Journal of Criminal Law and Criminology

Volume 58 | Issue 1 Article 14

1967

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Recommended Citation

Conrad K. Rizer, Estimating the Speed of a Motor Vehicle in a Collision, 58 J. Crim. L. Criminology & Police Sci. 119 (1967)

THE JOURNAL OF CRIMINAL LAW, CRIMINOLOGY AND POLICE SCIENCE
Vol. 58, No. 1

ESTIMATING THE SPEED OF A MOTOR VEHICLE IN A COLLISION

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Two motor vehicles collide in a tragic accident in which one or more persons are fatally injured. The driver of one car is charged with manslaughter. The prosecution wants to know the speed of the defendant's car at the time of the collision. However, in order to estimate the speed of the defendant's car, it may be necessary to also estimate the speed of the other vehicle at the time of the collision as well as the speeds of both vehicles after the collision. If these values can be determined from evidence in the case, they can then be used in a vector relationship in a conservation of momentum equation in order to obtain the speed of the defendant's car at the time of the collision.

In part I of this article the five methods for determining the speed of a vehicle in a collision are discussed, and in part II two cases are cited in which the five methods are used in order to determine the speeds of the vehicles.

PART I. METHODS

Method I. A Speed Estimated from Skidmarks. The estimated speed of a vehicle may be found from its skidmarks on a level surface by use of the equation

$$V = 5.5\sqrt{fs} \qquad (1)$$

where V is in miles per hour, f is the coefficient of friction, and s is the average length of the skidmarks in feet.

It is necessary to know the coefficient of friction for the tires of the vehicle concerned and for the road surface. Coefficients are available in charts and reports, but if possible, the coefficient should be obtained for the vehicle involved in the accident or for comparable vehicles and tires. In order to obtain the coefficient for a given vehicle, the brakes are applied at a given speed, causing the tires to skid until the vehicle comes to rest (fig. 1). Thus, if the brakes are applied at 30 mi/hr and the average length of the skidmarks for the four tires is 41 ft., the value of f is obtained by substituting these values in Equation (1) and solving this equation, $f = 0.71$.

Thus, Equation (1) can be used to obtain both the coefficient of friction and the speed of the vehicle in the accident.

Method 2. The Maximum Speed for a Vehicle Moving Along an Arc Without Side Slipping and Estimated from the Radius of Curvature of the Arc and the Coefficient of Friction. The frictional force between tires and road surface just balances the centrifugal force of the curvilinear motion. If the

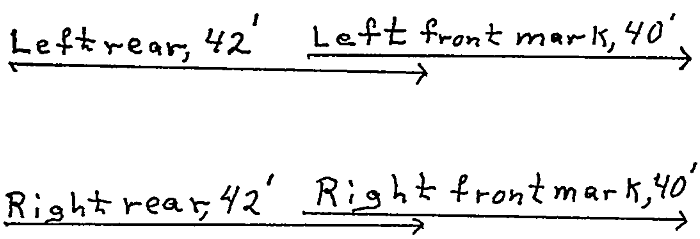

FIGURE 1
Average Skidmark Length

$$\frac{40' + 42' + 40' + 42'}{4} = 41'$$

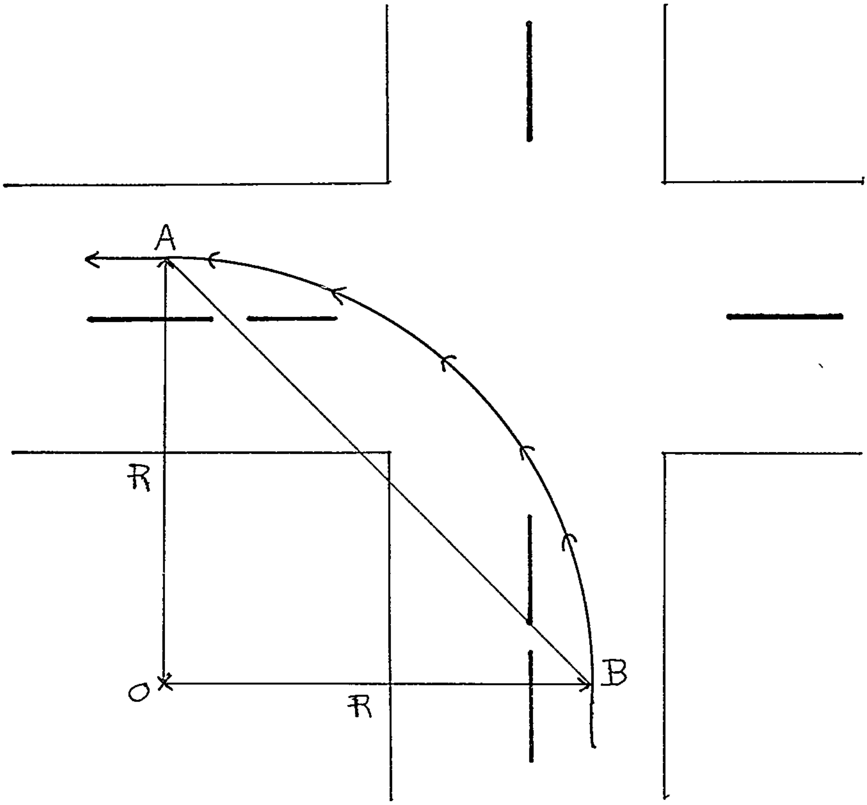

FIGURE 2

$$R = \frac{\text{chord } AB}{1.41} = OA \text{ and } OB$$

For $AB = 53.3$ feet, $R = 37.8$ feet

For $f = 0.7.$ in Equation 2, and $R = 37.8$ feet,

$v = 29.4$ ft/sec, and 20.0 mi/hr

vehicle's speed were greater, side slipping would occur. For the normal average driver the most probable course for a vehicle making such a turn would be along the arc of a quarter circle (fig. 2). The radius of this arc is found from the straight line distance between where the vehicle starts to turn and where the turn ends. The radius of the arc is equal to the measured distance divided by the square root of 2, or 1.41. The maximum speed V is found by the use of the equation

$$V = \sqrt{gfR} \qquad (2)$$

where g is the gravitational constant, 32.2 ft/sec^2, f is the coefficient of friction, and R is the radius of the arc. This speed will be in feet per second. The speed in miles per hour is obtained by multiplying this value by 15/22.

The above speed may be significant for a collision at an intersection.

Method 3. The Initial Speed for a Vehicle Caused to Side Slip along an Arc Due to the Driver Losing Control and Estimated from the Radius of Curvature and the Coefficient of Friction.[1] The width and density of the skidmarks are different for each tire. The skidmark which is widest and most dense is used for measurements. This mark will closely approximate the arc of a circle (fig. 3). On either

[1] RIZER, CONRAD K.: Mathematical Methods Used in a Manslaughter-by-Automobile Case, POLICE, Nov.–Dec., 1956, pp. 63–65.

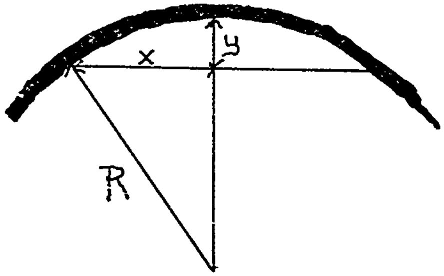

FIGURE 3

the outer or inner edge of the mark two points are selected as boundaries of an arc. The arc's length should be as great as possible provided that this portion of the skidmark approximates the arc of a circle. A straight line distance is measured between the two points and in mathematical terms is the chord of the arc. At the center of the chord a perpendicular distance is measured from the chord to the arc. Let this distance be represented by the symbol y and the half length of the chord by x. It may be shown that the radius of the arc is

$$R = \frac{x^2 + y^2}{2y} \tag{3}$$

The speed of the vehicle is found by using Equation (2)

Method 4. The Initial Speed for a Vehicle Caused to Side Slip along an Arc Due to Impact with Another Vehicle, and Estimated from the Length of the Arc and the Coefficient of Friction. When a vehicle is struck by another vehicle so that it rotates through an angle and that angle is known, it is possible to determine the vehicle's breakaway speed. This speed might be obtained through a calculation involving the use of the radius of some arc. However, in cases where the angle turned through can be found and the length of the chord between the vehicle's center of gravity at the initial and final positions is measured, the length of the arc turned through by the center of gravity can be determined by the use of the following geometric relationship for which it is not necessary to know and use the radius of the arc.

$$\text{Length of the arc} = \frac{A(\text{Length of the Chord})}{115 \sin \frac{1}{2}A} \tag{4}$$

A being the angle turned through in degrees.

The following example illustrates the use of Equation (4) (fig. 4). A vehicle, after being struck, rotates through an angle of 90°. The length of the chord is 40 feet.

$$\begin{aligned}\text{Length of the arc} &= \frac{90° \times 40 \text{ feet}}{115 \sin 90°/2} \\ &= \frac{90° \times 40 \text{ feet}}{115 \sin 45°} \\ &= 44 \text{ feet}\end{aligned}$$

The breakaway speed is obtained by the use of Equation (1), the length of the arc being the distance in the equation.

Method 5. The Breakaway Coasting Speed of a Vehicle in a Collision Estimated by Use of Graph and Slope Methods. A vehicle strikes and shears along a second vehicle, but moves on with wheels turning freely. The engine no longer delivers power; only the momentum keeps the vehicle moving as the speed slowly decreases. No human effort controls this motion. The breakaway speed of this vehicle cannot be calculated in terms of skidmark lengths or a coefficient of friction. However, if there is evidence that the vehicle came to a stop with a constant deceleration, then it is possible to find the breakaway speed by the use of graph and slope methods. This is discussed in Case 1.

PART II CASES

Case 1. A collision took place on a level two-

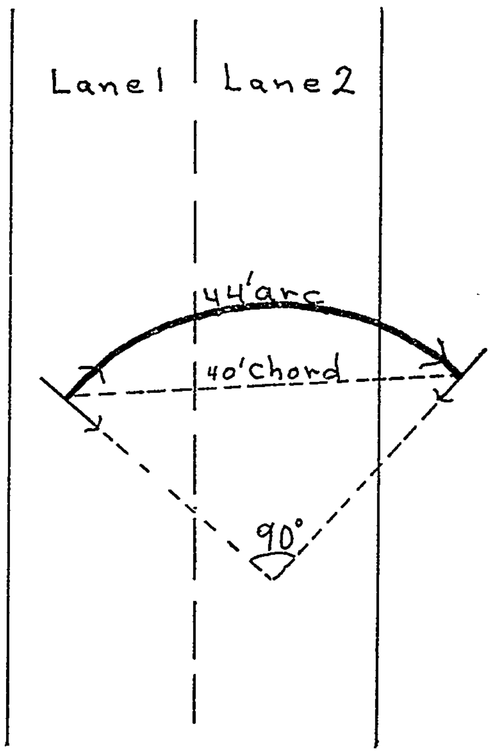

FIGURE 4

lane highway soon after nightfall. The weather was fair, and the cement twelve-foot lanes were conducive to high speeds. The cars, A and B, were coming from opposite directions. Shortly before the collision the driver of Car A lost control of his car so that it started to move into the opposing lane. As soon as the driver of Car B sensed that Car A was entering his lane, he tried to avoid a collision by turning right and then left. On impact, Car B was at an angle of 42°55′ with the direction of the highway, as shown by measurements taken by the State Police. The right front end of Car A sheared along the right side of Car B, causing Car B to rotate through an angle of 167° between the time of the breakaway of the two cars and the coming to rest of Car B. Car A experienced a rocker or turning action as it sheared along Car B so that at breakaway it was moving almost parallel with the highway—a difference of little more than 2°. The driver of Car A, the only occupant, was catapulted from his seat through the open door on the driver's side. The impact had caused the door to spring open. Even though the engine was not delivering power, the car had enough momentum to travel 268 feet along the highway before it reached the outer edge of the shoulder where it went down an embankment and a short distance into a field. It was reasonable to assume that if the car had remained on the highway, it would not have traveled much farther than 268 feet. In a subsequent study of the car it was determined that the wheels had turned freely the entire time.

The investigation of this accident resulted in a charge of manslaughter being brought against the driver of Car A. In order to estimate how fast Car A was traveling at the time of impact, it was necessary to find the speed of this car as it broke contact with Car B, as well as the speeds of Car B, both before and after impact.

In order to find the speed of Car A as it left Car B, the following test was conducted in the same area in which the accident took place, using a car similar to the defendant's car. The test car, with automatic transmission, was brought to speeds of 30, 40, 50, 60, and 70 miles per hour. At each of these speeds the ignition switch was turned off, but the selector lever for the automatic transmission was left in "drive". For each speed, the distance the car coasted until coming to a full stop was read on the speedometer. These data are:

Speeds	*Distance Coasted*
30 mi/hr (44 ft/sec)	0.20 mi (1056 ft)
40 mi/hr (59 ft/sec)	0.30 mi (1584 ft)
50 mi/hr (73 ft/sec)	0.40 mi (2112 ft)
60 mi/hr (88 ft/sec)	0.45 mi (2376 ft)
70 mi/hr (103 ft/sec)	0.55 mi (2904 ft)

Two tests were made for each speed.

When the above data were plotted, it became evident that there was a reliable relationship between speed and distance coasted for the first three speeds, 30, 40, and 50 miles an hour, but not for the last two speeds. The import of this information is that the first three speeds could be used to find the breakaway speed of Car A. This speed may be determined by either the graph or the slope method. (fig. 5).

1. Graph Method. Using the usual form of two-dimensional graph, the speeds are plotted on the horizontal axis, with corresponding distances on the vertical axis. These distances should be expressed in decimal parts of a mile and also in feet for reference convenience. It should be kept in mind that the graph may serve as evidence in court as to the speed of the car. Thus the graph should be of a size and legibility suited to this use. With the completion of the scaling of the axes, the coordinates of the three points are plotted. It is evident that the points lie on a sloping straight line. Such a line is drawn through them and extended to the horizontal axis. The graph may now be used in order to find the speed of Car A.

The distance of 268 feet is found and marked on the vertical axis. From this point a horizontal line is drawn to the sloping line through the plotted points. Vertically below the crossing of these lines the speed of the car will be found, which is approximately 15 mi/hr. That is, this graph method may be used if it is permissible to consider the value of the speed to only two places. If the 15 mi/hr were a final result, the two-place value might be acceptable, but since this speed is to be a part of a calculation to find the speed of Car A before the collision, let us now consider a method by which the value of this speed may be found to three places.

2. Slope Method. In the Graph Method four points were established on the straight line by means of pairs of coordinates. Each point had a speed and a distance value. These pairs of values may be written in parentheses for the series of

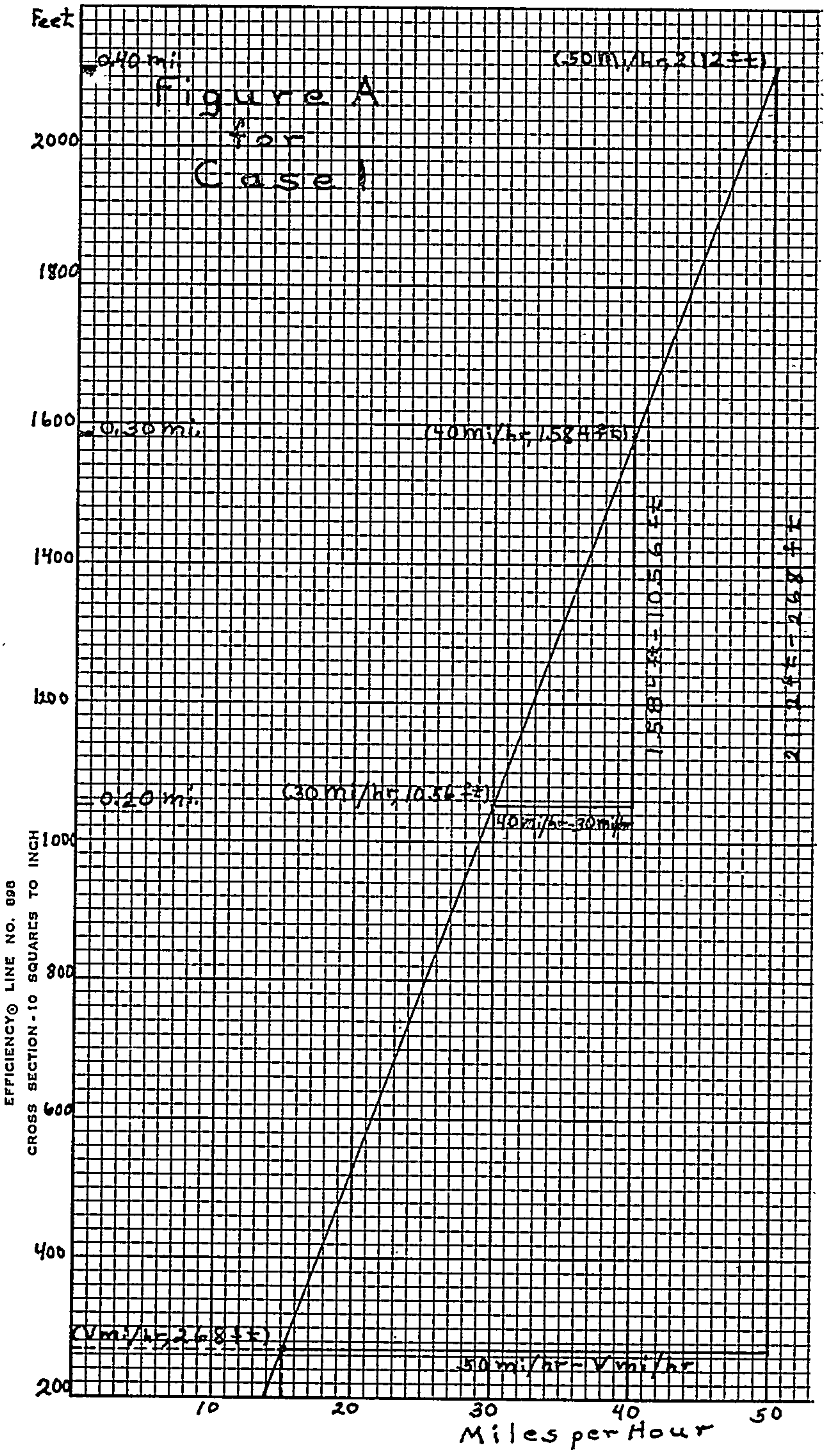
Feet
0.40 mi.
Figure A for Case 1
(50 mi/hr, 2112 ft)
2000
1800
1600
0.30 mi.
(40 mi/hr, 1584 ft)
1400
1584 ft − 1056 ft
2112 ft − 268 ft
1200
0.20 mi.
(30 mi/hr, 1056 ft)
40 mi/hr − 30 mi/hr
1000
800
600
400
(V mi/hr, 268 ft)
50 mi/hr − V mi/hr
200
10
20
30
40
50
Miles per Hour
EFFICIENCY LINE NO. 898
CROSS SECTION - 10 SQUARES TO INCH

FIGURE 5

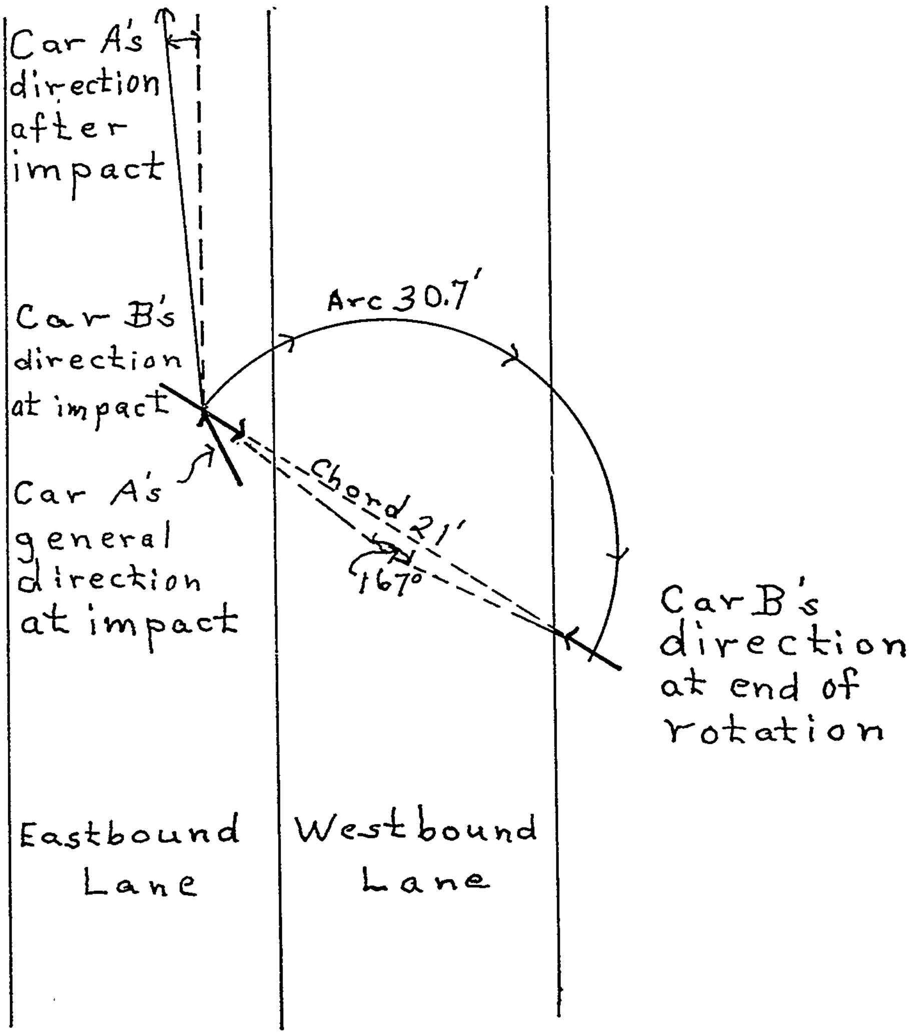

FIGURE 6

points as follows: (30 mi/hr, 1056 ft), (40 mi/hr, 1584 ft), (50 mi/hr, 2112 ft), and (V mi/hr, 268 ft). These coordinates may now be used to set up the following proportion in terms of the slope of the line.

$$\frac{1584 \text{ ft} - 1056 \text{ ft}}{40 \text{ mi/hr} - 30 \text{ mi/hr}} = \frac{2112 \text{ ft} - 268 \text{ ft}}{50 \text{ mi/hr} - V \text{ mi/hr}}$$

Solving this expression for V,

$$\frac{528}{10} = \frac{1844}{50 - V}$$

$$V = 15.1 \text{ mi/hr}$$

The more visual these methods can be made, the easier it will be for the court to understand them. While a blackboard might be available in the courtroom, it would be much better to have a prepared graph suitable for court use.

The driver of Car B told the State Police who investigated the accident that the speed of his car before impact was 35 mi/hr. It was possible to estimate the speed of Car B as it broke away from Car A in the following way. At the scene of the accident it was possible to determine the position of Car B when it was struck, and the angle between its direction and that of the highway. It was also possible to determine the final position of Car B and its direction with the highway. From this information it was found that the car had rotated through 167°, and that the distance between the car's center of gravity at the initial and final positions was 21 feet (fig. 6). This length is the chord of the arc swept out by the center of gravity as it rotated through 167°. To find the length of the arc, Equation (4) is used.

$$\text{Length of arc} = \frac{167° \times 21 \text{ feet}}{115 \times \sin (167°/2)}$$

$$= \frac{167° \times 21 \text{ feet}}{115 \times \sin 83.5°}$$

$$= 30.7 \text{ feet}$$

The breakaway speed is obtained by the use of Equation (1), the length of the arc being the distance in the equation, that is

$$V = 5.5 \sqrt{.71 \times 30.7}$$

$$= 25.7 \text{ mi/hr}$$

The three speeds for Cars A and B have been found, but before it is possible to find the speed of Car A at the time of the collision, the components along the direction of the highway, for each of the three speeds must be found. They are

Car A after impact: 15.1 cos 2°14′ = 15.1 mi/hr
Car B before impact: 35.0 cos 42°55′ = 25.6 mi/hr
Car B after impact: 25.7 cos 47°5′ = 17.5 mi/hr

These component speeds are now used in a conservation of momentum equation in order to find the speed of Car A along the highway at the time of the collision.

Momentum may be defined in this case as the product of the weight of the car and passengers and the speed of the car. The weights of the cars and passengers are: Car A = 4260 pounds, Car B = 4012 pounds. The momentum equation is

$$4260\, V + 4012(-25.6) = 4260 \times 15.1 + 4012 \times 17.5$$

$$V = 56.0 \text{ mi/hr}$$

The left-hand products are momenta before impact, the right-hand, after impact. The speed of Car B before impact is written with a negative sign because the direction of motion of B is opposite to that of A. The investigation of this accident brought to light no evidence as to the angle at which Car A struck Car B, except that it was at an angle between 0° and 42°55′ with the highway. The speed of 56.0 mi/hr, calculated above, is Car A's speed parallel to the highway. If this car had been traveling at any of the following angles with the highway, its speed would have been:

10°	$V = 56.0/\cos 10° = 56.9$ mi/hr
20°	$V = 56.0/\cos 20° = 59.6$ mi/hr
30°	$V = 56.0/\cos 30° = 64.7$ mi/hr
40°	$V = 56.0/\cos 40° = 73.1$ mi/hr

Mention was made of the rocker action of Car A as it sheared along Car B until it was traveling almost parallel with the highway. This concept of the action of Car A while in contact with Car B is the result of the study of the impacted areas of the two cars. On the basis of this situation, the probable speed of Car A at the time of the collision was in the sixties, possibly the upper sixties.

Case 2. In this case an open foreign sports roadster, with two occupants, was struck by a much heavier car, with five occupants. Let the roadster be referred to as Car C and the second vehicle as Car D. The action took place at night. Car C turned from a dual lane westbound highway into the dual lane eastbound highway. The two highways were connected by a crossover, 33 feet in length. During the time that Car C was turning from one highway into the other, Car D on the eastbound highway was approaching the crossover. The drivers of both cars had ample opportunity to observe the lights of the other car. There were no obstructions between the cars. The weather was clear, and there was no illumination near the cars. The concrete highways were dry, and level, with lane markings; each was 24 feet in width, with 12 foot lanes, and an 8 foot shoulder. The driver of Car C observed the lights of Car D as a head-on motion so that an estimate of speed would have been difficult. Conversely, the driver of Car D observed the lights of Car C as a transverse motion, so that an estimate of speed would have been possible.

The driver of Car C decided that there was time to turn into the slow lane of the eastbound highway before Car D arrived. This decision presupposed that the driver of Car D would turn into the fast lane in order to pass. There was evidence in the subsequent investigation that Car D could have turned into the fast lane and passed, not with panic effort, but with controlled driving effort. However, the driver of Car D kept to the slow lane, overtaking Car C 23 feet east of the

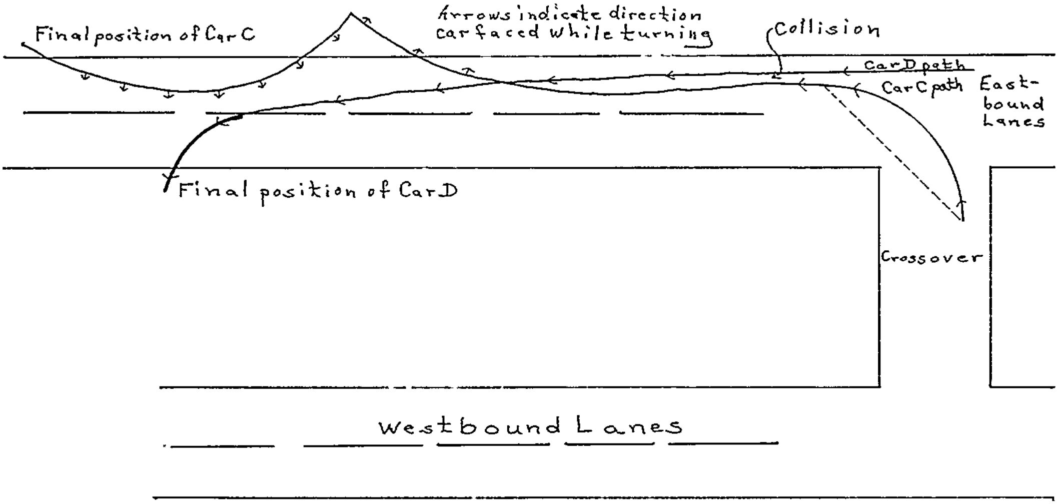

FIGURE 7

east edge of the crossover as indicated by tire marks and scratches on the pavement; the left side tire marks of Car C were 2.5 feet inside the lane boundary. There were no tire marks for either car prior to the collision.

The left front of Car D rammed into the right rear of Car C, causing Car C to hurtle along the highway for 198.5 feet with both translational and rotational motions. The evidence for the rotational motion was that left by the burning gasoline on the pavement. The gas tank had been ruptured. This scorch pattern indicated that the car had rotated clockwise along two successive arcs so that at the end of the journey the car was facing east as it had been when struck. Its final position was on the shoulder.

While Car C moved to the shoulder of the highway, Car D moved eastward into the fast lane, at first rotating slowly, but finally going into a spin to come to rest facing north, with the rear bumper 3 feet from the center line (fig. 7).

Speed of Car C at Time of Collision. The most probable course for Car C to have taken around the 90° turn would have been along the arc of a circle. The maximum speed for such a course is found by the use of Equation (2). The coefficient of friction in this case was 0.71 for the highway and the radius of the curve, estimated from measurements, was 37.8 feet. Substituting values in the formula, $V = 29.4$ ft/sec, or 20.0 mi/hr.

Car C was so wrecked by the impact and warped by the heat from the burning fuel that it could not be used for test driving, but other cars were used, one with a high-powered special engine with a "pick up" greater than Car C had. In all tests the cars traveled along a quarter circle having a radius approximately equal to that measured. In no test could a car attain a speed greater than 20 mi/hr without side slipping. This result confirmed the value of f to be 0.71. Thus, these measurements and tests established the fact that the speed of Car C at the place of collision was not greater than 20 mi/hr.

Speed of Car C after the Collision. From an inspection of the car after the collision, it was possible to conclude that the two rear wheels did not turn after the collision, but that the two front wheels must have dragged sideways for at least half of the time. Under these conditions the rear tires were dragged for the total distance of 198.5 feet, while the front tires were dragged for only half of the distance. Therefore, the average distance all four tires were dragged was $\frac{3}{4} \times 198.5$, or 148.9 feet. With this distance known, the speed of Car C after the collision is found by the use of Equation (1), that is, $V = 5.5\sqrt{fs}$ ($f = 0.71$ and $s = 148.9$ feet, $V = 57$ mi/hr). The distance of 198.5 feet was the straight line distance from where Car C was struck to where it came to rest. If the lengths of the tire drag marks are used instead of the straight line distance, the value of s is 163.5 feet and V is 59 mi/hr instead of 57 mi/hr.

Speed of Car D after the Collision. In the inspection of Car D after the collision, it was found that the left front wheel would not turn, but the other wheels were free to turn. Thus, the speed of this car after the collision is equal to the loss in speed during the time the left front tire was skidding plus the loss in speed as this car went into a side slip, indicated by heavy arcing skidmarks. The first loss in speed, V_1, is

$$V_1 = 5.5\sqrt{fs}$$

$$V_1 = 5.5\sqrt{0.71 \times 148.5/4}$$
$$= 28.2 \text{ mi/hr}$$

where 148.5 feet is the length of the skidmark for the left front tire. This distance is divided by 4 since only one tire was dragging. The second loss in speed, V_2, is

$$V_2 = \sqrt{gfR}$$
$$= \sqrt{32.3 \times 0.71 \times 21.6}$$
$$= 22.2 \text{ ft/sec., or } 15.2 \text{ mi/hr}$$

The value of R is found by the use of Equation (3), the x and Y values having been obtained for the heaviest skidmark of the side slip.

Thus, the speed of Car D after the collision is equal to the sum of $V_1 + V_2$, that is, 43 mi/hr.

Speed of Car D at Time of Collision. The speed of Car D at the time of the collision is obtained by use of the conservation of momentum equation. The weight of Car C is 2950 pounds and of Car D is 4320 pounds. These weights include the passengers. Since the cars were moving parallel at the time of impact and continued to be parallel for a brief period after impact, the velocities need not be resolved for use in the momentum equation. This equation is

$$4320V + 2950 \times 20 = 4320 \times 43 + 2950 \times 57$$
$$V = 68 \text{ mi/hr}$$

The two terms on the left side are the momenta for the cars before the collision, and the two terms on the right side are the momenta after the collision. If the speed of 59 mi/hr, instead of 57 mi/hr, had been used for the speed of Car C after the collision, the speed of Car D before the collision would have been 69 mi/hr instead of 68 mi/hr.

Let us assume that the driver of Car D came to trial for manslaughter, and the defense claimed that Car C had stalled as it turned into the eastbound highway so that it was not moving when the collision occurred. In order to answer this claim, let the speed of Car C before impact be zero instead of 20 mi/hr. The speed of Car D before the collision would have had to have been 82 mi/hr, not 68 mi/hr, in order to cause Car C to have had a speed of 57 mi/hr after the collision and Car D a speed of 43 mi/hr.

The methods discussed in this article have been used by the author in the preparation of his testimony as an expert witness in manslaughter-by-automobile cases. The author has worked with the police and the district attorneys in these cases in the preparation of arguments for the prosecution.