# Performing DOE Studies in Occupant Protection Using BETA CAE Tools

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## 1 Abstract

*One of the most important studies during the design process of a vehicle is its strength in different Crash scenarios. In particular the Safety of its occupants is one of the uttermost goals. Engineers try to cover as many possible cases from the reality by producing different simulations. DOE studies are inevitable to achieve that.*

*ANSA and META, the pre and post processors of BETA CAE systems, offer a wide range of tools for the handling of ATDs, seats and seat-belts as well as tools for the automatic setup of different load-cases, the setup of DOE studies and the evaluation of the results.*

*In this paper LS-DYNA® is used for a DOE study which is setup from the Optimization Tool of ANSA and examines how different parameters like the friction between the ATD and the seat-belt and between the ATD and the seat and the actual position of the dummy can affect the occupant's injury results.*

## 2 Introduction

Safety engineers should be able to position the seat properly according to the crash regulations and then position the dummy accurately on it. The restraining of the system dummy-seat with seatbelt is mandatory and the seatbelt shape should be proper to ensure the occupant safety. If a basic scenario is simulated successfully the next step is to study additional scenarios to capture more cases close to reality. DOE studies offer this ability to the engineers however, considering the time constraints in the industry, setting up such safety scenarios makes the accurate tools and automation mandatory.
The current paper explains in detail how a DOE study in occupant safety simulations is applicable within ANSA pre-processor, and META, post-processor of BETA CAE Systems.

## 3 Seat Positioning

Seat positioning is the first step of building an occupant safety simulation. In ANSA the positioning of a seat is based on the seat kinematic mechanism. The in-house multi-body dynamic solver of ANSA treats the members and the joints of the seat kinematic system. This way the seat can reach a desired position in an accurate and automated way based on real kinematics.
During this step engineers decide what the main protocol or user defined position is according to which the seat is positioned. The 'Seat Positioning' tool of ANSA offers the know-how of the majority of crash protocols. A wizard like functionality streamlines the steps of each protocol so there is no need for the user to search in the bibliography.

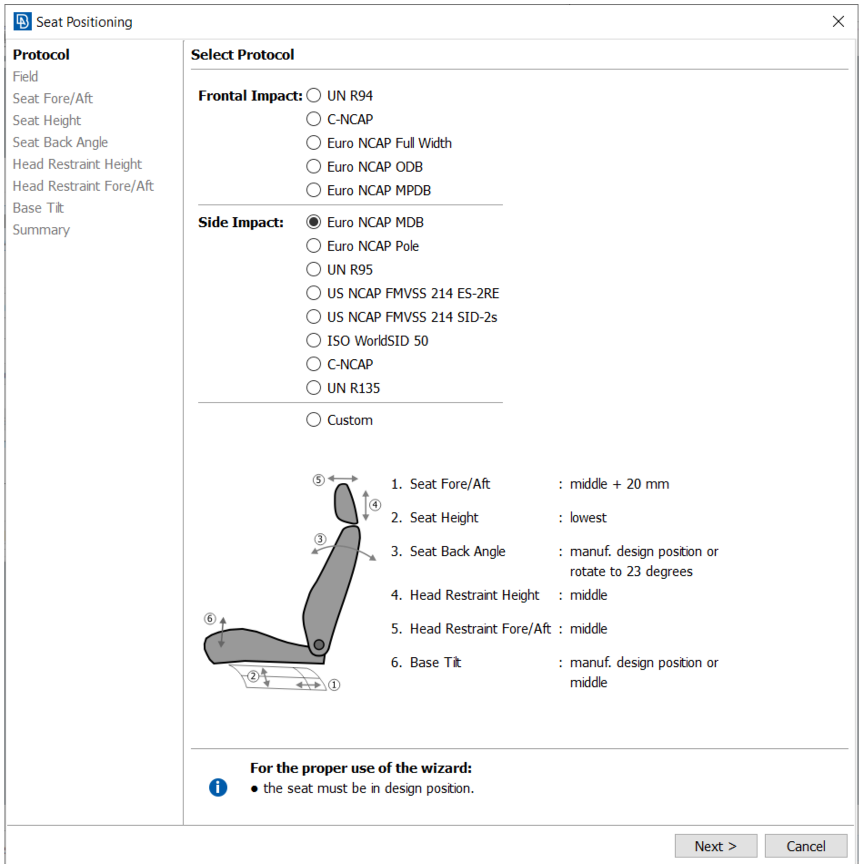



*Fig. 1: 'Seat Positioning' tool of ANSA*

Moreover it offers the ability to the user to apply any user defined movement at each protocol step but also to match the coordinates of an origin point to the ones of a target one so as the seat to move accordingly following the real kinematic movement (seat Fore/Aft combined with Height adjustment).
The tool, while the user navigates through the steps of the protocols, records the user actions and translates them in Python scripting creating a code for building any automated process.
Finally positions of a seat can be saved in a list and can be accessed at any time. For each of these positions ANSA can produce automatically files with *NODE or *NODE_TRANSFORMATION keywords. This way one can maintain the seat file as read-only ensuring that the original file will undergo no modification.

## 4 Dummy Positioning

After the positioning of the seat, dummy needs to be seated accordingly. It is important for the user to have a user-friendly interface where not only the dummy hierarchy is previewed but also one can easily move the limbs of the dummy. ANSA offers the 'Dummy' function which enables the analyst to make any rotations and translations needed to the dummy limbs respecting the degrees of freedom of each joint. It is essential to mention that any stop angles are defined either through *CONSTRAINED_JOINT_STIFNESS or within the dummy hierarchy ANSA 'Dummy' tool recognizes and previews them on screen preventing undesired movements.
A special contact-based algorithm can prevent any penetration of the dummy parts (during a limb movement) with the surroundings.

*Fig. 2: Humanetics THOR50 positioned in ANSA*

Similarly, to the case of the seat, the positions of the dummy can be saved and files with *NODE and/or *NODE_TRANSFORMATION keywords can be automatically created keeping the dummy file in a read-only mode.

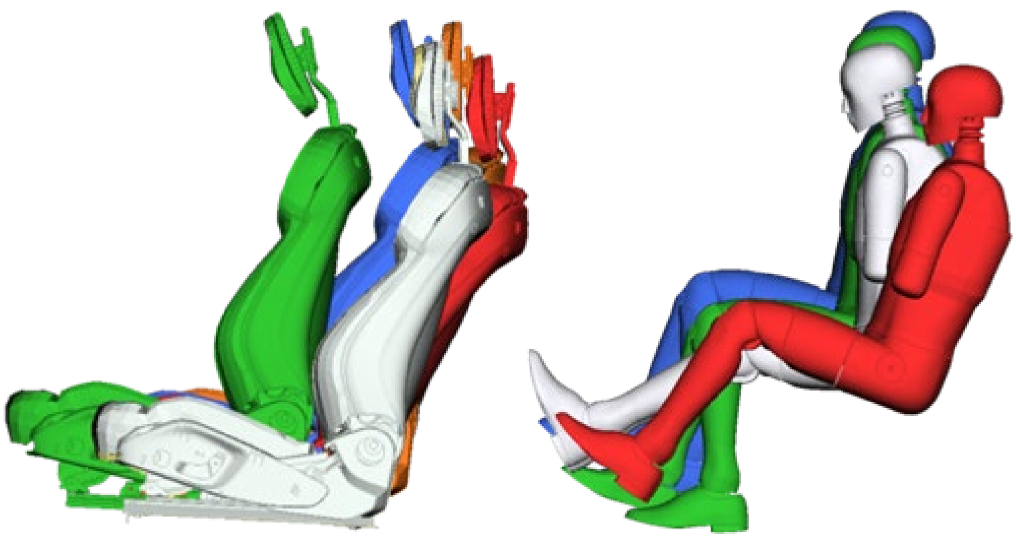


*Fig. 3: Saved Seat and Dummy Positions*

During the dummy positioning "self" penetration of the dummy limbs occur due to its adjustment. In case of small movements, the 'Dummy' tool of ANSA removes these penetrations between the limbs. However, in case of large movements is required to solve these penetrations within LS-DYNA. So dummy positioning will be completely done in the solver. For these cases ANSA has the 'Marionette' tool. It is a wizard that streamlines the necessary steps to create the pre-simulation file that is solved by LS-DYNA.

# 5 De-penetration of Seat-Dummy system

Dummy and seat positioning ensure that all the members of the mechanisms of both dummy and seat will be in the proper position. But in order to complete a proper working dummy-seat system there is the need to ensure a penetration free structure. ANSA with the aid of 'Seat De-penetrate' function can apply the deformation process of the seat so no penetration between dummy and seat exists. Simultaneously, the *INITIAL_FOAM_REFERENCE_GEOMETRY keyword is calculated for the necessary stress and strain calculation later on in LS-DYNA. The process above is a geometric movement of the nodes of the seat to a final penetration-free from the dummy position.
In case the user would like to apply the de-penetration process with the use of LS-DYNA there is a special plugin in ANSA to set up the pre-simulation LS-DYNA file.

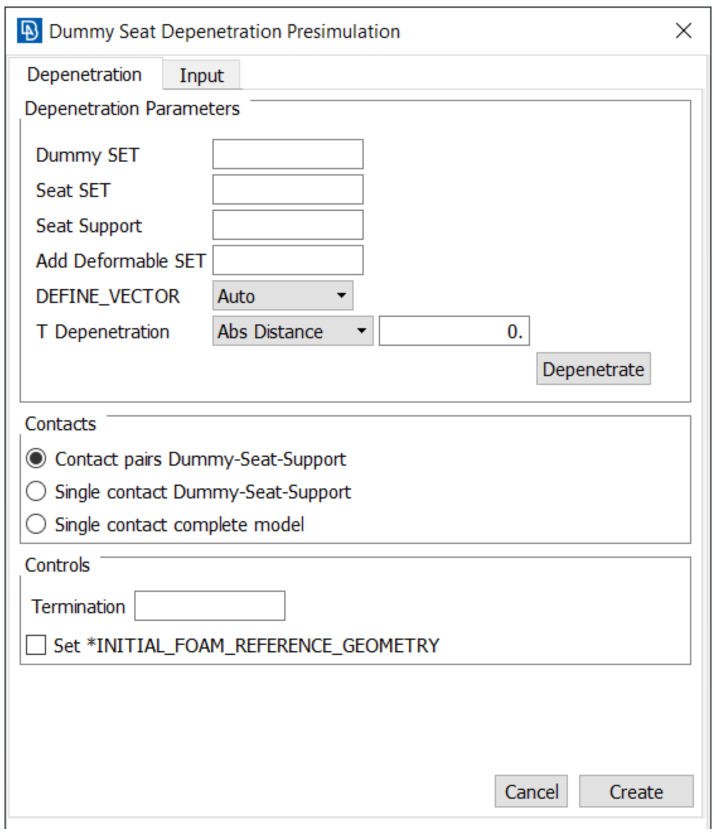



*Fig. 4: LS-DYNA Dummy Seat De-penetrate plugin of ANSA*

## 6 ANSA Seatbelt tool

The restrain of the dummy-seat system with seatbelt is one of the most important aspects of achieving the necessary safety in an occupant simulation.
The main characteristic of an ANSA seatbelt is the smooth and constant width shape. In ANSA it is possible to create a well-shaped seatbelt with the desired number of elements along the width, smooth and with constant width along the whole length. Using the 'Interactive' function one can modify real time the shape of the belt by dragging and dropping a specific point of the belt on to a desired position. 'Tension' functionality can stretch the seatbelt more in order to achieve the optimum shape.
The 'Seatbelt' tool of ANSA offers to the user the ability to create all the necessary LS-DYNA *ELEMENT keywords (1D and 2D belt elements, retractors, sliprings and pretensioners).
Moreover 'locked' points can be defined ensuring that the seatbelt will pass from specific coordinates whatever modification they undergo in their shape.
In terms of robustness analysis and DOE studies where the user has to study several scenarios automation is important. ANSA seatbelt tool offers the ability to script (in Python) all the functionality available in the graphical user's interface. Automated re-application of the seatbelt passing from desired 'locked' points and automatic re-adaption of the seatbelt shape in updated conditions enable the analyst to study any different seat-dummy position with an easily updated seatbelt.

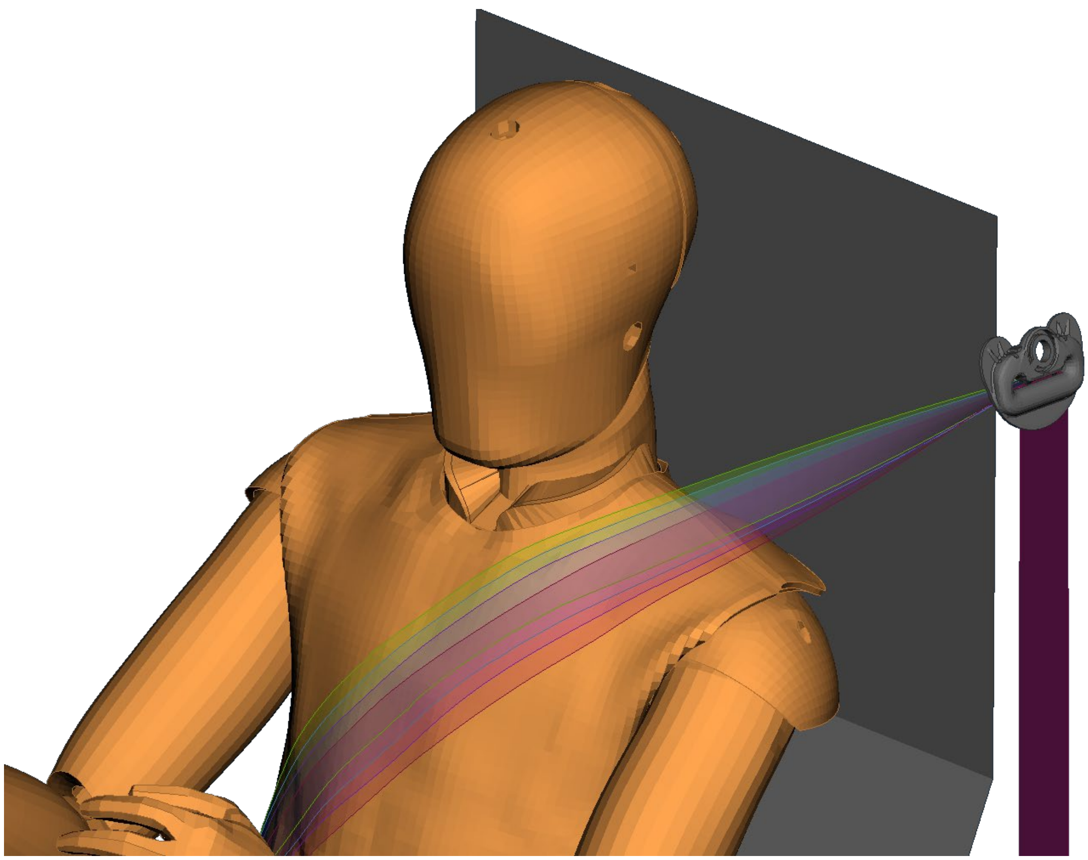


*Fig. 5: Multiple seatbelt application on different 'locked points'*

# 7 Optimization tool

After explaining in the sections above all the main tools needed to prepare a single case (seat-dummy positioning, de-penetration, seatbelt application), the next step is to make clear how different scenarios can be set up, in a bulk automated way in ANSA, to be solved by LS-DYNA and finally be evaluated in META. The 'Optimization Tool' of ANSA is the main functionality that enables the user to create a DOE study of the desired occupant safety simulations.

The most important thing in a DOE study is the optimization task, a sequence of task items. Each task item corresponds either to a specific pre-processing, output or post-processing action. These task items are executed in a specified order.

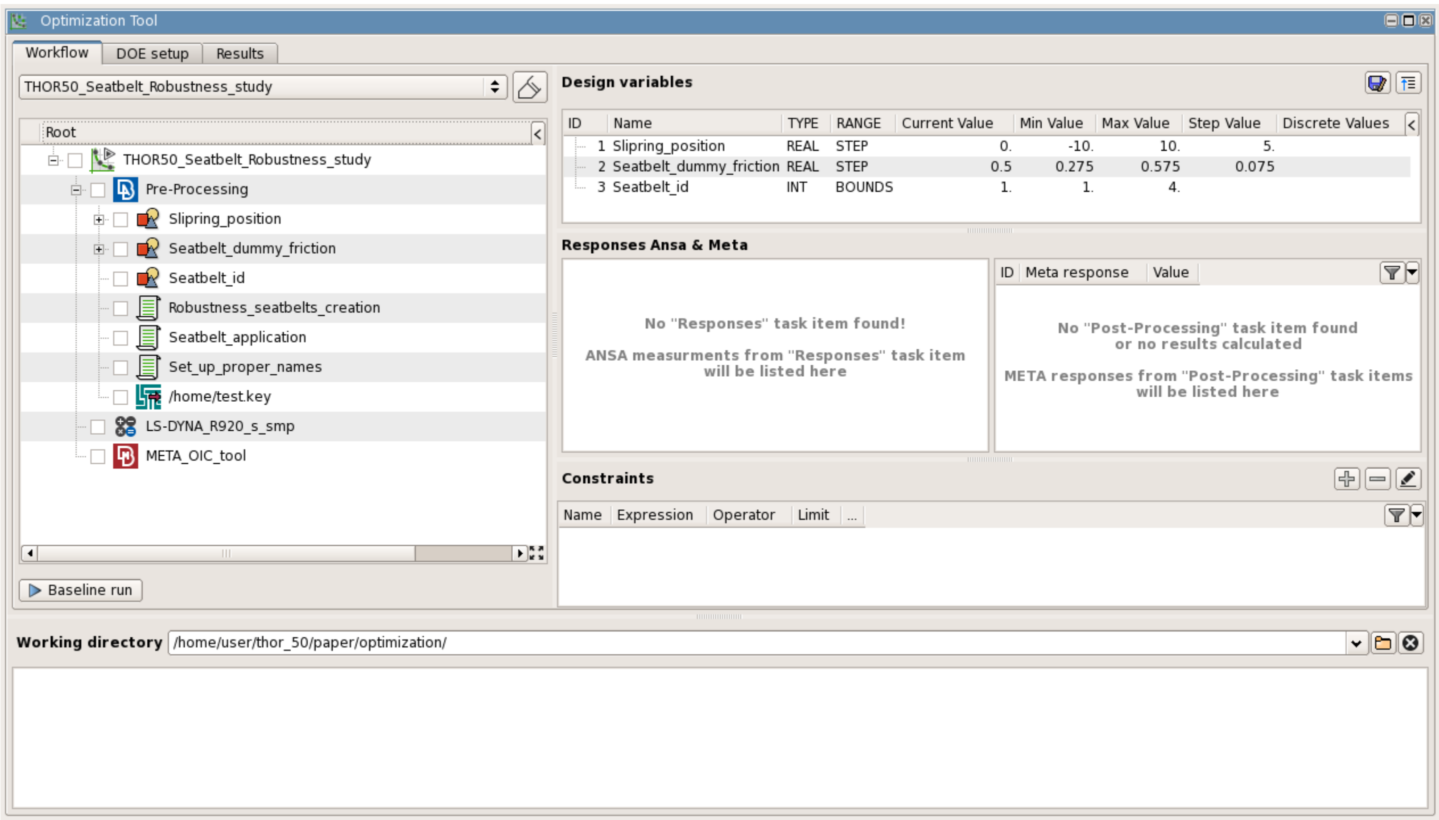



*Fig. 6: Seatbelt robustness study in ANSA Optimization Tool*

The main pre-processing actions that compose this sequence refer to do the definition and modification of the design variables. Each variable is a parameter that makes each occupant safety scenario different. In the current paper the design variables studied are the height of the slipring in the shoulder belt, the friction in the seatbelt-dummy contact and a different location on the thorax of the dummy from which the belt passes ('locked' point).

For the first case a morphing parameter is defined. With the use of 'Direct Fit Morphing' (DFM) the slipring position is modified along z'axis (global).

On the other hand, with the use of ANSA 'A_PARAMETER' the friction value in the seatbelt-dummy contact card is modified in a desired range of values.

For each combination of these modified parameters four belts are created passing from a different 'locked point' (coordinates on the thorax of the dummy) that lay along a specific vector. The creation of the multiple seatbelts along a vector is a result of the seatbelt 'postscript' function that runs during the seatbelt creation in the design position. This scripted sub process appears as an additional item in the optimization task.
During a single run of the optimization task the parameters (slipring location, contact friction and 'locked' point position) get a value according to the user definition and for each combination one seatbelt entity is created. Then a task item is responsible to output a file in LS-DYNA format and LS-DYNA is called to solve the simulation. When the solution is ready the 'Optimization Tool' calls META to extract all the responses and histories. These results are saved in a text file which can be read from the Optimization Tool.
The definition of the responses and histories that will be used in the DOE, the creation of the session that extracts them and the extraction is done by the 'Occupant Injury Criteria' tool of META.

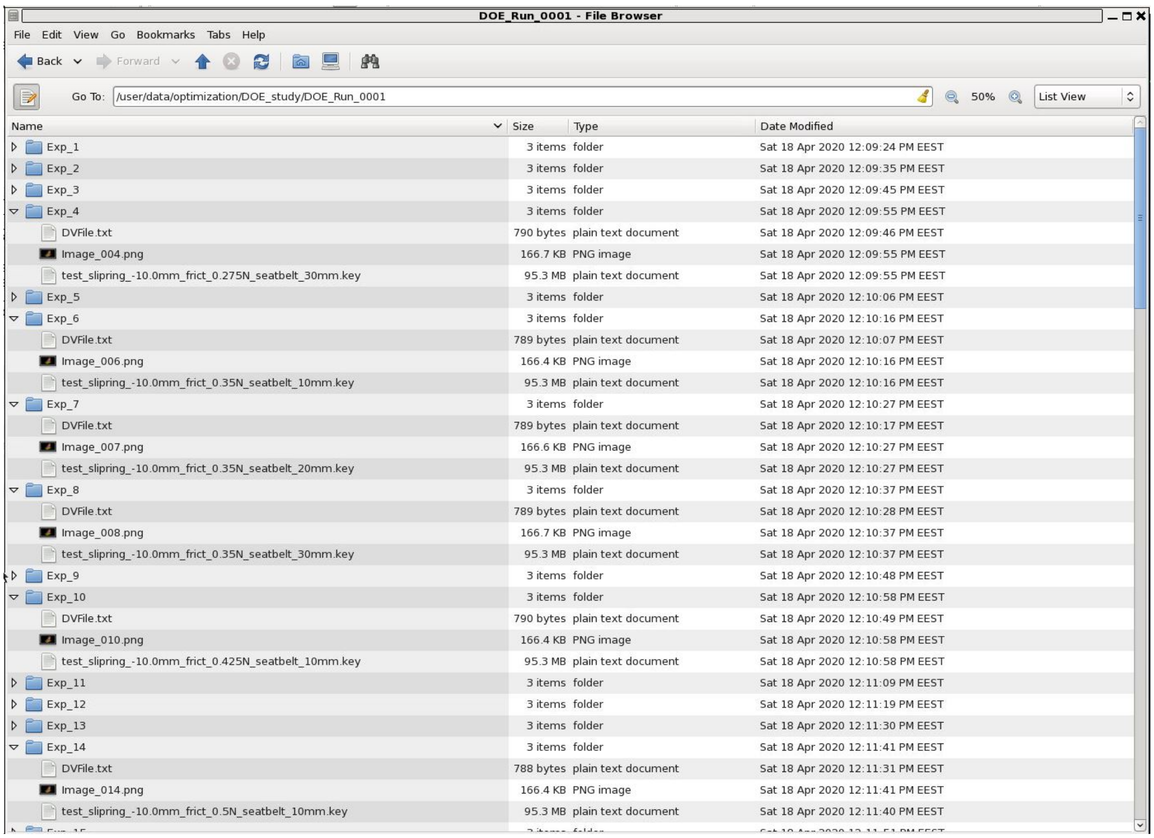



*Fig. 7: File Manager preview after DOE run from ANSA Optimization tool*

Since a single run of the optimization Task has been defined then the DOE study is really easily set up through the ANSA optimization tool. According to the range of values that each parameter gets, the 'Optimization tool' calculates all the different combinations of the modified parameters. For each combination the optimization task runs and the single process explained above runs in a bulk way.

# 8 Occupant Injury Criteria tool

The Occupant Injury Criteria tool streamlines the extraction of occupant injury results. Many simulations and physical tests can be processed simultaneously.

One of the capabilities of this tool is to define and extract occupant injury results to be used as responses and histories in DOE studies and optimizations. After running a base simulation, the analyst can select from a list that contains all the occupant injury results, which will be used as responses and histories. At the same time a session file is created which can be used from the Optimization tool of ANSA, or from optimizers like LS-OPT® to call META in order to extract the same responses again after each experiment's solution in LS-DYNA.

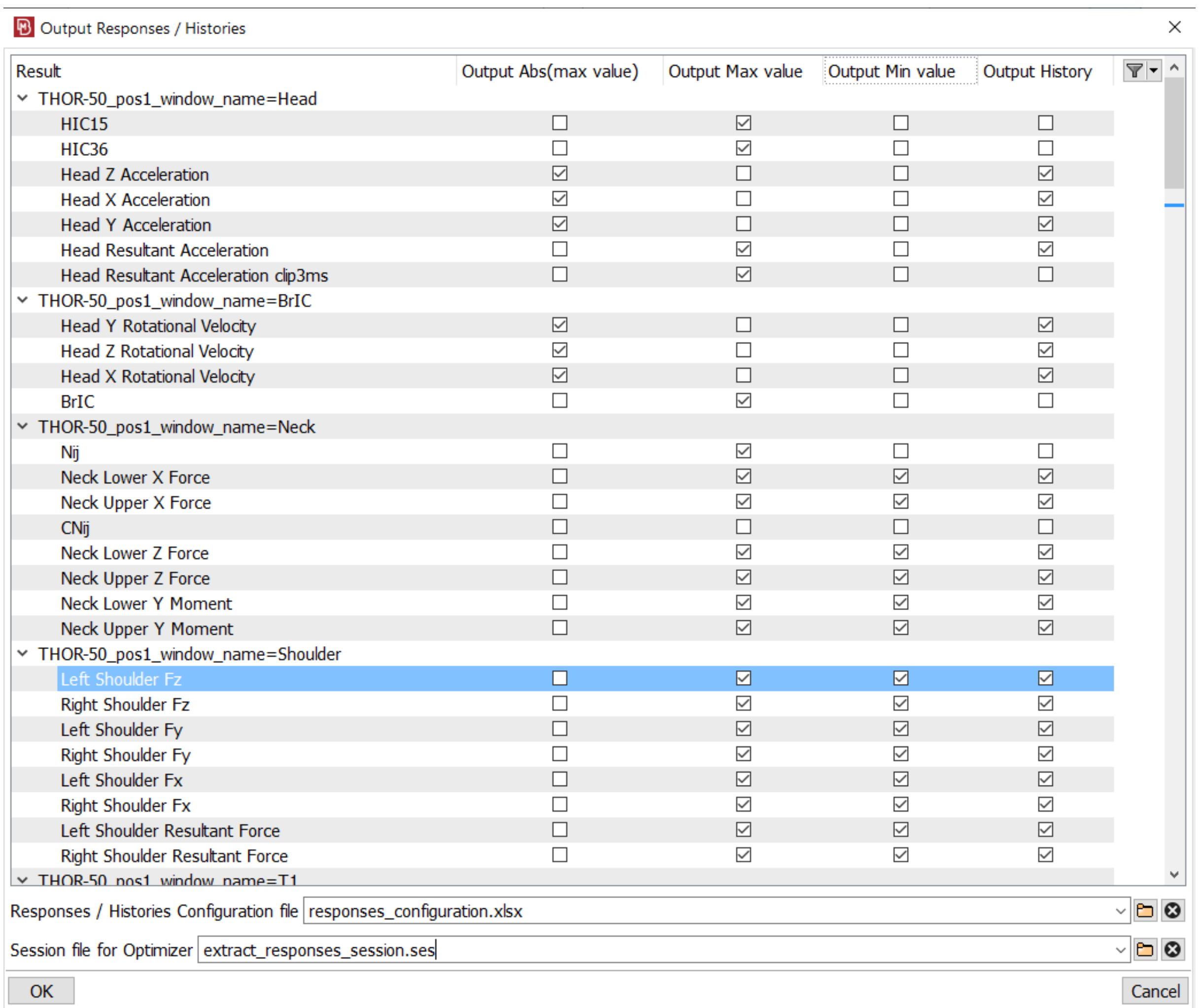
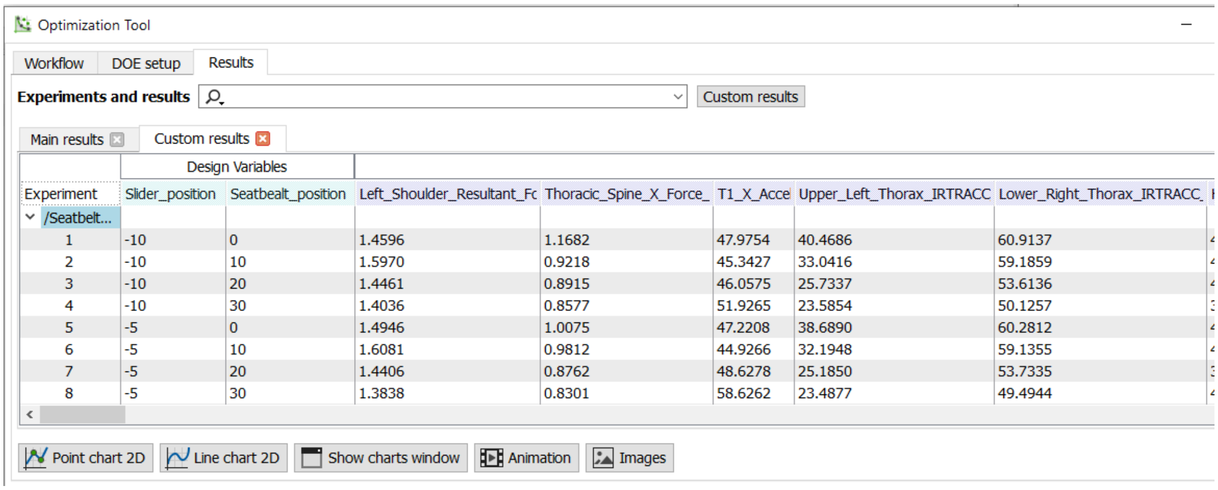



*Fig. 8: Definition of responses, histories and of the session file that extracts them in the Occupant Injury Criteria tool of META*

The same session can create a report with all the occupant injury results and can also save the results in native META databases in order to be opened later from the analyst for further evaluation of each experiment's results.

# 9 Results

In this DOE study a THOR-50M Anthropomorphic Test Device CAE model was used. After all the experiments are solved in LS-DYNA, an overview of the responses can be seen in the Optimization Tool of ANSA.




| Experiment | Slider_position | Seatbealt_position | Left_Shoulder_Resultant_Fc | Thoracic_Spine_X_Force_ | T1_X_Acce | Upper_Left_Thorax_IRTRACC | Lower_Right_Thorax_IRTRACC_ |
|---|---|---|---|---|---|---|---|
| | Design Variables | | | | | | |
| /Seatbelt... | | | | | | | |
| 1 | -10 | 0 | 1.4596 | 1.1682 | 47.9754 | 40.4686 | 60.9137 |
| 2 | -10 | 10 | 1.5970 | 0.9218 | 45.3427 | 33.0416 | 59.1859 |
| 3 | -10 | 20 | 1.4461 | 0.8915 | 46.0575 | 25.7337 | 53.6136 |
| 4 | -10 | 30 | 1.4036 | 0.8577 | 51.9265 | 23.5854 | 50.1257 |
| 5 | -5 | 0 | 1.4946 | 1.0075 | 47.2208 | 38.6890 | 60.2812 |
| 6 | -5 | 10 | 1.6081 | 0.9812 | 44.9266 | 32.1948 | 59.1355 |
| 7 | -5 | 20 | 1.4406 | 0.8762 | 48.6278 | 25.1850 | 53.7335 |
| 8 | -5 | 30 | 1.3838 | 0.8301 | 58.6262 | 23.4877 | 49.4944 |

*Fig. 9: Overview of responses in the Optimization Tool of ANSA*

The responses can be evaluated in point charts in which a selected response is plotted over a specific design variable or in line charts in which the response values are plotted over the experiment ids.

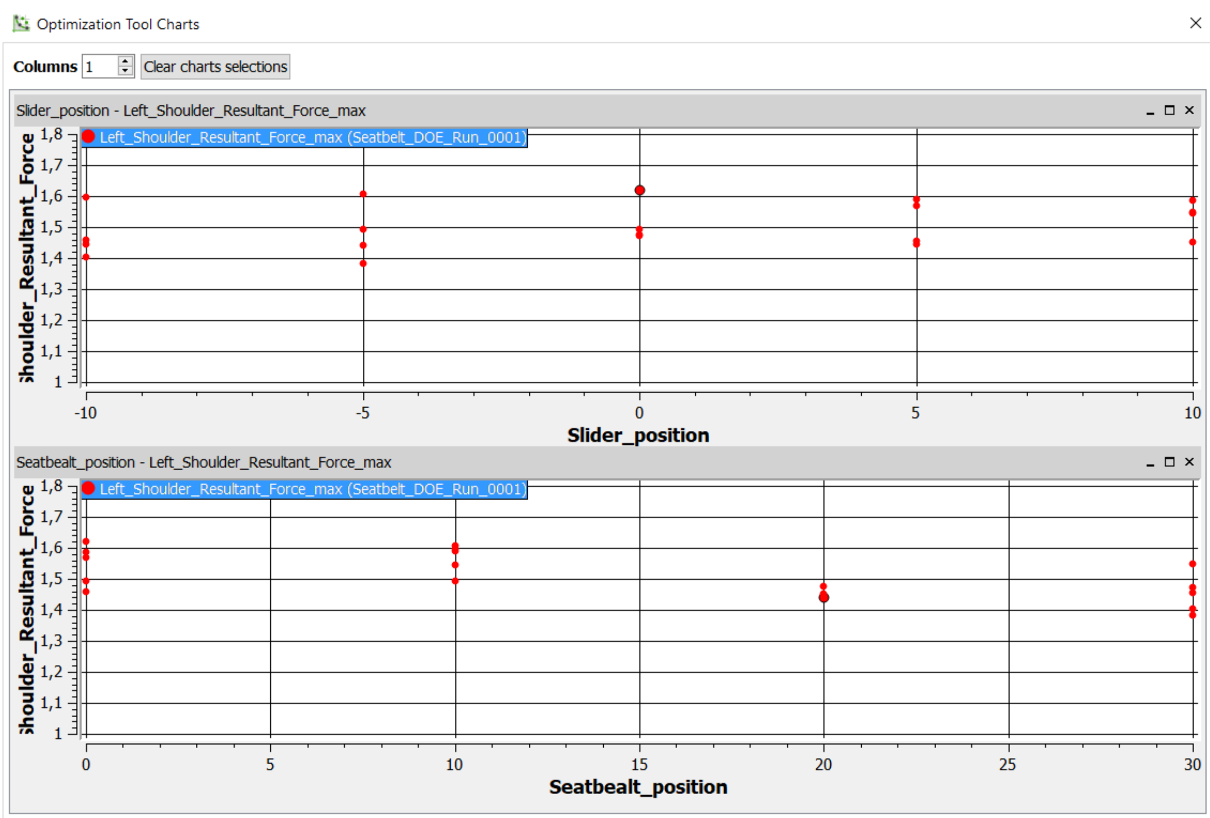



*Fig. 10: Left Shoulder Resultant Force response values over Slipring position change and over Seatbelt position change as point charts.*

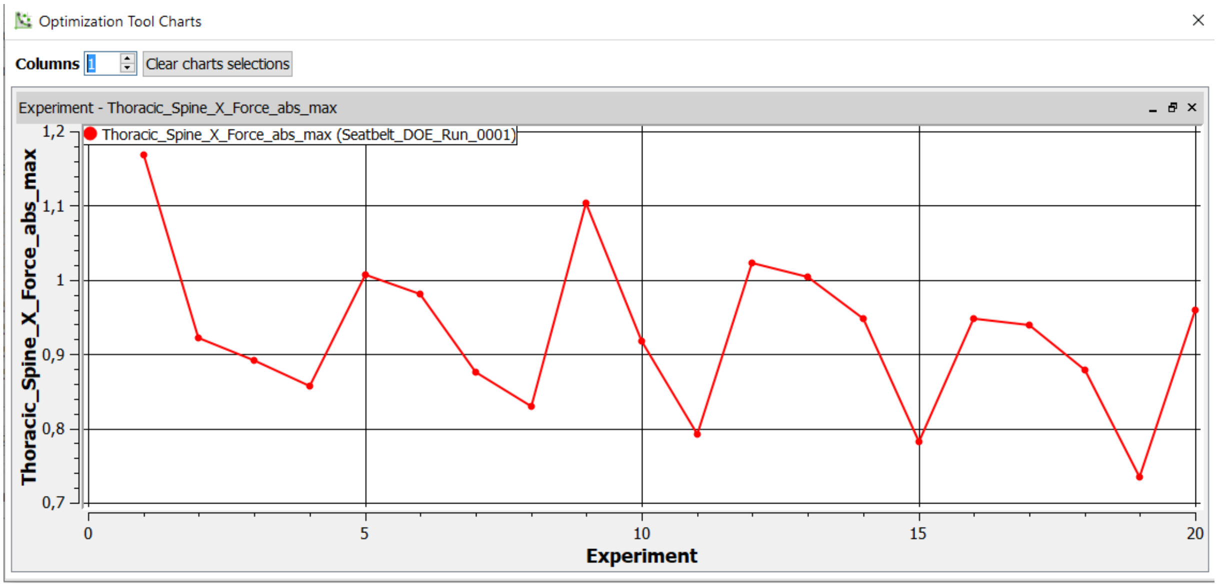



*Fig. 11: Thoracic Spine X Force response values over experiment ids in a line chart.*

The history results can be evaluated in META with the aid of Occupant Injury Criteria tool.

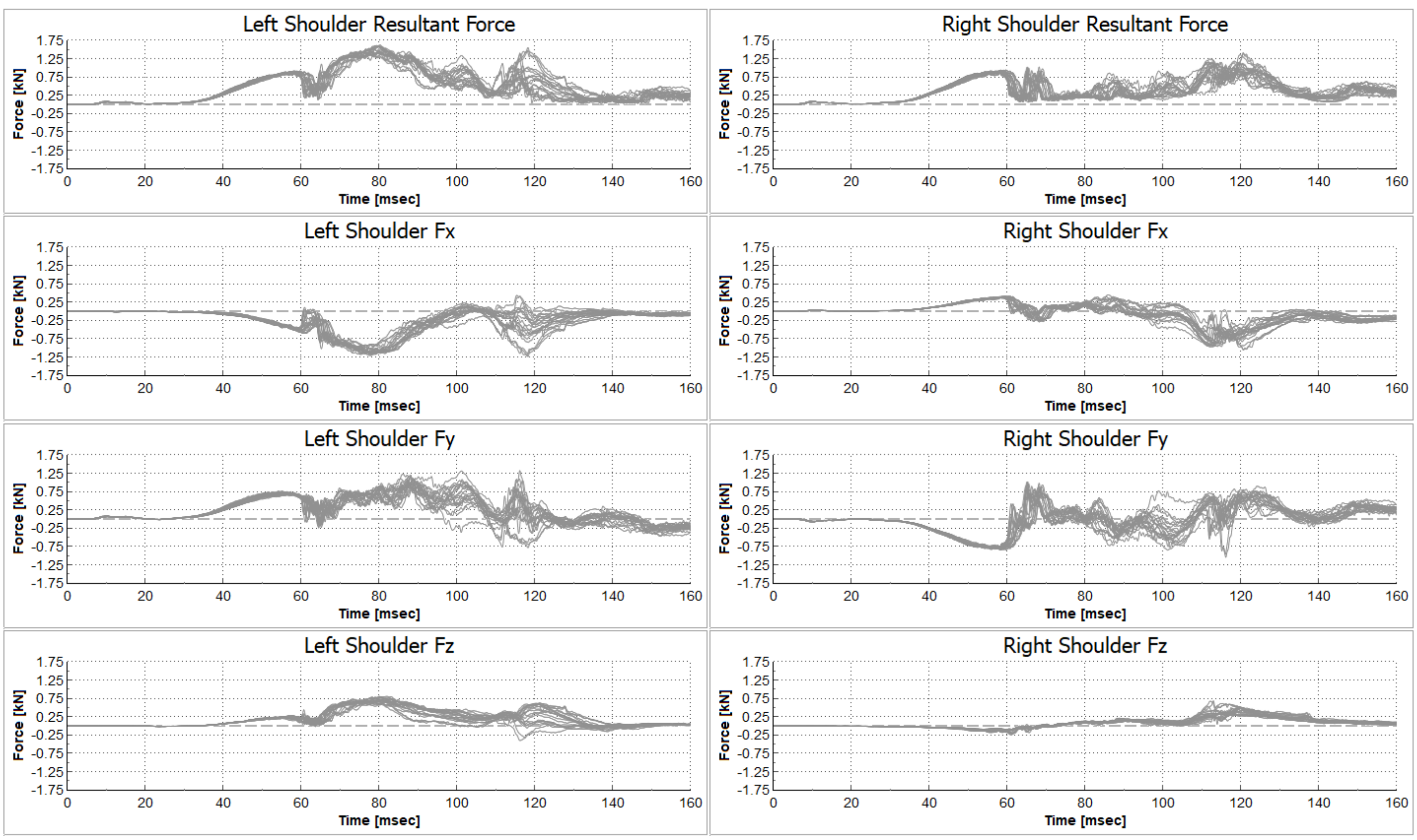



*Fig. 12: Left and Right Shoulder Force results of all experiments in META.*

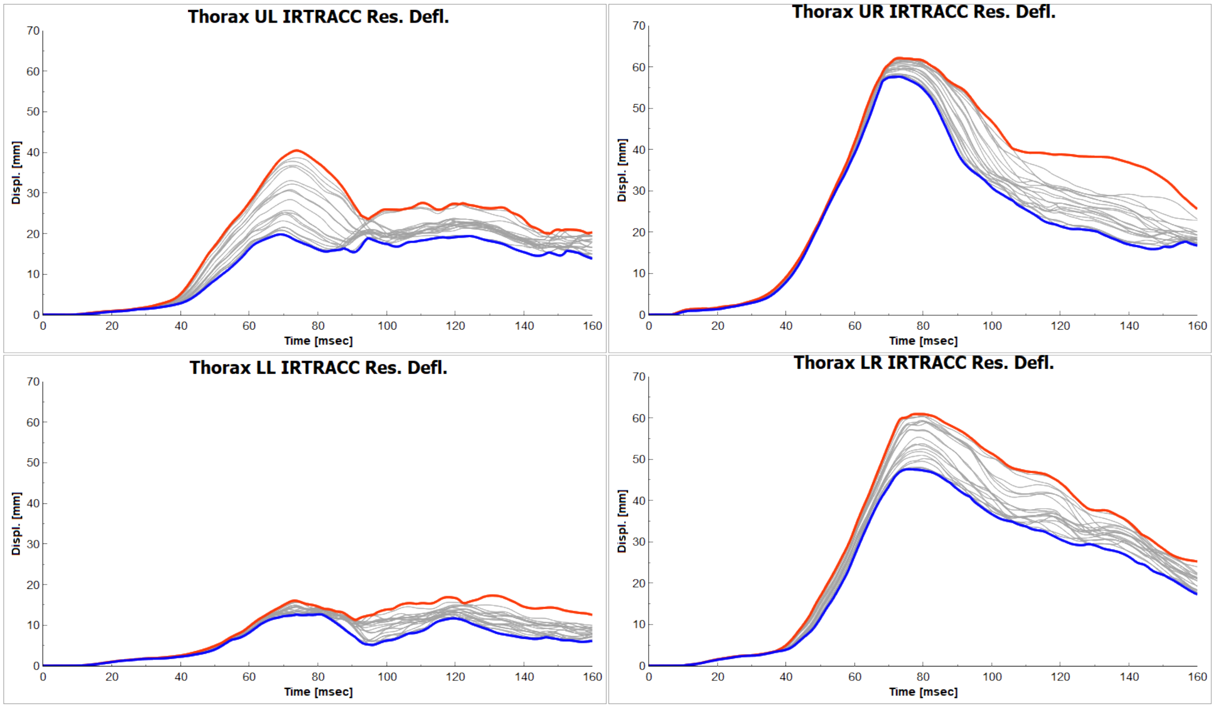



*Fig. 13: Left and Right Thorax Rib deflection results of all experiments in META.*

After evaluating the responses in the Optimization tool and the histories in META it is clear that changing the slipring's height and the position on the ATD's chest from where the belt passes, the injury results change.
If we focus on a specific slipring height and a specific belt position, we can see that the different friction coefficient values between the seatbelt and the ATD also affect the injury results.

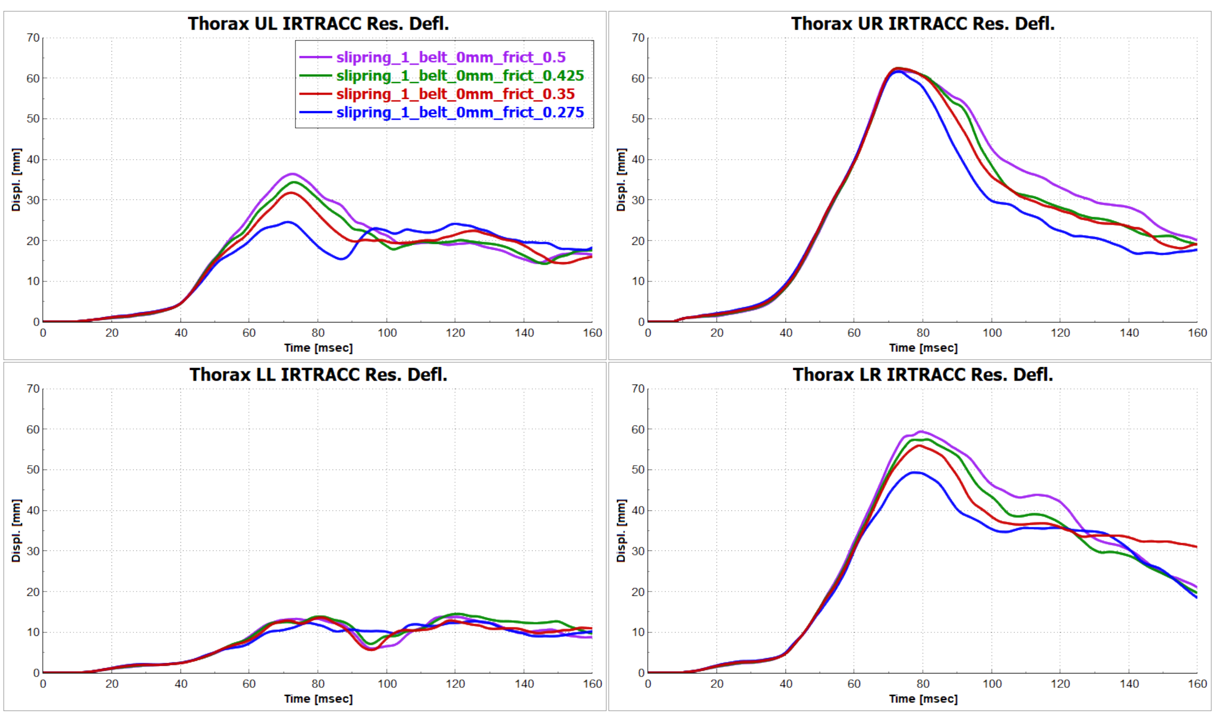



*Fig. 14: Different Thorax Rib deflections coming from different friction coefficients between the ATD and the seatbelt, for the same slipring and seatbelt position.*

Apart from evaluating the history results in META, for selected experiments the 3d deformations of the ATD can be loaded and evaluated next to the history results.

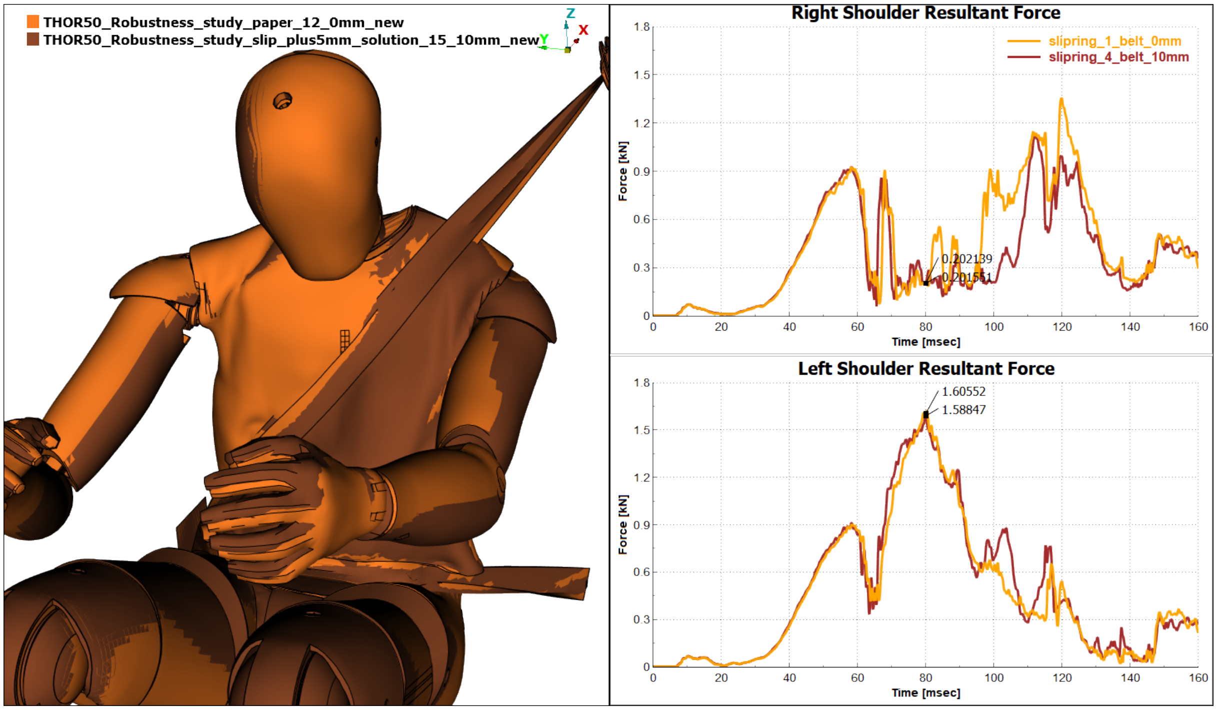



*Fig. 15: Experiments with the highest Left Shoulder Forces.*

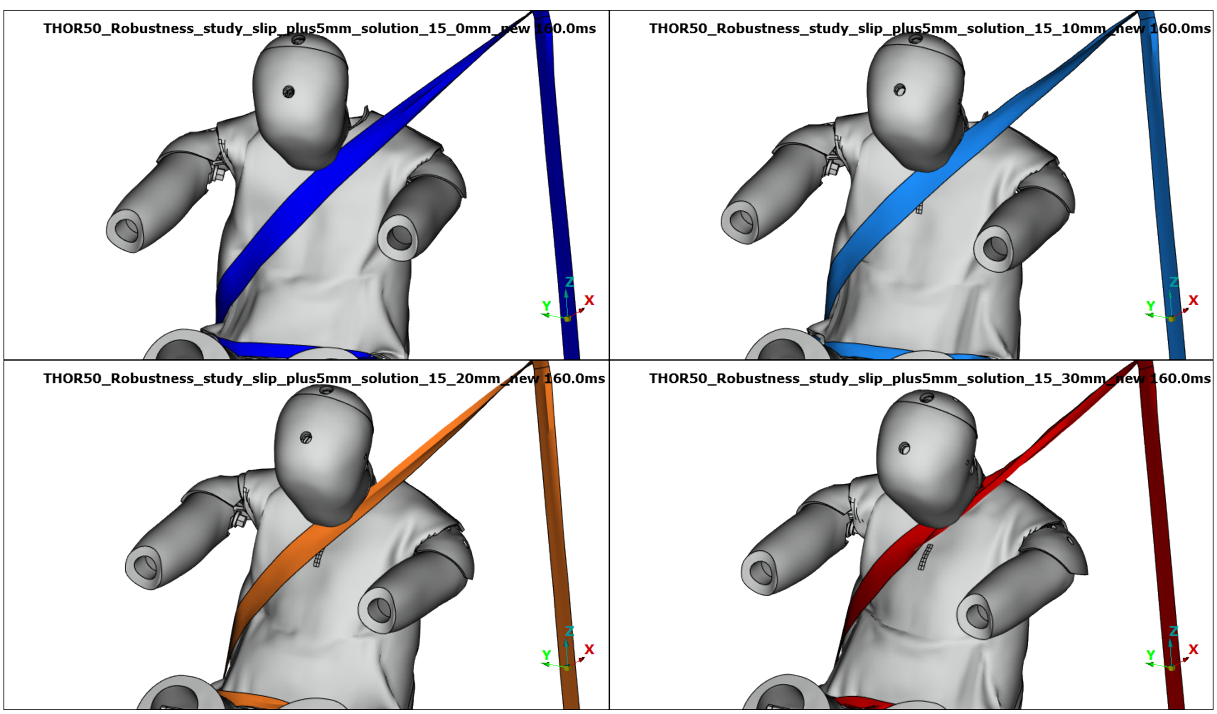



*Fig. 16: Same slipring height, 4 different belt positions.*

# 10 Summary

BETA CAE Systems offers a complete suite of tools for occupant safety simulations that ensure a proper seat and dummy positioning, their restrain with seatbelts and the final LS-DYNA loadcase output in an automated way. Moreover, through the Optimization tool an analyst can create easily DOE studies by setting up the necessary parameters, apply user defined actions with the aid of Python scripting and call automatically for each output file LS-DYNA. The Occupant Injury Criteria tool of META can automatically extract the occupant injury results, create a complete report of graphs and 3D images/videos for a thorough evaluation of the occupant safety results and extract the responses – histories in a DOE study or in an optimization loop.
Using the aforementioned functionality a THOR-50M ATD was used in a DOE that studied how the height of the slipring in the shoulder belt, the position on the chest from where the belt passes and the friction in the seatbelt-dummy contact affects the ATD's injury results.
All of the above 3 design variables affected the injury results. The most affected results were the forces measured on the Left Shoulder and the deflections of the Upper Left and Lower Right Thorax Ribs.

## References

[1] ANSA User's Guide v20.1.1
[2] META User's Guide v20.1.1
[3] Halquist, J.O., LS-DYNA Keywords User's manual Version 971 R9.0, Livermore Software Corporation, Livermore, 2016