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Crash Protection Virtual Testing

Protocol

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CONTENTS

DEFINITIONS

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

AC – Assessment criteria

AC_{Limit} – Assessment criteria performance limits.

Combined models – simulation models including driver dummy, passenger dummy and vehicle environment**d_{AC}** – The difference in ratio between the simulations and physical tests.

r_{AC} – The ratio between the derived assessment criteria and assessment criteria limits. This ratio can be for the simulations rACsim and for the physical tests rACtest.

T0 – The time when crash is starting.

Tend – The time where the maximum head excursion in the impact direction is reached with an additional time margin. For frontal impact, the maximum head excursion in x-direction is used, with a 40% additional time margin. For side impact, the y-direction and 20% additional time margin should be used.

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.

Qualified dummy Model – The CAE model of a dummy, which fulfils all qualification criteria defined in the respective Technical Bulletin and can therefore be used for validation of the vehicle environment as well as for the virtual test cases.

S_i – Individual axis sensor score.

S_{Sensor} – Individual sensor ISO score.

Separate models – 2 separate models. One for driver and one separate model for passenger dummy. In both separate models the relevant vehicle environment must be represented.

Simulation Data – Prescribed outputs from simulations of the virtual tests

Test Data – Measurement data and documentation from physical sled tests

Validation – The process of determining the degree to which a model represents the real world in the context of its intended use. The model response is compared to a ground-truth. The model's prediction capabilities are tested.

Validation Load case – Load cases for which simulations and tests are available and can be therefore compared to validate the virtual vehicle model.

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

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 by the VM beforehand. This happens based on material and component tests as well as observations from sled tests. It covers the model of the sled, the vehicle structure, seat and restraint systems.

Virtual Testing (VT) Load case – Load cases that are simulated to assess the specific car, where no hardware sled test data is available.

VTC Server – Virtual Testing Crashworthiness Web Application to upload, process and review 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 data exchange server.

W_i – Weighting factors.

1 VIRTUAL TESTING PROCEDURE

The overall procedure for the virtual testing is outlined in the flowchart below, with further explanation on the individual steps as follows:

Step 1 - The VM is free to use whichever CAE dummy model for virtual testing. However, to gain trust in the CAE dummy model(s) used, Euro NCAP has prescribed certain qualification requirements that models must meet for virtual testing. These model acceptance requirements are specified in Euro NCAP Technical Bulletins CP 510 and CP 520.

Step 2 - Simulations of the predefined load cases are to be performed by the VM with their vehicle simulation models and the qualified dummy model(s). The results are to be shared with Euro NCAP in the prescribed format via the VTC server no less than two weeks before the physical sled tests. The datasets must include all specified information and fulfil the specified quality criteria. When the simulation data is approved, a unique *VTC Validation Test Ref Number* will be provided to the vehicle manufacturer by Euro NCAP.

Step 3 - After step 2 is completed, physical sled tests of the two validation load cases are to be performed. Test results shall be submitted to Euro NCAP via the VTC server in the prescribed format. The *VTC Validation Test Ref Number*, that was supplied by the Euro NCAP Secretariat, must be physically placed on the sled and visible all videos and referenced in the .mme file.

Step 4 – Euro NCAP makes A comparison of the hardware sled test results and simulation-based predictions is performed on the VTC server to validate the VM's virtual model of the vehicle environment (including seat, seatbelt, airbags, centre console,…). In doing so, Euro NCAP can establish the necessary confidence in the VM model, without physically requiring access to the model.

Step 5 – If the validation results of step 4 meet the validation criteria, this step (5) can be skipped. If the validation results are not sufficient, the VM must provide evidence showing this was caused by the specific hardware test conditions, deviating from simulation parameters. The simulations of the two validation load cases may be repeated with adjustments to only the prescribed boundary conditions from the sled tests.

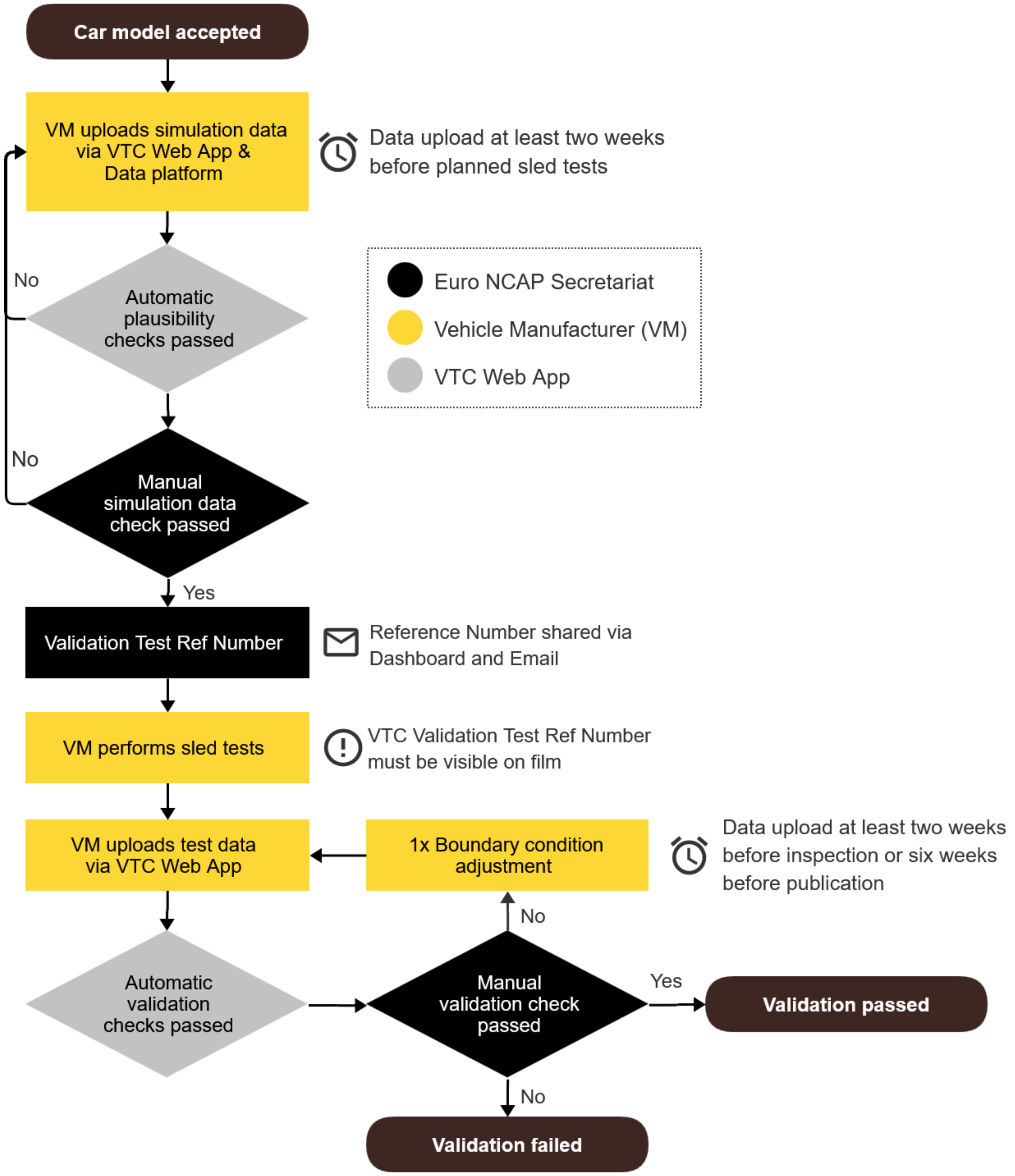
Step 6 – The results from the virtual testing load cases submitted in step 2 are considered for the vehicle rating.

It is essential that simulation results are provided and accepted (are complete and all quality criteria are fulfilled) before the sled tests are performed. The date of the hardware sled tests (validation load cases) shall be communicated to the Euro NCAP secretariat.

The sled tests must take place after the relevant type-approval processes and carried out with original car components.

Finally, the VTC server closes six weeks before publication date. All required data, including boundary condition adjustment, must be submitted prior to that date.

The overall work flow from vehicle selection up to scoring is shown below


Car model accepted
VM uploads simulation data via VTC Web App & Data platform
Data upload at least two weeks before planned sled tests
No
Automatic plausibility checks passed
Euro NCAP Secretariat
Vehicle Manufacturer (VM)
VTC Web App
No
Manual simulation data check passed
Yes
Validation Test Ref Number
Reference Number shared via Dashboard and Email
VM performs sled tests
VTC Validation Test Ref Number must be visible on film
VM uploads test data via VTC Web App
1x Boundary condition adjustment
Data upload at least two weeks before inspection or six weeks before publication
No
Automatic validation checks passed
Manual validation check passed
Yes
Validation passed
No
Validation failed

2 REFERENCE SYSTEM

All "Global coordinates" (x, y, z location) have to be in the global coordinate system according to ECE/TRANS/WP.29/78/Rev.6 Annex 1-Appendix 2) with x-direction is facing rearwards and z-direction is facing upwards. For the sled and buck accelerations and contact forces, the vehicle coordinate system which is in line with the global coordinate system should be used. All dummy measurements (forces, moments, displacements, velocities and accelerations) have to be in a local coordinate system according to SAE J1733.

3 SIMULATION DATA

3.1 Measurements and Variables

For all required channels data between T0 and Tend (see definitions) shall be provided.

All channels must be named according to the ISO MME channel codes listed in CP 005. The ISO MME codes have to be consistent between physical and virtual tests, where applicable.

3.2 Data Filtering

All time series data must be provided with a sampling frequency of at least 10 kHz and no additional filtering (e.g. CFC) shall be applied on the on the raw data which is outputted from the FE software . Simulation signals not found in testing (e.g. energies) shall have a sampling rate of at least 1 kHz.

3.3 Videos of the animated simulation results

The videos of the animated results shall meet the following requirements:

- Animations need to be analysed with an output interval of 2 ms or less.
- Videos are accepted with the following specification:
  - Frame rate: 10 frames per second
  - File size: 1-10 MB
  - Note: the resolution/frame size shall be maximised within the file size limit.

4 SIMULATION MODELS

Throughout this process, the exact same vehicle and dummy models shall be used. This specifically applies to:

- All control settings (time step, mass scaling, etc.),
- Material cards (including fracture mode),
- Contact cards including all settings,
- Constraints,
- Airbag models,
- Seatbelt system models (including pretensioner and load limiter),
- Output definitions (IDs and coordinate systems used for outputs),
- Geometries and represented components.

This requirement does not apply to parameters that need to be adjusted to define the different load cases. For example, node coordinates can be adjusted for replicating different positions of the dummy relative to the seat, the seatbelt, the steering column and the seat relative to the car as well as the initial seat cushion deformations and load curves defining the crash pulse and adaptive restraint system setting/behaviour/configurations (e.g. load limiter stage/level, airbag deployment stage) with related time to fire (TTF) have to be adjusted to simulate the different loading scenarios.

Furthermore, it is important that all simulations are performed with consistent settings. This applies to:

- Solver-Version and Processing Type,
- Solver-Precision (Single, Double Precision),
- Time-step settings (relating to initial and dynamic mass scaling),
- Contact settings (especially between occupant and vehicle simulation model),
- Control settings (which ensure also equal distribution of the model on the CPUs).

4.1Dummy simulation model

The dummy models used for each loadcase are specified in the Crash Protection protocols. Node coordinates shall be adjusted to replicate the different initial positions.

For example, can be adjusted for replicating different positions of the dummy relative to the seat.

4.2 Vehicle simulation model

The vehicle model is to be calibrated in advance and the VM must have confidence that the model is ready to predict occupant response in Euro NCAP load cases.

No modifications of the vehicle models are allowed during the virtual testing procedure and all settings are to remain constant.

This does not apply to load-case specific boundary conditions, such as the nodes of the seatbelt, the steering column and the seat relative to the car as well as the initial seat cushion deformations, load curves defining the crash pulse and adaptive restraint system setting, behaviour, configurations (e.g. load limiter stage/level, airbag deployment stage) with related time to fire (TTF).

4.3 Combined OR separate modelling

Simulation outputs for driver and passenger shall be generated with one combined, or for the frontal loadcase, also can be generated with two separate models.

In case of combined model, the resulting simulation output will be collected in one sub-test folder (see, CP005 1.1.10). For separate models, simulation results are provided separately, one for driver and one for passenger.

5 QUALIFICATION OF SIMULATION MODEL

5.1Qualification of the dummy model

The dummy model(s) used in this procedure must be qualified beforehand to ensure that it behaves consistently when compared to its physical counterparts. The qualification of the dummy models must be performed according to the specifications in Euro NCAP Technical Bulletins CP 510 and 520.

Documentation on the dummy qualification shall be uploaded together with the simulation results to the VTC server. The VM is responsible for ensuring that all requested dummy outputs are available with

5.2Quality criteria of the simulation set-up

The simulation results should meet the following quality criteria for each simulation:

- Max. Hourglass Energy of full setup must be < 10% of max. internal energy.
- Max. Hourglass Energy of all dummy components must be < 10% of max. internal energy for each dummy.
- Max. mass added due to mass scaling to the total model is less than 5 % (2.5% in case of separate models) of the total model mass at the beginning of the run.
- Less than 10 mm H-point z-displacement recorded in first 5 ms of the simulation (5 ms after t0).

The following parameters are monitored and therefore calculated on the VTC server, but currently no criteria are defined:

- Hourglass energy / internal energy at time of max. head excursion for setup, dummy, sled and seat.
- Max. added mass (Dummy, seat, sled).

For separate models, additionally the sled accelerations in x-direction are compared between both models and the derived ISO score calculated according to 5.3.1. has to fulfil the following criterion:

- $S_x > 0.95$.

5.3 Validation Criteria

Two validation criteria are used, the ISO score and KPIs based on assessment criteria.

5.3.1 ISO score

The ISO score, according to ISO TS 18571:2024, of all channels listed in the tables below are calculated. For all sensor locations where more than one axis is measured, weighting factors w_i are calculated for each axis based on the maximum amplitude of the axis in the physical tests:

$$w_i = \frac{\max\left(\left|Channel_{test_i}\right|\right)}{\max\left(\left|Channel_{test_x}\right|\right) + \max\left(\left|Channel_{test_y}\right|\right) + \max\left(\left|Channel_{test_z}\right|\right)} \quad with\, i = X, Y, Z$$

The weighting factors are used to summarise the individual ISO scores for each axis S_i of one sensor to one score per sensor (S_{Sensor}) according to the following equation:

$$S_{Sensor} = \sum_{\mathrm{i}} w_i * S_i \quad with\, i = X, Y, Z$$

5.3.2 Key Performance Indicator (KPI)

All applicable assessment criteria (AC) for each loadcase as specified in the Crash Protection protocols are calculated and compared between simulations and tests.

The ratio (r_{AC}) between the derived assessment criteria AC_{test} and the limits AC_{limit} are calculated for each criterion and for simulations and tests:

$$r_{AC_{test}} = \frac{AC_{test}}{AC_{limit}}$$

$$r_{AC_{sim}} = \frac{AC_{sim}}{AC_{limit}}$$

For any assessment criteria where $r_{(ACTest)}$ ≥50%, the difference in ratios between simulations and tests is calculated:

$$\begin{aligned} &if\ r_{AC_{Test}} \geq 50\% \\ &d_{AC} = \left|r_{AC\,Test} - r_{AC\,Sim}\right| \end{aligned}$$

For the frontal impact loadcase AC_{limit} corresponds to the lower performance limits listed in tables in chapters 3.5.1-3.5.4 in the Frontal Impact Crash Protection Protocol (Euro NCAP Protocol - Crash Protection - Frontal Impact).

For the farside loadcase, the capping limits listed in chapter 3.5.3 of the Side Impact Crash Protection Protocol (Euro NCAP Protocol - Crash Protection - Side Impact) are used as AC_{limit}. For the head excursion, the distance to the orange Zone is used as AC_{limit}.

5.4 Acceptance Criteria

5.4.1 ISO score

For those sensors in the tables below, the calculated Sensor Score must exceed 0.5 to fulfil the ISO score validation criteria.

Currently, the scores for all other sensors are only monitored and have no consequence on the acceptance of the data and the scoring.

Frontal Impact	Sensor location	Type	Axes
Head & Neck	Head CoG	Accelerations	x,y,z
Chest & Abdomen	Chest	Accelerations	x,y,z
		Deflection	x
Knee, femur and pelvis	Pelvis	Accelerations	x,y,z
Vehicle	Sled	Accelerations	x
	Shoulder Belt (B3)	Force	1D

Farside Impact	Sensor location	Type	Axes
Head	Head CoG	Angular velocities*	x,y,z
		Accelerations	x,y,z
Abdomen	Spine – T12	Accelerations	x,y,z
Pelvis	Pelvis	Accelerations	x,y,z
Vehicle	Sled	Accelerations	x,y
	Shoulder Belt (B3)	Force	1D

*For robustness loadcases only Head CoG angular velocities and B-pillar are looked at

5.4.2 KPI

For each considered assessment criteria as defined in the Crash Protection protocols, d_{AC} shall be below 30%. This does not apply to the Farside robustness loadcases, where only the head excursion in relation to the main loadcases is assessed.

5.5 Rerun of simulations with adjusted boundary conditions

If the qualification of the simulation model was not successful after uploading the tests data (not all validation criteria were fulfilled), Euro NCAP may allow the VM to re-run simulations and reupload simulation data of the two validation load cases. In this case, the VM can adjust only the following parameters to be closer in line with the laboratory tests:

- Initial position of the dummy (node coordinates),
- Initial seat deflection (node coordinates of the seat covering foam, wire mesh etc.),
- Initial belt positions (nodes of seatbelt including buckle and D-ring),
- Load curve describing the crash pulse.