A SEATBELT DEPLOYMENT SYSTEM FOR DRIVERS SEATED IN WHEELCHAIRS

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ABSTRACT

A seatbelt deployment system (SBDS) has been developed for use by drivers seated in wheelchairs and was successfully evaluated in three 48-kph frontal-impact tests. Drivers seated in wheelchairs typically use the lap/shoulder portion of the original vehicle seatbelt with an aftermarket cable-mounted seatbelt buckle receptacle installed on the inboard side of the driver space because the original buckle receptacle is removed with the vehicle seat. This aftermarket buckle receptacle often obstructs the driver from easily maneuvering his/her wheelchair into the driver area. With the SBDS, the buckle receptacle is attached to belt webbing that spools out from a seatbelt retractor mounted to the end of a motor-driven forward-anchored pivoting arm, thereby allowing unobstructed wheelchair access to the driver space. The SBDS requires minimal action and dexterity from the driver, and results in proper seatbelt fit when the driver is using a wheelchair with armrests that are open at the front.

BACKGROUND

To provide motor-vehicle occupants with a high level of crash protection, a properly fitted lap/shoulder belt is required [1]. Wheelchair users who cannot easily transfer to vehicle seats require customized after-market solutions to ensure that seatbelts can be properly used.

In a previous in-vehicle measurement study of drivers seated in their wheelchairs, 15 of 19 participants had either poor lap/shoulder belt fit or did not use a seatbelt [2]. Lap belts that are positioned near the top of the pelvis or over the abdomen increase the risk of abdominal and lumbar-spine injuries in moderate to severe frontal crashes, and shoulder belts that are not in contact with the occupant's shoulder and chest at the time of a crash will lead to increased risk of chest injuries from seatbelt loading [3]. Proper seatbelt fit also requires that the lap and shoulder belts connect near the driver's hip. In some cases, poor seatbelt fit is caused by interference with wheelchair components, but in other cases it is caused by the difficulties posed by donning the seatbelt.

Since the van-modification process requires the original driver seat to be removed and the receptacle half of most vehicle seatbelts is anchored to the seat, removal of the driver seat results in removal of the buckle receptacle. Most vehicle modifiers install a buckle receptacle attached to the top of a stiff cable stalk for use with the vehicle lap/shoulder belt. When positioned to allow for proper lap-belt side-view angles between 45 and 75 degrees from the horizontal, the cable stalk presents an obstacle to maneuvering the wheelchair in and out of the driver space.

In the previous study of wheelchair-seated drivers, 10 participants used an "active" seatbelt that requires buckling/unbuckling and many of these drivers had significant difficulty donning their seatbelt [4]. Drivers cited difficulty reaching and buckling/unbuckling as the primary reason not using a seatbelt [4].

DESIGN REQUIREMENTS

To provide wheelchair-seated drivers with a reasonable level of crash protection and independence, a seatbelt system that results in proper seatbelt fit with minimal driver action and dexterity is needed. Ideally, this seatbelt will not interfere with the driver's ability to maneuver his/her wheelchair in and out of the driver space and it must also provide for easy manual release in an emergency. This seatbelt system should be compatible with all vehicles that are commonly modified for use by people who drive while seated in a wheelchair. It should also be compatible with common wheelchair models and seating systems.

DESCRIPTION OF SBDS

The primary component of the SBDS is a pivoting arm (Figure 1A) that is rotated by a gear-reduced DC motor mounted to the vehicle floor near the dashboard to the right of the driver space. The length of the pivoting arm is customized to each wheelchair driver to locate the inboard lap-belt anchor point to achieve a

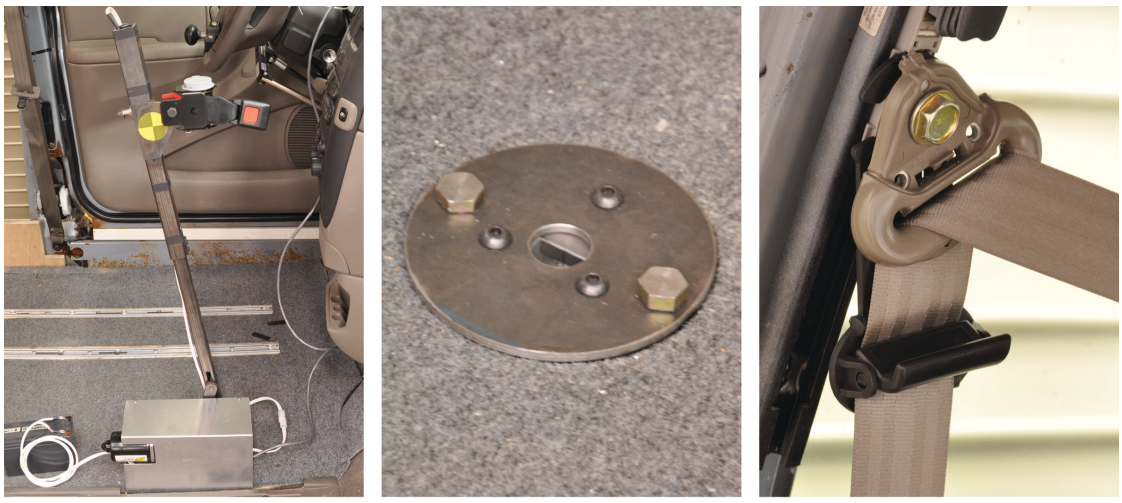
preferred lap-belt angle between 45 and 75 degrees from horizontal when used and to hold the belt above the driver's thighs and below the wheelchair armrests when the arm is in the up (stored) position. A buckle receptacle is attached to a length of webbing spooled onto a webbing-sensitive emergency-locking retractor (ELR) mounted to the end of the pivoting arm. The vehicle seatbelt is always connected to this buckle receptacle, but can be disconnected in case of emergencies. In the up position, the ELR removes seatbelt slack so that the belt webbing doesn't sag into the driver space. When the arm rotates down, the retractor pays out belt webbing leaving the buckle receptacle and the lap/shoulder-belt junction near the center of the driver's right hip.

An anchorage pocket (Figure 1B) is installed in the vehicle floor at the desired inboard seatbelt anchor point so that the pocket surface is flush with the floor surface. When the pivoting arm is in the down (locked) position, a spring-loaded plate in the anchorage pocket engages a slot in a hardened steel pin located on the end of the arm, locking the arm into the floor. A solenoid on the pivoting arm can be actuated to rotate the pin, which pushes the spring-loaded plate out of the way, releasing the arm.

The system also uses a locking clip (Figure 1C) attached to the original vehicle seatbelt webbing at the shoulder-belt D-ring on the vehicle pillar near the driver's left shoulder (B-pillar). The locking clip is adjusted on the vehicle seatbelt so the belt webbing is always spooled out to a length that positions the buckle receptacle on the ELR at the end of the pivoting arm at the driver's right hip when the SBDS is fully deployed. This allows the lap belt to be positioned low on the driver's pelvis and the junction of the lap belt and shoulder belt to be near the driver's right hip, thereby reducing the likelihood of abdominal injuries from seatbelt loading in frontal crashes.

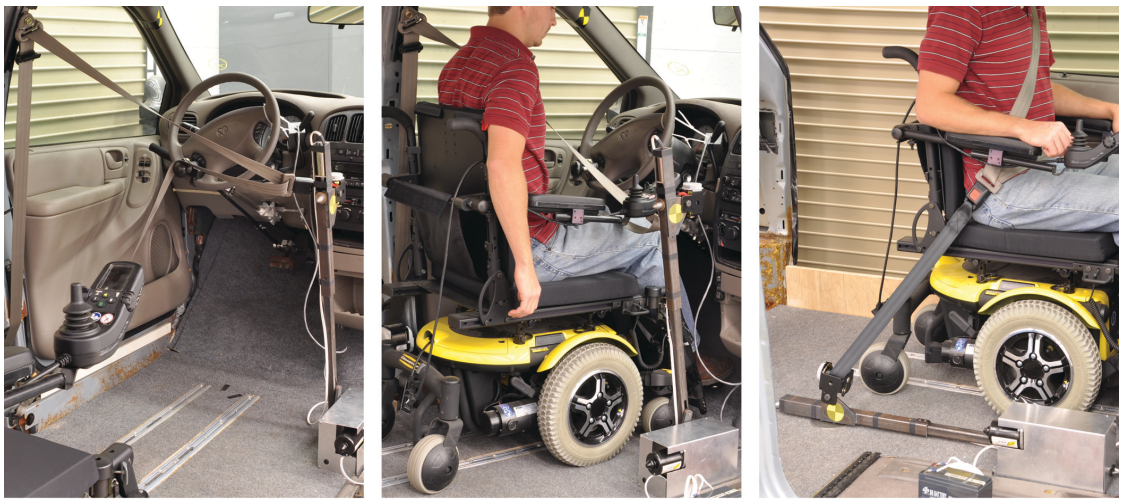
Using the SBDS

When the pivoting arm is in the up position, the vehicle seatbelt is spooled out and draped over an assistive steering device attached to the steering-wheel rim (Figure 2A). Once in position, the driver easily lifts the seatbelt off of the steering assistive device and places it over his/her thighs. The driver then presses a button to activate the motor and slowly rotate the pivoting arm down until it locks into the floor anchorage pocket. As the arm is rotating down, the vehicle seatbelt is held in the extended position by the locking clip and the retractor at



A B C

Figure 1: Photos of the three key components of the seatbelt deployment system: (A) the pivoting arm, (B) the floor anchorage pocket that engages an anchorage pin at the end of the arm, and (C) the vehicle seatbelt locking clip that keeps the seatbelt spooled out to a specified length for each driver to achieve proper seatbelt fit.



A B C

Figure 2: Photos of the wheelchair-driver seatbelt deployment system with the pivoting arm in the up position (A), with a wheelchair-seated driver after maneuvering into the driving position (B), and with the pivoting arm in the down and locked position (C).

the end of the arm pays out the belt webbing. In the down (locked) position, a limit switch stops the motor and movement of the arm.

With the arm in the down position (Figure 2C), the shoulder belt crosses the driver's left shoulder and travels under the right wheelchair armrest to the buckle receptacle near the driver's right hip. The lap belt runs from the ELR retractor on the pivoting arm to the buckle receptacle near the driver's right hip, under the right armrest, across the driver's lower pelvis, under the left armrest, and to the vehicle anchor point near the base of the vehicle B-pillar (near the driver's left shoulder).

After the driver presses the pin-release button to activate the solenoid that rotates and releases the anchorage pin from the floor anchorage pocket, he/she presses another button to activate the motor and slowly rotate the pivoting arm up. The driver then drapes the lap belt on the steering assistive device before exiting the driver space so that the seatbelt is ready for future use.

Belt fit with the new seatbelt deployment system is optimized for wheelchair armrests that are open at the front so good lap belt fit to the pelvis is not impeded by armrest hardware. While drivers in wheelchairs with closed-ended armrests can use the SBDS, achieving good lap-belt positioning is more difficult.

Crash-Test Evaluation of the SBDS

The crashworthiness performance of the prototype SBDS has been evaluated using different vehicle seatbelts in three 48-kph, 20-*g* frontal-impact sled tests. These tests were conducted in accordance with Appendix A of SAE J2249, *Wheelchair Tiedown and Occupant Restraint Systems for Use in Motor Vehicles* [5] but with the crash-test dummy seated in a 47-kg surrogate wheelchair base and surrogate seating system secured by a surrogate docking securement system instead of the 85-kg surrogate wheelchair. Table 1 compares the crash-dummy peak forward head and knee excursions measured from high-speed side-view videos to the excursion limits allowed in SAE J2249. With the exception of forward head excursion in Test #2 caused by excessive spool-out of the belt at the vehicle retractor

Table 1: Crash-Dummy Head and Knee Excursions Compared to Excursion Limits Allowed by SAE J2249.

	Vehicle Seatbelt Used	**Head Excur. (mm)**	**Knee Excur. (mm)**
SAE J2249 Limits		650	375
Test #1	Surrogate	391	308
Test #2	Vehicle Manufacturer	**666**	309
Test #3	After-Market Commercial	588	333

and a low-force (3kN) load limiter, all forward excursions are within SAE J2249 allowed limits. In addition, there were no failures of SBDS hardware in any of the tests.

DISCUSSION AND CONCLUSIONS

A new SBDS has been developed to improve lap/shoulder belt usage and performance for people who drive while seated in their wheelchairs. A key feature of the SBDS is elimination of seatbelt anchorage components that interfere with maneuvering wheelchairs into the driver space. In addition, the SBDS can be easily customized to optimize seatbelt fit to different drivers in different vehicles. However, achieving proper seatbelt fit is also highly dependent on the type of wheelchair armrests and it is strongly recommended that people who drive while seated in a wheelchair use armrests that are open at the front.

The high head excursions in Test #2 with the vehicle-manufacturer seatbelt point out a concern about unnecessary deactivation of driver airbags for people who drive while seated in wheelchairs. Airbags are frequently deactivated out of concern that steering assistive devices on the steering-wheel rim will interfere with airbag deployment. However, a study by Shaw et al. showed that these devices do not obstruct airbag deployment and are not a reason for deactivating the airbag [6]. In this regard, most driver seatbelts in late-model vehicles employ belt load limiters that reduce forces on the occupant's chest. However, these load limiters are designed to work in conjunction with steering-wheel airbags because they allow higher forward head excursions as occurred in Test #2. It is therefore important not to deactivate the steering-wheel airbag unless the driver is positioned so close (i.e., less than 23 cm) to the steering wheel and airbag module that the energy of the deploying airbag could cause serious chest or cervical-spine injuries.

Future efforts will be aimed at developing a smaller and more user-friendly version of the SBDS. This will involve conducting user evaluations of the SBDS.

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