Side Impact Systems Integration using BASIS Sled Testing and MADYMO PSM Simulation

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Abstract — A growing set of barrier tests has to be taken into account to design side impact restraints meeting worldwide safety requirements. This paper shows an efficient design process to meet side impact requirements using smart testing and simulation. In addition to full vehicle to barrier testing, innovative sled testing procedures are introduced. TNO has recently developed the BASIS sled test procedure, providing efficient and controlled evaluation of the restraint system, trim panel and seat. While full vehicle FE structural analysis is widely used, model sizes have been increasing which prohibits efficient design optimization. The use of prescribed structural motion (psm) provides an efficient alternative for restraint optimization. The objective in a typical psm simulation is to approximate a complex (and CPU expensive) loading scenario by prescribing (a part of the) structural nodes positions in time.

Keywords: Side Impact, PSM, Testing, Simulation, MADYMO

1 Introduction

The complex nature of side impact crash scenarios and the limited design space in which side impact restraints can be employed pose unique challenges for manufacturers. These challenges are compounded by the increasing number of different regulatory and consumer compliance tests, which in some cases have conflicting constraints or requirements. In addition, different crash dummies are used in the various compliance tests, each with significant differences in characteristics. With the introduction of the WorldSID 50th and 5th percentile this number is expected to grow in the near future before it will decline. Side impact compliance requirements (with applied dummy) include

- 96-27 EC (EuroSID-1)
- EuroNCAP side (ES-2)
- EuroNCAP pole (ES-2)
- FMVSS 214 barrier (US-DoTSID)
- FMVSS 214 NPRM barrier (ES-2 RE)
- FMVSS 201 pole (SID-HIII)
- FMVSS 201 NPRM pole (SIDIIs / ES-2re)
- IIHS (SID-IIs FRG)
- LINCAP/SINCAP (US-DoTSID)

Consequently, designing a robust and reliable side impact restraint system that meets several or all compliance tests is extremely complicated.

This paper shows System Development capabilities for Side Impact Safety designs, from the concept phase to final vehicle certification using an efficient combination of virtual testing, sled tests, and full scale barrier tests. The Development Methodology presented is sufficient flexible to accommodate requirements from legal and consumer tests, as well as customer specific requirements.

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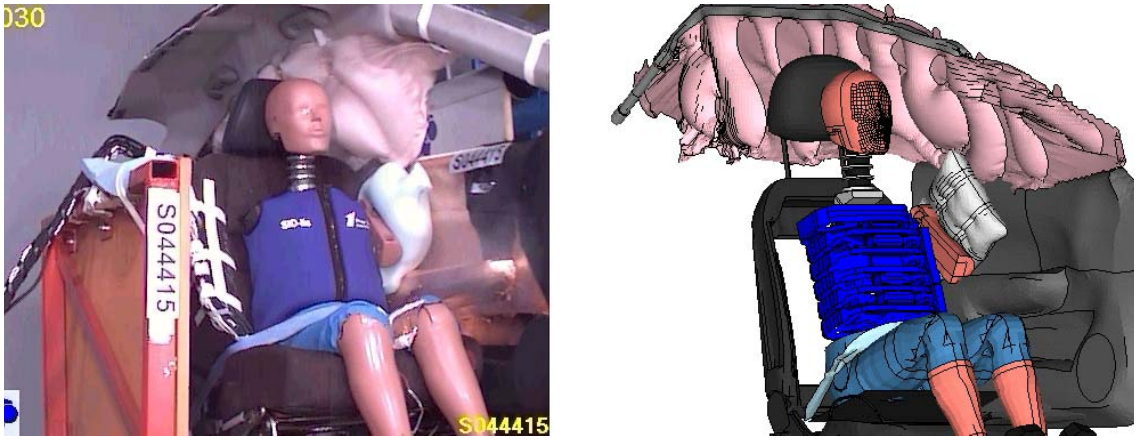

Fig.1 BASIS* sled test (left) and Prescribed Structural Motion simulation (right)

2 BASIS* Brake Assisted Side Impact Simulation

TNO Automotive have developed a test set-up on the Inverse Crash Simulator (ICS) that can support vehicle and airbag manufacturers in side impact safety-system development. TNO Automotive have developed a test set-up on the Inverse Crash Simulator (ICS) that accurately reproduces the forces of a full scale side impact at a fraction of the full-scale test cost. This set-up is known as BASIS* Brake Assisted Side Impact Simulation, and provides an affordable option between computer simulation and full-scale testing. This test set-up is suitable for:

- Restraint (airbag) development;
- Out of position testing (dynamic);
- Development of trim panel stiffness;
- Research of dummy-seat vs. door trim interaction;
- Comparison between different anthropomorphic test devices, (e.g., EuroSID-1 and ES-2);
- Validation of computer simulation models.

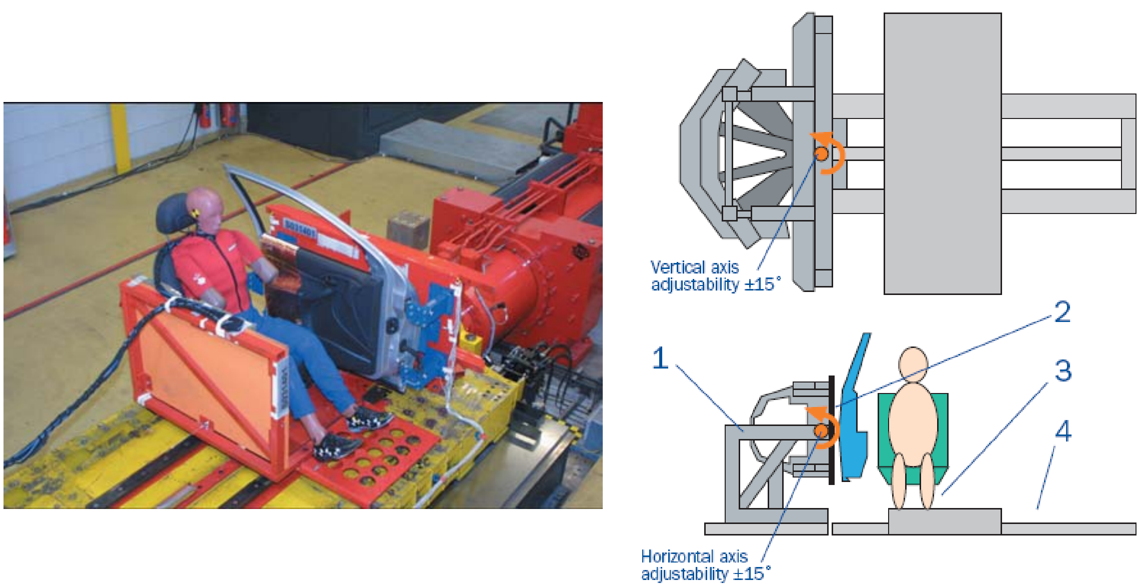

Fig.2 BASIS*. The test set-up is a frame (1) on which the door (2) is mounted. Next to it a seat, with a dummy, is placed on a smaller sled (3), running on linear rails (4). Both the frame and the rails are attached to the ICS sled.

How does BASIS* work

A pulse for the ICS is obtained from a full-scale test or from a computer simulation. When a pulse is applied to the test set-up, the seat with the instrumented dummy is moving on the linear rail, due to inertia, towards the door. Similar to a full-scale impact the dummy hits the door, which may deform. The dummy is loaded due to the impact and the injury criteria of the dummy are measured.

Correlation with full-scale tests

A study has been made to investigate the correlation between full-scale side impact tests and those recreated, using the BASIS* method. A review of the test data shows for the area of interest a compliance with the full-scale results within 10% for the contact velocities, contact timing and injury criteria results.

Fine-tuning

In order to further decrease the discrepancy between full-scale test data and the results from the Brake Assisted Side Impact Simulation, a number of parameters may be adjusted, such as:

- The angle of the door in both the Y and Z axis;
- The pulse for accelerating the ICS sled is easily and quickly changed;
- Seat acceleration is independently adjustable in order to obtain a correct door / seat interaction.
- Adding door trim underlaying support to take into account structural deformation during the crash.

Figure 3 shows that, as a result of carefully selecting the above parameters, the dummy loading in the full barrier test is well approximated in the BASIS sled test.

The benefits of BASIS* testing on the ICS:

- Low cost in comparison with full scale side impact testing;
- Several tests per day are possible with low set-up time for tests;
- Flexibility of testing with an adjustable door-angle, different pulses and adjustable velocity of the seat, etc;
- Excellent visibility of the interaction between occupant, restraint system and trim panel, due to the open structure of the test set-up;
- Requires far fewer vehicles to develop a robust safety system.

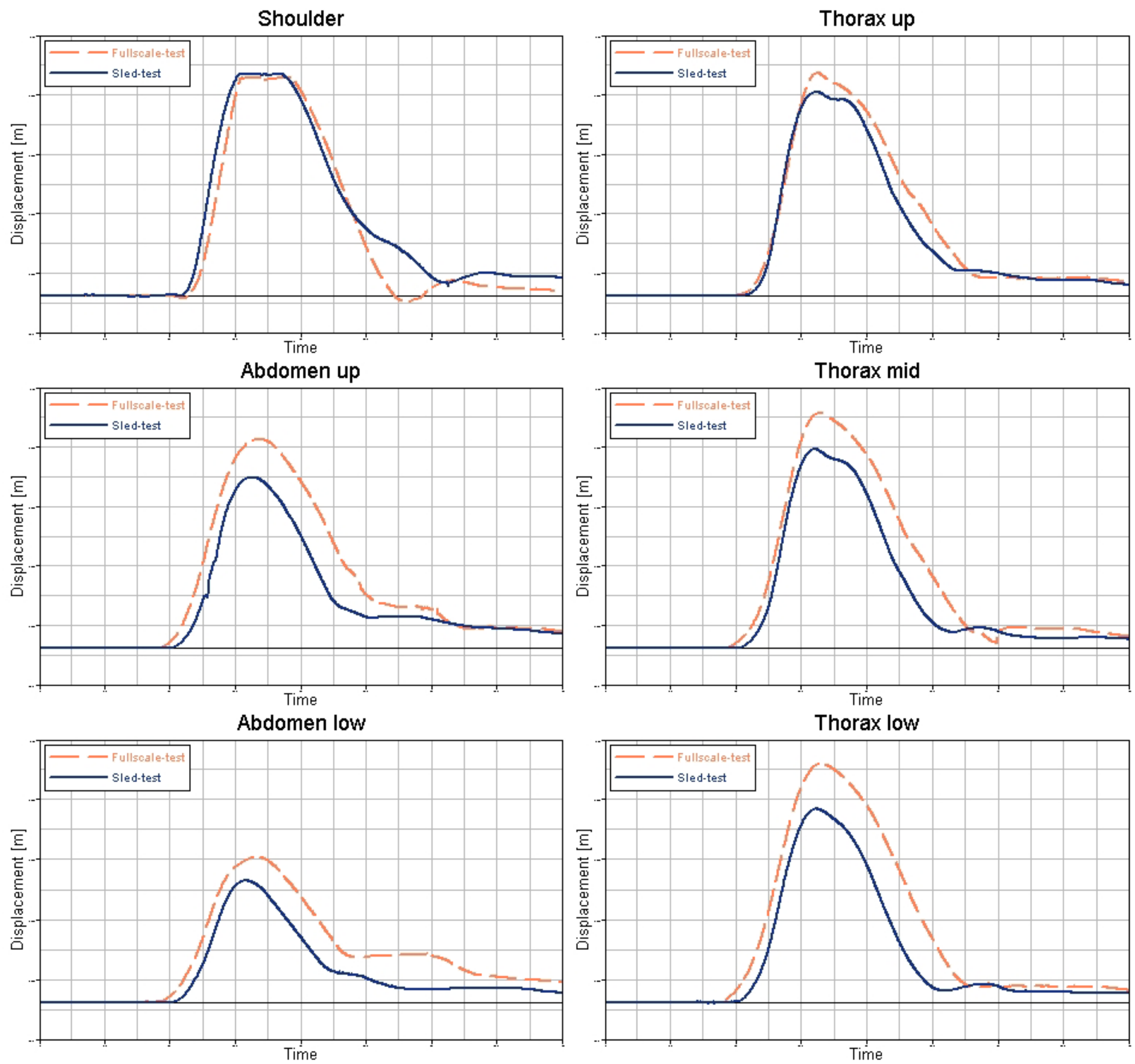

Fig.3 Dummy loading in full scale test (red dashed line) & BASIS sled test (black line) for IIHS test with SIDIIs small female dummy

3 Side Impact Simulation

A range of simulation methods has been employed successfully in side impact simulation.

- Multibody simulations for conceptual design
- Full FE vehicle simulations in MADYMO and other FE codes
- Prescribed Structural Motion simulations in MADYMO
- Coupling MADYMO with other FE codes

MADYMO offers full non-linear, explicit FE capabilities comparable to that of other commercially available simulation packages. This enables the user to perform FE simulations of the deforming vehicle structures and the resulting interactions with the validated MADYMO side impact dummies within MADYMO. The MADYMO Prescribed Structural Motion (PSM) technique allows the end user to accurately capture occupant response at a fraction of the CPU cost compared to full FE simulations, enabling Design of Experiment simulations and optimisation methods to be extensively used across a large design space. The PSM technique is especially suitable for efficiently designing and assessing side impact restraint systems, such as sensing performance of (curtain) airbags and belts. Coupling allows users to arbitrarily mix different crash codes in one simulation. For instance MADYMO models of occupants, restraint systems, and barrier can be introduced to an existing Ls-

Dyna vehicle model to validate the restraint design. Coupling is available for: MADYMO-Ls-Dyna, MADYMO-PAMCRASH, MADYMO-RADIOSS and MADYMO-ABAQUS.

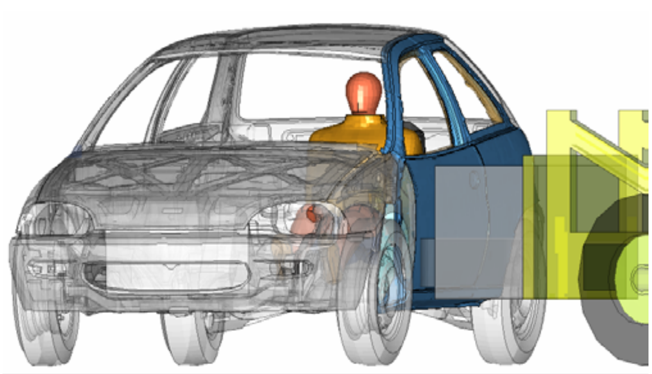

Fig.4 Full FE simulation (left) & PSM simulation (right)

4 Prescribed Structural Motion (PSM)

PSM is a simulation method where a set of nodal displacements of an FE model is prescribed as a function of time. The nodal displacements are generally derived from a full FE simulation using MADYMO or in other codes. Experimental data can also be used, but only through FE simulation a complex 3D deformation can be specified in detail. Tools such as Hypermesh facilitate the extraction of nodal displacements from FE simulations in several codes. As illustrated in Figure 5 the CPU time saved depends on the selected model area of which the deformation is prescribed.

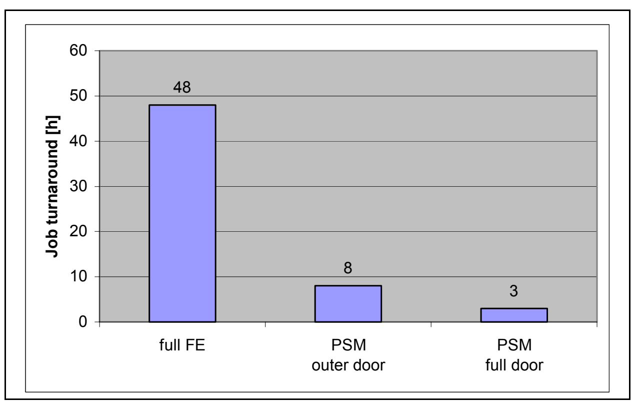

Fig.5 CPU load for a side impact simulation with full FE vehicle & barrier model (left), PSM applied to the outer door while door trim is modelled with deformable FE (middle), PSM applied to the full door thereby prescribing the door interior deformation (right).

5 Discussion

In a safety restraint system development project all mentioned methods will reach full efficiency by using a system integration approach. This approach integrates the use of component testing, sled testing, barrier testing and simulations. Practically this means that first a method is developed that uses the different tools at the right time and second that engineers involved are responsible as well for testing as simulation. With such approach simulation helps to define the test conditions needed and the testing will supply the data needed for model validation. With BASIS* and PSM new tools are available to support the system integration and the overall development process. At the end of the development the safety restraint system will have reached a better and more robust performance at lower cost by using the systems integration approach.

ANNEX: MADYMO DUMMY MODELS, SUBSYSTEM MODELS AND HUMAN MODELS

A full range of extensively validated models is available of crash dummies, crash barriers, and humans. Several human models and dummy models are also available in a scaleable version that can be adapted by the user to the desired anthropometry.

Frontal / Rear Impact dummies	***Side Impact dummies***	***Child dummies***
Hybrid-III 5th female	EUROSID-I	Hybrid-III 3YO
Hybrid-III 50th	ES-2 (RE)	Hybrid-III 6YO
Hybrid-III 95th	US DoTSID	CRABI 12MO
Hybrid-III 50th standing	SID-H3	Q3
Hybrid-III 50th + THOR lower legs	SID-IIs	P3/4
THOR	SID-IIs + airbag interaction arm	P1½
Hybrid-II	BioSID	P3
Hybrid-III 5/50/95th FAA aircraft	WorldSID (in preparation)	P6
Hybrid-III 50th + TRID neck		P10
RID-II		
BioRID-II		
MATD (motorcycle dummy)		
Subsystems	***Barriers***	***Human models***
FMVSS 201 headform	Offset Deformable Barrier (ODB)	Occupant 5/50/95th
Pedestrian child headform	FMVSS-214 MDB	FE occupant model
Pedestrian adult headform	EEVC-WG13 MDB	Pedestrian 3y/6y/5/50/95th
Pedestrian ACEA headform 3.5kg	IIHS-SUV MDB	Facet neck model
Pedestrian legform	FMVSS-201 impact pole	FE arm model
Pedestrian upper legform		FE buttocks model
ECE-R12 Bodyblock		Facet leg model
H-Point Manikin		FE lower extremity model
		FE brain skull model (on request)