III. Basic Principles of Occupant Protection

As indicated above, much of SAE J2249 is based on ensuring that the design of the WTORS adheres to some basic principles of occupant protection. For the most part, these principles are based on the simple fact that most serious injuries in a vehicle crash are due to:

- the occupant moving into and contacting interior vehicle structures,
- the occupant being ejected and contacting structures outside of the vehicle, or to
- the high restraint forces being applied to soft tissues rather than bony structures such as the pelvis and shoulders.

Thus, effective occupant protection requires effective occupant restraint which is best accomplished by:

- insuring that the vehicle seat (i.e., the wheelchair) is secured independently and effectively to the vehicle,
- using both upper and lower torso restraints to minimize lower and upper body excursions,
- applying restraint forces to bony regions of the body, such as the pelvis, shoulder, and chest,
- orienting occupants facing forward, and
- providing adequate clear space and energy absorbing vehicle interiors.

Causes of Injury and The Need for Occupant Restraint

For occupants in personal vehicles, effective restraint is provided by the vehicle manufacturer's three-point belt restraint system and the vehicle seat that work together to control occupant kinematics and allow the occupant to “ride down” the vehicle impact deceleration. For front-seat occupants, airbags now offer additional restraint and protection for adults, particularly to the head and chest of belt-restrained occupants in a frontal crash. For small children and infants, there is a variety of forward-facing and rearward-facing child safety seats that, if used correctly, offer a high level of protection in vehicle crashes.

Today, few if any wheelchairs have been designed for use as seats in motor vehicles. Therefore, effective occupant protection can usually be accomplished best if the wheelchair occupant transfers to the vehicle seat and uses the OEM's restraint system. The wheelchair can then be stored and secured more easily with effective tiedown hardware and procedures. For example, it may be possible to transfer small children to one of many types of child restraint seats (CRSs) that comply with FMVSS 213.

There are, however, many adults and children with disabilities for whom transfer is not practical or acceptable because of their size and/or types and degrees of disabilities. For these individuals, the wheelchair must serve as the vehicle seat, and the typical occupant restraint system intended for use by an occupant in the vehicle seat usually cannot be effectively utilized. In addition, the wheelchair must be secured to the vehicle so that it does not move in a crash and impose forces on the occupant and/or become a hazard to other vehicle occupants in a collision or sudden vehicle maneuver. Thus, for people in wheelchairs, an effective after-market occupant protection system must provide both wheelchair securement and occupant restraint - i.e**., it must be a wheelchair tiedown and occupant restraint system, or WTORS.**

Secure the Wheelchair Independent of the Occupant But not Visa Versa

As indicated in the previous section, one basic principle of crashworthiness design is to not allow the mass of the vehicle seat to increase the restraint forces applied to the occupant during a crash. Adhering to this principle is particularly important, but also problematic, for the person in a wheelchair, since the wheelchair has been designed to be mobile and can often weigh more than 200 lb (91 kg). The principle implies that the wheelchair must be effectively secured with limited movement during a crash. Also, the wheelchair must not tip over, collapse, or break-apart in a manner that could injure the user or other vehicle occupants. It also means that the wheelchair tiedown system should secure the wheelchair independent from the occupant. That is, ***the same belts or other devices should not be used to both secure the wheelchair and restrain the occupant***, so that the forces used to secure the wheelchair are not imposed on, and through, the occupant's body. Unfortunately, there are still securement devices in use that function in this manner.

While it important to secure the wheelchair independent of the occupant, this does not mean that the occupant should be restrained independent of the wheelchair. In fact, the opposite situation, where occupant restraints (i.e., the lap belts and the lower anchorage of the shoulder belt) are anchored to the wheelchair or to the tiedown components as near to the hip of the occupant as possible, is preferred. While this **integrated** configuration for the occupant restraint and wheelchair tiedown will produce higher forces on the vehicle anchor points for wheelchair tiedown, and on the tiedown system, dynamic testing has demonstrated that such forces can be effectively managed with reasonable hardware and components. More importantly, the integrated occupant restraint approach offers enhanced occupant protection by improving the fit of the occupant restraints to the wheelchair occupant, by reducing the potential for submarining under the pelvic belt, and by eliminating the possibility of the wheelchair mass adding to the forces applied to the occupant. The use of integrated occupant restraints also reduces the level of intrusion into the occupant’s personal space required during placement of the occupant restraint system on a wheelchair-seated passenger. Also, integrated occupant restraints offer the potential for a higher level of independent use of the restraint system by the wheelchair occupant.

Provide Upper and Lower Torso Restraint

Since the purpose of an occupant restraint system is to minimize, and ideally prevent, contact of the occupant's body with vehicle interior structures, both upper and lower torso restraints are required to reduce knee, chest, and head excursions in a crash environment. While a properly positioned pelvic belt alone will generally prevent an occupant from being ejected from the vehicle or from being thrown about inside, the torso will still flex forward in a frontal crash, allowing the chest and head to undergo relatively large excursions, increasing the likelihood of impact with vehicle interior components, or with other nearby occupants and wheelchairs. For wheelchair-seated occupants who lack upper torso and arm strength, this can be a problem even in low level impacts or emergency braking.

For small children, the optimal restraint system is a four- or five-point harness that is integrated into, and securely attached to, the seat frame of the wheelchair, as is done in child restraint systems. Recently, several wheelchair manufacturers have implemented harness restraints into wheelchairs designed for smaller children for whom the body mass and resulting occupant restraint forces are relatively low. However, this approach is generally not possible with wheelchairs intended for larger children or adults, due to strength limitations of current wheelchair seats and seatbacks. In these cases, a vehicle-anchored three-point belt offers the next best level of protection, until, and unless, wheelchair designs are improved and strengthened to handle pelvic restraint, or pelvic and shoulder restraint forces. (Note: changes in wheelchair design based on ANSI/RESNA WC/19 will hopefully change this situation in a few years)

Apply Forces to Bony Structures of the Body

An important principle that has often been ignored in the transportation of wheelchair-seated occupants is to **apply restraint forces to the bony regions of the body and not to the soft tissues, such as the abdomen.** For a pelvic belt, this means keeping the angle at 30 degrees to the horizontal or greater, and preferably at 45 degrees or greater, so that it has a higher probably of staying over the bony pelvis in a crash. Shoulder belts should be positioned so that the forces are applied across the clavicle or collar bone, as well as the chest. They should connect to the lap belt near the hip of the occupant rather than near the center of the body, so that the shoulder belt does not pull the lap belt up onto the soft abdomen during impact loading.

Postural Supports

Various types of postural belts and lightly padded hardware components are often attached to the wheelchair to provide support and positioning stability for the wheelchair occupant. Belts are often wrapped around the back of the wheelchair at the level of the pelvis, abdomen, or chest, and are connected by light-duty fasteners to the wheelchair frame. Such postural support belts and components should not be relied on for restraint in a moving vehicle unless they comply with relevant parts of SAE J2249. Although there are not yet standards for postural accessories, product designers should attempt to incorporate break-away features and eliminate sharp metal inserts in lateral thoracic supports and headrest components in future designs. Also, close fitting accessories, such as, "subasis" pelvic bars and knee blocks could reduce the effectiveness of the pelvic belt, and cause unnecessary injury to the wheelchair occupant in a crash situation.

Orient Occupants Facing Forward in the Vehicle

It has been well established by numerous studies of real-world, injury-producing crashes that over fifty percent of motor vehicle crashes resulting in serious and fatal injuries have the principal direction of impact toward the front of the vehicle. These statistics are the basis for forward-facing, high-back, padded seats in school buses manufactured after 1976, as required by Federal Motor Vehicle Safety Standard 222. However, wheelchair-seated students and adult passengers in public transit and personally licensed vehicles have often been transported backed up to the side wall of the bus facing the aisle, with several wheelchairs aligned next to each. From an occupant-protection standpoint, this side-facing orientation is probably the least preferred direction in terms of risk of injury if there is a frontal crash or sudden deceleration of the vehicle. Not only is the human body less able to withstand lateral loading and twisting that results from forces directed laterally to the occupant, but the upper torso restraint becomes largely ineffective, or even a source of injury to the neck. Furthermore, the wheelchair frame is in its weakest orientation to absorb loads imposed by a frontal crash.

It has long been recognized that the safest orientation for a vehicle occupant in a frontal impact is rearward facing if a properly designed, energy-absorbing structure is provided to dissipate and distribute impact loads over the occupant's back, shoulders, and head. However, implementing an effective rear-facing restraint and tiedown system for wheelchair-seated occupants is generally considered to be too costly and impractical. Furthermore, for many wheelchair designs, it is extremely difficult, if not impossible, to achieve good placement of the back support in close proximity to the wheelchair backrest. Finally, it is generally considered to be unacceptable for wheelchair-seated travelers to face rearward when all, or most, other occupants are facing forward.

Although potentially more costly because of reduced occupant seating and wheelchair-occupant capacity, a significant step toward improving occupant protection for people with disabilities can be made by facing the wheelchair forward and by providing adequate spacing between wheelchair stations and other occupants or structures. Facing wheelchairs occupants forward instead of sideways may have the additional benefit of improving ride quality through a reduction in lateral *body* movement associated with vehicle acceleration and deceleration, and elimination of problems of disorientation and nausea associated with viewing the passing scenery through the opposite-side windows.

Provide Adequate Clear Space and Energy-Absorbing Interiors

Because no occupant restraint system will completely prevent occupant movement, it is important to provide adequate clear space around wheelchair-seated occupants, in addition to providing an effective occupant-restraint system. Also, vehicle structures near wheelchair-seated travelers should be padded with energy-absorbing material of sufficient thickness and density to reduce the possibility of injury should contact occur (note: FMVSS 201 provides performance information on padding material). If possible and feasible, rigid trays or other equipment attached to the wheelchair, should be removed and secured during transportation so that the hard, sharp edges do not cause injury to the wheelchair occupant, or to other occupants in a crash event.

Larger Vehicles are Better

It is a well established fact that the frequency distribution of crash severities is a function of vehicle mass. Thus, the distribution of crash severities for larger vehicles, such as large school buses and transit vehicles, will span a significantly lower range of DeltaVs (changes in vehicle speed during an impact event) than smaller passenger vans and vehicles. This is so because most vehicle crashes involve impacts into other vehicles, and the higher mass vehicles will be decelerated less than the lower mass vehicle in such encounters.

For these reasons, it is possible to reduce the risk of injury to wheelchair seated occupants simply by transporting them in larger vehicles when the option exists. Transporting users of very heavy wheelchairs in larger vehicles is a particularly good idea since this reduces the likelihood that impact forces will exceed the dynamic strength of either the wheelchair tiedown system or the wheelchair. Also, users who may have particularly low tolerance to injury, will be exposed to less risk if transported in larger vehicles.