Integrating Mechanical Dynamics and Non-Linear Structural Analysis in Chassis Development

Rocco Longo, Fabio Orengo, AMET Srl
Jon Quigley, Altair Engineering Inc.
Philippe Krief, Eugenio Perri, Fiat Auto SpA

Abstract

System level structural analysis is fundamental for comprehensive virtual prototyping of mechanical systems, in particular for vehicle suspensions. In addition, the shortening of development cycles has required reduced time and prompt interactions among the several development environments involved. For these reasons an integration of the mechanical and structural development environments has become vital.

This paper is about a new methodology in which a system level structural analysis of a suspension system has been integrated in the mechanical development environment. The mechanical characteristics of the suspension are taken into account by the multibody model whereas the structural characteristics of the different members are taken into account by the corresponding structural models. In order to solve the system level model a non-linear finite element solver, such as Abaqus, has been used.

This integrated development environment has been verified and tuned during the 8C Competizione project, the Alfa Romeo’s high-class sport car. Hereafter this innovative methodology is presented.

Introduction

Mechanisms are often studied with Multi Body modeling techniques (hereafter MB) [1]. MB analysis are extremely flexible and efficient methods to perform kinematic and dynamic mechanism analysis. But once designers have defined the mechanism a new issue of structural integrity of bodies becomes apparent.

MB codes already help engineers in defining the structure by providing loads on connecting elements [2] and dynamic system behavior [3]. But also designers can make use of MB codes in packaging check of mechanical members [4] especially when their motion is not only kinematic but when the compliance of the mechanism (i.e. bushing, stabilizer bar, flexible link…) is also involved [5]. MB codes are efficiently used in determining the maximum space available (Design Space) for a topology optimization of each mechanical component [6, 7]. However MB codes show many weakness when they are called to solve and verify the link’s structure itself.

Component Mode Synthesis (hereafter CMS) flexible bodies [8] have been introduced in modern MB codes in order to account for member flexibility and to back compute the stress field on member structures. Many algorithms and methods have been implemented to perform the CMS condensation but all have an issue: they cannot account for non linearities because they are based on the superposition method. But the need to assess the structural performance of members also under misuse conditions occurs quite often, for example when plastic deformation and member collapse can occur.

This is an every day problem for suspension engineers. They have adopted a system level approach in structural analysis because the single component non-linear analysis is not always representative of the entire system behavior (i.e. the impact of the entire suspension system against a guard rail at the upper end of the rim).

Automotive chassis departments develop accurate MB models for suspension elasto-cinematic characterization [9] and for full vehicle handling and comfort performance evaluation [10, 11]. These models are generally realized making use of suspension libraries and are fully parametric. So generally a good and validated MB model of suspension systems is already available.

In order to perform a system level structural analysis the current engineering practice requires engineers to translate by “hand” the MB model (topology and data) into a non linear Finite Element (hereafter FE) codes [12], such as Abaqus [13]. In fact, most of FE pre-processor have not been designed to easily define mechanical elements such as joints, markers, bushings and many other entities typical for MB; so engineers are forced to manually edit the FE model deck exercising themselves in a tedious lengthy translation process which is prone to errors.

But during a development cycle it is most common to have many changes and iterations such that keeping synchronized MB model and non linear FE model by hand is extremely costly. For these reasons the missing of an integrated environment is recognized today as a slow down for the suspension development cycle. The current practice in suspension development is represented in **Fig. 1.**

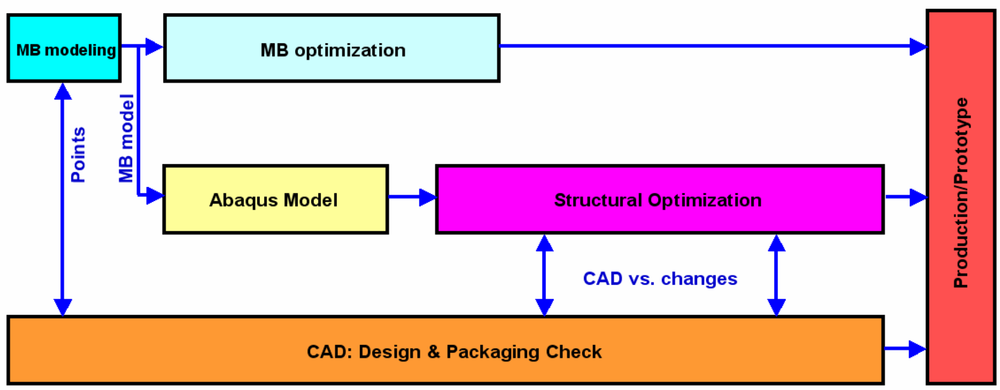

Fig. 1: flow chart of the current practice in suspension development.

FEA Body Methodology

To meet the needs of suspension engineers a new methodology called “FEA body” has been developed but its use is general and can be applied to any other mechanical fields. The FEA body methodology consists of a synergic use of the best tool for each specific environment:

1. the use of a specialized pre-processor, such as MotionView [14] for mechanical modeling,
2. the use of a specialized pre-processor, such as HyperMesh, for FE mesh modeling and
3. the use of a non-linear FE solver, such as Abaqus, for solving the system level problem.

In this way great advantages can be experienced.

It is well known that MotionView is able to write an input MB deck for general purpose MB codes such as MotionSolve, Adams… But it is also able to write an equivalent fully functional input deck for non linear FE codes, such as Abaqus. This automates the translation work that is so time consuming and error prone if done by hand. **Fig. 2** shows an example of a mechanical model run with Motion Solve, Adams and Abaqus.

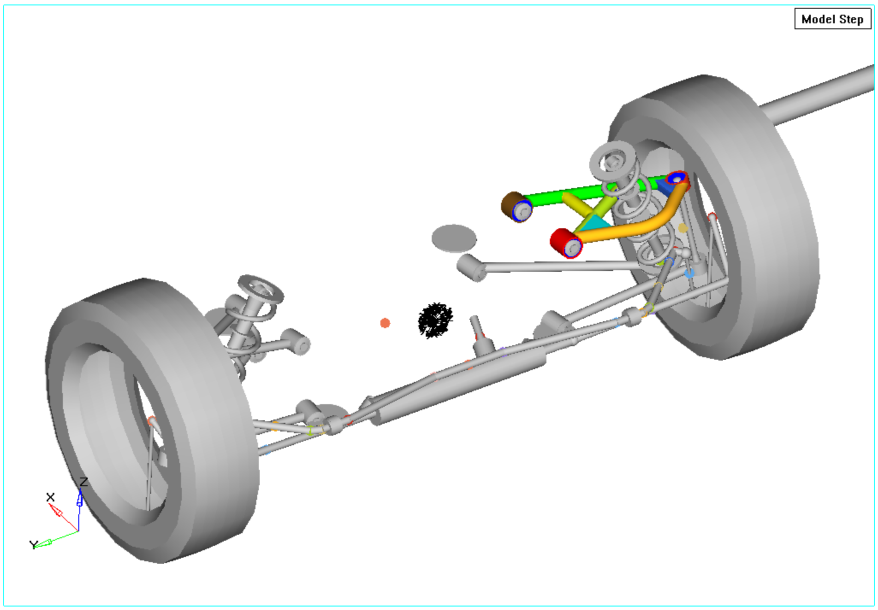

Fig. 2: multi rigid body model that can run with Motion Solve, Adams and Abaqus; with the CAD shape of the components also packaging check can be performed.

In addition to the CMS flex body, MotionView is also able to switch a rigid body into a special type of flexible body called “FEA body”.

The FEA body file contains a standard structural mesh of a specific mechanism member (i.e. a mesh model of a suspension’s upper control arm) that MotionView includes into the Abaqus’ input deck. The included file is not condensed and it supports any kind of non-linearities (i.e. material, geometry, contacts…) so that the resulting file that MotionView writes out is an Abaqus input deck that can perform general non linear FE analysis (i.e. plastic flow, post buckling collapse…).

It must be remarked that the most useful application of the FEA body methodology is not related to performing a typical MB analysis with a non linear FE solver. And it is not even related to the use of FEA body methodology as a substitute of classical CMS bodies analysis that – taking advantage of the reduced DoF – can be effectively used to save computational resources. The most useful application of the FEA body methodology is in system level structural analysis. In fact, if the MB model developed in the chassis department (generally good and validated) has been developed in MotionView, the system level structural analysis is automatically available also in ABAQUS solver.

Once the MB model of the suspension system has been developed engineers can go through the following steps:

1. Check for errors performing quick multi rigid body analysis with MB codes, such as ADAMS, MotionSolve (cfr. **Fig. 2**)
2. Switch to Abaqus solver mode, write out the model for Abaqus and run it. On PCs that rigid body run shall not last more than a few minutes and it can be fundamental to assess the analysis convergence performances. After these positive runs, the model is ready to be used as a robust platform to test structural performances of mechanisms (cfr. **Fig. 2**)
3. Activate the FEA body for one or more links of the mechanism and associate the corresponding mesh in order to simulate use, misuse and impact conditions under a system level approach (cfr. **Fig. 3**).

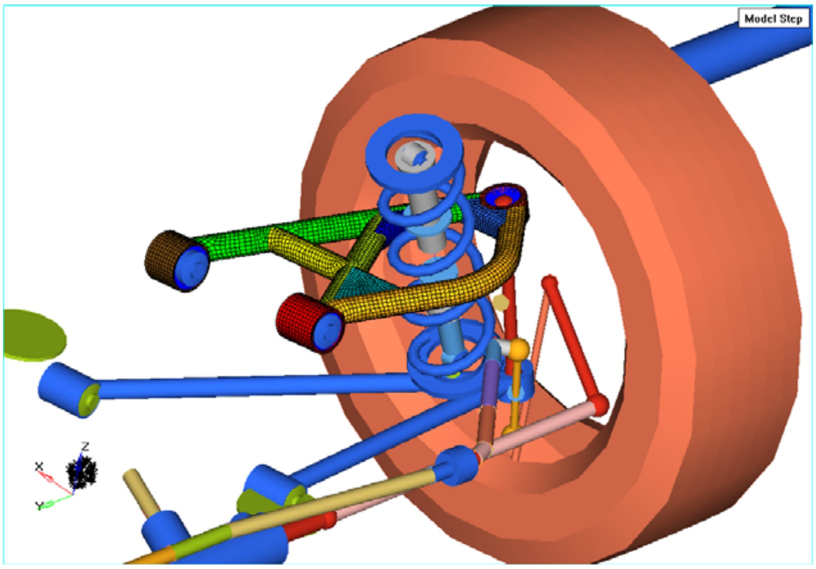

Fig. 3: system level structural model of the entire suspension system with the upper control arm included as FEA Body ready to be simulated with Abaqus Solver.

The FE input decks obtained with this methodology proved to have an amazing rate of simulation success since their first attempt; in fact, errors and mistakes are detected and removed with the aid of the previous rigid body runs first with a pure MB solver and later with Abaqus. This guarantees no more runs hanging in the server for many hours failing to converge for a simple mistake, such as a non linear bushing out of range, a wrong bushing orientation, an over constraint... Engineers can now concentrate themselves in finding engineering solutions rather than to be concentrated on the tools. The procedure outlined above is represented in **Fig.4** and can be executed by an engineer in about one order of magnitude less than the standard practice.

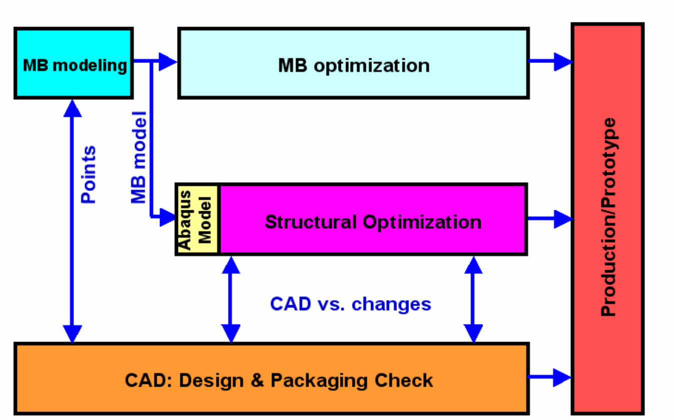

Fig. 4: flow chart of the FEA Body procedure applied in suspension development.

Application to Alfa Romeo 8C Competizione

The new methodology for system level structural analysis has been tested and tuned during several projects on suspension development so that its advantages could have been largely appreciated. For courtesy of FIAT AUTO S.p.A. we are allowed to show some of the results obtained during the chassis development of 8C Competizione, the Alfa Romeo's high-class sport car [15].

Fig. 5: prototype of Alfa Romeo 8C Competizione.

The project was about the development of a new set of suspensions in order to obtain the typical sport car performances characterized by the unmistakable Alfa Romeo's "steering feeling". But also comfort performances were very pressing for "road use" of the car. The 8C Competizione project concerned the complete development of the chassis – from concept to prototype - in order to make every necessary physical test on such a high-class sport car (cfr. **Fig. 5**).

The present paper covers mainly the innovative methodology used in this project with respect to the system level structural analysis. In particular **Fig. 6** shows the result of the suspension structural analysis that simulates the impact of the suspension system against a guard rail at the upper end of the rim. As can be seen, the figure shows the simulation with only one structural component at a time, in particular the upper control arm. On the left side of the figure the deformation of the upper control arm and the collapse shape can be noticed at the breaking instant; on the left side of the figure the normalized force vs. deformation curve can be appreciated with the breaking point after which the curve loose its physical meaning.

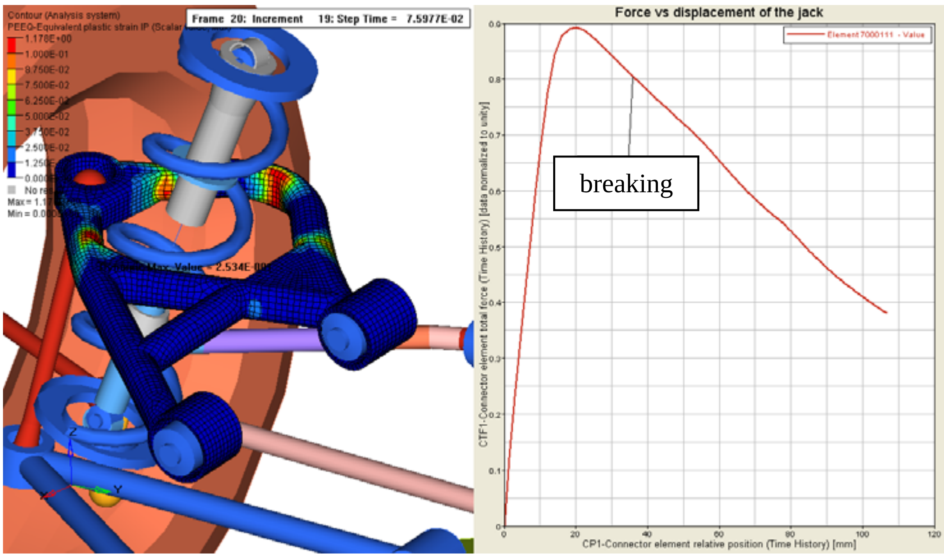

Fig. 6: results of a system level structural analysis of an impact of the suspension system against a guard rail at the upper end of the rim simulated with Abaqus (only one suspension component is considered).

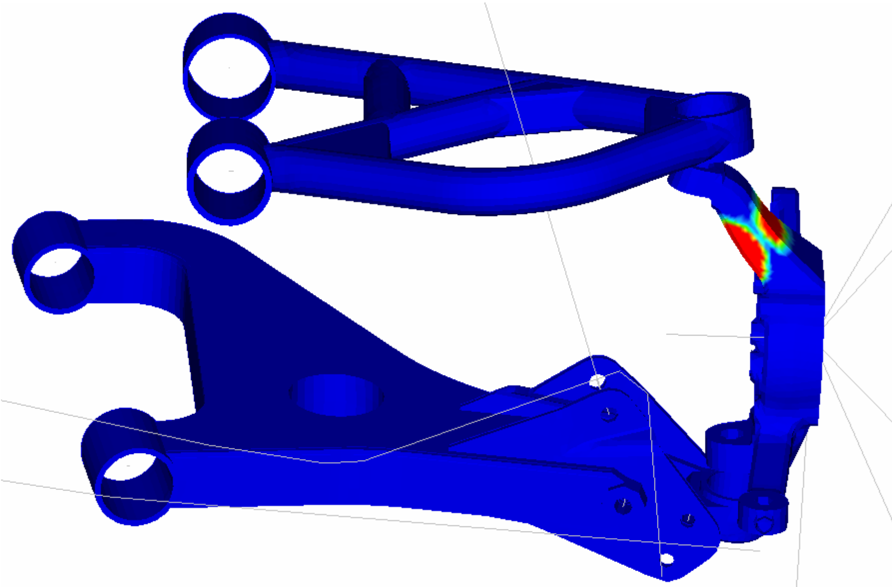

Fig. 7: results of a system level structural analysis of an impact of the suspension system against a guard rail at the upper end of the rim simulated with Abaqus (entire suspension components are considered).

The simulation with one only component is most useful during an early development stage. But the most powerful application of this new methodology is when more than one structural components are considered - generally them all - in order to simulate the overall behavior of the entire suspension system under certain conditions. In **Fig. 7** you can see an example of entire suspension system impacting against a guard rail at the upper end of the rim. **Fig. 8** shows one of the physical tests that validated the methodology and the project itself.

During the 8C Competizione project it has been immediately clear that this methodology led to a very high efficiency since engineering CAE departments could quickly test many design options taking advantage of the saving in computational and engineering time. This substantially sped up the product development cycle with the positive consequence of Time-to-Market reduction and better performance achievement.

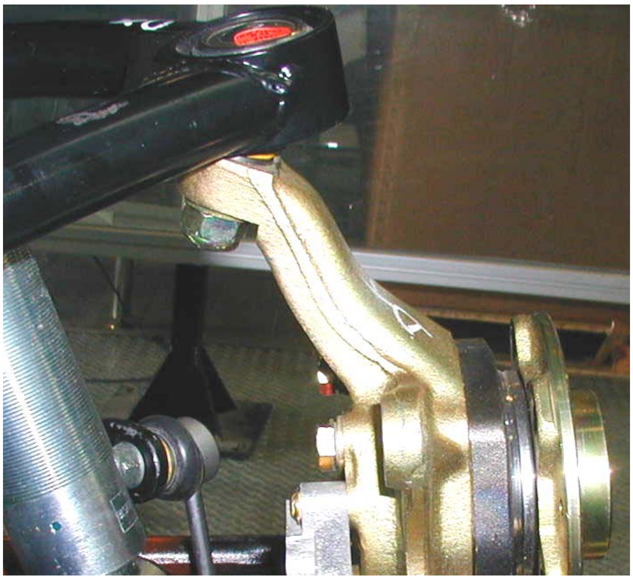

Fig. 8: a physical test of an impact of the suspension against a guard rail at the upper end of the rim.

Structural design iterations (i.e. structural member modifications) were made easy since it was enough to modify the specific component mesh file for verifying a new solution. The mesh have been created by resources different than the ones that were performing the analysis; this helped to parallelize the development activities and eventually to out-source the FE modelization.

Also mechanical design iterations (i.e. bushing stiffness variation) were made easy because MB entity parameters could be easily varied within MotionView. Only run-time expressions had to be removed or deactivated since non linear FE codes, such as Abaqus, do not support them yet. Nevertheless in structural analysis there is no need for complex outputs that use run time expressions, such as Roll Center Height, Virtual King Pin Inclination... DOE, Optimization and Stochastic Studies were easily performed due to the seamless integration with HyperStudy.

Another big advantage of this methodology is that MotionView allows topology changes for every analysis or load case; this has given the possibility to make minor but essential model modifications in order to test the system under different load cases, such as specific boundary conditions, lock of the damper during specific analysis and even a complete new test rig. All of this has been simply managed by MotionView because it automatically took care of writing a different model deck for each type of analysis.

A positive consequence of this methodology that has been experienced is that every model and resource related to the 8C project was always up to date no matter if it was MB or FE related. This is considered priceless by anyone whom manages a suspension development in terms of error savings and effectiveness of the analysis.

Another advantage of this methodology is that procedures can be easily standardized within and among departments because there is only one solver independent model that can be shared rather than a hand made input deck only suitable by its developer.

The development of this new methodology that integrates MB and non linear structural analysis has to be seen as a completion of the integrated environment for suspension development that integrates MB, PC, component structural linear optimization and finally system level non-linear FE analysis. In this way the MB model can act as master database with the positive consequence of keeping the different fields of the project always updated.

Conclusions

An integration of system level structural and mechanical development environments has been presented and illustrated with a car suspension virtual prototyping.

The mechanical characteristics of the suspension have been taken into account by the multibody model whereas the structural characteristics of the different members have been taken into account by the corresponding finite element models. In order to solve the system level model a non-linear FE solver, such as Abaqus, has been used.

A successful application of this integrated development environment has been presented making use of the 8C Competizione project, the Alfa Romeo’s high-class sport car.

The development of this new methodology that integrates multi body and non linear structural analysis has completed the effort to reach a suspension development environment that integrates multi body, packaging check, component structural linear optimization and finally system level non-linear structural analysis.

Acknowledgements

The authors would like to thank the other members of the project team: Christian Fagiano, Marco Testa, Gianluca Anedda, Andrea Accotto, Shafiqul Bari, Rajesh Jha, Michael Hoffmann, Elena Salino, Marco Cavallero, for their valuable collaboration.

References

1. Shabana A.A., "*Dynamics of Multibody Systems*", Ed.: Cambridge University Press, 2003.
2. Longo R., Abbatantuoni V., Toniato G., "Beyond geometrical DMU: assessing dynamic bodies interaction in mechanisms and operating systems ", *ATA 2003*, Firenze, May 2003.
3. Benoffi M., Longo R., "Simulazione dinamica di stampaggio. Una metodologia nuova applicata alla FIAT Stilo", (Die Dynamic simulation. A new methodology applied to FIAT Stilo), *Quaderni Tecnologici*, 2002, October, pp. 56-61.
4. Held M., Klosowski J. T., Mitchell J. S. B., "Evaluation of Collision Detection Methods for Virtual Reality Fly-Throughs", *Proc. 7th Canadian Conference on Computational Geometry*, Ed.: Gold - Robert, Québec City, Québec, Canada, August 1995.
5. Longo R., Testa M., Anedda G., Krief P., Perri E., "Vehicle Suspension Development Driven by Performance Optimization and Managed by a Master Multibody Environment", *Workshop sulla Dinamica dei Sistemi Multibody*, Paestum, April 2006.
6. Haftka R.T, Gurdal Z. , Gladwell G. M. L., "*Elements of Structural Optimization (Solid Mechanics and Its Applications, 11)*", Ed. Kluwer Academic Publishers, 2002.
7. Longo R., Testa M., Anedda G., Krief P., Perri E., "Integrated Multibody and Structural Optimization for Car Suspension Design", *International conference on CAE and Computational Technologies for industry*, Forte Village, October 2003.
8. Garcia de Jalon J., Bayo E., "*Kinematic and Dynamic simulation of Multibody Systems*", Ed.: Springer-Verlag, 1994.
9. Reimpell J., Stoll H., "*The Automotive Chassis: engineering principles*", Ed.: Arnold, 1996.
10. Milliken W.F., Milliken D.L., "*Race Car Vehicle Dynamics*", Ed.: SAE, 1995.
11. Longo R., Hall D., "Expanding Simulation Applications in Motorsports with New User-Friendly Tools", Race.Tech 2004, Garching (Munich), October 2004.
12. Bathe K. J., "*Finite element procedures in engineering analysis*", Ed.: Prentice Hall, 1982.
13. Abaqus Users' Manual (www.hks.com)
14. Altair HyperWorks Manuals (www.altair.com)
15. Beckert B. A., "Putting Simulation Muscle Behind a Sporty Concept Car", *Concept to Reality*, Altair Engineering, Inc. Publication, Fall 2004.