

Real World Accident Reconstruction with the Total Human Model for Safety (THUMS) in Pam-Crash

R Segura^{1,2}, F Fürst², A Langner³ and S Peldschus⁴

1 Arbeitsgruppe Biomechanik, Institute of Legal Medicine, Ludwig-Maximilians-University Munich, GERMANY

2 Entwicklung Front- / Heckschutz, AUDI AG, GERMANY

3 Automotive Safety Technologies GmbH

4 Campus Tuttlingen der Hochschule Furtwangen

Abstract - Further improvement of vehicle safety needs detailed analysis of real world accidents. According to GIDAS (German In-Depth Accident Study) most car to car front accidents occur at mid-crash severity. In this range thoracic injuries already occur. In this study a real world frontal crash with mid-crash severity out of the AARU database was reconstructed. The selected car to car accident was reconstructed by AARU by means of pc-crash software in order to get the initial dynamic accident conditions. These initial conditions were used to reconstruct the complete accident in more detail using FE models for the car structure and the occupants. Occupant simulations were performed with FE HIII-dummy models and the THUMS using Pam-Crash code.

An initial THUMS validation was performed in order to verify the model's biofidelity by means of table-top test simulations. THUMS bone stiffness values were modified to match the real world occupant age. A comparison between driver and passenger restraint system loading was done, as well as an injury prediction comparison between the HIII-dummy model and THUMS response for both cases. Detailed comparison between the HIII-dummy models and THUMS regarding thoracic loading are discussed.

Keywords: Accident reconstruction, biomechanics, dummy, simulation, thorax, THUMS

NOTATION

| | |
|--------------|------------------------------------|
| <i>AARU</i> | Audi Accident Research Unit |
| <i>acc</i> | acceleration |
| ΔV | Delta-V: Vehicle $V_{max}-V_{min}$ |
| <i>HIII</i> | Hybrid III Dummy |
| <i>THUMS</i> | Total Human Model for Safety |
| <i>v</i> | velocity |

INTRODUCTION / MOTIVATION

Moderate and serious [1] thoracic injuries already occur in mid-severity frontal crashes [2]. The frontal crash severity is defined as a proportional correlation to the change of velocity of the vehicle (ΔV) during the crash period including rebound [3]:

$$\Delta V = \max (v (t)) - \min (v (t)) [1]$$

Three different ranges of ΔV were defined based on an A. Ressler study [4] in order to create a crash severity scale as follows:

| Crash Severity Scale | ΔV [km/h] | Related car safety assessment program |
|----------------------|-------------------|---------------------------------------|
| Low | 0-15 | - |
| Medium | 16 - 39 | - |
| High | > 40 | e.g. EURONCAP (64 km/h) |

Table 1. Crash Severity Scale (Frontal)

Based on this scale it should be noted that the current car safety assessment programs take into account high crash severities, but the low and medium severities remain rather uncovered. Although the level of passive safety standards is currently high, car manufacturers should be encouraged to improve occupant protection in case of medium crash severity.

A search, selection and reconstruction of a real world car accident with medium crash severity and moderate thoracic injury severity (AIS 2) were carried out in order to analyze and understand the thoracic injury mechanisms under this loading conditions aiming for a better biomechanical-phenomena understanding and moreover, identifying the factors that could lead to further restraint system improvements.

ACCIDENT SELECTION

Outline AARU

The AARU (Audi Accident Research Unit) is an interdisciplinary research team between AUDI AG and the Clinic of the University of Regensburg (Bavaria, Germany). The research team is aiming for a traffic safety improvement. The result of the research effort go straight forward to the development of new car models at the AUDI AG and the introduction of new techniques in order to permanently increasing the traffic safety. The analysis of traffic accidents is the basis of these interdisciplinary research activities. It contains an accurate accident reconstruction and detailed analysis of related injuries. The understanding of the pre-crash, in- and after-crash phase are the basis for the final target: Mitigate crash severity or even avoid accidents.

In this context the AARU team supports the database search and provides a group of representative real world accidents, according to the motivation of this study: Mid-crash severity crash analysis. The AARU team also reconstructed the kinematic pre-conditions of the accident and established the necessary input data for the FE structural simulations.

Search-Tree out of the AARU database

The AARU database analysis involved frontal collisions with passenger cars. Side crash and rollovers were excluded. The cases were filtered as follows:

- Frontal collisions (nearly 100% overlap)
 - Car models from 2008 and newer
 - Medium Crash severity ($\Delta V \approx 20$ km/h)
 - Driver or/and Co-driver with medium thoracic injury severity (AIS 2)
 - Reconstructability criteria.

The filtering result showed 7 accidents that fulfilled the search requirements. The reconstructability criteria were used as deciding parameter. A collision in a junction between a Skoda Octavia Kombi and an Audi A4 was selected, whereas the Audi A4 was the car to be analyzed.

Selected accident description

Environment

The accident environment condition was:

- Daylight (11:15 a.m.)
- Dry road conditions
- Urban road
- Velocity limit = 50 km/h

Facts description

A Skoda Octavia Kombi (red) drives into the crossroad without braking with an estimated initial velocity of about 50 km/h. From the right side an Audi A4 (blue) collided onto the right side of the Skoda Octavia with an estimated initial velocity of 50 km/h and full overlap. Afterwards the Skoda Octavia breaks through a soft coppice. See Figs. 1 and 2.

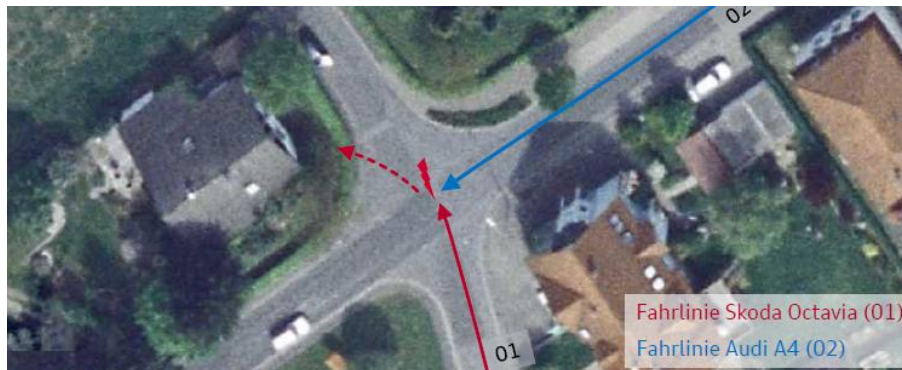


Figure 1. Selected accident scheme. Skoda Octavia (red), Audi A4 (blue)

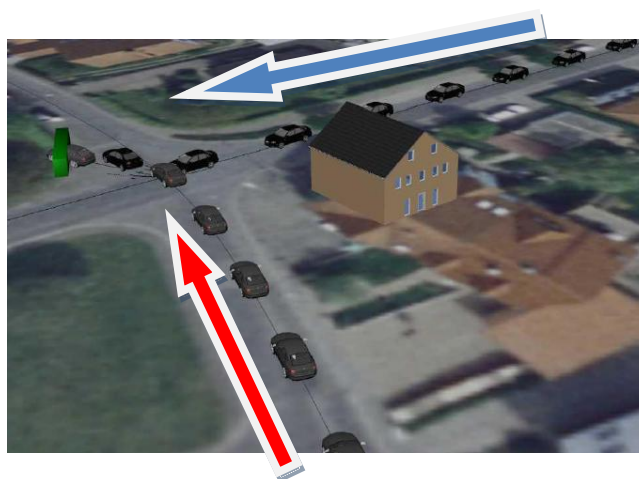


Figure 2. Selected accident scheme (another view) Skoda Octavia (red), Audi A4 (blue)

Occupant's injury description (Audi A4)

The driver sustained injuries with MAIS 1. The co-driver sustained injuries up to MAIS 2 due to a sternum fracture. The following table explains the anthropometric characteristics, age and injury severity of both driver and co-driver.

| Occupants A4 Data | Driver | Co-driver |
|-------------------|--------|-----------|
| Age [years] | 61 | 59 |
| Height [m] | 1,70 | 1,57 |
| Weight [kg] | 77 | 61 |
| Injury severity | MAIS 1 | MAIS 2 |

Table 2. Anthropometric characteristics, age and injury severity of the occupants in the Audi A4

ACCIDENT RECONSTRUCTION PROCEDURE

This accident reconstruction follows a methodological line of 4 steps that encompass the input-output relation for each one to the consecutive one. Those steps are explained as follows:

Kinematic Step

The AARU team carried out a PC-Crash® accident reconstruction using as input data the trajectories and final locations of both cars out of the database. In this step the target was to obtain the initial kinematic conditions necessary for the FE structural simulations. The PC-Crash® iterations resulted in the following results:

| Variable | Skoda Octavia | Audi A4 |
|---------------------------|---------------|--------------|
| Initial Velocity [km/h] | 50 | 50 |
| Collision Velocity [km/h] | 33 | 42 |
| ΔV [km/h] | 26 | 24 |
| Velocity Tolerance | ± 5 km/h | ± 5 km/h |

Table 3. Initial kinematic conditions obtained with PC-Crash® simulations

And for the trajectories:

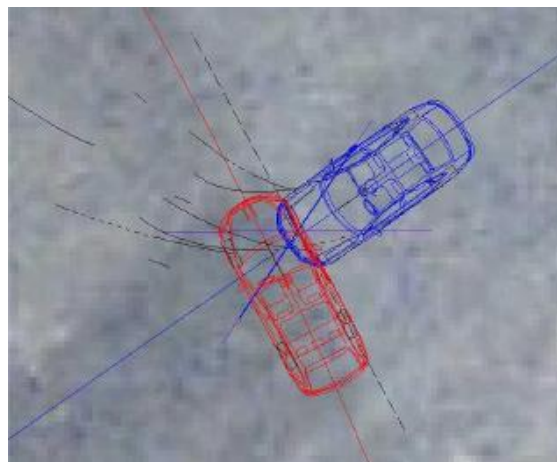


Figure 3. Collision trajectories for the selected accident. Skoda Octavia (red) vs. Audi A4 (blue)
Credits: Thomas Schenk (AARU)

Structural Simulation Step

The initial kinematic conditions and trajectories were used to set the initial and boundary conditions for this step. The structural simulation was represented by the collision of two Audi A4 FE Models because it was assumed that a Skoda Octavia FE models would have a similar structural behavior.

Assumptions

- Simulations were done using gravity
- Braking was neglected
- Road surface friction properties were neglected

Method

The chosen code to run the simulations was Pam-Crash®. The two FE A4 models were positioned as shown:

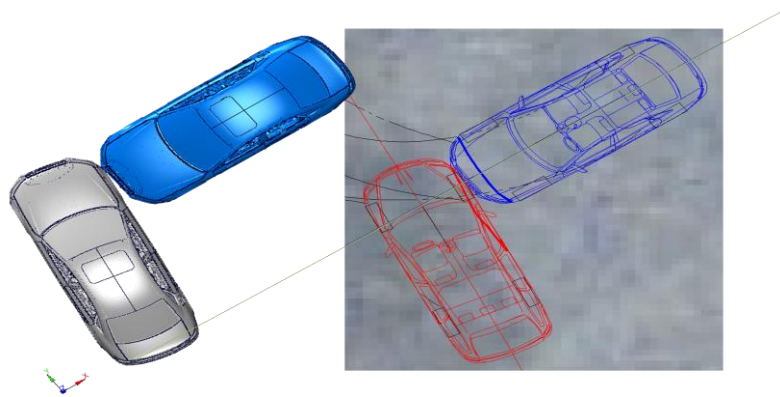


Figure 4. Left: FE models. Right: Resulting trajectories from PC-Crash®

Results

A qualitative deformation analysis shows the high similarity between the real crash and the deformations on the FE model. Realistic energy absorption and dissipation due to material plastic deformations and ruptures in the simulations could lead to realistic results that define the acceleration field for the occupants during the crash, this is, the crash pulse, necessary for the next step.

Moreover this result shows that the deformation outcome is obviously independent of the chosen assumptions regarding braking and road friction. Moreover the deformation outcome confirmed that the right initial conditions regarding velocities and directions of the colliding cars and the initial contact point at the beginning of the crash were chosen correct.



Figure 5. Structure deformation comparison. Right: Real accident. Left: Simulation.
Credits: Adrian Langner.

Sensor Simulation Step

The inspection of the Audi A4 showed that in this real world accident both occupants were buckled up. During the frontal crash of the Audi A4 the belt pre-tensioners were activated but the frontal airbags were not fired (see figure 6). This combination of fired belt pre-tensioners and not fired frontal airbags occurs in cases of low to mid crash severities where occupant are well restraint with fired belt pre-tensioners and belt force limiters.



Figure 6. Interior view of the Audi A4 after the crash

The crash pulse defines the fire times of the occupant restraint system. This process is done by means of an algorithm which analyzes the input signal (for instance the crash pulse) and defines under this condition the occupant restraint system fire times. Those fire times are substantial parameters for the occupant simulation step.

Occupant Simulation Step

As defined in the previous step, the fire times are the key factor to perform a realistic occupant simulation. The occupant simulation encompasses the previous steps representing each one of them in one single time-saving simulation.

Assumptions

Several assumptions were made concerning anthropometric representation and occupant environment and pre-crash muscle reaction

- For the occupant simulations both occupants were considered as 50th percentile American male.
- The initial positions of the occupants and seats into the car were assumed to be USNCAP like.
- Pre-crash muscle reaction was assumed to be negligible.

Method

An initial THUMS validation was performed in order to verify the model's biofidelity. This was done using as a reference table-top test biomechanical data found in the literature [6]. The human body model bone stiffness values were tuned to match the real world occupant age.

Four occupant simulations were carried out. Firstly two occupant simulations with Hybrid III dummy models were done, for the driver and co-driver location. Afterwards analogous simulations with the THUMS were done. All the simulations were carried out with the same boundary conditions and environment. See Figs. 7 and 8.

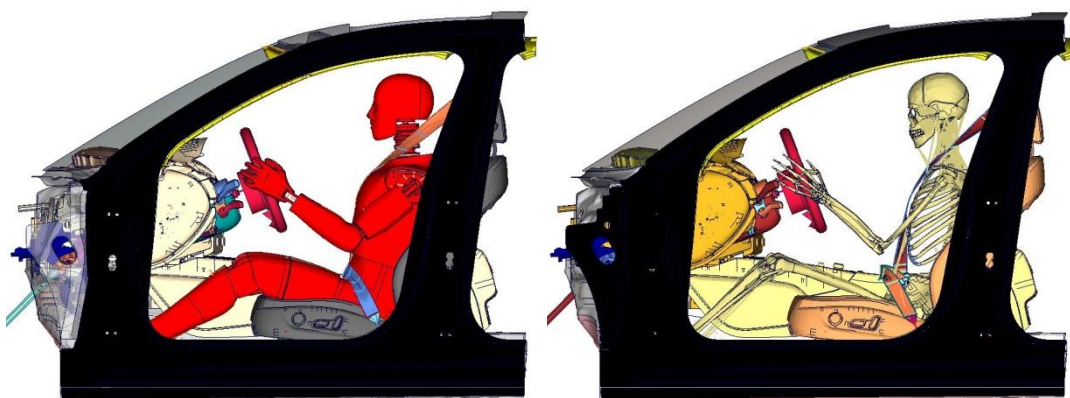


Figure 7. Left: HIII model on driver position. Right: THUMS on driver position

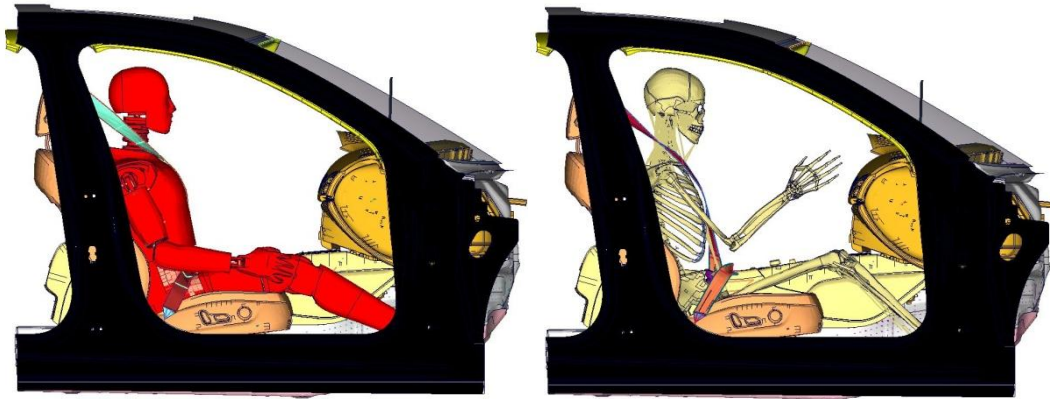


Figure 8. Left: HIII on co-driver position. Right: THUMS on co-driver position

RESULTS

The complete accident reconstruction process explained in this study was done in order to accomplish a comparative analysis between the Hybrid III model and THUMS results. Is the THUMS able to predict the sternum fracture for the driver and co-driver cases correctly?. The analysis has been grouped in two comparison cases: Driver and Co-driver.

Comparison HIII model vs. THUMS: Driver case

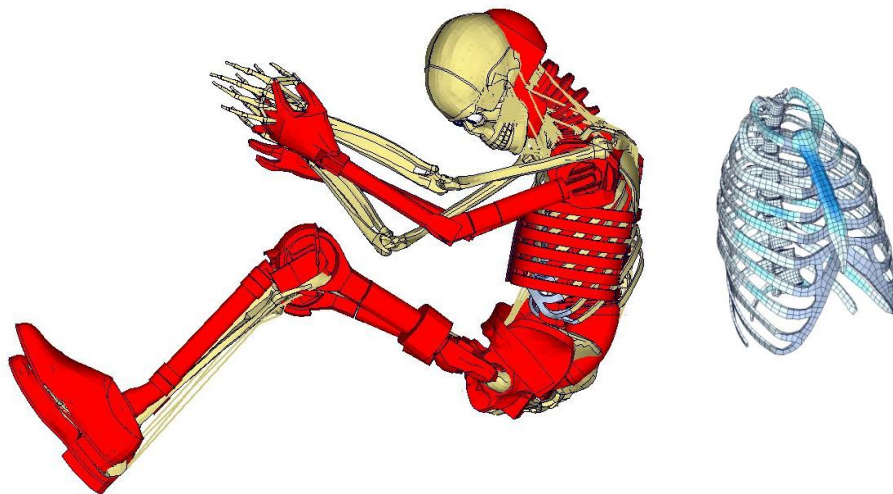


Figure 9. Hybrid III model (red) vs. THUMS (bone-colored) at maximum sternum (cortical bone) strain (Driver).

- The THUMS predicted higher rib cage rotation compared to the Hybrid III model. Fig. 10.
- The THUMS predicted no failure strain on the sternum. The Hybrid III model predicted a thoracic injury probability AIS 3 of 1,74%.
- The THUMS predicted higher head excursion compared to the Hybrid III model.

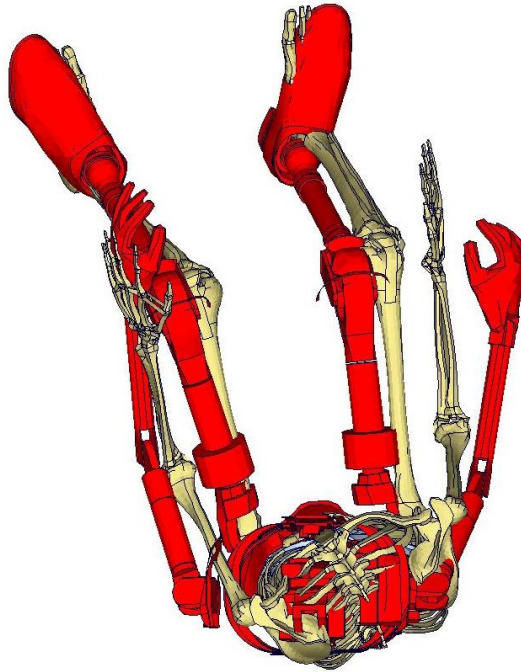


Figure 10. Hybrid III model (red) vs. THUMS (bone-colored):
Higher Rib Cage rotation in THUMS (Driver)

Comparison HIII model vs. THUMS: Co-driver case

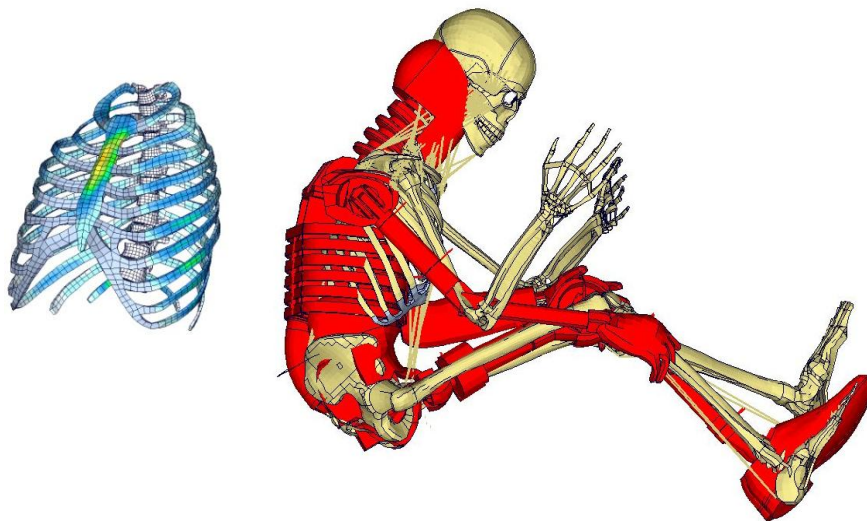


Figure 11. Hybrid III model (red) vs. THUMS (bone-colored)
at maximum sternum (cortical bone) strain (Co-driver).

- The THUMS predicted a higher chest excursion compared to the Hybrid III model
- The THUMS predicted a higher rib cage rotation compared to the Hybrid III model.
- The THUMS predicted a strain on the sternum cortical bone of 0,31% which correspond with a failure strain of cortical bone according to Kemper et al. [5]. The Hybrid III predicted an injury probability AIS 3 of 2,38%.
- The THUMS predicted higher head excursion compared to the Hybrid III model.

DISCUSSIONS

For the Hybrid III injury prediction should be noted that an AIS 2 injury curve would be a better prediction reference for moderate thoracic injury severity rather than the current AIS 3.

CONCLUSIONS

A real world frontal accident was reconstructed by means of detailed FE models and it was shown that the structural simulation is well predicting real world car deformation behavior and crash dynamics.

THUMS validation by means of table-top test simulations verified the model's biofidelity after the modification on the sternum and ribs material stiffness definitions. This modified model was found to have the capability to predict correctly thoracic injuries in medium severity crashes.

Biofidelity concerning rib cage rotation and thoracic deformation prediction seems to be higher on THUMS than on the HIII dummy model. The human-like thorax deformation under asymmetric loading, which is the loading case for most of the current restraint system configurations used in the automotive industry, cannot be seen on the Hybrid III model simulations results.

ACKNOWLEDGMENT

We would like to acknowledge the technical input, database filtering and PC-Cash simulations provided by Miklós Kiss, Thomas Schenk and Marcus Gerstenberger from the AARU team.

We would like to acknowledge the technical input, concerning the structural simulation provided by Adrian Langner.

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