TUC Validation Repository Validation Protocol

Whole-Body Pedestrian Impact with a Generic Buck

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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 3 (TUC3) 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, Mazda Motor Corporation, Mercedes-Benz AG, Porsche AG, Toyota Motor Corporation, Volkswagen AG and ZF Automotive Germany GmbH 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 anyuse of, reference to and/or reliance upon this manual.

University of Munich (LMU), AUDI AG, Autoliv, BMW AG, Mazda Motor Corporation, Mercedes-Benz AG, Porsche AG, Toyota Motor Corporation, Volkswagen AG and ZF Automotive Germany GmbH ask that the TUC3 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 a 50th percentile adult male daummy (SAE J2872) and corridors developed.

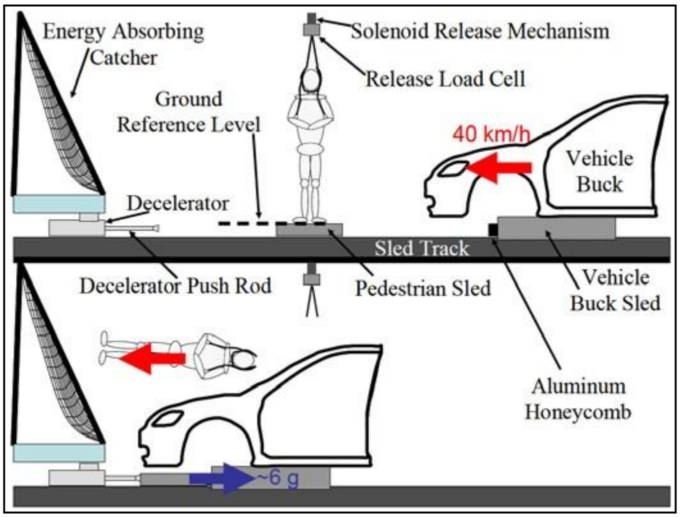

Figure 1: Experimental setup in Kerrigan et al. (7). Same test method was followed within experimental study of Forman et al. (1) using a standard generic vehicle front (SAE J3093)

Details of the Test Subjects with regard to age, gender and basic anthropometric measurements are given in the following table (Table 1).

Table 1: Details on PMHS used in the experimental tests (1)

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 takes PMHS V2371 into account exemplarily, since the other two PMHS show more distinctive anthropometries, e.g. amputated forearms. However, with appropriate adaptation, the protocol can be applied to these specimens as well, since in essence the procedure is similar.

1.3 Pre-Processing

This section describes how the human body model (HBM) needs to be prepared and positioned in the validation environment 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 one another in the global coordinate system. Boundary conditions corresponding to the experiments and additional definitions complete the setup.

3.1.1 Preparation of the Human Body Model

The following steps are to be taken to prepare and position the HBM to meet the specifications stated in the experiment. First, the model will be placed in the global coordinate system appropriately, then it will be scaled and positioned. It is recommended to put all additional HBM relevant keywords in a separate include file.

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 measurement points are provided in a separate document (*TUC_WB_PEDESTRIAN_SAE_VALIDATION-PROTOCOL_V02dev02-MeasurementPoints.pdf*) which is made available along with this protocol.

Coordinate system

The global coordinate system of the validation environment matches the coordinate system of the reference experiment. If the orientation of the HBM does not match this coordinate system yet, it must be aligned accordingly (see Figure 2). The z-axis points vertically in inferior direction. The x-axis aligns with the sagittal axis facing anterior.

Figure 2: HBM in reference to global coordinate system

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. In the experiments, a stature of h_{PMHS} = 1870 cm (supine anthropometry) and a weight of m_{PMHS} = 81,6 kg was determined for PMHS V2371. Figure 3 shows exemplarily the baseline THUMS Pedestrian model (A) and the scaled model (B).

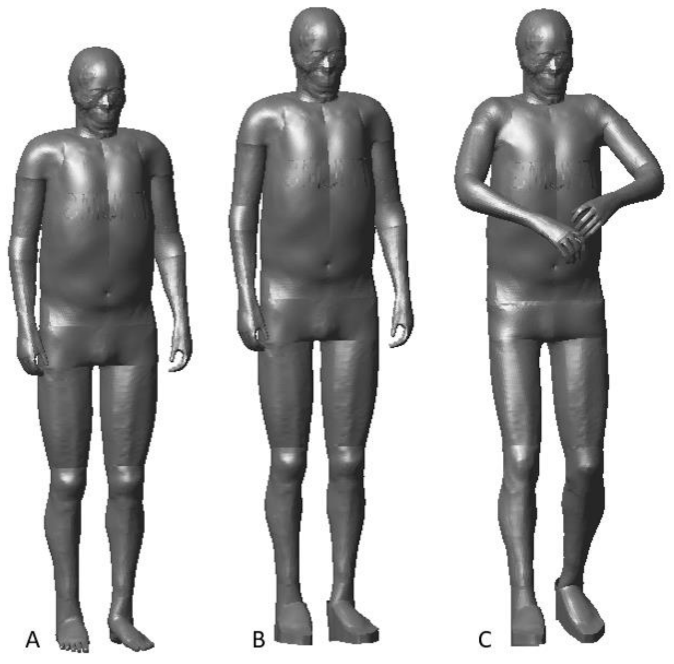

Figure 3: Process of HBM adjustment. A – Baseline model, B – Scaled anthropometry, C – positioned model

Shoes

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 approximately 25 mm. The shoes should be taken into account when measuring the initial position of the HBM in the following step (“Positioning”, Table 1)

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 4. Figure 3 shows the model before (B) and after positioning (C). Additionally, the hands need to be as close to one another as possible (as the hands were tied to one another in the experiments)

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 (mid-knee to lat. malleolus)	Impact Side	Deg	Y	65	60	70
M		Non-Impact Side	Deg	Y	96	91	101
T	Femur Lateral (gr. trochanter to knee)	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 (centerline)	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 (acrom. to lat. Epicondyle)	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	(acrom-troch.)	Deg	Y	85,6	82,9	88,1
AM		(centerline)	Deg	X	-5,1	-10,2	0,0

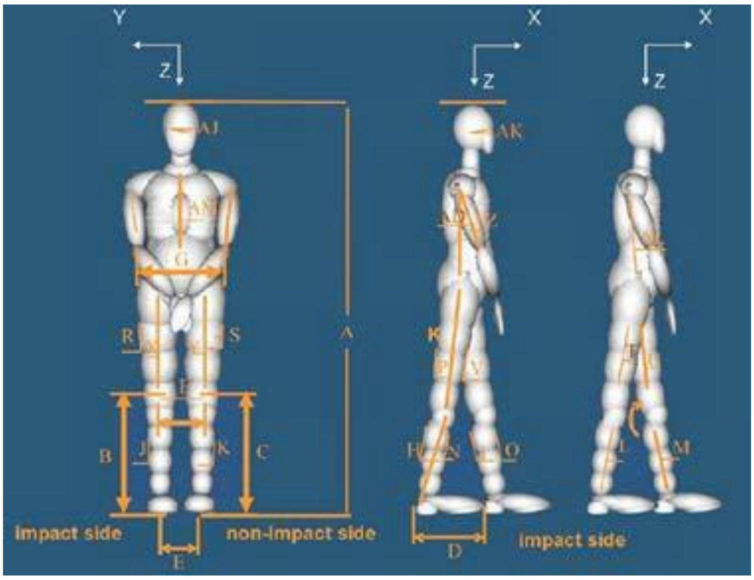

Figure 4: Initial measures taken in experiments (1)

Hand Constraint

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.

3.1.2 Preparation of the Simulation Environment

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

Global coordinate system

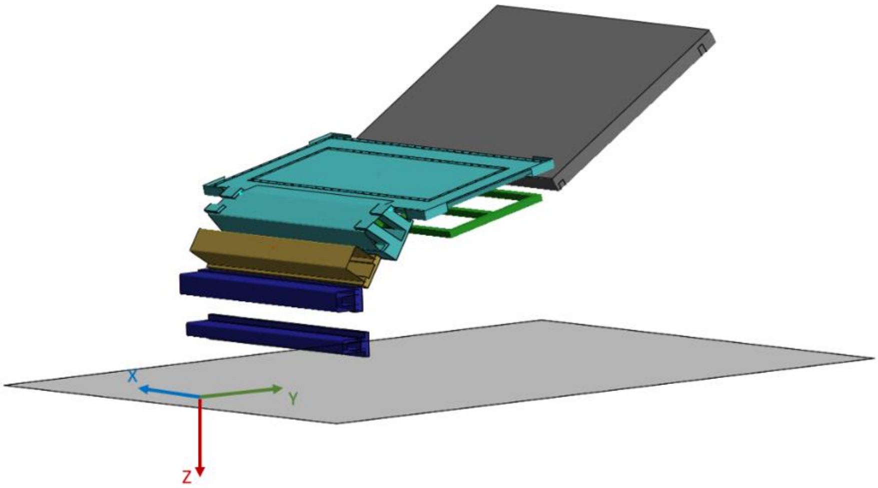

Figure 5: Global coordinate system of the validation environment

Provided in the FE file package, the buck is already oriented in the necessary way. As mentioned above and shown in Figure 5 also, the global z-axis (blue) points downwards. The y-axis (green) aligns with the direction of SAE buck motion.

Include the HBM

In the main file of the provided FE file package, include the prepared HBM file.

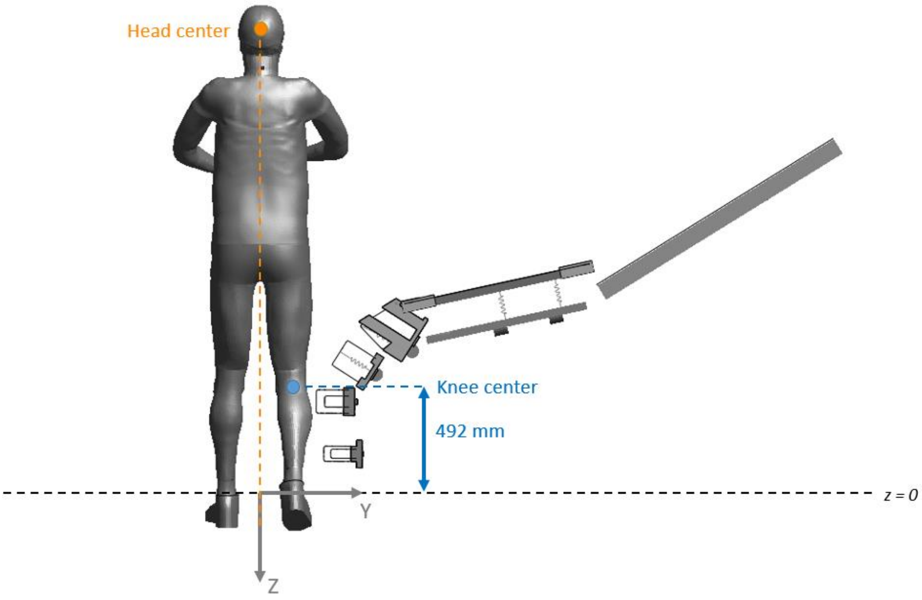

Figure 6: Head COG is centered above global origin; knee is at z = 492 mm[1]

Make sure, the HBMs head COG is centered above the global origin (see Figure 6). Additionally, the model is to be shifted along the z-axis so that the right knee measuring point is located at z = 492 mm[1]. This procedure corresponds to the experimental setup where the knee height relative to the buck reference plane was targeted when positioning the PMHS according to SAE J2872.

Additional Contact Definitions

Three contacts between HBM and validation environment are already implemented in the main file and are characterized by a friction coefficient $\mu_{static} = \mu_{dynamic} = 0.3$ (10). The buck contact surfaces are gathered in a part set with ID 329. Only the referenced part set contents referring to the HBM (outer surface only) need to be edited:

Contact ID 330: between HBM and ground plate
→ add all HBM surface parts to part set ID 330

Contact ID 331: between HBM head and vehicle
→ add HBM head surface parts to part set ID 331

Contact ID 332: between HBM body and vehicle
→ add remaining HBM surface parts to part set ID 332

The two contacts between HBM surface and vehicle allow for the determination of the head contact time using the contact forces.

[1] Initial PMHS platform height (39 mm below buck reference plane, see (1)) substracted from initial knee position (z = 531 mm, see Table 1).

Adjustment of the ground plane

In the provided FE file package, a shell part (ID 102) is already included which is used to represent the floor the PMHS was standing on in the experiments. Depending on the previous shift of the HBM in z-direction, the ground plate must now also be translated in z-direction accordingly. The distance between ground and shoes is supposed to be as small as possible without causing initial penetrations in the contact definition. See Figure 7 exemplarily.

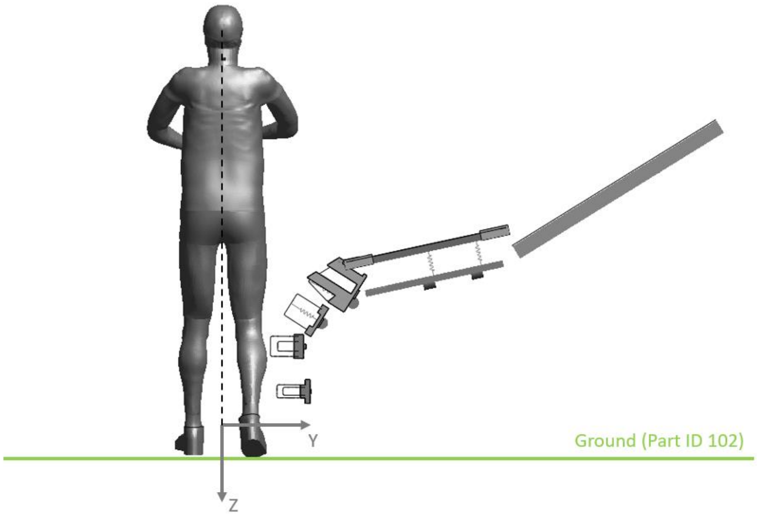

Figure 7: Ground part translated below feet (with minimal distance to HBM)

Translation of the generic buck

As provided in the FE file package, the vehicles centerline already aligns with the global y-axis with the front pointing in negative direction (i.e. Figure 5).

In the experiments, the PMHS was allowed to settle for t_{pre} = 30 ms after releasing it from the vertical attachment. For this reason, the vehicle must be moved in y-direction until the bumper is 328.33 mm away from the HBM (Figure 8). This distance can be measured, for example, between the skin of the lower leg and the BPR_UPPER_COVER.

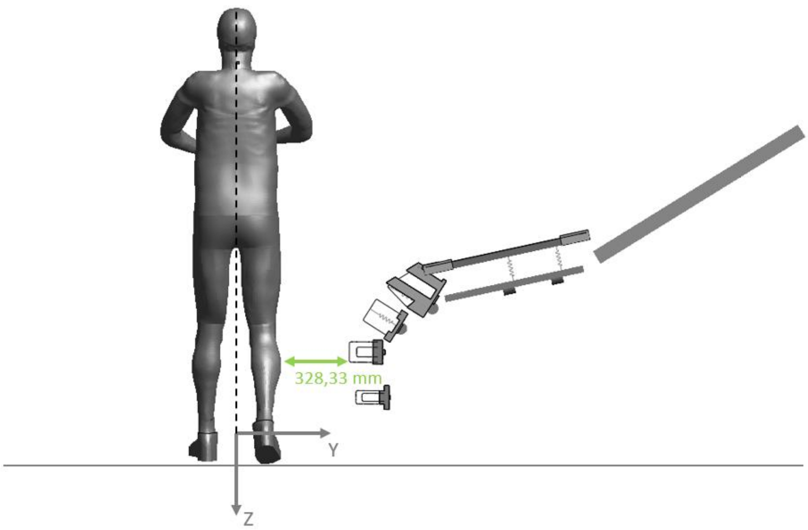

Figure 8: Adjust distance between HBM and vehicle by translating the buck in y-direction

3.1.3 Simulation Setup

The following definitions are already implemented in the provided FE file packages and do not need further adjustment.

Boundary Conditions

Throughout the simulation, gravity $g = 9.81$ m/s^2 acts in positive z direction (Figure 9). The corresponding keywords are implemented in the main file.

The SAE buck is initialized with a velocity of $v = 39.4$ km/h ≈ 10.9444 m/s in negative y direction, which corresponds to the velocity introduced in the experiments for this specific PMHS (V2371). Due to the positioning, the buck will struck the pedestrian at $t_{pre} = 30$ ms.

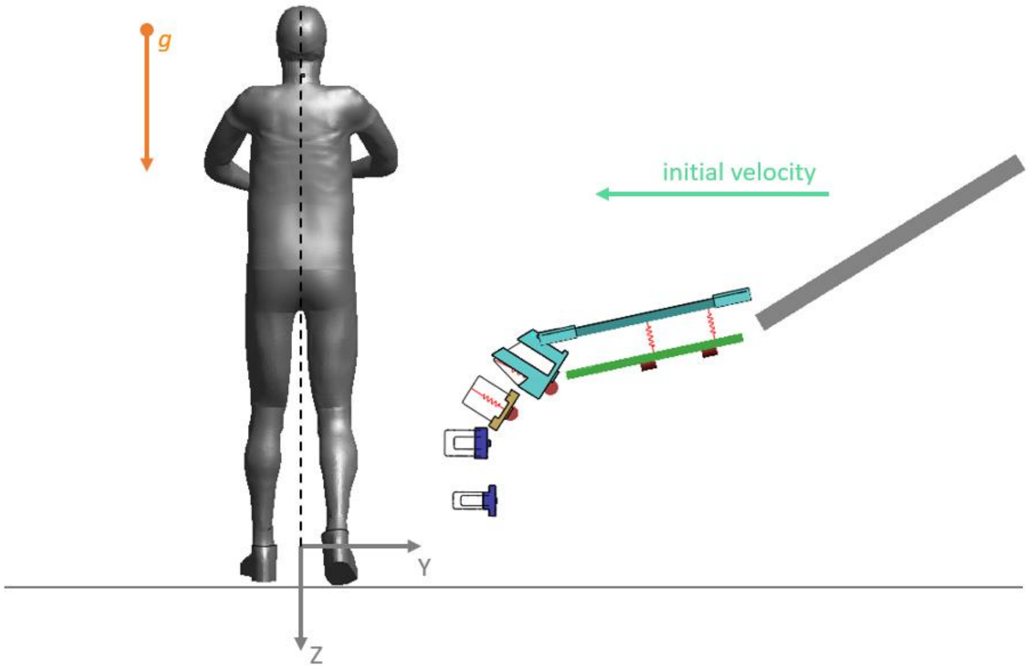

Figure 9: Boundary conditions implemented in the validation environment

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.

1.4 Post-Processing

The plausibility of the simulation is to be checked in addition to the head contact time.

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 (HIT) 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 10). 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 10: Example force curves for illustration of HIT measurement.

References

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8. Wu et al. (2017): Evaluation of biofidelity of THUMS pedestrian model under a whole-body impact condition with a generic sedan buck. Traffic Injury Prevention, p. 148-154.
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