How do Mobility Add-Ons Change the Loading Conditions on Manual Wheelchair Frames?

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INTRODUCTION

Over the past two decades, a variety of mobility add-ons for wheelchairs have emerged in the assistive technology industry, including pushrim-actuated power-assist wheels (PAPAW), motorized propulsion aids, manual and motorized front-end drive attachments, and passive attachable wheels. Mobility add-ons are defined as relatively small and lightweight accessories for manual wheelchairs that increase the chair's mobility capabilities, and which can be easily removed when not in use. Benefits of these devices include an improved ability to navigate rough terrain, a change in means of wheel propulsion, and power-assistance, which can increase the distances that can be travelled and compensate for reduced upper body function. Some examples of mobility add-ons are provided in Figure 1.

Currently, little is known about how mobility add-ons affect the durability, strength, and lifespan of manual wheelchairs, and whether they increase the risk of component failures. Component failures are a common cause of wheelchair rider injuries, particularly when they cause tips or falls [1]. Component failures can leave users stranded, which can represent a severe risk when the user is alone or in a remote location. There can be significant costs associated with repairing or replacing damaged frames when failures occur, and it is common for time to be taken off work due to loss of wheelchair function when a backup chair is not available [2].

In considering how mobility add-ons affect the likelihood of component failures, they can be grouped into three main categories: power-assist wheels, front attachments, and rear attachments. They can be further subclassified into passive devices, manually-powered devices, and power-assist devices. Power-assist wheels are devices that attach to or replace the wheelchair's back wheels, such as the eMotion. Front attachments often lift the chair's front caster wheels and replace them with a large, centered front wheel, which improves the chair's ability to traverse soft or uneven surfaces. Front attachments include passive devices such as the FreeWheel, manually-powered front attachments including the BATEC Manual and the Rio Dragonfly, and power-assist front attachments such as the BATEC Electric and the Rio eDragonfly. Hybrid systems also exist; an example is the BATEC Hybrid. Rear attachments push or stabilize the chair from behind and include devices such as Max Mobility's SmartDrive. Some examples of products currently on the market, categorized by their locations relative to the chair, can be seen in Table 1.

Figure 1. Examples of Types of Mobility Add-Ons: Passive Front Attachments (FreeWheel), Manually-Powered Front Attachments (Dragonfly), Power-Assist Front Attachments (Electric), Rear Attachments (SmartDrive), and Power-Assist Wheels (eMotion)

This categorization allows consideration of groups of devices that place similar magnitudes and directions of force on the wheelchair frame. Front and rear attachments are often attached to manual wheelchair frames at the footrest or the front or rear cross bars of the wheelchair frame through a quick-release clamping mechanism. Power-assist wheels attach to or replace the chair's wheels. This can result in unconventional loading scenarios for a wheelchair frame, including changes in torque and bending moments that result from the wheelchair being pushed or pulled by the add-on, and stresses resulting from changes to the location of the center of gravity and the ground contact points of the system, as shown in Figure 2. Manual wheelchairs are designed to be lightweight and are therefore often reinforced only where they need to be. As a result, even minor changes in loading may become significant over time, contributing to fatigue and impact failures.

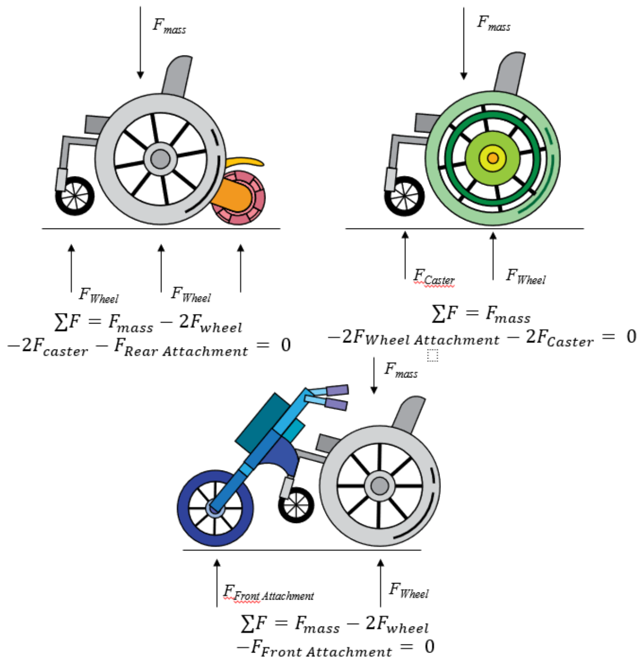

Figure 2. Types of Mobility Add-Ons: Rear Attachments, Front Attachments, and Power-Assist Wheels, and their Free Body Diagrams

For example, the FreeWheel is a passive front attachment which clamps to the footplate of a manual chair. Wheelchair footrests, as shown on the left of Figure 3, are designed to support a portion of the user's body weight and the weight of the footrest itself. As can be seen on the right, the addition of the FreeWheel lifts the caster wheels. As a result, the footrest is additionally supporting the portion of the wheelchair weight that is normally supported by the caster wheels, usually between 20-30% of the weight of the chair. The clamp of the FreeWheel also creates a bending moment at the attachment point on the footrest. As a result, it is reasonable to expect stress concentrations that wouldn't be present in the case of a standard footrest with no attachment.

The manufacture of wheelchairs is regulated by the ISO 7176 set of standards, and the risk of conventional component (e.g. footrests, armrests) failures is addressed through the ISO 7176-8 fatigue and impact tests. In practice, mobility add-ons are often assessed using modified versions of these tests, adjusted to accommodate the change in shape of the overall system. However, currently, no ISO standards directly address component failures associated with manual wheelchairs when used with add-ons.

This paper proposes a study method to assess the loading conditions on a wheelchair when used with mobility add-ons. The method uses a finite element analysis (FEA) modeling approach supported by physical testing to validate the models. Through identifying likely areas of failure and exploring design alternatives, design guidelines, such as changes to attachment location or recommendations for reinforcement in manual frames, can be provided to minimize risks of component failures. The results of this research could provide insight for designers and manufacturers of manual wheelchairs, as well as working wheelchair standards groups, such as those led by RESNA, that contribute to the development of ISO standards.

Figure 3 Manual Wheelchair Footrest (left) and Manual Wheelchair Footrest used with a FreeWheel (right)

Table 1. Classification by Location of Mobility Add-Ons Currently on the Market

Device Classification	Method of Power	Examples of Products Currently on the Market
Front Attachments	Passive	FreeWheel (FreeWheel)
	Manually-Powered	Dragonfly (Rio Mobility)
	Power-Assist	Firefly (Rio Mobility) eDragonfly (Rio Mobility), Electric (BATEC Mobility), Rapid (BATEC Mobility), Urban (BATEC Mobility), Hybrid, (BATEC Mobility), Raptor (Progeo), Triride (Triride Italia)
Rear Attachments	Powered	Smart Drive MX 2 (Max Mobility Inc.), Benoit Light Drive (Speedy Snail Mobility), ZX-1 (Spinergy)

Power-Assist Wheels	Power-Assist	eMotion (Alber), e-Fix (Alber), Twion wheel (Alber), z50 (Ottobock), e-Support (Ottobock), Xtender (Quickie), WheelDrive (Quickie), Servo (AAT), Solo (AAT), JWX-2 (Yamaha)

RELATED WORK

While manual wheelchair durability assessment has been described in the literature based on a variety of methods, including reporting field evidence of injuries and failures, computer simulations, and finite element methods, only a few studies have assessed fatigue strength, impact strength, and user risks of manual wheelchairs when used with a mobility add-on. One example is work done by Karmarkar et al. [3], who assessed several PAPAW wheels under ANSI/RESNA standards including static and dynamic stability, brake effectiveness, speed, energy consumption, and impact, static and fatigue strength. However, to the best of our knowledge, no studies have yet assessed failures associated with other mobility add-ons. Because front attachments lift the front wheels, they create a unique loading scenario on manual frames that is worth further examination.

A finite element structural analysis technique can be used to predict values of variables such as stresses or displacements in a mechanical body, such as a wheelchair frame, given well-defined loading conditions. In addition to increasing knowledge of stress concentrations indicating where manual wheelchairs might fail, FEA can be used to explore alternate designs without the cost of manufacturing prototypes [4]. FEA has been used in wheelchair design to optimize composite wheels [5] and composite frames [6], and to optimize specialized chairs for particular activities, such as racing [7].

PROPOSED METHODS

Since the objective of this proposed research is to assess the impact of changing loading conditions that mobility add-ons cause on manual wheelchairs, we propose to conduct an FEA on a passive front attachment. Additional physical testing will then be used to validate the FEA model and provide additional insights into locations of stress concentration.

During the first phase of this method, a static situation will be considered. The following steps summarize the proposed methodology:

Step 1. Pre-processing: A passive front attachment and manual wheelchair will be modeled in ANSYS (Canonsburg, PA, USA). Material properties, appropriate mesh parameters, boundary conditions, indicating where the displacements would be fixed, and loading conditions, indicating the location and magnitude of the loads, will be specified.

Step 2. Processing: An analysis will be run using ANSYS software, in which a set of algebraic equations are developed and solved by the software to simultaneously obtain displacements at the nodes of the elements.

Step 3. Post-processing: Displacements and resulting stresses will be displayed graphically, and locations of stress concentrations will be identified.

Step 4. Validation: A physical wheelchair and mobility add-on system closely matching the FEA model will be instrumented with strain gauges to assess the actual displacements caused by the loading conditions modeled in Steps 1-3. This step should confirm the stress-strain conditions on the frame predicted by the FEA.

The second phase of this method will be an analysis of a dynamic situation, considering reasonable speeds and impacts, to assess both fatigue and impact failures. Additional testing such as performing the ISO fatigue and impact tests (i.e. double drum and drop test) on a wheelchair with attached add-on could also supplement this work.

CONCLUSION AND FUTURE WORK

With the continued development of smaller and more powerful batteries and motors, along with more sophisticated control systems, a variety of mobility add-ons will likely continue to develop. This can result in unanticipated loading conditions on wheelchair frames, perhaps increasing the risk of component failures. This paper proposes a finite element analysis and physical testing method to investigate this. Results are expected to provide insights for designers, manufacturers and working standards groups such as RESNA.

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