# An Integrated Process for Occupant Safety Simulations with LS-DYNA® & MADYMO Coupling

Cédric Canadas[1], Paul van Catz[2], Tom Van Langenhove[1],
Peter Ritmeijer[2] Christophe Liefooghe[1]
[1] *LMS International, Belgium*
[2] *TASS, the Netherlands*

**Abstract**

*This paper presents an innovative integrated process to perform occupant safety simulation with LS-Dyna & Madymo coupling. More than ever before, the automotive industry operates in a highly competitive environment. Manufacturers must deal with competitive pressure and with conflicting demands from customers and regulatory bodies regarding the vehicle functional performance, which forces them to develop products of increasing quality in even shorter time. To address these challenges and deliver optimal collaboration between design and engineering, the integration between CAD and CAE is key.*

*Through a strong link between CAD and CAE, along with the integration of all simulation steps in one environment, new methodologies are developed, allowing the full utilization of parametric geometry based analysis, enabling quick "what if" scenarios simulation, and thus front-loading design with simulation. Complex CAD based assembly is fully automated, reducing the risk of modeling mistakes. Moreover, repetitive tasks such as definition of the model symmetry, are performed automatically. These functionalities allow crash engineers to focus on the impact/safety simulations set up and not on the model construction. LMS Virtual.Lab is fully integrated with Dassault System CATIA V5, therefore seamlessly linking CAD with CAE.*

*In the field of occupant safety, Virtual.Lab pushes the integration a step forward through the support of Madymo Coupling Assistant. Tedious dummy positioning and coupling contact creation becomes straightforward with the visualization of the Madymo dummy in its LS-Dyna FE model environment.*
*A real life industrial case is presented consisting of a CAD based assembly of a door sub-system is performed automatically through automation, and then integrated within a quarter body in white. A Madymo dummy is then positioned wrt the vehicle model, allowing to define coupling simulation of a side impact with LS-DYNA and MADYMO solvers. Back to back comparison of traditional CAE and the proposed new methodology is highlighted to provide a measure of the savings that can be realized.*

## Keywords

*Parametric CAD, Hybrid design, Occupant safety, Generic assembly, Integrated platform, LS-Dyna, CATIA V5, TASS, Madymo, LMS, Virtual.Lab*

# 1 Introduction

The highly competitive environment in the automotive industry drives OEMs and suppliers towards products with reduced time-to-market, while conflicting demands from customers and regulatory bodies push technical challenges to a higher level. These complex and challenging requirements are addressed by means of virtual modelling and simulation procedures.
From CAD design to simulation post-processing, many highly advanced tools are used, bringing huge confidence in all the design and simulations steps, but creating gaps in between due to lack of integration. While gaps are being more and more closed within the CAE world, some significant improvement can still be brought to improve and reinforce the link between CAD and CAE.
Another area of improvement is in simulations where 2 solvers / models are needed. A perfect example is safety simulation using coupling technologies between LS-Dyna and Madymo. Such simulations require the definition of a structural model and a dummy model in 2 different environments.

# 2 Integrated Methodology: Closing the gap between CAD and CAE

## 2.1 "Classical Approach"

In the classical approach, while it is very common to have a good integration of all CAE steps (meshing, pre-processing, solver driving and post-processing), there is usually a clear split between the CAD and CAE world.

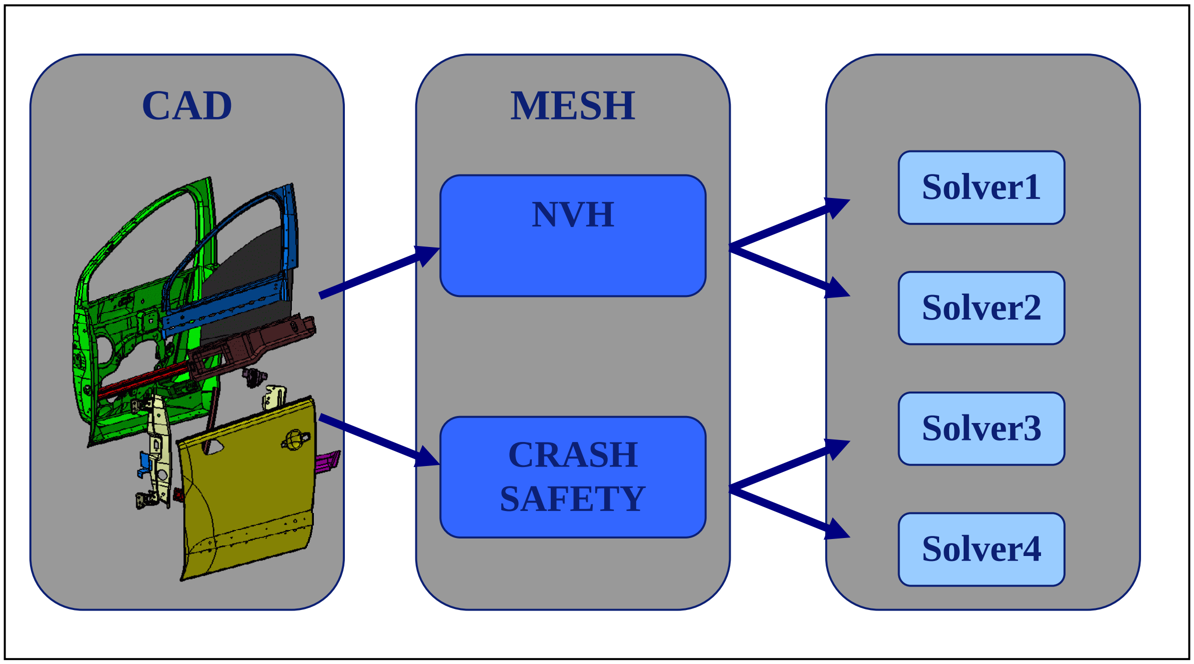


**Figure 1: Classical "sequential" process**

In current processes, too much time is lost in the generation of attribute specific full vehicle simulation models from the moment the detailed geometry becomes available. In case of updates, often too much time is spent re-assembling attribute specific full vehicle simulation models since little or no automation exists.
Moreover, partly due to the fact that a lot of time is spent in the modeling of the full vehicle, but also due to the fact that simulation of minor and major design changes has not obtained an

optimal efficiency yet, only a few iterations can be performed in a given time window leading to an over design instead of an optimal design.

### 2.2 New Approach: CAD/CAE Integration

In the new approach, the process becomes CAD based centric, seamlessly linking CAD data and CAE data. LMS Virtual.Lab is fully integrated with Dassault System CATIA V5, offering a unique platform for designers and simulation experts. The various process and simulation steps that would otherwise run separately and produce isolated results are thus integrated in a single process. Through that process, data translation is avoided. Instead, designers and simulation experts share the same set of information.

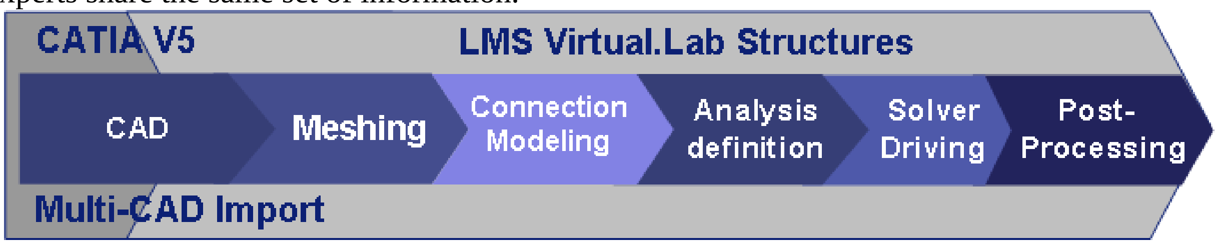


**Figure 2: CAD / CAE Integration**

This strong integration offers flexibility to run a full geometry based analysis, as well as a hybrid CAD/CAE process, or a fully CAE mesh based. The assembly can be defined directly on the geometry data, resulting in one CAD/FE unified assembly model for all the possible attributes. Starting from that generic assembly, different meshing engines can be called to create attribute specific component meshes. These attribute-specific component FE representations can then be associated as to this independent assembly. Then becomes straightforward and efficient to switch from one attribute to another, e.g. to convert an LS-DYNA model meshed with ANSA for crash to a NVH model meshed with CATIA.

Working in an integrated environment allows to run the definition process in a fully geometry-associative way. Any parametric change in the geometry can be automatically accommodated and lead to new models for different attributes with a simple push of a button.

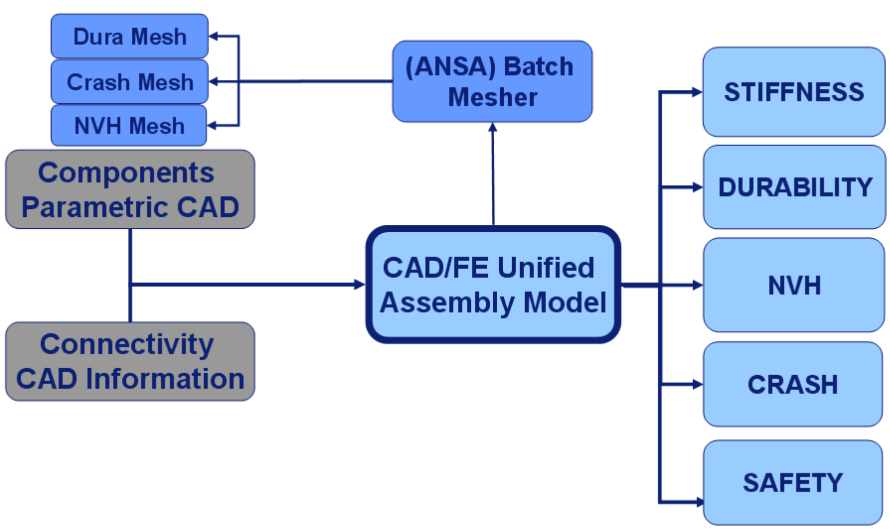


**Figure 3: CAD Based process**

The key element of this CAD based, multi-attribute approach, is the unified assembly model. This concept allows designers or simulation engineers to define connections using geometry data. The connectivity information from CAD is then leveraged and can serve as direct input for all attributes.
Time gain on initial assembly because only 1 common assembly instead of several attribute specific assembly (NVH, Crash, Durability …).

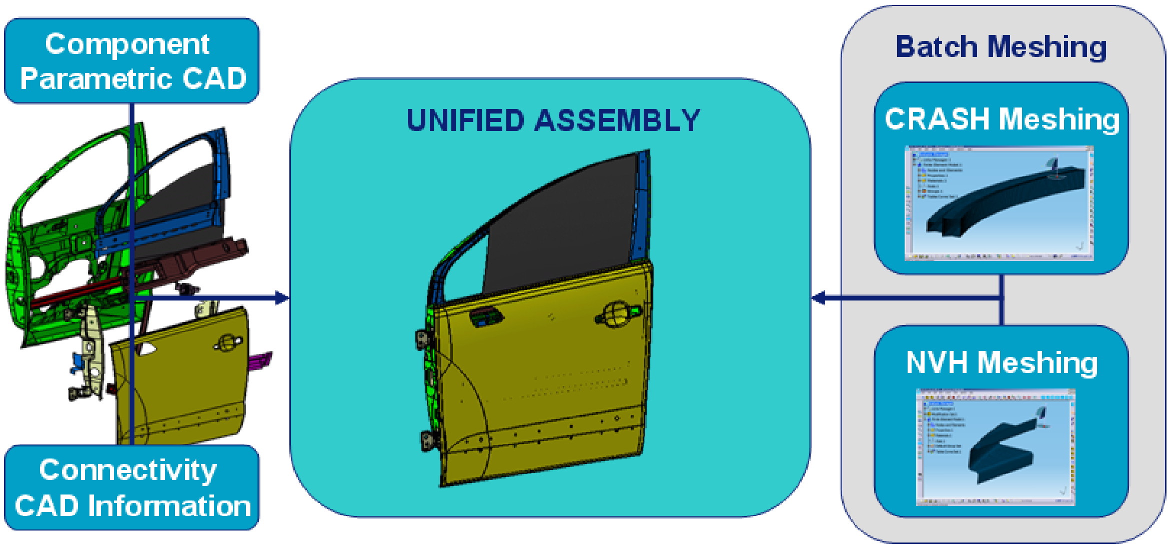


**Figure 4: CAD/FE Unified Assembly Model**

The unified assembly model becomes the new starting point for engineers to perform attribute-specific simulations. The work done to build up the assembly model does not need to be repeated for each independent attribute/simulation. As many attribute specific meshes as necessary can be added to the unified assembly without invalidating the generic connections. Moreover in case of design changes or components replacement, the unified assembly will automatically update and re-create connections, and batch meshing process will be triggered to generate new attribute specific models. This automatic “update” capability enables quick and reliable “what if” scenarios to be performed.
Creation of the unified assembly with attribute specific meshes can be fully automated via scripting. This requires some extra work up front to prepare and clean the geometry in order to make sure batch meshing will be efficient, but overall the complete process from CAD to a fully meshed assembly can be cut by half. **For an industrial BIW this could represent several weeks on the initial model**. Moreover, since during the development cycle many design iterations are performed, this time reduction is repeated over time, thus the overall gain is even more important.

# 3 Definition of Safety simulation for LS-Dyna & Madymo coupling

## 3.1 Best of both worlds: LS-DYNA coupled to MADYMO

Finite element codes are commonly used to predict the vehicle deformations during a crash. These codes can predict complex deformations accurately, but are computationally expensive. The design of occupant restraint systems requires that many different variables are analyzed,

resulting in hundreds to thousands of simulation runs. To do this in a timely manner requires fast simulations, so MADYMO is typically used for this.
The coupling of MADYMO with LS-DYNA enables safety designers to embed MADYMO models of the dummy and restraint system in the vehicle model. At each time step of the simulation run the coupling interface is used to exchange information between MADYMO and LS-DYNA on the forces resulting from the interaction between components modelled in the different codes (e.g. the MADYMO dummy model and the door trim modelled in FE). The combined result of the calculations performed in MADYMO and LS-DYNA can be visualized and post-processed in a single graphical tool.
By coupling MADYMO to LS-DYNA, car makers have been able to validate their structural and safety system designs together, without the need for any additional modelling. Since this coupling approach allows the use of a MADYMO dummy model in both the restraint design and the verification of the full vehicle, this approach also leads to a consistent assessment of the safety performance throughout the entire development process.

### 3.2 Creating the coupling in LMS Virtual.Lab

The definition of an occupant safety simulation for LS-DYNA & MADYMO coupling can be a very tedious job. While the communication and data exchanged between the 2 solvers is transparent for the user, giving the impression that only 1 model and 1 solver is used, the set up of a coupling simulation requires the definition of coupling features in both the LS-DYNA and MADYMO models.
In the "classical" approach, 2 softwares are used, therefore 2 different environments that are typically not the same as used for the vehicle assembly. Madymo model positioning is then performed through a trial and error process, increasing the pre-processing time. Moreover, coupling interactions, such as contacts and restraints, must be defined in both models, increasing the risk of inconsistency, and errors, between the 2 models.
The MADYMO Coupling Assistant, dedicated graphical tool developed by TASS, enables LS-DYNA experts to include a MADYMO model (such as a dummy model) in their LS-DYNA model without having to learn the details of MADYMO. The LS-DYNA input deck and the MADYMO input deck are generated including the coupling statements.
With the integration of the MADYMO Coupling Assistant in LMS VIRTUAL.LAB, the definition of coupling simulation is done in one single environment where also the vehicle is assembled and all the CAD data is available. This integration greatly improves the time needed for the pre-processing, and it strongly helps in reducing users mistakes.

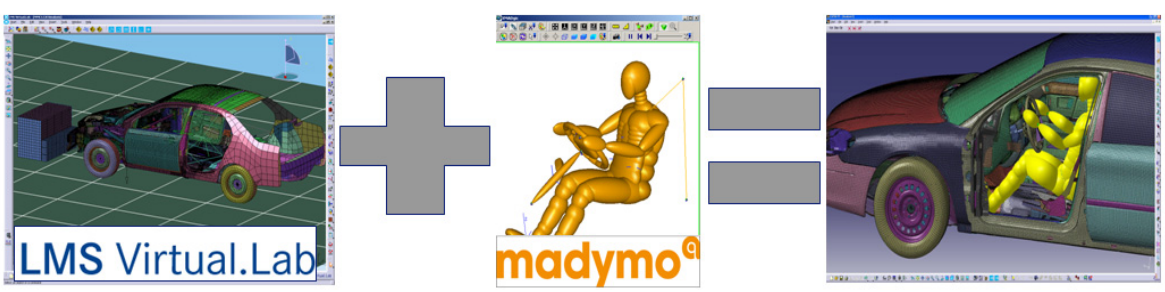


**Figure 5: Madymo Coupling Assistant integration in Virtual.Lab**

### 3.2.1 Positioning of Madymo model

One of the main functionality of the MADYMO Coupling Assistant in VIRTUAL.LAB is the capability to do positioning of the Madymo model in the same environment as the FE model. Global positioning is enabled, allowing end-users to quickly position a dummy within the vehicle. And dummy components (legs, arm …) can be moved through local positioning wrt to FE parts such as steering wheel, pedals system …
Working in a single environment gives visual feedback to the end users to better position its Madymo model wrt to CAD and FE data.

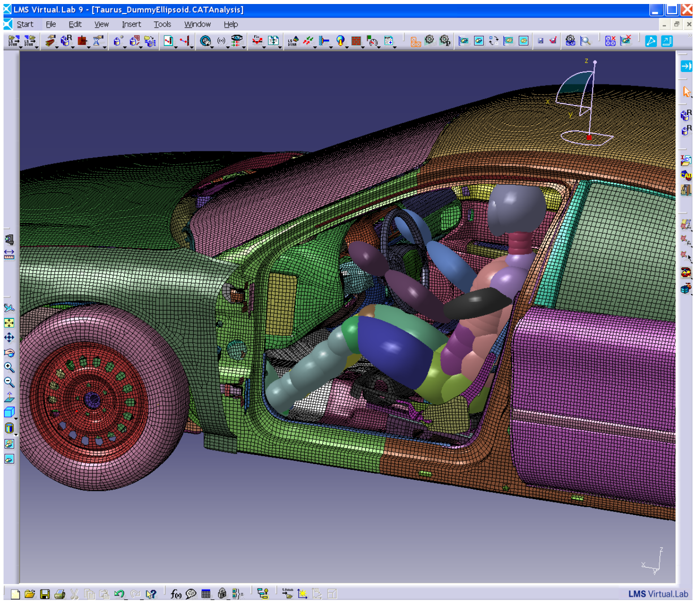


**Figure 6: Madymo Dummy positioning in vehicle compartment**

### 3.2.2 Definition of interactions

The strength of working in a single environment enables functionalities that would otherwise not be available regarding the definition of interactions. Having access to CAD data, FE data and to the MADYMO models, allows interactions to be created between different types of entities. For instance, it is possible to create a contact between a Madymo FE part and a CAD surface. Moreover through highlight of the selected entities, end-users have instant visual feedback. They can spot right away missing entities in a contact definition or in a restraint. Moreover, for both types of interactions support selection can be done by 3D picking no matter the type of entity (FE, CAD or Madymo body).

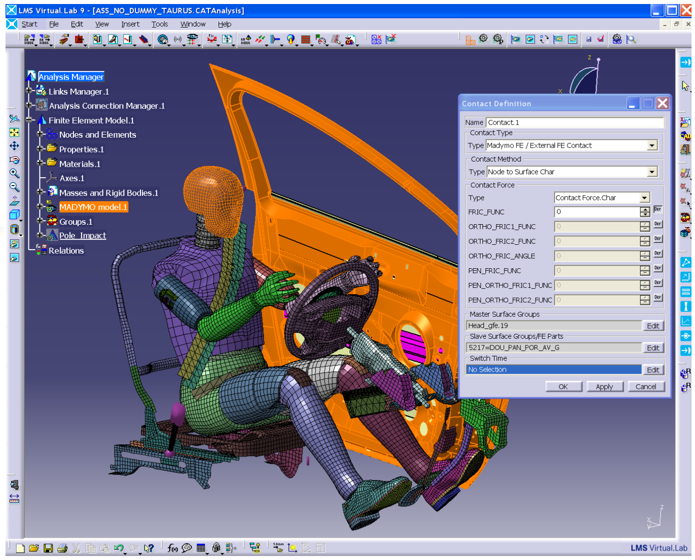

**Figure 7: Definition of contact between Madymo Dummy and CAD door panel**

### 3.2.3 Benefits of MADYMO Coupling Assistant in VIRTUAL.LAB

The integration of the MADYMO Coupling Assistant in VIRTUAL.LAB leverages the intrinsic capabilities of the application developed by TASS. While the MADYMO coupling assistant allows for easy and reliable coupling simulations definition, it benefits from the natural link with CAD available in VIRTUAL.LAB which allows for:

- Visualisation of CAD, FE and Dummy
- Dummy positioning wrt FE/CAD model
- Fast design iteration through CAD associativity

Adding optimization to this, all this capabilities enable to frontload pedestrian and occupant safety design decisions.

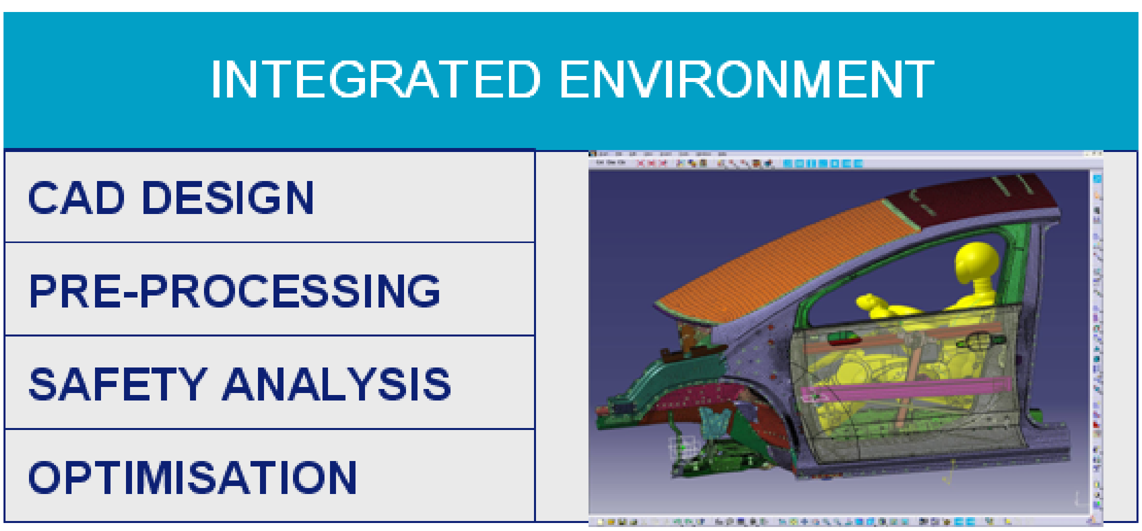


**Figure 8: Virtual.Lab and Madymo Coupling Assistant: An integrated environment**

### 3.3 MADYMO LS-DYNA coupling versions supported

In general can be said that MADYMO couples with LS-DYNA version 970 and 971. For detailed platform information please visit the TASS website at http://www.tass-safe.com. Currently developments are ongoing on the coupling integration between MADYMO and LS-DYNA which allow both executables to run in MPP mode. This approach benefits from the scalability of both programs and the unique feature that communication between both executables is parallel. Large performance improvements are resulting from this approach. First measurements showed improvements up to 40% of the run-time. The release of the MPP coupling with LS-DYNA is expected to be soon.

## 4 Application: Occupant safety case

To illustrate the methodology described in Section 2 and 3 of this paper, the definition of a safety load case for LS-DYNA and MADYMO coupling is explained. The model involved will consist in a quarter body in white, with the front door. To simulate a safety case, a seat, a steering column and a pedal system will be added, along with a MADYMO ES2 dummy.
First, it will be demonstrated how an assembly made of 5 different sub-systems can be easily created. In particular, automation capabilities will be used to perform the door sub-system assembly. Then, the definition of a coupling analysis will be detailed.

### 4.1 Assembly creation

To build our model, the first step is to create the door sub-system assembly. The door is made of many CAD components that need to be connected to each others and then meshed according to the attribute. Interactively, this task can be very repetitive, error-prone and time consuming. VIRTUAL.LAB automation capabilities enable to raise all these concerns. Through customized scripts, all door connections (welds, structural adhesive …) can be created on the geometry with all the necessary parameters such as dimensions, material … Thus, the door assembly can be performed with one mouse click. Then, still through scripting, meshing scenarios can be defined, including meshing parameters and elements quality criteria, and all CAD Parts can be automatically submitted for batch meshing.
This fully automated process takes around 20min to go from door CAD components to FE door assembly with attributes specific properties/material. If done interactively by a CAE expert, the assembly definition would require several hours.

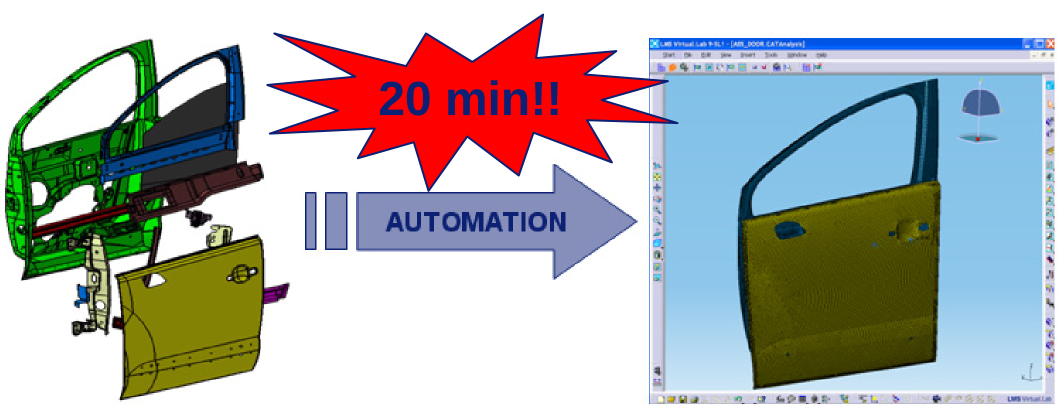


**Figure 9: Door assembly with automation**

Then using LMS VIRTUAL.LAB dedicated assembly commands, it is very easy and straightforward to add the other sub-systems to our model and to connect them all together:

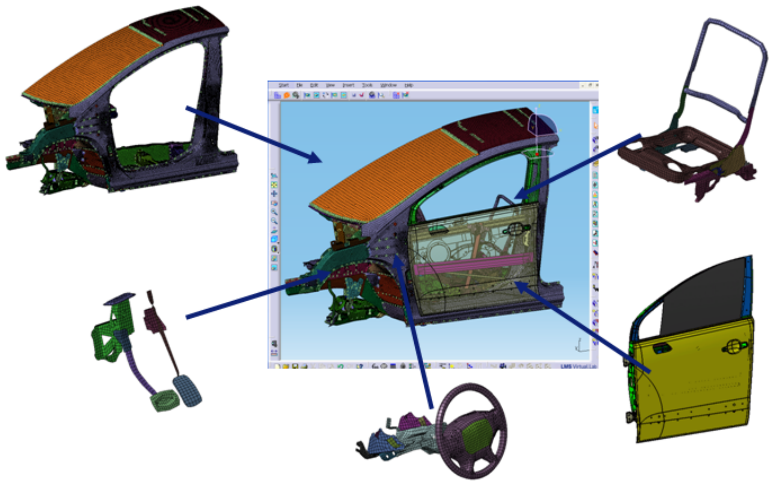

**Figure 10: Full assembly**

## 4.2 Coupling simulation definition

### 4.2.1 Dummy positioning and definition of interactions

Once the assembly is ready, it is time to set up the coupling simulation by first importing a Madymo model within our assembly. In our example, we import a Facet dummy ES2, along with airbags and seat belts.
First step is to globally position the complete MADYMO model through the "Initial Reference Space" feature. Once the Madymo model is positioned at the seat location, dummy components must be moved according to the vehicle environment, that is the seat, the steering wheel and the pedal systems. Through joint editing, and thanks to visual feedback, it takes a few minutes to have the dummy in position.


**Figure 11: Dummy positioning wrt LS-Dyna model**

Then, interactions have to be defined, in our example this implies contact between the MADYMO dummy and the LS-DYNA model, and restraint between the MADYMO seatbelts and the LS-DYNA seat.
The integrated environment and the high level of usability make the definition of this coupling case (both the positioning and the definition of interactions) in VIRTUAL.LAB very straightforward. For a trained user it takes only a few minutes **whereas it can take several hours using different environments** for the assembly creation, for the LS-DYNA model definition and for the MADYMO set up.

#### 4.2.2 Pole impact set up

Final step in this example is to define the LS-DYNA model boundary conditions. This is performed in the same environment. Clamp conditions are applied at the symmetry plane of the BIW and an initial velocity is applied to the pole. Note that in our example, a general contact, with all FE mesh parts and CAD components is defined.

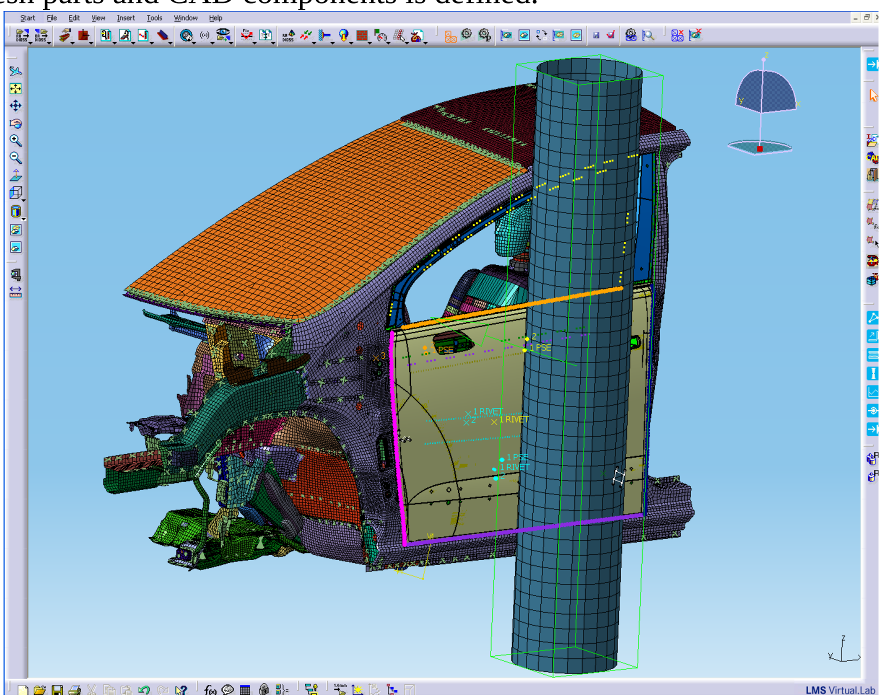


**Figure 12: Pole impact definition for safety analysis**

### 4.3 Design change: Quick model update for "What if" scenario

Once our nominal model is fully set up for a coupling simulation, it is very easy to generate new input decks to study the influence of some parameters or to investigate the effects of a component new design. Indeed, any CAD change, or any new component version, will trigger an update mechanism, and automatically generate new coupling models.

In our example, the most important component is the door reinforcement beam. This part has a predominant effect both in term of energy absorption and structure integrity. Therefore it is of strong interest to a crash engineer to study how cross section dimensions influence the structural deformation and the risk of injury for the driver. Therefore new set of dimensions (width, height

…) is input and automatically, through associativity a new coupling model is created. In particular the screw connections used to connect this beam to the door panels are automatically updated. Moreover, a new design for the cross section (tubular) is also used. Through VIRTUAL.LAB replace component functionalities, it is very easy to replace the old beam design with this new one. Connections are automatically recreated with the new component and the coupling model is updated.
In both cases, parametric changes and replace component, the time gain is very important. With this integrated and associative approach, the generation of a new coupling deck is done in seconds, whereas a conventional approach, where CAD is not linked with CAE, would require all definition steps (assembly creation, meshing, LS-DYNA model definition and MADYMO model definition) to be manually repeated. This manual approach can easily take several hours with a high risk of introducing mistakes and inconsistency.

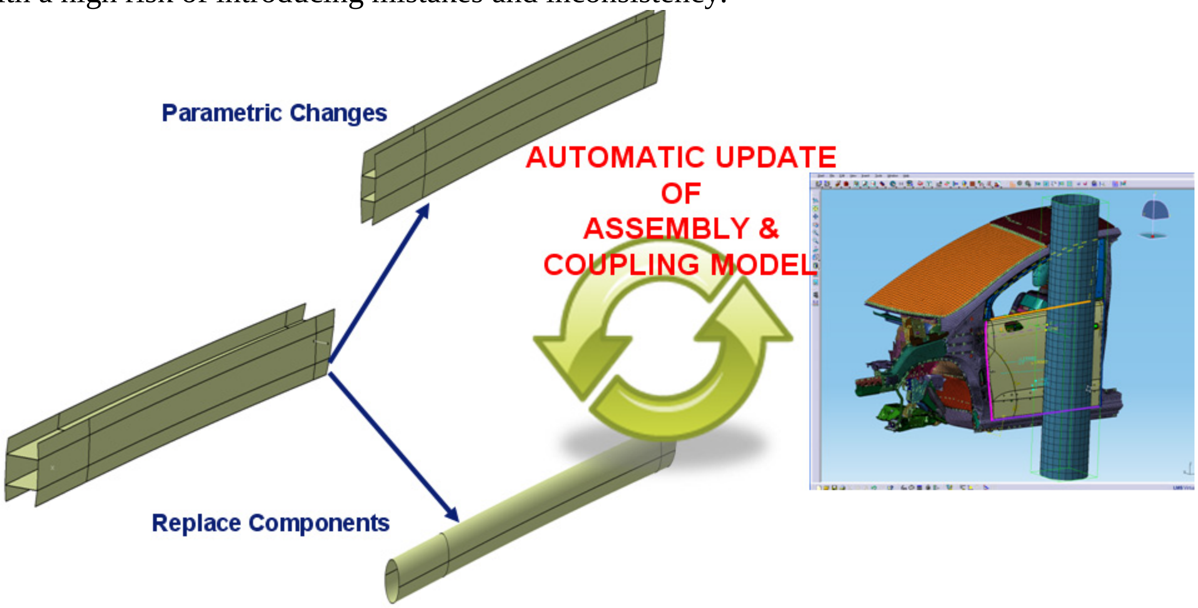


**Figure 13: Model update during CAD change or replace component**

## 5 Conclusions and outlook

This paper presents an innovative integrated process for safety analysis for LS-DYNA & MADYMO coupling. LMS VIRTUAL.LAB offers an integrated solution for CAD, FE or hybrid based simulations. Through automation and quick model update, model generation time for all various attributes is largely decreased. With the integration of the MADYMO Coupling Assistant from TASS, coupling simulations for safety analysis are no longer a tedious job for the CAE safety experts but are seamlessly part of this integrated process.
LMS VIRTUAL.LAB also offers optimization capabilities with the integration of OPTIMUS. It is envisaged to extend this paper with an optimization study (based on the pole impact use case) where mass of components, such as pillar and door reinforcements, is minimized while still meeting all safety and structural criteria.

# 6 Acknowledgements

Part of the work presented in this paper has been performed in the frame of the ongoing research project IWT-070401 “Simulation-Based Development of an Innovative Bumper Beam Concept with Integrated Crashbox Functionality (**I-CRASH**)”, which is carried out by PUNCH Metals N.V. and LMS International, and which is supported by IWT Vlaanderen.