Methodologies and Examples for Efficient Short and Long Duration Integrated Occupant-Vehicle Crash Simulation

R. Reichert, C.-D. Kan, D. Marzougui,
U. Mahadevaiah, R. Morgan, C.-K. Park, F. Tahan

Center for Collision Safety and Analysis, George Mason University

Abstract

This paper describes efficient methodologies for fully integrated occupant-vehicle simulations as well as sub-system evaluations using prescribed motion in LS-DYNA®. Examples include different short duration impacts such as frontal and side impact configurations with termination times of less than 200 milliseconds, and long duration impacts such as rollover events with termination times of 400 to 2500 milliseconds. A frontal offset and a frontal oblique impact was simulated using a Toyota Yaris model, side impact simulations were conducted with a Ford Taurus model, and a Ford Explorer model was used for rollover evaluations. Occupant models used include a Hybrid III, a THOR (Test device for Human Occupant Restraint), a US side impact, and a WorldSID dummy, as well as a THUMS (Total HUman Model for Safety) human model. Simulation results are compared to available full-scale crash test data. Parametric studies have been conducted to examine the influence of different input and output parameters when using sub-models with prescribed motion.

Introduction

Integrated occupant-vehicle analysis plays an important role in vehicle and occupant safety developments. Car manufacturers are using detailed full system models consisting of vehicle structure, interior, restraint systems, barrier, and occupant to develop safety measures and assure compliance with legal requirements, good rating results in consumer information tests, and vehicle safety in real life crash configurations. Suppliers are using sub-system models with to design and optimize interior and restraint system components with respect to various component and system requirements. While computer resources are becoming increasingly powerful, simulation models are becoming more detailed at the same time. Well organized modeling and simulation techniques are necessary in order to take full advantage of the numerical capabilities regarding meaningful occupant risk analysis. While full models are best suited to evaluate occupant risks in complex crash configurations taking the interaction of all participating components into account, reduced models can be useful for developing new restraint system or other component models. Depending on the purpose of a study, parts that directly interact with the occupant, such as the door trim in a side impact can be defined and applied with prescribed motion. In case the behavior of the door trim itself and its interaction with the occupant, seat, and airbag is the subject of interest, the vehicle door structure can be applied with prescribed motion and a model of the "deformable" door trim can be included in the sub-model, for example.

1. Methodologies

Fully Integrated Occupant-Vehicle Simulation

All examples presented in this paper use a modular LS-DYNA [1] input deck, as illustrated in Figure 1. The vehicle structure model, barrier, occupant, airbag, seat belt, and other interior components are included into a main input file. Using this technique the various components can be replaced or modified in an efficient manner without having to rebuild the entire integrated occupant-vehicle model.

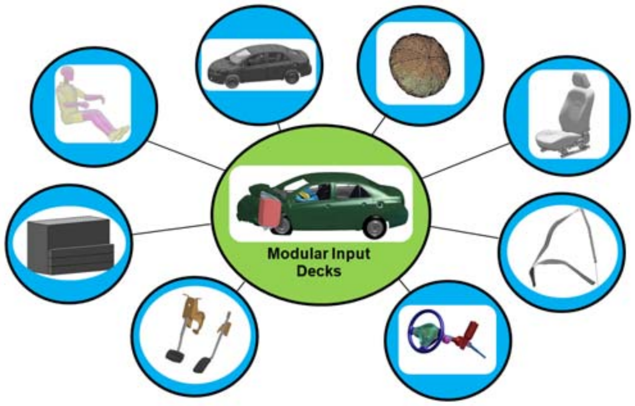


Figure 1: Modular input deck

Sub-Model Evaluations

Sub-model techniques were used for model development. Defined output from a full vehicle run is used to create a reduced model with prescribed motion of the occupant environment. Occupant and restraint systems are included in the sub-model in a similar manner as in the full occupant-vehicle model. The reduced model replicates the intrusion behavior and vehicle kinematics from the full model, and can therefore be used for optimization of interior components and for validation purposes. The sub-model technique is illustrated in Figure 2.

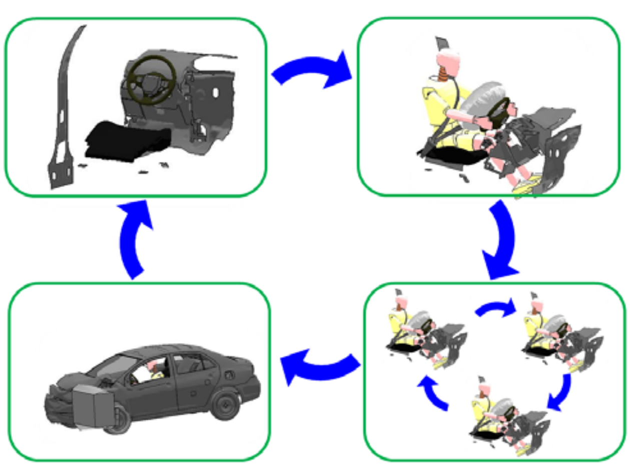


Figure 2: Sub-model technique

2. Frontal Impact Examples

IIHS Frontal Offset Impact with Hybrid III

A 2010 Toyota Yaris model with a 50th percentile Hybrid III [2] dummy in the driver seat was developed and used to simulate the Insurance Institute for Highway Safety (IIHS) 64 km/h, 40% offset impact into a fixed deformable barrier. Simulation results were evaluated with available full-scale crash test data [3] according to the IIHS normalized body region criteria. Simulation results match the "Acceptable" rating for the head and the "Good" rating for the other body regions when compared to the test results, as shown in Figure 3.

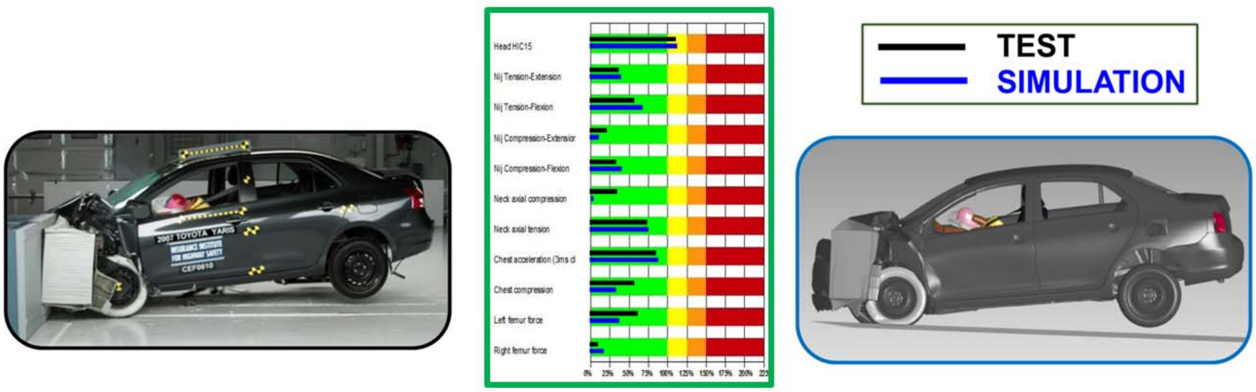


Figure 3: IIHS frontal offset impact

The described sub-model technique was used to develop and validate the fully integrated occupant-vehicle model [4]. Table 1 compares the full model on the left and the sub-model on the right regarding model size and time to complete the simulations. The turn-around time of the reduced model was about 20% when compared to the time required to run the full model. Absolute run times depend on the computer platform and number of cores and are used in this paper to outline the required run time of the sub-models relative to the full models.

Table 1: Comparison of full and sub-model in IIHS load case

		
Model size	~ 1 600 000 Elements	~ 190 000 Elements
Run time	~ 5h	~ 1h

Frontal Oblique Impact with THOR

The same Toyota Yaris model with a 50th percentile THOR dummy [5] has been used to simulate a NHTSA oblique impact, where a research moving deformable barrier travels at 90 km/h into a stationary vehicle, configured at a 15 degree angle with a 35% overlap. Figure 4 compares the results of the integrated occupant-vehicle simulation with an available full-scale crash test [6]. Test and simulation show similar values for femur, chest, and neck criteria, as well as a distinct head acceleration peak with comparable timing.

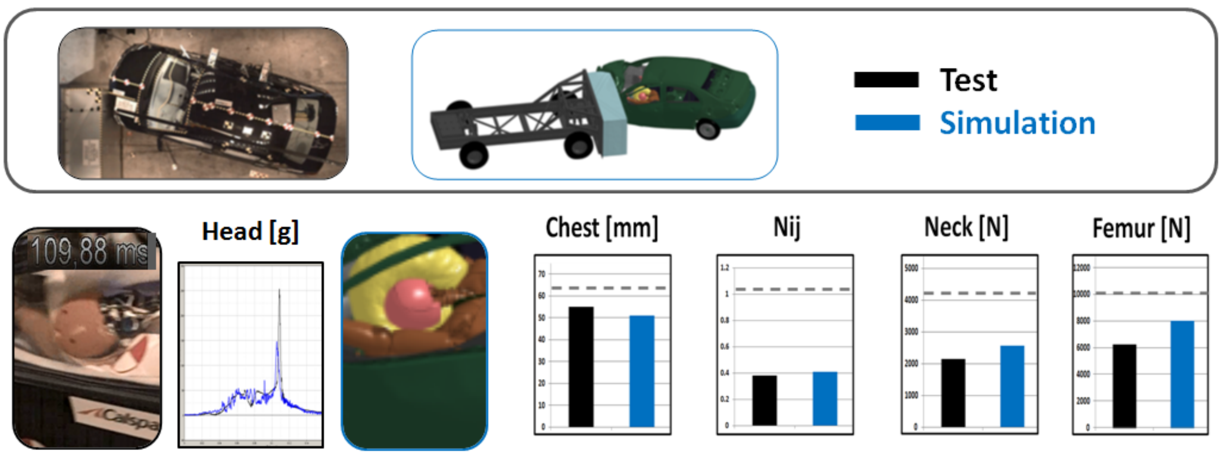
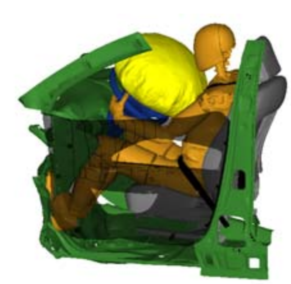


Figure 4: NHTSA oblique impact

The described sub-model technique was used to develop and validate the fully integrated occupant-vehicle model [4]. Table 2 compares the full and sub-model regarding model size and required time to complete the simulations. The turn-around time of the reduced model was about 27% when compared to the time required to run the full model.

Table 2: Comparison of full and sub-model in oblique load case

		
Model size	~ 3 200 000 Elements	~ 750 000 Elements
Run time	~ 22 h	~ 6h

3. Side Impact Examples

SINCAP load case with US Side Impact Dummy

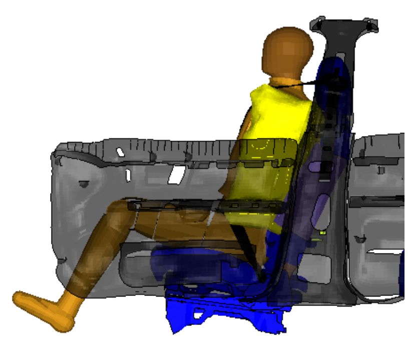
A 2001 Ford Taurus 4-door vehicle model and two US side impact dummy models [2] were used to simulate a NHTSA Side Impact New Car Assessment Program (SINCAP) load case, where a moving deformable barrier strikes a stationary vehicle in a 27 degree crabbed position at a velocity of 62 km/h. Figure 5 compares chest and pelvis injury criteria from the simulation with an available full-scale crash test [7] for the front and rear occupant. The difference of test and simulation results is less than 10% for both body regions for the driver as well as the rear passenger.

Test	Injury-Criteria	Simulation
85	Driver Chest [g]	83
112	Driver Pelvis [g]	102
85	Passenger Chest [g]	78
76	Passenger Pelvis [g]	69

Figure 5: Ford Taurus Side Impact

The described sub-model technique was used to develop and validate the fully integrated occupant-vehicle model. Table 3 compares the full model with front and rear passenger and a sub-model with driver dummy regarding model size and required time to complete the simulations. The turn-around time of the reduced model was about 17% when compared to the time necessary to run the full model.

Table 3: Comparison of full and sub-model in SINCAP load case with USSID

		
Model size	~ 1 200 000 Elements	~ 200 000 Elements
Run time	~ 3 h	~ 0.5 h

SINCAP load case with World-SID

The same Ford Taurus model that has been validated with an available full-scale crash test and the respective driver and passenger occupant models was used to analyze a WorldSID model [8], which is being developed in cooperation of the Center for Collision Safety and Analysis (CCSA) and the Livermore Software Technology Corporation (LSTC). Kinematics and numerical stability was evaluated for an early version of the WorldSID model under SINCAP loading conditions with seatbelt and side airbag interaction. The fully integrated occupant-vehicle model is shown in Figure 6.

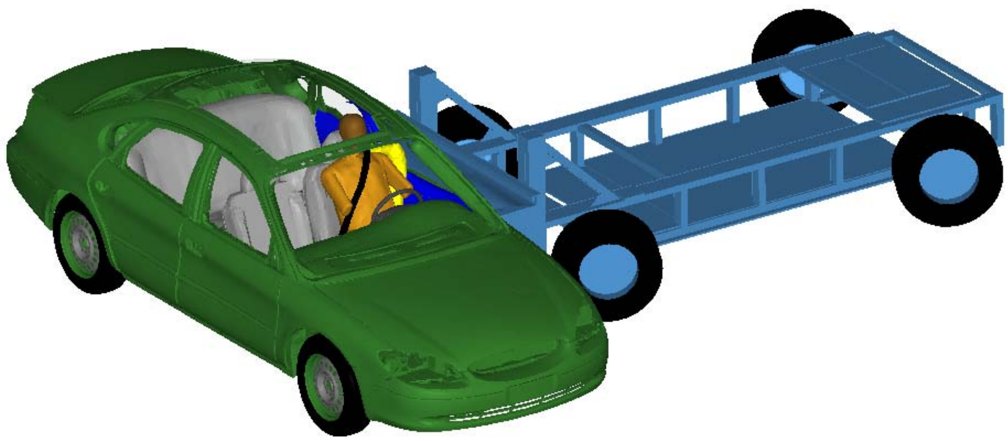


Figure 6: Ford Taurus Side Impact with WorldSID

Table 4 compares the full model and a sub-model with a 50th percentile WorldSID in the driver seat regarding model size and necessary time to complete the simulations. The turn-around time of the reduced model was about 25% when compared to the time required to run the full model.

Table 4: Comparison of full and sub-model in SINCAP load case with WorldSID

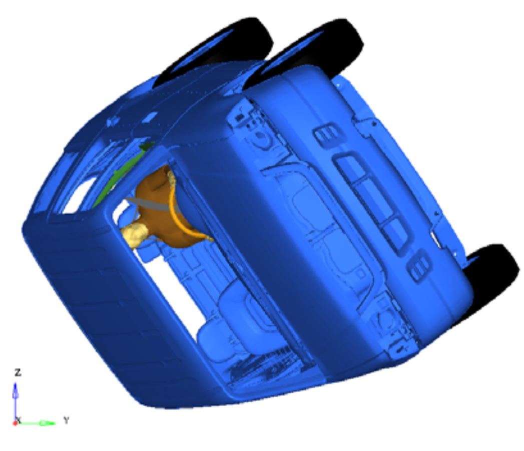
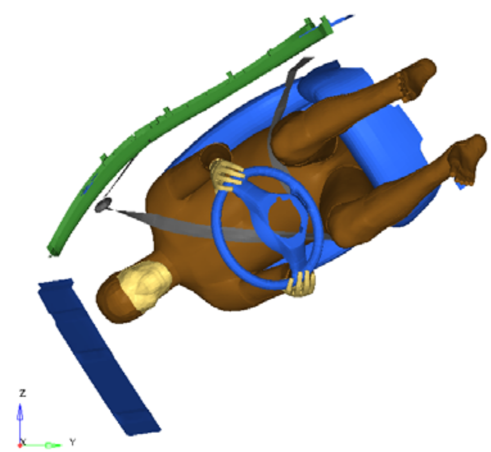
		
Model size	~ 1 350 000 Elements	~ 350 000 Elements
Run time	~ 3 h	~ 0.75h

4. Rollover Examples

Integrated full and sub-model simulation with THUMS till 400 milliseconds

A 2003 Ford Explorer vehicle model was used to simulate a rollover event together with a detailed 50th percentile THUMS [9] human occupant model. This example describes the results where initial conditions were applied to simulate the second quarter turn of a rollover configuration. Table 5 compares the full model and the sub-model regarding model size and required time to complete the simulations with a termination time of 400 milliseconds. The turn-around time for the reduced model was about 57% when compared to the time required to run the full model.

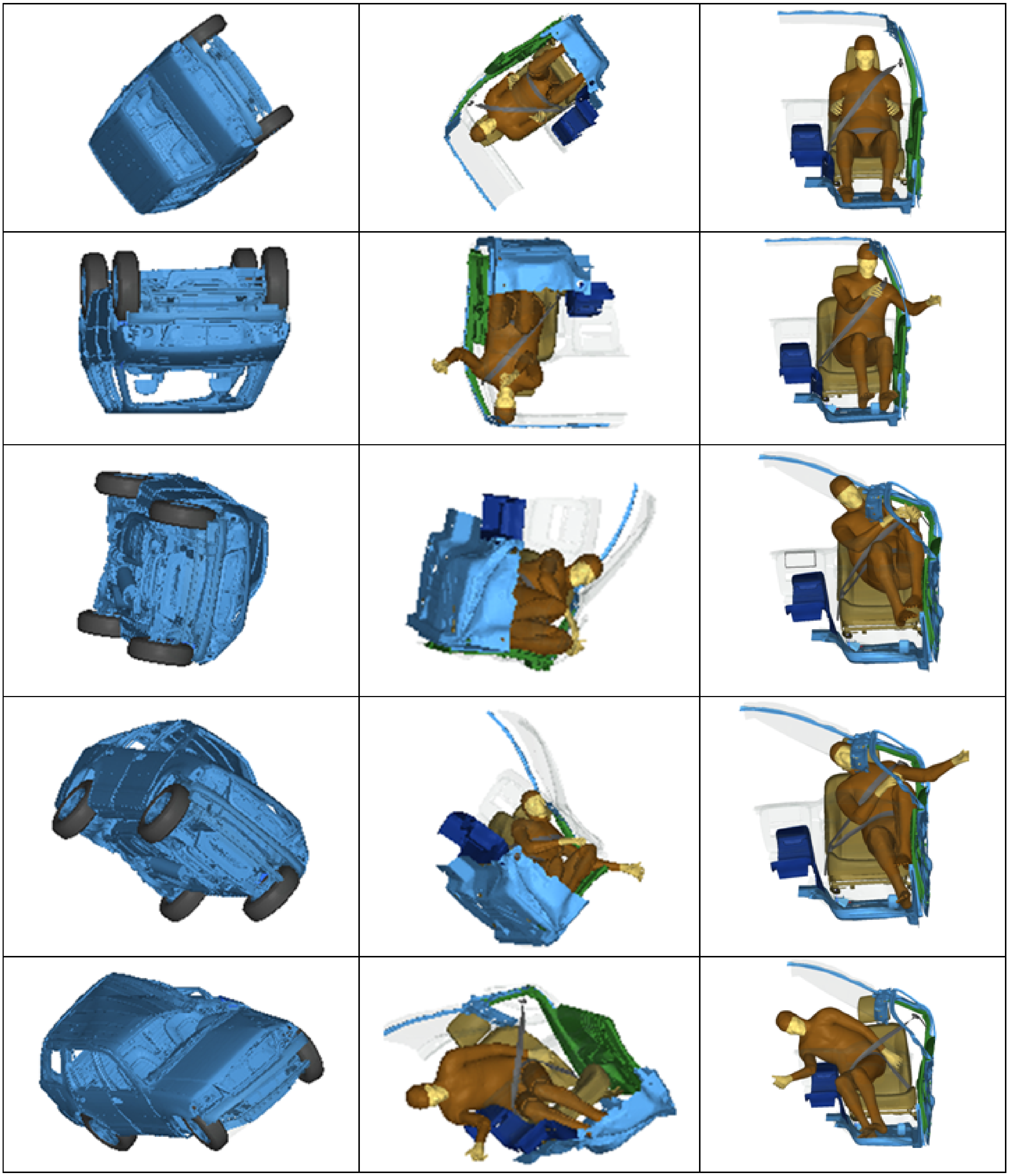
Table 5: Comparison of full and sub-model in a rollover with THUMS

		
Model size	~ 2 500 000 Elements	~ 1 750 000 Elements
Run time	~ 35 h	~ 20 h

Vehicle and integrated occupant sub-model simulation with THUMS till 2500 milliseconds

Another way of using the reduced model technique is to first conduct a simulation of the vehicle structure without occupant. The occupant is then included in the reduced model that has been generated from the first simulation. Table 7 below shows pictures from a rollover simulation with the same Ford explorer vehicle model with termination time of 2500 milliseconds, which is more than ten times the time necessary to capture relevant occupant risks in a typical frontal or side impact configuration. Initial conditions were applied to capture the second, third, and fourth quarter turn of a rollover event with a detailed THUMS human model in the driver seat. The left column shows a sequence of the simulation where the vehicle structure has been run by itself. The middle column depicts the reduced model together with the THUMS occupant and relevant interior. The right column illustrates the same sequence of the reduced model using a tracked view as it would be seen from an on-board camera.

Table 6: Simulation sequences of a 2500 milliseconds rollover event



5. Parametric Studies

The described sub-model technique is based on the motion of defined nodes from relevant parts which is taken from a full model simulation. Two parameters are being examined in this section. One is the output frequency which describes the time interval that is used to record the motion of specified nodes. The second parameter is the output quantity which defines the number of nodes that are being recorded for relevant parts. Theoretically one could use every single node of all parts that are relevant for a sub-model and the motion of these nodes could be recorded at every single time step of a simulation. This would result in a motion of the defined parts that is identical in the full and sub-model. Since this is neither practical nor necessary, different values for the two parameters have been exercised and the effect on selected occupant results is described using a frontal impact and a side impact example.

Sensitivity regarding output frequency

The frontal impact IIHS load case with Hybrid III dummy was used to evaluate how the output frequency of defined nodes influenced the occupant results in a sub-model when compared to the outcome in the full occupant-vehicle model. In a first simulation the motion of defined nodes has been recorded every 1 millisecond in a full model run and applied as prescribed motion in the reduced model. In a second simulation nodal information that was recorded every 4 milliseconds and in a third simulation prescribed motion that was recorded every 8 milliseconds has been used in the reduced model analysis.

Table 7: Comparison of full and sub-model using varying output frequency

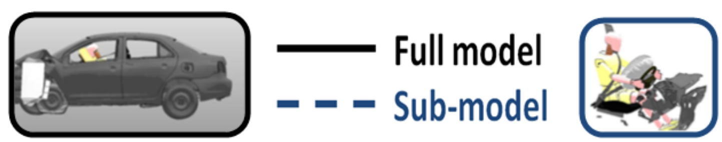
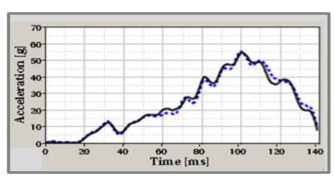
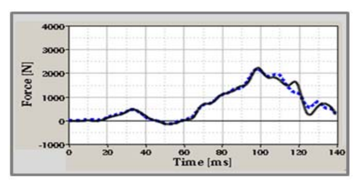
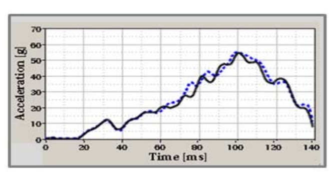
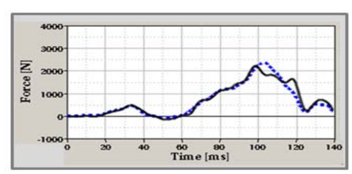
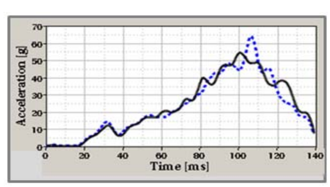
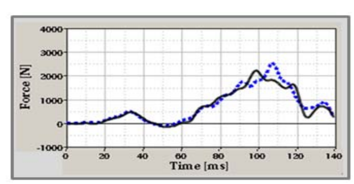
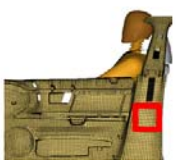
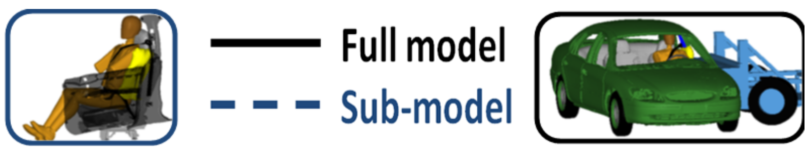
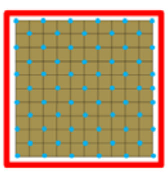
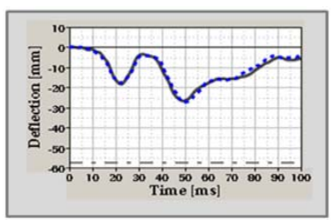
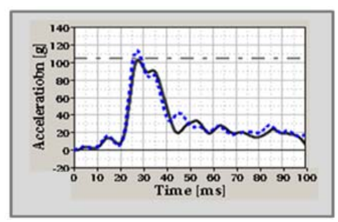
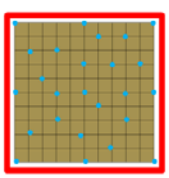
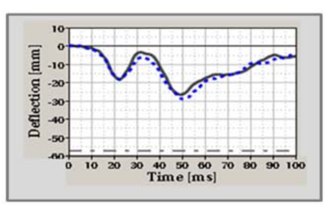
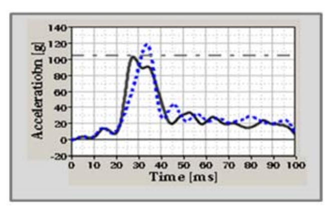
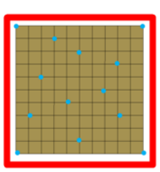
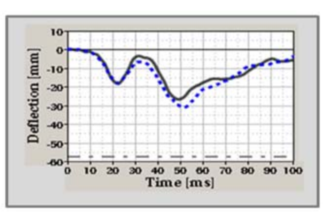
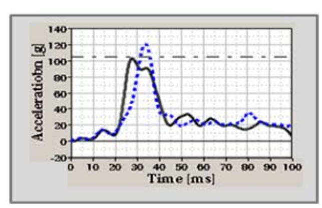
<table>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>Nodal information
was recorded
every 1ms</td><td>
</td><td>
</td></tr>
<tr><td>Nodal information
was recorded
every 4ms</td><td>
</td><td>
</td></tr>
<tr><td>Nodal information
was recorded
every 8ms</td><td>
</td><td>
</td></tr>
<tr><td></td><td>Chest Acceleration</td><td>Neck Axial Force</td></tr>
</table>

Table 7 exemplarily compares the chest acceleration and the neck axial force of the full occupant-vehicle simulation with the results of the respective sub-model runs. Close correlation can be noticed when prescribed motion that was recorded every millisecond was applied in the reduced model. More distinct differences between the sub-model and full model results can especially be noticed when an output frequency of 8 milliseconds has been used.

Sensitivity regarding output quantity

The side impact example with World-SID was used to evaluate how the number of nodes defined for the sub-model influenced the occupant results when compared to the outcome in the full model. In the first simulation the motion of every other node of the door and b-pillar trim has been recorded in a full model run and applied as prescribed motion in the reduced model. In the second simulation every 5th node, and in the third run every 10th node has been used. Table 8 exemplarily compares the maximum thorax rib deflection and the pelvis acceleration of the full occupant-vehicle and the respective reduced model simulations. It can be noticed that the time history plots compare well when every other node is applied with prescribed motion and that the discrepancy between full and sub-model is similar when every fifth and every tenth node is applied with prescribed motion.

Table 8: Comparison of full and sub-model using varying output quantity

		
Prescribed motion for **every 2nd** node 		
Prescribed motion for **every 5th** node 		
Prescribed motion for **every 10th** node 		
	Thorax Rib Deflection	Pelvis Acceleration

6. Summary and Conclusion

Methodologies

Efficient methodologies for integrated occupant vehicle crash simulations were described. Modular input decks provide a proficient way of setting up different crash configurations with varying vehicle, barrier, interior, restraint system, and occupant models . The sub-model technique uses only parts that are relevant regarding occupant interaction, for example. By using prescribed motion for defined parts, comparable kinematics and intrusion behavior of the occupant environment can be achieved in the full vehicle and sub-model simulation. Reduced models are useful for efficiently setting up occupant-vehicle simulations, evaluating and optimizing interior, restraint system, and occupant models. Due to the same input structure, the developed, optimized or tested component models can be easily transferred from the sub-model and integrated into the full occupant-vehicle analysis.

Examples

Application examples for frontal impact, side impact, and rollover crash configurations were outlined and occupant results were compared to available full-scale crash test data. They include a frontal offset impact configuration with a Toyota Yaris with a Hybrid III dummy, a frontal offset oblique impact with the same vehicle and a THOR dummy, a side impact configuration of a Ford Taurus with an US side impact and a WorldSID dummy, and a long duration rollover crash event of a Ford Explorer with a detailed THUMS human model. Fully integrated occupant-vehicle models as well as reduced models with termination times that ranged from 100 to 2500 milliseconds for the various load cases were described. Comparisons of the required computer "turn around time" show that the reduced models needed 17 to 57 % time to complete the simulations when compared to the fully integrated occupant-vehicle models, depending on their respective sizes.

Parametric study

Two parameters that are relevant when using sub-models were evaluated. The output quantity defines, for how many nodes (of a relevant part) prescribed motion is being applied. The output frequency defines, which time interval is being used to record the motion of these nodes in the full vehicle simulation. In the first study, selected occupant results in full occupant-vehicle and respective sub-model simulations were compared using every second, every fifth, and every tenth node as output quantity. In the second study varying output frequencies of 1, 4, and 8 milliseconds were evaluated and their effect on selected occupant results was demonstrated. Choosing the appropriate values depends on the application, the purpose of the reduced model analysis, and the material properties of the relevant parts.

Acknowledgment

The authors would like to thank all organizations that provided funding and simulation models to make this work possible, especially the National Highway Traffic Safety Administration (NHTSA) and the Federal Highway Administration (FHWA).

References

[1] LS-DYNA Keyword User's Manual Version 971, Livermore Software Technology Corporation, Livermore, California, 2013

[2] Maurath, C., Guha, S., Updates to LSTC's LS-DYNA Anthropomorphic Models, 12th International LS-DYNA Users Conference, Dearborn, Michigan, 2012

[3] Crash Test Report, 2007 Toyota Yaris (CEF0610), Insurance Institute for Highway Safety (IIHS), Arlington, Virginia, 2006

[4] Reichert, R., Park, C.-K., Morgan, R., Development of Integrated Vehicle-Occupant Model for Crashworthiness Safety Analysis, NHTSA report, Washington DC, 2014

[5] UNTAROIU, C., et al, Evaluation of a finite element model of the THOR dummy in frontal crash environment, 21st ESV Conference, Stuttgart, Germany, 2009

[6] Report for Frontal Oblique Offset Program, Testing on a 2011 Toyota Yaris, NHTSA No. RB5136, Calspan Corporation, Buffalo, NY, 2011

[7] New Car Assessment Program, Side Impact Test on a 2000 Ford Taurus, Report Nr. 214D-MGA-2000-04, Burlington, Wisconsin, 2000

[8] Mahadevaiah, U., Maurath, C., Kan, C.-D., Marzougui, D., Development of a World Side Impact Dummy (WorldSID) Finite Element Model", 13th International LS-DYNA Users Conference, 2014

[9] Toyota Motor Corporation, Total HUman Model for Safety (THUMS), AM50 Pedestrian/Occupant Model, Academic Version 4.0, October 2011