International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 3, July 2014

Research Paper

A STUDY OF THE EFFECT OF STEERING PARAMETERS ON ROLLOVER PROPENSITY

K K Dhande[1]*, N I Jamadar[1] and Vinod Sakhala[1]

*Corresponding Author: K K Dhande, ✉ kkdhande@gmail.com

Rollover propensity is an important safety issue which should be considered early in the design of a vehicle. Although there is a trend toward higher-tech solutions to mitigate rollover risk, we propose that a vehicle designer should also be fully aware of the impact many of the vehicle's design parameters have on rollover propensity. Such awareness is essential to making appropriate engineering trade-offs throughout the vehicle development process. This Study investigates the effect of various vehicle parameters on rollover propensity by performing simulations. The accuracy of the simulation was verified by comparing with experimental data from On-field testing of rollover of sport utility vehicles. The vehicle model used in the simulation study considers the non-linear, transient dynamics of both yaw and roll motion. The vehicle model was subjected to the specific steering input defined by the National Highway Traffic Safety Administration (NHTSA), the Slalom Test. Investigations were aimed at identification of correlations between the vehicle steering parametersand rollover propensity using validated vehicle simulation. During the study it was observed that one of the steering performance parameter aids in reducing rollover propensity. All such results are presented in this paper.

Keywords: VDC, ESP, RSC, ABS, NHTSA

INTRODUCTION

Over the past decade, the occurrence of rollover incidents in vehicle accidents has received much attention due to the increase in Sport Utility Vehicle (SUV) miles driven on the roadways and litigation claiming that engineers are to blame for designing unsafe vehicles. The NHTSA reported in 2010 that 3% of all light passenger vehicle crashes on Indian roads involve rollover, yet rollover accidents are responsible for 1/3 of all passenger vehicle occupant fatalities (Ponticel, 2003). The statistics reveal that SUVs rollover fatalities are more prevalent than in cars; 59% of total fatalities in SUV accidents occurred in rollover crashes, while rollovers accounted for only 23%

[1] Mech. Engg. Dept. Pad. Dr. D.Y. Patil Institute of Engg &Tech, Pimpri, Pune, India.

of total fatalities in car accidents. For the purposes of a dynamic rollover resistance rating test, NHTSA selected the Fishhook and Slalom steering manoeuvre as a primary candidate.

The rollover propensity of a vehicle is determined from the highest speed for which it can complete the selected manoeuvre without undergoing two-wheel lift. Since the vehicle testing is conducted on-road, the results are more repeatable and give more control over the test environment than do off-road tripped tests (Forkenbrock *et al.*, 2003). Even though the evaluation procedure is only meant to test vehicles for on-road, untripped rollover propensity (which accounts for a small percentage of rollover crashes), it is believed that the results are still a valuable measure of overall rollover stability for relative comparison of various vehicles (Viano and Chantal, 2003).

It is well known that steering performance depend on steering ratio and Ackerman percentage. These are the major vehicle parameters that contribute to rollover propensity. In this study, the effects of steering performance is evaluated to determine their influence on rollover propensity, while holding other vehicle properties such as suspension configuration and weight distribution constant. A detailed description of the basic simulation model, including validation testing, and a discussion of the results for several parametric variation studies are provided in the following sections.

SIMULATION MODEL

Dynamic simulation has proven to be an efficient and accurate method for analyzing vehicles and evaluating their dynamic behaviour (Allen *et al.*, 1990; and Garrott and Heydinger, 1992). As a part of the present effort, a simplified model that captures the essential vehicle dynamics associated with un-tripped rollover was developed and validated.

MODEL DEVELOPMENT

The primary dynamics that are of concern are those associated with the yaw and roll motions. And yaw and roll can be easily evaluated on the bases of dynamic testing of the vehicle. Simplified vehicle model was developed in IPG Car Maker (multi-body dynamic software) along with its all sub systems. Simulink was used for developing the vehicle control system.

MODEL VALIDATION

In order to validate the vehicle model described above, simulation results were compared with physical testing and experimental data for the Slalom manoeuvre. The Slalom manoeuvre uses a steering input such that driver has to negotiate the specified course at a set entrance velocity. The velocity profile of this manoeuvre is characterized by the vehicle reaching a desired steady state speed, known as the entrance speed, and coasting through the rest of the manoeuvre once the initial pylon is begun. The profile consists of an initial zero steer angle up to the target speed followed by going to a steer angle at a rate such that vehicle can negotiate the slalom course without any wheel lifts or without hitting any of the pylon.

In the Slalom manoeuver steering performance have more control on vehicle behaviour. If there is any unexpected behaviour of the vehicle during testing one can tune the various vehicle parameters to achieve good results in virtual world followed by real world.

The simulation model contains a 'virtual garage' that consists of 'virtual vehicles,' each with a configuration to match those of experimental vehicle used in the physical dynamic testing. Parameters in the virtual garage, such as wheelbase, track width, roll stiffness, roll damping, roll centre location, brake characteristics are held constant. The virtual vehicles varied from one another by having different steering performance and total weight.

Below Figures graphically compare the actual testing data with corresponding results from the simulation model. The inputs to the simulation are the steer angle, gear step, master cylinder brake pressure and velocity

Figure 1: Slalom Test Steer Angle Graph

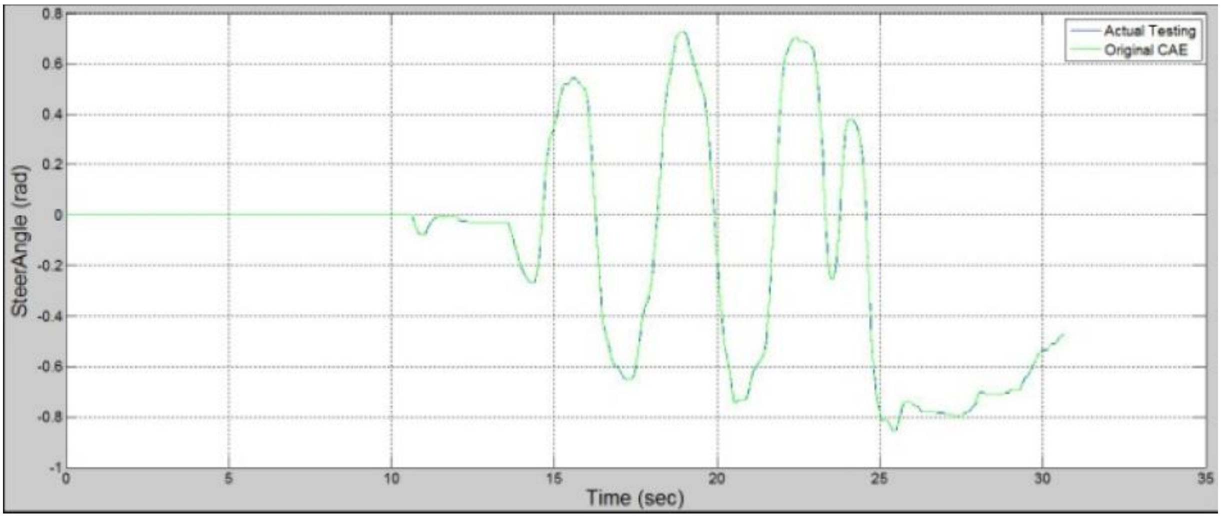


Figure 2: Slalom Test Longitudinal Speed Graph

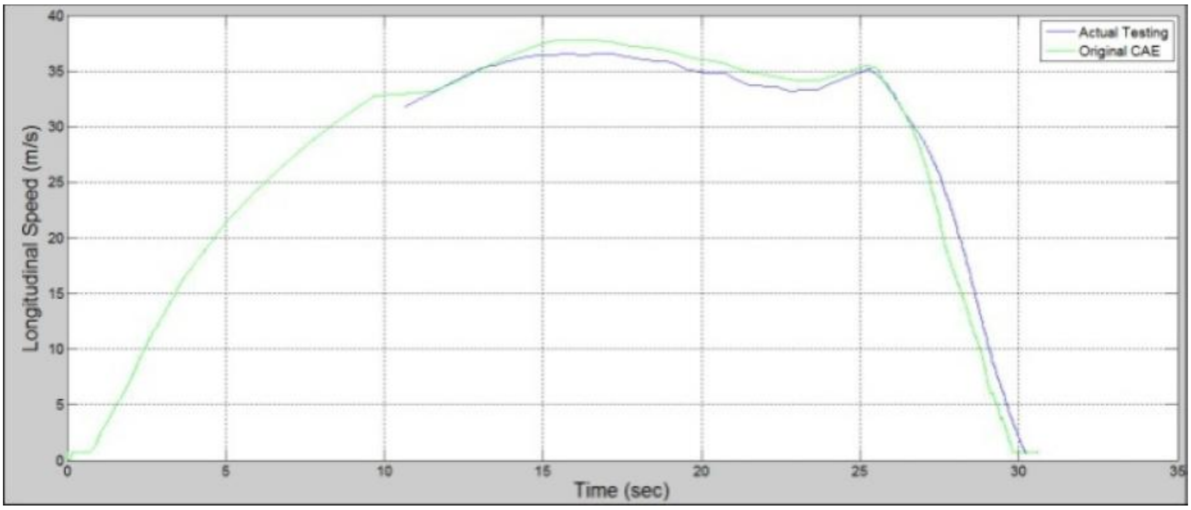


Figure 3: Slalom Test Lateral Acceleration Graph

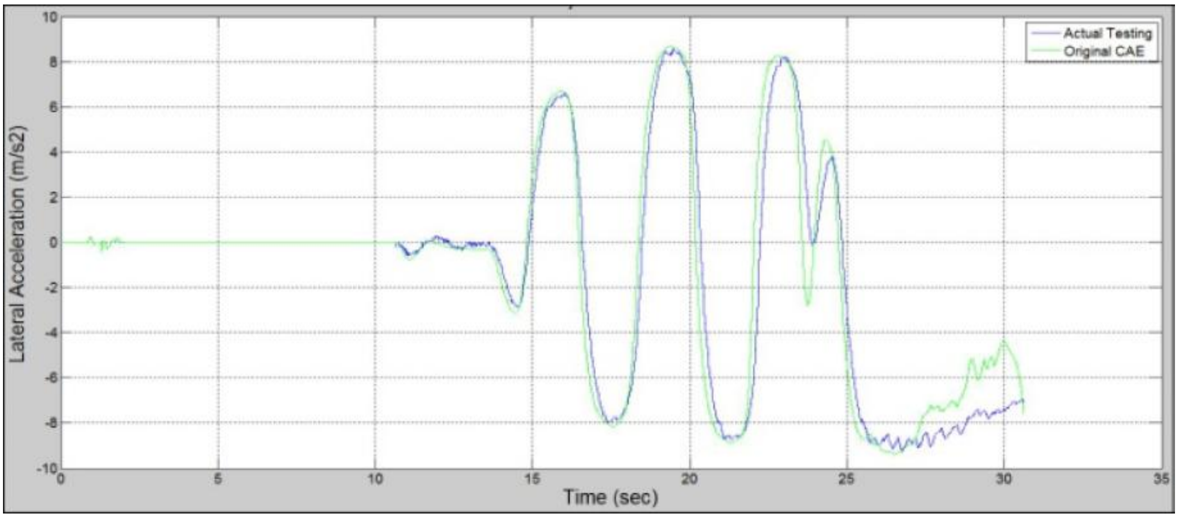
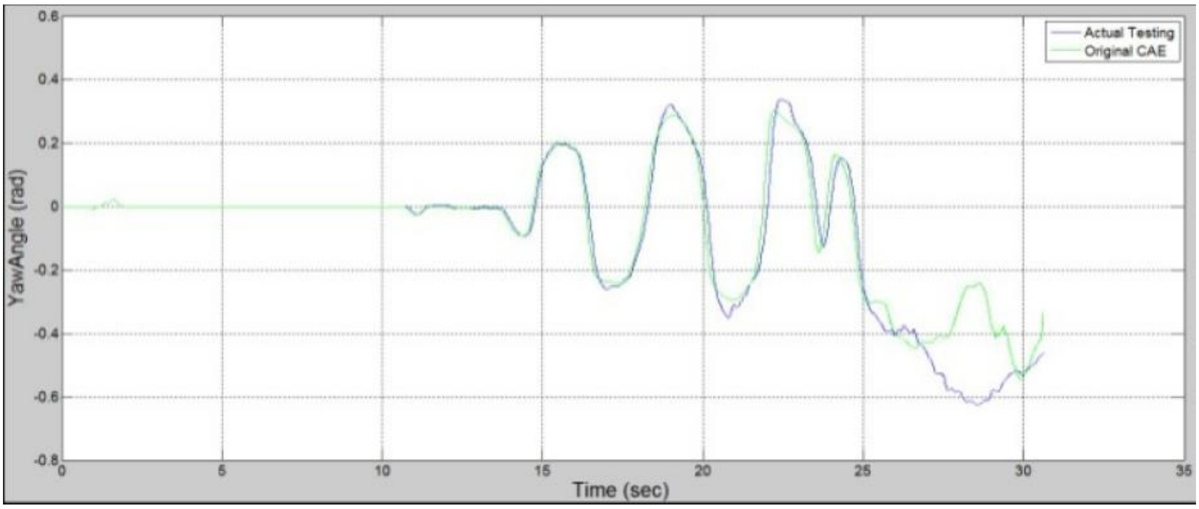


Figure 4: Slalom Test Yaw Angle Graph



data from the actual testing. The states compared are lateral acceleration, yaw rate, and roll angle.

SIMULATION STUDIES

Once the simulation model was validated, vehicle parameters were varied in order to assess their effect on rollover propensity. The dynamic test used to determine the effects of these properties is the Slalom manoeuvre. The Slalom is a highly repeatable manoeuvre as cited by NHTSA's research. For each parametric variation, a new Slalom constant had to be determined. This was accomplished by using the simulation to find the steer angle at maximum speed through which the vehicle negotiates the Slalom course. Rollover velocity is calculated by determining the vehicle speed at which a steering manoeuvre causes "two wheel lift or vehicle hitting the pylon." "Two wheel lift" is defined to occur when the normal forces on both inside tires drops to zero. By comparing the rollover velocities with the various vehicle properties, a correlation is identified between rollover propensity and those properties.

From the above graphs it was clear that the vehicle is skidding at after last slalom has passed, and this was not acceptable according to the standard protocol. To avoid this hazards behaviour of the vehicle it is mandatory to tuned the vehicle parameters from Vehicle Dynamic Controller (VDC). From the past experience I have modified the VDC parameter called LwGr. LwGr is the threshold for the steering angle front axle. LwGr was tuned from 0.1 to 0.02 in order to achieve as expected behaviour.

For any of the vehicle tuning process it has to be checked that whether the results from

Figure 5: Slalom Test Steer Angle Graph After Simulation

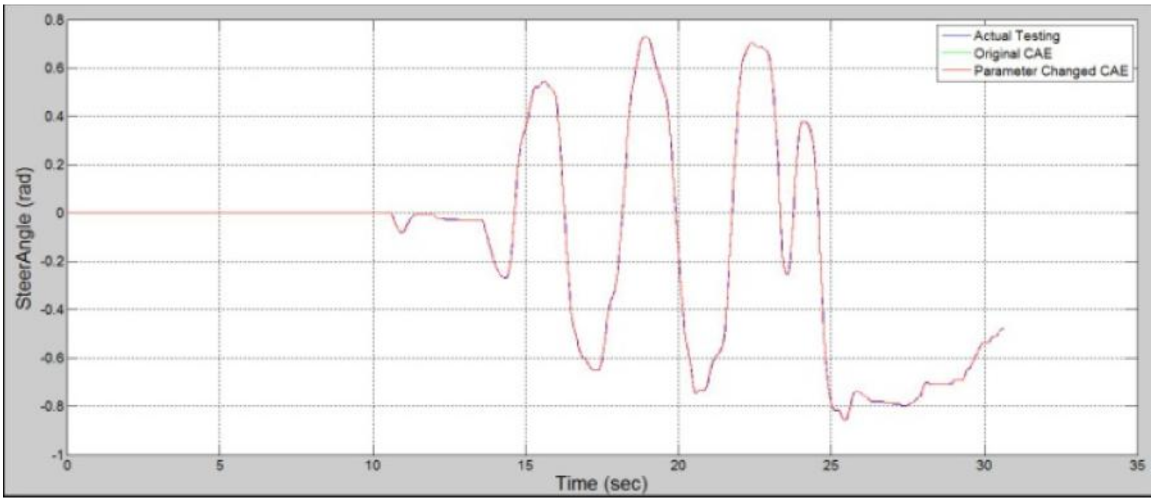


Figure 6: Slalom Test Longitudinal Speed Graph After Simulation

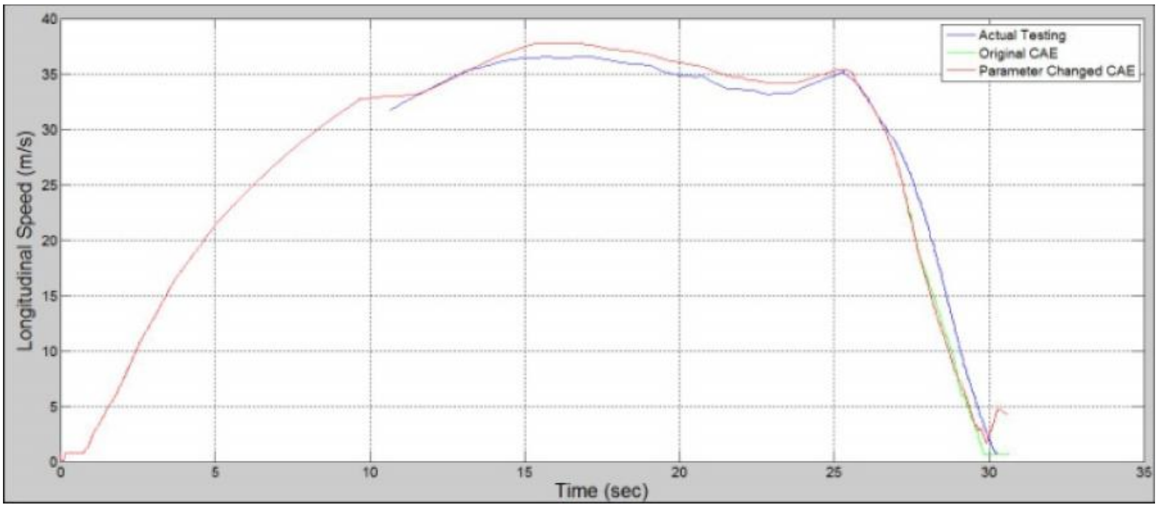


Figure 7: Slalom Test Lateral Acceleration Graph After Simulation

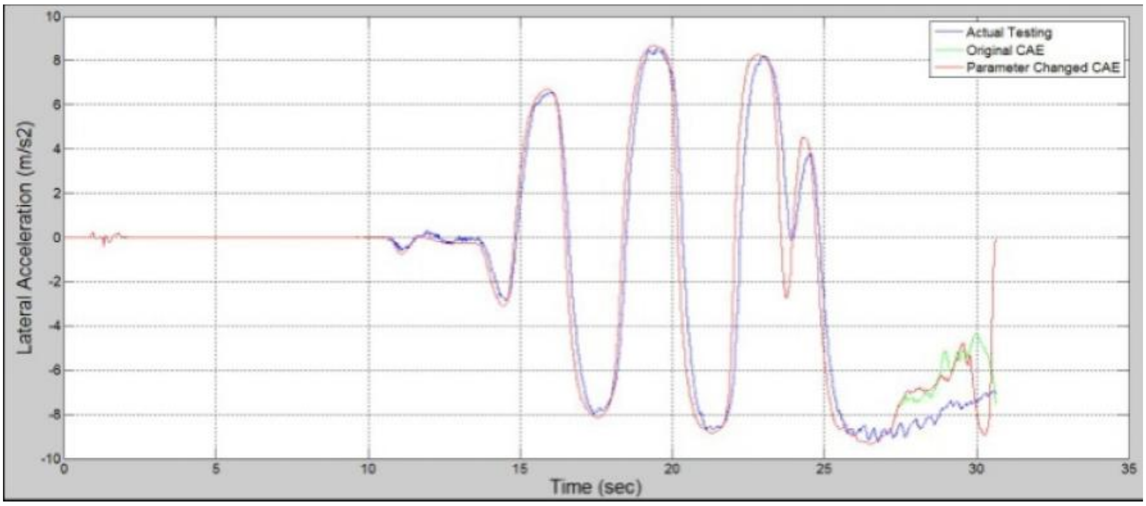
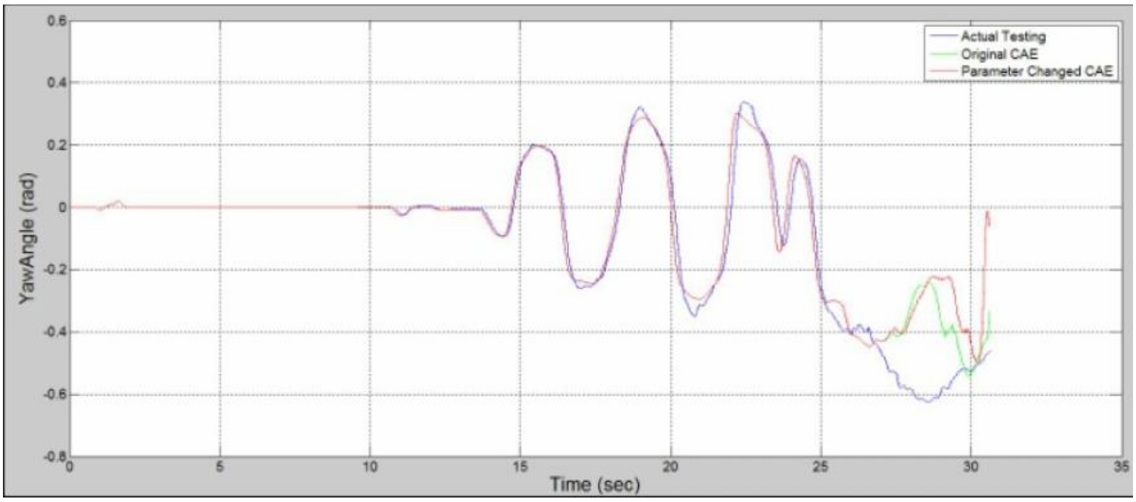


Figure 8: Slalom Test Yaw Angle Graph After Simulation



actual testing are matching with the results after simulation, once this correlation has been verified then go for the parameter tuning. From Figures 5 and 6, it was clear that the correlation results are matching.

CONCLUSION

This study has shown that a simple vehicle model developed to study the transient dynamics of SUV can capture the dynamics seen in events leading to rollover. This was demonstrated with a correlation between simulation results and field test data; therefore giving validation to using the simulation to study rollover propensity.

To improve vehicle performance and its stability the control system plays major role. So by tuning the vehicle control system in this case VDC, vehicle stability was improved. And the unexpected behaviour what we were facing at the last slalom during testing has been avoided at some acceptable range. Future research will investigate the effect of other vehicle properties, such as suspension setup, tire models, etc., on rollover propensity using simulation and scaled experiments.

FUTURE WORK

As rollover is an unwanted phenomenon, once the roll angle is calculated, some correction techniques may be developed, like steering correction required or braking torque required bringing the vehicle back from roll condition. Also a roll sensor which will work constantly with a controller taking steering input can predict the approach of serious rollover situation or may be indicate the driver about cornering speed and/or steering rate for safe cornering. Suspension is key element; rigid suspension would cause discomfort and soft suspension increases roll moment. Hence use of active or semi active suspensions can prove landmark in avoiding rollovers. All this changes can be implemented in the vehicle conjunction with vehicle control system like Electronic Steering Performance (ESP), VDC, Anti-lock Brake System (ABS), Roll Stability Control (RSC), etc.

REFERENCES

1. Allen R W, Szostak H T, Rosenthal T J and Klyde D H (1990), "Field Testing and Computer Simulation Analysis of Ground Vehicle Dynamic Stability", SAE Paper No. 900127.
2. Christos J P and Guenther D A (1992), "The Measurement of Static Rollover Metrics", SAE Paper No. 920582.
3. Cooperrider N K, Hammound S A and Thomas T M (1990), "Testing and Analysis of Vehicle Rollover Behavior", SAE Paper No. 900366.
4. D'Entremont K L, Zhengyu L and Nalecz A G (1993), "An Investigation into Dynamic Measures of Vehicle Rollover Propensity", SAE Paper No. 930831.
5. Forkenbrock G J, Garrott W R, Heitz M and O'Hara B C (2003), "An Experimental Examination of J-Turn and Fishhook Maneuvers that May Induce On-Road, Untripped, Light Vehicle Rollover", SAE Paper No. 2003-01-1008.
6. Garrott W R and Heydinger G J (1992), "An Investigation, Via Simulation, of Vehicle Characteristics that Contribute to Steering Maneuver Induced Rollover", SAE Paper No. 920585.
7. Gillespie T D (1992), "Fundamentals of Vehicle Dynamics", Society of Automotive Engineers, Warrendale, PA, ISBN: 1-56091-199-9.
8. Ponticel P (2003), "Dynamic Testing Rollover on the Way", *Automotive Engineering International*, November, pp. 26-28.
9. Viano D C and Chantal P (2003), "Case Study of Vehicle Maneuvers Leading to Rollovers: Need for a Vehicle Test Simulating Off-Road Excursions, Recovery and Handling", SAE Paper No. 2003-01-0169.