TASK: T-3 DEVELOPMENT OF DOCKING TYPE SECUREMENT DEVICES

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Rationale

The industry standard today for wheelchair securement in all types of vehicles is the four point strap-type tiedown device. Although this device performs adequately under crash conditions when properly installed and used, it has several major shortcomings. The main one is that it does not permit wheelchair users the independent use of transit vehicles. All belt-type tiedown devices require the vehicle operator or an attendant to fasten and unfasten both the wheelchair securement and the occupant restraint. A self-docking wheelchair securement device, combined with an "on-board"(integrated) occupant restraint, offers the potential to resolve many of the inherent shortcomings of the existing devices.

Review of the transit accident statistics and crash severities for large mass transit vehicles {Hobson, et al. 1997} strongly suggests that the chances of a transit vehicle occupant experiencing a high "g" crash event are very small. Therefore, one can take the position, with a relatively low degree of risk, that a wheelchair user seated forward–facing in a transit wheelchair compartment will only experience those "g" loads associated with normal driving, i.e., maximum braking, acceleration and rapid turning. Actual measurements have shown these "g" loads to be less than 0.65g [Bertocci, et al. 1997]. If this could be shown to be feasible, it could provide an immediate solution to improved securement, since the adoption of any approach using a universal interface drive (UID) is by necessity a long-term solution.

In order to demonstrate the feasibility of the proposed universal interface standard detailed in task T2 [Karg et al. 1997], it was essential to develop and test actual docking-type securement devices that could meet the standard. This was done with the expectation that successful designs would eventually lead to commercial products.

Another solution for wheelchair containment in large vehicles is to simply place the occupied wheelchair rearward facing in a designated station in the vehicle. The stability of the wheelchair is then dependent on its brakes, a hand-hold for the occupant, a padded bulkhead behind the wheelchair and a vertical stanchion, which prevents the wheelchair from rotating into the aisle. This study also looked at the importance of the floor material selection in optimizing the effectiveness of the brakes to prevent instability (sliding) towards the rear of the vehicle when the transit vehicle ascends hills.

Therefore, the multiple approaches taken in task T-3 were to first develop and test docking devices that meet two levels of crash severity: a) 30mph, 20g, frontal crash termed a high "g" crash; and b) loads associated with normal driving in large vehicles, termed low "g". Finally, to explore stability risks associated with rear-facing compartments as a means of wheelchair containment, now commonly used in many European and several Canadian public transit vehicles.

Goals

1. To design, develop, and demonstrate a high "g" docking-type securement devices for potential use in both private and public transport vehicles.
2. To design, develop, and demonstrate a low "g" docking-type securement devices for potential use in large public transit vehicles.
3. To explore the sliding stability risks of rear-facing containment compartments used in public transit vehicles.

Methods/Results Summary

1) High "g" - crash conditions

The Pitt RERC team took several steps to obtain the design criteria for the high "g" docking devices.

First, the Quality Function Deployment (QFD) tool was used in two focus group sessions to systematically seek and prioritize the views of researchers, transit operators and wheelchair users of transit vehicles. This information combined with the ADA requirements for public transit vehicles established the design goals for the device design. These criteria were used to develop a conceptual paper design.

The next step was to establish the crash loads that the device components would need to withstand during a 30mph, 20g, frontal crash event. This was done using a computer simulation model as shown in Figure 47.

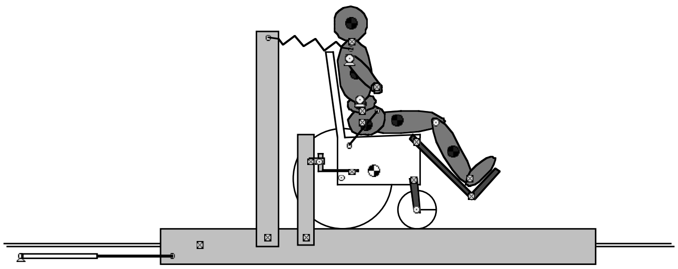


Figure 47 - Frontal Crash Simulation; Wheelchair Secured Using Proposed Universal Interface Hardware

A partnership was formed with Kinedyne Corporation, a commercial manufacturer of strap–type securement devices. This partnership was successful in securing an $100,000 NIH-STTR grant that began May 1, 1997. This resulted in the design and successful sled testing at the University of Michigan (UMTRI) of a prototype docking device which utilized the proposed T-2 universal interface standard (Figure 48). For this sled test, the docking system and wheelchair interface hardware were used to secure the surrogate wheelchair which was developed to evaluate securement system compliance with the SAE J2249 WTORS standard. Our prototype docking system met all test requirements established by the SAE J2249 standard.

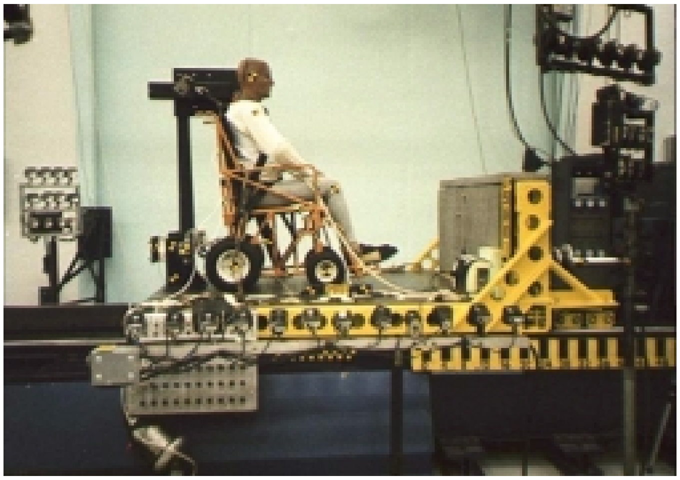


Figure 48 – 20g Frontal Impact Sled Testing of Prototype Docking System employing Universal Wheelchair Interface Hardware

To evaluate the ease of maneuverability when engaging the docking system, actual wheelchair stations in four types of local transit buses were measured for replication in our laboratory. The worst case (smallest) was used to develop a laboratory mockup of a wheelchair securement station. The prototype docking system unit was then installed in the mockup test station. Wheelchair users were invited to evaluate maneuverability and ease of docking.

Based on the results of the above testing, plans have been made to proceed with a Phase II, NIH-STTR proposal in an effort to further refine and commercialize the docking system.

2) Low "g" Docking Device

In summary, the focus of this aspect of the task was to develop a user-activated wheelchair containment device for use in large transit vehicles that would readily secure any wheelchair entering the vehicle. Again, the QFD process and focus groups were used to arrive at the design criteria. Two generations of prototype devices were constructed and tested in the laboratory and with wheelchair users. A goal of 1 g was established as the minimum load that the device must withstand when securing a variety of different wheelchairs, both manual and powered. This would provide a margin of approximately 0.35g above the maximum loads actually measured (0.65g) during normal driving maneuvers. Static pull tests were used to simulate the securement loading by an occupied wheelchair under maximum normal driving conditions. The static pull tests were applied in the frontal direction until the wheelchair released or substantially moved within the containment device (Figures 49-51).

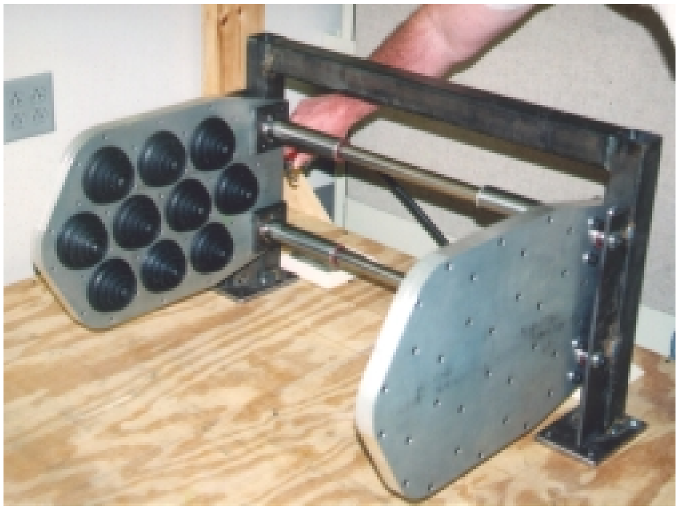


Figure 49 - Close-up of the low "g" Docking System Prototype

Figure 50 – Low "g" Docking System Securing Power Wheelchair

Docking Device Operation

The prototype consists of two horizontally adjustable plates that have inflatable bellows built into the plates. After backing the wheelchair into the securement device, the user flips an accessible switch, which activates two pneumatic cylinders that move the plates towards the wheelchair chair. The plate drive mechanism is self-centering so it can compensate for misalignment of the wheelchair in the docking station. Once the plates contact the wheelchair, the bellows inflate into the cavities of the wheelchair creating two modes of restraint – friction and mechanical interlocking. Both air pressures (plate drive, cylinders and bellows) are adjustable so possible wheelchair damage to wheelchairs can be minimized. The prototype securement device, if successful, would ultimately be designed to fit within the geometry of a standard bus seat.

Figure 51 – Pull testing set up of the low "g" prototype securement device

Test Procedure

Eight manual and powered wheelchairs were obtained for testing. The geometry and weight of the chairs were recorded. A person that approximated a 50th percentile male mass distribution was used as the occupant. Several measurements were taken on each wheelchair including the position of the rear wheels and into which cavities the bellows inflated. The wheelchair was then placed in the docking system with the brakes engaged. The setup includes a platform to which the docking system is fixed. A winch with a 4000 lbs. capacity was fixed to the base of the platform in order to apply a horizontal static load at the combined height of the wheelchair and users center of gravities. The docking system was then engaged. Plate pressure, bellows pressure, which bellows contacted the wheelchair and the nature of the contact (friction or mechanical interlocking), was recorded. The test involved applying a static load to the wheelchair in 40-pound increments, measuring the horizontal displacement of the wheelchair after each increment.

Results of Low G Tests

The following graphs summarize the second set of pull tests that were done, after a modification to prototype was done, based on the results of first pull test. The graph in figure 52 shows the load and horizontal displacement profiles for the eight wheelchairs tested three manuals and five powered. It clearly shows that two E&J manual wheelchairs had the largest displacements 12.8 and 13.2 ins, before breaking free of the securement device. The breakaway loads were 360 and 320lbs, respectively.

The graph in figure 53 shows the comparative static loads converted to equivalent "g" loads. As can be seen, most wheelchairs, except for the E&J Premier and Quickie 2, both manual wheelchairs, either closely approached or exceeded the 1 "g" design goal. It was determined that the grasp on the large wheels of the manual wheelchair was not as effective in restraining the wheelchair as was the engagement with the smaller wheels typical of the powered wheelchairs tested. Plans have been formulated to address this problem in a future design.

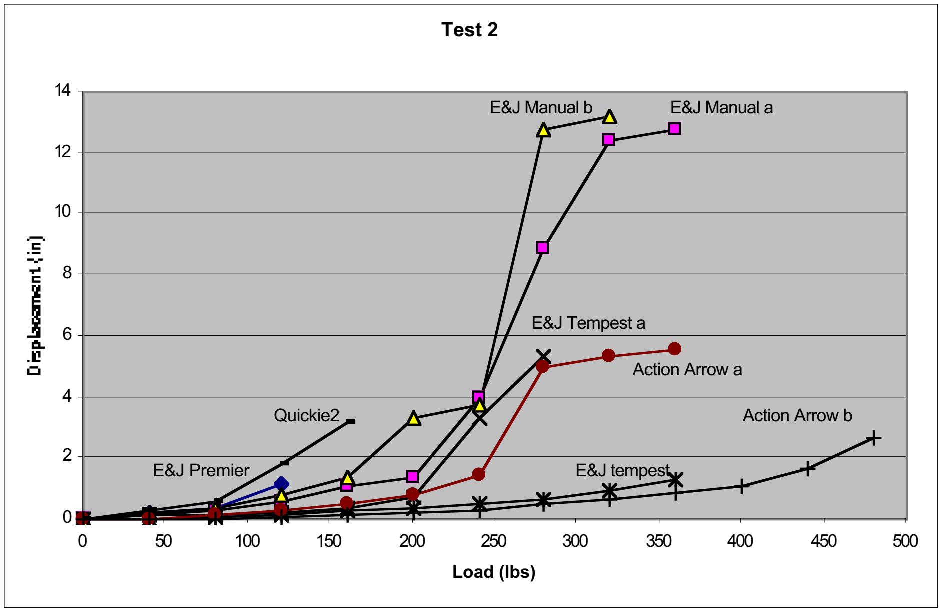


Figure 52 – Results of low "g" testing: wheelchair displacement vs. applied load

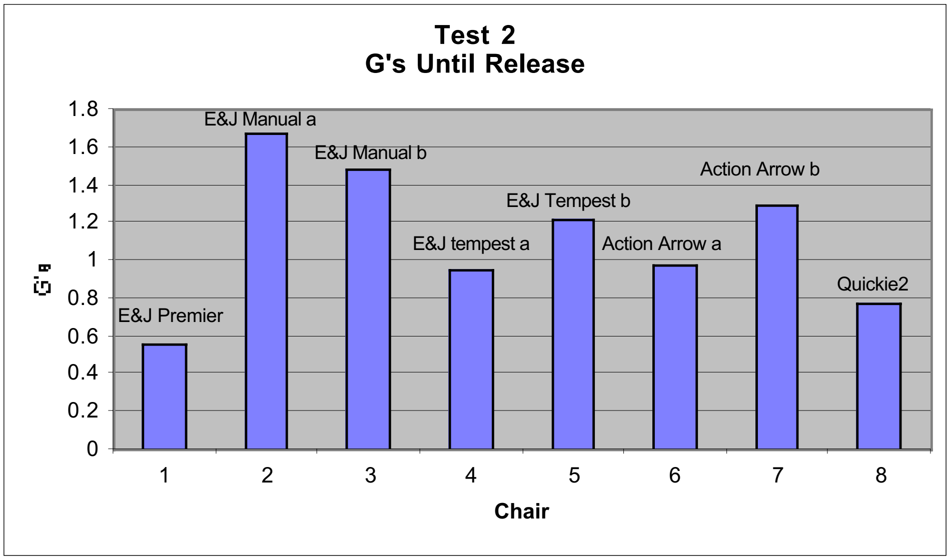


Figure 53 – Low "g" testing: "g" values vs. wheelchair types

3) Sliding Stability Tests of Rearward Racing Wheelchairs

Background

Wheelchairs and their occupants transported on large vehicles in European countries are often secured using a compartment approach. Similar methods are currently under consideration in Canada for use in large transit vehicles traveling at low speeds and having low incidence of frontal crash [Shaw, 1997]. Compartmentalization consists of a rear facing wheelchair positioned in front of a padded bulkhead, which is used as back restraint. A vertical stanchion is aligned with the aisle to prevent rotation of the wheelchair into the aisle and to provide a hand-hold for occupants. Under such conditions, the ability of the wheelchair to stay in place without slipping during normal driving maneuvers is critical to the safety and security of the occupant and other passengers.

In the US, wheelchair stations on public transit vehicles are typically equipped with four tiedown straps to secure the wheelchair. However, due to inconveniences, it is not uncommon to find a high level of disuse of these wheelchair tiedown systems. Under these conditions, wheelchair slippage also becomes a concern during normal driving. Since wheelchair slippage is dependent upon the friction between the wheelchair tires and vehicle flooring, it is of interest to evaluate the effects of various flooring surfaces on wheelchair slippage. (Note: The authors do not advocate traveling without wheelchair securement and recommend the use of four tiedowns and occupant restraints under all conditions.)

Goal

The goal of this study was to evaluate the influence of floor surface materials on wheelchair slippage under conditions simulating normal driving maneuvers and typical road terrain.

Method

This study utilized a tilt platform, shown in Figure 54, to simulate conditions of normal driving.

Figure 54 - Sliding test procedure using tilt platform

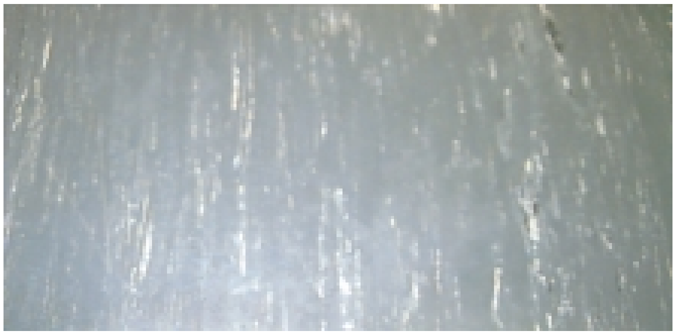


Figure 55a - Smooth surface

Figure 55b - Fluted surfaceFigure

55c - Round dimpled surface

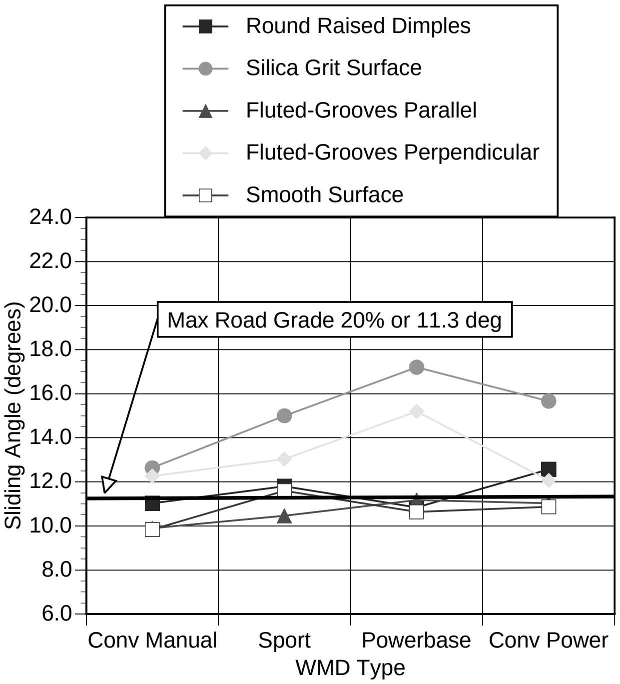
Figure 55d – Silicagrit surface

Four different types of vehicle flooring materials, shown in Figures 55a-d, were mounted to the tilt platform. A 75th percentile (220 lb) male anthropomorphic test device (ATD) was seated in each of four wheelchair types, which were placed on each of the four flooring surfaces. Wheelchair types included a conventional manual wheelchair (22 lb), a sports manual wheelchair (18 lb), a powerbase (189 lb), and a conventional power wheelchair (135 lb). The wheelchair and ATD were positioned so as to simulate a rear facing orientation in a vehicle. Wheelchair brakes were locked and the ATD was restrained using a pelvic belt. To replicate the compartmentalization approach and securement system disuse, no wheelchair securement was used during testing. Test conditions simulated a vehicle ascending a hill and vehicle acceleration. These conditions consist of a road grade near 20% or an 11.5 degree slope, and an acceleration of 0.2g [Adams, 1995 and City of Pittsburgh Public Works, 1997]. To simulate these conditions, the tilt platform was designed to rotated from 0 to 45 degrees, where sin [tilt angle] is equal to equivalent acceleration expressed in "*g*'s". The rate of platform incline was constant at 1.25 degrees/sec. An inclinometer was mounted to the platform to monitor the tilt angle. A tape marker was placed on the rear wheel to aid in detecting initial sliding.

With an ATD occupied wheelchair placed upon the flooring sample, the platform was raised from 0 degrees. Tilt platform angle was monitored and recorded as the wheelchair began to slide. This process was repeated for each flooring surface using each of the wheelchair types. Three trials of each wheelchair-flooring combination were conducted to verify repeatability. The fluted flooring surface was evaluated in two configurations; with fluting parallel and fluting perpendicular to direction of travel.

Results

The average sliding angle of three trials was calculated for each wheelchair positioned on each of the five flooring surface conditions. Figure 56 indicates the angle at which sliding began for each of the evaluated wheelchairs using each of the floor surfaces. Performance can be compared to the steepest terrain encountered or 20% in the Pittsburgh area.

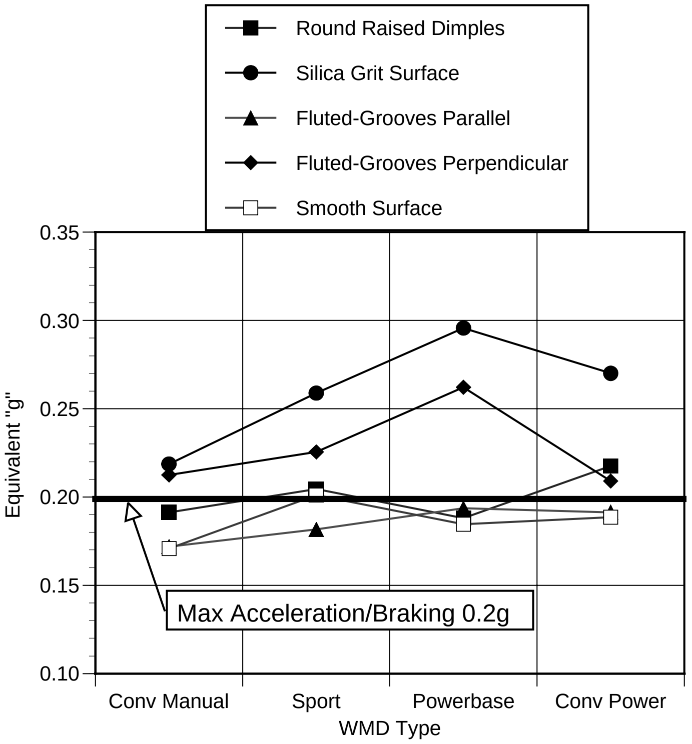


Notes:
1. All tests conducted using 75th %tile male ATD seated in WMD.
2. Rate of tilt platform rise=1.25 deg/sec
3. Tests conducted using dry surface.

Figure 56 - Sliding angles vs WMD type for various surfaces

The same test data is presented (Figure 57) in terms of "equivalent acceleration" through the conversion sin [platform tilt angle] = equivalent acceleration. In this form, results can be compared to the level of acceleration experienced during vehicle acceleration, or 0.2g.

Results show that the silica grit surface provided the greatest resistance to wheelchair slippage for all evaluated wheelchairs. The silica grit surface and the fluted surface installed with fluting perpendicular to travel direction, prevented wheelchair slippage under conditions of normal acceleration (0.2g) and ascending maximum city street grades (20%). Other evaluated flooring surfaces would be questionable in their ability to prevent wheelchair sliding under these conditions.



Notes:
1. All tests conducted using 75th %tile male ATD seated in WMD.
2. Rate of tilt platform rise=1.25 deg/sec
3. Tests conducted using dry surface.

Figure 57 - Equivalent "g" sliding point vs WMD type for various surfaces

Discussion

The resistance to sliding is influenced by the friction force generated between the wheels and the floor surface. The magnitude of the friction force is directly related to the weight of the occupied wheelchair and the coefficient of friction between the floor surface and the tires. Clearly the increased weight associated with the powerbase testing improved resistance to sliding when using the silica grit or fluted-perpendicular surfaces.

These tests were conducted under controlled laboratory conditions. Any road surface irregularities transmitted to the wheel/floor interface or wet surfaces, are most likely to promote sliding at inclinations less than those determined under laboratory test conditions.

Conclusions

The results from the tests show that differences in wheelchair slippage can be expected across different flooring surfaces. Vehicle manufacturers can decrease the risk of slippage through careful selection of flooring surfaces. Wheelchair securement stations and compartments should be constructed using only those flooring surfaces, such as silica grit, which reduce wheelchair slippage.

Outcomes Summary

The key outcomes of task T-3 may be summarized as follows.

a) Development Activities

- The successful feasibility design, development, testing and demonstration of a high "g", universal interface-compatible docking system working in collaboration with an industry partner (STTR-Phase I/Kinedyne Corp.) and local transit authorities. Plans call for the continued transfer of this development upon successful acquisition of Phase II STTR support.
- The successful feasibility design, development and testing of low "g" docking system. This development is now ready for design refinements, followed by identification of an industry partner and the formal initiation of the technology

transfer phase. We will welcome any partners who wish to join our efforts to move this development forward.

b) Education activities

In total, seven instructional courses have been held related to wheelchair transportation safety. These courses have been well received and have stimulated the plan to produce both video and WWW-based instructional materials. These courses are:

- Preconference instructional course entitled "Wheelchair Transportation Safety", the International Seating Symposium, Pittsburgh, PA, January 22, 1997.
- Preconference instructional course entitled "Wheelchair Transportation Safety", RESNA Annual Conference, Pittsburgh, PA, June 20, 1997.
- Preconference instructional course, International Seating Symposium, Vancouver, BC, "Wheelchair Transportation Safety", February 26-28, 1998.
- Overview of ANSI/RESNA wheelchair standards. Assistive Technology Training Program for Rehabilitation Technology Suppliers, University of Pittsburgh, Pittsburgh, PA, February 6-7, 1998.
- Keynote speaker at Medtrade '98, "Issues and Standards on Transporting People Who Use Wheelchairs in Motor Vehicles", Atlanta, GA, November 1998.

Recommendations for Future Developments

Future efforts will focus on the refinement of the high "g" and low "g" docking systems designs in cooperation with industry partners. Funding for this effort will be pursued through a Phase II STTR or SBIR grants. Phase I activities will allow further feasibility analysis of the both concepts from both the user and the transit application perspectives. No further work is anticipated on the sliding stability of rearward facing securement compartments.

Publications

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