# A comparison between Finite Element Modells and MBS models in automotive safety applications

**Jörg Fehr, Christian Kleinbach**

Institute of Engineering and
Computational Mechanics
University of Stuttgart
Pfaffenwaldring 9, 70569 Stuttgart, Germany
[joerg.fehr, christian.kleinbach]@itm.uni-stuttgart.de

**Abstract**

Automotive safety is currently at a crossroads: With active safety systems being progressively available in cars and autonomous vehicles being developed by all major Car Manufacturers, changes in the safety concepts of our cars are inevitable. For the last two decades the development of safety systems has been driven by simulations. In view of the challenges posed by active safety, novel problems regarding the simulation process arise. Active safety systems use the time period prior to contact, the so-called pre-crash stage, to actively reduce the risk of injury for the occupants. Taking the pre-crash stage into account increases the simulation time by one order of magnitude. Also, with active safety systems and especially with autonomous vehicles, a large variety of crash scenarios can be imagined. Another problem that needs to be addressed is the biofidelity of the models of the human body in the pre-crash stage. Currently, the safety concepts of cars are developed by simulating and testing cars with a multiple set of crash test scenarios and crash test dummies. Crashtest dummies are developed to measure forces, accelerations and deformations on humans during crash events where the usage of humans is impracticable due to the severe injury risk. The dummies are designed for the in-crash stage and have low biofidelity in the pre-crash stage, as shown by e.g. [1]. In simulations, models directly derived from the human body, so called human body models (HBMs), can be used. Contrary to dummy models, which are designed with one specific crash scenario in mind, these human body models can be used in all kinds of crash scenarios, e.g. front, rear or side impact. Furthermore, they can be equipped with active muscles control [2] to increase biofidelity.

In automotive safety simulations the explicit nonlinear finite element (FE) method or the multibody system method are used to evaluate and optimize safety concepts. Therefore, dummy and human body models exist for both methods. The Total Human Model for Safety (THUMS) and the Global Human Body Model Consortium (GHMBC) model are nonlinear FE models while the Active Human Body Model (AHBM) is based on multi body dynamics. The nonlinear FE models with more than 1 000 000 elements with high biofidelity allow a sophisticated analysis of strain and injury risk occurring in a crash, see [3]. However, the application of the THUMS or GHMBC model requires large computational resources due to its large number of elements. The AHBM with active muscles is especially run-time efficient enabling the simulation of crash scenarios including the pre-crash and in-crash stage, see e.g. [4].

In order to compare and evaluate existing and future models of the human body for automotive safety applications in various computational codes, a generic side impact setup shown in Figure 1 is designed. The setup is motivated by cadaver sled tests like reported in [5]. A side impact scenario is chosen, because side impacts remain crucial even in modern cars due to the narrow space between driver and interior. In a first step, the setup is used for a comparison of the ES-2 FE dummy with the ES-2 MBS dummy. The ES-2 dummy is a side impact dummy used in European regulations and consumer ratings. The dummy is moving with an initial velocity towards the 5 plates, then force is applied to these plates in order to decelerate the dummy. The force applied to each plate is determined by a controller based on injury criteria for the body region the plate is located at, see Fig. 2. This model allows to analyze and calculate the forces and energies that can be transmitted to the body parts of the models in order to most adequately decelerate the passenger considering the injury risks to be met and the available deceleration space. Injury criteria for dummies are based on measurements of deflection, acceleration or force. Limits are found through combined tests using cadavers and dummies, as shown in [6] for injury criteria in side impacts for the ES-2 dummy model. The setup presented here allows to show how much energy is

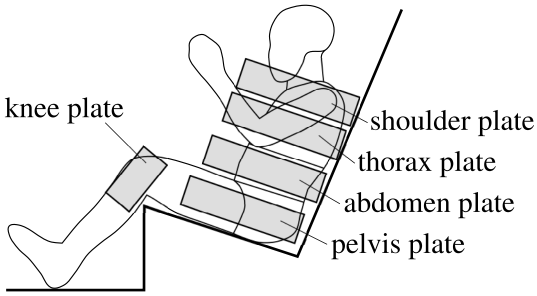


Figure 1: Generic side impact setup designed for evaluation of models of the human body.

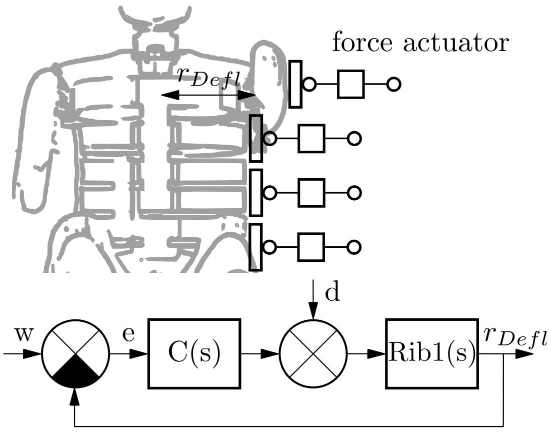


Figure 2: Controller approach for an optimal deceleration of a passenger considering the injury risks to be met.

absorbed by different body regions, which can be regarded as a macroscopic measure for the biofidelity of the dummy or human body model. In addition, ideal safety concepts are supposed to be derived from these calculated optimal forces. This procedure fundamentally differs from previous development procedures that imply the a priori development of a safety concept and the subsequent derivation of the forces and injury risks for the passenger through the respective design.
The next steps will include a comparison of existing FE and MBS HBMs in the side impact setup. Here, the role of muscle activation is of special interest. Since computational costs are high for FE HBMs the GHBMC has started developing HBMs with rigidized components. In this context, the possibilities of using the theory of elastic multibody systems in combination with advanced model reduction schemes, see e.g. [7], might offer a good compromise between biofidelity and computational costs.

**References**

[1] Schoeneburg, R.; Baumann, K.H.; Fehring, M.: The efficiency of PRE-SAFE systems in pre-braked frontal collision situations. In Proceedings of the 22th ESV-Conference, 2011.

[2] Östh, J.; Brolin, K.; Carlsson, S.; Wismans, J.; Davidsson, J.: The Occupant Response to Autonomous Braking: A Modeling Approach That Accounts for Active Musculature. Traffic Injury Prevention, Vol. 13, No. 3, pp. 265–277, 2012. PMID: 22607249.

[3] Smith, R.D.; Hayashi, S.; Kitagawa, Y.; Yasuki, T.: A Study of Driver Injury Mechanism in High Speed Lateral Impacts of Stock Car Auto Racing Using a Human Body FE Model. Tech. rep., SAE Technical Paper, 2011.

[4] Velardocchia, M.; Unger, M.; Vigliani, A.; Leone, N.; Kietlinski, K.; Galvagno, E.: Integrated Active and Passive Systems for a Side Impact Scenario. Tech. rep., SAE Technical Paper, 2013.

[5] Cavanaugh, J.M.; Waliko, T.J.; Malhotra, A.; Zhu, Y.; King, A.I.: Biomechanical Respone and Injury Tolerance of the Thorax in Twelve Sled Side Impacts. Tech. rep., SAE Technical Paper 902307, 1990.

[6] Kuppa, S.; Eppinger, R.H.; Mckoy, F.; Nguyen, T.; Pintar, F.A.; Yoganandan, N.: Development of side impact thoracic injury criteria and their application to the modified ES-2 dummy with rib extensions (ES-2re). Tech. rep., SAE Technical Paper, 2003.

[7] Fehr, J.: Automated and Error-Controlled Model Reduction in Elastic Multibody Systems, Vol. 21 of Schriften aus dem Institut für Technische und Numerische Mechanik der Universität Stuttgart. Aachen: Shaker Verlag, 2011.