EFFECTS OF TYPES OF VEHICLES AND MANEUVERS ON VEHICLE KINEMATICS DURING STEERING-INDUCED SOIL-TRIP ROLLOVERS

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ABSTRACT

Controlled rollover test methods have been developed where touchdown conditions of the vehicle are specified as test inputs. Rollover crash touchdown parameters can vary widely due to variations in road surface and topography, maneuvers, and vehicles. While vehicular accident reconstruction teams have performed steering induced rollover tests and reported on touchdown conditions in the literature, such kinematic parameters are only available for an extremely limited set of conditions and vehicles. Furthermore, information about the sensitivity of touchdown conditions to changes in vehicle and maneuvers is missing from the literature. Thus, the goals of this study were threefold: to develop and validate two vehicle models in ADAMS^{TM}, use them to simulate common types of steering-induced soil-trip rollovers, and to evaluate how differences in maneuvers and vehicle type affect vehicle kinematics at touchdown.

First, vehicle inertia measurement tests, suspension tests, tire tests, bushing tests, and driving tests, including double lane change, J-turn, and fishhook, were performed using a sedan and a pickup truck. Next, vehicle models for each vehicle were built and validated with the experimental data. A straight highway was modeled following road design guidelines and a soil-tire interaction model was implemented. Analysis of NASS-CDS cases showed that rollover accidents occurred as a result of the vehicle leaving the roadway and either attempting to drive back onto the road (corrective) or continuing to steer from the road (non-corrective). Then specific cases exemplifying the corrective and non-corrective maneuvers were reconstructed with the two vehicle models to determine baseline driver inputs. Lastly, 120 Monte Carlo simulations were performed to compare vehicle kinematics and touchdown conditions of the two types of vehicles and maneuvers.

The two vehicle models showed good correlations with the static and dynamic test data. The median values of roll rates of the sedan were 290 deg/sec and 380 deg/sec in corrective and non-corrective maneuvers, respectively. The pickup truck showed lower roll rates in the same maneuvers (210 and 250 deg/sec, respectively). Touchdown roll angles were higher in the sedan (120 and 190 degrees) than in the pickup (103 and 104 degrees) and higher in the non-corrective maneuver for both vehicles. Vertical speeds at touchdown were about 2.6 m/s higher in the non-corrective maneuver than in the corrective maneuver.

The vehicle models were validated with results from component tests, static tests, and dynamic tests but no steering-induced rollover test data were available to validate the vehicle models. Subsequent to this study, steering-induced rollover tests will be performed to validate the models further and the soil model will be validated by testing the soil at the test site.

Despite these limitations, the methodology and results presented provide for the best available means to determine touchdown parameters for use in controlled rollover crash testing. The data presented show a substantial difference in touchdown conditions with respect to types of vehicles and maneuvers. Therefore, when a

rollover test is performed, the test conditions should be carefully selected depending on types of vehicles or maneuvers to generate realistic outcome.

INTRODUCTION

Rollover accidents accounted for 35.5 percents of all occupant fatalities in 2008 in the United States [1]. Although there has been a lot of research to investigate injury mechanisms and mitigate injuries during rollover accidents, a standardized dynamic rollover test method has not been developed. One of the reasons is because it requires much more information to fully define states of a vehicle and an occupant when the vehicle touches down to ground than any other crash modes.

Therefore, identifying vehicle kinematics from pre-ballistic to touchdown conditions is a crucial step to investigate rollover accidents because it can be used to determine touchdown conditions of a vehicle and an occupant for rollover testing and further computer-aided engineering studies. Many rollover test devices have been proposed. To conduct a rollover test, initial conditions of a test vehicle should be chosen carefully to consider realistic rollover scenarios. However, there exist many questions such as dependency of touchdown conditions of vehicles and occupants on the types of vehicles and types of maneuvers. It is, however, not suitable to obtain these kinds of information by conducting steering induced rollover tests due to the varieties of possible rollover scenarios, costs, and safety issues.

There were studies that simulated rollover scenarios by using simplified vehicle models but those models were not validated to various dynamic maneuvering tests [10-11] or focused on rollover sensing so there was little considerations on steering induced trip rollovers which turned out to be one of the common types of rollover accidents [12].

NASS-CDS database has been investigated and it was found that the one of the common rollover scenarios were a steering induced soil-trip rollover. Two types of vehicle models, a sedan and a pick-up truck, were considered in this study to see the effects of vehicle types on touchdown parameters during rollover crashes. The two vehicles were built and validated to static and dynamic tests. Two target maneuvers from NASS-CDS cases were reconstructed to determine baseline driver's inputs and initial speeds of vehicles. Lastly, Monte Carlo simulations were carried out based on the identified baseline driver's input and initial speed of vehicle to compare touchdown conditions of the two different types of vehicles and maneuvers.

METHODOLOGY

Vehicle Testing

Suspension modeling A sedan and a pick-up truck vehicle models have been developed for rollover simulations. The models have been developed by using mainly 3D measurement data and limited CAD data. The sedan model has a Mcpherson type and a multi-link type suspensions as the front and rear-ends, respectively. The pickup truck model has a double wishbone type and leaf springs with solid axle suspensions at the front and rear-ends, respectively. The leaf spring of the pickup truck model was modeled by using a three-link and nonlinear bushings [2].

Bushing component test Component tests for bushing have been conducted at Axel^{TM} (MI, USA) to reduce the number of parameters to be tuned in the vehicle models. The bushings which are near control arms and leaf spring of the suspensions were tested in a static mode and the test data were directly used to model non-linear bushings (Figure 1).

Figure 1. An example of bushing test

Inertial properties and kinematics and compliance test Inertial properties of both vehicles were measured (Table 1) and kinematics and compliance tests were performed at SEA^{TM} (OH, USA) to validate the suspension models under static conditions such as ride test, roll test, lateral compliance test, and steering compliance test.

Driving test Driving tests of the sedan and the pickup have been performed at TRC™ (OH, USA) to generate data for validation of the two models under dynamic loading conditions. Driving test modes include constant radius turn, single lane change, double lane change, J-turn, and slalom (Table 2). It should be mentioned that the driver's inputs were not the standardized forms such as ISO double lane change [15]. The driving tests were performed under high speeds and aggressive steering inputs to induce loss of control of the test vehicles, in-order to mimic the conditions of soil trip rollover accidents. Since the roll behavior of the vehicles were one of the main interests of these tests string potentiometers were installed near each strut to measure suspension deflection (Figure 2). In addition, vehicle's linear acceleration, linear velocity, angular velocity, wheel speeds, throttle input, and brake pressure were measured by using Differential GPS (DGPS), inertial sensors, and Controller Area Network (CAN) during the tests.

Table 1.
Mass properties of two vehicles

	Sedan	Pickup	unit
cg height (h_{cg})	559	742	mm
track width (t)	1580	1725	mm
SSF (=t/(2h_{cg}))	1.41	1.16	
mass	1460	2440	kg
I_{xx}	563	1130	kgm^2
I_{yy}	2550	6770	kgm^2
I_{zz}	2810	7154	kgm^2
I_{xz}	62.4	-231	kgm^2

Table 2.
Driving test matrix

Test maneuver	Speed for sedan [km/h]	Speed for pickup [km/h]
100 feet circle	0-56	0-53
Single lane change	80-113	80-113
Double lane change	80-129	80-129
Slalom	121	113-121
J-turn w/ or w/o brake	121	121

Vehicle Model Validation

To run a simulation for model validation, longitudinal speed and steering wheel angle collected during the tests were used as inputs for the vehicle models. In most cases the longitudinal speed of the vehicle model followed to the test data. (Figure 6 (b)).

The vehicle models were validated with respect to static suspension tests by adjusting locations of joints and properties of bushings that were not tested. Since inerital properties of the fully instrumented test vehicles with a test driver were not available the inertial properties including the location of center of mass and I_{xx}, I_{yy}, I_{zz}, and I_{xz} were matched to the test results without instrumentation or a driver. Then, masses of driver and instrumentation equipment were added in corresponding locations.

Figure 2. String potentiometers installed along damper and DGPS installed at the center of vehicle

Then, the two vehicle models were validated by using the driving test data and selected results were represented in the result section.

Soil Model

To model soil-to-tire interaction, a semi-empirical soil model was considered [3]. This model assumes rigid wheel and is based on Bekker's method [4] to predict sinkage depth of a tire. Then, bulldozing force was calcaulated by using the area of the side wall of a tire sunk into the soil and Mohr-Coulomb failure criterion. Soil parameters measured from a mud-like soil (Table 3) were used in the simulations [5]. This soil was chosen because it generates high bulldozing force enough to roll over a vehicle but it would be interesting to check how different soils change touchdown parameters.

Table 3.
Soil properties [5]

Terrain	Heavy clay
Moisture content [%]	25
k_c [kN/m^{n+1}]	12.70
k_φ [kN/m^{n+2}]	1555.95
c [kPa]	68.95
φ [deg]	28°

Road Model

The two lane highway has been modeled in ADAMS (Figure 3) following roadway design guidelines and AASHTO's Green Book [6-8]. For the paved area, which includes lanes and shoulders, friction coefficient of 0.95 has been used. For the rest of the area friction coefficient of 0.6 has been used. The recommended slope of shoulder wedge, recovery, and median is between 6 to 1 and 4 to 1, so 6 to 1 has been used. The soil model was engaged when the wheel center moved outside of the paved area during the simulations.

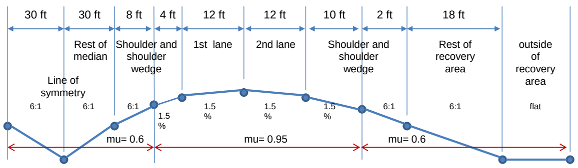


Figure 3. Cross section of two-lane highway model

Target Maneuvers

Several rollover cases from NASS-CDS database were investigated to determine target manevers. Among single vehicle rollover cases many soil trip rollovers were observed and two common patterns could be found. The two patterns were determined as target maneuvers and these were reconstructed by using the two vehicle models by adjusting driver's inputs (Figure 8 and Figure 9). These were used as baseline driver's inputs for subsequent Monte Carlo simulations.

Monte Carlo Simulation

Monte Carlo method is widely used to estimate the distributions of outputs of nonlinear systems under given variations of inputs. As the number of simulations increases the estimated mean values approaches to the population faster than deterministic design of experiment when the dimension of design space is large [13].

Vehicular rollover is a highly non-linear phenomenon, and slight change in driver's input can change vehicle kinematics drastically. Therefore, comparing the touchdown conditions by using only two simulation results is not reliable. Therefore, Monte Carlo simulations were performed by imposing variations in the parameters that were used to define baseline driver's inputs to consider variations in touchdown conditions of the target maneuvers. Then, the the effect of types of maneuvers and vehicles on touchdown conditions were examined by comparing the median values of touchdown conditions.

RESULTS

Validation of Vehicle Model

The two vehicle models were first validated to static test data and some of results were shown in *Figure 4* and *Figure 5*. Then, the inertial properties were validated as mentioned earlier. The two vehicle models validated to the static test data and inertial measurements showed good correlations with driving test data under various maneuvers such as double lane change, slalom, and J-turn. There were slight modifications on bushing properties and joint locations of steering systems to improve the correlation. Comparisons of the results of a double lane change test of the sedan and a slalom test of the pickup truck were depicted in Figure 6 and Figure 7, respectively. It should be noted that the vehicle models showed similar roll motion to the test vehicles as well as yaw motion (Figure 6 and Figure 7).

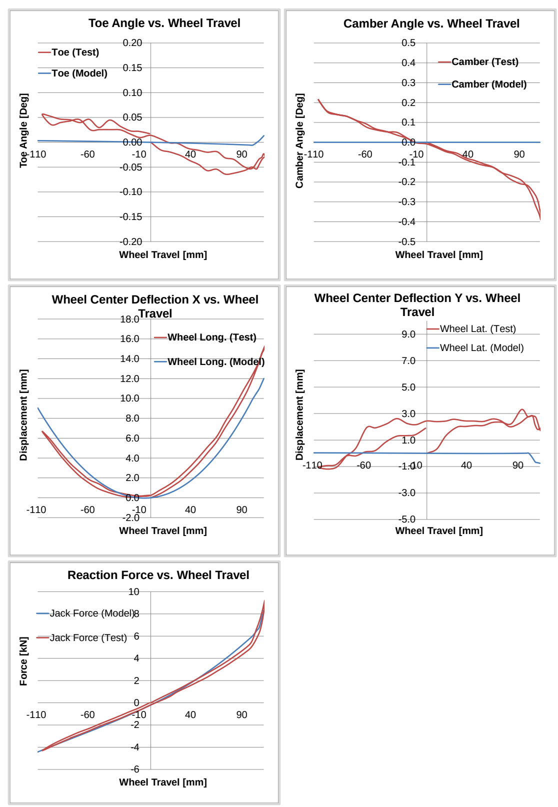


Figure 4. Comparison of ride behaviors of rear suspension of pickup truck

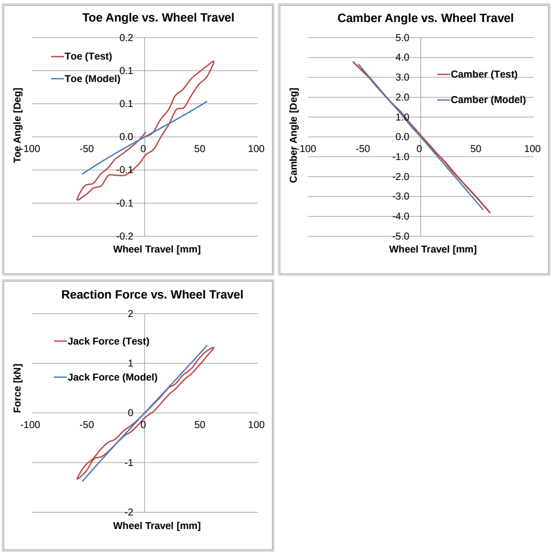
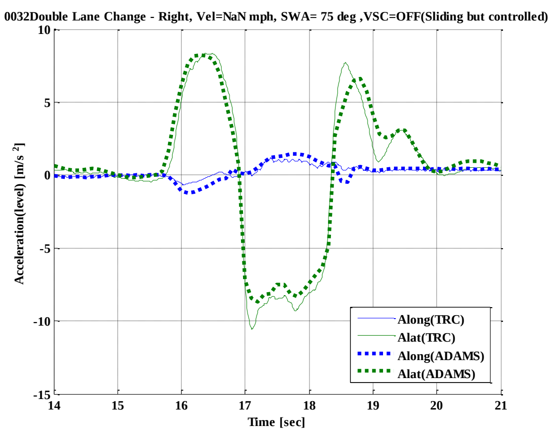
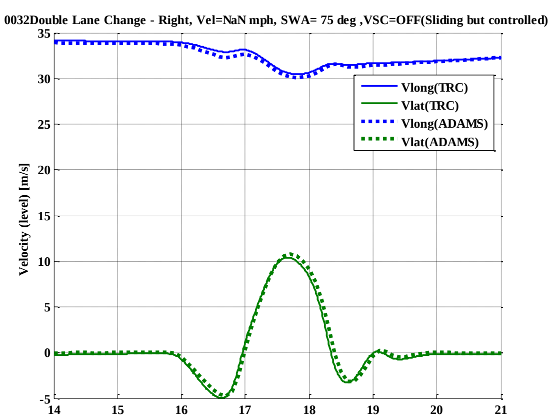


Figure 5. Comparison of roll behaviors of front suspension of pickup truck

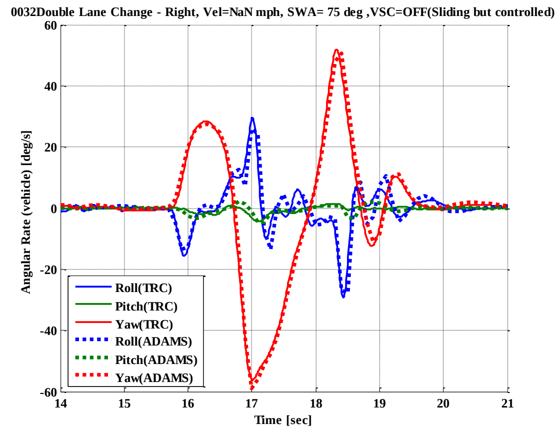


(a) Longitudinal and lateral accelerations

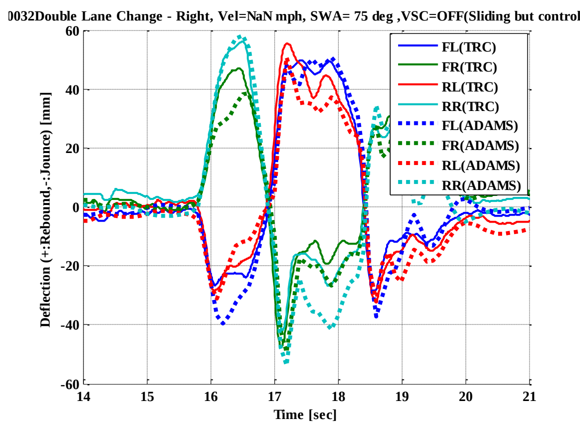


(b) Longitudinal and lateral speeds

Figure 6. Comparison of test data and simulation results of double lane change of sedan (cont'd)

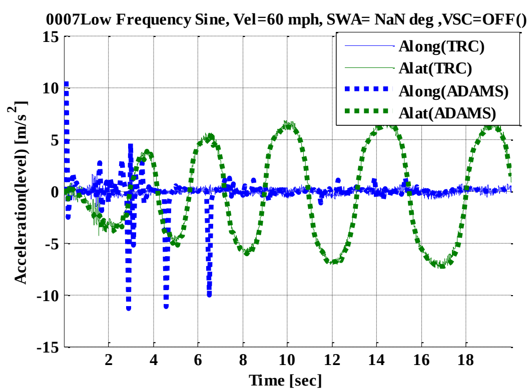


(c) Angular rates



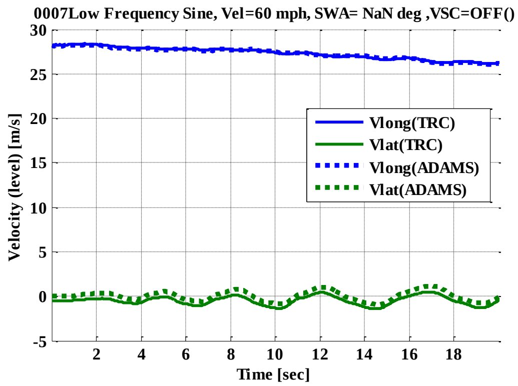
(d) suspension deflection amounts

Figure 6. Comparison of test data and simulation results of double lane change of sedan

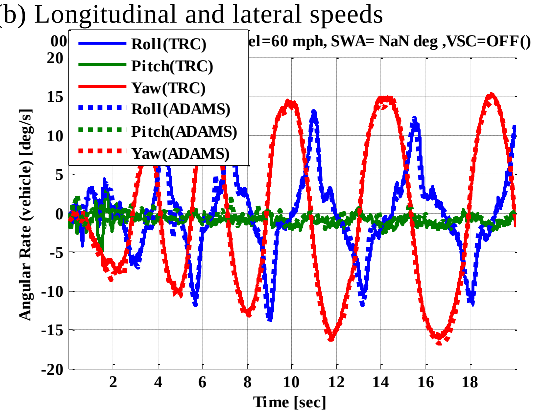


(a) Longitudinal and lateral accelerations

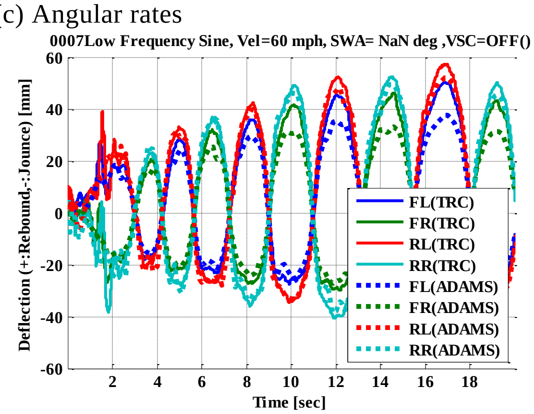
Figure 7. Comparison of test data and simulation results (Pickup truck, slalom) (cont'd)



(b) Longitudinal and lateral speeds



(c) Angular rates



(d) suspension deflection amounts

Figure 7. Comparison of test data and simulation results (Pickup truck, slalom)

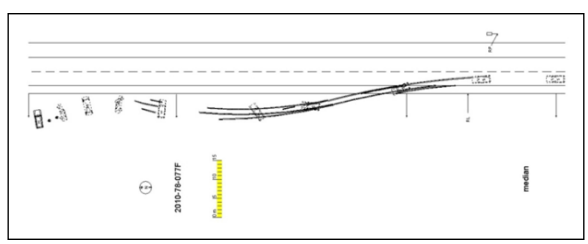
Baseline Simulation

Two target maneuvers were selected from NASS-CDS database (Figure 8 and Figure 9). The case vehicles, which rolled over due to soil tripping force, usually went off the road and either changed its yawing direction (corrective maneuver) or not (non-corrective maneuver). It should be mentioned that the terms, corrective and non-corrective, are only based on the trajectories of vehicles in this study. There can be various kinds of driver's inputs that result in the similar vehicle trajectories and rollovers but there was limited information on NASS-CDS database about driver's steering and brake input. So, we have chosen to use the simplest forms of steering input time histories. To reconstruct the corrective maneuver case the fishhook-like driver's input (Figure 8 (d)) was used and to reconstruct the non-corrective maneuver case the J-turn-like driver's input (Figure 9 (d)) was used. Since many skid marks were observed on scene diagrams, a step brake input was considered and applied with major steering inputs.

The baseline driver's inputs (Table 4) that resulted in similar vehicle trajectories and rollovers to target maneuvers were identified by performing multiple simulations with changing parameters for driver's input time histories (Figure 8 (d) and Figure 9 (d)).

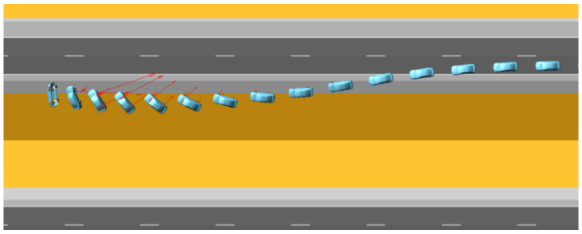
Table 4.
Input parameters used in the baseline simulations

Corrective maneuver	**Sedan**	**Pickup truck**
Initial speed [mi/h]	74	64
SWA1 [deg]	-34	-52
SWR1 [deg/s]	-23	-42
DT1 [sec]	0.4	0.32
SWA2 [deg]	130	130
SWR2 [deg/s]	400	431
Brake [g]	0.3	0.3
Non-corrective maneuver	**Sedan**	**Pickup truck**
Initial speed [mi/h]	84	74
SWA1 [deg]	155	191
SWR1 [deg/s]	131	516
Brake [g]	0.3	0.25

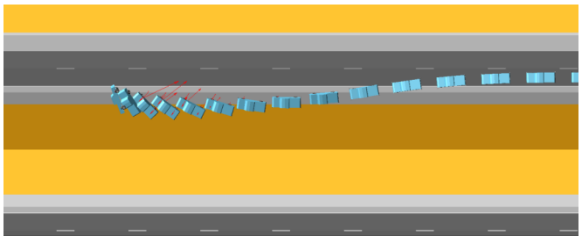


(a) NASS-CDS scene diagram

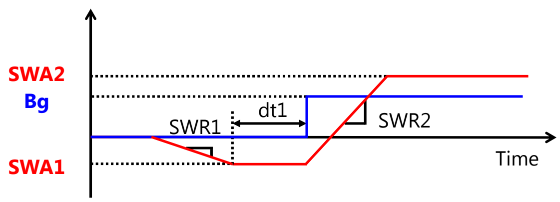
Figure 8. Baseline simulation results for corrective maneuvers (cont'd)



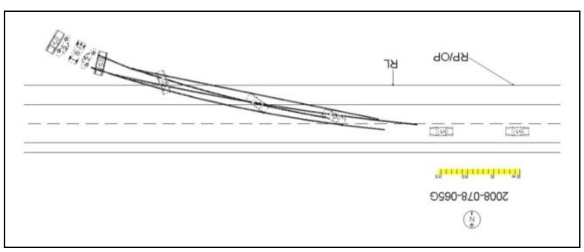
(b) Reconstructed case by the sedan model



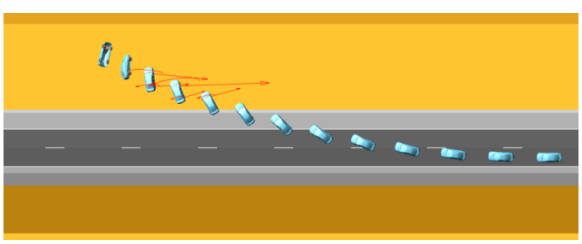
(c) Reconstructed case by the pickup model



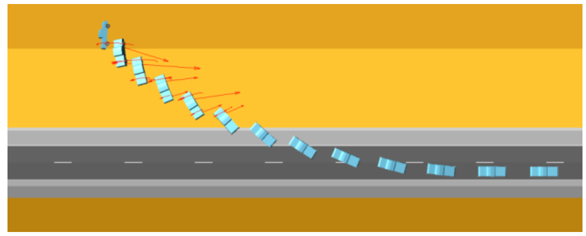
(d) Driver's input for corrective maneuvers
Figure 8. Baseline simulation results for corrective maneuvers



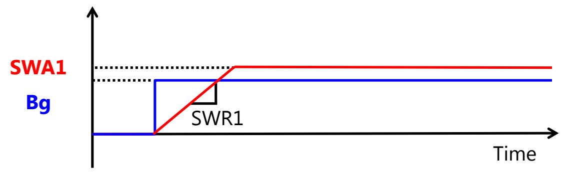
(a) NASS-CDS scene diagram



(b) Reconstructed case by sedan model
Figure 9. Baseline simulation results for non-corrective maneuvers (cont'd)



(c) Reconstructed case by Pickup truck model



(d) Driver's input for non-corrective maneuvers
Figure 9. Baseline simulation results for non-corrective maneuvers

Touchdown Parameters

The functional forms for driver's input (Figure 8 (d) and Figure 9 (d)) for the baseline simulations were used and certain amounts of variations were imposed on each parameter following Gaussian distribution (Table 6). Thirty cases of rollover simulations were run for each target maneuver and vehicle type and the distributions of touchdown conditions were obtained (Figure 10). The sign conventions for touchdown parameters were summarized in Table 5.

Table 5.
Sign conventions for touchdown parameters

Parameters	Description
Roll Rate	(+): passenger side leading rollover
Roll Angle	0 deg < roll angle < 180 deg: passenger side touchdown first
Pitch Angle	(+): touchdown rear-side of vehicle first
Side Slip Angle	0 deg < side slip angle < 180 deg: passenger side tripping

The convergence of the analysis results should be checked by increasing the number of simulations but 30 simulations per each case were used due to the limit of time. Further detailed analysis by using Monte Carlo simulation will be conducted in the future research.

Table 6.
Distributions for sampling driver's inputs

Corrective maneuver	Sedan	Pickup truck
Initial Speed [mi/h]	N(75,10^2)	N(75,10^2)
SWA1 [deg]	N(-35,5^2)	N(-40,6^2)
SWR1 [deg/s]	N(-35,5^2)	N(-40,6^2)
DT1 [sec]	N(0.45,0.15^2)	N(0.5,0.075^2)

SWA2 [deg]	N(130,30^2)	N(120,18^2)
SWR2 [deg/s]	N(-400,100^2)	N(-475,71.3^2)
Brake [g]	N(0.3,0.1^2)	N(0.3,0.1^2)
Non-corrective maneuver	**Sedan**	**Pickup truck**
Initial Speed [mi/h]	N(75,10^2)	N(75,7.5^2)
SWA1 [deg]	N(155,45^2)	N(200,20^2)
SWR1 [deg/s]	N(135,45^2)	N(530,53^2)
Brake [g]	N(0.3,0.1^2)	N(0.25,0.1^2)

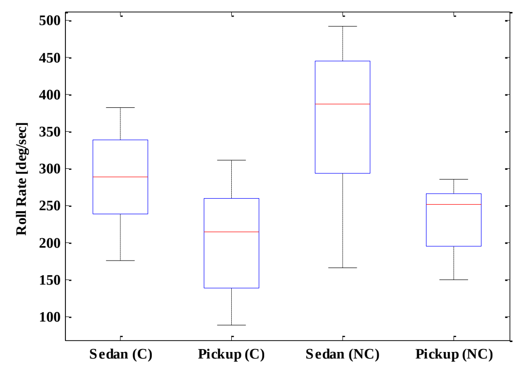
For corrective maneuver, there were 15 and 8 rollover cases of sedan and pickup truck, respectively. Most of the distributions were not Gaussian or unimodal distributions due to the high dimensions of the design space and nonlinearities of vehicle model and road shape so boxplots were used to represent the results. For non-corrective maneuver, there were 13 and 19 rollover cases of sedan and pickup truck, respectively. Most of the distributions of touchdown parameters were not Gaussian or unimodal distributions like the corrective maneuver due to the same reasons mentioned previously.

The median values of roll rates of the sedan were around 290 *deg/sec* and 380 *deg/sec* in corrective and non-corrective maneuvers, respectively. The pickup truck showed lower roll rates in the same types of maneuvers (210 and 250 *deg/sec*, respectively) than those of the sedan. Both vehicles showed higher median values of roll rates in the non-corrective maneuver than those in the corrective maneuver.

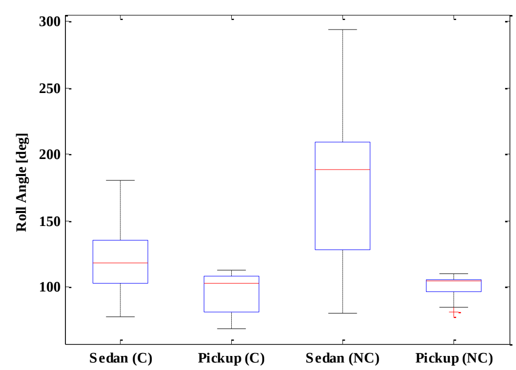
The median values of roll angles at touchdown were higher in the sedan (120 *degrees* in corrective maneuvers and 190 *degrees* in non-corrective maneuvers) than in the pickup (around 103 and 104 *degrees*). The different roll angles at touchdown between the two vehicle types suggest that different countermeasures may be needed to protect occupants in different types of vehicles.

The median values of the drop speeds, which is known to be one of the most influential factors in structural responses of a vehicle during rollover [9], were 1.9 *m/s* and 2.3 *m/s* higher in the non-corrective maneuver (sedan: 2.4 *m/s* and pickup: 2.8 *m/s*) than those in the corrective maneuver (sedan: 0.47 *m/s* and pickup: 0.48 *m/s*) for the sedan and the pickup truck, respectively. This is because the vehicles tended to roll over while going down the slope in non-corrective maneuvers but roll over while going up or along the slope in corrective maneuvers. The higher drop speed can cause more structural deformation during vehicle-to-ground interaction. For the same reason, the signs of median values of pitch angles were different between corrective and non-corrective maneuvers (Figure 10 (d)).

The side slip angle is angle between the longitudinal and traveling directions of a vehicle in vehicle dynamics [14]. In this study, the angle between the projected forward direction of the vehicle on level ground and the direction of tangential velocity of the vehicle was defined as a side slip angle at touchdown. The larger magnitude of this angle means that the vehicle was traveling in more laterally than longitudinally. Since the sedan is more agile than the pickup truck the magnitude of the median values of side slip angles of the sedan were higher than those of the pickup truck (Figure 10 (f)).

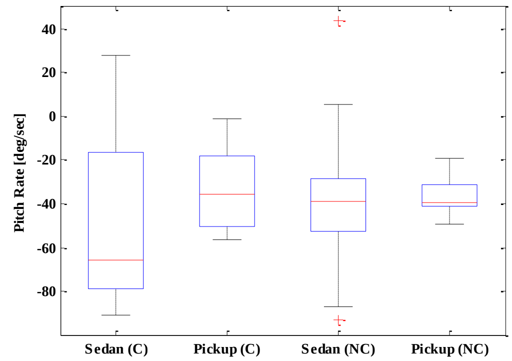


(a) Roll rates at touchdown

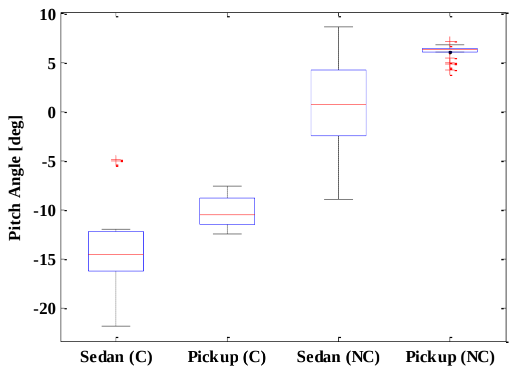


(b) Roll angle at touchdown

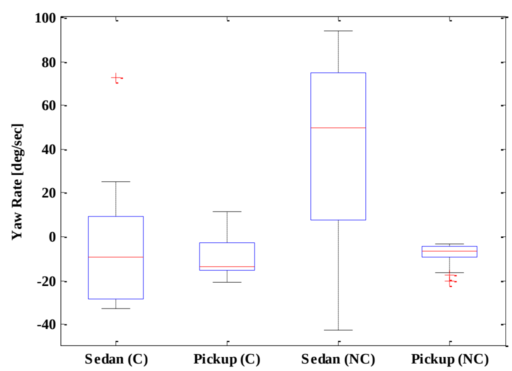
Figure 10. Distribution of touchdown parameters (cont'd)



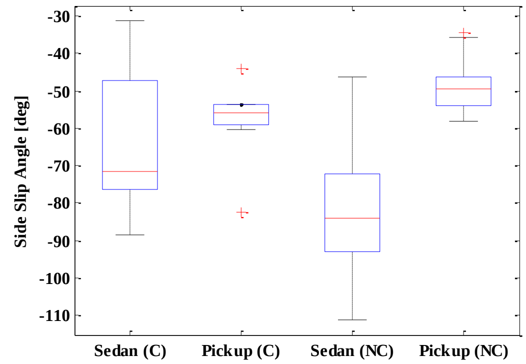
(c) Pitch rate at touchdown



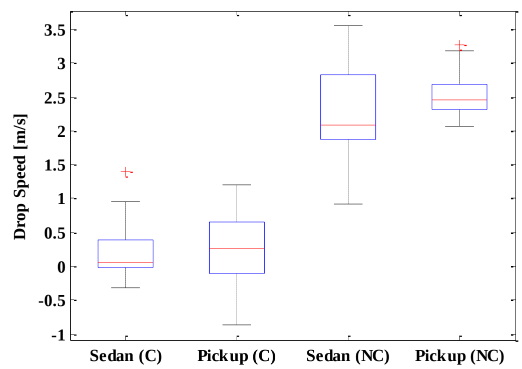
(d) Pitch angle at touchdown



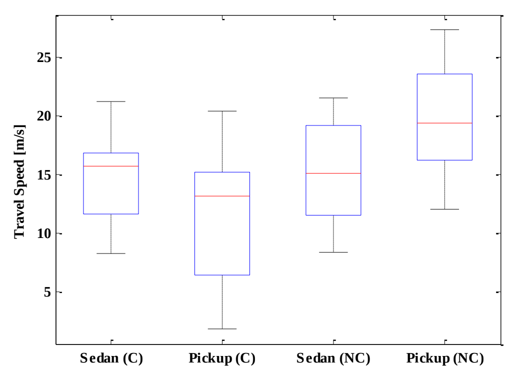
(e) Yaw rate at touchdown
Figure 10. Distribution of touchdown parameters (cont'd)



(f) Side slip angle at touchdown



(g) Drop speed at touchdown



(h) Tangential speed at touchdown
Figure 10. Distribution of touchdown parameters

DISCUSSION

The two vehicle models built in this study showed good correlations with the static and dynamic test data.

Most distributions of the touchdown parameters were not Gaussian-like or unimodal distributions. It seems that the number of simulations was insufficient compared to the level of complexity of the rollover phenomenon because the distributions of touchdown parameters did not show any typical distributions. The result, however, suggested clear differences in some of the touchdown parameters with respect to the types of maneuvers and types of vehicles.

The non-corrective maneuvers resulted in higher roll rates, roll angle, and drop speed at touchdown than those of corrective maneuvers regardless of the considered types of vehicles. The roll angles at touchdown in the non-corrective rollover case tended to larger than those of the corrective rollover case due to the longer airborne phase and higher roll rates. The roll angles of the pickup truck were around 100 *degrees*, which implies touchdown on ground on the side of the vehicle rather than roof area.

The drop speeds were a lot lower in corrective maneuver than those of the non-corrective maneuver because of the travel direction of the vehicles with respect to the slope. The vehicle tended to roll over toward uphill or along the level direction of the slope in corrective maneuvers but the vehicle tended to roll over toward downhill in non-corrective maneuvers. This implies that there could be larger deformation during rollovers induced by non-corrective maneuvers because the drop speed is one of the significant factors that affect the vehicle deformation [9].

The pickup truck showed lower roll rates and roll angles in the both maneuvers than those of the sedan. The different roll angles at touchdown between the two vehicle types suggest that different countermeasures may be needed to protect occupants in different types of vehicles. Interestingly, the median values of drop speeds of the two vehicles were similar to each other in contrast to the differenced in roll behavior.

Another thing, which should be noted, is that in many cases the vehicle touched down on slope due to the road geometry (Figure 3). Many dynamic rollover tests are performed on flat ground and the effect of the geometry of ground should be evaluated to justify the test conditions.

Despite the detailed validations performed on the vehicle models, no steering-induced rollover test data were available to validate the vehicle and soil models. Subsequent to this study, steering-induced rollover tests will be performed to validate the models further. Especially, the soil model should be validated by testing the soil at the test site.

The vehicle kinematics time histories generated through this study can be used for occupant simulations for injury risk assessment during rollover accidents which includes pre-ballistic, ballistic, and until the touchdown. This would be meaningful because vehicle kinematics during pre-ballistic and ballistic phases could affect the location of occupants at the times of counter-measure activation and touchdown. After the touchdown finite element model should be incorporated to consider vehicle deformation after touchdown.

CONCLUSION

Despite these limitations, the methodology and results presented provide for the best available means to determine touchdown parameters for use in controlled rollover crash testing. The data presented show a substantial difference in touchdown conditions with respect to types of vehicles and maneuvers.

Therefore, when a rollover test is performed, the test conditions should be carefully selected depending on types of vehicles or maneuvers to generate realistic outcome.

Especially, the different drop speed suggests that the vehicle will deform more during rollover accidents initiated from non-corrective maneuvers. In addition, different touchdown roll angles imply that different countermeasures for a rollover accident may necessary for different types of vehicles.

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REFERENCES

[1] NHTSA Traffic Safety Facts 2008, Early Edition
[2] P. Jayakumar, J. Alanoly, and R. Johnson. 2005. “Three-Link Leaf-Spring Model for Road Loads” Society of Automotive Engineers, Warrendale, PA, SAE Paper 2005-01-0625
[3] Chi-Ying Liang, R. Wade Allen, Theodore J. Rosenthal and Jeffrey P. Chrstos. 2004. “Tire Modeling for Off-Road Vehicle Simulation”

Society of Automotive Engineers, Warrendale, PA, SAE Paper 2004-01-2058
[4] Bekker, M. G. 1969. “Introduction to terrain-vehicle systems” University of Michigan Press, Ann Arbor, 1969
[5] Wong, J. Y. 1978. “Theory of Ground Vehicle” John Wiley & Sons, New York, 1978
[6] Road Design Manual. 2004. Delaware Department of Transportation
[7] Roadway Design Guidelines. 2007. Arizona Department of Transportation Roadway Engineering Group
[8] A Policy on Geometric Design of Highways and Streets. 2004. American Association of State Highway and Transportation Officials
[9] Daniel P. Parent, Jason R. Kerrigan & Jeff R. Crandall (2011): Comprehensive computational rollover sensitivity study, Part 1: influence of vehicle pre-crash parameters on crash kinematics and roof crush, International Journal of Crashworthiness, 16:6, 633-644
[10] Madana Gopal, Ken Baron, and Minoo Shah. 2004. “Simulation and Testing of a Suite of Field Relevant Rollovers” Society of Automotive Engineers, Warrendale, PA, SAE Paper 2004-01-0335
[11] Terry D. Day. 2005. “Simulation of Tire Interaction with Curbs and Irregular Terrain’, Engineering Dynamics Corporation, HVE White Papers, Library Ref. WP-2005-6.
[12] David C. Viano and Chantal S. Parenteau. 2004. “Rollover Crash Sensing and Safety Overview” Society of Automotive Engineers, Warrendale, PA, SAE Paper 2004-01-0342
[13] George S. Fishman. 2011. “Monte Carlo: Concepts, Algorithms, and Applications”,New York, NY: Springer.
[14] Thomas D. Gillespie. 1992. “Fundamentals of Vehicle Dynamics” Society of Automotive Engineers
[15] ISO 3888-1:1999 Passenger cars – Test track for a severe manoeuvre – Part 1: Double lane-change