The new multibody model in PC-Crash – Simulation and validation of single track vehicles

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Abstract

This paper presents the new multibody model in PC-Crash. Especially the new joint types are discussed (hinge joints, translatoric joints etc.). With these additional joints single track vehicles can be simulated at a high level of detail, gyroscopic effects due to spinning wheels and self-steering as well as suspension travel are taken into account.

The new single track vehicle model shows to be able to reproduce the specific behavior of movement of single track vehicles. Many different factors have to be taken into account to be able to model these effects in the simulation. These different factors are also discussed in the paper.

Zusammenfassung

In diesem Artikel wird das neue Mehrkörpersimulationsmodell in PC-Crash vorgestellt. Auf die neuen Gelenkstypen (Scharniergelenke, translatorische Gelenke u.a.) wird im Speziellen eingegangen. Mit Hilfe dieser neuen Gelenkstypen können Einspurfahrzeuge sehr detailgetreu simuliert werden. Kreiselmomente durch drehenden Räder und das resultierende Eigenlenkverhalten sowie die Einfederung können berücksichtigt werden.

Es wird gezeigt, dass das neue Einspurmehrkörpermodell das spezifische Verhalten von Einspurfahrzeugen sehr gut nachbilden kann. Viele verschiedene Faktoren beeinflussen das Verhalten und müssen daher berücksichtigt werden. Die verschiedenen Einflussfaktoren werden auch in diesem Artikel angesprochen.

Introduction

The simulation of single track vehicles is a very complicated task as many effects like gyroscopic effects due to spinning wheels, self-steering and suspension movement have to be taken into account to be able to reproduce all the different effects, which influence the movement of the motorcycle or bicycle.

This paper presents the calculation models used in the first part. In the second part of the paper a selected number of crash tests is used for the validation of the model, the differences between simulation and crash tests are discussed.

As a motorcycle or single track vehicle consists of several different parts like the wheels, suspension, steering, frame, engine and others, which also move relative to each other, the use of multibody systems is a very common approach. For the rider and pillion rider additional multibody systems have to be added.

In a motorcycle accident different phases of movement exist, where the interaction between the motorcycle rider(s) and the motorcycle and other objects differ. The following phases can be identified:

- Pre impact phase: the motorcycle and rider(s) have a common movement
- Impact phase: significant contact interaction between the motorcycle and another vehicle, the riders and the riders with the other vehicle exist
- Post impact phase: the motorcycle and the riders may or may not have separate

paths of movement, the main contact interaction occurs with the road

Model description

To simulate the specific behavior of single track vehicles the following effects have to be taken into account:

- Spinning wheels: spinning wheels and their gyroscopic effects contribute significantly to the motorcycle self-stability. Spinning wheels also effect the movement of a motorcycle once it is sliding on the side
- Suspension: Front and rear suspension travel of the motorcycle changes during braking, contact and post impact movement depending on the loading situation
- Steering: The rotational degree of freedom along the steering axis has to be taken into account for the simulation during movement and contact. The steering geometry (caster angle) significantly influences self-stability of the motorcycle. After a collision, even if the driver left the motorcycle, in some cases the motorcycle can move more or less stable for a relatively long distance.
- Braking and acceleration of individual wheels: Depending on whether the front wheel or rear wheel is over braked the resulting movement and stability of the motorcycle is different.
- Constraint limits: The degrees of freedom in the joints of a motorcycle are constrained (the maximum steering angle is limited as well as the suspension travel)

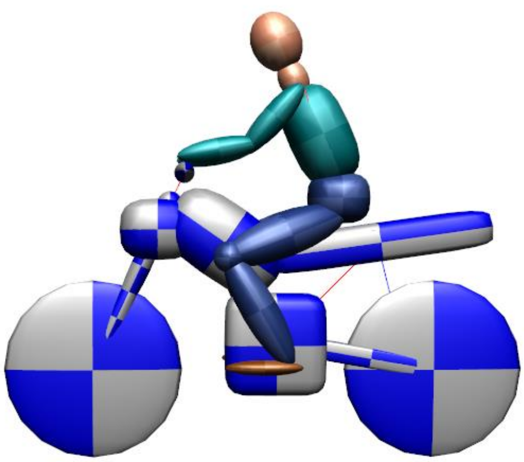


Figure 1: Motorcycle model with rider

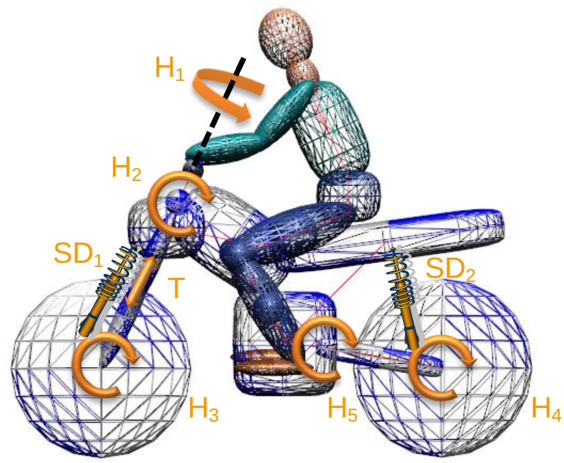


Figure 2: Joint definitions used in the motorcycle model

All specific effects mentioned above can be simulated using the multibody model in PC-Crash 10.0. Additional joint types have been added using a submatrix pattern of the Jacobian matrix using generalized velocities. The kinematic constraint for joint l between body i and j can be written as follows: [1], [2], [3]

$$J_l \cdot u_l = 0 \qquad (1)$$

where

J_l Jacobian matrix for joint l

u_l generalized velocities for joint l

$$\begin{bmatrix} J^{i}_{lin} & J^{i}_{ang} & J^{j}_{lin} & J^{j}_{ang} \end{bmatrix} \cdot \begin{bmatrix} v_i \\ \omega_i \\ v_j \\ \omega_j \end{bmatrix} = 0 \qquad (2)$$

where

J^{i}_{lin}, J^{j}_{lin} Jacobian submatrices for linear velocity terms for body i and j

J^{i}_{ang}, J^{j}_{ang} Jacobian submatrices for angular velocity terms for body i and j

v_i, v_j linear joint velocities for body i and j

ω_i, ω_j angular joint velocities for body i and j

Depending on the joint type to model the Jacobian submatrices J_{lin} and J_{ang} differ. To simulate a single track vehicle the following joint types have been used (Figure 2)

- Fixed joint: 0 degrees of freedom in the joint to connect frame parts of the motorcycle, which do not move relative to each other (e.g. frame and engine)

- Hinge joints: 1 rotational degree of freedom, used for the wheel joints (H_3, H_4), the rear wing (H_5) and the steering joint (H_1). To model the deformation of the front fork and additional joint (H_2) with a high friction torque and joint limits is used
- Translational joint: 1 translatoric degree of freedom, used for the front suspension (T)

In addition the following elements are part of the model

- Spring damper elements for the front and rear suspension (SD_1, SD_2)
- Joint limits to limit the movement of the suspension and the rotation angle of the steering bar
- Joint friction torque and friction force to brake or accelerate the wheels

Validation

In the validation part of this paper the motorcycle model described above is analyzed with respect to being able to reproduce the specific behavior of single track vehicles in driving maneuvers and during a collision event.

In all the simulations shown below there is no steering input from the driver of the motorcycle, steering is generated by the motorcycle itself.

Driving in a curve (50 km/h)

In this simulation the motorcycle and rider start at an upright position and a velocity of 50 km/h (Figure 4). The driver then leans to the right, which introduces a self-steering behavior of the motorcycle. At equilibrium the motorcycle and rider will drive along a constant turning circle (Figure 3). As the velocity of the motorcycle is reducing due to the steering, at a certain point of the simulation (in this example approximately when the full circle is finished) the equilibrium condition is not fulfilled anymore, and the motorcycle will fall to one side.

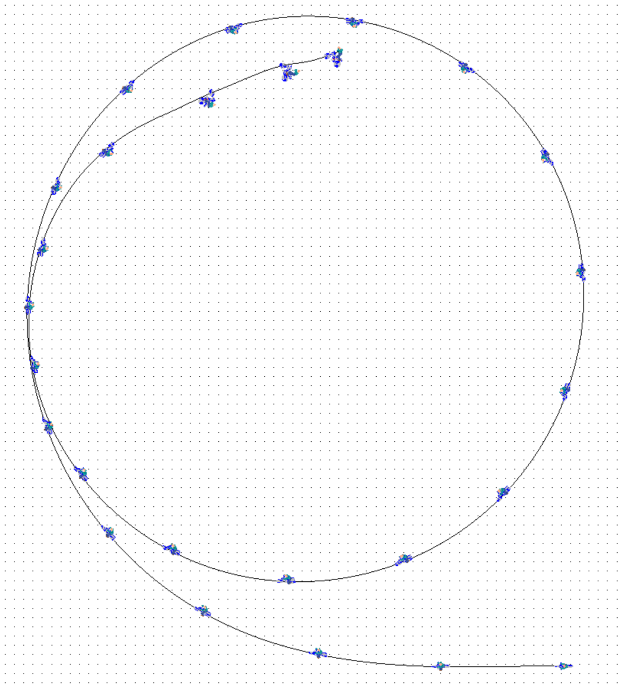


Figure 3: Motorcycle steering due to load shift

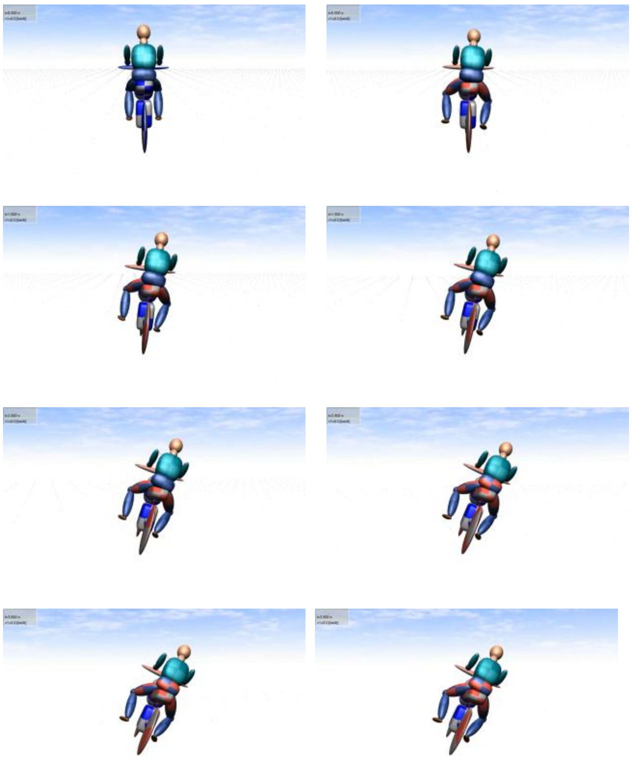


Figure 4: Motorcycle steering due to load shift (0.5 s time increment between the pictures up to the stationary condition)

Braking

A braking torque can be applied to the individual wheels of the motorcycle. The difference between over braking the front or rear wheel is analyzed. The initial speed of the motorcycle is 50 km/h for all simulations, the braking torque is applied at the start of the simulation. The simulation shows that blocking the front wheel almost immediately leads to instability of the motorcycle as the gyroscopic effects of the front wheel diminish and the motorcycle cannot stabilize anymore. In contrast if the rear wheel is blocked the motorcycle stays stable for a much longer time. (Figure 5)

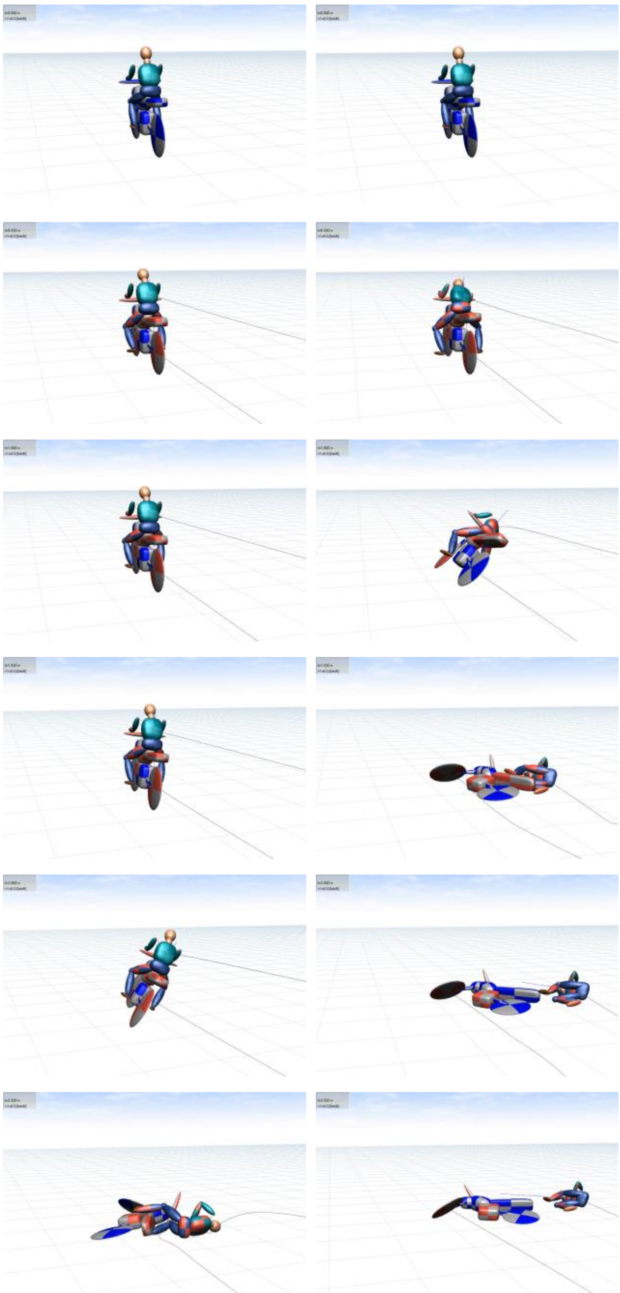


Figure 5: Rear wheel braking (left) and front wheel braking (right) – 0.5 s time increment

„Stoppy“

In severe braking maneuvers a motorcycle might also flip over, which is also called “Stoppy”. If the brake is not released quickly enough, this might easily leed to an accident as this movement is highly unstable. Depending on the deceleration, center of gravity height of the motorcycle and rider, suspension and load shift the rear wheel lifts off during braking and a significant pitch movement is generated (Figure 6). The initial speed of the motorcycle for this simulation is 50 km/h.

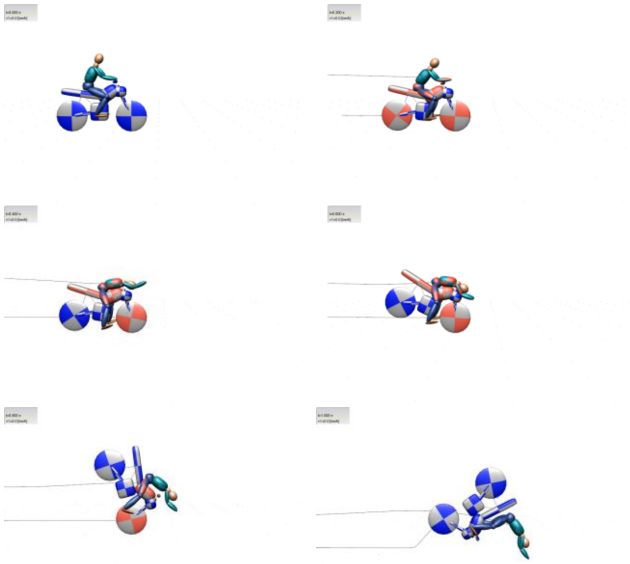
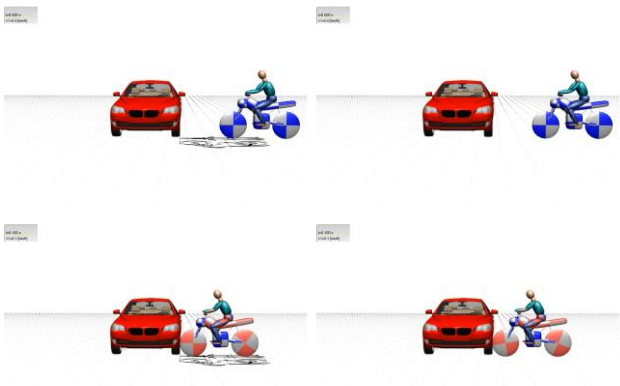


Figure 6: Simulation of a “stoppy”, front wheel severly braked, 0.2 s time increment

Typical collision

This simulation shows a typical motorcycle collision at the left front of a car. The velocity of the motorcycle in this simulation is 40 km/h, the velocity of the car is 0 km/h. The motorcycle stops almost at the point of collision and the motorcycle rider moves across the front hood of the vehicle and is thrown further for a certain distance. In Figure 7 the difference between using a front fork deformation joint is shown. The front fork deformation reduces the amount of elasticity for the motorcycle in the collision, for this reason the rotation of the motorcycle is not as high as in the case without front fork deformation, which can be seen in the final position of the motorcycle also (Figure 8).



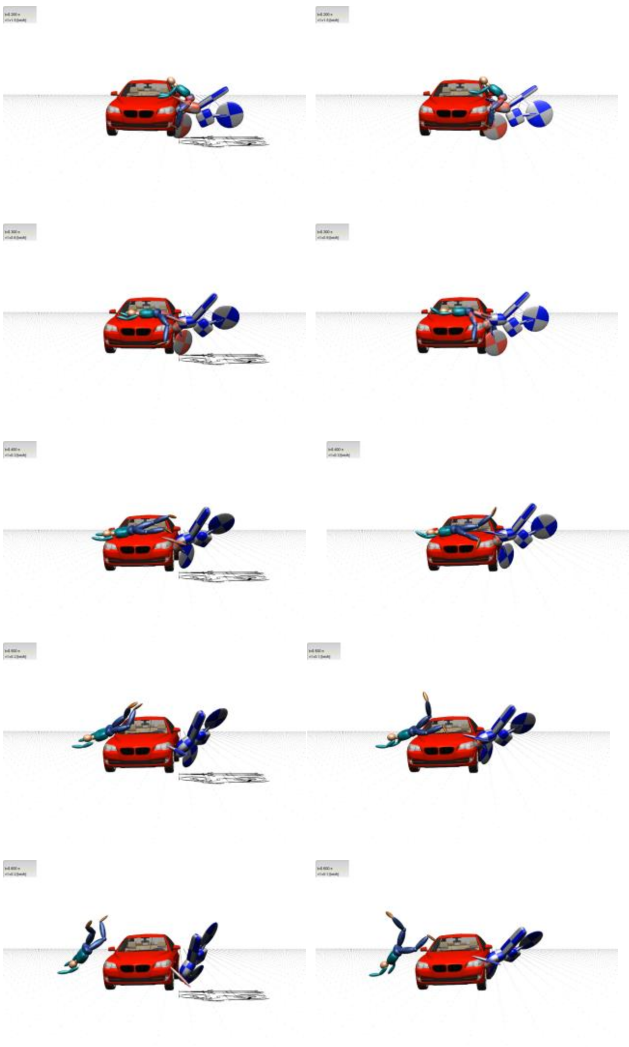


Figure 7: Motorcycle to vehicle impact, model without front fork deformation (left) and front fork deformation joint, 0.1 s time increment

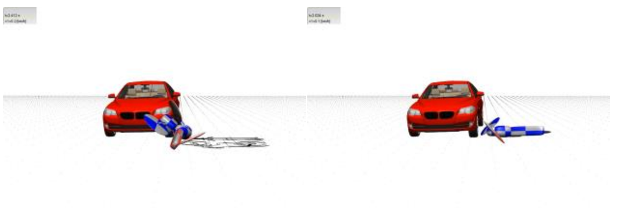


Figure 8: Final positions

Sliding collision AREC2009 V08

In this example a crash tests performed at the AREC conference in 2009 was used, where a motorcycle hit a vehicle (Ford Escort) at an angle of approx. 40 deg. The impact speed of the motorcycle in this test was 47.1 km/h, the velocity of the car was 25.4 km/h. In the course of the collision the motorcycle rider left the motorcycle, the motorcycle itself was diverted but stayed more or less stable for some time after the collision before it fell over. (Figure 9)

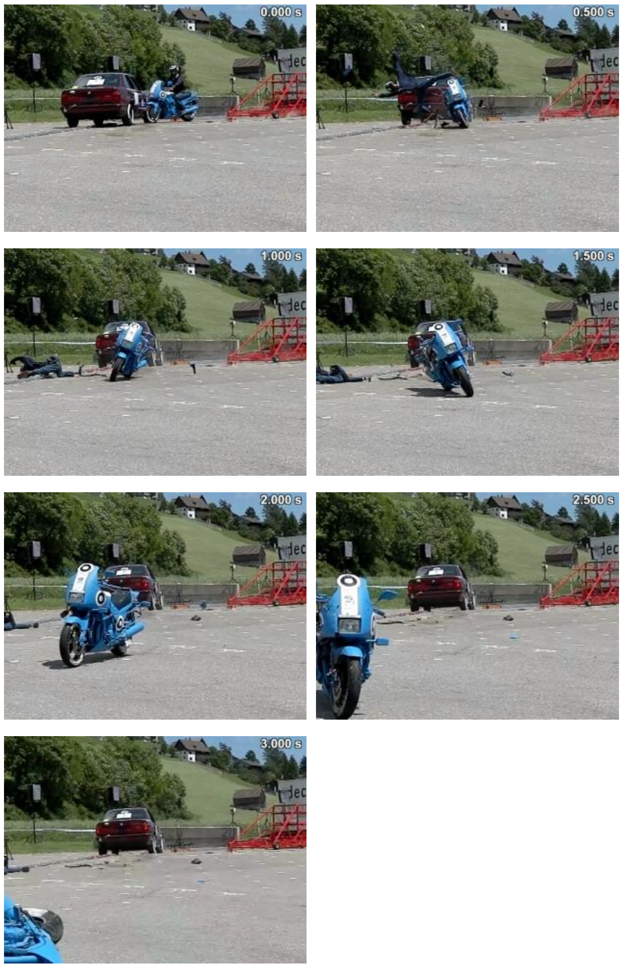
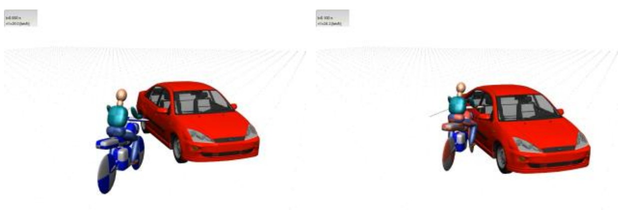


Figure 9: AREC 2009 Test 08, 0.1 s time increment [4]

There are many factors, which influence the movement of the motorcycle and rider in general (like the contact surface, friction on the road and contact area, restitution, seating position of the rider, braking of the wheels, road surface etc.). For this reason the type of movement of the motorcycle will change significantly if the starting conditions are changed slightly (the motorcycle for example might just fall to one side without moving a long distance). This applies for reproducing the crash test but also for the simulation).

However, the simulation in Figure 10 and Figure 11 show that the model can also reproduce this specific behavior.



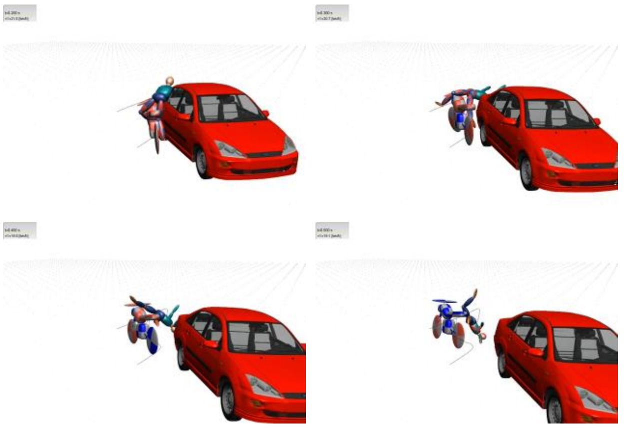


Figure 10: Simulation of the sliding collision, 0.1 s time increment

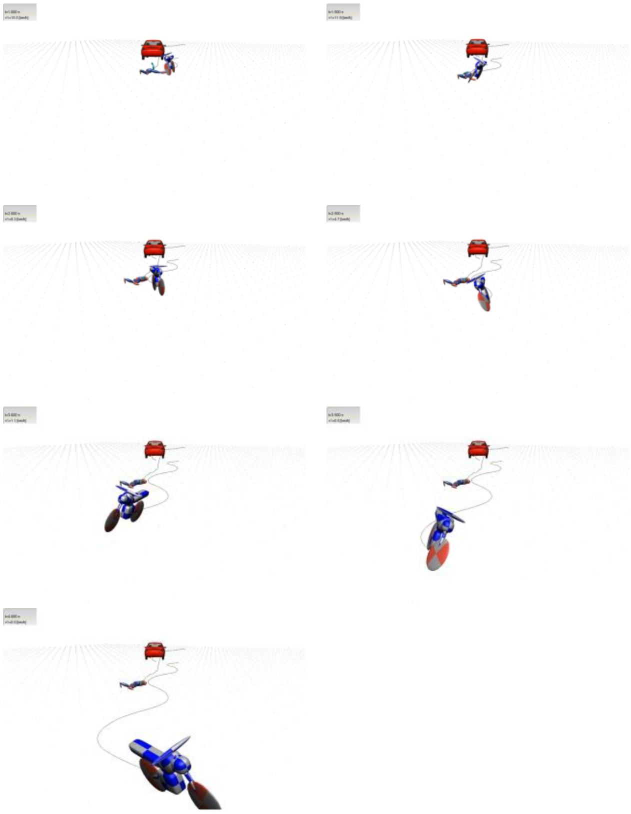


Figure 11: Post impact movement of motorcycle and rider, 0.5 s time increment

Summary/Outlook

The simulations show that the motorcycle model presented in this paper can reproduce the specific behavior of single track vehicles especially motorcycles very well. Adoptions to the model (e.g. changing the geometry, weights etc.) can be done easily, which will lead to a different dynamic behavior depending on the type of motorcycle modelled. Further validation work should be performed.

The introduction of an additional joint to model the front fork deformation reduced the amount of elasticity for the motorcycle leading to more realistic results in the impact calculation. This also generates a better starting condition for the rider's flight phase. The calculation of the deformation behavior of the motorcycle using multibody systems is, however, limited. If the deformation behavior is of interested Finite Element calculation can be used in PC-Crash also using the model provided by [7].

Figure 12: Simulation of a wall impact of the Finite Element motorcycle model presented in [8]. Calculation performed in PC-Crash 10.0.

References

[1] Moser A., Steffan H., Kasanický G., The Pedestrian Model in PC-Crash - The Introduction of a Multi Body System and its Validation, SAE 1999-01-0445, SAE Technical Paper No. 1999-01-0445 Warrendale PA 1999

[2] Erleben K., Sporring J., Henriksen K., Dohlmann H., Physics-Based Animation, Charles River Media, Inc. 2005

[3] Moser A., Hoschopf H., Steffan H., Kasanický G., Validation of the PC-Crash pedestrian model, SAE Technical Paper No. 2000-01-0847, Warrendale PA 2000

[4] AREC – Accident reconstruction conference group, www.arecgroup.info

[5] NCAC - National Crash Analysis Center, 45085 University Drive, Ashburn, VA 20147, www.ncac.gwu.edu

[6] PC-Crash 10.0 operating and technical manual, DSD Linz, Austria

[7] Senad Omerović, Faculty of Mechanical Engineering, University of Ljubljana (www.fs.uni-lj.si)

[8] Use of computer simulation in motorcycle traffic accidents analysis, Senad Omerović, dr. Simon Krašna, Ana Trajkovski, prof. dr. Ivan Prebil University of Ljubljana, Proceedings of the 22nd EVU Annual Contress Firenze 2013

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