IDEA

Innovations Deserving
Exploratory Analysis Programs

Transit IDEA Program

Restraint System for Wheelchair Users on Transit Buses

Final Report for
Transit IDEA Project 16

Prepared by:
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Cleveland Clinic Foundation

May 2002

TRANSPORTATION RESEARCH BOARD
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RESTRAINT SYSTEM FOR WHEELCHAIR USERS ON TRANSIT BUSES

Final Report

Transit IDEA - 16

Prepared for
Transit IDEA Program
Transportation Research Board
National Research Council

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Table of contents

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EXECUTIVE SUMMARY

The objective of this project was to develop and evaluate new occupant restraint design concepts with focus on minimizing the efforts to operate the system while maintaining the safety and crash protection of the wheelchair traveler on transit buses. Traveler protection during transit and vehicle impact is the primary objective of occupant restraint design including occupant restraints of travelers using wheelchair in transit vehicles.

The investigation started with the formation of the design criteria based on multiple inputs from a resource panel of experts, existing guidelines, wheelchair users, transit administrators, vehicle operators, human factors testing of wheelchair using travelers and an experienced public transit vehicle designer.

A survey was developed and disseminated to administrators at 12 transit agencies around the country and transit vehicle operators involved with transportation of wheelchair users. Overall the surveys indicated conflicting information on priorities of safety, lack of use of lap and shoulder belts, fastening time between fixed route and paratransit application and the need for alternatives to the existing occupant restraint designs. New design criteria was indicated for restraints to be used independently and rapidly by many wheelchair users with reduction of stop dwell time and driver involvement. The human factors testing established anthropometric envelopes of wheelchair seated posture, reach, hand strength and the functional ability for wheelchair positioning by the occupants.

The design criteria from all these inputs were finalized and presented in Table 5. The criteria established specifications for activation time, user independence, durability, component locations, operating hand function requirement, body size accommodations and crash safety in terms of load and deflection parameters.

Using the design criteria, three conceptual models of wheelchair occupant restraint systems were developed and investigated. The early concepts of the Stanchion-mount and the Wall-mount designs were evaluated and not implemented because of potential user indicated undesired obtrusive bulkiness for the first and because of vehicle structural design incompatibility for the second. In previous sled impact testing (30 mph, 20-g and 5-g lateral impact) the Stanchion-mount design performed well and appeared to be superior to the three point belt restraints.

The final Panel-mount design was developed and improved and a full scale prototype was built for limited user tests and strength evaluation. To minimize costs and to enhance commercial appeal an effort was made for a simple design with off the shelf components and cost effective tolerances. The prototype was installed in a 44 foot in-service transit vehicle at the Greater Cleveland Rapid Transit Authority (RTA) and was driven to wheelchair users for a hands-on field trial.

The limited field trial in the non-moving vehicle by experienced wheelchair travelers pointed out a general acceptance of the principles of the prototype design, a dissatisfaction with the current lap belt system and a need for further improvements in slimmer design and in the operation of the panel mounted restraint design.

The final evaluation of the prototype restraint system was a static pull test to determine compliance with the Federal Motor Vehicles Safety Standard (FMVSS) - 210 for seat belt anchorages. This test was performed at the National Aeronautics and Space Administration (NASA)-John H. Glenn Research Center in Cleveland, Ohio. The test results indicated the ability of the restraint prototype to carry nearly half of the 5000 lbs. of target load, displacement and duration. The early failure of the prototype restraint in this test did not occur in the design concept, but was due to a faulty welding and the incorrect accommodation of the belt anchor to the commercial wheelchair.

BACKGROUND

Current automotive restraint philosophies and regulations are increasingly moving toward passive restraints with the realization that many travelers will not make even small efforts to apply an occupant restraint system. It should not be surprising, therefore, that occupant restraints for wheelchair users that are difficult, awkward and time consuming to apply are seldom used. Although totally passive restraints for wheelchair users on public transit is not yet feasible, new designs need to focus on minimizing the efforts to operate the systems. This project is an attempt to move the industry in that direction.

Contributing to the complexity of occupant restraint systems is the Americans with Disabilities Act (ADA) (*1*) and Society of Automotive Engineers (SAE) (*2*) objective to offer the same level of crash protection to wheelchair users on transit vehicles as received by individuals using Original Equipment Manufacturer (OEM) seats in personal automobiles. This approach requires the restraint systems to be able to pass a 20 g 30 mph simulated impact test. Since the completion of the Transportation Research Board (TRB) *Guidelines for Wheelchair Securement and Personal Restraint for Public Transit Applications,*(*3*) discussion has resurfaced among standards groups concerning the design loads for securement and restraint systems that are used on large, public transit buses. (*4,5*) There is little or no data validating that these large buses, driven primarily on crowded city streets at low speeds, sustain crashes close to 20-g. Until these governing documents reduce their test requirements, however, restraint designs must be made robust enough to meet the demanding requirements. This strength is provided with a compromise in appearance, cost, and ease of use.

Protection of travelers during a vehicle impact is an essential objective of an occupant restraint design. This project recognizes that unless a restraint system meets nearly all the needs of the user and transit provider, it will not be used, or may be used incorrectly, and the intended crash protection will not be realized. Particular attention was therefore given to convenience and operation using the criteria identified from the surveys and interviews of wheelchair users, transit providers, and vehicle manufacturers.

IDEA PRODUCT

The investigating team developed a conceptual model for a universal wheelchair occupant restraint system as part of an earlier TRB project – Transit Cooperative Research Program (TCRP) C-1. (*6*) Whereas most products and research work have tried to include wheelchair securement and occupant restraint in a single system, this project focused its resources on the occupant restraint part of the problem. The design is intended to be used in parallel with a wheelchair securement system. The prototype uses the proven concept of lap and shoulder belts for occupant protection, but uses an innovative design (Figure 1) to improve its operation with wheelchair seated passengers. The proposed system offers a significantly easier and faster operation that virtually eliminates the need for the vehicle operator to reach to the floor or contact the wheelchair user, and many wheelchair users will be able to position the restraint themselves. This overcomes a major barrier to the use of occupant restraints.

When the device is not in use, it is stored so that it does not interfere with passenger seating or ambulation. The lap belt is also stored on a small retracting spool so that the belting will remain clean when not in use.

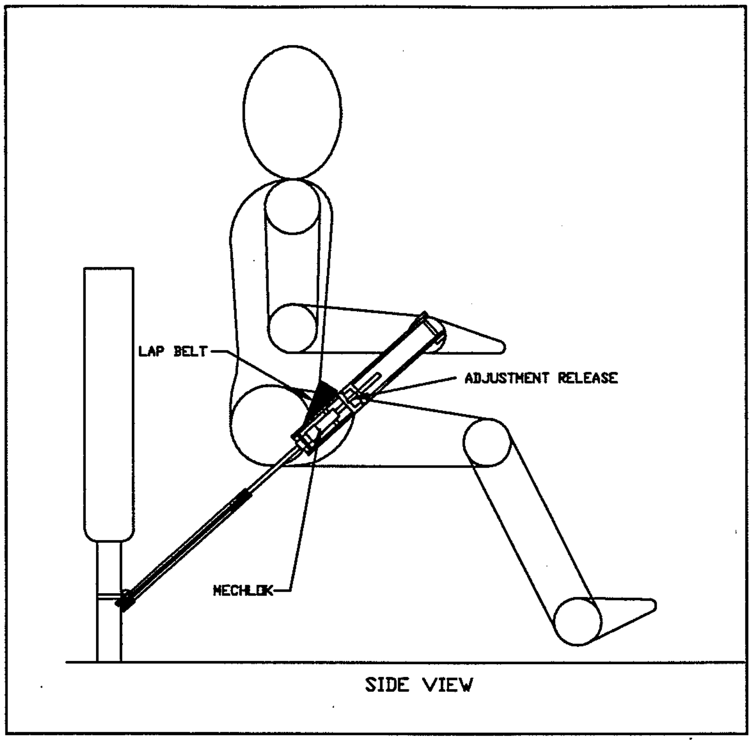

FIGURE 1 Design concept for restraint system

The occupant restraint has been developed with attention to the needs of transit service and wheelchair travelers. The restraint system was designed to be compatible with cost effective manufacturing processes, vehicle design, operating procedures, human factors, and occupant protection practices.

The final prototype design was developed through three iterations, each one incorporating further improvements that enhanced the performance of the previous design. To minimize costs and develop a prototype that will encourage commercialization, significant effort was devoted toward establishing a simple, but functional design. Off the shelf components were selected, and machined parts were designed with large tolerances whenever possible. The components were assembled to verify that the geometry and operation were satisfactory. An important aspect of this concept is integration into the vehicle designs currently used on most transit buses.

ESTABLISHING DESIGN CRITERIA

The formation of the design criteria was based on multiple inputs from a resource panel, the existing guidelines, user and transit administrator surveys, human factors testing of wheelchair using travelers and an experienced public transit vehicle designer. These inputs are summarized below.

RESOURCE PANEL

To assure objectivity and a practical design, a diverse and highly qualified resource panel was established to oversee the project progress. This panel was an essential component of this project and provided balanced and objective input to the project staff. The composition of the panel emphasized the commitment to meet the joint needs of the transit industry and its consumers. The panel members have been active participants in the field of wheelchair transportation on public transit, and their qualifications are listed below in Table 1.

TABLE 1 Resource Panel Membership

Member	Affiliation	Experience
Barry Barker	Transit Authority of River City	Executive Director
Norm Santos	Chicago Transit Authority	Project Engineer
Alan Smith	Akron Metro RTA	Director of SCAT (Paratransit service)
Frank Polivka	LAKETRAN	General Manager
Frank Anderson	Paralyzed Veterans of America	Executive Director, Uses a manual wheelchair
Jesse Anderson	Consumer	Board of Directors of GCRTA, Uses power-wheelchair
Joe Kiren	Paralyzed Veterans of America	Executive Director, Uses a manual wheelchair
Margaret Meyer	Services for Independent Living	Project Director, Uses a power wheelchair
John Feather	AARP Andrus Foundation	President, Advocate for the elderly
Gil Haury	Invacare, Inc.	Director of wheelchair testing SAE/ISO committees wheelchair transportation

TRB GUIDELINES

The TRB publication *Guidelines for Wheelchair Securement and Personal Restraint for Public Transit Applications(3)* identified initial objectives for occupant restraint systems and provided quantitative design criteria for public transit use. The guidelines give specific test conditions and recommended results for evaluating occupant restraints. The guidelines generally state that the operation of restraint systems must be simple, convenient and rapid and include human factors issues and operation times. Systems not meeting these criteria were previously unacceptable. Additionally, they specify that occupant restraint systems must control the occupant motion during specific test conditions simulating a frontal or lateral vehicle impact.

SURVEYS

To evaluate the compatibility with transit needs and attitudes, a survey was developed by the National Transportation Consortium and the Cleveland Clinic and disseminated to high level administrators with input to the purchasing decisions at 12 transit authorities throughout the country, representing large and mid-sized organizations. A small number of authorities were targeted, to achieve a 100% return rate. This technique prevented biased data from selectively returned surveys not representative of the entire population. Transit systems included in the survey were:

BART (Bay Area Rapid Transit District, Oakland, CA)
CTA (Chicago Transit Authority, Chicago, IL)
GCRTA (Greater Cleveland Regional Transit Authority, Cleveland, OH)
LACMTA (Los Angeles County Metropolitan Transportation Authority, Los Angeles, CA)
METRO RTA (Akron, OH)
METRO (Metropolitan Transit Authority, Houston, TX)
METRO-Dade Transit Agency (Miami, FL)
NJ Transit (Newark, NJ)

RTD (Regional Transit District, Denver, CO)
SEPTA (Southeastern Pennsylvania Transit Authority, Philadelphia, PA)
TARC (Transit Authority of River City, Louisville, KY)
WMATA (Washington Metropolitan Area Transit Authority, Washington, DC)

The restraint concept was also presented to vehicle operators who must address the day-to-day issues involved with transportation of wheelchair users. Theses surveys were developed and disseminated by the Greater Cleveland RTA and the Cleveland Clinic. Nineteen forms were completed by paratransit operators, and thirteen forms were completed by fixed-route operators. Survey forms were also distributed to wheelchair users who travel on GCRTA vehicles and from these, seven were completed and returned.

The most significant finding from the survey data, is that although crash safety is consistently reported as being the highest priority, vehicle mounted lap and shoulder belts are seldom used. The following data illustrates this conflict:

- All three surveys confirm that crash safety of the wheelchair user is considered the single most important aspect of occupant restraint (92 % of administrators, 85% of fixed route drivers, 100% of paratransit drivers).
- Lap belts are <u>usually used</u> with only 31% of fixed route drivers and 74% of paratransit drivers.
- All seven wheelchair users indicate that vehicle mounted lap belts are <u>not</u> needed because they can balance themselves or have a wheelchair anchored lap belt.
- All seven wheelchair users indicate that shoulder belts are not used.
- Shoulder belts are <u>usually used</u> with only 15% of fixed route drivers and 6% of paratransit drivers.
- The administrators felt that the current occupant restraint systems are acceptable for crash safety (92%).

This conflicting data reinforces the **critical need for a nationwide educational effort** to inform those involved in transporting individuals seated in wheelchairs that crash safety can only be obtained when vehicle anchored lap and shoulder belts (or other restraint devices) are properly positioned on all trips.

The second priority in occupant restraints depended on the type of service. Fastening time was most important for fixed route drivers (77% vs. 28% of paratransit drivers) while user comfort was more important for paratransit drivers (74% vs., 28% of fixed route drivers). Interestingly, none of the transit systems had quantitative data related to the cost of using the current occupant restraint system.

The survey also showed strong interest from the transit administrators (75%) in pursuing an alternate occupant restraint design, while about half of the vehicle operators were willing to use the illustrated proposed design on the vehicles they drive. The ease of use was considered the most significant advantage for using the proposed design, while the large size of the supporting structure was viewed negatively. The transit administrators strongly favored (87%) a restraint system that which was integrated into the vehicle structure rather than a modular after market component.

Overall, the survey results indicated a need for restraint systems that can be used independently and rapidly by many wheelchair users. The full benefit of improved designs will be realized only when individuals seated in wheelchairs are able to reach and operate the controls. Although in practice some individuals will require assistance with any design, appropriate designs can minimize the amount of assistance needed. Consequently, the reduced driver involvement will allows for less stop dwell time, as the operator can be seated and preparing to drive as the wheelchair users secure their wheelchairs and fasten the occupant restraint.

HUMAN FACTORS TESTING

The difference in functional abilities among wheelchair users and the lack of available data demanded human factors testing of typical wheelchair travelers. Characteristics needed for user operable restraint systems were identified through anthropometric and functional abilities testing as described below:

Anthropometry	Functional Abilities
Strength	Wheelchair location
Range of motion	Wheelchair orientation
Dexterity	Positioning time
Body position	

Anthropometry

The sample population consisted of 6 female and 10 male wheelchair users with an average age of 37 $\pm$ 8 years. They used 10 manual wheelchairs, 4 power wheelchairs and 2 scooters. Hand strength was measured according to standard occupational therapy practice using a Jamar™ dynamometer and pinch meter. Dexterity was measured using various types of karabiner and open hooks that required different levels of coordination of the fingers and thumb to attach and remove each from a closed tubular form. Range of motion data was obtained by measuring from the intersection of the wheelchair seat and back to the furthest point where a test subject could grasp an object. Measurements were made in several directions as shown on the data collection form in Figure 2.

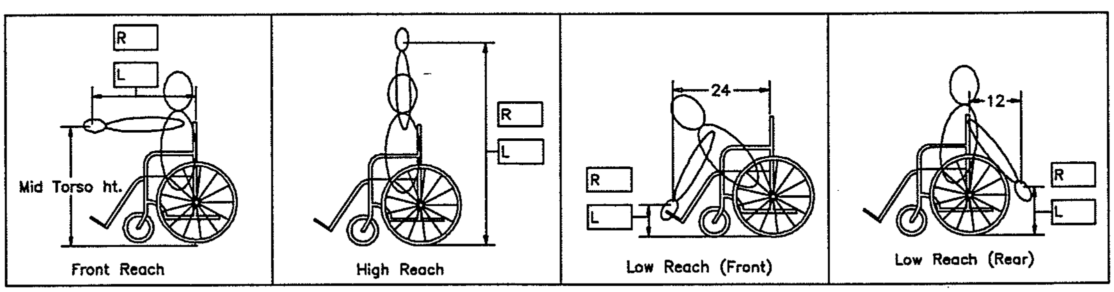

FIGURE 2 Anthropometric measurements

The results from this testing are shown in Table 2. This data provided general design guidelines for accessible components. Many wheelchair users can reach components located between 15 and 60 inches above the floor, from 12 inches behind them to 24 inches in front of them, and they can apply a grip strength of 40 lbs., and a pinch strength of 10 lbs. Many of them, however, had difficulty performing tasks that required fingertip control.

TABLE 2 Anthropometric data

Anthropometric characteristic	SI units, (mean ± stand. dev.)	English units, (mean ± stand. dev.)
Seat height	51 ± 5 cm	20.1 ± 2.0 in
Seat to rear	30 ± 5 cm	11.8 ± 2.0 in
Low reach	38 ± 16 cm	15.0 ± 6.3 in
High reach	147 ± 20 cm	57.9 ± 7.9 in
Front reach	60 ± 12 cm	23.7 ± 4.6 in.
Grip Force	200 ± 150 N	45.5 ± 34.1 lb.
Pinch Force	50 ± 35 N	11.4 ± 8.0 lb.

Functional Abilities

To simplify the operation and design of the occupant restraint, the number of adjustments were minimized. The data above showed that seat position was relatively constant (± 2 in.) relative to the wheelchair position. Additional information was needed that identified how accurately wheelchair users could position their wheelchairs. To obtain this data, testing was performed with wheelchair users at three different locations.

Fifteen wheelchair users (9 females and 6 males, using 11 power wheelchairs, 3 scooter, and 1 manual wheelchair) volunteered for testing. Testing was performed indoors, with orange cones defining the edges of the aisle and wheelchair bay in the simulated vehicle interior. A 12-inch high target was positioned on the floor at the rear of the wheelchair bay to represent the target. A bracket was attached to each wheelchair so that it rolled along the floor behind the wheelchair. Each wheelchair user was asked to maneuver their wheelchair into the simulated wheelchair bay and then back up to position the bracket as close as possible to a target.

The wheelchair bay used for testing was 30 inches wide and 56 inches long, matching the dimensions of the Flxible buses used by Cleveland RTA. Different visual guidance patterns shown on Figure 3. were used on the floor of the simulated wheelchair bay to evaluate their effectiveness in helping position the wheelchair.

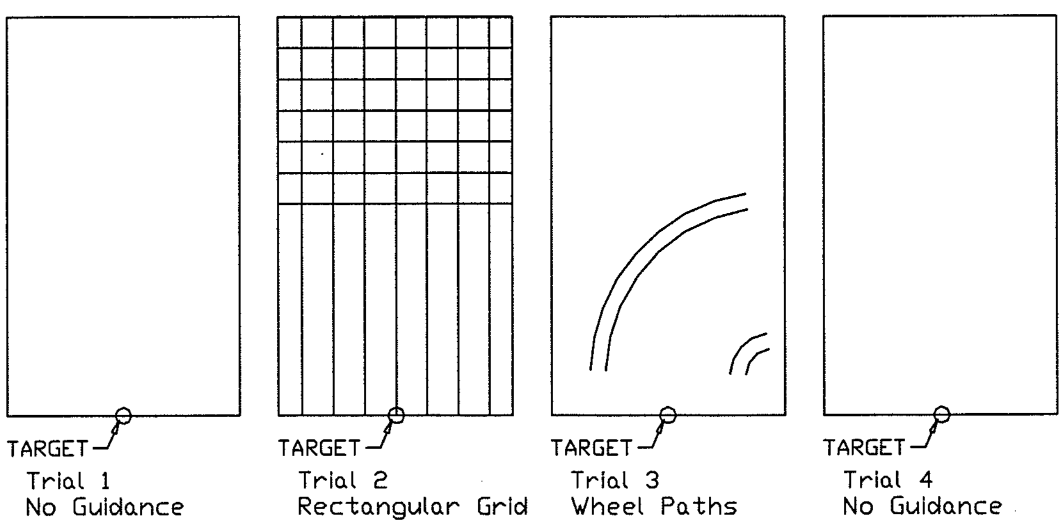

FIGURE 3 Floor patterns to assist with wheelchair positioning.

Each test subject completed the maneuver 4 times, using the floor patterns shown above. The performance difference between the first and last runs demonstrated the benefit of training.

The tests were videotaped by two cameras, providing an overhead and rear view of the bracket as it approached the target. Global Lab software was used to analyze the videotapes, and record the distance between the center of the bracket and the target, the angle between the bracket and the centerline of the wheelchair bay, and the overall time to position the wheelchair.

While there was significant variation among users in overall performance and the effectiveness of visual guidance, the users generally improved in accuracy, orientation, and time with each run, as shown in Table 3. The results indicated a consistent ability to reach the target in the wheelchair bay, and the motivation to travel and improve their accuracy with training. Thus, an occupant restraint requiring center positioning of the wheelchair or scooter in the bay is a reasonable and attainable objective for the design.

TABLE 3 Wheelchair Positioning Data

	No Guidance	Rectangular Grid	Entry Path	No Guidance
Final distance from the target (in.)	1.0 ± 1.0	0.7± 0.7	0.6± 0.6	0.5± 0.4
Final wheelchair angle (degrees)	11± 8	9± 8	11± 12	7± 7
Positioning time (sec.)	75± 50	70± 40	60± 35	50± 30

CONCEPT AND INNOVATION

DESIGN CRITERIA

Collectively, the input from the survey, human factors evaluations, and resource panel finalized the design criteria for developing the occupant restraint system, focusing on the needs of all the users involved. The summary of the design criteria is given below in Table 4.

INVESTIGATION

PROTOTYPE DESIGNS

During the project, the current occupant restraint design evolved through two earlier designs. Each of these three designs is described below to illustrate both the design process and the rationale leading to the final prototype design.

1. STANCHION -MOUNT DESIGN

This concept, shown in Figure 4, was developed and tested under previous TCRP funding (Project C-1) and its potential benefits were the catalyst for this project.

TABLE 4. Design Criteria for Restraint Prototypes

Criteria	Specifications
Attach / release time	1 minute
User independence	80 %
Tamper resistant	Cannot be made inoperable without tools
Durability	400 lb. vertical load
	Seals around opening
Components in passenger area	Permanently attached to vehicle structure
	Cannot block windows, normal seating, or aisles
	Store out of normal seating area
Components that touch person	Maintained off floor
Accessible components	15 - 60 inches above floor
	36 inches from rear of w/c bay
Mechanisms	Operable with whole hand function
	Operable with less than 40 lb. of grip
	Operable with less than 10 lb. force
Adjustments	Fit 5th to 95th %tile
	Compatible with a 5 wheelchair styles
Crash safety	Support sustained 5,000 lbs. forward load (FMVSS 210)
	Allow less than 375 mm of forward motion at the lap belt
	Support 1320 lb. lateral (5 g. lateral impact)

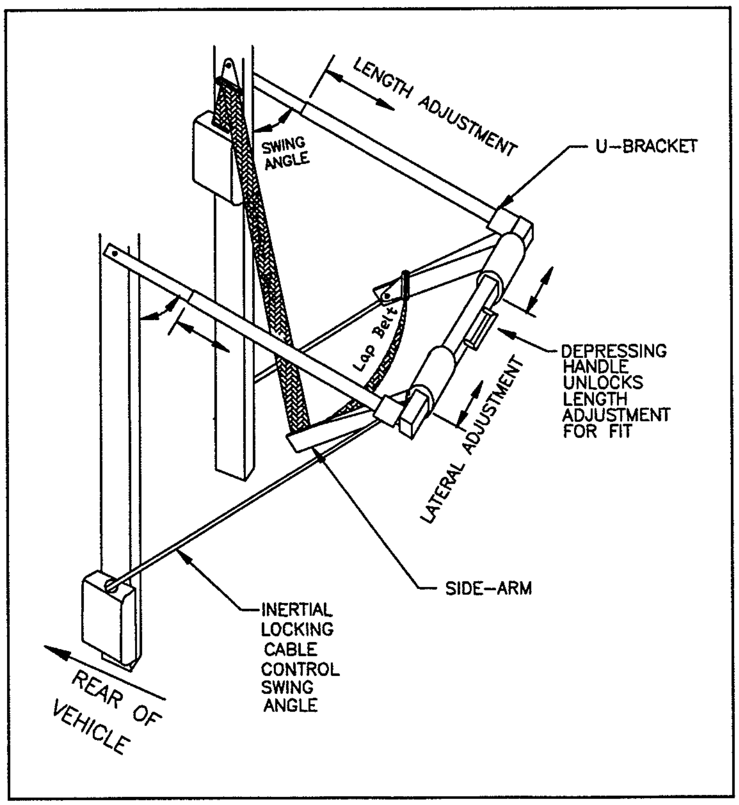

FIGURE 4 Stanchion Mounted Design

Design

Two vertical stanchions are mounted to the vehicle structure in the back of the wheelchair bay. A U-Bracket is mounted to the two stanchions, and pivots about a horizontal axis. The lap belt is anchored on two folding side-arms are attached to the base of the U-bracket. The side-arms have a limited amount of lateral motion, so that they can accommodate different size individuals and different wheelchair positions. The lateral resistance, however, is sufficient to limit the lateral motion of the wheelchair user. To assure the side-arms are correctly located for various seat heights and wheelchair positions, the length of the U-Bracket is adjustable. An internal locking mechanism is released by depressing a handle located on the front of the U-Bracket. When locked the mechanism will hold in excess of 5,000 lbs.

Another unique feature is that the shoulder belt is mounted to the structural stanchion, which is correctly located relative to the wheelchair seat. Nearly all other wheelchair occupant restraint systems rely on the vehicle side-wall for providing a structural member for mounting the shoulder belt, and these members are seldom in an appropriate location for optimal safety.

Operation

When a wheelchair user boards the bus and approaches the wheelchair bay, the vehicle operator will lift the U-Bracket and unfold the side-arms. The lap belt, anchored to the ends of the side-arms, will extend as the arms unfold. Once the wheelchair is in place, the U-Bracket is lowered, with each side arm sliding between the user's hips and the armrest of the wheelchair automatically positioning the lap belt against the user's pelvis and anchoring it near the hip joints for optimal protection. Once the lap belt has been correctly set, the stanchion-mounted shoulder belt can be attached to the lap belt similarly to many existing occupant restraint designs. During normal traveling, the U-Bracket may be lifted at any time, giving the feeling of freedom that is comparable to that provided by emergency locking retracting shoulder belts. During an impact or severe vehicle maneuver, however, the U-Bracket position is locked using a similar inertia responsive device.

When the system is not in use, the U-Bracket is stored in the down position, with the side-arms folded. In this position, the restraint system will not interfere with the use of the wheelchair bay for other seating.

Evaluation

This design demonstrated acceptable performance during 30 mph, 20-g sled impact testing based on performance criteria specified in recent ISO and SAE draft standards. It was also tested according to the test procedures for 5-g lateral impacts identified in the TRB *Guidelines for Wheelchair Securement and Occupant Restraint for Public Transit Applications.* Its performance during this test met the stated criteria, and appeared to be superior to that of traditional three-point restraint systems. The concept was presented to transit administrators, vehicle operators, and wheelchair users, through surveys, and the results suggested the need and desire for several changes to the original concept.

2. WALL- MOUNT DESIGN

The feedback received through the surveys are reflected in a less obtrusive design which deploys from a frame mounted along the vehicle side wall as shown in Figure 5.

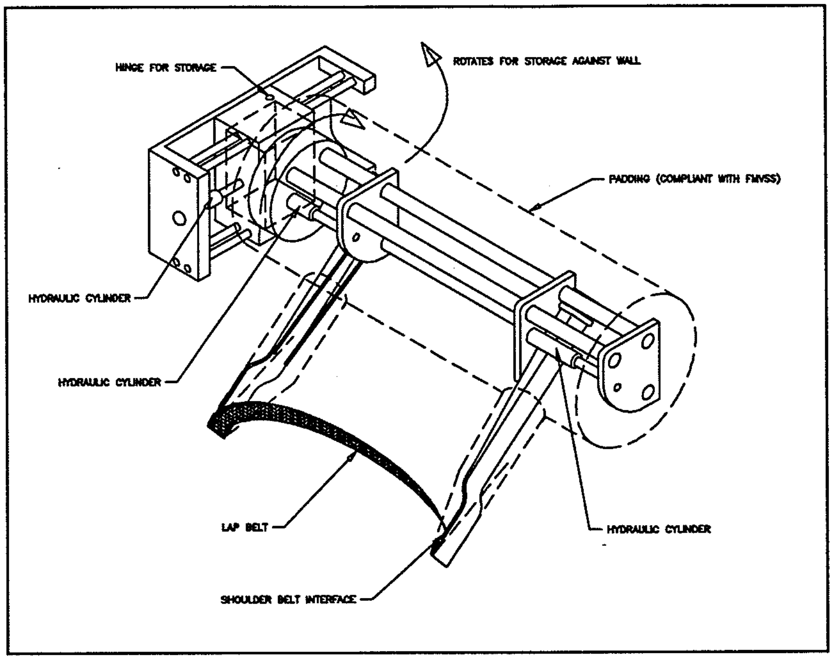

FIGURE 5 Wall-mounted restraint design

Design

The changes made from the stanchion-mount design, and the rationale for each is listed below.

1. The occupant restraint mounts to the vehicle wall rather than the floor.
   Rationale: All three surveys indicated a concern with the physical size and appearance of the original design. This new concept will eliminate any components near the aisle or in the foot space of passengers when not in use.
   The transit administrators indicated that they prefer a system that is integrated into the vehicle structure, thus allowing structural components to be built into the vehicle wall for supporting the occupant restraint.

2. The unit is stored by swinging it horizontally until it rests against the wall, just above any seats that may be in the area, and at the bottom of any windows on the wall.
   Rationale: There was a significant amount of concern that the original design could allow the device to fall down from the overhead stored position and injure a passenger. The new design keeps the device against the wall and low.

3. The occupant size adjustment will be forward/rearward, rather than rotating about a point near the occupant shoulder.
   Rationale: A human factors review of individuals seated in wheelchairs, indicates that the range of pelvic heights is less than the range in the location of safe lap belt anchorages.

4. Hydraulic dampers will restrict motion during an impact while allowing free adjustment. This replaces mechanical locks.
   Rationale: Hydraulic dampers will prevent rapid motion, as during vehicle impacts, but will allow slow motions, such as those needed to position the restraint device. This concept allows the user to feel unrestricted, while maintaining a rigid system when needed without cumbersome locking mechanisms.

5. The shoulder belt will be optional and anchored on a separate floor or wall mounted stanchion next to the vehicle wall.
   Rationale: The ADA mandates that shoulder belts be available for wheelchair users, (although the surveys indicate that they are seldom used). Since the rear mounted stanchions are no longer part of the design, a separate component may be needed to properly locate the shoulder belt. This requires a single stanchion, however, that can be mounted next to the wall where it will be out of the way. Shoulder belts from other system could be used and mounted with the procedures currently used by transit systems, with an appropriate interface on the lap belt anchorage of the revised occupant restraint system.

Operation

The individual in a wheelchair positions themselves facing forward in the wheelchair bay. They then reach forward, unlock the device, and swing it toward them until it latches (similar to a door latch needing no further action). The contoured lap belt arms are rotated down around the person's pelvis, automatically locating the lap belt correctly. The arms will fit between the person's pelvis and the sides or arm rests of the wheelchair.

When the device is not in use, the contoured arms that anchor the lap belt are rotated upward and are locked in place vertically. The entire arm is then rotated so that it rests above the seat backs at that bottom of the windows.

Evaluation

This design was presented to the resource panel and project collaborators. While it was widely agreed that this represented a major improvement and addressed the primary issue of appearance and safety, further revisions were suggested. The wall mount design was not feasible on the selected vehicle design due to the relative position of the window frame and the seat. To overcome the window to seat interference, the final panel-mount design was conceptualized with input from the transit vehicle designer, Mr. Lance Watt, formerly of Flxible Corp.

3. PANEL-MOUNT DESIGN

Design

Although a one-piece unit is desirable to minimize the amount of adjustments, the demands of a low profile identified during the evaluation of the stanchion mounted prototype, and the vehicle structure identified during the evaluation of the wall-mounted prototype, required a two-piece solution. This design, schematically shown in Figure 6 uses two independent rails that are mounted to the panel behind the wheelchair. This panel matches the geometry of the wheelchair barrier that is currently used on buses.

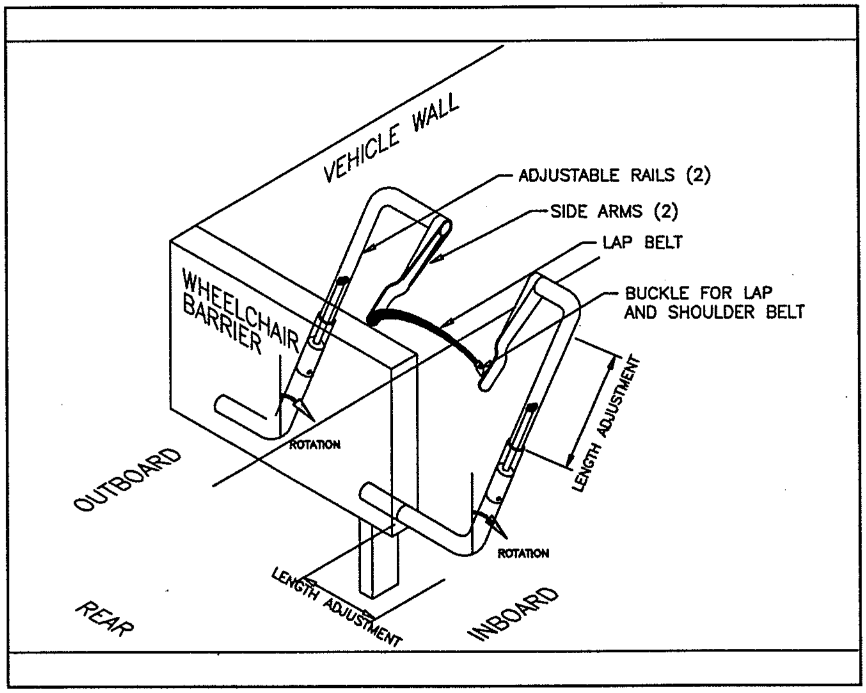

FIGURE 6 Panel Mounted Design

Mechlok™ devices (P.L. Porter, Inc.) with a 12-inch stroke were found to meet the design requirements and were selected to control the length adjustments and horizontal position. These are sliding mechanisms that are normally locked, but can be temporarily released using reliable Bowden (Bicycle brake) cable systems The locking mechanisms can withstand in excess of 2200 lb. each, and two can be controlled simultaneously with a single lever supplied by the manufacturer. Rotational control of the rails are controlled by two retracting belts (not shown) mounted on the panel and fastened to center of each rail.

To facilitate easy assembly, adjustment, and access, a preliminary prototype with an open rectangular frame was developed rather than the more aesthetic round frame shown in the concept picture. This model demonstrated that the range of adjustments was adequate and a final design incorporating enclosed tubes was constructed through a sub-contract with Cleveland State University.

Operation

Since the wall side rail is not width adjustable, the wheelchair user must position the wheelchair so that the side-arm will fit between their hip and the arm-rest of the wheelchair. The human factors data has demonstrated that many wheelchair users can achieve this, while others will need assistance. Once the wheelchair is positioned, each rail is raised from its vertical stored orientation (Figure 7a), and positioned with the lap belt anchorage next to the user's hip. When the release lever is squeezed on the underside of the rail (Figure 7b), all adjustments are unlocked for easy positioning. Once the lever is released, all adjustments are locked and the lap belt anchorages will remain in place. (Figure 7c).

FIGURE 7a Restraint system stowed.

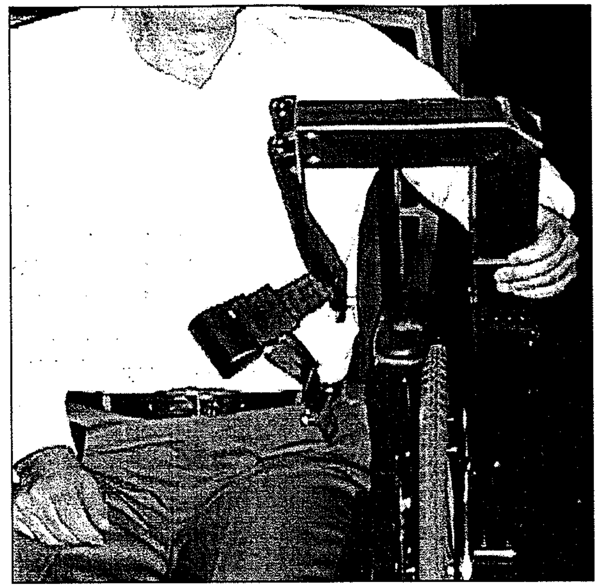

FIGURE 7b User adjusting the restraint.

FIGURE 7c Restraint system in place.

Evaluation

The prototype was mounted on a GCRTA bus in place of the usual wheelchair barrier. Measurements were made regarding geometric fit within the bus interior. Three individuals then used the system while seated in a manual wheelchair. The following observations were made during the evaluation of the prototype on-board the vehicle.

1. The centerline of the panel is approximately 1 inch to the rear of the centerline of the current wheelchair barrier. This is caused by a uniform panel width whereas the current wheelchair barrier is contoured to better match the geometry of the side-mounted seat in the wheelchair bay.
2. Knee clearance behind the panel was 10-1/2 inches compared to 11-1/2 inches for other seats on the bus.
3. Able-bodied individuals seated in a wheelchair were able to operate the restraint without needing assistance.
4. The lap belt anchorages were placed correctly relative to the users' hips.
5. Operation of the retracting lap belt was confusing for a user who was not familiar with its design
6. The lower portion of the rails needs to be stiffened.

CONTROLLED ENVIRONMENT USER FIELD TRIALS

The restraint system was field tested with a selected group of disabled individuals living in a accessible housing complex. The restraint system was installed on a Greater Cleveland RTA fixed route 44 ft. vehicle under the direction of Mr. Anthony Russo, General Manager of Garages. The vehicle was brought to the complex and the residents asked to try the system on the parked vehicle (Figures 8a, 8b). Five residents provided opinion and user feed back of the operation and functional characteristics of the prototype. The disabilities represented were minimal to severe including paraplegia, multiple sclerosis and quadriplegia. There were one male and four female subjects, all of them experienced users of fixed route and paratransit service on their manual and powered wheelchairs.

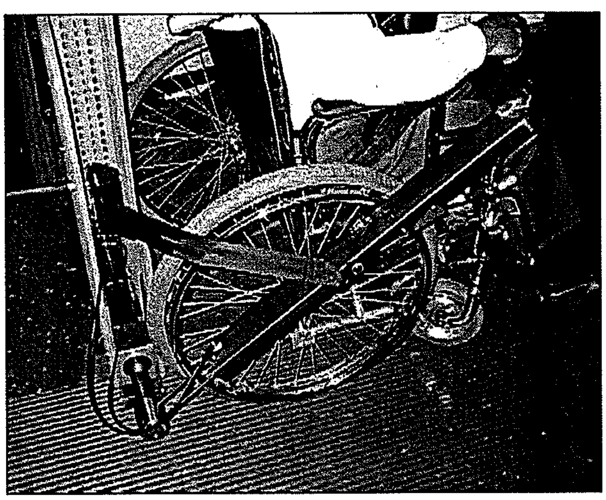

FIGURE 8a View of the restraint from the side.

Figure 8b. Front view of the restraint in use.

Their system evaluation focused on handling and applying the restraint system by responding to specific questions. Their answers are summarized below:

4/5 could reach the restraint system easily.
3/5 could remove it from storage with difficulty.
1/5 could position the lap belt next to their hip.

3/5 allowed the belt to be positioned and fastened next to their hip.
4/5 felt comfortable with the belt fastened.
2/3 indicated willingness to use the system during normal travel.

The evaluators were also asked for their comments about the comparative value of the restraint system relative to floor mounted lap belts. On the questionnaire used for data collection all evaluators indicated not usually applying lap belt attached to the floor, suggesting the dislike for this mode of personal restraint. Concerning the experimental prototype system, 2/5 reported satisfaction, expressed as easier use and enhanced sense of security from the side arms. Furthermore, 3/5 preferred the prototype and only 1/5 preferred the floor mounted belts more than the prototype.

When asked about suggestions for improvements the following list was generated:

Hand clearance (3 in.) lateral to the wall-side arm.
Greater length variation (2 in.) to clear back of wheelchair.
Different geometry of belt anchor locations for users with wider hips than the wheelchair seat (2/5).
Softer anchor locations to prevent pressure problems.
Guidance for positioning wheelchair.

Overall the limited user evaluation was surprisingly favorable despite the bulky design and the unfinished nature of the prototype. These results thus suggest a general acceptance of the principles of the prototype design, a dissatisfaction with the current lap belt system and the need for further improvements in the operational characteristics of the prototype system.

STATIC PULL TEST

The final evaluation of the prototype panel mounted system was conducted at the NASA-John H. Glenn Research Center, Cleveland, Ohio in the laboratory of Dr. Anthony Calomino. The static pull-test was conducted using a newly modified hydraulic servo-system in accordance with the Federal Motor Vehicle Safety Standard for seat belt anchorages (FMVSS-210). In a splendid collaboration Dr. Calomino and his colleagues made this equipment available and assisted the project to complete the pull-test.

The test was conducted using the same prototype restraint which was evaluated by wheelchair users on the Greater Cleveland RTA bus. The prototype was mounted on a reinforced platform including the modified wheelchair barrier, adjustable rails, side arm and lap belt. Prior to installation the adjustable rails were redesigned and a four bar cage construction implemented for higher bending and torque resistance. A commercial manual drive folding wheelchair with reinforced seat and pneumatic tires was placed on the platform in the forward facing position similar to the wheelchair position on a moving vehicle. A body block loading gauge, compatible to the FMVSS-210 requirement was placed on the wheelchair seat cushion. A loading ram was attached to the body block connecting it to the hydraulic servo with 18" displacement and placed in series with a 5000 lbs. load cell to record the applied load as a function of time. On a lateral view, the resulting displacement of the body block was also recorded on video tape for later analysis and correlation with the applied load. The components and the orientation of the experiment instruments are shown on Figure 9 and 10.

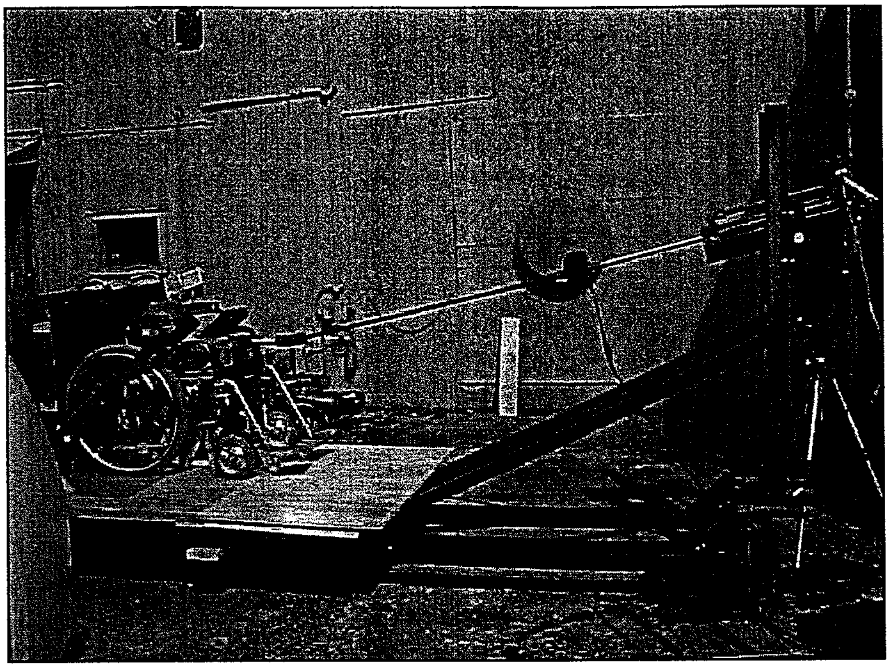

FIGURE 9 Pull-test platform and hydraulic servo.

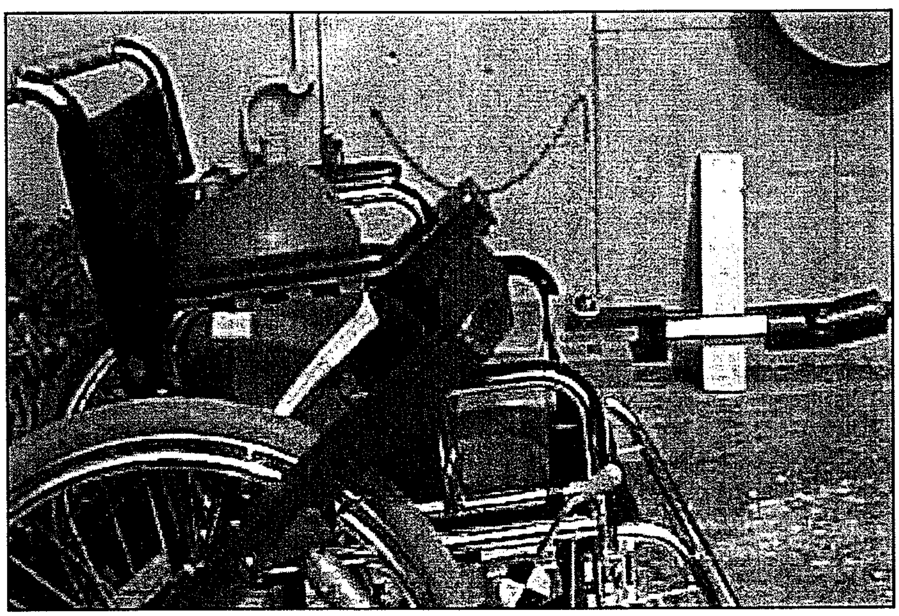

FIGURE 10 Side view of restraint on body block in wheelchair.

The load application commenced and continued for 19 sec to reach a maximum of 2300 lbs. During the first half of this time the restraint lap belt held the body block steady with slight displacement (<2 in). At a load of about 2000 lbs the right side arm began to yield in bending and the body block displacement advanced until near 2300 lbs. of load, a faulty weld, connecting the left side arm and adjustable rail, fractured. The forward motion of the body block is shown on Figure 11 as a function of time of the applied load. The applied load as a function of displacement of the body block is shown on Figure 12.

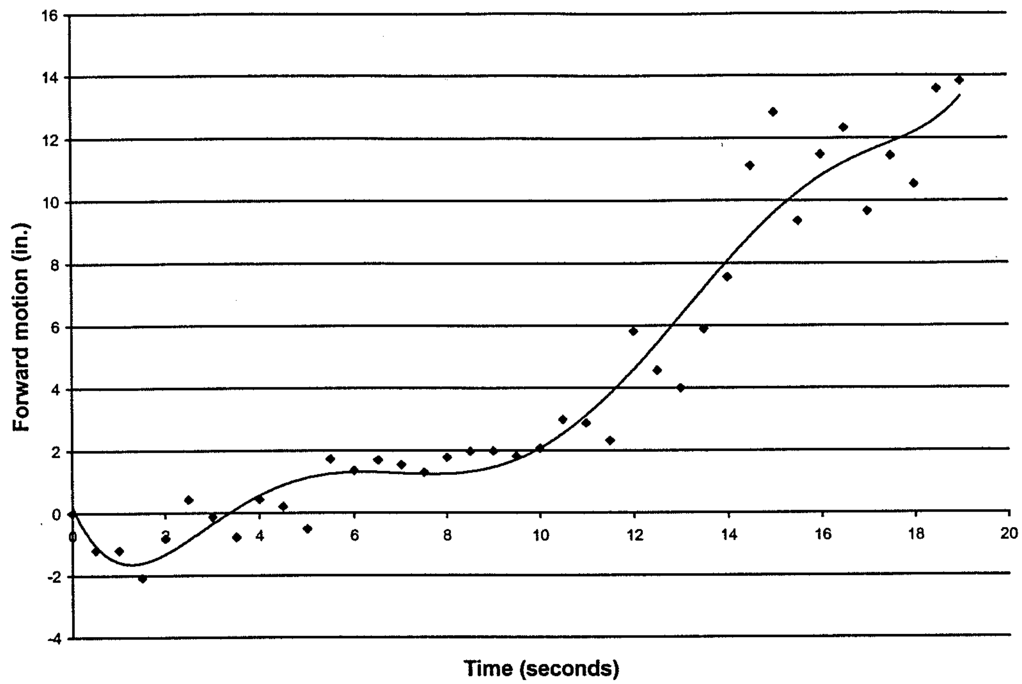

FIGURE 11 Body block motion in FMVSS 210 pull-test.

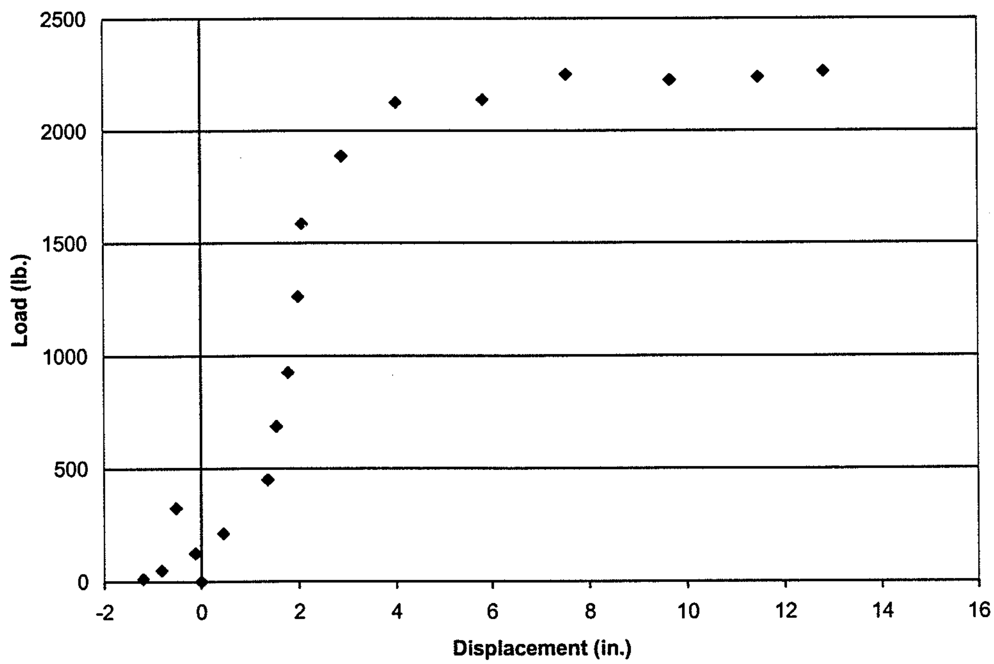

Figure 12. Body block load-displacement in FMVSS 210 pull-test

The plots indicated the beginning of the side arm yield at 2000 lbs. and 3 in. of displacement at approximately 12 sec into the test with weld failure occurring at 2300 lbs. and 13 in. of displacement.

There was no other yield or failure noted at the end of the experiment in other parts of the test assembly. The Mechlock™ devices (P.L. Porter, Inc.), lap belt and the stiffened adjustable rails held well during this test.

The bending yield and failure of the side arms however was surprising and unexpected since the same components had been previously tested and passed much higher loads in 20g and 30mph impact simulation. Below is an attempt to describe the differences in the earlier and the current experiments and analyze the results.

The previous prototype of the occupant restraint system anchored the lap belt to contoured side arms which were mounted on a cross-bar in front of the occupant. The side arms were inserted between the test dummy pelvis and the wheelchair armrests. This prototype was successfully crash tested using the SAE surrogate wheelchair with a width between the armrests of 14 inches. The cross bar and rigid wheelchair frame assured that the side arms were held tightly against the dummy occupant pelvis and the lap belt was parallel to the side arms at the anchorage location. The lap belt tension was therefore applied in line with the side arms.

The prototype developed during this current project anchored the lap belt to the same side arms used in the previous crash test, but the side arms were mounted to the ends of independent adjustable rails on either side of the wheelchair. This configuration was much more acceptable to the wheelchair users than the previous design using the crossbar. The pull-test executed during this project used a commercial wheelchair with armrests 19-1/2 inches apart. The extra wheelchair width allowed the side arms to be displaced from the occupant pelvis. The resulting gap noted on Figure 13 between the lap belt anchorage and pelvis allowed for a slight angle between the lap belt and side arm.

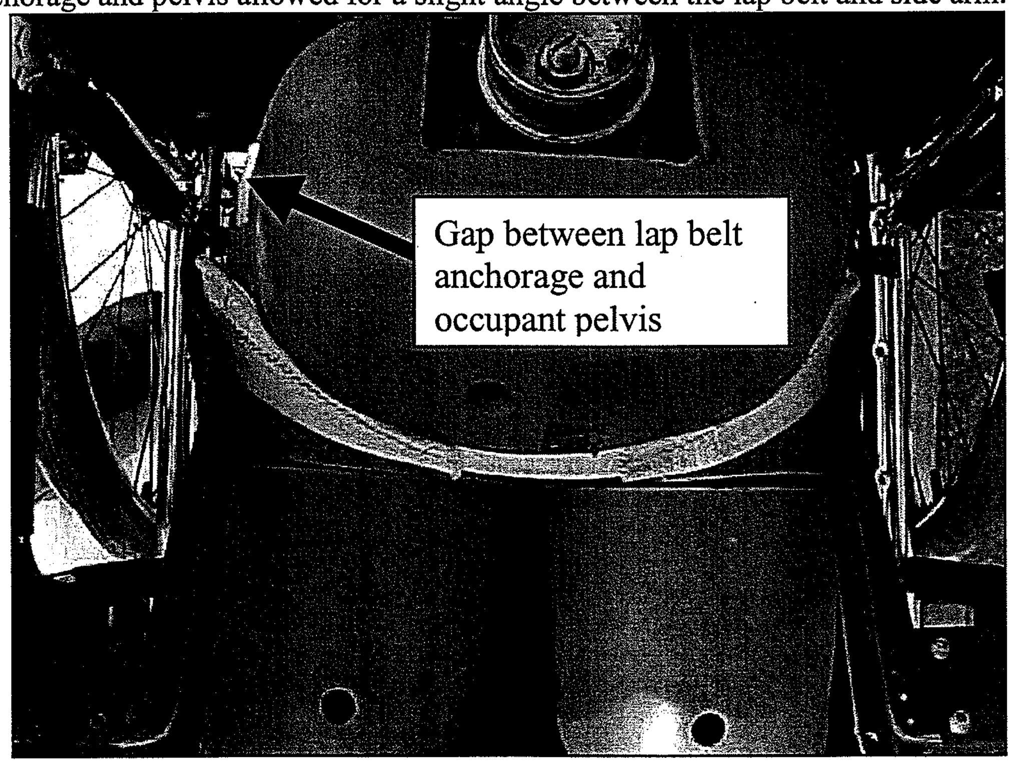

FIGURE 13 Top view of body block on wheelchair seat.
Note the difference in the fit of the belt anchorage on the left and right.

As the pull force was applied to the body block, the lap belt tension developed and a bending moment was applied to the side arm due to the angle between the belt and the side arm. This bending moment was not possible in the previous crash testing, because the tight fitting seat kept the lap belt parallel to the side-arms, but the looser fit led to bending yield and failure in this pull-test.

In summary, the panel mounted restraint prototype was able to carry nearly half of the FMVSS-210 recommended target load, displacement and duration. Early failure, however, did not occur in the concept of the design but rather was due to a faulty welding and lack of accommodation to the commercial size of the wheelchair.

SUMMARY

Traveler protection during transit and vehicle impact is the primary objective of occupant restraint design including occupant restraints of wheelchair using travelers in transit vehicles. The objective of this project was to develop and evaluate new occupant restraint design concepts with focus on minimizing the efforts to operate the system without sacrifice of the crash protection of the wheelchair traveler.

The investigation started with the formation of the design criteria based on multiple inputs from a resource panel of experts, the existing TRB guidelines, wheelchair users, transit administrators, vehicle operators, human factors testing of wheelchair using travelers and an experienced public transit vehicle designer.

A survey was developed and disseminated to administrators at 12 transit authorities throughout the country and vehicle operators involved with transportation of wheelchair users. Overall the surveys indicated conflicting information on priorities of safety, lack of use of lap and shoulder belts, fastening time between fixed route and paratransit application and the need for alternatives to the existing occupant restraint designs. New design criteria was indicated for restraints to be used independently and rapidly by many wheelchair users with reduction of stop dwell time and driver involvement. The human factors testing established anthropometric envelopes of wheelchair seated posture, reach, hand strength and the functional ability for wheelchair positioning by the occupants.

The design criteria from all these inputs were finalized and presented in Table 5. The criteria established specifications for activation time, user independence, durability, component locations, operating hand function requirement, body size accommodations and crash safety in terms of load and deflection parameters.

Using the design criteria, three conceptual models of wheelchair occupant restraint systems were developed and investigated. The early concepts of the Stanchion-mount and the Wall-mount designs were evaluated and not implemented because of potential user indicated undesired obtrusive bulkiness for the first and because of vehicle structural design incompatibility for the second. In previous sled impact testing (30 mph, 20-g) and 5-g lateral impact simulation the Stanchion-mount design performed well and appeared to be superior to the three point belt restraints.

The final Panel-mount design was developed and improved and a full scale prototype was built for limited user tests and strength evaluation. To minimize costs and to enhance commercial appeal an effort was made for a simple design with off the shelf components and cost effective tolerances. The prototype was installed in a 44 foot in-service vehicle at the Greater Cleveland RTA and was driven to wheelchair users for hands on trial.

The limited field trial in the non-moving vehicle by experienced wheelchair travelers pointed out a general acceptance of the principles of the prototype design, a dissatisfaction with the current lap belt system and a need for further improvements in slimmer design and in the operation of the panel mounted restraint design.

The final evaluation of the prototype restraint system was a static pull test to determine compliance with the FMVSS-210 for seat belt anchorages. This test was performed at the NASA-John H. Glenn Research Center in Cleveland, Ohio. The test results, partially successful, indicated the ability of the restraint prototype to carry nearly half of the 5000 lbs. of target load, displacement and duration. Reassuring was that the early failure did not occur in the design concept but was due to a faulty welding and the incorrect accommodation of the belt anchor to the commercial wheelchair.

CONCLUSIONS

This project attempted to satisfy many sets of criteria. Conflicts between these criteria have thus far prevented developing a commercially feasible system. A structurally acceptable safe system, compatible with the existing vehicle structure was found to be aesthetically unacceptable by transit personnel and wheelchair users. A revised wall-mounted system developed to overcome this objection, however, was not compatible with current vehicle designs. The final design was well accepted by wheelchair users and transit personnel, was compatible with the vehicle structure, but its design was too sensitive to occupant positioning to withstand the high impact loads required by current regulations.

The potential benefits to transit practice from this project arise from the surveys of transit administrators, fixed route and paratransit operators indicating conflicting understanding of crash safety and belt restraint use. This data reinforces the critical need for a nationwide educational effort to inform providers of the importance of properly positioned lap and shoulder belts for wheelchair traveler crash safety. The project has also demonstrated the need to reduce operator assistance and enhance rapid user application of restraint system and therefore reduce stop dwell time and improve operational efficiency. Finally the project established and tested with partial success a design criteria for restraint prototypes for transit application.

PLANS FOR IMPLEMENTATION

The successful development of a safe, easy to use, and universal occupant restraint system for wheelchair users will require a cooperative effort among vehicle manufacturers, wheelchair users, transit personnel, and regulatory groups to reach a consensus on realistic design criteria.

The investigators will continue the development and improvement of the prototype system and locate effective collaborative efforts for the implementation as further funding support become available. This project has brought together representatives of all these groups from District of Columbia, Illinois, Kentucky, Ohio and Pennsylvania and initiated the needed collaborative effort.

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