

Modeling of Truck-Car Sideswipe Collisions Using Lug Patterns

Michael S. Varat, Stein E. Husher, John F. Kerkhoff
Christopher D. Armstrong and John C. Steiner
KEVA Engineering, LLC.

Copyright © 2008 SAE International

ABSTRACT

Vehicle to vehicle sideswipe collisions may involve contact between a vehicle body and a contacting vehicle's rotating wheels, tires and lug nuts. During a sideswipe collision between a truck and an automobile it is not uncommon to see lug marks in the shape of consecutive damage loops or strikes on the side of the impacted vehicle. The damage loops or strikes are generated by the protruding lug nuts of the truck wheel as it passes by the impacted vehicle at a shallow angle. Additionally, rubber transfers due to contact with the tire sidewall and metal scraping from the wheel rim also leave distinctive shapes on the sides of the contacted vehicle body. The tire, rim, lug nut markings and associated damage manifest themselves as a special case of the epitrochoid and can be geometrically and mathematically described. Presented is a derivation of the equations that govern the lug, rim and tire positions and relative motions. The equations are derived in terms of the speeds of the two impacting vehicles as well as the relevant geometry. A spreadsheet implementation of the equations facilitates their application to accident reconstruction. Staged collision testing using instrumented vehicles at known speeds was conducted. The mathematically derived shapes were compared to the staged collision test contact patterns. The application to transportation accident reconstruction is discussed.

INTRODUCTION

Over the years the authors have analyzed numerous real world collisions involving a rotating truck wheel contacting the side of a moving vehicle. It was observed that a distinctive pattern resulted on the side of the contacted vehicle and that a detailed analysis could yield information regarding the relative position and speeds of the two vehicles.

LITERATURE REVIEW

Hurt [Hurt, 1973] studied sideswipe collisions between cars and motorcycles and noted cycloidal marks developed by contact between the outer tread rib of the rotating front motorcycle tire and the side of the car. In examining the angle of the cycloidal marks, it was noted that the relative speeds between the vehicles could be determined. Hurt also noted that this technique yielded a value for the "proportion" of speed between the vehicles but did not yield absolute speeds. The absolute speed of one of the vehicles must be determined using other accident reconstruction techniques. While Hurt examined one aspect of the angle of the cycloidal strike, he did not attempt a reconstruction of the entire cycloidal shape and associated characteristics. Neither did he study the interaction and relationship between multiple strikes to the vehicle in the determination of relative speed.

Levy [Levy, 2000] performed an analysis identifying some of the equations governing the cycloidal marks on a vehicle from a rotating truck tire. Levy's work studied the width of the mark left by the trace of a single rotation of the truck tire. Multiple strikes were not examined and the spacing between multiple lug mark impressions was not studied. No crash testing was performed, no field studies were included and no validation of the method was presented.

REAL WORLD EXAMPLES

Figures 1 and 2 show typical markings seen in truck to car sideswipe collisions. While the truck involved in this collision was never identified, several conclusions can be drawn from the residual marks. The strikes on the left rear lower bumper return and quarter panel are at the correct height and orientation to be caused by truck front wheel lugs. The circular pattern on the left front door (Figure 2) was made by the protruding lugs of a heavy truck front wheel.



Figure 1. Lug contacts on left rear of vehicle.



Figure 2. Circular lug contacts on left front door.

A second example of markings due to truck to car interaction is shown in Figures 3 and 4. Lug marks can be seen at the left rear corner of the rear bumper return along with a round orange paint transfer where the bumper return meets the fender. Figure 4 shows the truck wheel that interacted with the car in Figure 3. Note that the darker hub in Figure 4 is the same orange color as the paint transfer seen in Figure 3.



Figure 3. Left side contact on right rear corner.



Figure 4. Right front truck wheel that contacted the left side of the car in Figure 3.

Figures 5 and 6 demonstrate another example of truck to car interaction. Lug contact marks are evident forward of the left rear wheel. Note also the forward deformation of the wheel cutout.



Figure 5. Lug markings ahead of left rear wheel.



Figure 6. Right front truck wheel that contacted the left side of the car in Figure 5.

Figures 7 and 8 show a final example of truck to car interaction. Note the distinct forward arcing marks on the black plastic trim.



Figure 7. Lug contact mark on lower left rear trim.



Figure 8. Wheel of truck that contacted the car in Figure 7.

Real world collisions often generate marks from the wheel lugs of the contacting vehicle, Figures 1 through 8. Careful inspection, and/or photo analysis, allows the investigator to determine many key details about those marks. This present research is to determine whether an analysis of the lug patterns will yield information about the speeds of the colliding vehicles.

TEST PROCEDURE

A series of 8 tests were performed to investigate the nature and characteristics of the markings left by a rotating truck wheel contacting the side of a car at a shallow angle and various differential speeds. The testing was performed at a closed test facility on a straight, level, asphalt road surface. A test summary is given in Table 1.

Table 1. Test summary.

Run #	Time (sec)	Truck Impact Speed kph (mph)	Olds Impact Speed kph (mph)		Speed Differential kph (mph)
		Impact Duration	VBox III	VBox II Datron	At Impact
1	0.23		80.0	81.4	82.1
			(49.7)	(50.6)	(51.0)
2	0.30		75.8	71.7	73.1
			(47.1)	(44.6)	(45.4)
3	0.52		84.0	73.1	74.2
			(52.2)	(45.4)	(46.1)
4a	0.37		70.2	70.8	71.9
			(43.6)	(44.0)	(44.7)
4b	0.57		69.8	70.5	71.5
			(43.4)	(43.8)	(44.4)
5	0.67		53.1	45.6	45.7
			(33.0)	(28.3)	(28.4)
6	0.42		72.2	82.0	no data
			(44.8)	(51.0)	no data
7	0.47		77.4	89.5	91.6
			(48.1)	(55.6)	(56.9)
8	0.30		49.1	60.5	61.0
			(30.5)	(37.6)	(37.9)

For this test series, a 2006 International stake bed truck was used to strike a 1997 Oldsmobile Cutlass Supreme SL Sedan. The test vehicles are shown in Figures 9 and 10. The front bumper and hood were removed from the International truck and the fuel tank was repositioned. This allowed the truck front wheel to mark the side of the car without interference from other structures that may have caused overlying damage. It should be noted that in field accident cases, bumpers, fenders, and other truck components may interact and cause associated damage to the car that may affect the residual lug mark patterns. This associated damage was not studied in this test series. Additionally, a metal framework was added to the truck, above the cab, for camera mounting.



Figure 9. Test truck.



Figure 10. Test car.

The Oldsmobile was non-operational during most of the testing and was towed using a tow strap. During vehicle interaction slack was allowed to develop in the tow rope so that it did not influence vehicle dynamics. No prior body damage was present on the Oldsmobile. The impacts were aligned to concentrate damage on the Oldsmobile doors and to minimize damage to other areas of the car. A second set of doors was obtained for the Oldsmobile in order to perform 8 tests using a single vehicle chassis. Both vehicles were photographically documented before and after every test.

The truck was instrumented with a Racelogic VBOX III data acquisition package collecting data at 100 Hz. Collected data included velocity, position, 3 axis acceleration, 3 axis rotational rate, and steering wheel force. The car was equipped with a Racelogic VBOX II data acquisition package collecting data at 20 Hz. A Datron DLS optical speed sensor was also used on the Oldsmobile collecting data at 10 Hz. Collected data included velocity and position. Additionally, multiple video cameras were employed on the truck, on the car, and at ground based stationary positions to capture the impacts from multiple vantage points.

Impacts were performed on the sides of the Oldsmobile. Impacts to the right side of the Oldsmobile involved equal or slower car speeds when compared to the truck speed. Conversely, contacts to the left side of the Oldsmobile involved faster car speeds. Figures 11-13 show the approximate impact alignment between the Oldsmobile and the rotating truck tire.

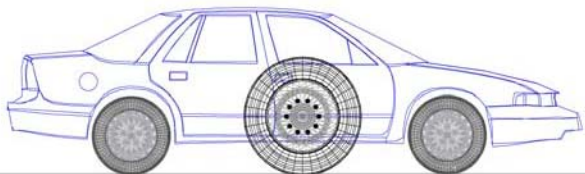


Figure 11. Side view alignment drawing.

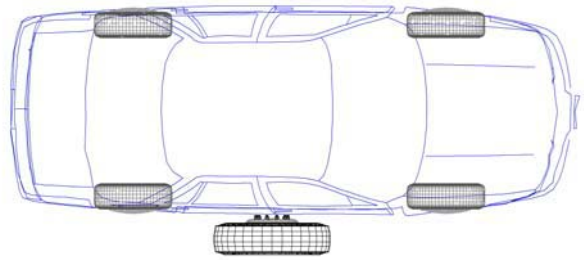


Figure 12. Plan view alignment drawing.

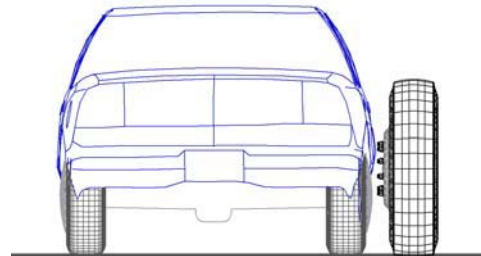


Figure 13. Rear view alignment drawing.

TERMINOLOGY

As was previously noted, distinctive patterns develop due to the contact between the exposed lugs of a truck and the vehicle sheet metal. Figure 14 presents some of the pertinent aspects of a single lug contact pattern to consider when viewing the test results. Specifically, the lug patterns develop concavity oriented upward or downward. The associated loops are also oriented upward or downward. The lug patterns can be further described by their cycle span and loop width.

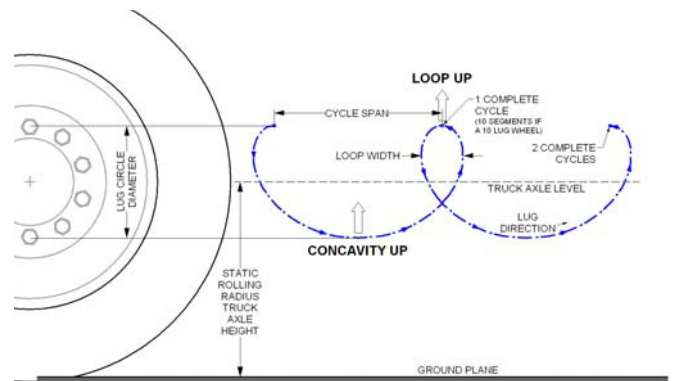


Figure 14. Terminology.

TEST RESULTS

When analyzing the test results it was necessary to determine the point at which contact began, the Start of Contact (SOC), and the point at which contact ended, the End of Contact (EOC). These parameters, along with the vehicle stopping point, allowed the test data to be referenced to a common time base.

While the test protocol dictated that the primary impacts would occur at the door area, the practical aspects of conducting the tests occasionally resulted in contact to adjacent areas of the vehicle. In those

instances photos are included showing the associated damage to the car.

Test 1, Figures 15 and 17, involved a very light contact. In this test both vehicles were at approximately the same speed. As can be seen, the lugs lightly marked the beltline trim in two localized areas. The marks were from the front and rear of the rotating lugs.

Test 2, Figures 16 and 18, involved a truck interacting with the right front door of a slower moving car. As can be seen, the aft edge of the door was crushed forward and the concavities of the lug marks are downward.

Test 3, Figures 19 and 20, also involved a slower moving car. This time the right rear door was impacted. The forward portion of the right rear wheel opening was deformed forward. The lug pattern over the door had a downward concavity.

Test 4, Figures 21 and 22, was a two impact event. Both vehicles were at approximately the same speed. The impacted door was the right front. The lugs traced a circular pattern in the sheet metal of the door. As contrasted with the equal speed Test 1, Test 4 was a more sustained contact that caused contact to and deformation of the sheet metal.

Test 5, Figures 23 and 24, involved a slower moving car impacted at the right rear door. The door from Test 3 had been removed prior to this test and replaced with an undamaged door. While the damage to the forward portion of the right rear wheel opening was from Test 3, Test 5 clearly tore the aft portion of the right rear door forward. The lug pattern trend moved upward due to the truck wheel moving upward, relative to the car, as the contact progressed. While the truck driver provided small steering wheel inputs in order to bring the vehicles together, the contact and interaction resulted in some observed induced steering of the contacted wheel due to impact forces. Figure 31 shows the tire during the contact period and

the induced steering can be seen in the middle frame. Care should be exercised when trying to reach conclusions regarding driver steer input based on the depth of the observed marks. Induced steering affects are a confounding variable in this analysis and must be considered.

Test 6, Figures 25 and 26, involved a faster moving car contacting the right front wheel of the truck with the left front door. As contrasted with the previous runs, the lug pattern in this test was concave upward. Additionally, in this test, we saw the complete loop cycle tracing of the lug pattern. In previous runs the loop cycle tracings were not as well defined. The relative vertical position of the truck wheel against the side of the car also changed during the contact period which can be seen as an upward and downward trend to the damage markings on the door.

Test 7, Figures 27 and 28, involved a faster moving car contacting the right front wheel of the truck with the left rear door. The instrumentation failed to record data for the truck in Test 7. Analysis of the overhead video was performed and differential speed between the truck and car was determined. Using the measured car speed (GPS based) and the differential speed data (video based) allowed calculation of the truck speed. The damage pattern showed a distributed contact area to the left rear quarter panel, left rear wheel, and left rear door. As with Test 6 the lug pattern is concave upward.

Test 8, Figures 29 and 30, involved a faster moving car contacting the right front wheel of the truck with the left front door. The door from Test 6 had been removed prior to this test and replaced with an undamaged door. The damage pattern showed upward concavity in the lug markings. The damage to the left front fender, ahead of the door, occurred during Test 6. The damage to the forward portion of the left rear door also occurred during Test 6 and Test 8. There are light lug marks from Test 6 which are overlaid by heavier lug marks generated during Test 8.



Figure 15. Test 1 – Right front door post test.



Figure 16. Test 2 – Right front door post test.

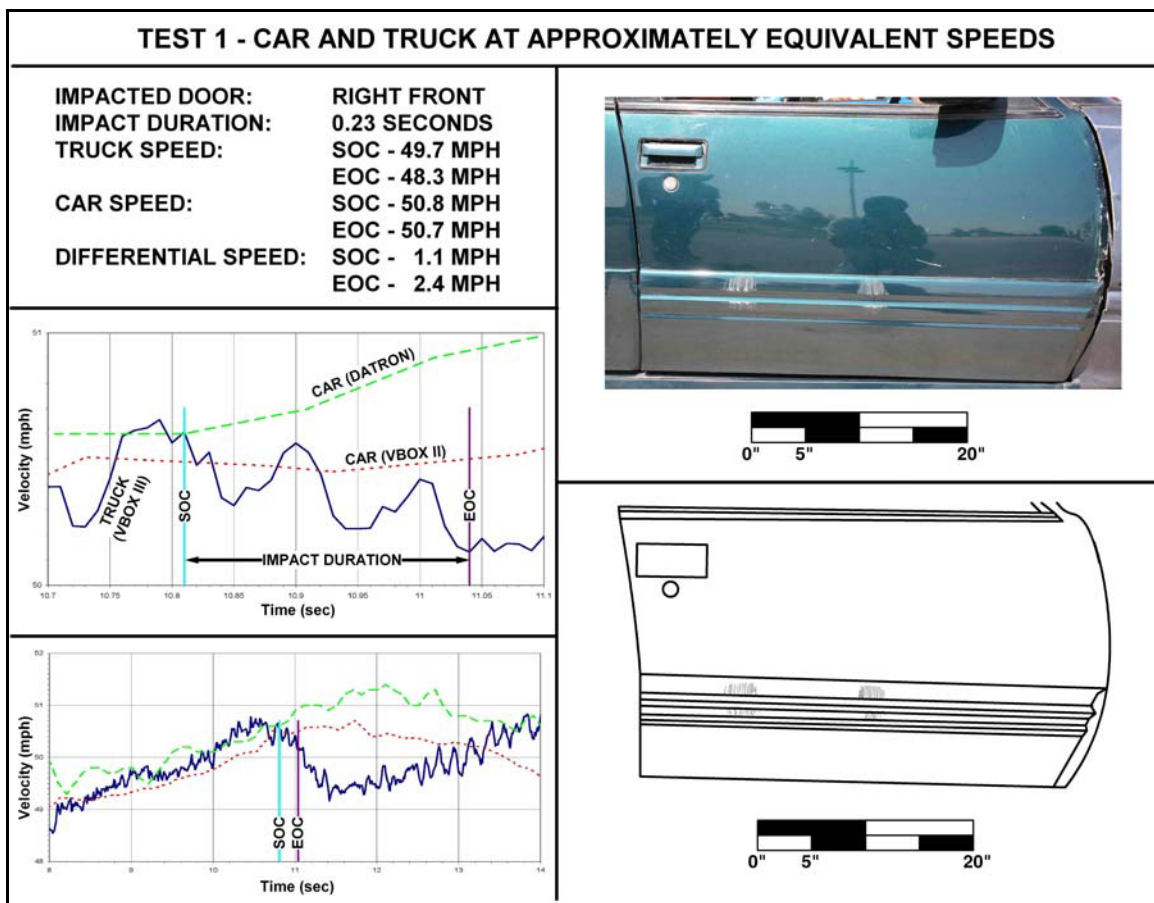


Figure 17. Test 1 results.

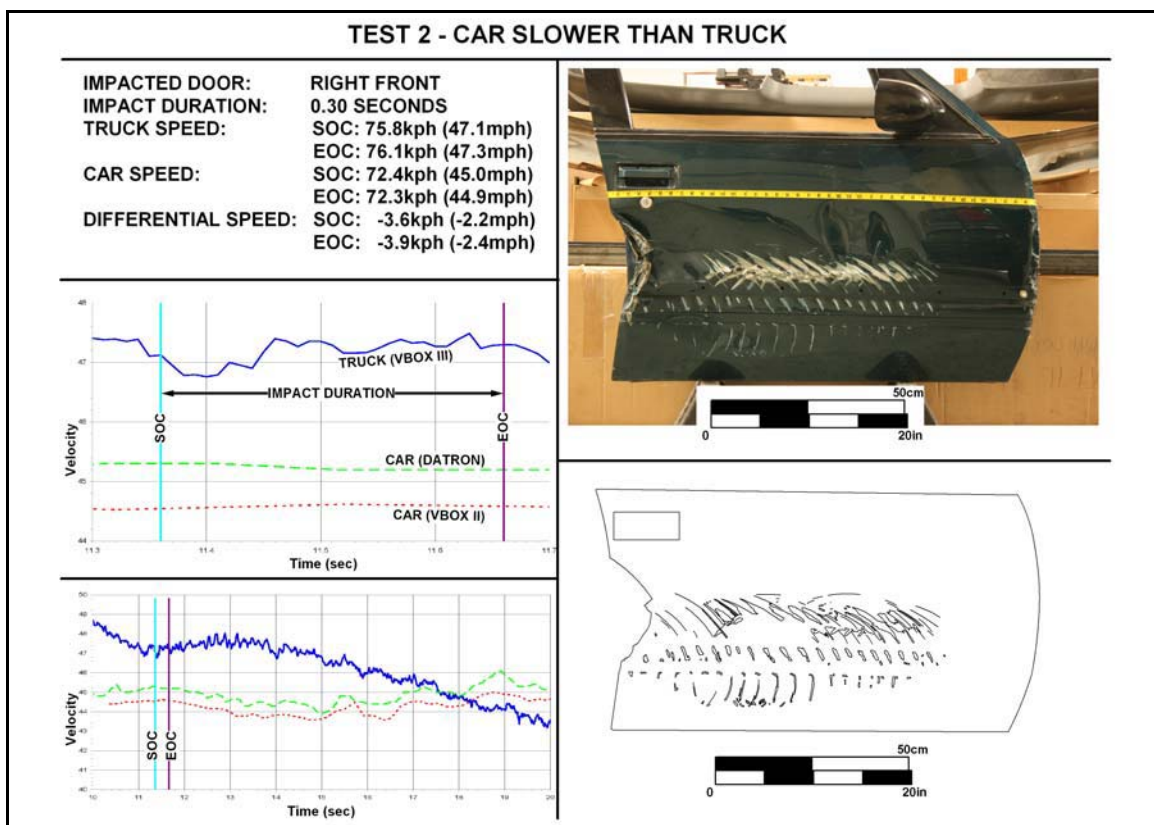


Figure18. Test 2 results.