

III. IMPROVED WHEELCHAIR TRANSPORTATION

- ◆ T-1 DESIGN CRITERIA FOR TRANSPORT WHEELED MOBILITY DEVICES
- ◆ T-2 DEVELOPMENT OF WHEELCHAIR SECUREMENT INTERFACE CONCEPTS
- ◆ T-3 DEVELOPMENT OF DOCKING TYPE SECUREMENT DEVICES
- ◆ T-4 RESEARCH COORIDINATION RELATED TO STANDARDS DEVELOPMENT FOR
WHEELCHAIR TRANSPORTATION

TASK: T-1 DESIGN CRITERIA FOR TRANSPORT WHEELED MOBILITY DEVICES

Investigators: Gina Bertocci, Kennerly Digges, Douglas Hobson
Collaborators: Linda vanRoosmalen, Dongran Ha, Stephanie Szobota

Rationale

Motor vehicle seats are designed to protect their occupant in a crash. Wheelchairs designed for normal mobility are not commonly designed to be crashworthy. This task was intended to ultimately provide manufacturers with design guidance for producing wheelchair products intended to serve as seats in motor vehicles.

Goals

1. Develop design strategies and criteria for safer transport of Wheeled Mobility Devices (WMDs).
2. Facilitate the commercial availability of transport WMDs manufactured in accordance with nationally recognized industry standards.

Methods Summary

This task has relied upon a combination of computer simulation and experimental testing. Computer crash simulation models were developed and validated for use in the study of factors influencing injury risk of wheelchair occupants in a crash. A wheelchair transportation-specific Injury Risk Assessment method was developed and used in the comparison of injury risk associated with various wheelchair transportation scenarios.

Outcomes Summary

- Developed and validated a production powerbase, dynamic model using crash simulation software.
- Developed and validated a dynamic model of a conventional production power wheelchair.
- Investigated the influence of rear securement point location on frontal crash safety using developed conventional power wheelchair and powerbase models.
- Defined “transport wheelchair” design criteria

using computer simulation.

- Developed an Injury Risk Assessment Method appropriate to the WMD transportation crash environment.
- Evaluated injury risk associated with various securement configurations through the use of the developed Injury Risk Assessment Method.
- Evaluated the affects of shoulder belt anchor location on wheelchair crash safety.
- Surveyed 80 various types of WMDs and developed characteristics database appropriate for use in WMD transportation design and research.
- Through the use of the WMD database, redefined the ISO/SAE surrogate test wheelchair to better represent production powered wheelchairs.
- Awarded a “Wheelchair Integrated Restraint System” STTR grant to investigate the integration of a total occupant restraint system.
- Demonstrated the occupant protection advantages associated with a wheelchair integrated restraint as compared to vehicle-mounted restraint systems through the use computer simulation and the developed Injury Risk Assessment method.
- Developed a psuedo-dynamic test to evaluate the crashworthiness of commonly used caster assemblies.
- Evaluated the crashworthiness of common wheelchair caster assemblies using developed test methods.
- Evaluated the crashworthiness of commercially available wheelchair seating systems through the use of FMVSS 207 ‘Seating Systems’ test methods.



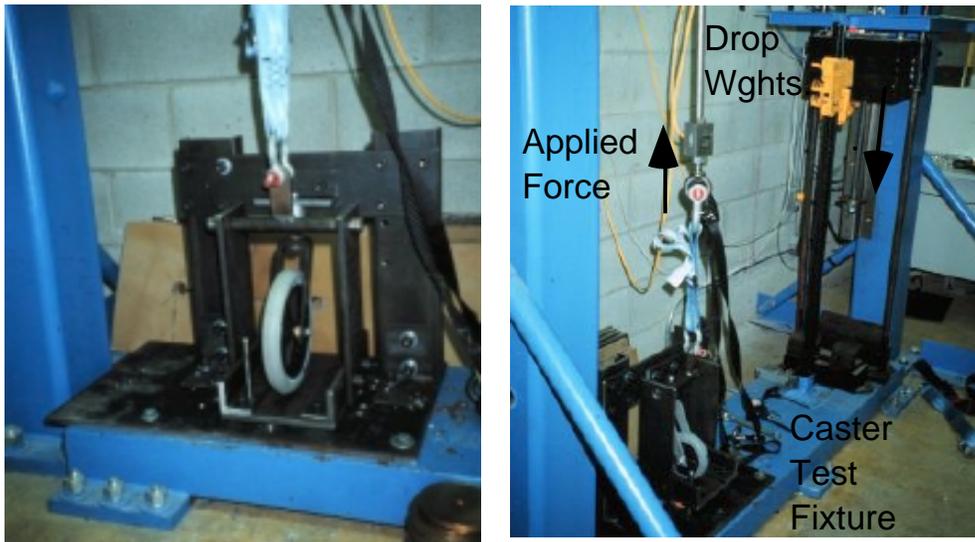


Figure 42 – Dynamic Drop Testing of Caster Assemblies

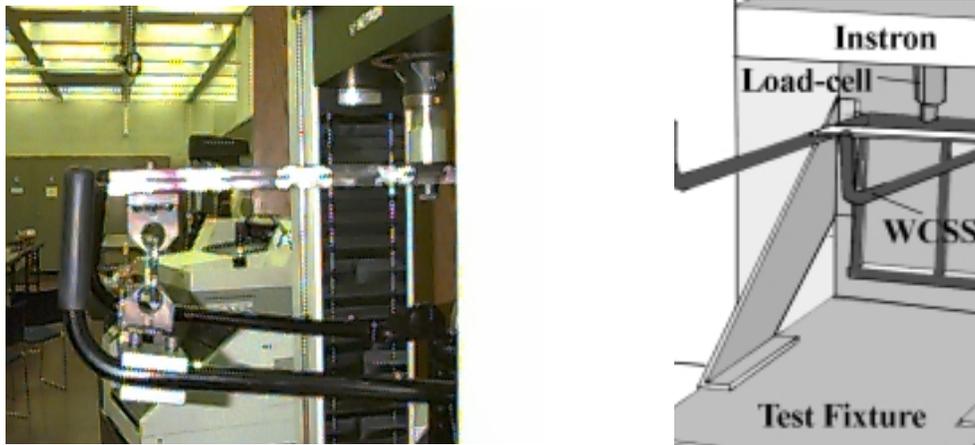


Figure 43 – FMVSS 207 Seating System Testing of Wheelchair Seats

Recommended Future Research

Future research efforts will focus on the crashworthiness of wheelchairs and their components in rear and side impact scenarios. Additional efforts related to the study of frontal impact will concentrate on the development and validation of a computer model to predict occupant submarining when seated in a wheelchair. Various seating characteristics will be evaluated to determine their influence on injury risk and in particular submarining.

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TASK: T-2 DEVELOPMENT OF WHEELCHAIR SECUREMENT INTERFACE CONCEPTS

Investigators: Gina Bertocci, Jules Legal, Douglas Hobson and Patricia Karg

Rationale

Wheelchairs, their securement devices, occupant restraints and transport vehicles all must function as a system, if individuals are to safely and independently use both public and personal vehicles while remaining seated in their wheelchairs. Currently, securement systems for wheelchairs are often inadequately applied, are time consuming to use, and require the involvement of a vehicle operator or an attendant. A universal solution is needed that provides independent, quick, and safe securement. Improving accessibility and safety relies upon standardized methods being developed and adopted for interconnecting the respective technologies. The successful development of new docking-type securement devices, that eliminate several of the disadvantages of commonly used belt-type devices, depends upon standardized ways of interconnecting the wheelchair with vehicle-mounted securement hardware. The adoption and promulgation of a universal interface device (UID) standard for docking

devices can ultimately mean that a person can access and have their wheelchair secured in any transport vehicle, in a manner offering equivalent safety to other riders seated on the vehicle.

Goals

The goal of this project was to facilitate the adoption of a universal interface device standard developed by a trans-industry effort. The approach chosen to reach this goal was as follows:

1. research, develop and evaluate design specifications for universal interface hardware designs that meet constituency-defined needs;
2. conceptualize universal interface device concepts that will foster compatibility between present and future technologies; and
3. foster acceptance and inclusion of concepts and design specifications in national and international standards development.

Universal Interface Concept

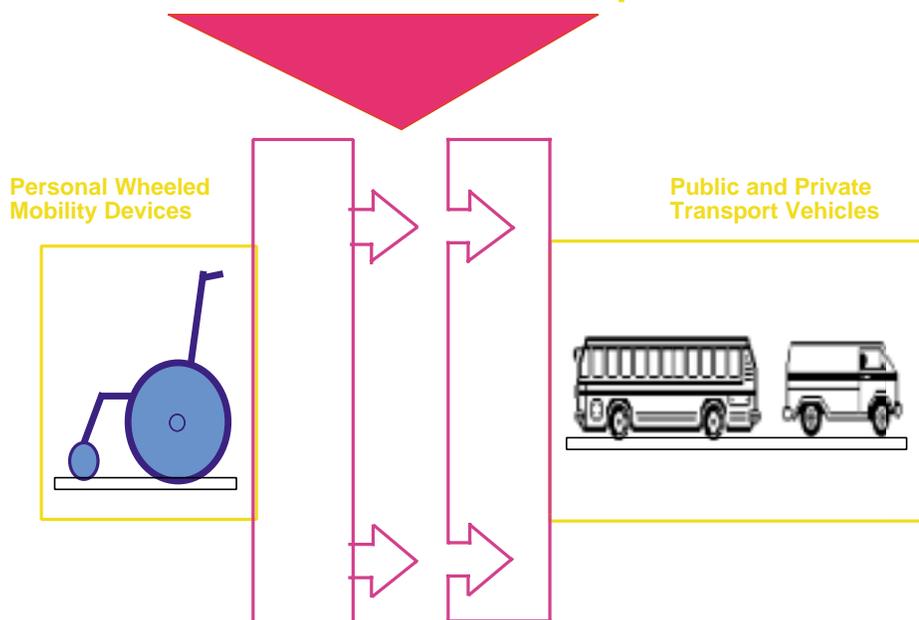


Figure 44 - Illustration of Universal Interface Docking concept

Standardization of the geometry and location of the docking hardware on wheeled mobility devices will allow industry to design and produce vehicle-mounted docking securement devices that are universally compatible.

Methods Summary

The first step in the process was to characterize wheelchair frames and determine the feasibility of adding a common universal attachment. A database of wheelchair frames was developed in this process. This work helped to identify the optimal location for placement of the hardware, as well as necessary clear zones surrounding the hardware. Another initial step was to gather information on the state of the technology in transport vehicles and securement design. In addition, consensus among the involved constituents on the need for a UID had to be established. Reaching agreement on a UID for docking devices between diverse interests such as wheelchair users, wheelchair manufacturers, tiedown manufacturers, vehicle manufacturers and transporters is a challenging undertaking. Focus group meetings, one involving wheelchair users and the other involving industry, were held to this end. Once it was established that there was a need for a UID standard, the two groups worked toward defining and prioritizing the design criteria.

Establishment and priority ranking of the criteria and definition of the clear zones was only the first step. To be adopted universally and eventually promulgated through national and international industry standards, feasibility of the approach had to be demonstrated. Therefore, a series of potential interface hardware designs meeting the criteria were developed and tested. To ensure that the designs met the defined criteria, the RERC, as in other tasks, used the Quality Function Deployment (QFD) design process. The QFD is a design tool that involves a multidisciplinary design approach. It is a process for translating customer requirements into appropriate technical requirements at each stage of the product development process. This process allows for proactive quality control and focuses on planning and problem prevention, rather than problem solving down the road. The process is accomplished through

a series of matrices and charts that deploy customer requirements and related technical requirements through the product development phases. The first step of the QFD process involves developing the matrix known as the "House of Quality", which is a basic design tool. The defined and ranked design criteria and identified clear zones were used as inputs to the QFD design matrix.

Several conceptual hardware configurations were designed and fitted to test wheelchairs (Figure 44a&b). The initial concepts were evaluated through feedback from users and industry, strength testing and compatibility testing with production wheelchairs. The evaluations and feedback led to a final design that was further evaluated. The latter design was incorporated into a draft standard and submitted to an independent standard development group (ANSI/RESNA) for further development and creation of a standard. Details of the outcomes of this process are presented below.

Outcomes Summary

Design and Development

The concept of the universal interface was first presented in the 1995 RESNA Proceedings {Hobson, 1995}. Initial development activities were reported in the 1997 RESNA Proceedings {Karg, 1997}. The initial activities focused on an investigation of the array of wheelchair frames in an effort to categorize them and determine commonalities. A survey data form of 45 data points was developed to record relevant wheelchair characteristics, and a database was constructed to maintain and organize the information {Bertocci, 1996; Bertocci, 1997}. This survey provided important information such as the location of the center of gravity and the nature of the existing frame configurations with respect to the ease of adding a common universal attachment design for the purpose of docking securement on motor vehicles. This was used to identify the optimal location for placement of the hardware, as well as the necessary clear zones.

Additional efforts included gathering information on flip-up bus seats, current securement configurations and wheelchair compartment designs on vehicles. Current docking devices were also

obtained for evaluation. Visitations to leading securement companies were made, providing insight into the current state of the technology.

The next step was to organize and host industry meetings and consumer focus groups to identify the desire and need for a universal design standard, and to identify design specifications. Two industry meetings have been held that included wheelchair manufacturers, securement manufacturers, vehicle manufacturers, and transporters. A focus group comprising manual and power wheelchair users that use public and/or private transportation was held in the time between the two industry meetings.

There was overwhelming agreement on the need for a universal interface for docking devices and that a design standard should be pursued. To that end, the two groups then generated lists of design criteria for the universal interface; a list of 19 criteria resulted from the two groups. The eight criteria listed below were included in the top 6 ranked criteria of the consumer group and/or the industry group. The first two bullets were ranked first and second priority by both groups independently, and the third and fourth appeared on both lists. The remaining four appeared on only one of the ranked lists as indicated by either an "I" (industry) or a "C" (consumer) following the criterion. These criteria and their ranking provided a target for the ensuing research effort. These results have been disseminated to two standards development groups.

The partial listing of the design criteria for the universal interface, as referenced above, is as follows.

- Meet all applicable safety standards (I, C)
- Promote independent securement (I, C)
- Maintain original function of wheelchair (e.g., folding, feel, maneuverability) (I, C)
- Accommodate all wheelchair types and sizes that are used as motor vehicle seats (I, C)
- Compatible with all vehicle types that transport passengers seated in wheelchairs (driver docking and fold-down seats accommodated) (C)
- Promote quick securement time (less than 1 minute from being positioned at the securement station to securement) (C)

- Does not preclude use of existing tie-down and occupant restraint systems (I)
- Allow retrofit to existing wheelchairs (I)

The design criteria were used to implement the Quality Function Deployment (QFD) design process. This method was used to assure the needs and desires of all project stakeholders have been considered and are effectively incorporated into the design of the hardware. Finally, several hardware designs were developed and some fabricated for consideration and evaluation. Clear zone requirements with respect to the wheelchair to allow access to interface hardware were also established. Industry and consumer representatives indicated they would like the feasibility of the designs evaluated before the standard was created and subsequent work was performed to this end. The evaluation of the proposed hardware designs and status of these efforts were reported at the 1998 RESNA Conference [Karg, 1998].

The UID standard will provide the basis by which all involved industries can design and produce compatible wheelchair securement products. Design of the docking devices will be limited only in that the wheelchair hardware (i.e., the universal interface) geometry, location in space, and surrounding clearance will be defined. The industry meetings centered around the debate of two configurations of a UID located on the lower rear portion of the wheelchair. One configuration, that was favored after the second industry meeting, is two vertically oriented structures (Figure 44a), aligned side by side [Karg, 1997]. However, the discussions in the third meeting (June 1997) tended to return to the appealing approach of having a horizontal bar across the rear, similar to the grab bars offered on several scooters (Figure 44b). Evaluations of these two configurations revealed several pros and cons of each (detailed below). The horizontal bar proved better for ease of retrofit to existing wheelchairs however, did not provide a reaction point to prevent rear or end wheelchair rotation during a crash. Thus, two horizontal bars may be necessary. The vertical configuration would allow for the needed stability, however appeared to be more difficult to retrofit and integrate into existing wheelchair designs.



Figure 44 – Conceptual designs: (a) vertical concept (b) horizontal concept

Evaluation

Compatibility testing: Field tests were performed to evaluate the compatibility of the vertical and horizontal design configurations with existing production wheelchairs to assess the ease of retrofit, as well as the ease of incorporation in future designs. Approximately a dozen wheelchairs representing the different classes, including pediatric wheelchairs, were evaluated. In general, the wheelchairs surveyed more readily accommodated the horizontal interface. However, in some cases, overall wheelchair length was increased, which is undesirable. The problems generally found with the vertical configuration were

battery box interference in placement, and inadequate distance between the battery box and wheel for access of the interface. In addition, the various wheelchair widths dictated various spacing of the vertical interface components, placing more demands on the docking system design.

Dynamic testing: The vertical interface design was dynamically tested for strength using a drop test jig to simulate dynamic conditions for a 20 g crash with a 200-220 lb wheelchair and a 50% male occupant. The load was applied perpendicular to the 3/4" solid aluminum tubing making up the vertical interface component. With successive testing at these loads only slight deformation occurred.

Reaction point analysis: Since the primary concern with using a rear-only securement was wheelchair rotation, crash simulations were performed to analyze various interface configurations. The simulations use a surrogate wheelchair used in sled testing of belt-type securement systems. The surrogate was designed to represent a standard power wheelchair occupied by a 50% male wearing an integrated restraint. The simulations were not validated with sled testing, but could be used for comparative purposes. Front wheel excursions at time of 250 msec during the rebound phase of a frontal crash were used to characterize the crash response of the wheelchair. Initially a 1" diameter horizontal bar was placed 11" above the floor (at the center of gravity of the wheelchair) and had an excursion of 6.9". Then two horizontal circular bars were tested separated by 5" and 2" and had excursions of 3.5" and 3.9", respectively. The analysis emphasized the need for a second reaction point to prevent excessive wheelchair rotation when securing the wheelchair at the rear only. The results showed that a double horizontal bar would provide the desired second reaction point.

Based on the information and research to date, the group at the June 1997 industry meeting discussed the relative merits of the vertical versus the horizontal interface configurations. The vertical configuration had been chosen as the most promising in previous meetings. In light of new data, the group decided the horizontal configuration looked promising as well and that it should be further researched by the RERC

team, especially with respect to stability and wheelchair rotation.

Hybrid interface design and evaluation

The hybrid interface (Figures 45 and 46) appears to provide the advantages of both the horizontal and vertical design concepts, along with providing the critical anti-rotational reaction points. This approach has an advantage over the double horizontal bar approach by reducing the level of complexity of docking system-to-interface engagement. Additionally, the hybrid interface promotes docking system centering on the wheelchair. The proposed dimensions are intended to be wheelchair compatible, and are based upon the previous surveys and data analysis across varying wheelchair types.

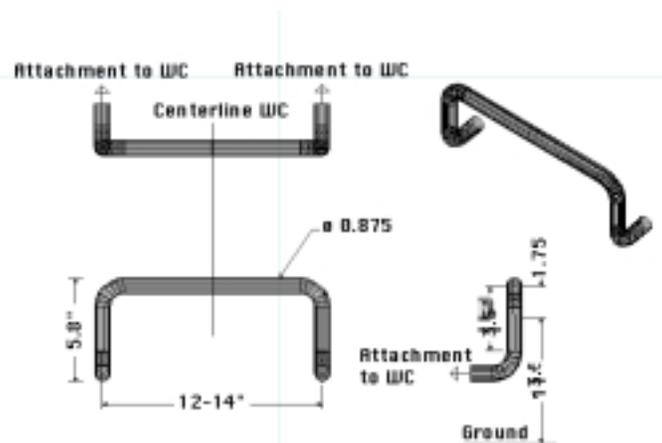


Figure 45 - Hybrid UID concept and design specification

We conducted preliminary simulations using a 2-D Working Model analysis. The model was not validated, but was used to obtain a general evaluation of the crash dynamics and response of the wheelchair with the hybrid interface. The wheelchair exhibited a controlled response in these simulations. The next step was to perform static testing on the hybrid design. The testing showed that the UID maintained up to a 10,400-lb load. When failure occurred, it was at the point where the UID interfaced with the test jig, which in this case was a press fit into the UID tubing, resulting in an area of stress concentration. The final evaluation was a dynamic test that used the hybrid design to interface an SAE surrogate wheelchair with a docking system that had been designed, in part, to prove the feasibility that a docking system could be designed that would

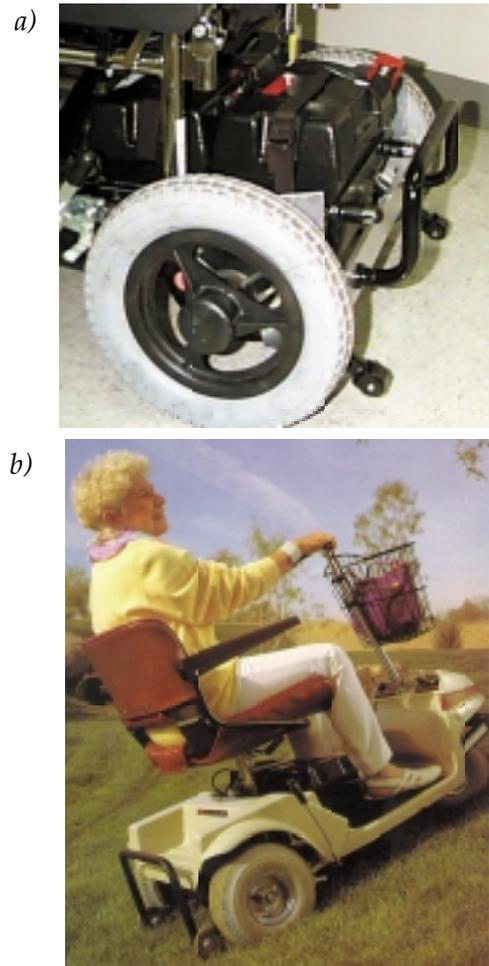


Figure 46 - Hybrid UID concept, example of integration into (a) a powered wheelchair and (b) a scooter

successfully mate with the hybrid interface design. The sled test was performed according to the SAE J2249 specification [SAE, 1996]. The test met J2249 requirements for wheelchair and occupant response and proved the feasibility of the hybrid UID concept.

Recommended Future Developments

The final step as the RERC funding period came to a close was to formalize the standard development process with an independent standard agency. In Spring 1998, a formal request and draft standard was submitted to ANSI/RESNA Technical Guidelines Committee to initiate a new work item on the UID Standard. The new work item has been approved and work will begin in Spring 1999. The draft standard must now continue through the standard development process in the hands of the ANSI/RESNA working group for the transport wheelchair (SOWHAT).

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TASK: T-3 DEVELOPMENT OF DOCKING TYPE SECUREMENT DEVICES

Investigators: Douglas Hobson, Gina Bertocci, Patricia Karg and Mark McCartney
Students: Linda van Roosmalen, Jonathan Evan Collaborator: Jules Legal

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.

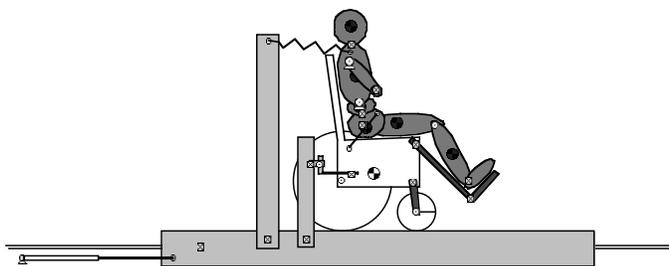


Figure 47 - Frontal Crash Simulation; Wheelchair Secured Using Proposed Universal Interface Hardware

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.

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

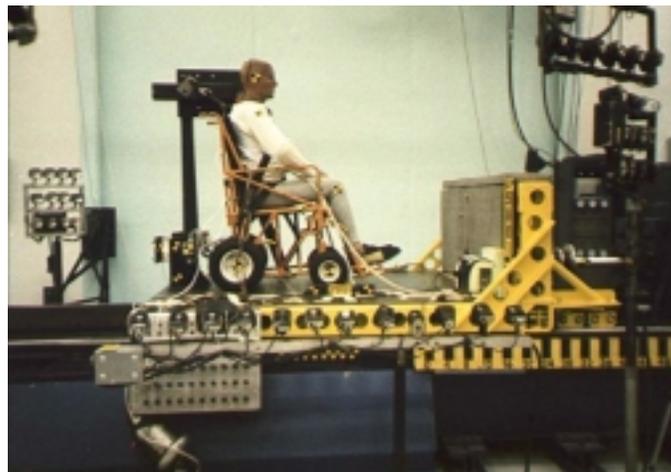


Figure 48 – 20g Frontal Impact Sled Testing of Prototype Docking System employing Universal Wheelchair Interface Hardware

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 manual 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.

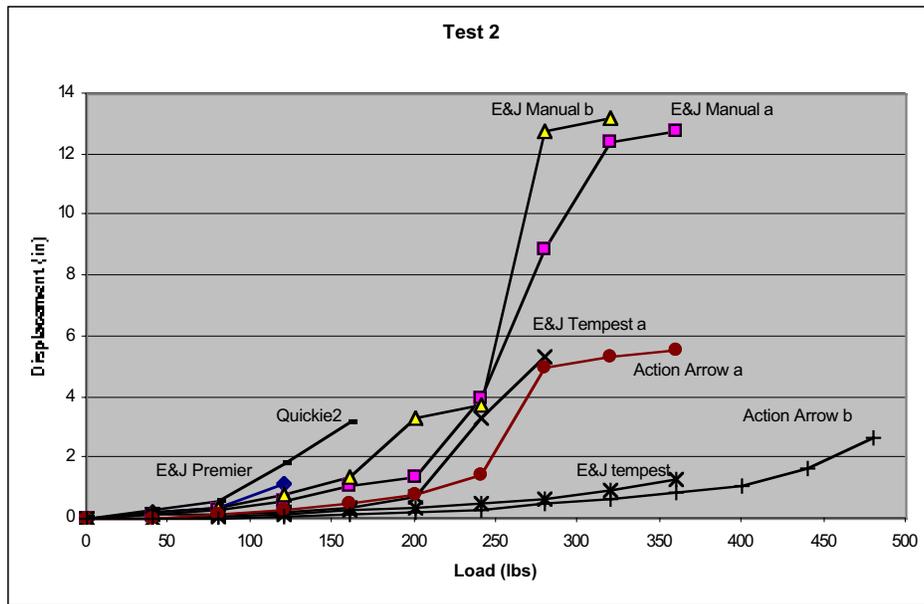


Figure 52 – Results of low “g” testing: wheelchair displacement vs. applied load

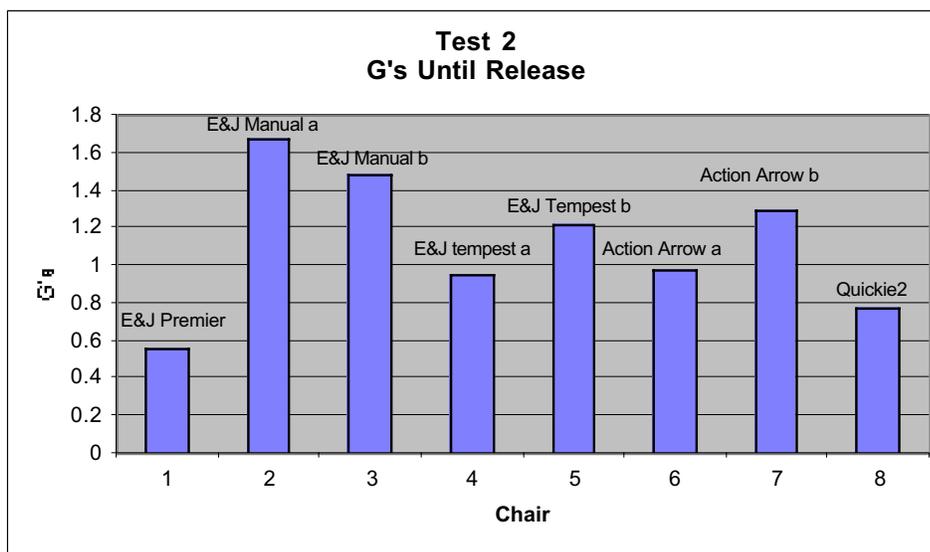


Figure 53 – Low “g” testing: “g” values vs. wheelchair types

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 surface



55c - Round dimpled surface



Figure 55d – Silicagrit surface

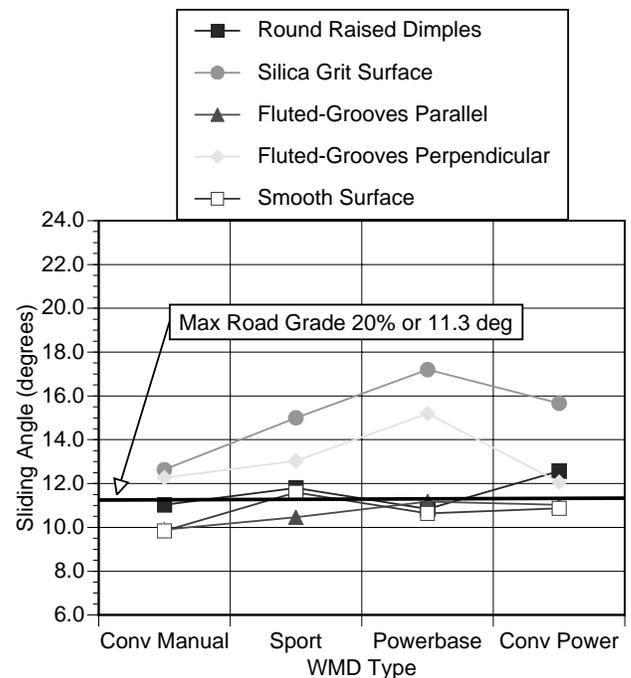
Four different types of vehicle flooring materials, shown in Figures 55a-d, were mounted to the tilt platform. A 75th percentile (220 lb) male anthropomorphic test device (ATD) was seated in each of four wheelchair types, which were placed on each of the four flooring surfaces. Wheelchair types included 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:

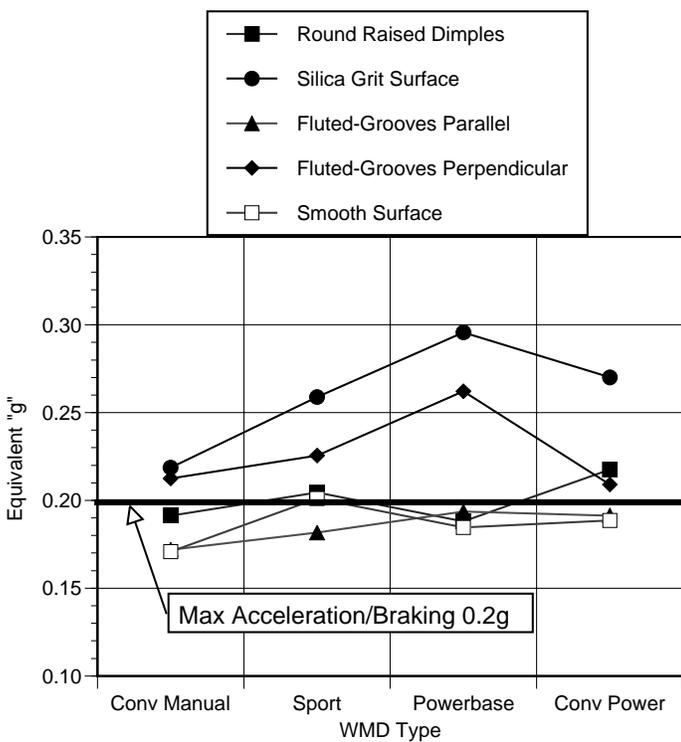
1. All tests conducted using 75th %tile male ATD seated in WMD.
2. Rate of tilt platform rise=1.25 deg/sec
3. Tests conducted using dry surface.

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 $\sin [\text{platform tilt angle}] = \text{equivalent acceleration}$. 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

Hobson DA, Bertocci GE, Bernard R, McCartney M, Wheelchair Transit Safety; A Conceptual Case for Low 'g' Securement Approach. *Proceedings of the RESNA '97 Annual Conference*, Pittsburgh, PA, June 1997.

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TASK: T-4 RESEARCH AND COORDINATION RELATED TO STANDARDS DEVELOPMENT FOR WHEELCHAIR TRANSPORTATION TECHNOLOGY

Investigators: Douglas Hobson, Gina Bertocci, Kennerly Digges, and Patricia Karg

Rationale

In 1993, there were no voluntary industry standards for wheelchair securement devices or for wheelchairs used as seats in motor vehicles. Through the adoption of voluntary wheelchair transportation standards by the involved industries, the safety of those using wheelchairs as seats in motor vehicles will begin to approach that of non-disabled persons using OEM vehicle seats. This task has been committed to improving the safety and convenience of wheelchair transport through facilitating the development and adoption of voluntary industry standards on a worldwide scale.

Goals

1. Provide research and administrative support in the development of voluntary product performance standards that will ultimately facilitate the safe transport of those using wheelchairs as vehicle seats, and
2. Facilitate the implementation of the standards throughout the user and service provider communities.

Outcomes Summary

The RERC on Wheeled Mobility has provided working group leadership and research support towards the following standards development:

- The Society of Automotive Engineers (SAE) J2249 Wheelchair Tiedown and Occupant Restraints Systems (WTORS) for Motor Vehicles standard has been adopted as a recommended practice (completed January 1997). This standard serves as a benchmark for design and testing of four point strap-type wheelchair securement systems. A companion applications guideline for J2249 is due for completion in January 1999 (revised draft in process).
- SAE J2252, provides the details on the design and construction of the surrogate wheelchair used in the testing of WTORS to the J2249 standard.
- The ANSI/RESNA Subcommittee on Wheelchairs and Transportation (SOWHAT) has completed the transportable wheelchair standard (ANSI/RESNA WC-19). A collaborative research effort between the University of Pittsburgh, University of Michigan and University of Virginia has led this effort with support from private and federal sources. A draft companion document describing the rationale for transport wheelchair standards is currently under development. This document will provide wheelchair users, care givers, transporters and manufacturers with practical guidance on the use of the standard. It will be available for general distribution in spring 1999.
- A parallel WTORS standard's effort (ISO 10542, parts 1&2), conducted under the auspices of International Standards Organization (ISO), has been under way since 1985. The effort on parts 1&2 (general requirements and requirements for strap-type WTORS) is now proceeding to the final stages of international approval and is due for completion in 1999. Due to collaborative efforts by the RERC and others, this standard has been closely harmonized with the U.S. recommended practice document, WTORS-SAE J2249.
- ISO 7176/WC-19, Wheelchairs Used as Seats in Motor Vehicles standard, which parallels ANSI/RESNA WC-19, is also moving forward at the ISO level. This standard is scheduled for completion in spring 2000.

- The progress, current status (meeting minutes), and most recent working group versions of the above standards and companion documents can be viewed and downloaded from the RERC's WWW site (<http://www.rerc.upmc.edu/>).

Publications

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