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Wheelchair and Wheelchair Tiedown/Restraint Testing at UMTRI

The Biosciences Division of UMTRI conducts sled impact tests of wheelchairs and wheelchair tiedowns and occupant-restraint systems (WTORS) to determine their impact response characteristics and to evaluate products with respect to voluntary national and international standards and recommended practices. UMTRI has been involved in wheelchair occupant safety research for more than twenty years and the Biosciences research staff has been active in standard-development efforts worldwide since 1985.

Currently, most impact testing of wheelchairs and wheelchair seating systems at UMTRI is conducted in accordance with Section 19 ANSI/RESNA WC/Volume 1 "Wheelchairs Used as Seats in Motor Vehicles," which is also referred to simply as "WC19." This voluntary standard was approved in May 2000. The primary test conducted is the 48-kph, 20-*g* frontal impact test of Annex A, which is conducted on the UMTRI rebound sled. Additional wheelchair tests are conducted in accordance with Annex B, Annex C, and Annex E to assess the wheelchair with regard to clear paths from securement points to anchor points, lateral stability, and accommodation of vehicle-anchored occupant belt restraints. Although the international version of this wheelchair standard, ISO 7176/19, does not yet apply to pediatric wheelchairs, adult wheelchairs tested successfully to WC19 will also be in compliance with ISO 7176/19.

WTORS are dynamically tested on the UMTRI sled using the methods and performance criteria outlined in Appendix A and Section 6.2 of the Society of Automotive Engineers (SAE) J2249 "Wheelchair Tiedown and Occupant Restraint Systems for use in Motor Vehicles." The test methods and performance criteria are the same as those of ISO 10542-1 "Wheelchair tiedown and occupant restraint systems – Part 1: Requirements and test methods for all systems," and thus, compliance with SAE J2249 implies compliance with ISO 10542-1.

UMTRI IMPACT TEST FACILITY

Impact Sled

The UMTRI impact sled consists of a sled platform that travels on sixty-foot track consisting of two steel rails. The wheelchair or WTORS to be tested is installed on the sled platform using appropriate test fixtures and methods specified in the different ISO, ANSI/RESNA, and SAE standards. To conduct a test, the platform is accelerated up to a pre-impact speed from one end of the track by means of a pneumatically powered ten-foot-stroke piston. The sled platform travels to the opposite end of the track where it is decelerated by a pneumatic pressure cylinder that functions as an air spring to cause the

sled to reverse direction and travel back down the track. The UMTRI sled therefore operates on a rebound principle, achieving the desired velocity change during impact by reversing its direction of motion during the impact event. As shown in Figure 1, the UMTRI sled impact or deceleration pulse is trapezoidal in shape and is similar to that generated in frontal barrier tests by small vehicles or vans with limited crush zones. In a typical wheelchair or WTORS frontal-impact sled test to current standards, the change in sled speed is between 30 and 32 mph, and the deceleration pulse falls within the shaded zone shown in Figure 1.

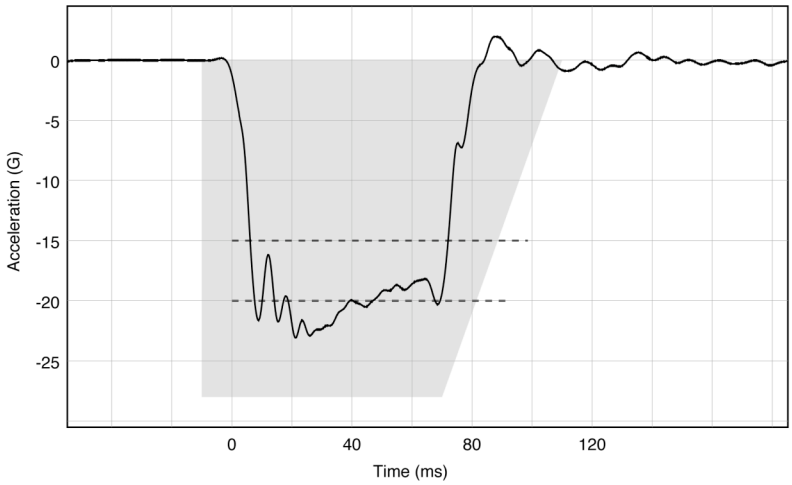

Figure 1 - Typical UMTRI 30-mph sled deceleration pulse compared to corridor required by SAE, ANSI/RESNA, and ISO standards. The pulse must exceed 20 *g* for a continuous 20 ms and 15 *g* for a cumulative 40 ms.

Anthropomorphic Test Devices (ATDs) or Crash Dummies

Several different sizes of anthropomorphic test devices (ATDs), or crash test dummies, are available at UMTRI for use in wheelchair and WTORS testing. The size, weight, and instrumentation capabilities of each are provided in Table 1. For wheelchair testing, the ATD selected is based on the weight range of user sizes for which the wheelchair has been designed, with an ATD near the upper end of the range being chosen for use in the test. For wheelchairs intended for use by adults, either the Hybrid II or Hybrid III mid-size adult male ATDs at about 170 lb must be used, but wheelchair manufacturers can also choose to use the large adult male ATD at about 225 lb.[1] For pediatric wheelchairs, the small-female ATD at about 106 lb is often the appropriate ATD, but the new Hybrid III 10-year old or the 6-year old ATDs may also be appropriate for some wheelchair models and/or restraint conditions (e.g., testing a pediatric wheelchair with wheelchair-integrated four- or five-point harness). Some additional mass can be added to most ATDs to achieve an ATD mass that is between the standard ATD masses.

For WTORS testing, a midsize male Hybrid II or Hybrid III ATD is usually used, since almost all WTORS are intended for use by both adults and children. However, currently the WTORS manufacturer may choose to test with the large adult male ATD instead.

[1] A revised version of wheelchair standards will be more specific about the sizes of ATD to be used for wheelchairs of different occupant capacities and will require the use of the midsize adult male ATD for all but bariatric wheelchairs.

For WTORS that are designed for limited use with children with a body mass that is considerably less than that of an adult, such as a WTORS with wheelchair integrated upper and lower belt restraints, one of the smaller ATDs, such as the small female, 10-year old, or 6-year old might be the appropriate size ATD to use. UMTRI sled engineers will provide manufacturers with advice on the appropriate size ATD to use and any product labeling requirements that this might imply.

Table 1
UMTRI ATDs and Instrumentation
Available for Use in Wheelchair and WTORS Impact Testing

	Weight (lb)	Seated Height (in)	Buttock-Knee Length (in)	Hip Breadth (in)	Knee Height (in)
Part 572:C Hybrid II 3-Year Old Head triaxial accelerometer Chest triaxial accelerometer	35	22.5	12.7	7.0	10.4
Part 572:P Hybrid III 3-Year Old Head triaxial accelerometer Chest triaxial accelerometer	37.5	22.5	12.7	7.0	10.4
Part 572:I Hybrid II 6-Year Old Head triaxial accelerometer Chest triaxial accelerometer	47.3	25.6	14.9	8.8	13.5
Part 572:N Hybrid III 6-Year Old Head triaxial accelerometer Chest triaxial accelerometer Upper-neck six-axis load cell Chest deflection potentiometer	50	25.6	14.9	8.8	13.5
Hybrid III 10-year Old Head triaxial accelerometer Chest triaxial accelerometer Upper-neck six-axis load cell Chest deflection by IRTRAC	77.6	28.5	18.0	10.4	14.8
VIP Small Adult Female Head triaxial accelerometer Chest triaxial accelerometer	106	31.0	19.0	14.0	16.8
Hybrid III Small Adult Female Head triaxial accelerometer Chest triaxial accelerometer Pelvis triaxial accelerometer Upper-neck six-axis load cell Chest deflection potentiometer	108	31.0	21.0	12.4	16.0
Hybrid II Midsize Adult Male Head triaxial accelerometer Pelvic triaxial acceleromoter	168	35.0	23.0	15.5	20.0
Hybrid III Midsize Adult Male Head triaxial accelerometer Chest triaxial accelerometer Pelvis triaxial accelerometer Upper-neck six-axis load cell Femur load cells Chest deflection potentiometer	172	34.8	23.3	14.4	19.5
VIP Large Adult Male Head triaxial accelerometers Chest triaxial accelerometers	225	38.0	24.0	16.5	20.0

Instrumentation, Data Acquisition, and Signal Processing

Although not required by the current WTORS and wheelchair standards, most ATDs used in UMTRI sled tests are instrumented with head and chest (thoracic spine) triaxial accelerometers. The sled platform is also instrumented with two accelerometers to measure the sled deceleration-time history during each test for comparison with the specified corridor as shown in Figure 1. Use of two sled accelerometers allows for checking of the sled acceleration measurements between calibrations. The change in sled speed during impact deceleration is measured directly by a light-based sensor system that detects the time of sled travel between precisely spaced "fingers" on the sled track just prior to and immediately after the sled deceleration pulse.

Measurement of loads in tiedown straps and belt restraints is not required by the standards, but this information can be useful to manufacturers, particularly in the event of a component failure. Therefore, webbing load cells are often used on restraint belts and tiedown straps when this is feasible and desired by the test sponsor, and strain-gaged shafts of the rod ends that comprise the anchorage components of the surrogate four-point strap-type tiedown are used to measure the force-time histories in the rear tiedown straps during wheelchair testing.

All signals generated by accelerometers and load cells used in a test are digitized in real time using a dedicated on-board data-acquisition system and are processed and digitally filtered according to the requirements of SAE J-211. The polarities of all signals are adjusted to conform to the sign convention of SAE J-1733. The data from ATD head and chest accelerometers are processed through algorithms to determine peak head resultant acceleration and head injury criterion (HIC), and the 3-ms clipped chest resultant acceleration. Plots of the individual transducer signals as well as calculated resultants are generated within minutes after completion of a test, with printed values for peak head and chest accelerations, and HIC.

Accelerometers and load cells used in sled tests are generally calibrated every six months, or more frequently if there is any indication that a transducer is not working properly. Chest deflection potentiometers in the Hybrid III ATDs are generally not used in wheelchair and WTORS testing but are calibrated prior to each use when they are used. In addition, the outputs of the two sled accelerometers are routinely compared to ensure that the difference in peak values is less than 0.5 *g*.

CONDUCTING SLED TESTS

Objectives and Performance Criteria

In typical government regulatory impact testing, injury criteria computed from ATD head, chest, neck, and thigh instrumentation are compared to, and must be less than, maximum-allowed reference values that have been related through research to the likelihood of serious injuries. Examples are the Head Injury Criterion or HIC, the peak 3-ms-clipped chest resultant acceleration, and peak chest deflection. While an instrumented ATD is typically used in wheelchair and WTORS testing, and many of these injury criteria are calculated and provided to the sponsor with the test report, these measures are not currently used in the pass/fail criteria for the wheelchair or WTORS. This is because the primary purpose of the impact tests in these standards is to evaluate the dynamic strength of the WTORS or wheelchair under 30-mph, 20-g frontal impact loading conditions, and vehicle components are not represented in the tests for the ATDs to interact with. Thus, the primary performance criteria specified in these standards for the frontal-impact sled tests are peak horizontal excursions of the wheelchairs and ATDs based on analysis of high-speed videos, and observations of structural and component failure based on post-test inspection of the test samples.

For these reasons, the primary purpose of the ATD in WTORS and wheelchair tests is to simulate the dynamic forces on the wheelchair and WTORS that would be generated by a typical wheelchair occupant in a frontal impact. As has historically been the practice in government safety testing, the midsize-male ATD (i.e., about 50th percentile by U.S. male stature and weight) at about 170 lb is used for testing wheelchairs and WTORS intended for use by adults. For WTORS testing, the wheelchair tiedown system is dynamically loaded by a rigid, reusable surrogate wheelchair (SWC) with a mass of 187 lb. For wheelchair testing to WC19, the wheelchair is secured by a surrogate four-point strap-type tiedown that also provides for measurement of the force-time histories at the rear tiedown anchor points.

Wheelchair Tests

Tests of wheelchairs for dynamic strength are performed using the sponsor's wheelchair and UMTRI's surrogate four-point, strap-type tiedown system. The wheelchair is placed facing forward on the sled's rigid steel-plate platform and secured with the surrogate four-point tiedown system. The securement hooks of the four tiedown straps are attached to the wheelchair frame at the manufacturer's designated securement points. An appropriate size (for the wheelchair) ATD is placed in the wheelchair's seating system and restrained using a belt-type restraint system consisting of both upper and lower torso restraints. Until May 2002, wheelchair manufacturers could comply with ANSI/RESNA WC19 using a totally independent (of the wheelchair) occupant restraint system. For these tests, a surrogate vehicle anchored three-point belt restraint assembled with replaceable standard belt webbing and reusable hardware is provided by UMTRI. Since May 2002, WC19-compliant wheelchairs must be tested with a pelvic/lap belt provided by the manufacturer that anchors to the wheelchair and that provides the standard pin-bushing connection for attaching the lower end of a vehicle-anchored shoulder belt. In these cases, a surrogate shoulder belt is provided by UMTRI to

connect between the lap belt and the simulated vehicle upper anchor point on the sled. Wheelchair manufacturers can also design and test their products with fully integrated (i.e., wheelchair-anchored) upper and lower torso belt restraint systems, in which case surrogate belt restraints are not needed. In this regard, a revision to WC19 is expected to required wheelchairs designed for children under 50 lb to provide and be crash tested with a fully integrated five-point harness, similar to that provided on standard child safety seats.

WTORS Tests

Impact tests of wheelchair tiedown and occupant restraint systems intended for general use are performed the 187-lb structurally rigid surrogate wheelchair (SWC) that is specified in ISO 10542-1 and SAE J2249. The SWC is placed facing forward on the sled's steel-plate platform and secured with the sponsor's tiedown system. A Hybrid II or III midsize adult-male ATD (or large-male ATD if the manufacturer prefers) is placed in the SWC and restrained using a vehicle-anchored three-point belt restraint that is set up with geometry specified in the test procedures of the standards. In those limited cases where a WTORS is designed for limited use with a specific wheelchair and/or occupant because of special wheelchair features required for securement or lower wheelchair mass, or because the occupant restraints are designed to anchor to, and thereby transfer forces to, the wheelchair frame,[2] the test is conducted with the particular commercial wheelchair rather than the SWC. In these cases, the test is a "system" test that evaluates the dynamic strength of the WTORS-plus-wheelchair *system*, and the WTORS must be clearly labeled as to the limitations of its use.

PHOTO AND HIGH-SPEED VIDEO DOCUMENTATION

Photo and video documentation of each test consists of pre- and post-test photos taken with a high-resolution digital camera and high-speed digital video cameras that record the kinematics of the ATD and test components during impact at 1000 frames per second. For wheelchair tests, two off-sled high-speed video cameras are typically used, with one placed to view the main impact event and peak forward excursions of the wheelchair and ATD from the side, and the other camera is placed behind the main side-view camera to record the ATD rebound and interaction with the wheelchair backrest. For WTORS tests, a side-view camera is typically used and a second camera is often positioned to obtain a close-up rear-oblique view of the tiedown system and surrogate wheelchair. These digital videos are viewed immediately after each test to evaluate the performance of the tested components. Color printouts of digital photos are provided with each test report (see below) along with selected frames from the side-view high-speed video. Copies of the pre- and post-test pictures, test videos, and data are available to download at the UMTRI online database soon after testing at the following website: https://141.211.187.80/SOD/login.php.

[2] In a revised version of SAE J2249 (to be WC18 in ANSI/RESNA Volume 4), occupant restraints with lap belts designed to transfer loads directly to the wheelchair will be able to be tested using the SWC.

Test sponsors will be provided with a username and password, which they will be able to use to login and access the media for specified tests. Copies of the video frames are also provided in CD format upon request.

MACHINING AND WELDING CAPABILITIES

UMTRI is well equipped with welding and machining facilities and technical support staff who can fabricate special test fixtures when needed for a test, or make modifications to test components before and between tests. The latter allows manufacturers to quickly evaluate how changes in product design might resolve problems noted in a particular test. When these additional services are needed, the cost of labor and materials is added to the standard per test cost at the time of invoicing.

TEST REPORT

Upon completion of each test, a written report is prepared that includes the following information, depending on the test requirements and the ATD used:

- Sled velocity and acceleration
- Pre-test and post-test measurements
- Forward head, knee, and wheelchair excursions
- Rearward head excursion
- Head accelerations and resultant
- Head injury criterion (HIC)
- Chest accelerations and resultant
- Chest deflection
- Neck forces and moments
- Belt loads during impact
- Comments on structural performance

Included with each report are color prints of pre-test and post-test digital photographs, and color prints of time-sequence frames selected from the side-view high-speed video cameras. This report is usually sent within two to three weeks of the test date.

DATA LIMITATIONS AND USE

Results of sled tests conducted at UMTRI are advisory in nature and do not constitute endorsement of a product or certification to ANSI/RESNA, SAE, or ISO standards. However, the test results can be used to provide technical support for manufacturer's self-certification of WTORS and wheelchair products, and copies of test reports may be provided to interested parties at that manufacturer's discretion. At no time shall the name of the University of Michigan or Transportation Research Institute (UMTRI) be used in any advertising material or public media release in connection with any product tested.

CONTACTS

For further information about test procedures, fees, and scheduling of tests, contact:

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TEST COSTS

FRONTAL IMPACT SLED TEST (Wheelchairs to WC19 and WTORS to SAE J2249)	$2,000
WC19 Wheelchair tests for tiedown clear paths (Annex B), lateral stability (Annex C), and accommodation of vehicle-anchored belt restraints (Annex E)	$600

OTHER SERVICES

Overnight shipping	At cost
Fabrication	approx. $50/hour plus components