OSCCAR:

FUTURE OCCUPANT SAFETY FOR CRASHES IN CARS

Public available description of Virtual Assessment procedures on two pilot cases

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1 EXECUTIVE SUMMARY

This deliverable summarises the considerations on procedures of using Human Body Models (HBMs) in Virtual Testing (VT) scenarios within the OSCCAR project. The content of this report is derived from previous technical deliverables and reports of the OSCCAR project and is addressing a wider and more general public.

The procedures executed in the OSCCAR homologation test case are described in brief. For Finite-Element (FE) models as well as for Multi-Body (MB) models those procedures were used. The test case also included the consideration of the transition between pre-crash phase and in-crash phase of the HBM.

For general considerations derived within the OSCCAR project, elements of Virtual Testing procedures with HBMs are explained in this deliverable. Addressing the wider stakeholder community, they are presented in the form of answers to typical questions of stakeholders collected in project-internal workshops.

With this report, OSCCAR project attempts to provide a widely usable contribution to discussions preparing the future use cases of VT procedures including HBMs.

Keywords: Virtual Testing, Human Body Modeling, Homologation Test Case, pre-crash phase and in-crash phase

2 DESCRIPTION OF WORK

2.1 Description of procedures applied in OSCCAR (ViF)

This chapter describes the procedures which were defined to achieve comparable results in occupant simulations with HBMs in a validated environment (OSCCAR homologation testcase). Comparable simulations in this respect means that:

- Simulations are conducted under the same boundary conditions (environment, pulse, sitting position)
- Output definition is harmonized
- Assessment method is harmonized

The procedures were defined for two cases. First, a solely incrash simulation and second a combined pre- and incrash simulation.

The procedure for the first case (incrash) is valid and used as well for the second case(combined pre- and incrash), which presents only the additional points for the pre-crash phase. The procedures for both cases were applied to Finite Elements(FE) and Multibody (MB) models.

Links are provided for the public available models and data which were used in the homolgation testcase. See chapter 3 in this report or Deliverable D4.3 [1].

2.1.1 Alignment for comparable occupant simulations with HBMs for in-crash simulations

Prior to the simulation, following parameters were predefined. Note, that e.g. the belt system was partly encrypted and allowed the adaption of the activation times. Further modifications, like load curves, belt anchor points, etc. were not possible, but would be necessary in a completely open model. The same applies to the seat model, which did not require any additional parameters to be set.

- Boundary conditions (crash pulse and environment)
  - Pulse
  - Belt activation times
- Anthropometric percentile
- Initial HBM position including harmonized landmark definitions

2.1.2 Assessment and evaluation parameters to ensure objectively comparable environment performance

The following subchapters list the parameters which are assessed after the simulation, to ensure comparability. Figure 1 shows the steps in the conducted order.

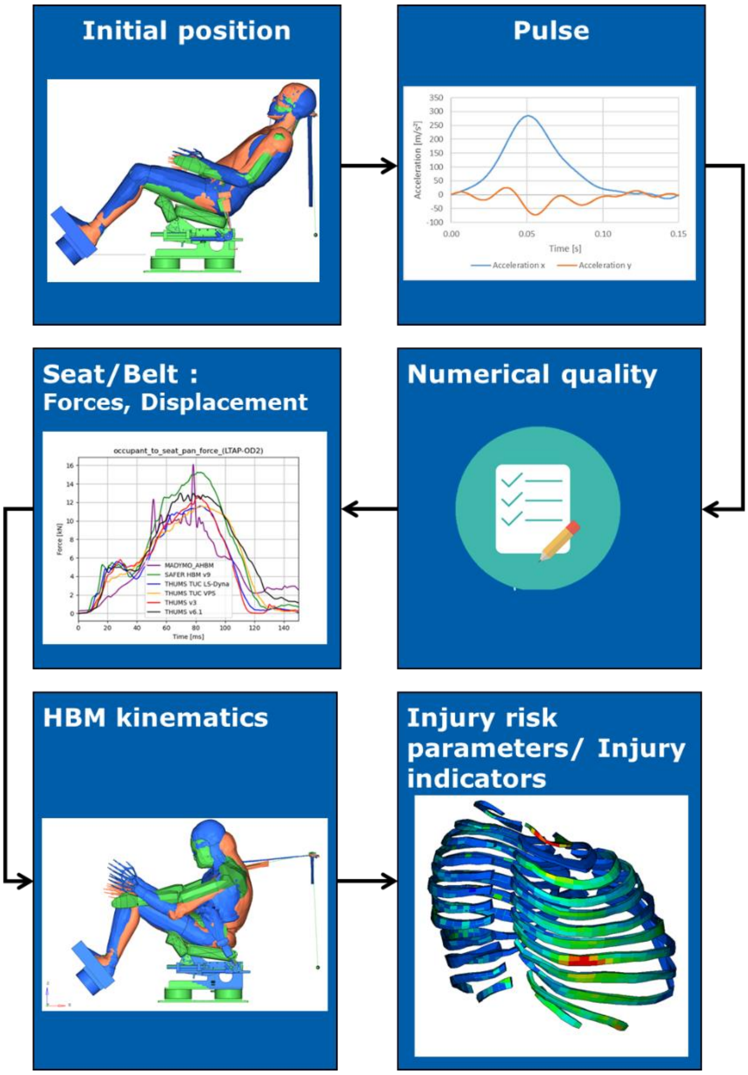

Figure 1 Assessment steps to ensure comparable HBM simulations

2.1.2.1 Numerical quality checks

- Hourglass energy < 10% of total energy
- Artificial mass increase < 3%

2.1.2.2 Environment

The lists in this chapter contain the parameters which are assessed in the post-processing. Most of the listed parameters already depend on the interaction between the occupant model and the environment. Therefore, the are not equal if different occupant models are used. The only exception is the sled pulse, which must be equal for comparing simulations.

2.1.2.2.1 Sled

Assessed output	Information
Sled node (Vehicle CoG)	x(t), y(t), Rotation z-axis (t)

Table 1 Sled parameters

2.1.2.2.2 Seat

The listed parameters for the seat refer to the used seat (LAB CEESAR) in the OSCCAR project. They might vary fundamentally if other models are used.

Assessed seat output	Information
Seat pan	Angle (t)
Sub pan	Angle (t)
Contact force HBM – seat force x/z	Force (t)
Contact force HBM – sub pan force x/z	Force (t)

Table 2 Seat paramters

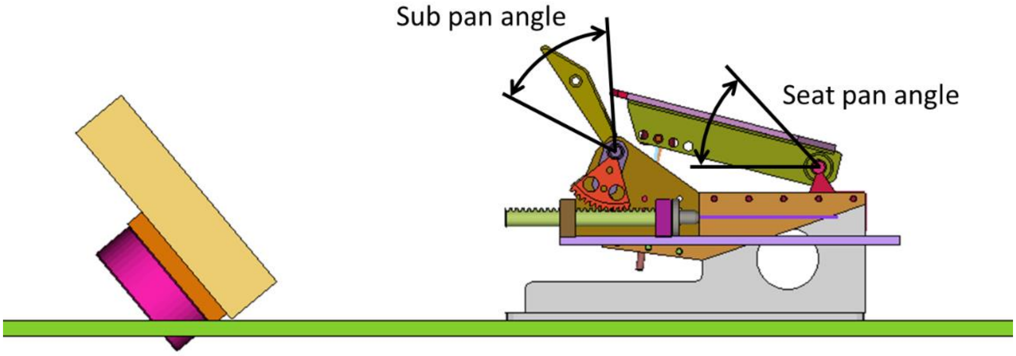

Figure 2 Seat pan and sub pan angle on the LAB CEESAR seat

2.1.2.2.3 Seatbelt system

Assessed belt output	Information
Belt pay in/out shoulder belt retractor	Displacement (t)
Belt pay in/out lap belt retractor	Displacement (t)
Buckle pull in	Displacement (t)
Webbing transport through tongue	Displacement (t)
Shoulder belt force (B2, B3)	Force (t)
Lap belt force (B4, B5, B6)	Force (t)
Buckle force (B4, B5)	Force (t)

Table 3 Seatbelt parameters

2.1.2.2.4 Floor / Vehicle

Assessed floor output	Information
Toe pan resultant force	Force (t)

Table 4 Floor / Vehicle parameters

2.1.2.3 Recommended landmarks for HBM kinematic assessment

Deliverable D4.3 [1] lists the proposed landmarks and a reasoning for the selection. The head needs to be described in terms of its kinematic response during the crash phase as the risk of contacting surrounding structures within the vehicle is to be observed. The movements of markers on the upper part of the spine are relating to payout and force of the shoulder belt, which in turn influences the thorax loading. The points further down the spine are important to be tracked in order to understand deformations and potential threads to the lumbar spine and to analyse potential differences in stiffness of the different spine segements. Together with the reference points on the pelvis, the markers in the lower spine positions are relevant for the investigation of submarining phenomena. Most markers are tracked in three dimensions, only the lower spine markers are limited to x and z direction, as no relevant asymmetric response is expected there.

Landmark	Assessed data
Porion (left/right)	x(t), y(t) z(t)
T1 (Left/right midpoint)	x(t), y(t) z(t)
T8 (Left/right midpoint)	x(t), y(t) z(t)
T11 (Left/right midpoint)	x(t), z(t)
L1 (Left/right midpoint)	x(t), z(t)
L3 (Left/right midpoint)	x(t), z(t)
Acetabular centre (left/right)	x(t), z(t), y angle(t)
ASIS / PSIS	Pelvis angle (t)

Table 5 Proposed landmarks

2.1.2.4 Injury indicators and injury risk parameters

Injuries are documented in two groups. Injury indicator lists parameters, for which a injury risk curve does not exist currently. In contrast to that, the injury risk for certain AIS level can be determined for the injury risk parameters.

Injury indicators

A definition for the section forces can be seen in Deliverable D3.3 [3].

Injury indicator	Information
Lumbar spine forces	z-Force (t)
Lumbar spine moments	y-Moment (t)
ASIS forces	Resultant Force

Table 6 Injury indicators

Injury risk parameters

Injury risk were assessed for head (HIC 15, BrIC and SUFEHM) and for the Thorax (Forman criteria, maximum rib strain).

Body region	Criteria	AIS level
Head	HIC 15	AIS 2+
	BrIC	AIS 2+
	SUFEHM	AIS 2+
Thorax	Forman criteria	AIS 1 - 3
	Maximum rib strain	

Table 7 Injury risk parameters

Head injury risk determination was done with SUFEHM, which requires local head accelerations and rotational velocities according to the SAE J211 definition.

Rib fracture risk was determined for two models according to Forman et al. [2]. The criteria is based on the determination of the maximum principle surface strain per rib. Deliverable D3.3 [3] lists three suggestions for the determination of the maximum principle surface rib strains.

- Timestep for output generation: 0.2 ms
- Smoothing the risk curve
- Exclusion of certain shell elements on the ribs from the assessment

2.1.2.5 Alignment for continuous pre- and in-crash assessment with HBMs

Alignments

- **Pulse transition between pre- and in-crash at t0**
  Usually, an incrash pulse starts with an acceleration of zero, whereas the end of a pre-crash pulse has most likely a certain value. To avoid an unsteady pulse it has do be defined how pre- and incrash pulse can be combined. Figure 3 shows, how that is defined in the OSCCAR homologation testcase.

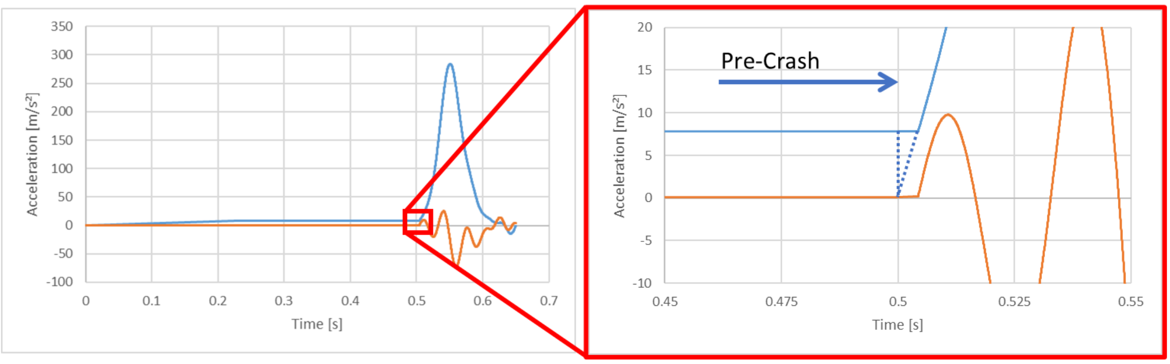

Figure 3 Combination of pre- and incrash pulse

- **Initial HBM position**
  Some controller concepts for active HBMs require a certain amount of time for initialization / stabilization, before the pre-crash pulse can be applied. During that time the initial position of the HBM changes slightly. In the OSCCAR homologation testcase report it is simply documented, to which model this applies and how much time they need.

Assessment and evaluation

- **Belt forces**
  Evaluation of the correct activation time for pre-crash systems in the belt is done with the belt forces.
- **Pre/Incrash capabilities of the HBMs**
  Among the available (active) HBMs several strategies were developed to consider the kinematics of the pre-crash phase. Some models are capable of simulating both phases, while others use transition methods to hand over the kinematic information between a pre- and an incrash model. In the OSCCAR homologation testcase it was simply documented, which model is capable of the points listed below:
  - **Continuous or transition approach**
    Is the combined simulation done with a single model or is the kinematic information handed over?
  - **Stress/ Strains in the model**
    Are stress and strain in the HBM transferred between pre- and incrash simulation
  - **Tension in the belt**
    Is the method capable of transferring the state of the belt (tension, pull out and contact with the HBM) from pre- to incrash
  - **Activation of muscles**
    Is the muscles activity during the incrash phase switched off, constant or controlled

2.2 Long-term considerations for Virtual Testing procedures (BASt, LMU)

Challenges arising with the new or modified occupant loading scenarios in automated vehicles will further motivate the use of Virtual Testing procedures. So does increasing the ambitions in covering the occupants' diversity. Therefore, some vision and considerations on the long-term perspective of Virtual Testing incorporating Human Body Models are given in this section, grouped into answers to questions which stakeholders might ask, based on the project-internal workshops in WP5.

2.2.1 What is needed for a VT process with Human Body Model?

Like any testing-based procedure for the assessment vehicle safety the definition of an assessment load case is needed (Phase 3) is needed. This requires the definition of the test and assessment tool, which in this case is the HBM. A requirement therefor is a process that makes sure the HBM is certified for this specific load case, which also requires validation.

To make sure also the vehicle model is certified in a may that it can be admitted two phases are proposed by the OSCCAR project. These phases apply to the vehicle as shown in Figure 1CROSSREF. The actual homologation or assessment is performed in the third phase.

In the first phase, a model is developed and questioned by the developers. There is a distinct phase between (phase 2), dedicated to answering the question whether it is justified to use this model in phase 3. By passing this phase successfully, a model is admitted to the actual VT and certified for that use.

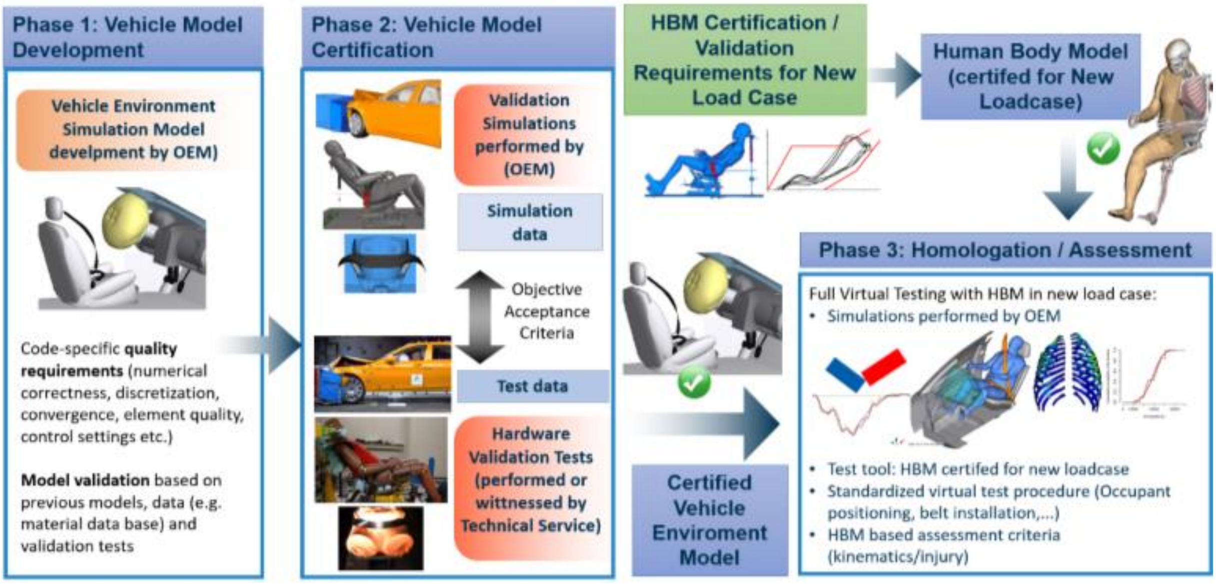

Figure 4 Flowchart OSCCAR HBM-based virtual testing procedure

2.2.2 Why is it that important to specify in detail how the models are admitted to VT?

One of the huge advantages of using HBMs is their potential to depict more precisely and more widely than anthropomorphic test devices (ATDs) how injuries may form in a certain scenario. If this potential is to be exploited, the application of HBMs by definition goes beyond the application scenarios of the existing ATDs. An example is a positioning in a reclined seat, which may be difficult to be addressed with ATDs.

If an assessment of the occupant’s protection with an HBM is made in a (sub-) scenario for which testing with an ATD is not an option, there will not be any alternative procedure to derive this specific assessment. This means, for certain parts of an assessment there is no fall-back solution. If the assessment with the HBM in VT fails, it cannot be done otherwise. If there is doubt about the correctness of the assessment, there is no option to confirm the results with a physical test.

Such scenario of virtual assessment without physical fallback option is a full Virtual Testing (in contrast to a hybrid VT). After admitting models to the process there needs to be trust in those models.

2.2.3 Why is the vehicle side that important in Virtual Testing with HBMs?

Due to confidentiality reason the vehicle model not shared in consumer testing or regulatory with the consumer testing organisation or with the technical service responsible for the type approval testing. Therefore, an objective proof of validation of the vehicle model is needed to guarantee a similar level of trust in the virtual testing results as it would be expected from hardware based real testing.

To make such processes credible, there needs to be an option, at any point in time, for the inspector/technical service or similar to answer the question whether a vehicle model (here more precisely: the models of the vehicle parts directly surrounding the occupant) is a valid model. This leads to the need of comparing one or more simulations to a single experimental test conducted afterwards.

2.2.4 What sources of scatter need to be looked at when developing a VT procedure?

Comparing a deterministic output signal of a validation simulation conducted with the vehicle model to the output of one corresponding test conducted afterwards will always show some deviation. The reason for this deviation is mainly the test scatter observed in the real tests. To decide whether this deviation can be explained and justified by the expected amount of real test scatter or non-acceptable deficiencies in the simulation model, basic understanding of the different sources of scatter are necessary.

The main courses of scatter are:

- Scatter originating from process/procedure
- Scatter from a physical device (Validation Device)
- Scatter from vehicle components

2.2.5 Is scatter of vehicle components relevant in today's occupant protection assessment procedures?

Today, to pass a test or achieve a desired rating threshold OEM implements safety margins in the design of the relevant vehicle components. If vehicle components are designed in a robust way it possible to reduce the needed safety margin. In a virtual testing procedure, it would be desirable to keep this motivation for robust design and implementation of safety margins.

2.2.6 What can the decision to admit a HBM to such process be based on?

Because many different HBMs are available it is important to specific requirements which HBMs have to fulfil to be admitted for one specific Virtual Testing procedure. To use the HBM output for an objective comparable assessment of vehicle safety the comparability of the model and finally the comparability of results generated with the models is crucial.

However, in the first place, as the main motivation is to increase the safety for human occupants, it is the biofidelity of the HBMs that needs to be ensured. Therefore, one key requirement as part of the model certification requirements should be validation of the HBM against human subject (PMHS, volunteer) test results.

2.2.7 Why distinguish between validation and comparability?

Small changes in HBM versions regarding a new code version, improvement in contact modelling, fixing of small modelling issues might not require a new check of all validation requirements. In these cases, it would be sufficient to ensure that a new, slightly updated model still provides comparable results like a previously validated model. However, larger changes in an HBM model or significant evolution of HBM modelling techniques would require a new check of relevant validation achievements.

2.2.8 What preprocessing needs to be defined for HBMs in VT?

The application of HBMs in VT introduces a challenge in finding the appropriate level of detail of describing the geometric properties of the considered occupant(s). On the one hand, human body modelling offers a great potential to represent diverse occupants and populations, as such models are much easier modified in terms of their anthropometry than dummies (ATDs). On the other hand, as with any testing procedure, it is in the interest of all stakeholders to describe as precisely as possibly how an assessment is made in order to avoid ambiguity and uncertainty.

Currently, the most realistic approach to describing occupant geometry in VT preprocessing is the definition of target anthropometries and target positions. For that, standardised methods are needed. One part of the description of a target anthropometry is the definition of lengths with according tolerances. For such measurements, reference points need to be used which can be identified unambiguously in every possible HBM. Therefore, a description of the process of identifying such reference points (e.g. the centre of a joint) is required. OSCCAR has contributed to such descriptions and the standardised naming of such points.

2.2.9 Which targets are to be prescribed for HBMs in VT?

Which target anthropometry is to be included in a VT procedure definition, would theoretically depend on the ambitions concerning protection of occupants. This might lead to the definition of representations of occupants at high risk. However, stakeholders will likely include considerations on anthropometries already covered in existing testing when defining new procedures. Human body models are usually based on the anatomy of individuals. The definition of tolerances for length measurements allows the acceptance of geometries originating from different individuals. This does however not represent a real variety in anthropometry.

For a given anthropometry, positioning targets need to be defined in a second step. This typically includes the prescription of the position of certain reference points with respect to the direct environment of the occupant and angles between articulated segments. It is the unambiguous definition of those targets rather than the prescription of a certain tool that is needed as part of the preprocessing of HBMs for VT.

2.2.10 Can injury risks be calculated independently from the actual HBM used?

The general procedure of how to translate a mechanical parameter into an injury risk should be model-independent and needs to be defined in a harmonised way.

Field quantities like strain are unlikely to be model-independent in the mid-term perspective. Injury risk curves relating a field quantity to the risk of sustaining an injury therefore need to be included in the preparation of an HBM for a specific application field. Based on a validation ensuring the necessary underlying body responses being human-like, injury risk curves have to be adapted to the specific HBM (and possibly to the specific application/load case). If different modelling techniques, such as multi-body systems and Finite-Element models are to be applied in the same procedures, the injury risk assessments will be based on different mechanical responses anyway, and therefore need to be addressed with specific risk curves.

3 DISSEMINATION, EXPLOITATION AND STANDARDISATION

The content of this report can be used for the development of future procedures of Virtual Testing. The observations and findings are brought into the discussions within HBM4VT group in the EURONCAP context.

Models of the elements of the reclined load case have been published on TUC repository (https://tuc-project.org/frontal-sled-reclined/) together with experimental data provided by University of Virginia and Autoliv. A positioning tool as used in the work for deliverable D4.2 [4] is available through https://openvt.eu/osccar/positioning. A postprocessing tool addressing the work described in D4.3 [1] is available at https://gitlab.com/VSI-TUGraz/Dynasaur .

Concepts and findings described in this report have been included in publications at carhs CAE Grand Challenge, VDI Vehicle Safety Conference, Aachen Body Engineering Days and IRCOBI.

4 REFERENCES

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A. ABBREVIATIONS AND DEFINITIONS

Term	Definition
ATD	Anthropomorphic test device
FEM	Finite-Element model
HBM	Human body model
MBS	Multi-body system
VT	Virtual testing