



SURFACE VEHICLE INFORMATION REPORT

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(R) Pedestrian Dummy Full-Scale Test Results and Resource Materials

RATIONALE

Evaluating the biofidelity of pedestrian dummies is crucial to ensure the validity of research results obtained using such dummies. This SAE Information Report provides performance results for a pedestrian dummy at both the component and full-scale assembly levels. While a previous version of this SAE Information Report, published in October 2010, provided performance results for a previous research pedestrian dummy, results from both component and whole-body tests are now included for an updated pedestrian dummy. The updated biofidelity test requirements are specified in SAE J2782, while the generic buck used in the whole-body tests is specified in SAE J3093.

FOREWORD

Worldwide, vehicle impacts with pedestrians constitute the most frequent cause of traffic-related fatalities. With this background, the SAE Human Biomechanics and Simulations Standards Steering Committee formed the Pedestrian Dummy Task Force with the goal of developing initial performance specifications for a pedestrian research crash-test dummy which could be used to study the motions and sequence of body component impacts which lead to pedestrian trauma. Additional uses for such a dummy could also include the:

- Study of pedestrian kinematics
- Facilitation of crash reconstruction techniques including pedestrian kinematics
- Assessment of injury probabilities for given vehicle, crash, and countermeasure combinations
- Design of countermeasures
- Evaluation of active systems (pop-up hoods, airbags, etc.)
- Refinement of component test parameters and procedures
- Validation of computer simulations

The primary result of the Pedestrian Dummy Task Force was the preparation of SAE J2782. During the preparation of SAE J2782, the Task Force interacted with several key technical reports which, although not included in SAE J2782, can provide helpful background and test and analysis examples for those working with SAE J2782 or otherwise studying pedestrian safety. These documents and information were collected into this SAE Information Report (SAE J2868) by the SAE Pedestrian Dummy Task Force.

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Documents

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1. SCOPE

The materials included in this SAE Information Report are not intended to represent a complete summary of pedestrian safety research activities, but are rather a collection of materials which can be helpful to users of SAE J2782.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE and Stapp Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J211-1 Instrumentation for Impact Test - Part 1 - Electronic Instrumentation

SAE J2782 Performance Specifications for a Midsize Male Pedestrian Research Dummy

SAE J3093 Design and Performance Specifications for a Generic Buck Representing a Small Family Car used in the Assessment of Pedestrian Dummy Whole Body Impact Response

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2.1.2 ESV Publications

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2.1.3 ISO Publications

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ISO/DIS 13232-4	Motorcycles - Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles - Part 4: Variables to be measured, instrumentation, and measurement procedures
ISO/DIS 13232-5	Motorcycles - Test and analysis procedures for research evaluation of rider Crash protective devices fitted to motorcycles - Part 5: Injury indices and risk/benefit analysis
ISO/TR-9790:1999(E)	Road vehicles - Anthropomorphic side impact dummy - Lateral impact response requirements to assess the biofidelity of the dummy
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2.2 Related Publications

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2.2.1 SAE and Stapp Publications

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2.2.2 Code of Federal Regulations (CFR) Publications

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49 CFR 572.34 Subpart E - Anthropomorphic Test Devices: Hybrid III Test Dummy

2.2.3 ESV Publications

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2.2.4 IRCOBI Publications

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3. DEFINITIONS

3.1 ARM

That portion of the upper extremity from the shoulder to the elbow.

3.2 FOOT

That portion of the lower extremity from the ankle to the end of the toes.

3.3 FOREARM

That portion of the upper extremity from the elbow to the wrist.

3.4 HAND

That portion of the upper extremity from the wrist to the finger tips.

3.5 IMPACT POINT

The point in space where the vehicle/buck first contacts the pedestrian.

3.6 LEG

That portion of the lower extremity from the knee to the ankle.

3.7 STUB ARM

A dummy upper extremity which terminates at or proximal to the elbow (i.e., does not include the forearm and the hand).

3.8 THIGH

That portion of the lower extremity from the hip to the knee.

3.9 VALGUS BENDING

Bending about the fore-aft dummy axis (x).

3.10 VULNERABLE ROAD USERS

Terminology used in Global Technical Regulations, European Union regulations, and commonly used in the field of safety research (refer to ESV session guide) to describe pedestrians, cyclists, and motorcyclists.

4. SYMBOLS, SUBSCRIPTS, AND ABBREVIATIONS

4.1 Abbreviations

ATD	Anthropomorphic test dummy
AMRL	Aerospace Medical Research Lab (refer to Chandler, 1975)
AMVO	Anthropometry for Motor Vehicle Occupants Database as established by UMTRI-83-53-1
ANSUR	1988 Anthropometric Survey of U.S. Army Personnel (refer to Gordon et al., 1989)
C1, C2, etc.	Cervical vertebrae number 1, 2, etc.

CAESAR	Civilian American and European Surface Anthropometry Resource (refer to Harrsion and Robinette, 2002)
c.g.	Center of gravity
COR	Center of rotation
CV	Coefficient of variation defined as the standard deviation divided by the average
DAS	Data acquisition system, normally consisting of sensors, signal conditioning, and recorders
ESV	Conference on the Enhanced Safety of Vehicles
FMVSS	Federal Motor Vehicle Safety Standard
FPS	Frames per second
IRCOBI	International Research Council on the Biomechanics of Impact
ISO	International Organization for Standardization
MT	Mid-thorax
NHTSA	National Highway Traffic Safety Administration
PMHS	Post-mortem human subject (i.e., cadaver)
SAFE	Survival and Flight Equipment Association
SD	Standard deviation
T1, T8, etc.	Thoracic vertebrae number 1, 2, etc.
THOR	Test device for human occupant restraint, an advanced frontal crash test dummy developed by the NHTSA beginning in the 1990s
UMTRI	University of Michigan Transportation Research Institute
US	Upper spine
WorldSID	World side impact dummy

4.2 Symbols

4.2.1 Vehicle Reference System (Fixed with Respect to the Moving Vehicle) (Refer to SAE J2782, 6.9.4.1.2)

x	Positive motions are forward with respect to the car
y	Positive motions will be directed away from the vehicle's left to its right
z	Positive motions are downward
V_r	Resultant velocity in the vehicle reference system X-Z plane
t	Time

4.2.2 Dummy Positioning Reference System (Refer to SAE J2782, 6.9.3) per SAE J211-1

X + forward from dummy

Y + right from dummy

Z + down

t Time

4.2.3 Imager Frame Reference System (Refer to SAE J2782, 6.9.4.1.2)

x_F + left in the image (assuming the image is of the left side of the car and the rear of the dummy)

y_F + back in the image (assuming the image is of the left side of the car and the rear of the dummy)

z_F + down in the image

5. WHOLE-BODY KINEMATIC BIOFIDELITY COMPARISONS BETWEEN DUMMY AND POST-MORTEM HUMAN SUBJECT (PMHS) TEST RESULTS

A properly designed and fabricated pedestrian crash test dummy should provide overall impact kinematics which are representative of humans. For example, the trajectory and velocities of a dummy head in a vehicle impact should be similar to what would be expected of a human head in a similar impact. Typically, such whole-body dummy kinematics are evaluated by making comparisons between dummy and post-mortem human subject (PMHS) motions and velocities.

The materials which follow in this section of the document provide the reader with an example of how such kinematic comparison studies can be performed. The procedures are based on a test series conducted at the University of Virginia and are described by Forman et al. (2015, paper no. 2015-22-0016). The test series included three PMHS tests. The anthropomorphic test dummy (ATD) tests were performed by Asanuma et al. (2023). All tests were conducted with the pedestrian in an upright posture at a vehicle impact speed of 40 km/h. PMHS motions were scaled as needed to adjust for PMHS height, PMHS motion corridors were calculated, an ATD was tested using the PMHS setup and test procedures, and the ATD motions were compared to the PMHS corridors (Forman et al., 2015, conference paper no. IRC-15-49; Asanuma et al., 2023).

5.1 Test Procedures

5.1.1 General Test Setup

The general test setup is shown in [Figure 1](#).

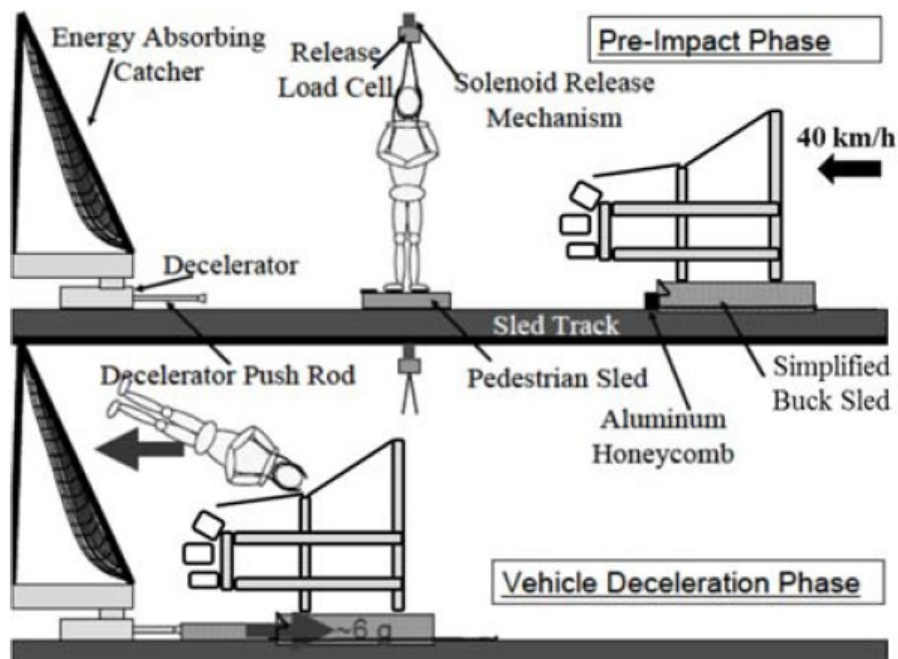


Figure 1 - General test setup

5.1.2 Impact Buck Details

5.1.2.1 Buck Construction

The vehicle used for this example was the generic buck representing a small family car described in SAE J3093 (Figure 2). For reference, the geometric locations of specific front end assembly details are found in [Figure 3](#).



Figure 2 - Vehicle buck

The vehicle buck included the front half of the vehicle structure, including the windshield (see [Figure 3](#)).

5.1.2.2 Buck Attitude

[Figure 3](#) provides a right-side cross-sectional view of the assembled buck along its centerline. In order to provide buck-pedestrian interactions as intended, it is necessary to ensure that the external contour of the constructed buck is consistent with its intended design. Thus, all rigid supports for the buck front-end components (i.e., rigid supports for the lower bumper, bumper, grille, and hood edge) shall conform to the dimensions provided in [Figure 3](#) within ± 3 mm for applicable linear dimensions, and within ± 1 degree for all applicable angle specifications.

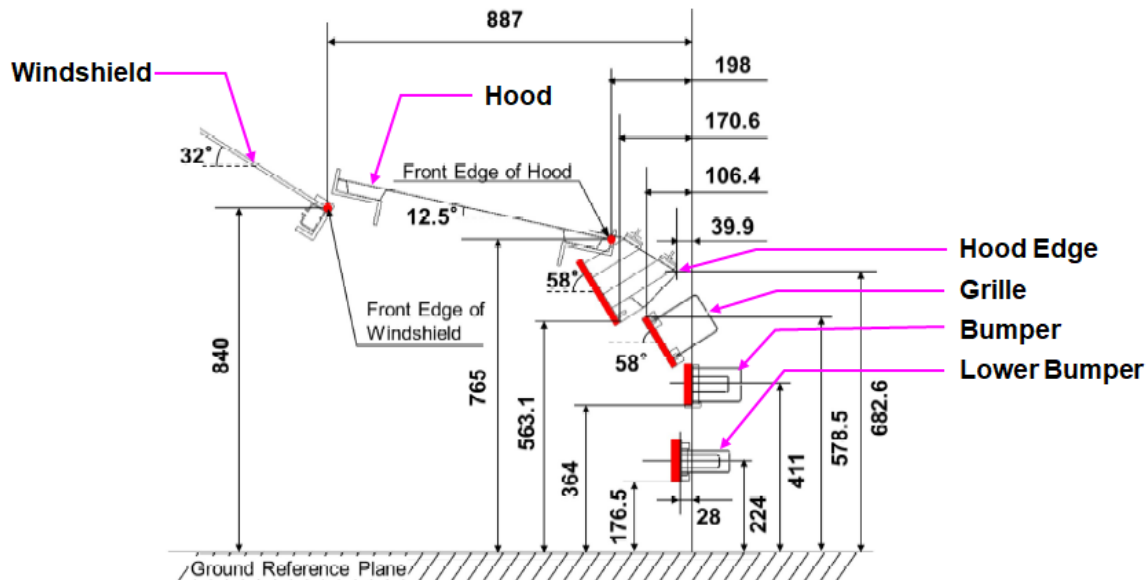


Figure 3 - Generic buck details

5.1.2.3 Buck Condition

The front structure of the vehicle buck was in good condition and was repaired after each test. The structure was constructed out of parts obtained from the original equipment manufacturer and did not include aftermarket replacement parts. Typical replacement parts included the lower bumper, bumper, grille, hood edge, hood, and windshield.

5.1.3 Impact Speed

The impact velocity for all tests was $40 \text{ km/h} \pm 1 \text{ km/h}$. No vehicle braking occurred until after primary head to vehicle impact.

5.1.4 PMHS Pre-Test Position

PMHS and dummy pre-test positions, support and release for all tests were based on the requirements specified in SAE J2782, 6.9.3.

5.1.5 High-Speed Cameras and Targets

5.1.5.1 Imaging

High-speed video shall be recorded using a posterior view of the pedestrian. The video camera used in the video analysis shall have a frame rate of at least 1000 FPS, a lens focal length of at least 30 mm, and should possess an image resolution of at least 1024×1024 pixels (1.0 mega pixel). The camera's field of view shall be perpendicular to the buck motion and should stretch horizontally from approximately 1 m before the impact point to a location approximately 3 m from the impact point (alternate imagers and fields of view can be used as long as the resolution is no more than 4 mm/pixel and all dummy body regions of interest are visible up to the time of head to buck impact). In order to facilitate the scaling of the image, two targets a known distance apart (e.g., 1 m), located in the plane of the pedestrian (i.e., center line of the buck) should be visible. Alternative scaling procedures, utilizing the transformation of other established reference distances in alternate frames or planes, can be used as long as parallax is taken into account.

5.2 Motion Analysis Procedures

5.2.1 PMHS Photo target Tracking

Motion analysis for all PMHS and dummy tests followed the requirements specified in SAE J2782.

On the test subject, the motion of the head centroid (henceforth called “head” for convenience) and photo targets at the upper spine (US), mid-thorax (MT), and pelvis reference points were measured. In all cases, a photo target was used. In addition to the photo targets on the surrogate, the motion of a quadrant-type photo target on the vehicle was tracked.

5.2.2 Data Scaling Analysis

NOTE: The following procedures assume a camera view of the left side of the car. Reverse left and right directions for the right side view.

For the purpose of the trajectory data manipulation two coordinate systems were defined. The second coordinate system, the vehicle coordinate system, was defined in [4.2.1](#) (it should be noted that neither of these coordinate systems is the same as the dummy positioning coordinate system described in [4.2.2](#)). The imager frame coordinate system is defined by the view of the high-speed imager. This coordinate system is fixed with respect to the laboratory. The x_F direction is defined as the horizontal axis of the imager frame and z_F is defined as the vertical axis of the imager frame. Positive x_F is to the left (for an impact to the right side of the dummy the buck travels in the positive x_F direction) and positive z_F points down. The motions of all of the photo targets were tracked in the frame coordinate system by digitizing the location of the photo target in each analysis frame. The origins for the frame coordinate system were as follows:

$x_F = 0$ Corresponds to a vertical line passing through the head centroid, upper spine reference point, mid-thorax reference point, and pelvis reference point at $t = 0$. If some alignment error between points exists, the line should be located so as to minimize the cumulative X^2 errors.

$z_F = 0$ Corresponds to the horizontal surface on which the bottom of the dummy shoes rests prior to impact.

5.2.3 Motion Analysis

Motion analysis proceeded as follows:

- Identify the image frame which just precedes the first indication of contact between the car bumper and the test subject. (This could be the last frame prior to the illumination of a contact light or prior to any visible movement or deformation of the subject.) This frame becomes analysis frame 0, and corresponds to $t = 0$
- Identify a series of analysis frames (i.e., frames in which the targets will be digitized) prior to and after frame 0 with a time interval between analysis frames of approximately 4 ms. For example, when using a 1000 FPS video camera every 4th frame prior to and after frame 0, will be an analysis frame.
- For each analysis frame, digitize the location of the head centroid, upper spine, mid-thorax, and pelvis reference points, and the car side target.
- To prevent the impact altered post-impact motions and the position averaging filter from affecting the calculated pre-impact and impact positions and velocities of the head, the x_F and z_F coordinates of the head in the 4 ms interval prior to head-to-buck impact shall be used to straight line extrapolate virtual x_F and z_F coordinates after head-to-buck impact. Such virtual points will be unaffected by the impact decelerations.
- Using reference targets a known distance apart (or other similar means), located in a plane coincident with the subject targets, and in a plane coincident with the buck target, determine geometric scale factors for the subject and buck target which can be used to convert image dimensions to real dimensions. For example, if the field of view at the subject centerline is 4 m and the camera image consist of 1024 horizontal pixels, the scale factor would be:

$$SF_{Dummy} = 4000 \text{ mm} / 1024 \text{ pixels} = 3906 \text{ mm} / \text{pixel} \quad (\text{Eq. 1})$$

Note that the scale factor for the buck side target will generally be different than that used for the test subject.

- f. The filtering convention specified in ISO 13232-4 was used to smooth the position data. All signals shall be filtered with four passes of the moving average filter:

$$\begin{aligned} x_{Fi,f} &= \frac{x_{Fi-1} + 2x_{Fi} + x_{Fi+1}}{4} \\ z_{Fi,f} &= \frac{z_{Fi-1} + 2z_{Fi} + z_{Fi+1}}{4} \end{aligned} \quad (\text{Eq. 2})$$

where:

$x_{Fi,f}$, $z_{Fi,f}$ = the filtered x_F and z_F position at frame i , in mm

x_{Fi} , z_{Fi} = the unfiltered (or filtered on the previous pass) x_F and z_F positions, in the frame coordinate system at frame i , in mm

$i - 1$ and $i + 1$ = designate the preceding and next analysis frames

- g. To further account for differences in subject height and body segment length, the trajectories were scaled via the length (scaling method outlined by Yanaoka et al., 2016). For each photo target location, a length scale factor was calculated by dividing the knee-to-target height (vertical distance from the struck knee to the photo target) expected of a 50th percentile male dummy (SAE J2782, Table 5) by the knee-to-target height of the PMHSs. For each target, the scaled Y-axis position time-history was then calculated by multiplying the unscaled Y-axis position by the length scale factor for that target at each point in time.

The scaled Z-axis position was calculated by:

1. Subtracting the initial ground-to-knee height (vertical distance from the buck ground reference plane to the struck knee at time t_0) from the unscaled Z-axis position of each target at each point in time.
 2. Multiplying this re-zeroed Z-axis position by the length scale factor for each target at each point in time.
 3. Un-zero and aligning initial positions by adding the initial photo target height expected of a 50th percentile male dummy as described by SAE J2782.
- h. For the purposes of calculating scaled velocities, and for average/corridor development, the time variable t_i , defined as the time at frame i , had to be scaled as well. However, since there are numerous scale factors, an individual signal for the scaled time at frame i , t_i^* , had to be calculated for each body region and each test. If the mass density and modulus of elasticity are considered to be constant among the test subjects, the time can be scaled using the length scale factor (Eppinger et al., 1984), so t_i was multiplied by each of the scale factors to obtain each of the t_i^* signals. It should be noted that the use of a single scale factor (based on height for example) for a given test would result in different initial positions for the body region targets when the test data is combined, which would in turn lead to wider motion corridors. Refer to Kerrigan et al. (2005) for further details.

- i. Transfer the origin of all scaled surrogate photo target position signals to the vehicle reference frame as follows:

$$\begin{aligned} x_{V,i} &= x_{Fi,f} - (vx_{F,i,f} - vx_{F,o,f}) \\ z_{V,i} &= z_{Fi,f} - (vz_{F,i,f} - vz_{F,o,f}) \end{aligned} \quad (\text{Eq. 3})$$

where:

$x_{Fi,f}$, $z_{Fi,f}$ = the filtered x_F and z_F position of each of the surrogate photo targets at analysis frame i , in mm, in the frame coordinate system

$vx_{F,i,f}$, $vz_{F,i,f}$ = the filtered x_F and z_F positions of the vehicle photo target at frame i , in mm, in the frame coordinate system

$x_{V,i}$, $z_{V,i}$ = the x and z positions of each of the surrogate photo targets at frame i in the vehicle reference coordinate system, in mm

$vx_{F,o,f}$, $vz_{F,o,f}$ = the filtered x and z positions of the vehicle photo target at analysis frame 0, in mm, in the frame coordinate system

The second coordinate system is the vehicle coordinate system. The vehicle coordinate system is fixed to the vehicle, and defined as follows:

1. Positive x towards the front of the car.
2. Positive z down.
3. $x = 0$ is the same vertical line as the frame coordinate system at analysis frame 0, but is fixed and moves with the vehicle.
4. $z = 0$ is the same horizontal surface as the frame coordinate system at analysis frame 0.

NOTE: The vehicle coordinate system moves in the frame coordinate system positive x direction.

- j. Scaled body segment and vehicle velocities in the frame coordinate system were calculated using the methodology recommended in ISO 13232-5. The component velocities in the x and z directions of each body segment were calculated as:

$$\begin{aligned} V_{x,i} &= \frac{x_{i+1} - x_{i-1}}{t_{i+1} - t_{i-1}} \\ V_{z,i} &= \frac{z_{i+1} - z_{i-1}}{t_{i+1} - t_{i-1}} \end{aligned} \quad (\text{Eq. 4})$$

where:

$V_{x,i}$, $V_{z,i}$ = each photo target's component velocity, in m/s, in the x (fore/aft) and z (vertical) directions at frame i , in the buckcoordinate system

t_i = the time, in ms, at frame i

$i + 1$ and $i - 1$ = the next and preceding analysis frames

Resultant velocities were computed using the length of the velocity vector defined by the components in Equation 4.