Potential of Virtual Crash Simulation to Examine Crash Injury and Crash Safety

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Abstract: The objective of the study is to demonstrate the potential of virtual crash simulation to examine injury causation, injury risk and effectiveness of safety measures in different accident types. In particular, complex accident situations are considered, i.e. frontal impacts with occupant interaction and rollover crashes.

Two examples of severe frontal crashes are presented in which interaction of non belted rear seat passengers could have contributed to fatal injury. Crash dynamics of vehicles was analysed with PC-Crash® delivering vehicle motion and acceleration data needed as an input for MADYMO® simulations of occupant kinematics then performed. Occupant models used were 50 percentile male Hybrid III crash dummies. Dummy loadings in a non belted, but airbag exposed driver, and a belted driver without airbag, both impacted by unbelted rear occupants, are reported and related to injuries sustained in the real crashes. Furthermore, two standard rollover car crashes are presented: Sliding laterally into a kerb and sliding sideways into a gravel pit. Data of vehicle dynamics needed for MADYMO® simulations performed were measured in real full scale crash tests. Mathematical crash simulation was carried out in two ways: Using MADYMO® 50% Hybrid III models and MADYMO® 50% human models. Significant differences could be identified in the kinematics of dummy model and human model. This raises the question what model (human or dummy) could be best qualified to investigate crash safety.

In conclusion, virtual crash simulation is a valuable method to examine crash injury and crash safety. Better than the dummy model the human model seems to reflect realistic occupant kinematics. However, future investigations should focus on the improvement of occupant models with special emphasis on muscle activity (varying stiffness of limbs, trunk and neck, arm bracing), reflexes and (active?) voluntary movements of occupants.

Key Words: Virtual crash simulation, occupant kinematics, loading parameters, dummy model, human model, injury risk.

1 Crash simulations with passenger interaction

Recently, The Lancet published a Japanese investigation reporting that in car crashes the risk of death for front seat occupants is raised nearly fivefold by unbelted rear seat passengers. Almost 80% of the front seat fatalities could have been avoided, if seat belts would have been used on rear seats [1]. In accordance with accident study in the last two years a number of cases have been examined at the Munich University Institute for Legal Medicine in order to identify whether the fatal injuries of front seat occupants are caused by non-belted rear seat passengers. Two representative cases are presented.

1.1 Case No. 1:

Frontal car to car collision (cf. PC-Crash collision analysis Figure 1): Peugeot 405 (#1 left vehicle in Figure 1) v1 = 90 km/h, Taxi Mercedes E 220 (taxi #2) v2 = 65 km/h, Δv2 (taxi #2) = 75 km/h. Two adult passengers on rear seats in the taxi #2, unbelted. Unbelted taxi driver, 54 years old male, sustained fatal injury (critical thoracic and abdominal trauma). Driver's airbag activated.

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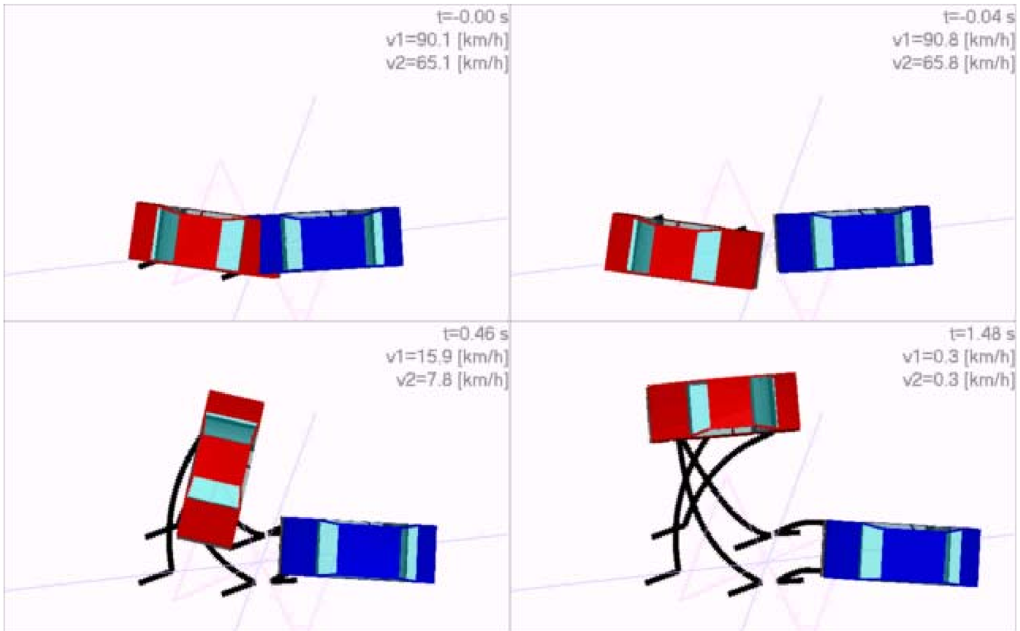


Figure 1: PC-Crash Collision Analysis Case No. 1

Based on PC-Crash collision analysis shown in Figure 1 MADYMO®-Simulations of occupant kinematics (Multi-Body-System 50% male Hybrid III Dummy Model [2]) were performed. Figure 2 illustrates two simulations: (1) Interaction of unbelted driver (airbag activated) and unbelted rear seat passenger representing the real crash situation (left column) and (2) driver's kinematics without that interaction in order to demonstrate the loading situation without impact of the rear seat passenger (right column).

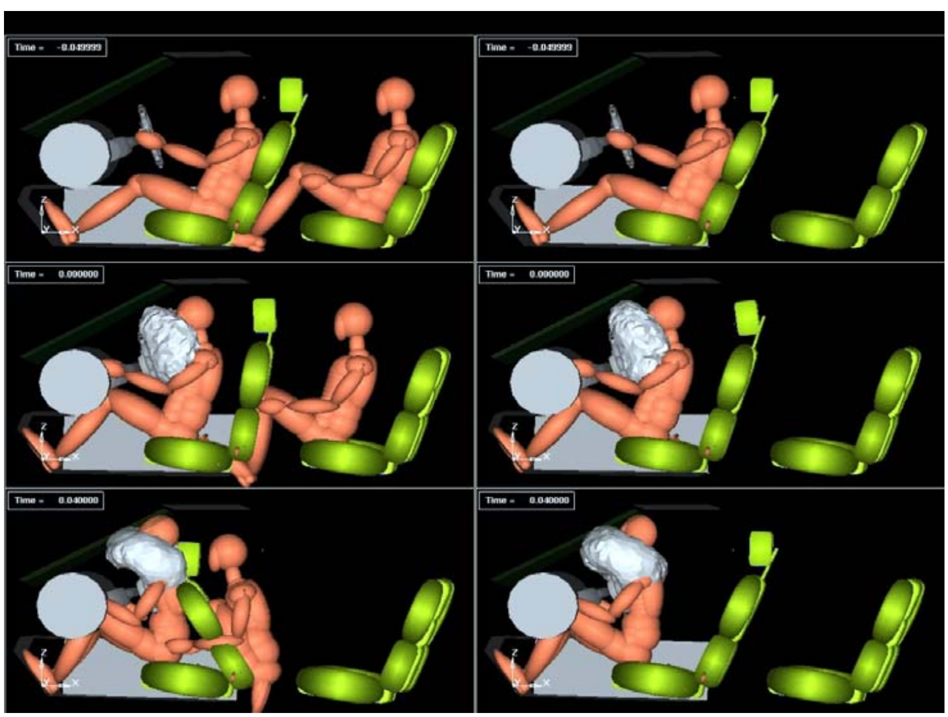


Figure 2: MADYMO®-Simulation of occupant kinematics (Dummy Model)

Thorax loading parameters of the driver are shown in Figure 3 and 4. The impact of the rear seat occupant causes additional chest loading indicated by a second acceleration peak at 0,05 s as high as the primary acceleration peak from the primary airbag/steering-wheel contact (750 m/s^2 or 75 g). Associated to this an extended chest deflection of about 7,5 cm is evident (cf. Figure 3).

This additional chest loading does not occur in the situation without an impact of the rear seat passenger. As shown in Figure 4 there is only one acceleration peak similar to that in Figure 3 and a much shorter deflection of the sternum. However, these loading parameters alone are so high to explain serious chest injury.

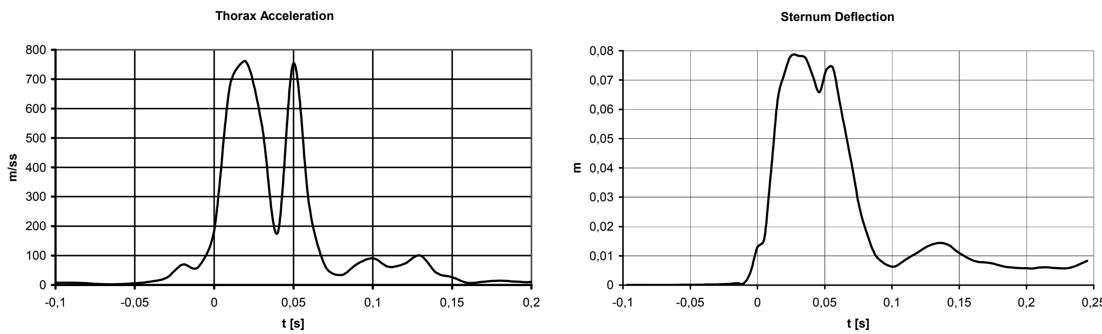


Figure 3: Loading Parameters Thorax (Impact of rear seat passenger)

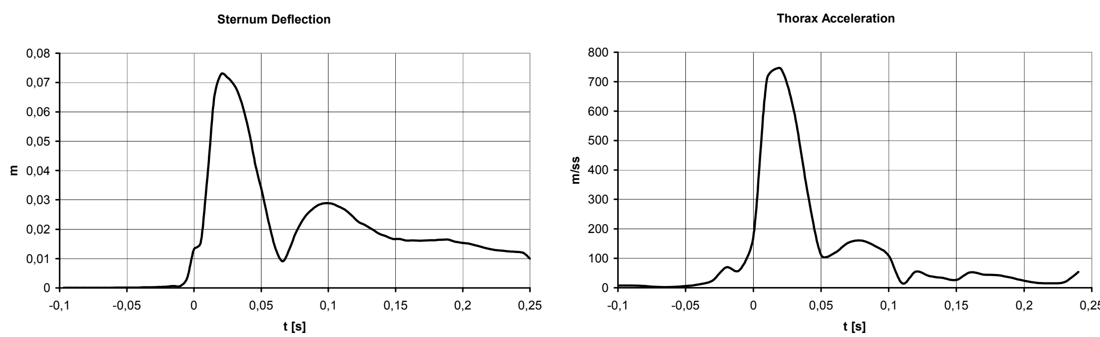


Figure 4: Loading Parameters Thorax (No impact of rear seat passenger)

1.2 Case No. 2:

Frontal car to car collision (cf. PC-Crash collision analysis Figure 5): VW Sharan (#1 left vehicle in Figure 1) v1 = 53 km/h, Mercedes 190 D (car #2) v2 = 65 km/h, Δv2 (car #2) = 68 km/h. Two adult passengers on rear seats in car #2, unbelted. Belted driver, 21 years old male, sustained fatal injury (aortic rupture). Case vehicle not equipped with airbags.

PC-Crash collision analysis is shown in Figure 5 needed to provide input data for MADYMO®-Simulations of occupant kinematics (Multi-Body-System Hybrid III 50% male Dummy Model [2]). Again, two simulations are presented in Figure 6: (1) Interaction of belted driver (no airbag) and unbelted rear seat passenger representing the real crash situation (left column) and (2) driver's kinematics without that interaction in order to demonstrate the loading situation without impact of the rear seat passenger (right column).

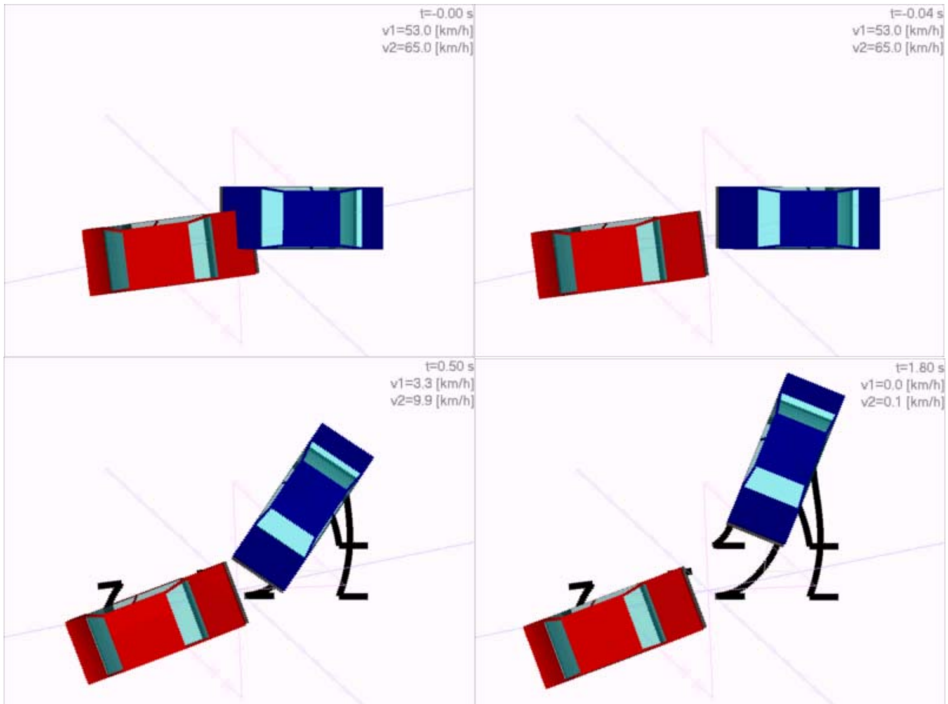


Figure 5: PC-Crash Collision Analysis Case No. 2

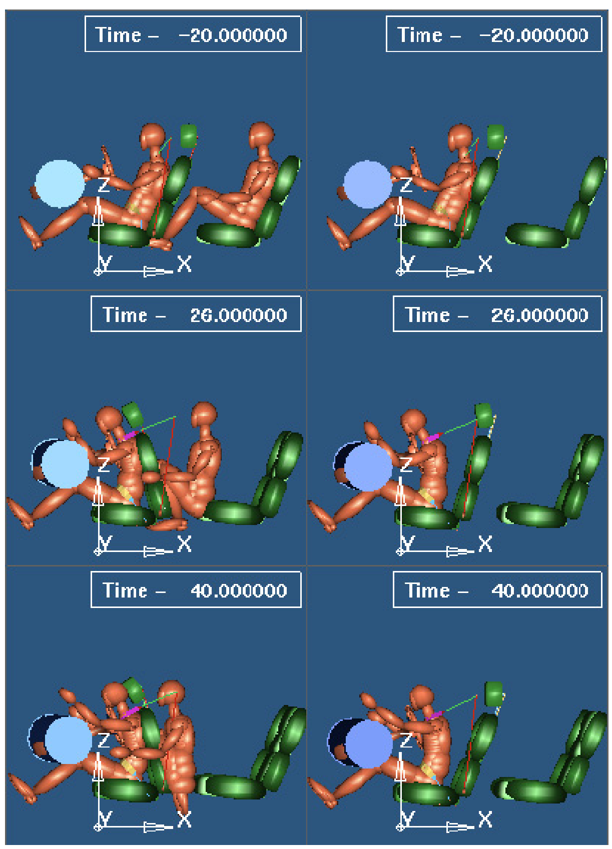
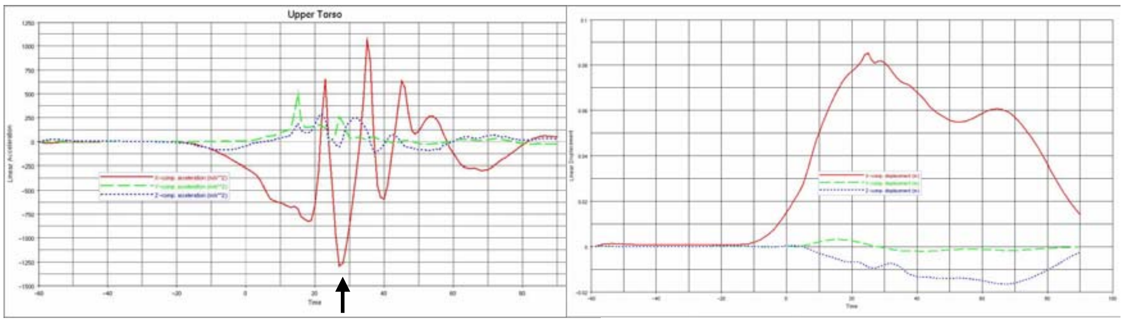


Figure 6: MADYMO®-Simulation of occupant kinematics (Dummy Model)

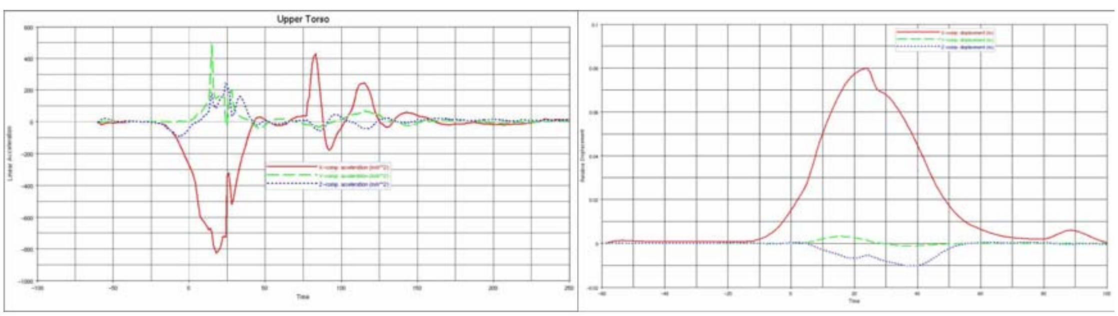
Loading parameters of the driver's thorax are presented in Figures 7 and 8. The impact of the rear seat occupant causes additional chest loading for the belted driver indicated by a second acceleration peak at 28 ms considerably higher as the primary acceleration peak from the airbag/steering-wheel contact (1250 m/s^2 or 125 g compared to 800 m/s^2 or 80 g). Associated to this an extended chest deflection with a maximum of about 8.5 cm is evident (cf. Figure 7).



Thorax Acceleration Sternum Deflection

Figure 7: Loading Parameters Thorax (Impact of rear seat passenger)

This additional loading does not occur without an impact of the rear seat passenger. As shown in Figure 8, there is only one acceleration maximum similar to that in Figure 7 and a much shorter deflection of the sternum of 8 cm. However, these loading parameters alone are so high to explain serious chest injury.



Thorax Acceleration Sternum Deflection

Figure 8: Loading Parameters Thorax (No impact of rear seat passenger)

In both cases presented the unbelted rear seat passengers cause significant additional thoracic and abdominal loading for front seat occupants responsible for the extensive injuries sustained. Seat belts used on rear seats could have reduced injury severity and possibly avoided fatal outcome.

2 Rollover crash simulation with dummy and human models

In road traffic rollover crashes occur not as frequent as frontal, lateral and rear-end collisions, but are associated with a high injury risk for occupants. Specific for rollover crash is a complex vehicle motion, a long duration and relative low linear accelerations. Up to now, no particular rollover crash test dummy has been designed, so that only available standard dummies can be used in real world crash tests to investigate occupant kinematics. Virtual crash tests have the potential not only to use dummy models validated in real word crashes, but also human models developed are more and more in recent years [3,4,5].

To demonstrate the potential of virtual crash simulations the kinematics of a belted driver was examined for two different rollover scenarios: Sliding laterally against a curb and sliding sideways into a gravel pit. The speed contacting the curbstone and the gravel pit is 32.1 km/h each. Both scenarios were simulated using a dummy occupant model and a human occupant model seated in a FE- modelled compartment consisting of bottom, seats, belts, doors, roof, windows, steering wheel, knee bolster and the instrument panel (cf. Figure 9). Force-deformation characteristics of the interior acquired by component tests was applied in the simulation model to calculate the contact forces.

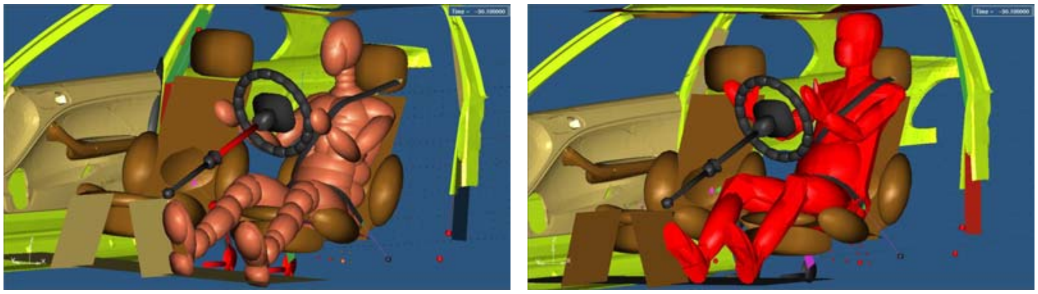


Fig. 9: Dummy and human occupant model in driving position.

2.1 Sliding laterally against a curb

Figure 10 shows the vehicle kinematics of the first phase of the rollover simulation "sliding laterally against a curb".

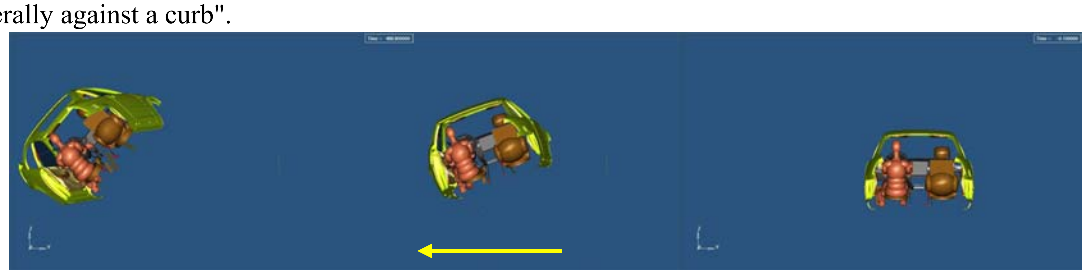


Figure 10: Vehicle kinematics: "sliding against a curb" from right to left

Occupant kinematics for this rollover crash test configuration was simulated and analysed using a dummy occupant model (MADYMO 50% Hybrid III [2]) and a human occupant model (MADYMO 50% human male [2]) (c.f. Fig. 11)

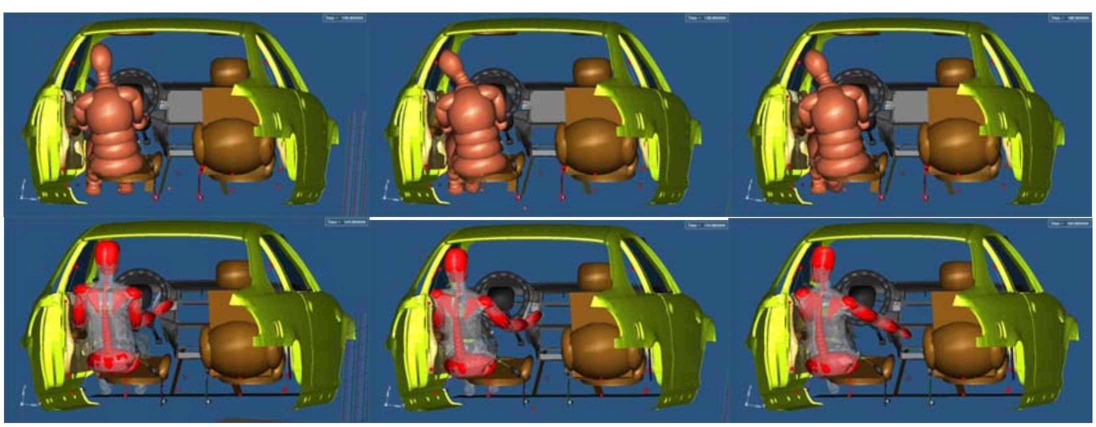


Figure 11: Significant occupant positions (dummy model above human model)

Differences in the kinematics of the human model and the dummy model are obvious: The human model slides sideways to the door, the shoulder is contacting the door and the head is oriented parallel to the window until the head contacts the side window. The cervical spine is only slightly bent. In contrast to the human model kinematics the dummy is slightly tilted towards the door and the head is strongly tilted towards the side window. This results in a strongly bent cervical spine.

Despite of these differences in the kinematics the head of the human model contacts the side window only 9 ms prior to the head of the dummy model (cf. Table 1).

Table 1: Time of head to side window contact for the simulation of "sliding against a curb"

	Time of head to side window contact
Human model	126 ms
Dummy model	135 ms

The reason for the tilting of the dummy model is its stiff "soft tissues" and its stiff torso. When the dummy is accelerated sideways the hip is immediately constrained by the lap belt because there is very little compliance of the body parts of the dummy. So the translational motion of the dummy model is limited and a torque around the hip is induced. The induced rotation around the hip is constrained by the lap belt too so the rotation movement is shifted towards the lumbar and thoracic region of the spine. This part of the dummy is less flexible than in the human model (and in real humans), there is no human like spine, i. e. no vertebras are modelled, and so there is only little flexibility in this region. This stiffness of the dummy torso and shoulder in combination with the flexible cervical spine results in a whip-effect of the head, i. e. the head is accelerated with respect to the upper body.

The difference between the dummy and human model kinematics caused by different body flexibility and pliability is well documented in Figure 7. This differences have an influence on the injury mechanics and therefore are important when looking for optimised restraint systems and safety design.

2.2 Sliding into a gravel pit

Figure 12 shows the vehicle kinematics of the first phase of the rollover simulation "sliding into a gravel pit". The vehicle kinematics of this rollover type shows in principle the same tilting movement as of "sliding against a curb". But this particular vehicle kinematics has a longer lateral deceleration phase when the vehicle is sliding in the gravel pit, the tilt starts later than in the "sliding against a curb".

Figure 12: Vehicle kinematics: "sliding into a gravel pit " from right to left

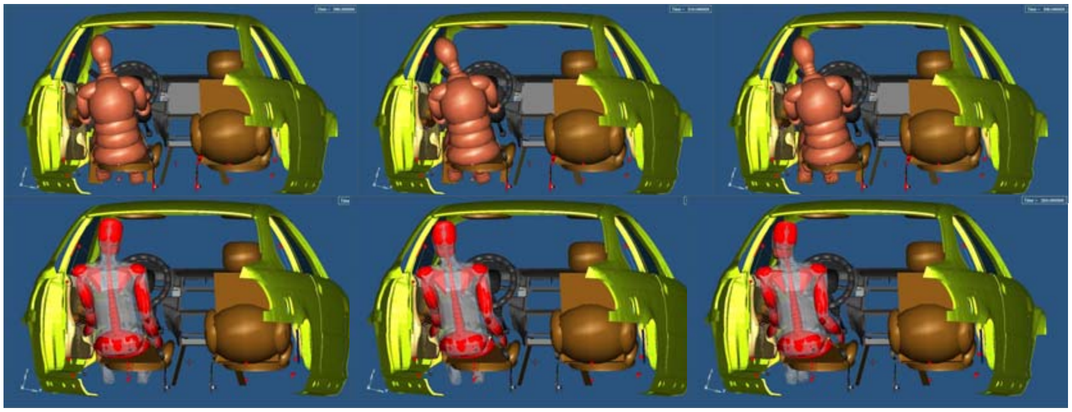


Figure 13: Significant occupant positions (dummy model above human model)

Figure 13 shows in principle the same differences between the kinematics of the dummy model and the human model. But the head of the dummy model hits the side window 13 ms earlier than the human model (cf. Table 2). This is in contrast to the findings in the "sliding against a curb" rollover where the human model hit the window earlier than the dummy model. Therefore, that differences between the dummy and human model kinematics can not be transferred from one accident scenario to another. The movement of a multibody system is a very complex process and depends strongly on the used model.

Table 2: Time of head to side window contact for the simulation of "sliding into a gravel pit"

	Time of head to side window contact
Human model	313 ms
Dummy model	300 ms

3 Summary and Conclusion

The examples presented demonstrate that virtual crash simulation is a valuable method to examine occupant kinematics, crash injury and crash safety. In particular, complex crash scenarios, such as occupant interaction and rollover crashes, are qualified to apply virtual simulation, because of the option of input parameter variation, e.g. impacts speeds, belt usage etc., easier and cheaper than in real crash tests.

The results of virtual crash simulations are sensitive to the models used. The well known problem of often unsatisfactory biofidelity of crash test dummies and inevitably of dummy models can obviously be improved by using human model. However, current human models are not perfect, either. In particular, crash scenarios with accelerations not too high and taking relatively long time, such as the presented rollover crashes, require not only a passive model to represent the human, but also reflex reactions and even voluntary movements. Therefore, further model refinements that would allow muscle contraction and relating changes are need to obtain results better comparable to real world situations. Ongoing research projects, e.g. HUMOS II, address the development of advanced human models which hopefully could be available for improved virtual simulations in the future.

4 References

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