A Finite Element Study of a Patient Lift Conceptual Design

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ABSTRACT

Developing countries such as Latin America and the Caribbean must be innovative in solving common engineering problems. Particularly due to limited access to resources that are more readily available in developed countries. Further, the costs associated with developing a solution can be overwhelming to most developing countries. As an example, a detailed study reviews the prominent reason why healthcare providers sustain injuries during lifting and transferring patients. A cost effective approach is presented to designing a patient lift device analyzing three different materials. A design optimization is achieved by performing a Finite Element Analysis (FEA) of the lift's boom. Design optimizations for material, shell thickness and geometry were then applied to all elements of the lift. The method and results are presented for design considerations of steel, Polyvinyl Chloride (PVC), and aluminum.

Keywords: Design, Patient Lift, FEA, Healthcare, Parametric

1. Introduction

Nurses and healthcare providers continue to sustain injuries mainly due to lifting patients. According to the U.S. Bureau of labor Statistics, "In 2008, more than 36,000 healthcare workers were injured by lifting and transferring patients." Safety is critical to both patients and healthcare providers. Therefore, the patient lift apparatus serves as a viable solution. The device can be made affordable to developing nations such as Latin America and the Caribbean by considering inexpensive materials that are native to those regions. Achieving this requires serious consideration for carefully selecting and testing materials under applied loads. The lift is conceptualized and designed using parametric modeling techniques. In addition, a Finite Element Analysis (FEA) was conducted to determine resultant stress simulations of three materials. Steel, Polyvinyl Chloride (PVC), and aluminum were simulated using ProEngineer Mechanica version 5.0 software. Overall design specifications are determined from the results of the FEA. Since weight was an important consideration in designing the patient lift, the results from the FEA was also used to minimize weight while maintaining good form synthesis.

2. Objectives and Scope

Low back pain and injury have been cited as the most frequent musculoskeletal disorder among nurses (Kutash et al. 2009). Multifaceted interventions that have been shown to decrease patient handling-related injuries include use of patient handling equipment and devices such as ceiling lifts, floor lifts, stand assist devices, lateral transfer aids, minimal lift policies, patient care ergonomic assessment protocol, and patient lift teams.

As a result, the objective of the study is to design and analyze a patient lift using good form synthesis principles. Moreover, the patient lift will assist nurses and hospital orderly personnel in lifting a patient for movement, linen changes, bathing or transfers. Furthermore, material selection for costs reduction was explored through FEA methods. The major constraints for consideration included the overall weight, reliability and cost of the patient lift.

3. Technology Review

Within the healthcare equipment industry, there are many organizations that provide services and medical equipment. A survey of the literature identified two major varieties of patient lifts. A permanent ceiling mounted lift where patients can be transferred along the lift line. And, a mobile lift, where patients have more freedom to move around. The fixed mounted lift consists of a ceiling track and a patient support structure. The patient support structure glides along the ceiling track. In contrast, the mobile patient lift is more popular than the fixed mounted lift. In the mobile patient lift, wheels allow for mobility between rooms. Patients are supported with a sling which is raised to the travel height before the lift is operated. Although both lifts are effective, certain advantages and disadvantages are inherent in both. The ceiling lift, for example, requires one caregiver for operation, as compared to the mobile lift which may require at least two caregivers for safe operations. The mobile lift, on the other hand, is more flexible in moving around and is not limited to a fixed tracking system such as the ceiling lift. To fully consider the operating conditions of the patient lift, further reviews of standard hospital beds was conducted. The review determined that hospital beds are available in a variety of sizes and functions. Beds range from a standard basic bed to an adjustable bed for added patient comfort. Functions include raise and lower, head and foot adjustments and tilt. The following dimensions were considered for the lift design:

Bed Height:	15” (min) – 23” (max)
Mattress:	6” – 10”
Clearance:	10” (min)

4. Sling Considerations

According to an article from a leading lift manufacturer (Hill Rom, 2010), “Recent studies have shown that up to 40 percent of all nurses working in hospitals and nursing homes have reported suffering back injuries or related musculoskeletal disorders caused when lifting patients.” The author further adds, “fifty percent of the lift’s effectiveness is dependent on the sling, therefore the patient and caregiver should work together toward the best possible application fit.” The following questions must be carefully considered in selecting the appropriate sling:

- How will the sling be used?
- Does the patient need full back support?
- Does the patient have clinical limitations?
- Can the patient participate in the lift?
- Is the patient an amputee?
- Will the sling be used in the bathtub?
- Will the patient remain in the sling for long periods of time?

In addition to selecting the size of the sling for comfort and proper fit, addressing those questions will improve the patients’ experience. Slings come in a variety of sizes and shapes based on their functions. Knowing how the sling will be used for transferring the patient makes a huge difference. If full back support is not necessary, the sling will be designed differently to allow for cost savings. Any clinical limitations must be considered, as patients’ safety is paramount during transfers. Additionally, if the patient is an amputee, the sling style and size will also vary. The sling’s fabric must be considered, especially if the sling will be used in varying conditions of extreme moisture and dryness. Strength is another factor in considering the sling. Will the sling be used primarily as a transfer device or will it be under continuous load for long periods of time. Material selection of the sling will also depend on the needs. However, some common materials such as cotton, polyester and nylon can be considered.

5. Manufacturing Overview

The lift (fig. 1) can be manufactured out of a variety of materials and finishes. Raw materials are cut to desired lengths and formed to specifications. Holes are drilled and mounting brackets welded on. Although many different types of finishes can be applied based on the material used, one of the most economical methods provides a brushed chrome finish. Brushed chrome finishes requires the application of satin chrome that is plated onto the material, for example steel material. The finish is applied to the entire patient lift for an even and consistent look.

The Mast consists of two hollow cylindrical tubes. No forming is required for the mast, however tubes must be cut to length and support material welded to base. Slits are cut from the bottom of the mast in order to firmly secure it to the base. Special care is given to creating a tight fitted Tolerance between the mast and base. Handles are welded onto the mast and rubber sleeves are inserted on handles. Holes are drilled and inserts added for casters. During final assembly, the actuator is installed and tested for functionality. Finally the end caps are fitted on the assembly.

Figure 1: Assembly of Patient Lift

5.1. Functional Overview

The lift is designed to be controlled with a wireless remote to activate the actuator for vertical displacement. Two major design features were incorporated to allow for increased loads and greater stability. First, is the three position actuator adjustment. Operators can adjust the actuator position depending on the load application. Adjustments consist of securing the actuator to one of three positions. The actuator is secured in position using a pin and clip. Most standard operations can be performed at the middle position, however, heavier loads will require adjusting the actuator. The second feature is the contoured leg with larger casters to improve reliability and stability of the lift. The contoured leg design with different sized casters creates a counter balance for even load distributions.

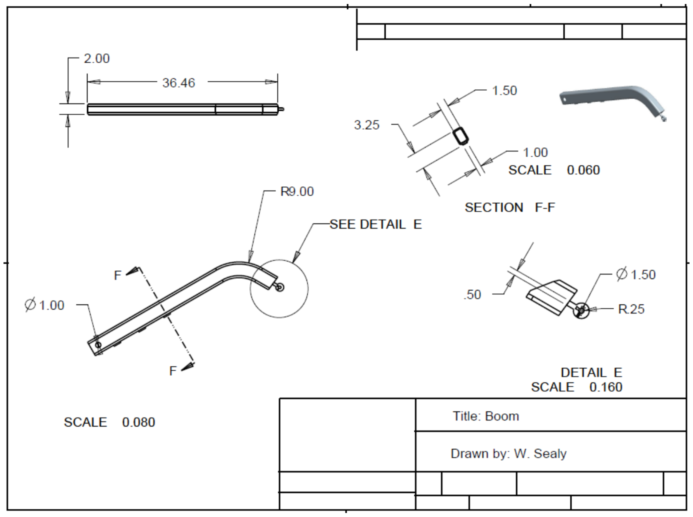

Figure 2: CAD Drawing of Boom

5.2. Conceptual Design and Simulation

Design considerations can be quite extensive and include many factors, such as, applied forces (location, direction, and magnitude), design life of the part, maximum allowable cost, weight limits, space limits, environmental conditions, number of units required, aesthetic factors, material selection, kinematics, and function. In order to keep the scope of the study manageable, a detailed analysis of how applicable forces can be simulated for optimal design and material selection were explored. Optimization of the lift design is achieved through conducting an FEA of the boom (fig. 2). In the article, *Finite element concept modeling methodologies for pickup truck boxes*, the authors assert, "…by dividing a vehicle structure into functional components – beams, surfaces, assembly joints, and Major Compliance Joints (MCJ) – and modeling those components in a simple, direct fashion, it is possible to develop an attribute-based first-order model…(Osborne et al. 2010)." In the study, the boom was selected as a major beam member of the patient lift. Boundary constraints were applied to the boom to simulate operating conditions and MCJ operation. All Degrees Of Freedom (DOF) were fixed for the pin pivot location except one rotational DOF around the pin axis. To fully constrain the boom, fixed constraints were applied to the actuator position. A load was applied to the cradle hook to simulate forces created by lifting a patient. From the resultant Von Mises stresses (index representing strain), designs were evaluated for each of the three materials. Furthermore, the optimized design parameters of the boom were applied to the remaining components of the lift.

Table 1: Material Properties

Properties	**Materials**		
	Steel	**PVC**	**Aluminum (AL2014)**
Type	Isotropic	Isotropic	Isotropic
Density	0.282771 [lbm/in^3]	0.0505776 [lbm/in^3]	0.100924 [lbm/in^3]
Young's Modulus	1.11966e+10 [lbm/(in sec^2)]	1.67987e+08 [lbm/(in sec^2)]	4.09254e+09 [lbm/(in sec^2)]
Poisson's Ratio	0.27	0.4	0.33
Conductivity	2074.07 [in lbm/(sec^3 F)]	6.95732 [in lbm/(sec^3 F)]	9266.13 [in lbm/(sec^3 F)]
Specific Heat	407600 [in^2/(sec^2 F)]	902100 [in^2/(sec^2 F)]	829900 [in^2/(sec^2 F)]
Thermal Expansion	6.5e-06 [/F]	5e-05 [/F]	1.28e-05 [/F]
Shear Stiffness	4.4081e+09 [lbm/(in sec^2)]	5.99954e+07 [lbm/(in sec^2)]	1.53855e+09 [lbm/(in sec^2)]

The study consisted of calculating and exploring how the maximum displacement, strain response and overall mass of steel, PVC and Aluminum (AL2014) can be considered in design optimization. For the FEA the following material properties were defined in table 1. The overall Von Mises stresses were calculated as follows (Han et al 2007):

$$\sigma_{VM} = \sqrt{\tfrac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2]} \qquad (1)$$

Where:

- $\sigma_{VM} = Von\ Mises\ Stress$
- $\sigma_1, \sigma_2, \sigma_3 = Principle\ Stresses$

The maximum Von Mises stress (Eq. 1) is compared to the yield strength of the material to determine if the resultant strains are operating within the elastic region of the material. For strains occurring within the plastic region of the material, the boom was redesigned to achieve elastic region operations. Continuous operation of stresses within the plastic region permanently deforms material leading to ultimate product failure. Optimization is achieved through an iterative process by monitoring and evaluating the mass and displacement while keeping maximum Von Mises within the specified tolerance (fig. 3). In the study, the yield strength of steel, PVC and aluminum (AL2014) were defined as 72K, 2600, and 43K psi respectively.

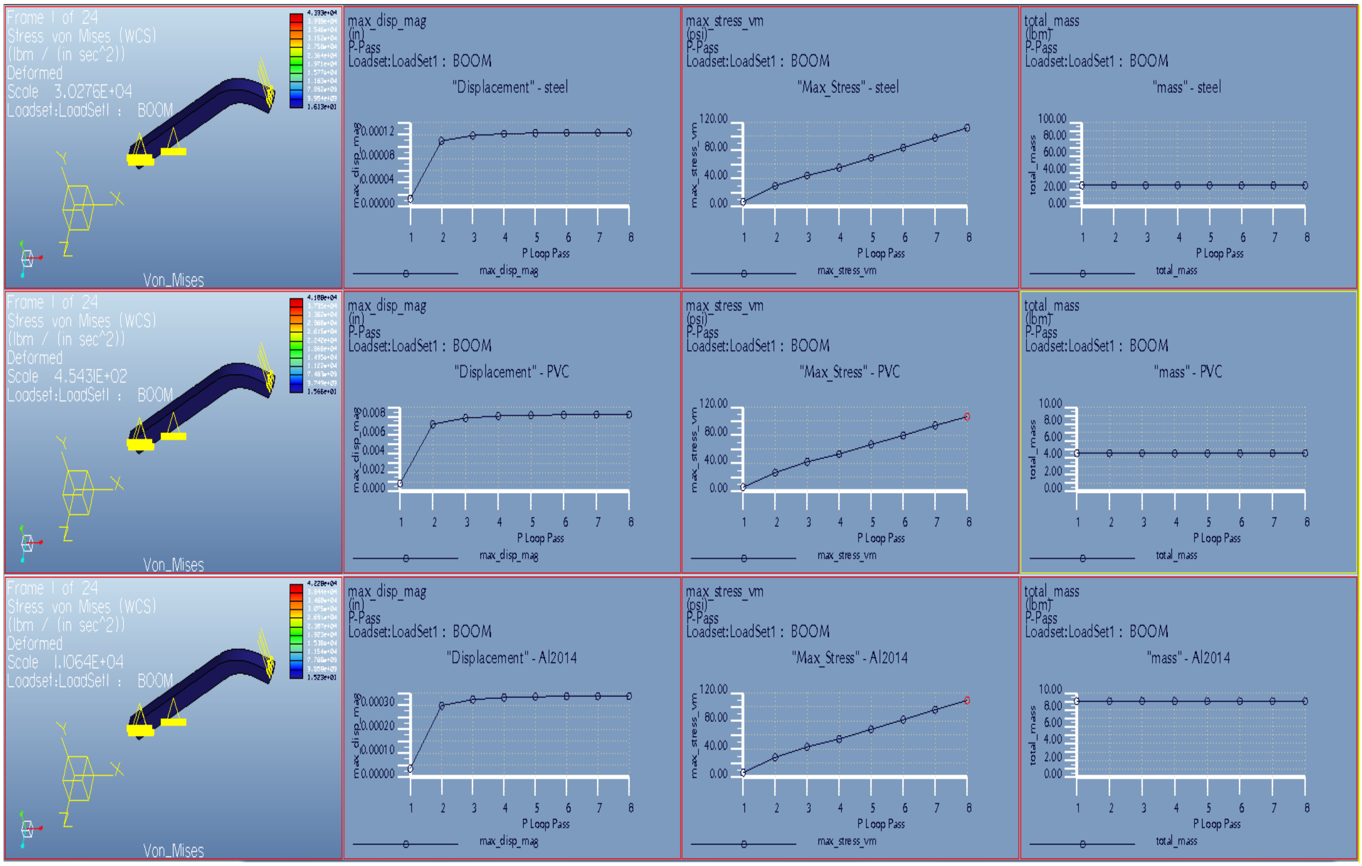

Figure 3: Results of FEA

From the results (fig. 3), rows 1, 2 and 3 represents steel, PVC and aluminum respectively. For each material, the results of the fringe graph, maximum displacement, maximum Von Mises stresses and total mass are represented in columns 1, 2, 3 and 4 respectively. The fringe graph represents a visual of where the maximum Von Mises stresses occur. Additionally, an animation of the fringe model verified the anticipated direction of displacement and confirmed forces were applied correctly. Based on predetermined specifications, such as maximum weight, stresses and displacement, materials were selected and designs optimized. Although maximum Von Mises stresses varied slightly between materials, maximum displacement, however, was more prominent in PVC (8 mils), as compared to the least displacement of steel (0.12 mil). On the one hand, similar loads, with the constant dimensional designs, PVC material would show a greater defection than steel. However, on the other hand, PVC weighed five times less than steel (~5 lb. vs. ~25 lb.). Therefore, if weight is of paramount importance, one design consideration to decrease the displacement of PVC could be to increase the shell thickness or change the geometry of the design. Another, since steel resulted in an extremely small displacement, would be to decrease the shell thickness to satisfy a lighter weighted boom which would also result in a greater displacement. Consequently, it is essential to remember that conceptual design is an iterative process, where, various design considerations are explored. All in all, the design process requires simulating design optimizations, and material selection, while considering costs and specification constraints.

Conclusion

In summary, although developing countries such as Latin America and the Caribbean requires more innovative approaches to solving common engineering problems, simulation and modeling such as parametric modeling and finite element analysis can significantly reduce the costs associated with developing a solution. In response to healthcare providers' injuries as a result of lifting or transferring patients, a study of the conceptual design of a patient lift proved common engineering problems can be explored. Granting, developed countries have the resources readily available for solving those problems, less developed countries can also reduce overall costs by modeling and simulating design consideration. Through finite element analysis, studies can be developed to explore native materials for product design. Low cost materials that are readily available in those countries can be simulated under desired operating conditions. Product design can be optimized through an iterative process. Furthermore, maximum Von Mises stresses can be reduced below the material yield strength threshold. Design optimizations can also be conducted on major compliance members, and then applied to the remaining members. This study proves that although developing countries are limited on resources, they too can explore the possibilities of designing a cost effective patient lift or solving similar engineer problems utilizing simulation technique and materials that are native to their homelands.

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