EURO NCAP
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Human Body Model Simulation for Frontal Impacts

Crash Protection

Technical Bulletin CP 551

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PREFACE

During the test preparation, vehicle manufacturers are encouraged to liaise with the laboratory and to check that they are satisfied with the way cars are set up for testing. Where a manufacturer feels that a particular item should be altered, they should ask the laboratory staff to make any necessary changes. Manufacturers are forbidden from making changes to any parameter that will influence the test, such as dummy positioning, vehicle setting, laboratory environment etc.

It is the responsibility of the test laboratory to ensure that any requested changes satisfy the requirements of Euro NCAP. Where a disagreement exists between the laboratory and manufacturer, the Euro NCAP secretariat should be informed immediately to pass final judgment. Where the laboratory staff suspect that a manufacturer has interfered with any of the setup, the manufacturer's representative should be warned that they are not allowed to do so themselves. They should also be informed that if another incident occurs, they will be asked to leave the test site.

Where there is a recurrence of the problem, the manufacturer’s representative will be told to leave the test site and the Secretary General should be immediately informed. Any such incident may be reported by the Secretary General to the manufacturer and the person concerned may not be allowed to attend further Euro NCAP tests.

DISCLAIMER: Euro NCAP has taken all reasonable care to ensure that the information published in this protocol is accurate and reflects the technical decisions taken by the organisation. In the unlikely event that this protocol contains a typographical error or any other inaccuracy, Euro NCAP reserves the right to make corrections and determine the assessment and subsequent result of the affected requirement(s).

CONTENTS

DISCLAIMER

This document describes the Euro NCAP Virtual Testing Crashworthiness (VTC), simulations with Human Body Models (HBMs), which are requested to collect data to investigate the usage of HBMs for Euro NCAP assessments for research purposes.

HBMs are currently not a standardised tool for vehicle assessment: HBMs demonstrate good prognostic capabilities in kinematic analyses. However, HBMs are currently not considered as standardised state-of-the-art measurement devices for predicting thoracic injuries.

Provided simulation results do not represent vehicles crash performance. The results are not used to evaluate vehicle passive safety performance, but rather the performance of the procedures and the HBMs instead. Therefore, currently dummies are the standardized tool for vehicle assessment. The evaluation results obtained using the procedure outlined in this document inherently reflect HBM variability and the technical limitations associated with vehicle simulation, including the modelling of airbags and other vehicle components.

Research regarding HBMs will continue and in 2029, HBM simulations shall become part of the Euro NCAP assessments.

The qualification procedures of the HBMs, used throughout this protocol, are included in Technical Bulletin CP 550.

The quality and validity of the simulation models of the vehicle interior and restraint systems are evaluated according to the HIII Simulation Protocol as a prerequisite for the procedures described in this document.

1 INTRODUCTION

1.1 Definitions

Throughout this protocol, the following terms are used (listed in alphabetical order):

50M – 50th percentile anthropometry (of the HIII dummy or HBM)

Crash Time Zero (t0) – The time when crash simulation pulse is starting (sled acceleration >0, ignoring pre-crash braking).

Sled Test Protocol – **Euro NCAP Protocol - Crash Protection - Frontal Impact**

HIII – Hybrid III dummy

HIII Simulation Protocol – **Euro NCAP Supporting Protocol - Crash Protection - Virtual Testing**

ISO Scores – As validation criteria, ISO scores are calculated according to the implementation of the python script 'Objective Rating Metric for non-ambiguous signals according to ISO/TS 18571' available at https://openvt.eu/validation-metrics/ISO18571, which is based on ISO TS 18571-2024.

LS-Dyna – LS-Dyna finite element solver from ANSYS, Inc

OpenRadioss – Free, publicly available FE solver licensed under AGPL-3.0

Radioss – Altair Radioss finite element solver

Simulation Data – Prescribed outputs from simulations of the virtual frontal tests in the prescribed format according to Section 5.

Vehicle Manufacturer (VM) – Vehicle/car manufacturer, or supplier, contractor/consultant performing simulations for the virtual assessment.

VPS – Virtual Performance Solution finite element solver from ESI Group, a part of Keysight Technologies

Vehicle Simulation Model – A virtual model of the vehicle and/or body in white on a sled, which has been calibrated (parameters have been optimised to reach a target response (reference) defined) and validated (predictions have been compared with the results from mechanical tests without any modifications to the model parameters after calibration) by the VM beforehand. This happens based on component, sled and vehicle tests. It covers all vehicle relevant structures and objects.

VTC Server – Virtual Testing Crashworthiness Web application for uploading, processing, and reviewing the provided data and store it on the Euro NCAP Server. It is accessible by VMs through the link https://vtc.euroncap.com and can be accessed with the user account used for data upload on the Euro NCAP dashboard.

1.1 Overall Process

Only simulations with HBMs, which fulfil the requirements in CP 550, will be accepted. The documentation of the fulfilment of these requirements has to be uploaded together with the HBM simulations. Further information on this documentation is provided in CP 550.

The HBM simulations have to be submitted together with the HIII simulations according to the Crash Protection Virtual Testing and Frontal Protocol.

2 REFERENCE SYSTEM

The reference system of the vehicle shall be the same as defined in the Crash Protection Virtual Testing protocol

3 SIMULATION DATA

3.1 Requested Files

The following files are requested for each vehicle:

- Documentation of the HBM requirements according to CP 550.
- Simulation metadata – Definition files providing the relevant IDs of the HBM and vehicle simulation model in JSON format. Templates are available at https://openvt.eu/EuroNCAP/vtc-hbm-templates.

The following files are requested for each load case[1]:

- Simulation output files, depending on the used solver:
  - LS-Dyna:
    - binout files, or
    - CSV files derived from the binout files using the Jupyter notebook available at openvt.eu/EuroNCAP/vtc-hbm-templates/tree/main/Data_Extraction
  - VPS:
    - ERFH5 files, or
    - Selected ERFH5 files and/or complementary CSV files derived from the ERFH5 files with a script available from the Keysight Technologies Support
  - Radioss/OpenRadioss:
    - Time history (T01) files
- Filled-in Excel file on Frontal Settings, Initial Position and Mesh Quality:
  - Frontal_VTC.xlsx
- Animated results: Videos of the animated simulation results, meeting the following requirements:
  - Animations need to be analysed with an output interval of 2 ms or less.
  - Videos are accepted with the following specification:
    - Format: .mp4 or .avi
    - Codec: H.264
    - Frame rate: 10 frames per second
    - File size: 1-10 MB

    Note: the resolution/frame size shall be maximised within the file size limit.
  - 5 videos need to be prepared per load case with the same views used for the HIII simulations

[1] Templates are all available on https://openvt.eu/EuroNCAP/vtc-hbm-templates/

3.2 Simulation output files

All outputs except the strain data must be provided with an output frequency of 10 kHz and no additional filtering shall be applied[2] on the raw data. For the strain and energy data, an output frequency of 1 kHz is sufficient

All outputs listed below are to be provided. If any output is missing (except airbag-related channels, if no airbag is present), the data upload will be automatically rejected from the VTC server:

- All HBM outputs specified in CP 550 as required for VTC
- The same vehicle specific outputs as used for the HIII simulations
- The same outputs of the whole setup as for the HIII simulations

The raw data output file of the FE software will be used to derive the trajectories, velocities, accelerations of nodes, contact forces, energies of the whole setup and part groups as well as rib strains defined in the ID.def file by the VM. Only the extracted data and the hashes of the raw data files will be stored at the Euro NCAP server, not the raw output file. For the analysis of the strains in the ribs, the raw outputs of the FE software will be transformed to the principal directions for each integration point. The maximum and mean value of the integration point for each element are then used and summarised as maximum and 95th percentile strain of each rib at each time step of the simulation. The data will be anonymized and shared among the participants of the Euro NCAP VTC Working Group. The aim of this analysis is to investigate, within the VTC WG and in anonymized form, the potential use of strain outputs for injury prediction, which may be implemented in 2029. Tools and scripts to perform a transparent and standardized process (at each step of data processing) shall be established and reviewed within Euro NCAP VTC WG before HBM assessment in 2029.

The data extraction can be applied already beforehand by using the scripts available on https://openvt.eu/EuroNCAP/vtc-hbm-templates. The derived CSV files can be shared alternatively for Euro NCAP as interim step. In 2029, it is intended that only raw data generated from the FE solver directly will be accepted to ensure traceability in non-testable conditions.

[2] In LS-Dyna IACCOP has to be set to 1 to get meaningful accelerations.

4 SIMULATION MODELS

Throughout this process, the exact same vehicle simulation models[3] as used for the HIII simulations have to be used according to the specification in section 4 of the Frontal Sled Test Protocol.

The HBM also needs to remain unchanged after qualification, except for the position of the nodes, which require repositioning for the different load cases.

4.1 Load Cases

The load cases shown in Table 1 have to be simulated and set up accordingly.

If position 3 and/or 4 leads to a clearly unrealistic initial position (e.g. pedals not reached, unrealistic high compression of the seat causing numerical instabilities), these positions can be skipped. Evidence needs to be provided to the secretariat, as to why one of these positions could not be simulated. If another position cannot be reached, the secretariat should be contacted.

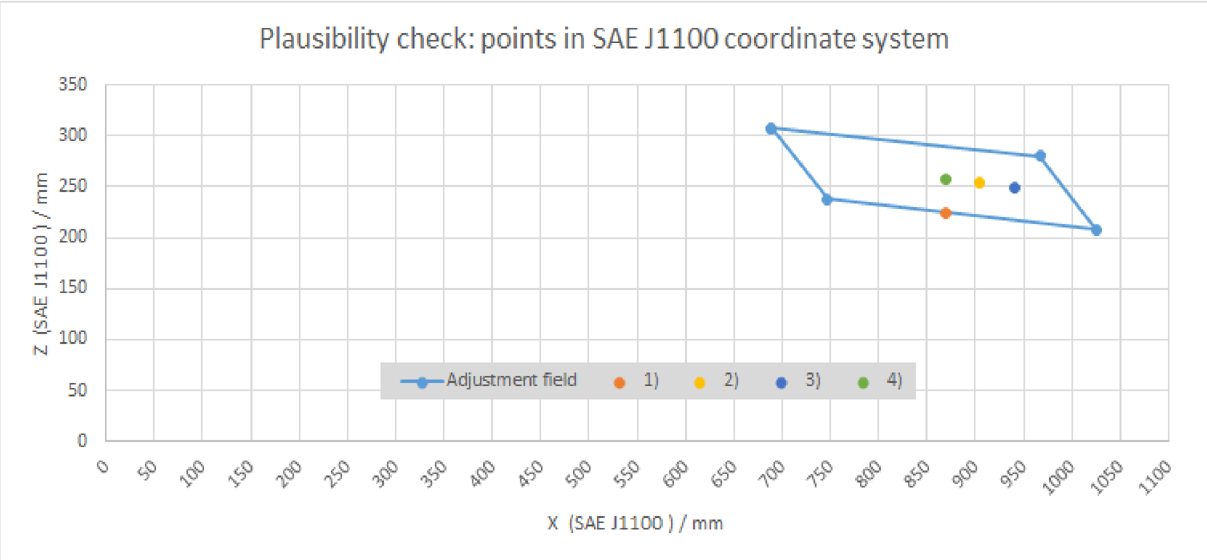

Figure 1: Simulated Load Case Positions (Hip Centre of HBM)

[3] For 2026-2029 the usage of a smaller time step compared to the HIII simulations is allowed.

Table 1: HBM load cases.

Nr	Seat x	Seat z	Acetabulum Centre (HBM equivalent to H-Point) position	D-Ring (if adjustable)	Seatback angle
1	HIII 50M	HIII 50M (lowermost)	Based on ergonomic model for given seat position +- tolerance from volunteer tests	Same as used for HIII 50M (reference)	Same as used for HIII 50M
2	Based on ergonomic model for HBM	Based on ergonomic model for HBM		Move according to seat height adjustment	
3	Based on ergonomic model for HBM + Tolerance from RMSE	Based on ergonomic model for HBM		Reference increased by delta z of seat or; if this is below lowermost D-Ring position, the lowermost position has to be used	
4	Based on ergonomic model for HBM - Tolerance from RMSE	Based on ergonomic model for HBM		Reference increased by delta z of seat or; if this is above uppermost D-Ring position, the uppermost position has to be used	

The same crash pulse shall be applied for all simulations, which needs to be exactly the same as the crash pulse used for the HIII 50 kph load cases.

4.2 HBM Positioning inside the Vehicle

The HBM has to be positioned according to the load case matrix specified in Table 2 in an ergonomic way as specified in the Appendix.

4.2.1 Target Seat Position

The following positioning procedure shall be applied:

1. The seat shall be moved into the x and z H-Point Positions resulting from the calculations in Frontal_VTC.xlsx (explained in Appendix A)
2. The backrest angle shall be kept constant
3. If notches do not allow to reach the target position, the position one notch higher in z and one notch rearward in x shall be used
4. There shall be no initial contact between head and roof. If it is observed that the head is contacting the sunshield, the z position of the seat should be lowered so that a clearance of 75 mm[4] between the head and the roof is ensured.
5. If contact between an integrated head restraint and the roof is observed, the seat position should be lowered as little as possible to avoid initial contact
6. If initial contact occurs between the steering wheel column and the HBM, the steering wheel column shall be slightly adjusted, just to avoid the initial contact (a minimum distance of 10 mm).
7. If this adjustment is still not sufficient, the seat can be adjusted longitudinally (x-position) as little as possible to avoid initial contact between the steering wheel (column) and the HBM.
8. The finally used positions should be documented in Frontal_VTC.xlsx.

4.2.2 HBM posture

To reach the initial postures of the HBM, the VM can use their preferred positioning tool and method. The same settling / seat squash method as for the HIII simulations shall be applied.

- The targeted Hip_x and Hip_z points shall be reached within the provided tolerances specified in Frontal_VTC.xlsx/HBM Positioning.

Direction	Tolerance [mm][5]
x	± 27.6
z	± 13.7

- The complete spine, sacrum and pelvis posture should remain unchanged from the qualified HBM. Only full body rotations around AC are allowed and only the extremities should be positioned to fit into the vehicle and to fulfil the following boundary conditions:
    - The mid-sagittal plane of the HBM should be aligned with the longitudinal-vertical (x-z) plane passing through the H-Point of the seat.
    - The HBM hands shall have their palms in contact with the steering wheel at a position of a quarter to three. The hands do not have to grasp the steering wheel.

[4] Reed, M. P., & Schneider, L. W. (1999). Investigating Driver Headroom Perception: Methods and Models. In SAE Technical Paper Series. https://doi.org/10.4271/1999-01-0893
[5] Derived from RMSE for hip point from Reed et al., 2002

    - The elbows should be positioned as close as possible to the torso.
    - There shall not be any intersection between the HBM and the seat.
    - The HBM’s back should be in contact with the seat back (no full contact required, but contact force should be >0 at 0.1 ms after t0) if possible. If no contact can be reached within the tolerance specified for the Hip_x location, a gap is allowed, but has to be documented.
    - The upper legs of the HBM shall be in contact with the seat cushion.
    - The left foot should be placed on a footrest and the right foot should be positioned onto the accelerator pedal. Both heels should be on the floor.
    - The initial distance between the knees of the HBM shall be 210 mm ± 5 mm when measured at the medial femoral epicondyle. If this leads to a posture where the foot is not aligned with the footrest, the distance should be increased or decreased and documented. The left and right tibia axes (axes from the midpoint of the femoral epicondyles to the inter-malleolar point) should be aligned as much as possible with the longitudinal-vertical plane to avoid unnatural abduction or adduction of the knee or ankle joint.
    - The HBM head does not have to be in contact with the headrest. The eye position should be documented (measured on the lowermost point of the orbit).
- The mesh quality of the original and positioned HBM shall be documented in the VTC_frontal.xlsx file. The same pre-processing software (free choice of the tool) has to be used for both analyse.
- The HBM’s contacts shall be checked for initial penetrations and intersections after positioning before running the simulations with a pre-processor tool. The control settings shall be defined to ensure warnings for initial penetrations are outputted and if any warning is reported, those have to be documented as part of the report.
- The HBM shall be settled / positioned in the seat, so that no non-physical spring-back occurs at the simulation start (see quality criterion on initial displacement of AC-Point specified in section 6.1).
- The Excel file Frontal_VTC.xlsx needs to be filled in to specify the initial position of the HBM and the seat. The measures shall be taken in the global vehicle coordinate system. For the seatbelt routing, the point of intersection on the middle line of the sternum with the upper edge of the shoulder belt is to be measured.

5 QUALIFICATION OF SIMULATION MODELS

5.1 Qualification of Human Body Models

The qualification requirements for HBMs as described in Technical Bulletin CP 550 need to be fulfilled.

5.2 Quality criteria for simulation setup

The simulation data is only accepted for the monitoring phase if all quality criteria for all load cases are fulfilled. If any of them fail, the simulation dossier will not be accepted. The quality criteria are calculated automatically on the VTC server as soon as the data is uploaded. A preview is provided to the user and the upload needs to be confirmed by the user after checking the preview.

5.2.1 Quality Criteria

- Max. hourglass energy of full setup must be <10% of max. internal energy.
- Max. mass added due to mass scaling to the total model is less than 5% of the total model mass throughout the simulations.
- Max. mass added due to mass scaling to the HBM is less than 5% of the total HBM mass throughout the simulations.
- Less than 10 mm H-point z-displacement recorded in first 5 ms of the simulation (5 ms after t_0).
- The simulation time needs to exceed the minimum time (T_{end}) defined in the Crash Protection Virtual Testing protocol for frontal impacts.

Monitored:

- Max. hourglass energy of all HBM components / max. internal energy of the HBM
- Hourglass energy of all HBM components / internal energy of the HBM at the time of max. head excursion

APPENDIX A ERGONOMIC HBM POSITIONING

To determine the ergonomic posture of the HBM within the vehicle environment, the excel file Frontal_VTC.xlsx shall be used, which is based in Hu et al., 2019.

Therefore, the following inputs are required:

- Seating height / stature ration SHS of the HBM. If not known it shall be set to 0.52
- Stature of the HBM
- BMI of the HBM
- L27 (CA) seat cushion angle (according to SAE J826 using the HPM with the 95th leg lengths in the Seat reference point SgRP reference position)
- H30 seat height of Seat reference point SgRP (according to SAE J1100)
- L6 steering wheel to ball of foot reference point (BOF) distance in X (according to SAE J1100)
- STA seat track angle

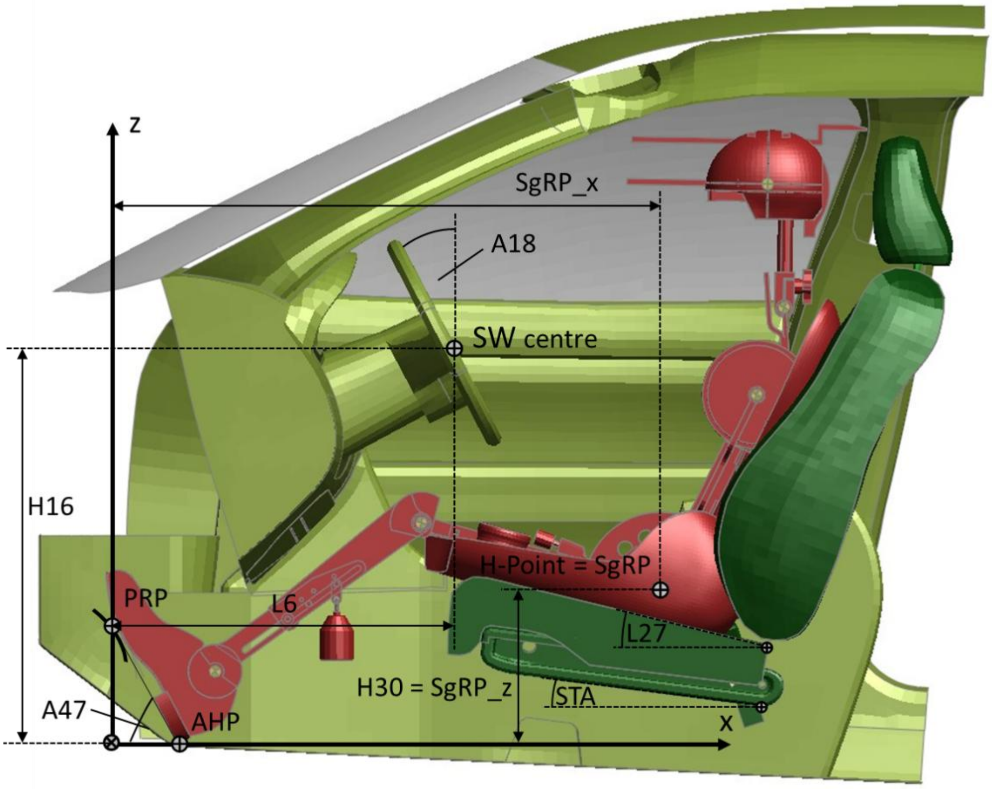

Figure 2: Measures used in the regression model for positioning (Pachoinig, 2025)

The excel file Frontal_VTC.xlsx shall be filled in to derive the target location of the hip center of the HBM for each configuration.

References:

- Reed, M. P., Manary, M. A., Flannagan, C. A. C., & Schneider, L. W. (2002). A Statistical Method for Predicting Automobile Driving Posture. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *44*(4), 557–568. https://doi.org/10.1518/0018720024496917
- Hu, J., Zhang, K., Reed, M. P., Wang, J.-T., Neal, M., & Lin, C.-H. (2019). Frontal crash simulations using parametric human models representing a diverse population. *Traffic Injury Prevention*, *20*(sup1), S97-S105. https://doi.org/10.1080/15389588.2019.1581926
- Judic, J.-M., Cooper, J. A., Truchot, P., van Effenterre, P., & Duchamp, R. (1993). More Objectives Tools for the Integration of Postural Comfort in Automotive Seat Design. In *SAE Technical Paper Series, SAE Technical Paper Series*. SAE International400 Commonwealth Drive, Warrendale, PA, United States. https://doi.org/10.4271/930113
- Pachoinig, P. (2025). Beyond percentiles – Influence of deviations in human proportions on kinematics and injury risks in frontal crashes. *Graz University of Technology, Master's Thesis.*