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DESIGN ENGINEERING OF COMPLEX PRODUCTS USING THE MULTI - FUNCTIONAL SYSTEM MOCK - UP

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Abstract: *The traditional demands for improved performance, time-to-market and competitive price setting are strained by requirements related to product branding, personalization and ecological, safety and legislation aspects. This leads to increasingly complex products, implemented by heterogeneous technologies and more and more relying on active components and systems.*
A key challenge is the inherent multidisciplinary in the design engineering, integrating thermal, hydraulic, mechanical, electronic and control functions. The corresponding test and simulation methodologies must extend beyond the traditional CAD-driven approach and support the use of system and functional models crossing the boundaries of multiple disciplines and integrating systems engineering with control engineering. These concepts will be illustrated by case studies from vehicle design engineering, demonstrating the combined use of 3D and 1D system models. It can be concluded that the research challenges for the future are hence lying both in further breakthroughs in method performance and in expanding the scope of system complexity to a truly multifunctional system mock-up.

Keywords: multifunctional system mock-up, multidisciplinary design

1. INTRODUCTION

1.1 The virtual prototype engineering paradigm

The aerospace and ground vehicles industry faces the competitively critical but conflicting demands to come up with more innovative designs and get them to the market before anyone else, developing better products in a shorter time and at a lower cost. A major step was the shift towards a “Digital” design approach. Most companies have adopted an all-digital development environment for design (Computer-Aided-Design or CAD), covering the “form-and-fit” stages of the process in a “virtual space”. Similarly, numerically controlled machining, robots, and a direct link of manufacturing with CAD models allow a Computer Aided Manufacturing (CAM) process. Many companies furthermore heavily invest in PDM (Product Data Management) systems and explore collaborative business models.

But next to knowing how a product looks like and how the components fit together, it is as important to get the design perform as expected for the functions required by the product’s mission. Typical performances for air- and ground vehicles are propulsion efficiency, noise and vibration, reliability, safety, emissions. Many of these relate to customer requirements, and are hence competitively critical in view of the product’s brand image. But they are also increasingly imposed by legislation. To take these properly into account in the design is a complicated process as they are dependent or even in conflict with each other (e.g. in relation to weight).

Traditionally, these performances were dealt with late in the development process, performing product refinement on physical prototypes, more in a way to troubleshoot problems, than as true design targets. Several advanced experimental procedures were developed hereto. But at that late stage, many development gates have been passed and the main design decisions are frozen, leading to costly, suboptimal, palliative solutions. Recent evolutions towards the use of numerical models resulted in a Virtual Prototype Engineering paradigm based on simulation tools. Detailed electrical, mechanical and other multiphysics modelling capabilities allow simulating the various performances and adapting the design to meet prior set targets. Examples are the many analytical, system-theoretic, structural finite element, vibro-acoustical, multibody, aero-acoustics, durability, thermal etc. simulations which are performed for each design.

The objective is to extend this process, leading to development cycles expressed in months instead of years. This can only happen through frontloading the engineering of the critical product qualities, using upfront concept analysis, cross-disciplinary model based product optimization and performing in-depth testing only on a reduced number of physical prototypes. Figure 1 shows the relative effort (now and desired) in each stage of the development process.

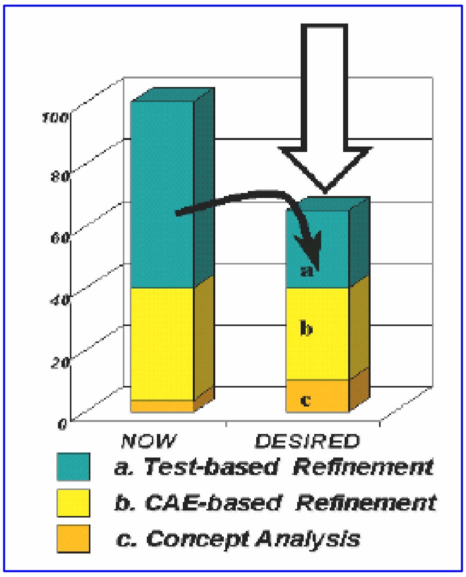


Figure 1: Innovation targets

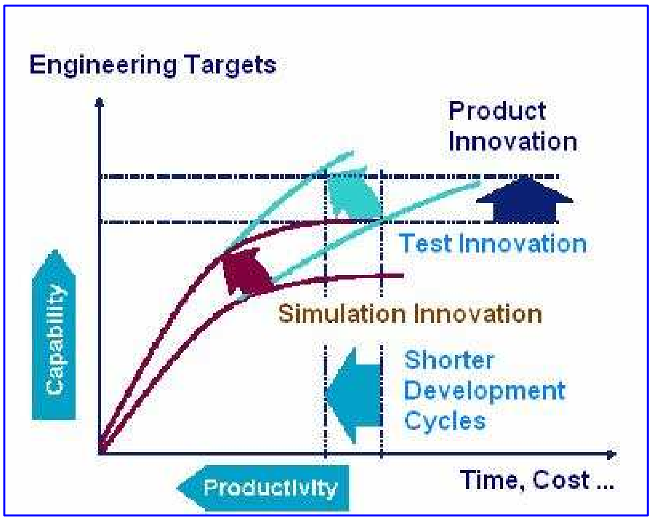


Figure 2: Combining Test and Simulation to deliver innovation

1.2 Combining Test and Simulation to deliver engineering innovation

While a purely digital design is the ambition, a fully virtual approach is not yet realistic. Insufficient calculation speed and performance of solvers is only part of the explanation since important breakthroughs in terms of computing power, parallel processing and optimized algorithms were made. Missing knowledge on exact material parameters, lack of appropriate models for complex connections, or insufficiently accurate model formulations remain major bottlenecks. The required optimization process is too complex, covering too many interrelated unknowns. Hence a combined use of test and simulation is adopted, allowing solving engineering problems not only faster, but also more accurately compared with exclusive use of one or the other. This is illustrated in Figure 2, the Y-axis showing the required technical capability for an engineering task, the X-axis the time needed to complete the task. The “Test Only” curve shows how the task is completed with traditional test-based methods. The “Simulation” curve shows how with simulation, part of the task can be done faster, but in general not completed. As the required performance is available with the traditional method, test can take over where simulation reaches its limits. However, the combination of test and simulation not only delivers the required technical capability, but exceeds it. To adopt such hybrid test and simulation approach, the total development process has to be reconsidered
in view of what is feasible at which stage of the development process. At each stage, Test data and Models contribute to increase accuracy and even speed up the process. The appropriate use of experimental data and experimentally obtained models on existing systems and their integration with numerical models for new designs results in a true “Hybrid” simulation approach.

2. MULTI-PHYSICS SYSTEM MODELLING, SIMULATION AND VALIDATION

To engineer intelligent systems, there is an expanded need for multi-physics system modelling, simulation and validation. For example, the performance engineering of an electrical assisted steering system requires a combination of mechanical and electrical system modelling. A brake system requires mechanic, hydraulic and electric system models. An engine requires models for combustion, kinematics, dynamics, structural analysis, including specialized models for bearings. An important challenge is to extend the capabilities for multi-physics system simulation from component and subsystem level, to full system level, where more types of physical behavior need to be taken into account.

Multi-physics system modelling, simulation and validation will also need to handle an increasing diversity and complexity of sensors and actuators that are used in intelligent systems. For example, to simulate the working of an active piloting assistance system in a aircraft, one needs the modelling of flight mission scenarios including traffic (like approaching aircraft, ATM communications and signals, etc.), the modelling of the functioning of the radar that is used as sensor for traffic, and the integration with aircraft flight dynamics. When additionally combined with advanced vision systems (cameras, head-up displays, etc.), one needs the simulation of pilot-in-the-loop scenarios in a virtual environment with high realism, to simulate for example the functioning of the vision system for operation in different weather conditions (rain, fog…) or light conditions (day, night…), critical missions profiles, so as to properly validate the functioning of the vision system, and how it will interact with the pilot and the flight dynamics.

Interaction and integration between heterogeneously modeled components and (sub) systems is a prerequisite which requires flexible and open simulation platforms. The approach must be a scalable one, starting from “frontloaded” conceptual and functional descriptions where models of increasing complexity can be added when the design cycle proceeds and more detailed knowledge (e.g. in terms of 3D models) is built up, leading to hybrid approaches combining 1D and 3D models for those parts where each model is best suited.

Mechanical and electrical/electronic system models need to be integrated as soon as possible in the design process such that the divide between the 2 V-cycles can be reduced or even eliminated.

An important, but uncharted domain is furthermore the development of test-based solutions for multi-physics system characterization just as they exist in the 3D field. Parameter identification, model validation and updating, up to the development of hybrid models will enable to exploit the unique combinations of test and simulation to advance multi-physics simulation. A clear requirement hence exists to stepping up the capability for multi-physics system simulation, to respond to a critical need in the industry to accelerate product development of intelligent systems through an integrated, multifunctional system mock-up approach (Figure 3).

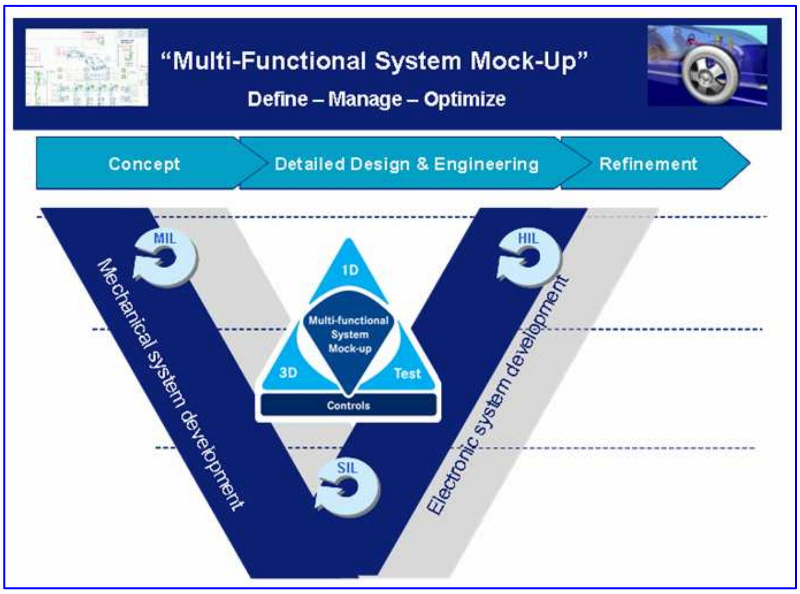


Figure 3: Multi-Functional System Mock-Up

3. MODEL REDUCTION FROM 3D TO 1D

At the very beginning of the product concept phase, because of the lack of information and data, evaluation models are often constructed in a simplified 1-D environment. Going forward in the development phase, more inputs about different arguments are given to the designers, who in the end will be able to reproduce virtual prototypes in a 3D CAD environment using CAE tools dedicated to investigate different aspects. In this process it is often needed to go through a model reduction process to achieve real time performance in the integrated system environment. In the space of multibody dynamics this model reduction usually takes the form of removing or combining bodies in the model or translating portions of the 3D model back into a 1D model but with a much more accurate representation.

One of the key requirements of any model reduction process is to maintain associativity with the CAD based high-fidelity model and this association must be maintained in both directions. This mutual correspondence will allow changes in either model to be replicated in the other version of the model.

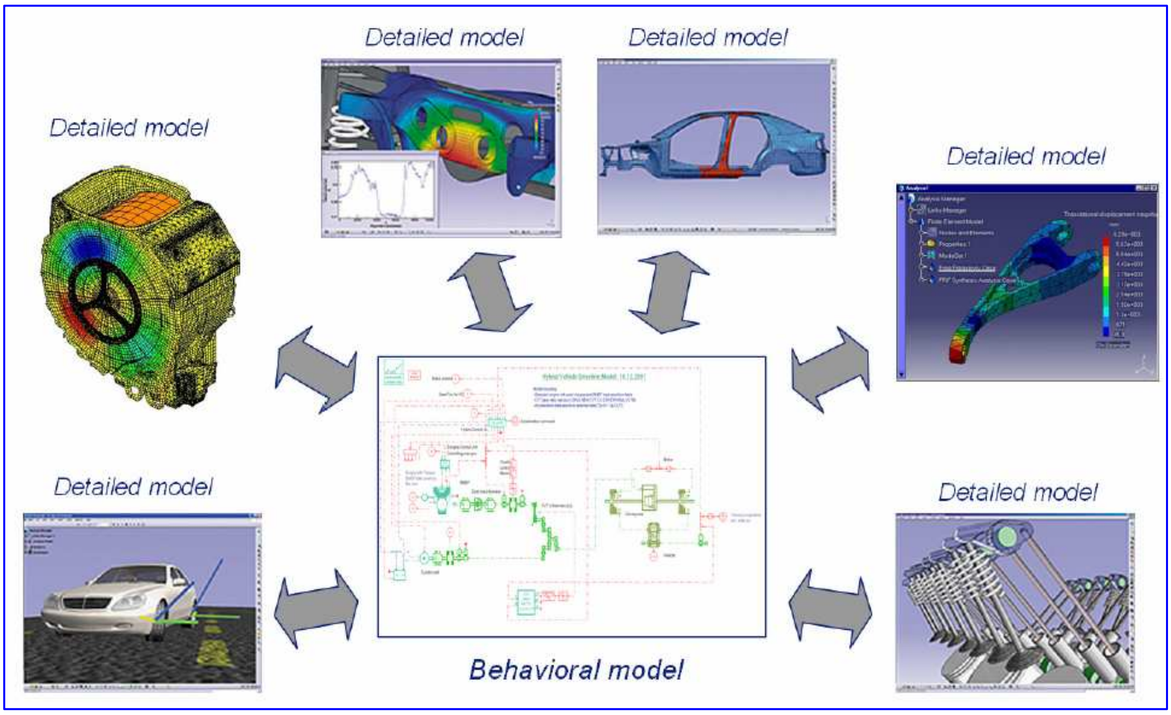


Figure 4: The model reduction technique: from detailed to behavioral models

Therefore, a change in a parameter in a high fidelity model can be used to study the resulting controller performance in the simplified environment. Likewise, parameter changes in the simplified environment can be translated back to the high-fidelity model to study their effects on joint loads, fatigue, etc.

In order to give an example of some of the aspects to be considered in the translation from a 3D MBS complex model to a 1D behavioral model, one can consider the particular technique of reducing car model, through the generation of table look-up models for the suspensions.

Often a kinematic map between the spindle motions relative to the chassis is used instead of modelling all the separate suspension bodies. However, a kinematic model alone is not enough. Instead, an elasto-kinematic map should be used, which will allow compliance in the suspension to be included.

The high fidelity model can be used to derive an accurate elasto-kinematic map by driving the model through a set of maneuvers designed to exercise the suspension through a full range of motion.

The reduced model obtained can then be used to develop a number of studies in different fields, from the design optimization of chassis components to the generation of real time capable codes for HiL applications.

4. CASE: OFF-ROAD VEHICLES

Among off-road equipment many diverse applications are found ranging from the construction and agriculture industry up to mining and urban works. The size of the machines and the environment in which they operate will also vary very much and a number of crucial requirements are common between different off-road machines. Compatibility and easy interchange of attachments such as a bucket, dimensioning of the power supply for hydraulic or electric drives, speed, precision, stability and of course resistance to the harsh operating conditions are just a few of them. Seeing the cost and little availability of prototype testing and the wide range of manufactured products, simulations help engineers better predict, understand and optimize the dynamic behavior of their designs. As there are strong interactions between the mechanical and hydraulic subsystems only a total system simulation provides representative results. 3D analysis provides state-of-the-art capabilities to model vehicles such as wheeled or crawler loaders and backhoes, cranes, as well as smaller systems like skid steers or forklifts. Dedicated toolkits allow engineers to create wheeled and tracked vehicles, and other mechanical transmission systems, driven by the control unit with power supply from the engine and hydraulic circuit. Several circuits might be interconnected to manage precision, stability, and optimal power supply. The latter subsystems are modeled in 1D and in dedicated control packages and are then plugged in to the multibody system to form the total system (see Figure 5 below).

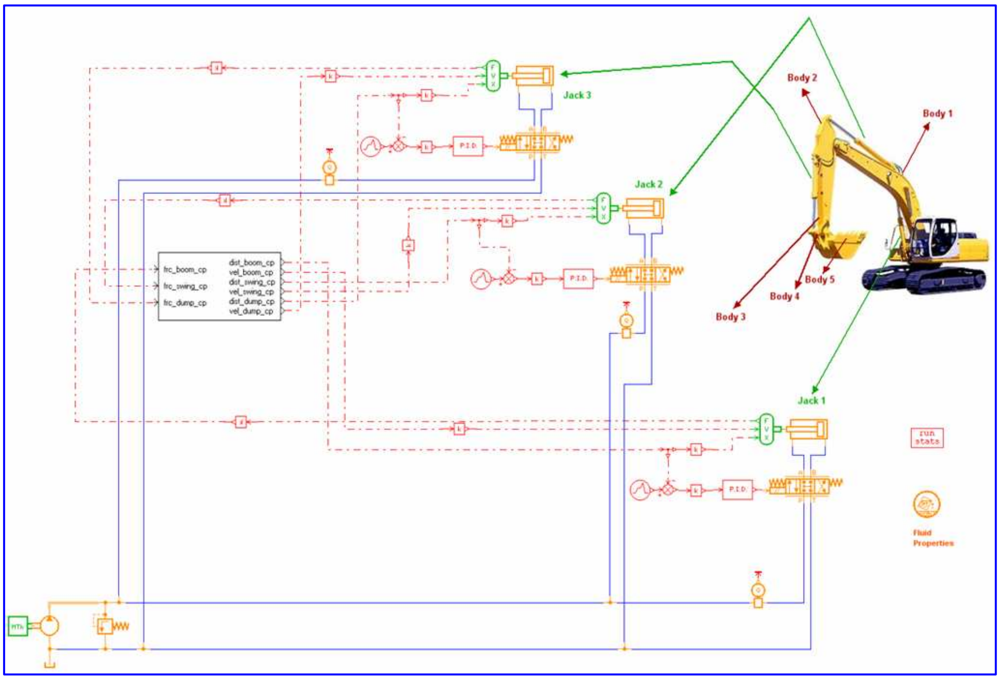


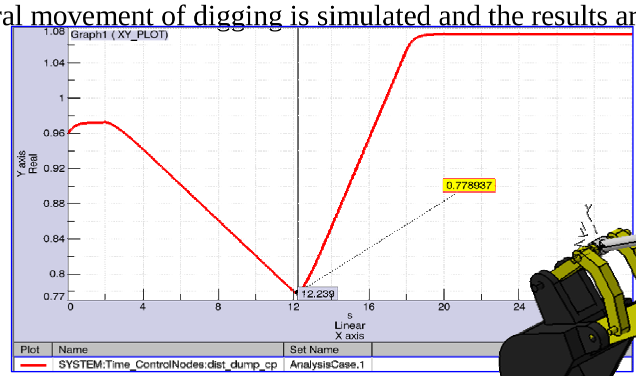
Figure 5: Excavator total system with hydraulic system and precision controls

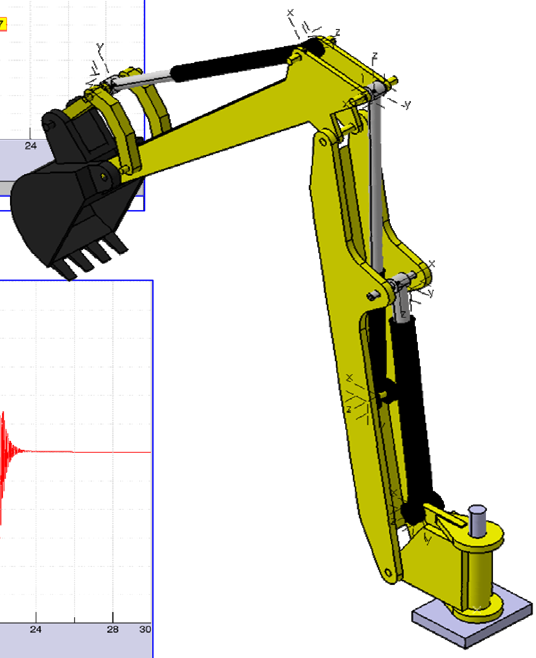
Hydraulic hardware has undergone a great evolution in recent years, evolving from purely hydro-mechanical devices to electro-hydraulic systems controlled by microprocessors. The use of electronic controllers opens the door to improving dynamic performance and enhancing traditional hydraulic off-highway construction machines with new features such as increased energy efficiency, improved operator controllability, and overall increases in productivity. With these added capabilities often comes added system complexity, particularly in the area of system controls.

A useful tool for design engineers seeking to develop more efficient and effective control algorithms for hydraulic machines is the simulation of different load cases before commitment of the design. The mock-up is unique because of its simple construction and inherent ability to emulate static, resistive, and overrunning loads of two-port actuation systems with differential areas, such as hydraulic cylinders, where the flow rates into and out of the actuator are unequal.

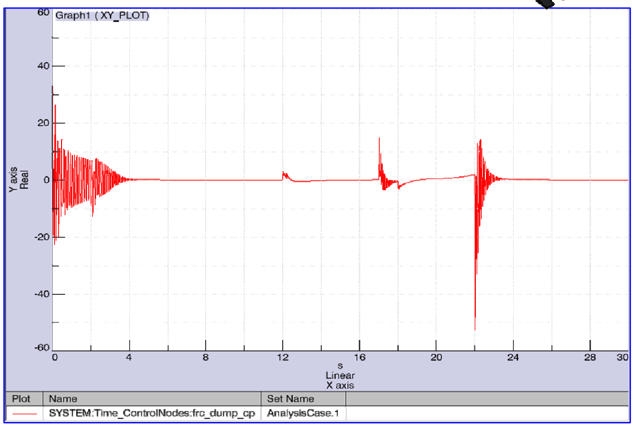
The model is compiled into 1D and the data available after this process is sent towards 3D MBS software as a response. On all these levels, the provision of adequate and realistic system models will be essential to synchronize the control development with the mechanical system development, leading to a true multi-functional system mock-up.

The 1D model receives the displacement and velocities of hydraulic piston mountings and provides towards the 3D model the necessary force as responds to the loads of the system. In this case a general movement of digging is simulated and the results are presentenced in the Figure 6.





The displacement sent to 1D model



The force received from 1D model

Figure 6: 1D – 3D excavator system model simulation results

5. CASE: VEHICLE ANTI-LOCK BRAKING SYSTEM (ABS) EVALUATION

This case shows the integration between system and control simulations for vehicle ABS (Anti-lock Braking System) evaluation. Multi-attribute models are developed to optimize and balance vehicle performances such as handling and road noise. The typically optimized parameters are hard point locations as well as suspension bushing stiffness values.

Figures 7 and 8 show part of the MBS model (front axle), the ABS control model and some simulation results.

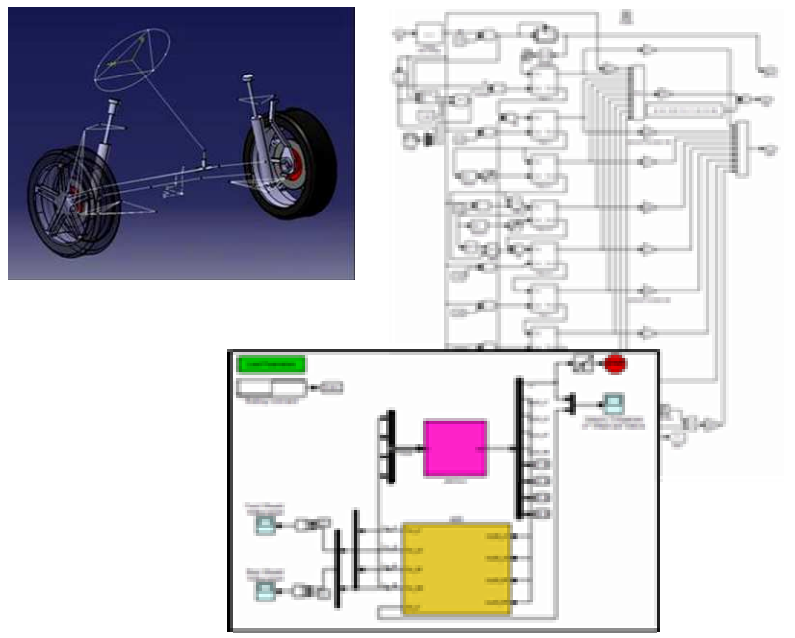


Figure 7: ABS-chassis system co-simulation model

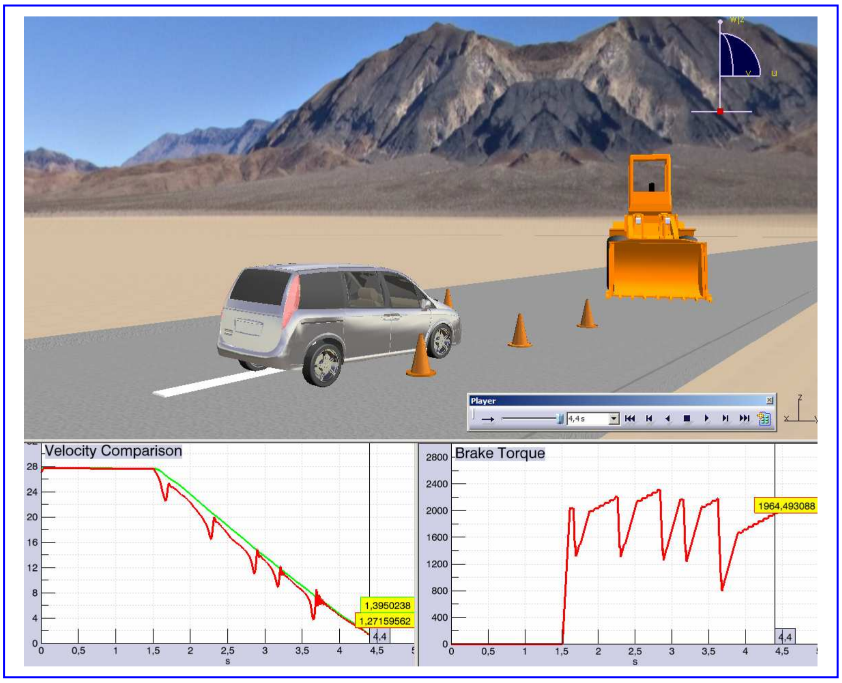


Figure 8: ABS-chassis co-simulation results

6. CONCLUSIONS

Today's industrial products are getting more intelligent and more complex than ever which raises the needs for engineers of design tools able to manage multi-domain systems with smart coupling methods. Detailed modeling and optimization of subsystems is not sufficient to ensure the performance and reliability of the complete product brought to the market. Using multi-functional system mock-up products, engineers accurately model their subsystems and products taking detailed mechanical and multi-physical actuators into account with integrated controls. This allows real-life dynamic behavior and load prediction to be computed in a seamless manner.

The smart combination of strengths of these software's together with fast and robust co-simulation solver scheme alternatives enable design teams to avoid redundant or less efficient modeling. It also provides the means for an increased understanding of the total mechatronic system showing strong dynamic coupling effects and that are necessary for engineers to optimize the performances of products. The seamless interface indeed allows engineers to perform from one single environment parameter sensitivity analysis and total system optimization.

7. REFERENCES

[1] H. Van der Auweraer, K. Janssens, L. de Oliveira, M. da Silva, W. Desmet, (2007), *"Virtual Prototyping for Sound Quality Design of Automobiles"*, Sound and Vibration, Vol. 41, No.4, Apr. 2007, pp 26-31.

[2] H. Van der Auweraer, P. Mas, P. Segaert, L. de Oliveira, M. da Silva, W. Desmet, (2007), *"CAE-based Design of Active Noise Control Solutions"*, SAE Paper 2007-26-032, Proc. SIAT 2007, Pune (India), 17-20 Jan. 2007.

[3] J. De Cuyper, M. Gubitosa, J. Kang, G. Lethé, M. Furmann, D. Kading, *"Vehicle Dynamics Control – A Case Study in LMS Virtual.Lab Motion"*, Proc. 4th Asian Conference on Multibody Dynamics 2008, Aug. 20-23, 2008, Seogwipo-city, Korea

[4] H. Van der Auweraer, J. Anthonis, J. Leuridan, *"Virtual and Physical Testing for Design Engineering of Intelligent Vehicles"*, Proc. SIAT 2009, 21-22 Jan. 2009, Pune, India

[5] M. Gubitosa, J. De Cuyper, V. Cibrario, *"Optimized design method of vehicle Suspension systems using a Reverse Engineering Approach"*, Proc. IMECE2008, Nov, 2008, Boston, USA.