Parametric ROM Technology for Fast Optimization of Crash Problems.

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1. ABSTRACT

The purpose of the Crashworthiness analysis is to assess how well a vehicle's structure can protect its occupants during a collision. This study involves transforming the vehicle Crash Model Partially into a Lumped Parameter representation using DEP MeshWorks' - Reduced Order Modelling (ROM) technology. The ROM model shows an impressive 85-95% correlation with the original Detailed Finite Element model. The complex process of converting the Detailed Finite element model into lumped parameter representation is automated through the ROM approach. The ROM model is further parametrized with a broad ranging category of parameters involving a) shape, b) gage, c) material, d) spot welds, e) adhesives, f) seam welds, g) crush-initiators, h) reinforcements, i) darts, j) bulk-heads, k) slots/holes, l) laser welded blanking, m) ribbing and o) composite lay-up to convert it to an intelligent 'Parametric ROM Dyna model' using DEP MeshWorks. This parametric ROM model is integrated with a DOE (Design of Experiments) based Optimization scheme to obtain an optimized design that maximizes Crashworthiness performance and minimizes weight & hence cost. Thanks to the significantly reduced number of nodes/elements in the parametric ROM model, the entire optimization process can be completed in less than 50% of the time that detailed models would require.

Mass & Inertia representation, condensed stiffness & damping and other related techniques form the foundation of the ROM technology available in MeshWorks. The combining of two significant technologies – ROM & Parametric CAE provides users the advantages of optimization executed in a drastically reduced timeframe.

2. INTRODUCTION:

The process of developing a new vehicle in the automobile industry typically involves a comprehensive timeline of 3 to 4 years. This duration is necessary to conduct a wide array of tests and adhere to various regulations across different domains, particularly focusing on aspects such as Crashworthiness and Safety standards. In an alternative 'mid-cycle refresh' design and development process, the industry also considers introducing a new vehicle by making 'delta' mechanical/electrical and technological changes to an existing vehicle design. Either of the vehicle development processes require extensive virtual validation through CAE simulations of Crashworthiness load cases.

Current trends in vehicle development process requires faster completion of CAE validations on crashworthiness analysis, DEP has proposed Reduced Order Modelling (ROM) technology, which helps to reduce time close to 50% for Crash simulations as well as Crash Optimizations.

DEP MeshWorks is a comprehensive pre and post-processing tool. The integration of ROM technology within MeshWorks has been emphasized, specifically focusing on reduce the model size in terms of number of Nodes & Elements and then Parameterization of the ROM for optimization studies.

3. RELEVANT RESEARCH:

Reduced Order Model (ROM) Technology has been widely used in Aerospace Industry [1]; we want to use ROM technology into automobile vehicle crashworthiness analysis as it most expensive because huge time-consuming for running analysis & hardware cost. So ROM technology will address virtual validation through CAE simulations of Crashworthiness load cases in short time compare to detailed model and hence reduce the overall cycle of product development.

3.1 PROPOSED ROM TECHNOLOGY: The primary objective of this study is to transform the vehicle Crash Model Partially into a Lumped Parameter representation using DEP MeshWorks' - Reduced Order Modelling (ROM) technology.

- ROM simplifies complex simulations by reducing the number of variables and equations needed to describe a system.
- The complex process of converting the Detailed Finite element model refer fig.1 into lumped parameter representation refer fig.2 is automated through the ROM approach, table1.shows the Mass & Inertia representation, condensed stiffness & damping and other related techniques form the foundation of the ROM technology available in MeshWorks.
- Finally, Delta mass function used after ROM creation adds the missing "Mass & its Inertias values" during ROM creation because of any unsupported materials or encrypted materials, so that delta mass balances the total mass & inertia values with original model before ROM creation.

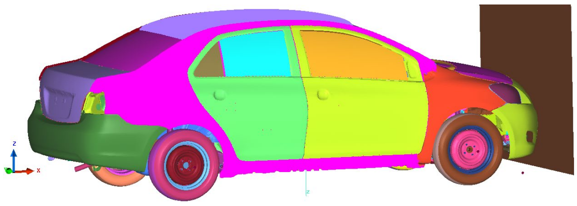

Figure 1. Detailed finite element model

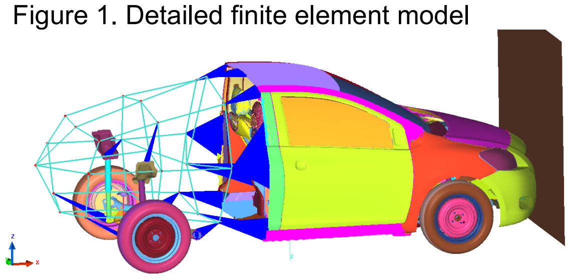

Figure 2. Reduced Order Model (ROM)

In addition to ROM-Technology, Mesh Coarsening techniques are used for various components of powertrain system to further reduce the FE model size. Table 1 shows the % Reduction of entity count in ROM.

Entity	Base Model	Reduced Model	% Reduction
Node Count	8038793	3657507	54.50%
Element Count	9203264	4534986	50.72%
Mass(kg)	2.271E+03	2.27E+03	

Table 1. % Reduction of entity count in ROM

4. Parametric ROM and Optimization:

4.1 Parametric ROM

The ROM model is parametrized with a broad ranging category of parameters involving a) shape, b) gauge, c) material, d) spot welds, e) adhesives, f) seam welds, g) crush-initiators, h) reinforcements, i) darts, j) bulk-heads, k) slots/holes, l) laser welded blanking, m) ribbing and o) composite lay-up to convert it to an intelligent 'Parametric ROM Dyna model' using DEP MeshWorks.

4.2 I-Sight Optimization

This parametric ROM model is integrated with a DOE (Design of Experiments) based Optimization scheme to obtain an optimized design that maximizes Crashworthiness performance and minimizes weight & hence cost. The ROM model shows an impressive 85-95% correlation with the original Detailed Finite Element model.

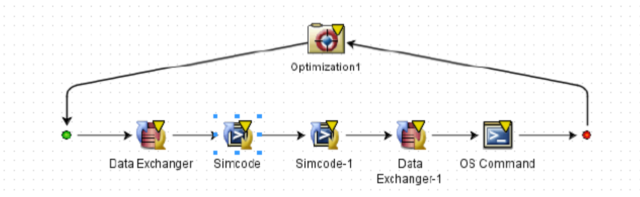

Figure 3. Isight Optimization Loop

5. Validation of Results:

Figure 4 illustrates line charts displaying the correlation between Detailed model and ROM Sectional forces at Rocker region

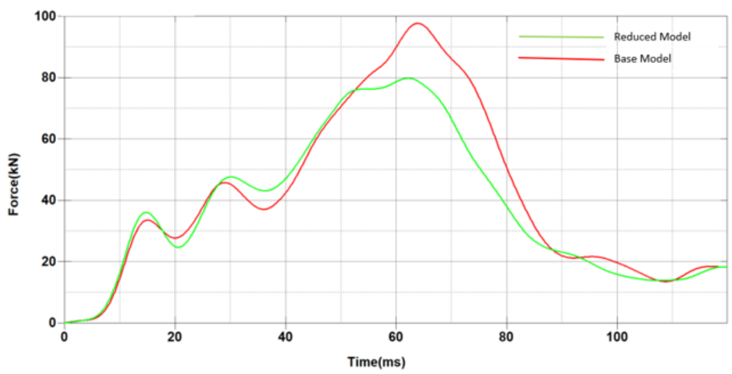

Figure 4. Sectional force at Rocker

Figure 5,6 illustrates line charts displaying the correlation of Sectional forces at Left and Right Front rails.

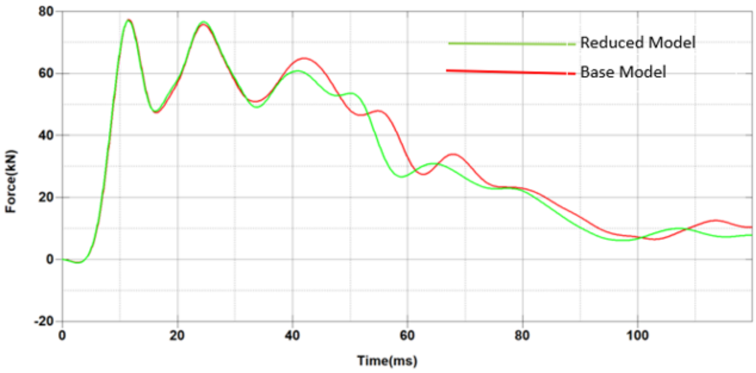

Figure 5. Sectional force at Left Front Rail

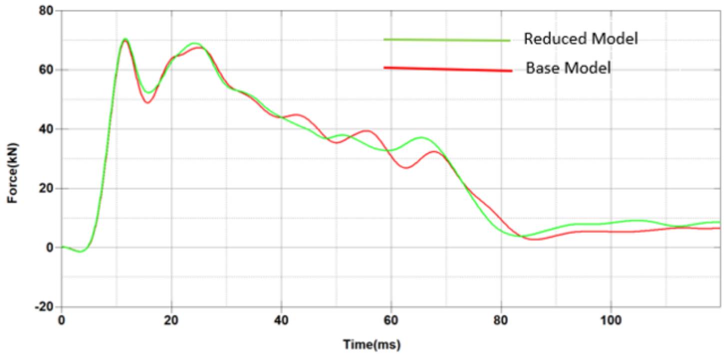

Figure 6. Sectional force at Right Front Rail

Figure 7, illustrates line charts displaying the correlation of Velocity Plot.

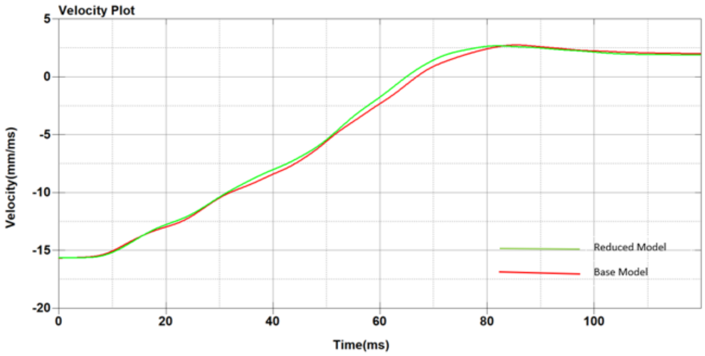

Figure 7. Velocity curve

Figure 8, illustrates line charts displaying the correlation of Acceleration.

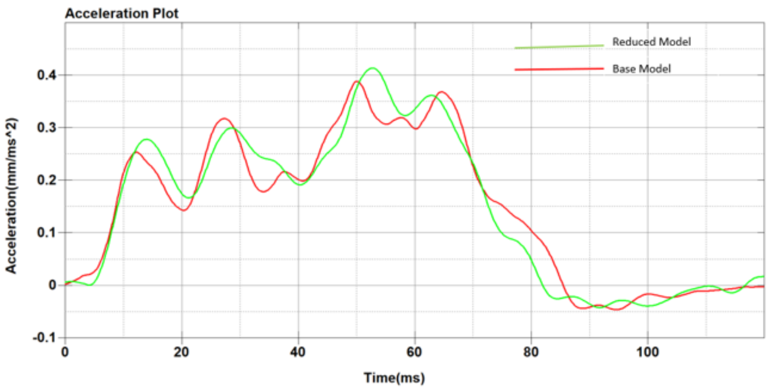

Figure 8. Acceleration curve

Below Table 2 explains the Intrusions in (mm) at different points of the front compartment of the vehicle, all the below intrusions are showing a high correlation percentage with respect to Detailed model.

Node Ids	Desc	Base Model Intrusion in mm	Reduced Model Intrusion in mm	% Correlation
1044	Firewall Mid	177.49	173.9	97.98%
1052	Firewall Driver side Lower 1	89.49	79.166	88.46%
1060	Firewall Driver side Lower 2	87.68	78.85	89.93%
1068	Firewall Driver side Lower 3	102.05	94.159	92.27%
1076	Firewall Passenger side Lower 3	103.06	100.8	97.81%
1084	Firewall Passenger side Lower 2	97.458	97.448	99.99%
1092	Firewall Passenger side Lower 1	53.494	71.188	66.92%
1100	Firewall Passenger side 1	149.81	173.02	84.51%
1108	Firewall Passenger side 2	117.25	108.61	92.63%
1116	Firewall Passenger side 3	155.21	142.39	91.74%
1124	Firewall Passenger side 4	140.08	136.8	97.66%
1132	Firewall Driver side 4	136.13	133.54	98.10%
1140	Firewall Driver side 3	154.11	143.56	93.15%
1148	Firewall Driver side 2	119.12	110.89	93.09%
1156	Firewall Driver side 1	123.69	107.48	86.89%

Table 2. Intrusion Values

5. Summary

We have developed a Reduced Order Crash Model that utilizes lumped mass and delta mass techniques to represent detailed aspects of the crash model within the DEP MeshWorks environment. This innovation significantly accelerates crash and safety optimization by drastically reducing analysis run times.

1. The proposed interactive tool offers substantial time savings for mass and performance optimization through its built-in parametric capabilities. During the initial development phase, it will be an efficient resource for enhancing model performance.

2. With a user-friendly graphical interface (GUI) and a streamlined Reduced Order Modeling process, novice CAE engineers can easily convert detailed crash models into reduced order models.

6. Literature

1. José E. Valenzuela del Río, Arun Ramamurthy and Hyunjee Jin, Title : Reduced Order Model for Standard Computer-aided Engineering Design Workflows, 19 Jan 2023

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3. Carlberg, K., Bou-Mosleh, C., & Farhat, C. (2011). Efficient non-linear model reduction via a least-squares Petrov–Galerkin projection and compressive tensor approximations. *International Journal for Numerical Methods in Engineering*, **86**(2), 155–181.

Abbreviations

ROM–ReducedOrdermodel
DEP-DetroitEngineeredProducts
CAD-ComputerAidedDesign
CAE-ComputerAidedEngineering
DOE-DesignofExperiments
GUI - Graphical User Interface