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Effect of tire camber on vehicle dynamic simulation for extreme cornering

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Vehicle behaviors under extreme cornering are complex events that might result in rollover accidents. Simulations have been extensively used in the auto industry to protect vehicles from such accidents. Predictive capability of simulation relies on how accurate the math-based model represents the vehicle and its operating condition. Camber effects of tire are studied in this paper to promote the accuracy of simulation. First, a tire model with simplified camber effect is introduced, and the comparison between the model results and test data is shown. Then, a more precise model that includes camber effects on cornering stiffness are friction coefficient is presented. The comparison between these model results and test data is also given. In addition, the camber effects on tire overturning moment and loaded radius are studied. Finally, vehicle fishhook simulation with different tire models is conducted to further investigate the effect of tire camber on vehicle dynamics.

Keywords: Vehicle dynamics; Tire model; Camber effect; Rollover; Simulation

1. Description of tire test

Tire tests for P235/60R17 were conducted and the operating conditions and specifics include:

- pressure: 262 kPa;
- rim width: 7 in;
- test speed: 40 kph;
- slip angle (in degrees): sweep −25 to −25;
- camber angle (in degrees): 0, ±2, ±4, ±6, ±8, ±10, ±12;
- normal loads (in kN): 1.6, 4.9, 8.2, 11.5, 14.8,18.1, 21.4, 24.8.

Forces (F_x, F_y, F_z), moments (M_x, M_y, M_z) and loaded radius (R_l) were measured as average values at steady state.

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2. Camber effect on tire lateral force

In this paper, UniTire model, developed by Prof. Konghui Guo of Jilin University, is used to model the lateral force [1, 2]. The outline of the UniTire model for lateral slip combined with camber properties includes the following equations:

$$F_y = \operatorname{sgn}(S_y) \cdot \bar{F} \cdot \mu_y \cdot F_z \tag{1}$$

$$\bar{F} = 1 - \exp\left(-\phi - E_1\phi^2 - \left(E_1^2 + \frac{1}{12}\right)\phi^3\right) \tag{2}$$

$$\phi = \left|\frac{K_y \cdot S_y}{\mu_{y0} \cdot F_z}\right| \tag{3}$$

$$S_y = -\left(\tan\alpha + \sin\gamma \cdot \frac{K_{y\gamma}}{K_y}\right) \tag{4}$$

$$\mu_y = \mu_{ys} + (\mu_{y0} - \mu_{ys}) \cdot \exp\left\{-\mu_{yh}^2 \cdot \log^2\left[\left|\frac{V_{sy}}{V_{sym}}\right| + \exp\left(-\left|\frac{V_{sy}}{V_{sym}}\right|\right)\right]\right\} \tag{5}$$

$$V_{sy} = V \cdot \cos(\alpha) \cdot S_y \tag{6}$$

In these equations, α, γ and F_z are input quantities, α the slip angle, γ the camber angle and F_z the vertical load. F_y is the tire lateral force, μ_y the dynamic lateral friction coefficient determined by lateral slip velocity V_{sy}, μ_{y0} the tire static friction coefficient at $V_{sy} = 0$ and μ_{ys} the tire slip friction coefficient at $V_{sy} = \infty$. $\bar{F}$ is the non-dimensional lateral force, ϕ the normalized slip ratio, S_y the slip ratio due to slip angle and camber angle, $K_{y\gamma}$ the camber force stiffness, K_y the cornering stiffness. E_1, K_y, $K_{y\gamma}$, μ_{y0}, μ_{ys}, μ_{yh} and V_{sym} are the UniTire model parameters, which can be expressed by certain fitting functions of vertical load and/or camber angle.

2.1 *UniTire model with simplified camber effect*

In most cases, camber slip is simply considered as an equivalent lateral slip input of tire model, and the camber effect on cornering stiffness and friction coefficient is neglected. The comparisons between simulation results of this simple model and test data are shown in figures 1 and 2. It was observed that the simplified tire model gives obviously larger predictive lateral forces under high vertical load.

2.2 *UniTire model of camber effect*

Considering camber effect on cornering stiffness and friction coefficient, the new version of UniTire–UniTire 2.0 is presented [1, 2]. The comparisons between model results and test data are shown in figures 3–6. It can be seen that the simulation results of UniTire 2.0 have a better agreement with the test data.

3. Camber effect on tire overturning moment and loaded radius

Tire overturning moment is also important in the investigation of vehicle rollover [3]. In addition, the difference in the loaded radius of left and right tires yields tire roll angle, which also affects the vehicle roll behaviors [4].

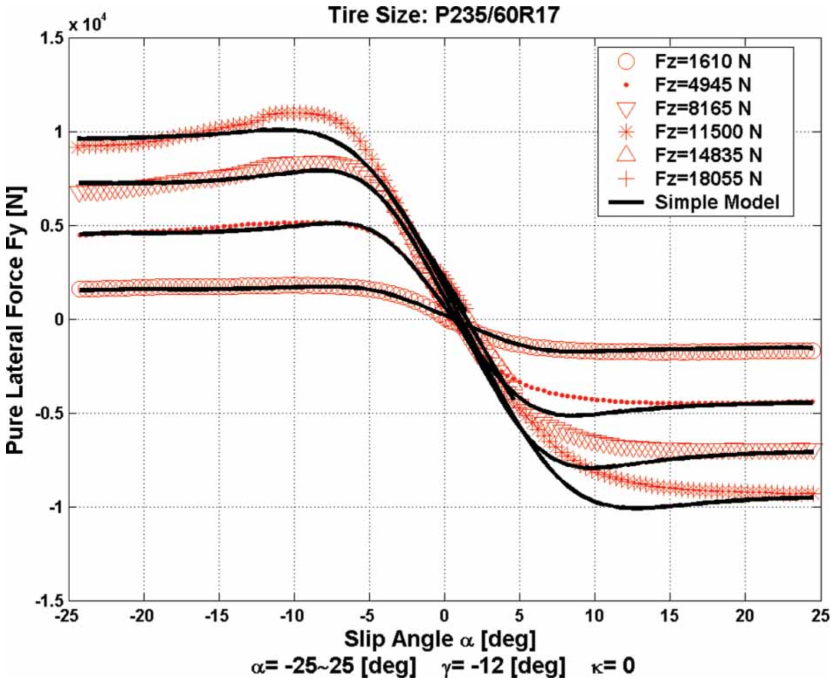

Figure 1. Comparison of simple model with test for camber = −12°.

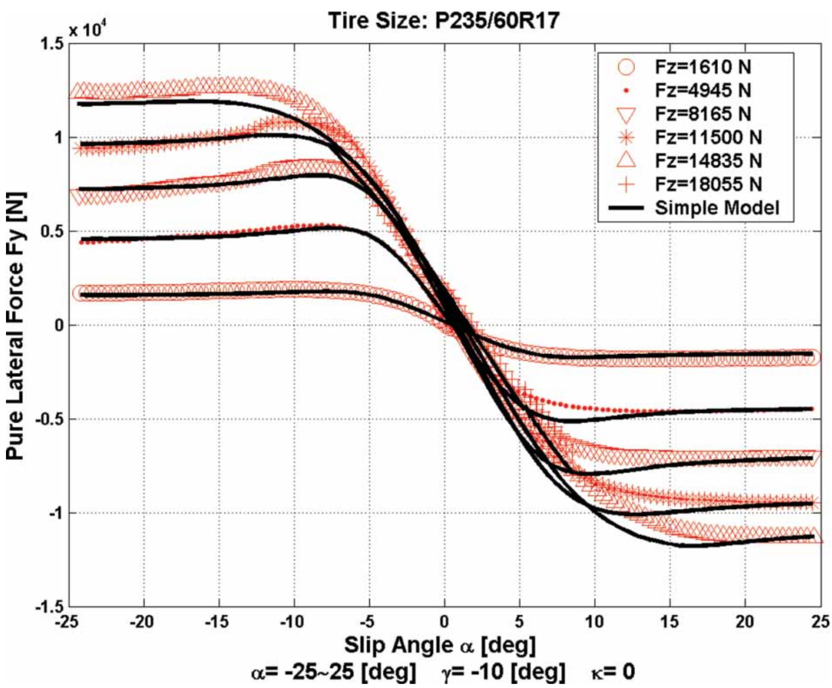

Figure 2. Comparison of simple model with test for camber = −10°.

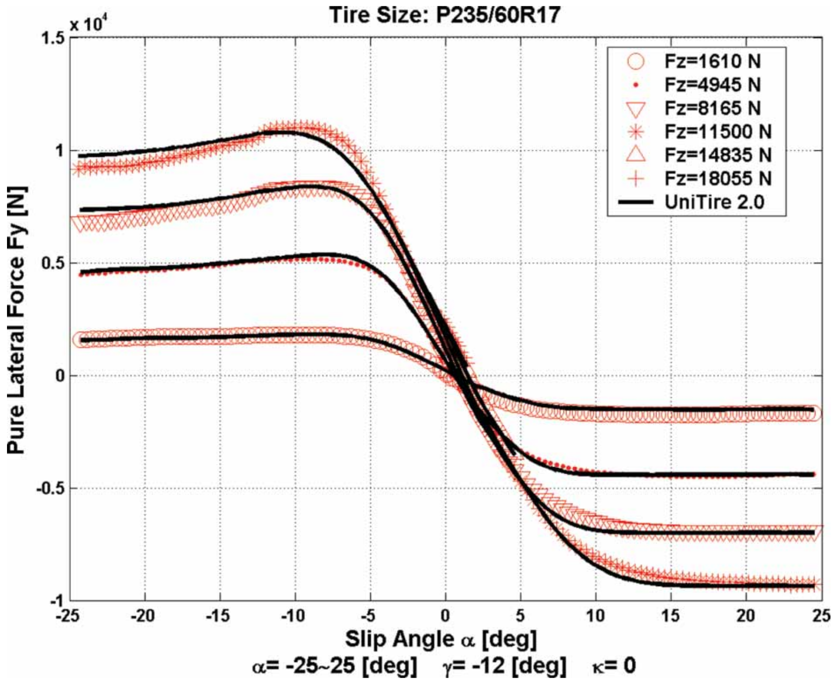

Figure 3. Comparison of UniTire 2.0 with test for camber $= -12°$.

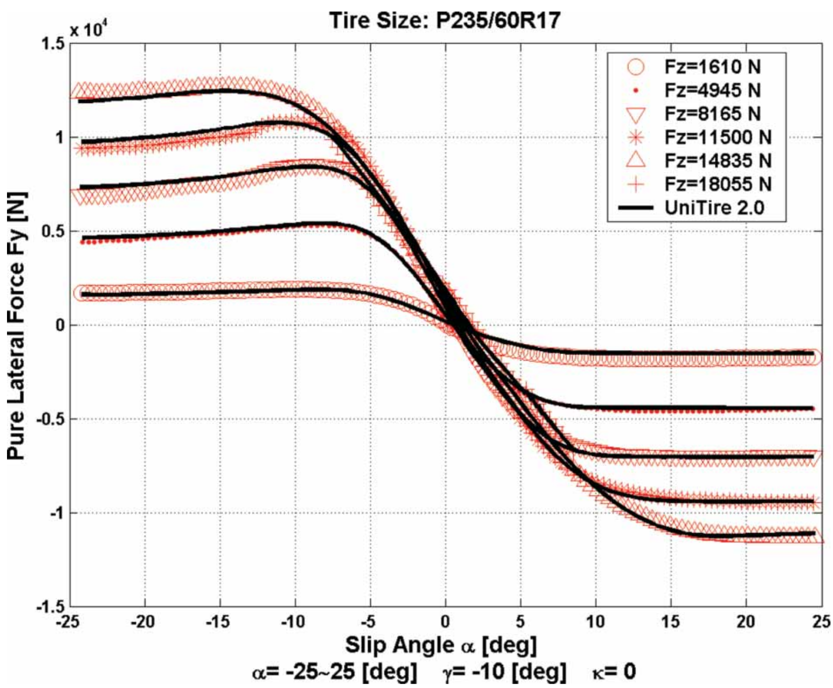

Figure 4. Comparison of UniTire 2.0 with test for camber $= -10°$.

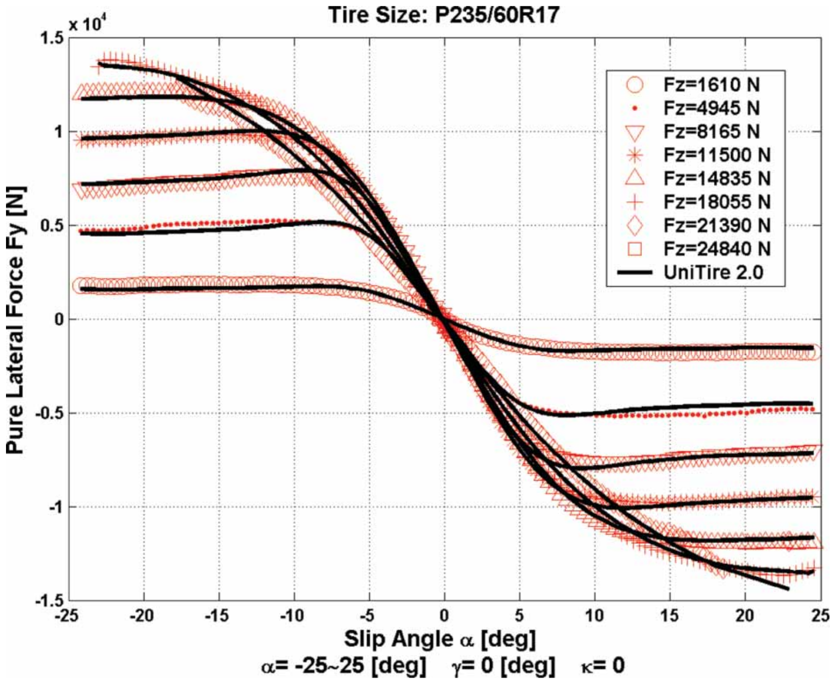

Figure 5. Comparison of UniTire 2.0 with test for camber = 0°.

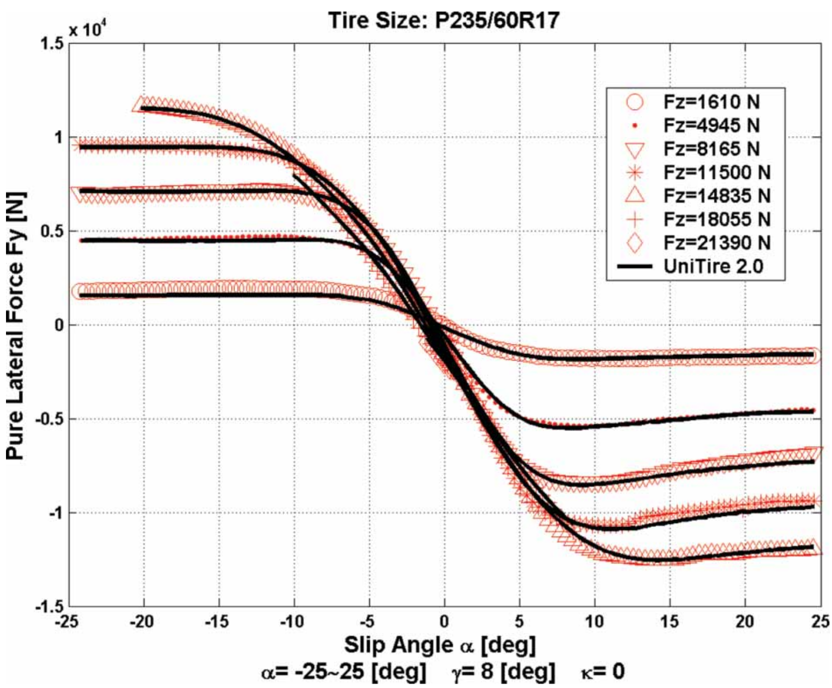

Figure 6. Comparison of UniTire 2.0 with test for camber = 8°.

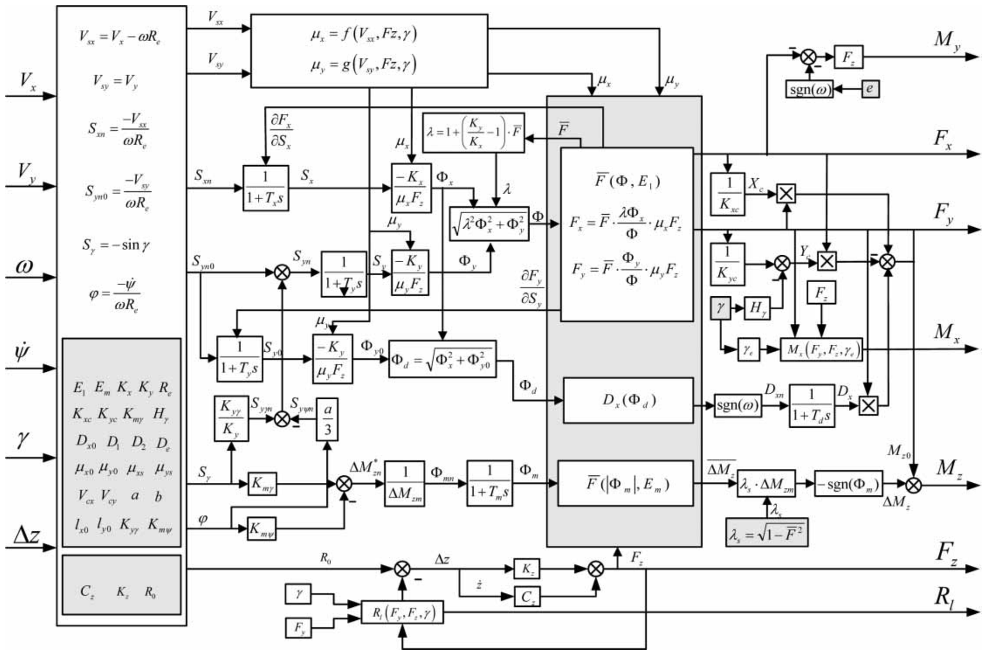

Figure 7. Block diagram of UniTire 2.0.

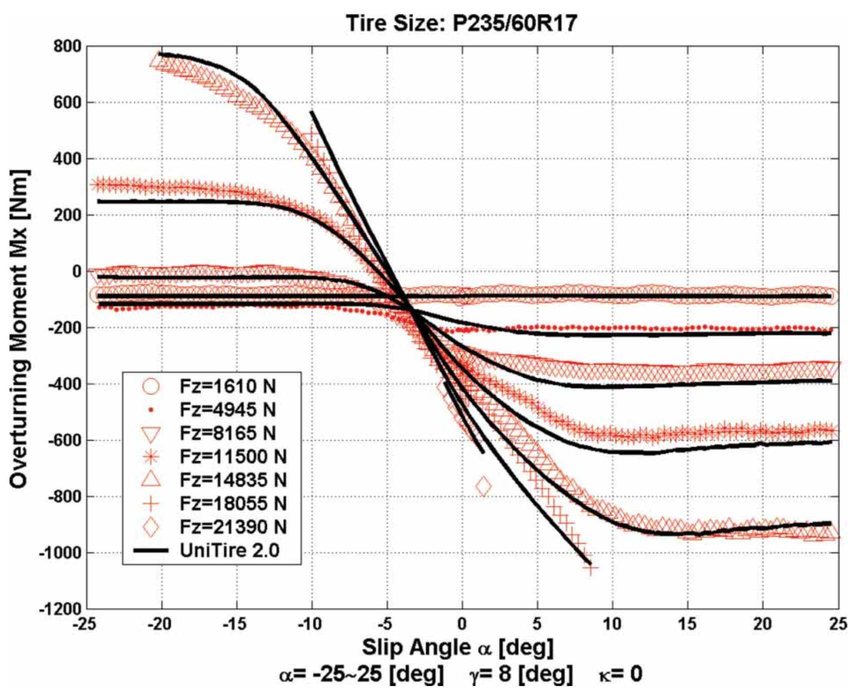

Figure 8. Modelling results of TOM for camber = 8°.

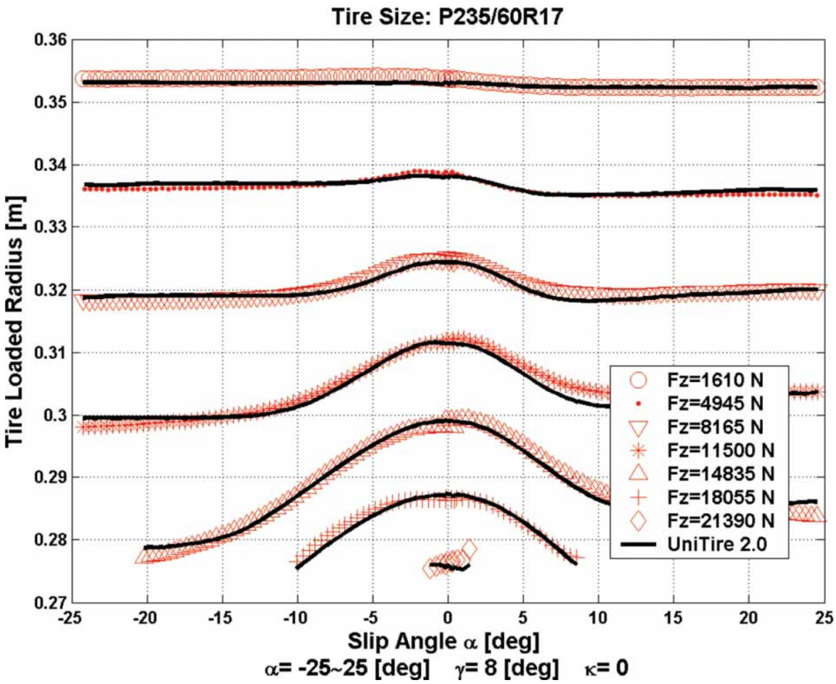

Figure 9. Modelling results of loaded radius for camber = 8°.

Tire camber angle has great influence as well on overturning moment and loaded radius, and this camber effect has been considered in UniTire 2.0 [5, 6], as shown in figure 7; figures 8 and 9 show the comparisons between simulation results and test data.

4. Camber effect on vehicle fishhook simulation

In order to investigate the effect of tire camber on vehicle dynamics, vehicle fishhook simulation with different tire models is conducted. A vehicle model of an SUV with independent front suspension and the rear suspension of solid axle is built in CarSim®, shown in figures 10 and 11. The open-loop steer control is shown in figure 12, with vehicle speed maintained constant.

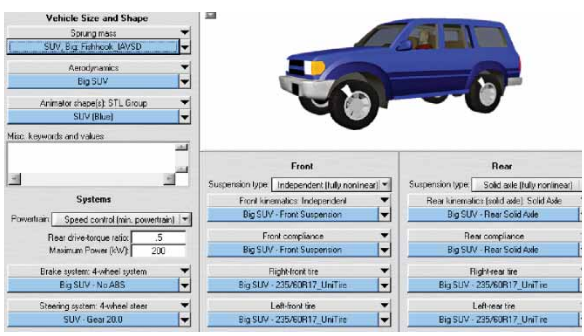

Figure 10. Vehicle configuration.

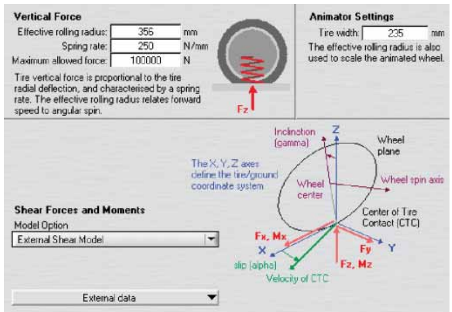

Figure 11. Input screen of external tire model.

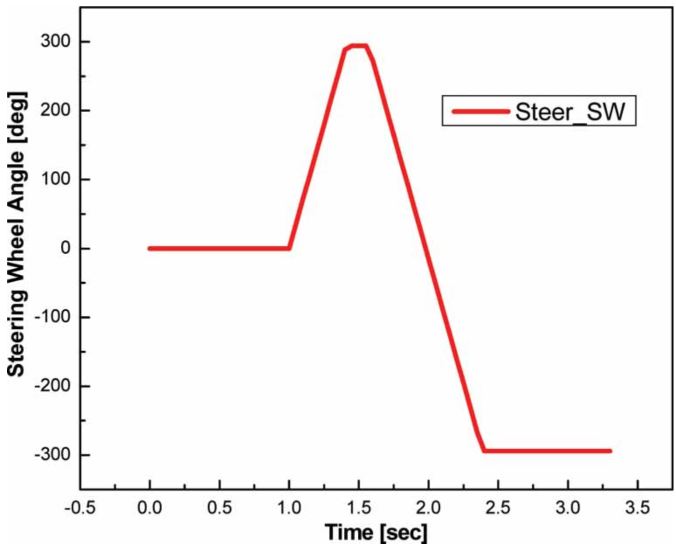

Figure 12. Input angle of steering wheel.

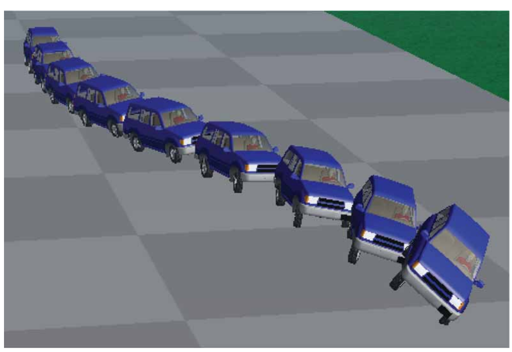

Figure 13. Fishhook simulation.

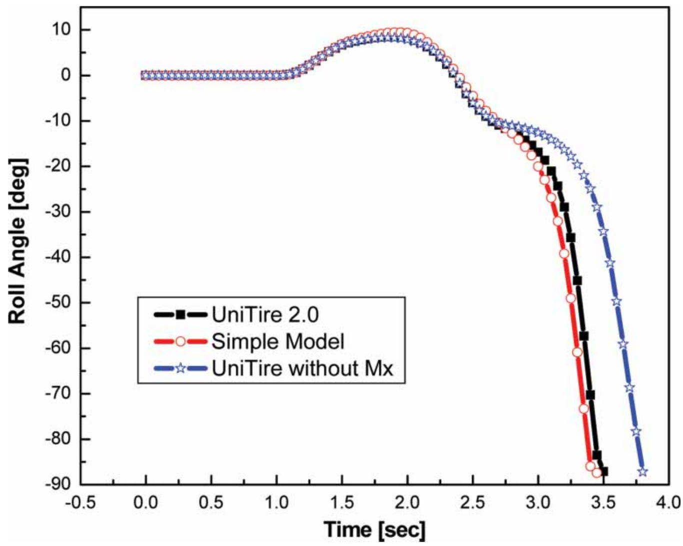

Figure 14. Comparison of roll angle.

Through external.c file, the external tire model can be embedded in CarSim's solver. When the vehicle roll angle reaches 87°, the simulation is stopped. Figure 13 shows the simulation results, and the comparisons of vehicle behaviors between UniTire 2.0, simple model and UniTire without M_x are shown in figures 14–17.

From the simulation results, it can be observed that the tire model has great effect on vehicle behavior and the simplified tire model gives overpredictive results for the occurrence of rollover; the tire overturning moment needs to be considered for an accurate vehicle simulation.

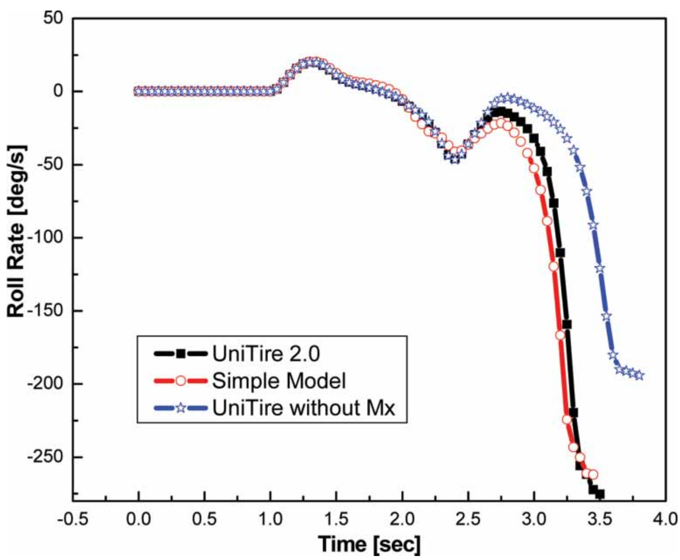

Figure 15. Comparison of roll rate.

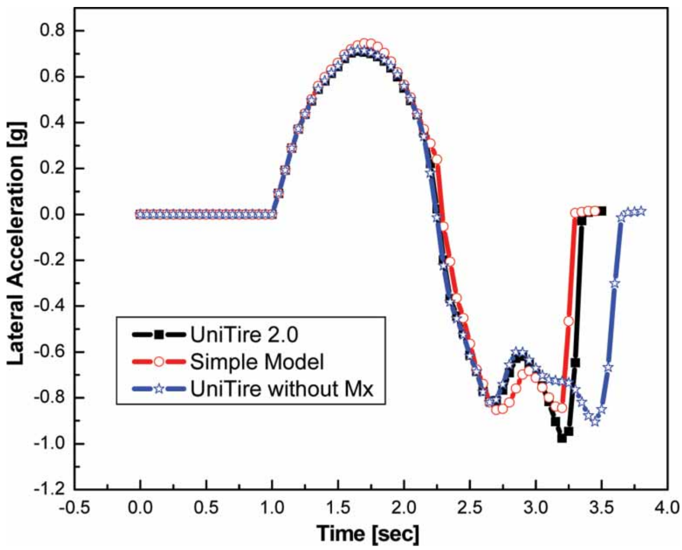

Figure 16. Comparison of lateral acceleration for rollover.

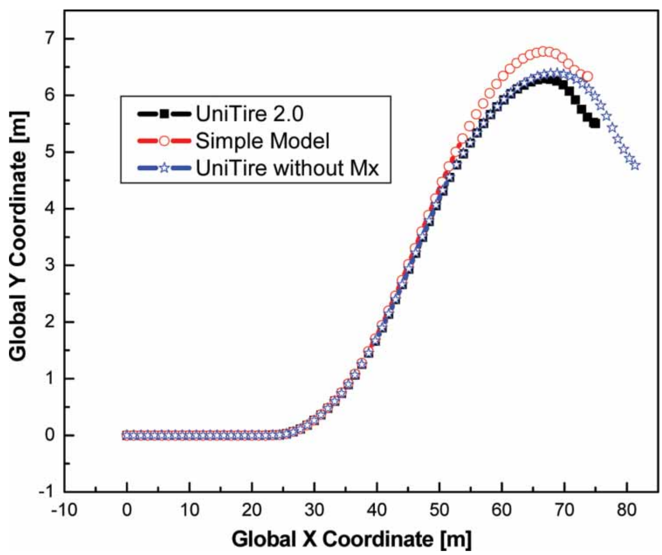

Figure 17. Comparison of trajectory.

5. Conclusions

1. Tire camber not only has a strong effect on the tire lateral force as an additional equivalent lateral slip ratio but also leads to significant variation in the structural parameters of friction coefficient and cornering stiffness.
2. If camber effects on K_y and μ_y are not accounted properly in tire force generation, the resulting force from calculation will be too large in simulation of vehicle rollover. This might explain why the existing vehicle simulation often overpredicts the occurrence of rollover.

3. Modeling of tire overturning moment, especially under large camber, would improve the accuracy of the simulation.
4. The accuracy of tire model has a significant impact on the simulation result of vehicle for extreme cornering maneuvers.

References

[1] Guo, K., Lu, D. and Ren, L., 2001, A unified non-steady non-linear tyre model under complex wheel motion inputs including extreme operating conditions. *JSAE Review*, **22**(4), 395–402.

[2] Guo, K., Lu, D., Chen, S., Lin, W.C. and Lu, X.-P., 2004, UniTire Model–non-linear and non-steady tire model for vehicle dynamic simulation. 3rd International Tyre Colloquium, Vienna, Austria, 29–31 August.

[3] Pacejka, H.B., 2002, *Tyre and Vehicle Dynamics* (Butterworth-Heinemann, an imprint of Elsevier Science).

[4] Gim, G. and Choi, Y., 2001, Role of tire modeling on the design process of a tire and vehicle system. ITEC ASIA 2001, Busan, Korea, 18–20 September.

[5] Lu, D., Guo, K., 2004, Experimental and theoretical study on tire overturning moment property (in Chinese). *China Mechanical Engineering*, **15**(15), 1317–1319.

[6] Lu, D., Guo, K., Wu, H., Chen, S. and Lu, X-P., 2005, Modelling of tire overturning moment and loaded radius. 19th IAVSD Symposium, Milano, Italy, August.