Enhancing Vehicle Safety Assessments through Advanced Virtual Testing Crashworthiness with the aid of ANSA and META

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1 Abstract

The automotive industry is continually evolving to meet stringent safety standards and enhance occupant protection in crash scenarios. With Euro NCAP supplementing far-side impact testing with Virtual Testing Crashworthiness (VTC) starting in 2024, real tests and CAE simulations come closer more than ever. The VTC protocol mandates the use of simulation and physical test data to robustly evaluate far-side impact protection, requiring detailed compliance with validation and quality criteria, as well as specific data formatting for submission. Consequently apart from far-side more protocols will be implemented in the virtual testing raising more challenges to the safety engineers. As a result there is an increasing need for efficient tools that streamline the assessment process offering 'know how' of the different protocols and simultaneously minimize the human interaction with the aid of automation.

This paper introduces the solutions that BETA CAE has come up with, in order to bridge CAE with real testing covering all the current but also the future needs of VTC. In ANSA the pre-processor a new tool has been introduced that automates the ATD/HBM positioning process following the specifications of each protocol or utilizing experimental data coming either from posture landmarks or scanned STL meshes. Along with the already known in the market, seat positioning, seatbelt and impactor tools form a complete suite to ensure an easy and proper preparation of the model for ANSYS LS-DYNA safety simulations. Additionally, an innovative software tool has been integrated within META, BETA CAE Systems post-processor, designed to meet and exceed the requirements of the Euro NCAP VTC protocol. The tool offers comprehensive functionalities to facilitate the evaluation process, ensuring accuracy, efficiency, and compliance. Key features of the tool include the ability to read and process all necessary LS-DYNA simulation and physical test results, and export the data in the ISOMME format with precise adherence to protocol requirements, ready to be uploaded to the Euro NCAP website. Additionally, the tool performs pre-assessment in the same manner as Euro NCAP, allowing automotive manufacturers to know their potential rating before submitting the results officially. This pre-assessment ensures that manufacturers can refine their designs to achieve the desired safety ratings.

By automating the critical aspects explained above, the aforementioned tools significantly reduce the time and effort required for vehicle safety assessments. They ensure that automotive manufacturers can efficiently comply with the latest Euro NCAP standards and beyond, ultimately contributing to the development of safer vehicles.

2 Introduction

The automotive industry is adapting to stringent safety standards, particularly with the introduction of the Euro NCAP's Virtual Testing Crashworthiness (VTC) protocol starting in 2024. This protocol requires a combination of simulation and physical test data to assess far-side impact protection, emphasizing compliance with validation and quality criteria. As more virtual testing protocols emerge, there is a growing demand for efficient tools that streamline assessments while minimizing human intervention through automation.

This paper discusses BETA CAE's solutions to integrate CAE simulations with real testing needs, particularly for VTC. The pre-processor ANSA features a new tool for automating the positioning of ATD/HBM models based on specific protocols or experimental data. This complements existing tools for seat positioning and seatbelt placement, creating a comprehensive suite for preparing models for ANSYS LS-DYNA safety simulations so as to cover the loadcases needs of VTC.

Additionally, a new tool in the META post-processor addresses the Euro NCAP VTC requirements, offering functionalities to process LS-DYNA simulation results and export data in the required

ISOMME format. This tool also allows for pre-assessment, enabling manufacturers to estimate their potential safety ratings before official submission. By automating these processes, BETA CAE's tools significantly reduce the time and effort needed for vehicle safety assessments, helping manufacturers meet evolving Euro NCAP standards and ultimately enhance vehicle safety.

3 VTC procedure

The first critical step for car manufacturers is to establish a clear understanding of the main procedures required for compliance with Euro NCAP standards. After acquiring a verified dummy CAE model, engineers must perform eight simulations—two specifically for validation and six additional simulations that provide the necessary data for a comprehensive safety assessment.

Upon completion, these simulations are uploaded to the VTC website, where they undergo rigorous quality checks to ensure they meet Euro NCAP's stringent criteria. Once the simulations pass these checks, manufacturers conduct two sled tests. The results of these tests are then submitted to the Euro NCAP platform for validation, where they are compared to the simulation data. This comparison validates the accuracy of the virtual vehicle model, ensuring that it reflects real-world performance.

If the comparison is satisfactory and the simulation model is validated, the uploaded simulations and sled test results will contribute to the vehicle rating. However, if the comparison does not meet expectations, the simulations for the two standard validation load cases may need to be repeated, with adjustments made only to the prescribed boundary conditions based on the sled tests.

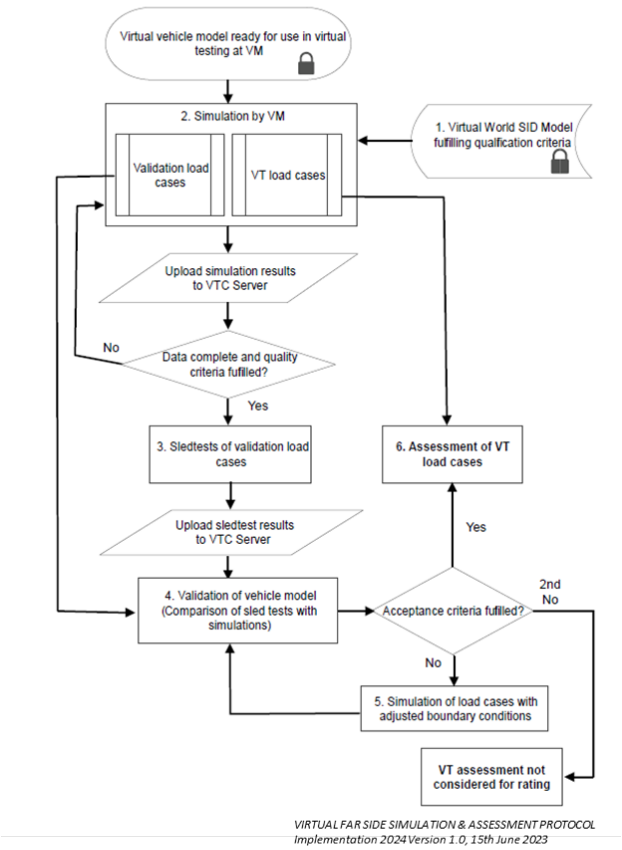


Fig.1: Schema representation of the VTC procedure

As it is easily understood the process of vehicle safety assessment involves numerous iterative steps that demand precision and reliability from automotive manufacturers. Consequently, they face a variety of challenges.

Manufacturers must adhere to stringent compliance requirements set by Euro NCAP, which includes ensuring that data is formatted according to specific submission standards. Additionally, the

simulations submitted must meet certain quality criteria to be deemed valid. This requirement adds another layer of complexity and necessitates a high degree of accuracy in the submission process.
Moreover, data processing can be both time-consuming and error-prone. The manual handling of extensive datasets from simulations and physical tests often leads to inaccuracies that can compromise the validity of assessment results. This inefficiency, along with the potential for mistakes, presents significant challenges for manufacturers.
These hurdles not only increase the workload for manufacturers but also demand more resources to ensure compliance with regulations. As a result, there is a growing need for pre-assessment tools that assist analysts in efficiently setting up all necessary simulations. Such tools can predict safety ratings prior to official submission, enabling manufacturers to make the necessary adjustments to enhance safety outcomes. By streamlining the assessment process and reducing the potential for errors, these tools can significantly improve the overall efficiency and effectiveness of vehicle safety evaluations.

4 Simulation loadcases setup

Engineers are required to complete a total of eight load cases—two for validation and six additional simulations. Each load case demands the application of different seat and ATD (Anthropomorphic Test Device) positions, necessitating corresponding adjustments to the seatbelt for each scenario. Furthermore, the Pole and the Advanced European Mobile Progressive Deformable Barrier (AE-MDB) must be accurately positioned in various locations as dictated by the test protocols.
To streamline this process, ANSA, the pre-processor from BETA CAE Systems, offers a suite of automated tools equipped with built-in protocol knowledge. These tools ensure precise and efficient setup for each load case, minimizing manual effort while maintaining adherence to regulatory standards.

4.1 Seat positioning tool

The Seat Positioning tool in ANSA is a highly user-friendly solution, designed with comprehensive knowledge of the protocols for Front, Side, and Rear crash simulations. Through an intuitive interface, users can easily select from various crash protocols and immediately view a summary preview of all the positioning steps. The tool functions like a wizard, guiding users step-by-step, offering protocol-recommended seat movements alongside the flexibility for custom adjustments.
Once the seat position is finalized, it can be saved for future use throughout the seat model's lifecycle. Additionally, the tool allows for outputting **`*NODE_TRANSFORM`** files to store positioning data separately. This ensures the seat model remains a ‘read-only’ file in each simulation, with different positions saved independently, guaranteeing that any simulation errors are unrelated to the seat model—especially important since it is a validated component from the seat manufacturer.
The tool also generates a script that enables users to recreate the exact seat position and parametrize variables for stochastic analysis. Its versatility allows for application across all seat configurations and accommodates digital models with a wide range of design positions, providing a robust solution for managing complex seat positioning requirements in crash simulations.

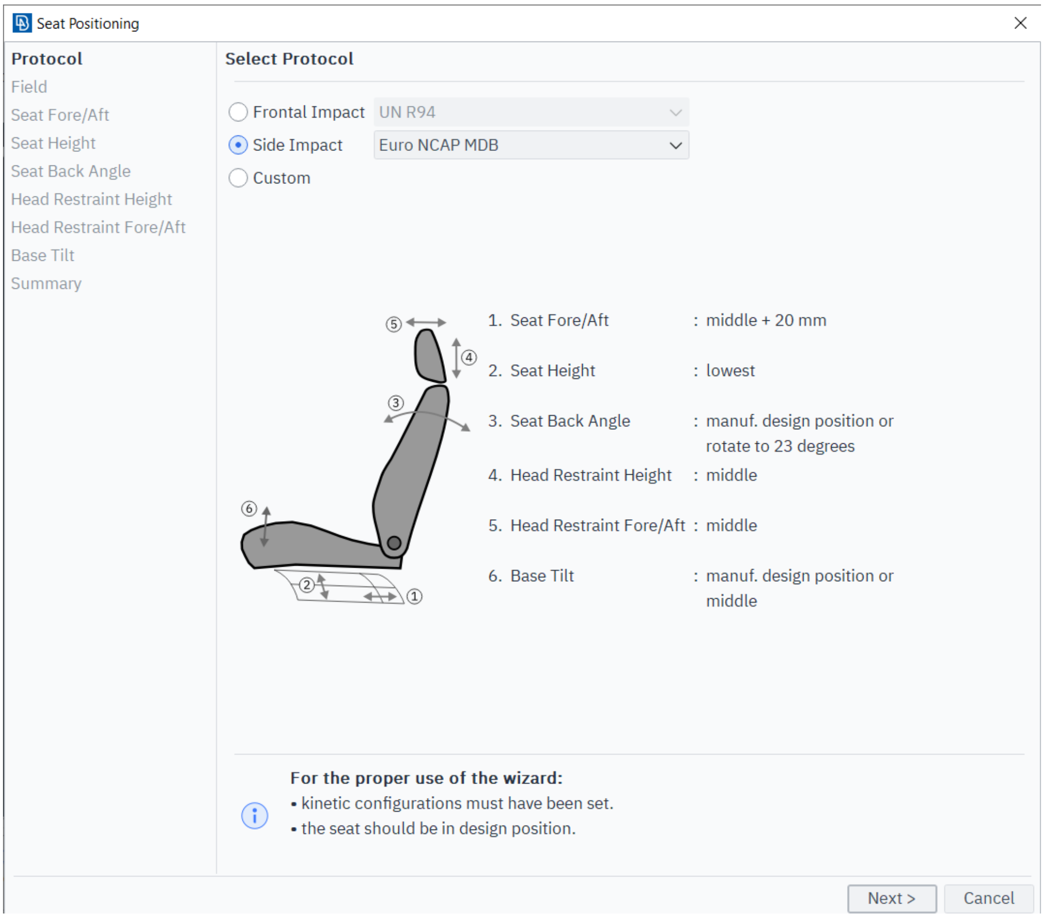


Fig.2: Seat Positioning tool of ANSA

4.2 ATD/HBM positioning tool

ATD positioning in ANSA has been a widely used feature for several years, recognized in the market for its robust capabilities. The 'Dummy' tool allows users to read and preview the complete dummy hierarchy, offering a seamless interface for translating and positioning the dummy on the seating reference point. Its user-friendly menu also facilitates precise limb rotation, ensuring that the dummy achieves the desired final position for crash simulations.

This finalized dummy position is then utilized in the next stage by ANSA's Marionette Wizard, which prepares the pre-crash simulation, resolving any penetrations or intersections, and refining the posture with the help of ANSYS LS-DYNA.

A recent innovation introduced by ANSA is a specialized tool designed to streamline the entire ATD positioning process by integrating protocol-specific knowledge. This tool minimizes user input while automating the steps required by regulatory standards, efficiently positioning the dummy to its final posture. The key advantage lies in its ability to use a selection of key nodes from the model to not only position the dummy accurately on the seat but also adjust the ATD limbs in relation to the surroundings. This includes proper placement of feet on the floor, footrests, pedals, and arms on the steering system (if needed – in VTC is not), ensuring both driver and passenger dummies are correctly positioned as per each protocol's requirements.

The tool also allows the saved dummy position to be easily integrated into the Marionette Wizard for quickly setting up LS-DYNA load cases, with the solver fine-tuning the dummy's position.

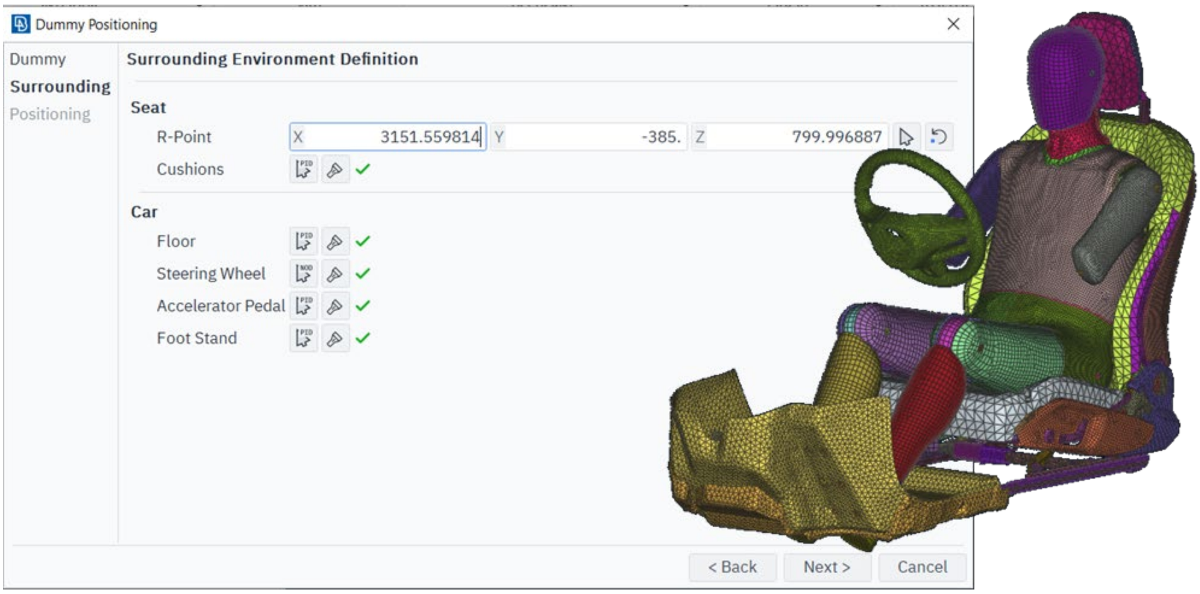


Fig.3: Auto Positioning tool working on WorldSID-50th

Another notable advantage of the new ANSA positioning tool is its ability to handle Human Body Models (HBMs), which have been increasingly adopted in recent years and are expected to become part of the VTC process soon. ANSA is prepared for this shift by offering a tool that seamlessly integrates HBMs into the pre-processor.
The tool automatically positions the HBM within the model, ensuring that the body is penetration-free without the need for extensive manual adjustments. The only subsequent step required is a Marionette Wizard operation to de-penetrate the model from the seat, optimizing the setup for crash simulations. This feature significantly simplifies the process, making it more efficient for engineers to incorporate HBMs into safety simulations.

4.3 Seatbelt tool

The ANSA seatbelt tool provides an efficient solution for restraining the ATD/HBM-seat system. It enables users to quickly create a smooth, well-shaped seatbelt with a constant width along its entire length. A unique feature of the tool is its ability to generate an optimized seatbelt shape by selecting just three points per component, wrapping the belt directly around the ATD/HBM surface.
All essential LS-DYNA keywords, including 1D and 2D belt elements, retractors, sliprings, and pretensioners, are supported. Additionally, **`*DATABASE_CROSS_SECTIONs`** can be created for further post-processing. The tool also allows users to modify the belt’s shape during creation, making it adaptable to the ATD/HBM surface even if there are changes in posture. The ‘Tension’ function further enhances this by tightening the seatbelt as needed to achieve the desired fit. The automatic passage of the belt through geometric sliprings is a functionality that significantly boosts productivity. Additionally, for child seats, ANSA offers the capability to locally modify the belt's shape by applying custom adjustments with direct morphing. This feature allows the belt to navigate complex paths, even through challenging spaces between the dummy and seat components.
For robust analysis and Design of Experiments (DOE) studies, where multiple scenarios must be evaluated, automation plays a crucial role. The ANSA seatbelt tool supports scripting in Python, allowing users to automate all functions available in the graphical interface. This includes the automatic re-application of the seatbelt from defined locked points and its re-adaptation to updated conditions, enabling analysts to easily assess different seat-dummy configurations with a consistently updated seatbelt.

5 Barrier positioning

Final stage of the VTC setup is the positioning of the pole or the AE-MDB. It is a difficult case in the real tests in the laboratories. So it is in the simulations setup. The specific procedure needs accuracy and of course protocol’s ‘know-how’.

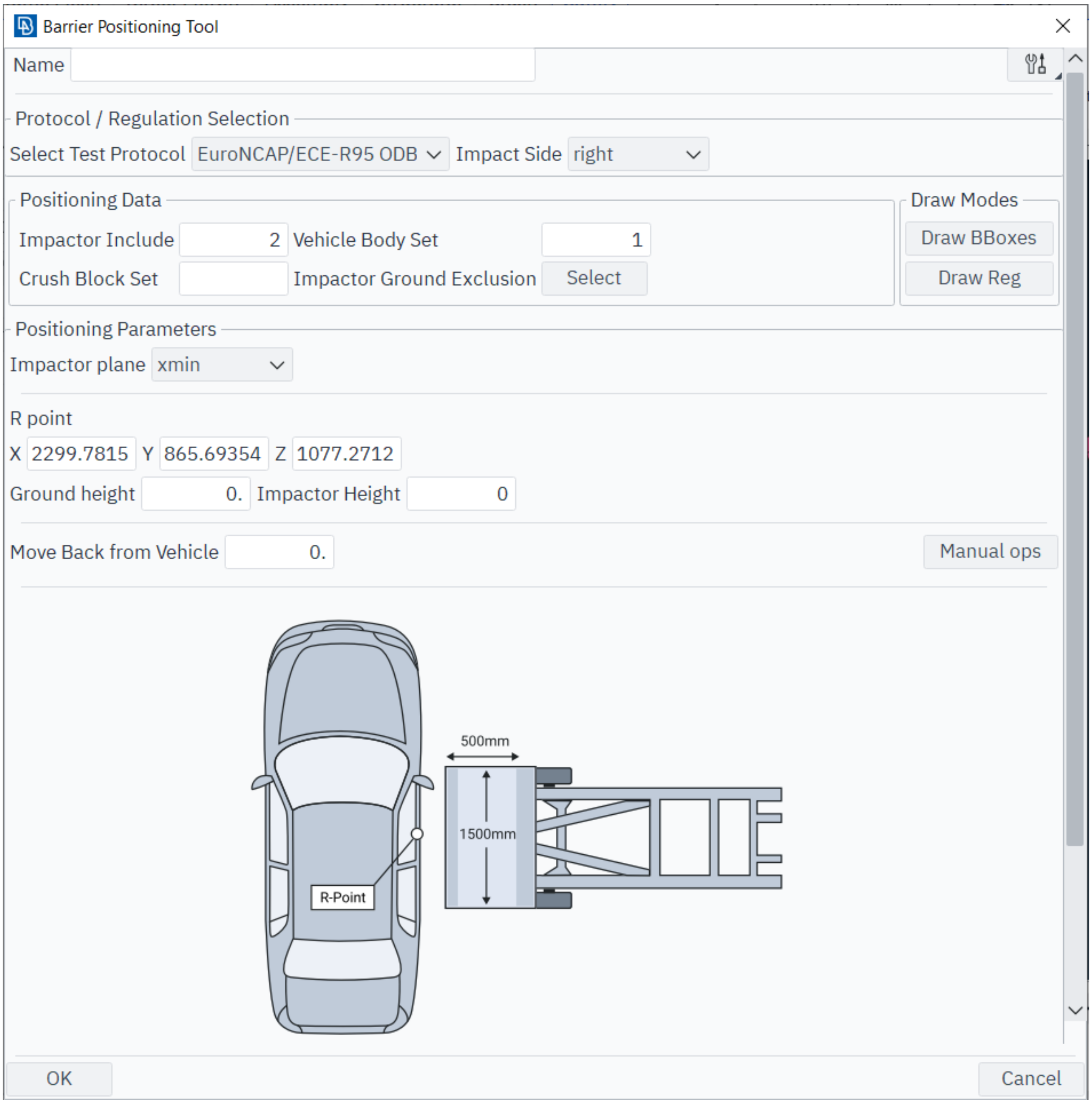


Fig.4: ANSA Barrier positioning tool

ANSA has implemented in its safety tools suite a dedicated tool for this aspect, the barrier positioning. It is an assistant functionality that guides the user through each step of the selected protocol. With the minimum input and manual effort one can position the barrier quickly and accurately. LS-DYNA *NODE_TRANSFORM or **`*INCLUDE_TRANSFORM`** is automatically created for the barrier, either for a **`*SET`** or for a **`*INCLUDE`**).

6 META VTC tool

To address the challenges of post-processing in virtual testing using META, BETA CAE Systems has developed a specialized tool that simplifies the VTC process while ensuring full compliance with Euro NCAP standards.
This tool provides several key features that help users navigate the complexities of VTC. First and foremost, the META VTC tool fully supports the Euro NCAP protocol, adhering to all the specific requirements for data formatting, validation, and quality assurance. Additionally, it is capable of reading and processing results from both CAE simulations and physical tests.

Beyond simple data handling, the tool performs the critical calculations needed for the VTC protocol, ensuring that users can efficiently and accurately meet the demanding criteria of virtual testing certification.

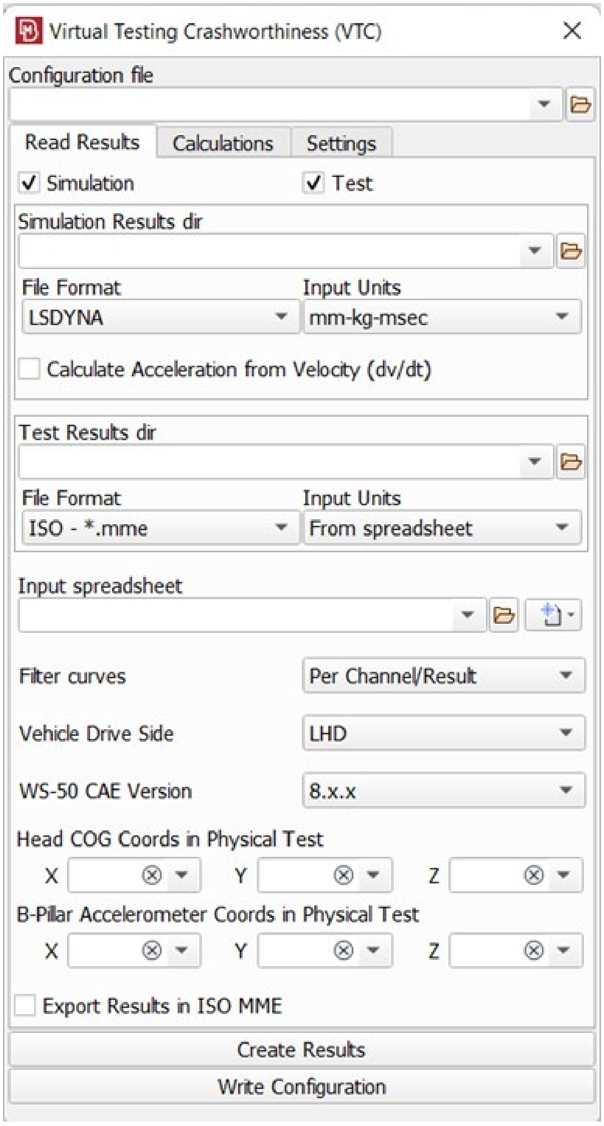
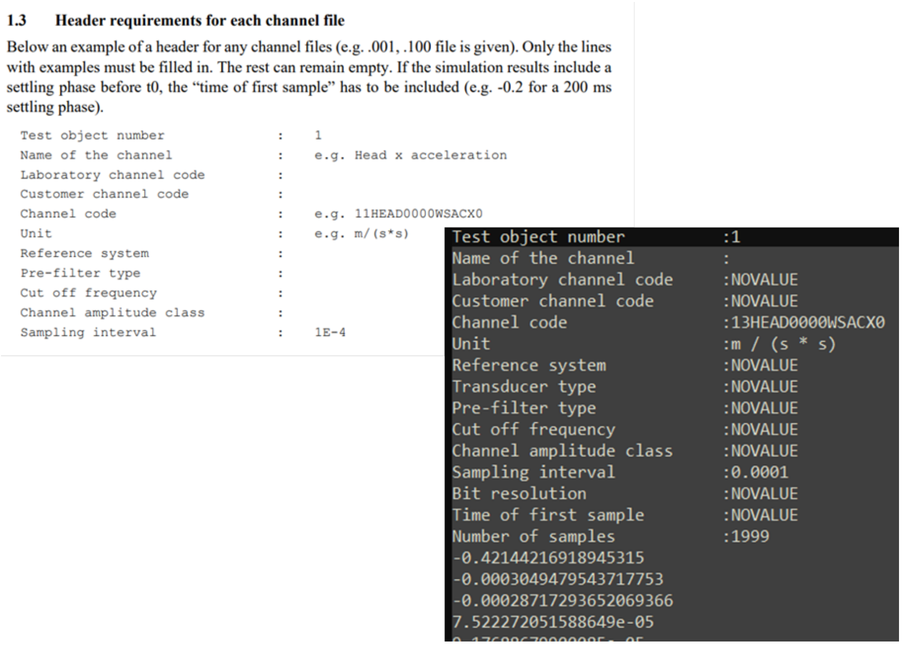


Fig.5: VTC tool of META

6.1 Results export

The key functionality of the META VTC tool is its ability to export all necessary results in the ISOMME format, ensuring they are ready for direct upload to the Euro NCAP VTC web application.
Specifically, the tool automatically includes all required information in the MME headers, which is provided by the user. Similarly, each channel file is generated with the correct header information, following the Euro NCAP protocol for naming conventions and result units. Furthermore, the tool resamples the output curves to achieve a standardized sampling interval of 10kHz, ensuring full compliance with the protocol's data formatting requirements. This streamlined process simplifies the preparation and submission of results, significantly enhancing efficiency in the VTC workflow.



1.3 Header requirements for each channel file

Below an example of a header for any channel files (e.g. .001, .100 file is given). Only the lines with examples must be filled in. The rest can remain empty. If the simulation results include a settling phase before t0, the "time of first sample" has to be included (e.g. -0.2 for a 200 ms settling phase).

```
Test object number          :   1
Name of the channel         :   e.g. Head x acceleration
Laboratory channel code     :
Customer channel code       :
Channel code                :   e.g. 11HEAD0000WSACX0
Unit                        :   e.g. m/(s*s)
Reference system            :
Pre-filter type             :
Cut off frequency           :
Channel amplitude class     :
Sampling interval           :   1E-4
```

```
Test object number          :1
Name of the channel         :
Laboratory channel code     :NOVALUE
Customer channel code       :NOVALUE
Channel code                :13HEAD0000WSACX0
Unit                        :m / (s * s)
Reference system            :NOVALUE
Transducer type             :NOVALUE
Pre-filter type             :NOVALUE
Cut off frequency           :NOVALUE
Channel amplitude class     :NOVALUE
Sampling interval           :0.0001
Bit resolution              :NOVALUE
Time of first sample        :NOVALUE
Number of samples           :1999
-0.42144216918945315
-0.0003049479543717753
-0.00028717293652069366
7.522272051588649e-05
```

Fig.6: Headers of a channel according to VTC

6.2 Quality Checks

The META VTC tool replicates the same quality check process as the Euro NCAP website, ensuring seamless alignment with the official validation criteria.
The tool automatically verifies key CAE quality criteria, such as the ratio of maximum total hourglass energy to maximum total internal energy, as well as the corresponding ratio for the WorldSID-50th dummy. It also checks the added mass versus the initial mass ratio, simulation time, and H-POINT displacement, all in accordance with the Euro NCAP protocol. These checks are summarized in a detailed table, where each result is presented individually, along with a final verdict indicating whether the test has passed or failed. Additionally, the tool flags any missing results, providing a comprehensive report to the user for further review.

Simulation Quality Criteria

Simulation name: cae_binouts

Quality Criterion	Requirement	Result
Max Total Hourglass energy / Max Total Internal energy	< 10%	0.86%
Max WS-50 Hourglass energy / Max WS-50 Internal energy	< 10%	0.59%
Max Total Added Mass / Total Initial Mass	< 5%	0.63%
Max H-Point Z displacement in the first 5 ms	< 10mm	0.2 mm
Simulation time Vs time of max Head Y excursion	> 1.2 * time of max excursion	Pass
Missing Results	0	15

Fig.7: Table of quality checks from META VTC

6.3 Validation criteria

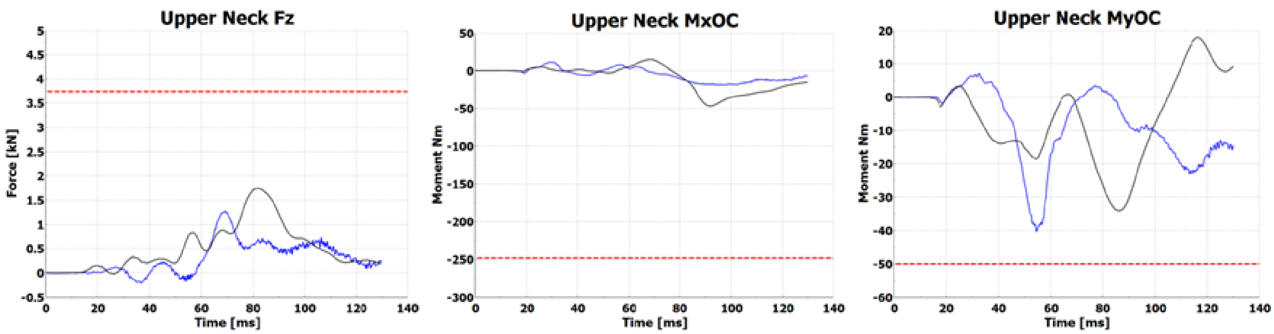
The META VTC tool also performs simulation model validation in accordance with Euro NCAP standards, mirroring the process followed by Euro NCAP itself.

When both simulation and physical test results are processed simultaneously, the tool calculates ISO correlation (ISO 18571 of year 2024) for comprehensive comparison. At the conclusion, a summary report containing all ISO scores, as well as a detailed report for each sensor, is generated.
Similar to the ISO scores, the validation criterion 2 (Injury results) is computed. A summary report is produced that includes all injury-related results including the limit values, the maximum values from both the test and CAE results, the ratio between these values and the corresponding limits (rAC), as well as the difference between the two ratios (dAC value). In addition to the summary, a slide with detailed reports for each component of the WorldSID-50th dummy is generated, offering a thorough analysis of the results for each part.

Injury Assessment Criteria: Upper Neck

CAE: cae_binouts

Test: example_test



Assessment Criterion	AC limit	Test	CAE	rAC Test	rAC CAE	dAC
Upper Neck Fz	3.74 kN	1.751	1.277	0.468	0.341	
Upper Neck MyOC	-50 Nm	34.129	40.290	0.683	0.806	0.123
Upper Neck MxOC	248 Nm	46.785	19.097	0.189	0.077	

Back to Top

Fig.8: Report for WorldSID-50 sensors by VTC tool of META

6.4 Customization

The META VTC tool offers extensive customization options for both calculations and report generation, allowing users to tailor the process to their specific needs.
For instance, CAE accelerations can be derived from velocities to reduce noise in the results. Curve filters can also be applied to refine the calculation of validation criterion 1, with the default filters following the specifications outlined in Euro NCAP TB 021.
Users have the flexibility to modify the default thresholds for ISO Score and dAC validation. Beyond generating reports with the standard 0.5 ISO score threshold, the tool allows for exploratory analysis by adjusting thresholds to more stringent levels, such as 0.6 or 0.7, to see how the ISO correlation validation is affected.

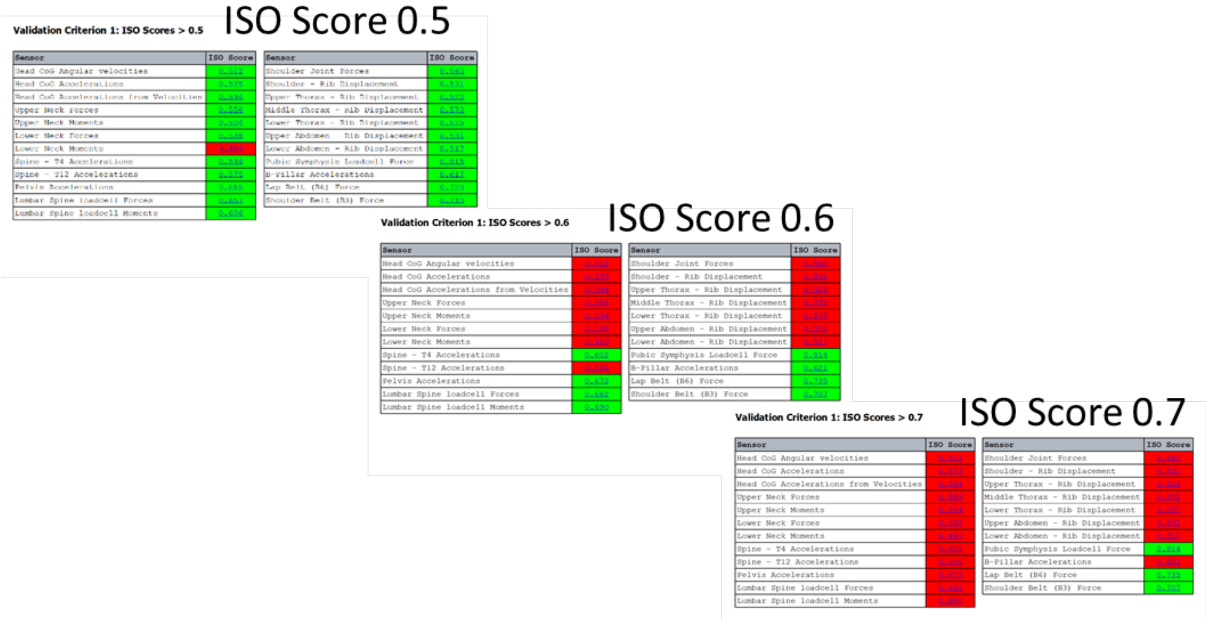


Fig.9: Customization of the ISO validation

Additionally, for the calculation of Head Excursion and Lateral Rib Deflections, users can select different methods for processing CAE and test results. The tool also supports "what-if" analyses for head excursion calculations, enabling users to adjust the initial rotation and velocity of the head directly within the tool—without needing to rerun the simulation—providing a quick and efficient way to assess various scenarios.

7 Summary

The process of vehicle safety assessment for Euro NCAP compliance involves several critical steps. After obtaining a verified dummy CAE model, manufacturers conduct eight simulations: two for validation and six for additional data. These are uploaded to the VTC website for quality checks, followed by two sled tests, whose results are validated against the simulations. If discrepancies arise, validation load cases may be repeated.

This process is demanding, requiring precise data formatting, quality criteria adherence, and careful pre- and post-processing of both simulations and physical tests. To meet these challenges, BETA CAE offers a suite of tools in the ANSA pre-processor and META post-processor.

ANSA provides automation for seat, dummy, and seatbelt positioning, as well as barrier placement, all adhering to Euro NCAP protocols. Its dummy positioning tool ensures proper alignment of all components, even allowing for adjustments without rerunning simulations. A key feature is its support for HBMs, which are increasingly being incorporated into virtual testing.

The META VTC tool streamlines the virtual testing certification (VTC) process, ensuring compliance with Euro NCAP standards. It processes both CAE and physical test results, performs necessary calculations (e.g., Head Excursion, Lateral Rib Deflections), and exports results in ISOMME format for direct upload to Euro NCAP's platform. The tool also mirrors Euro NCAP's quality check process and allows for comprehensive validation reporting.

Customization options enable users to adjust calculation methods, filter curves, and modify ISO score thresholds. The "what-if" analysis feature helps engineers explore different head excursion scenarios without rerunning simulations. These tools significantly enhance efficiency, reduce errors, and streamline vehicle safety assessments.

8 Literature

[1] ANSA version 25.0.0 User's Guide, BETA CAE Systems International AG, August 2024
[2] LS-DYNA Keyword Users' Manual Version R14, ANSYS, Copyright© 1992-2023 ANSYS, Inc ("ANSYS"). All Rights Reserved.