TUC Validation Repository

Validation Protocol

Whole-Body Pedestrian Impact with a Generic Buck

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LS-Dyna version provided by:	Autoliv
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1. General

This document is part of the validation kit for the validation of a FE Human Body Model (HBM) against the loading condition specified under 1.1. The validation kit is composed of the following parts:

1. FE model of validation environment and documentation

   The setup files of the available codes are provided separately for download. In addition to the FE files, documentation on their structure is also included. The HBM to be validated needs to be prepared and integrated into the validation environment according to this protocol.

2. Experimental corridors

   Experimental corridors will be provided in a later update of the validation kit.

3. Validation protocol incl. a description of the load case

   This document is the validation protocol, which also contains a brief description of the load case.

1.1 Classification of validation load case

Body region	Whole-Body
Level	Global
Load case	Whole-Body Pedestrian Impact with a Generic Buck
References	Experiments published in: *J Forman, H Joodaki, A Forghani, P Riley, V Bollapragada, D Lessley, B Overby, S Heltzel, J Crandall (2015), Biofidelity corridors for whole-body pedestrian impact with a generic buck.* *IRCOBI Conf. Vol. 49.*
Unit system	kg - mm – ms – kN – GPa
Code	LS-Dyna

1.2 Disclaimer

The validation kit was developed in close cooperation within the THUMS USER COMMUNITY 2 (TUC2) research project. Any use of this validation environment shall be entirely at the user's own risk and responsibility. University of Munich (LMU), AUDI AG, Autoliv, BMW AG, Daimler AG, Porsche AG, Toyota Motor Corporation, Volkswagen AG and ZF TRW do not assume any responsibility for the validity, accuracy, or applicability of any results obtained from this research model and do not assume any liability or responsibility whatsoever for any damage, claims, injury or loss of any kind that may arise from or in connection with any use of, reference to and/or reliance upon this manual.

University of Munich (LMU), AUDI AG, Autoliv, BMW AG, Daimler AG, Porsche AG, Toyota Motor Corporation, Volkswagen AG and ZF TRW ask that the TUC project will be acknowledged under references for any use of this FE model resulting in papers and publications.

2. Short description of experimental setup and selection of configuration

In the experimental study of Forman et al. (1) three male post-mortem human surrogates (PMHS) were subjected to 40 km/h pedestrian impacts using a standard generic vehicle front (SAE J3093) (2-5). The PMHS were struck laterally in mid-gait stance. Pedestrian test methods described in detail by Kerrigan et al. (6) and Kam et al. (7) were used. Trajectories of the head centre of gravity (CoG), T1, T8 and the pelvis were recorded up to the time of head impact. The data were scaled to 50th percentile adult male and corridors developed.

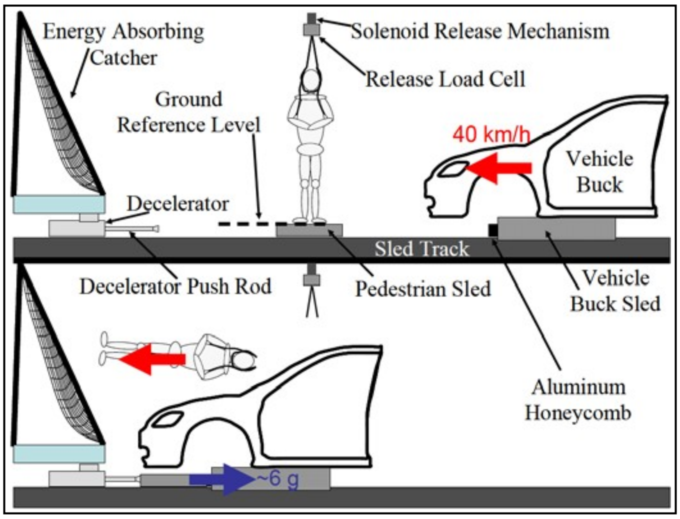

Figure 1: Experimental setup in Kerrigan et al. (7). Same test method was followed within experimental study of Forman et al. (1) using a standard generic vehicle front (SAE J3093)

Details of the Test Subjects with regard to age, gender and basic anthropometric measurements are given in the following table.

Test #	Age	Gender	Stature (cm)	Body Mass (kg)
V2370	73	Male	179,5	72,6
V2371	54	Male	187,0	81,6
V2374*	67	Male	178,0	78,0

Further design and performance specifications of the standard vehicle buck can be read in SAE J3093 (2).

This validation kit will provide the FE model of the validation environment (available), experimental corridors (coming soon) as well as a detailed protocol (available) for the validation of any FE pedestrian Human Body Model (HBM).

3. Validation Protocol

The following validation protocol is a step-by-step procedure to safeguard a credible validation of any HBM this validation environment is used for. The protocol highlights the requirements resulting from the experimental setup and, as validation, the head contact time that is being measured. The protocol is composed of two parts containing the following information:

1. Pre-processing
2. Post-processing

It is envisaged that the following protocol can be applied to any HBM which is to be validated against the above mentioned loading condition.

In the experiments, three PMHS tests were run. The following procedure considers PMHS V2371.

3.1 Pre-Processing

This section describes how the human body model (HBM) needs to be prepared and positioned in the above described environment (Section 3) and what other adaptions need to be made to meet the specifications in the referenced paper (1). Once the HBM is positioned, both buck and HBM are placed relative to the global coordinate system. Boundary conditions corresponding to the experiments and additional definitions complete the setup.

3.1.1 Human Body Model Pre-Processing

The following steps are to be taken to prepare and position the HBM in the above described environment to meet the specifications stated in the experiment. It is recommended to put all additional HBM relevant keywords in a separate LS-Dyna include file.

Local coordinate system of HBM

The local coordinate system of the HBM is defined in accordance with the experimental setup (Figure 2) and will be used to describe the positioning targets in the following sections. The z-axis of the local coordinate system points vertically in inferior direction. The x-axis aligns with the sagittal axis facing anterior.

Definition of reference nodes

Reference nodes allow comparison of the HBM position and the experimental measurements taken before the run. The precision of the defined nodes effects the positioning directly. Recommended definitions are provided in a separate document (coming soon).

Adjustment of anthropometry

In reference to Wu et al. (8), the following scaling factors are applied to the human body model to adjust its body height and mass-dependent width to the corresponding PMHS, which is stated to be the most appropriate method when evaluating head contact times (9).

$$\lambda_z = \frac{h_{PMHS}}{h_{HBM}}, \lambda_x = \lambda_y = \sqrt{\frac{m_{PMHS}}{m_{HBM} \cdot \lambda_z}}$$

where λ_i is the scaling factor for each dimension, h_i is the height and m_i is the mass of the PMHS and HBM, respectively. In the experiments, a stature of $h_{PMHS} = 1870$ cm (supine anthropometry) and a weight of $m_{PMHS} = 81{,}6$ kg was determined for PMHSV2371.

Positioning

The goal of this pre-processing step is to align the position of the HBM with the one documented during the experiment in order to achieve a reasonable enough agreement of the initial setups. The positioning targets are specified in Table 1 that further refers to Figure 2.

Table 1: Initial position measures of V2371 (1). [1]measured from ground plate, [2]to be confirmed

	Segment	Aspect	Unit	Axis	V2371	Lower Bound[2]	Upper Bound[2]
A	Height[1]	-	mm	Z	1885	1866	1904
B	Knee Height[1]	Impact Side	mm	Z	531	520	542
C		Non-Impact Side	mm	Z	553	542	564
D	Heel to Heel Distance	-	mm	X	382	325	439
E		-	mm	Y	239	227	251
F	Knee to Knee Width	-	mm	Y	219	208	230
G	Elbow to Elbow Width	-	mm	Y	562	534	590
L	Tibia Lateral	Impact Side	Deg	Y	65	60	70
M		Non-Impact Side	Deg	Y	96	91	101
T	Femur Lateral	Impact Side	Deg	Y	94,1	89,1	99,1
U		Non-Impact Side	Deg	Y	100,1	95,1	105,1
X	Femur Anterior	Impact Side	Deg	X	94,4	89,4	99,4
Y		Non-Impact Side	Deg	X	88,5	83,5	93,5
AD	Humerus lateral	Impact Side	Deg	Y	52,6	47,3	57,9
AE		Non-Impact Side	Deg	Y	56,7	51,0	62,4
AL	Torso Angle	-	Deg	Y	85,6	82,9	88,1
AM		-	Deg	X	-5,1	--10,2	0,0

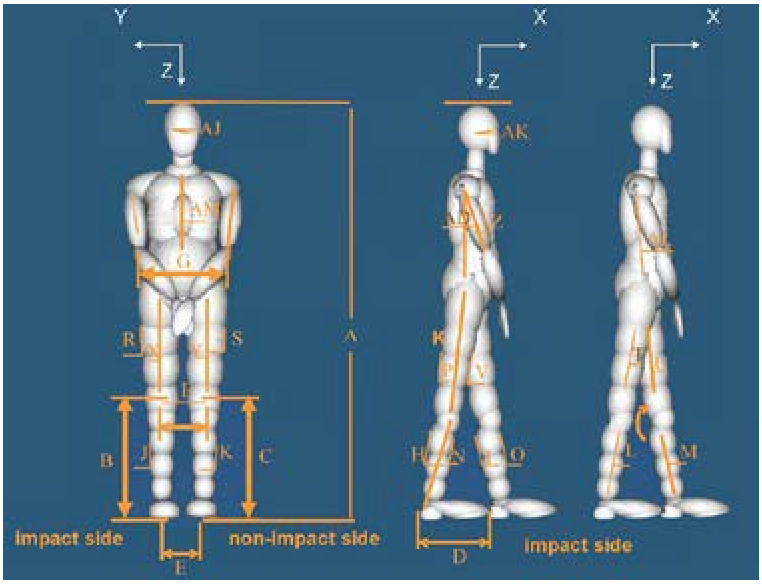

Figure 2: Initial measures taken in experiments (1)

During the collision with the buck, the hands of the PMHS were tied to one another. The movement of the arms has a large effect on the head impact time (10). Therefore, the same constraints are required to be implemented for the HBM, for example by adding tied contacts. Additionally, the PMHS wore general-purpose athletic shoes. Modeling these is of advance and can be achieved by either a whole shoe or a sole only. Either way, an appropriate sole height measures 25 mm.

3.1.2 Preparation of the Simulation Environment

Global coordinate system
In the simulation environment (Figure 3), the global z-axis points downwards which is in accordance with the local coordinate system of the HBM. The x-axis will be used to define the direction of SAE buck motion in the next steps.

Inserting the HBM
Below the HBM, a set of rigid 2D elements represents the ground plate. Referring to the experiment V2371, this plane is located at z_{ground} = 39 mm. A contact between the HBM and ground plate is characterized by a friction coefficient $\mu_{static} = \mu_{dynamic}$ = 0.3 (10). The HBM is moved to the center of the plate with the shoes as close to the plate as possible without causing initial penetrations in the contact definition. The HBM head center of gravity is supposed to be located above the global origin.

Placement of the generic buck
The SAE Buck which is used in this setup has been validated extensively (4). Therefore, no additional pre-simulations to prove its applicability are necessary.

In the experiment, the vehicle front struck the PMHS from the right (Figure 3). The vertical position of the lowest point of the SAE buck bumper is defined to be z_{buck} = - 96 mm (4). The vehicles centerline aligns with the global x-axis. In the experiments, the PMHS was allowed to settle after releasing it from the vertical attachment for t_{pre} = 30 ms. For this reason, the buck is positioned in the x direction with the front most node 328 mm (Δx_{pre}) from the human model.

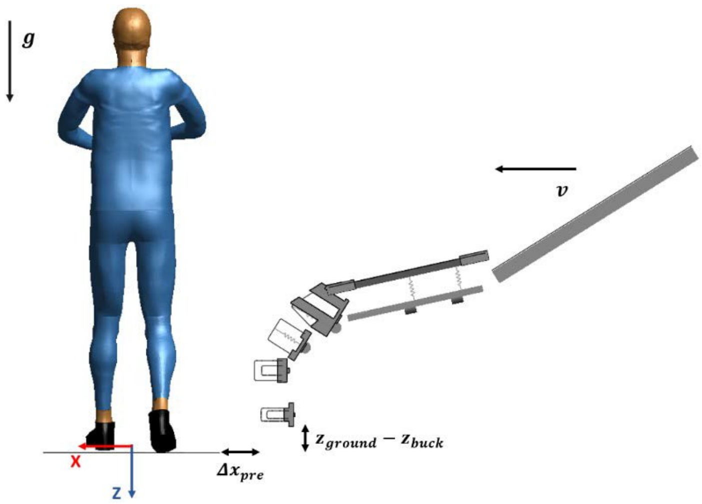

Figure 3: The simulation setup of the Forman experiment. Shown are the distances between the human model and the SAE buck, the global coordinate system and also the acting direction of gravity g and initial velocity v.

Two contacts between buck and the outer surface of the HBM must also be implemented. One includes the head surfaces only, the other the remaining HBM surfaces. This allows the determination of the head impact time. Friction is characterized by $\mu_{static} = \mu_{dynamic} = 0.3$.

3.1.3 Simulation Setup

Boundary Conditions

Throughout the simulation, gravity g = 9.81 m/s^2 acts in positive z direction (Figure 3). The SAE buck is initialized by a velocity of v = 40 km/h ≈ 11.1111 m/s in positive x direction, which corresponds to the velocity introduced in the experiments. Due to the positioning, the buck will struck the pedestrian at t_{pre} = 30 ms.

Output Definitions

In general, visual output and energies are helpful when examining plausibility. For the evaluation of the head contact time, the contact forces (see section above) must be reported, also. A sufficient output resolution is 1 ms and 0,1 ms for energies and reaction forces, respectively.

3.2 Post-Processing

General check of plausibility

To check plausibility in general, global energies are considered which must meet the following requirements (10):

- Total energy is constant within a 15 % tolerance.
- Hourglass energy is less or equal to 10 % of total energy.
- Initial contact energy needs to be less or equal to 1 % of initial total energy.
- Contact energy is less or equal to 5 % of total energy.
- Artificial mass increase is less or equal to 3 %.

Additionally, a first inspection of the simulation animation may reveal major errors in the setup and give further understanding of the resulting energies.

Head Impact Time

Head Impact Time is defined as time elapsed from initial HBM bumper contact until the first head contact. Therefore, time is measured from first non-zero bumper contact force until first increase of head contact force (Figure 4). In case, contact times are not clearly identifiable, checking the animation can help with determining the correct time step.

The head impact time can then be compared to the experimental result ($t_{PMHS,HIT}$ = 138 ms). The result is considered acceptable if it falls within the corridor of T_{target} = [120 ms, 156 ms] (to be confirmed).

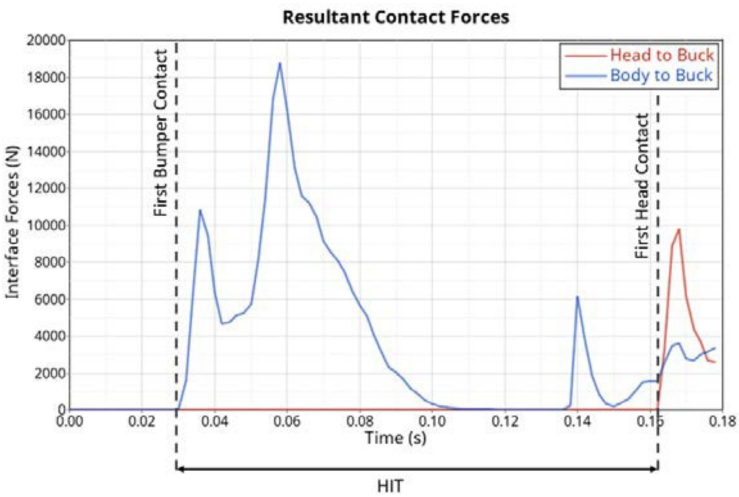

Figure 4: Example force curves for illustration of HIT measurement.

References

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