's specifications of the manual forklift and lift actuator lists 227 kg and 454 kg (500 lb and 1000 lb), respectively. Maximum speed can be adjusted via the drive amplifier but has been set at 0.7 m/s (28 in/s). A conservative tilt estimate is shown in the table as 0.06 rad (10°) as determined using a CAD model of the HLPR Chair as previously shown in

[13]. However, Stability tests, explained in Section 4, note a larger static tilt in some orientations. A future test of the battery per-charge range is expected.

Size:	
Mobility Configuration	145 cm long x 58 cm wide x 178 cm high (57 in long x 23 in wide x 70 in high)
	with 57 cm (22 ½ in) seat ht. above floor
Full Lifted Configuration	145 cm long x 58 cm wide x 241 cm high (57 in long x 23 in wide x 95 in high)
	with 125 cm (49 in) seat ht. above floor – currently <i>can be adjusted to lift 91 cm (36 in)</i>
Weight (unloaded)	136 kg (300 lbs)
Payload:	136 kg (300 lbs) (designed) 91 kg (200 lbs) (tested to date)
Tilt	0.06 rad (10°)
Max. Speed	0.7 m/s (28 ips)
Turning Radius	86 cm (34 in) centered about the rider
Chair Rotate Angle	0.5 rad (90°) CCW to 1 rad (180°) CW
Wheels:	
Rear Drive/Steer	25.4 cm (10 in) diameter pneumatic
Front Caster	12.7 cm (5 in) diameter solid
Ground Clearance	4.4 cm (1 ¾ in)
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 Charger	off-board

Table 1: HLPR Chair Specifications.

4. STABILITY TESTS

A test platform measuring 2.4 m x 1.2 m (8 ft x 4 ft) was recently designed and built, as shown in Figure 2, to perform static stability tests on the HLPR Chair. The platform, made of extruded aluminum framing and plywood base, was lifted with a hoist on one end. Safety straps attached to the facility structure were attached to the HLPR Chair during all tests. Slip prevention bars were also attached to the platform to prevent HLPR Chair from slipping down the ramp as the platform was tilted.

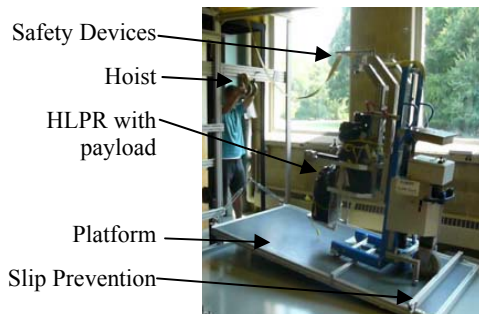


Figure 2: Static Stability Test Set-up.

For stability tests, we needed to verify safe operating parameters of HLPR Chair, including: maximum safe loading capabilities and angle of operation, braking/retardation capabilities, and lift height in relation to the payload. We followed existing wheelchair (patient mobility and transfer application) and forklift (manufacturing application) standards as a basis for the development of the stability tests. For wheelchair standards, we studied various ANSI/RESNA (American National Standards Institute)/(Rehabilitation Engineering and Assistive Technology Society of North America) and ISO (International Organization for Standardization) standards. Those standards were:

- ANSI/RESNA WC/Vol. 1-1998 Wheelchairs- Volume 1: Requirements and test methods for wheelchairs (including scooters)
- ISO 7176-1 Wheelchairs- Part 1: Determination of static stability
- ISO 7176-2 "Wheelchairs- Part 2: Determination of dynamic stability of electric wheelchairs.

For manufacturing, we studied the ISO 1074 Counterbalanced fork-lift trucks - Stability Tests standard.

In the static stability tests the discrete tip angle was measured by placing a piece of paper under the tipping wheel as suggested by the above standards. When the paper could easily be removed from beneath the wheel, the angle was recorded. The test was not designed to measure mechanical failure or device durability using a payload of 114 kg (250 lbs). Instead, the discrete tip angle in the most and least stable configuration was tested. Factors included: load/lift height, load orientation, and HLPR orientation on the test platform. Load height was chosen to be a medium height of 1.3 m (4.2 ft) and a high height of 1.8 m (5.9 ft), the highest the HLPR Chair can lift. Figure 3 shows a series of example test configurations including the forward, lateral and rear configurations. Figure 4 shows a series of load or seat orientations including forward, side and rear orientations. Results of the static stability test are shown in Table 2.



Figure 3: Photos of example test configurations, including: (left) forward, (middle) lateral, and (right) rear configurations.



Figure 4: Load/Seat Orientations of the HLPR Chair with respect to the frame including: (left) forward, (middle) side, and (right) rear orientations.

Test Configuration	Seat Orientation to Frame	Ramp Angle	
		Medium Load Ht. 1.3 m (4.2 ft)	High Load Ht. 1.8 m (5.9 ft)
Forward	Forward	18.4° (0.32 rad)	12.9° (0.23 rad)
	Side (90°)	17.8° (0.31 rad)	12.7° (0.22 rad)
	Rear	17.3° (0.30 rad)	12.2° (0.21 rad)
Lateral	Forward	8.0° (0.14 rad)	4.9° (0.09 rad)
	Side	8.1° (0.14 rad)	4.8° (0.09 rad)
	Rear	8.7° (0.15 rad)	5.1° (0.09 rad)
Rear	Forward	>25° (>0.44 rad)	>25° (>0.44 rad)
	Side	>25° (>0.44 rad)	>25° (>0.44 rad)
	Rear	>25° (>0.44 rad)	>25° (>0.44 rad)

Table 2: Static Stability Test Results.

In future dynamic stability tests, we will be looking for loss of contact of the load-bearing wheels when the platform angle relative to horizontal is at 0, 0.05, 0.1, and 0.15 rad (0°, 3°, 6°, and 9°, respectively). Results will be based on the severity of the lost wheel (drive, caster or stabilizer) contact with the ground as follows:

- 3 – No Tip
- 2- Transient Tip (lifting wheels lose contact then drop back onto the test plane)
- 1- Stuck on Anti-tip device
- 0- Full Tip (device is $\pi/2$ (90°) or more from original orientation)

Dynamic tests will include:

- Rearward dynamic stability on a ramp
- Forward dynamic stability on a ramp
- Lateral dynamic stability on a ramp
- Lateral dynamic stability while turning in circles
- Lateral dynamic stability while turning suddenly
- Dynamic stability while traversing a step

Suggestions for changes or additions to current standards, regarding static stability tests, include:

- “Loose” tie-down supports for the vehicle base to the ramp allowing wheel lift from the ramp without catastrophic tip,
- Safety straps to support structures near or at the top of the lift-wheelchair,
- Duplicate tests for aligned-seat-with-base-frame and various misaligned-seat-with-base-frame configurations.
- The standard reads that the operator can currently use a sheet of paper beneath the lifted wheel caused by the tilted platform. Instead, suggested text stating to “use a paper-retractor device (e.g., spring or rubber-band) attached to the paper under the wheel” will allow a safer, single operator for the static tests.

Once dynamic tests are completed, further suggestions to wheelchair standards can be made.

5. CONCLUSION

The HLPR Chair has been prototyped in two versions. Static stability tests were completed on the first HLPR Chair prototype. The results proved higher than expected tilt angles. The second prototype has been loaned to the Florida Gulf Coast University as an example device for their Bio-Engineering Product Design

Course. Improvements to the HLPR Chair design are the subject of the course. Future plans are to perform dynamic stability tests and to transfer the HLPR Chair design to the healthcare industry and to the manufacturing industry for semi-autonomous forklift control research.

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