Forensics Commentary
Accident Reconstruction: The Estimation of Speed Based on Yaw Mark Analysis

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Introduction

In 2015, over six million people reported car accidents to the police.[1] Those collisions resulted in over 2.4 million personal injuries and 32,000 fatalities.[2] These incidents often result in significant civil and criminal litigation. When the lay testimony or other physical evidence does not make the attribution of fault clear, an attorney may choose to retain an accident reconstruction expert. Accident reconstruction experts evaluate the evidence at the scene of the crash in order estimate the speed at which a vehicle was traveling prior to the collision.

However, the discipline of accident reconstruction has come under fire. In *Wilson v. Woods*,[3] the Fifth Circuit of Appeals affirmed a trial court decision in which the trial court stated that it was not convinced that there is such a thing as accident reconstruction expertise under the guidelines announced in the U.S. Supreme Court's celebrated 1993 decision, *Daubert v. Merrell Dow Pharmaceuticals, Inc.*[4] *Daubert* overturned the traditional, general acceptance test for the admissibility of scientific evidence and substituted a new reliability/

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[1]Edward L. Barrett, Jr. Professor of Law Emeritus, University of California, Davis School of Law; coauthor, Paul Giannelli, Edward J. Imwinkelried, Andrea Roth & Jane Campbell Moriarty, Scientific Evidence (5th ed. 2015).

[1]U.S. Dep't of Transp., Nat'l Highway Traffic Safety Admin., Fatality Analysis Reporting System—General Estimates System—General Estimates System, *Quick Facts 2015*, at 1 (2017), *available at* https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812348.

[2]U.S. Dep't of Transp., *supra* note 1, at 1.

[3]*Wilson v. Woods*, 163 F.3d 935, 937, 51 Fed. R. Evid. Serv. 177 (5th Cir. 1999).

[4]*Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. 579, 113 S. Ct. 2786, 125 L. Ed. 2d 469, 27 U.S.P.Q.2d 1200, Prod. Liab. Rep. (CCH) P 13494, 37 Fed. R. Evid. Serv. 1, 23 Envtl. L. Rep. 20979 (1993).

empirical validation test derived from Federal Rule of Evidence 702.[5] Thus, accident reconstruction is at a critical juncture. Will most courts continue to liberally admit accident reconstruction testimony, as they have largely done in the past, or, as *Wilson* suggests, will the courts scrutinize such testimony more closely in the future? Does accident reconstruction rest on sufficient empirical validation to pass muster under *Daubert*?

Rather than generalize about the broad domain of accident reconstruction, this article focuses on a particular methodology employed in accident reconstruction. One accident reconstruction method used to estimate the speed of a turning vehicle is yaw mark speed analysis. Yaw refers to the orientation of a vehicle. A vehicle is in yaw when the vehicle is rotating about its *x* axis as it moves along its path.[6] In other words, the vehicle's tires are still rolling, but at the same time the vehicle is sliding laterally. Typically in a controlled turning motion, the rear tires track inside the corresponding front tires.[7] When traveling around a turn, the rear tires are closer to the inside of the turn than the front tires. However, when a vehicle exceeds "critical speed," the vehicle will begin to side slip;

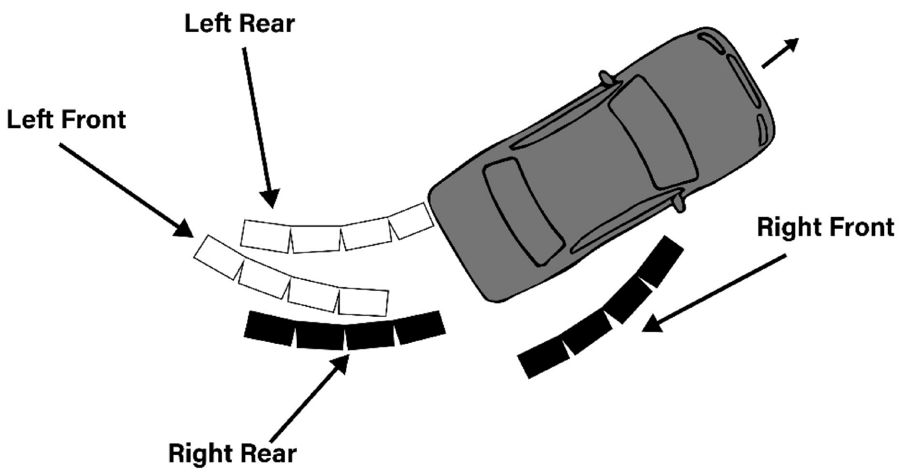
[5] 2 Paul C. Giannelli, Edward J. Imwinkelried, Andrea Roth & Jane Campbell Moriarty, Scientific Evidence § 27.02 (5th ed. 2012) [hereinafter Giannelli Et Al.]; J. Tarantino, Strategic Use of Evidence § 14.32, at 558 (1988). In *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. 579, 113 S. Ct. 2786, 125 L. Ed. 2d 469, 27 U.S.P.Q.2d 1200, Prod. Liab. Rep. (CCH) P 13494, 37 Fed. R. Evid. Serv. 1, 23 Envtl. L. Rep. 20979 (1993), the Supreme Court initially held that the traditional general acceptance test for the admissibility of scientific testimony is no longer good law under the Federal Rules of Evidence. The test was a creature of case law, and the Court construed Federal Rule of Evidence 402 as impliedly abolishing uncodified exclusionary rules of evidence. The Court then extracted a new test from the expression, "scientific . . . knowledge," in the text of Rule 702. Drawing on several amicus briefs filed by scientific organizations and individual scientists, the Court defined the expression in methodological terms. The Court described scientific methodology in classic Newtonian terms: formulating an hypothesis about a phenomenon, subjecting the hypothesis to empirical testing (controlled laboratory experimentation or systematic field observation) to verify or falsify the hypothesis, and finally evaluating the test results. The Court ruled that an expert may base testimony on a purportedly scientific technique or theory only if there is adequate, methodologically sound validation of the technique or theory.

[6] *Accident Investigation and Data Collection—Investigation of an Accident Scene—Physical Roadway Evidence*, in Crashworthiness Litigation § 9:6 (2d ed., Larry E. Coben, ed., 2008 & 2018 Supp.) [hereinafter "Crashworthiness Litigation"].

[7] John Kwasnoski, Crash Reconstruction Basics For Prosecutors: Targeting Hardcore Impaired Drivers 1, 21 (Am. Prosecutors Res. Inst., 2003), *available at* https://ndaa.org/wp-content/uploads/crash_reconstruction_basics.pdf [hereinafter Basics].

and the rear tires can track outside the corresponding front tires.[8] In this situation, the rear tires swing out until they are farther than the front tires from the inside of the turn.

Figure 1: Turning Positions



[8]John C. Glennon, C*alculating Critical Speed — A Motor-Vehicle Crash Reconstruction Method Fraught with Error*, CRASHFORENSICS.COM, (Aug. 2006), http://www.crashforensics.com/papers.cfm?PaperID=42; BASICS, *supra* note 7, at 21.

Note that when the vehicle is turning, the rear tires track to the inside of the front tires.

Critical speed is the speed at which a vehicle surpasses its maximum performance and the vehicle's tires lose lateral control on the roadway.[9] This loss of control occurs because there is not enough frictional force to provide the necessary centripetal force to keep the vehicle on its intended path.[10] The resulting marks are called yaw marks.[11] It is true that other types of curved skid marks may result from events such as a vehicle's driver locking up the brakes and spinning or the vehicle colliding off another object and spinning. Yaw mark speed analysis is intended for use only in situations when a vehicle began to side slip because it surpassed its maximum performance.[12]

The point at which a vehicle's front tires shift from tracking inside the rear tires to tracking outside the rear tires is called the crossover point in the yaw pattern.[13] Accident reconstruction experts search for and attempt to identify the crossover point to determine that the mark is a true yaw mark that can serve as a basis for a speed estimation.[14] The crossover point can be difficult or impossible to identify because of roadway surface conditions.[15] Furthermore, yaw marks are short lived and can degrade when other traffic later travels over the same section of roadway.[16] Thus, it is critical that yaw marks be quickly identified and preserved by means such as photography and diagramming.

The body of this article consists of six parts. The first two describe the science of yaw mark analysis. The initial part explains the derivation of formulae used to determine speed based on a yaw mark. This part focuses on Newtonian laws and applied physics. The second part addresses the methods of gathering evidence necessary to apply the formulae. By way of example, the second part addresses the various ways that experts can determine the drag factor input to the formula.

The remaining parts of the article shift from the science to the law governing the admissibility of testimony based on yaw mark analysis. The third part delves into the credentials necessary for a witness to qualify as an expert on yaw mark analysis under Federal Rule of

[9] Glennon, *supra* note 8.

[10] BASICS, *supra* note 7, at 21.

[11] Glennon, *supra* note 8.

[12] Glennon, *supra* note 8.

[13] Glennon, *supra* note 8.

[14] Glennon, *supra* note 8.

[15] Glennon, *supra* note 8.

[16] Glennon, *supra* note 8.

Evidence 702. The article points out that the courts routinely accept experts with scientific backgrounds in fields such as physics and notes the ongoing controversy over the expert status of witnesses such as police investigators who lack a scientific background but possess practical experience.

The article then turns to the law governing the substance of the expert's proffered testimony. In most cases, the expert's proposed testimony is syllogistic in structure: The expert proposes testifying to an opinion (the conclusion) derived by applying a general accident reconstruction technique or theory (the major premise) to the case-specific facts (the minor premise). The fourth part addresses the expert's major premise. As that part explains, in most jurisdictions a version of Federal Rule of Evidence 702(c) and *Daubert* determine whether a scientific technique or theory may serve as a basis for expert testimony. This part discusses the admissibility of testimony about the formulae derived from the Newtonian Laws. The fifth part of the article discusses the expert's minor premise. This part reviews both the law governing the permissibility of the expert's reliance on certain types of sources for the case-specific information and potential weight attacks on admissible testimony. The sixth and final part discusses the conclusion or ultimate opinion that the expert derives by applying the major premise to the minor premise.

I. The Science of Yaw Mark Speed Analysis

Yaw mark speed analysis is a method that accident reconstruction experts employ to estimate the speed that a yawing vehicle was traveling.[17] The equation used to analyze a yaw mark is the Critical Speed Formula.[18] Subpart A provides an overview of the derivation of the formula. Subparts B, C, and D elaborate on the critical role of three elements of the formula: *R*—the radius of the yaw mark, *f*—the drag factor, and *e*—superelevation.

A. An Overview The Derivation of the Critical Speed Formula

Accident reconstruction is applied physics resting on classic mechanics developed by Sir Isaac Newton.[19] Newton's First Law of Motion states that any object in a state of uniform motion tends to remain in a state of uniform motion unless an external force is ap-

[17] *See* Glennon, *supra* note 8.

[18] *Newton's Laws and the Basics of Accident Reconstruction*, *in* 3 Handling Motor Vehicle Accident Cases § 11:6 (John W. Chandler & Karen Koehler eds., 2000 & 2018 Supp.) [hereinafter "Handling"].

[19] Derek Mayor & Edward J. Imwinkelried, *Skid Mark Analysis: The Central Importance of the Minor Premise*, 51 Crim. L. Bull. 437, 439–42 (2015).

plied to it.[20] A body moving on a circular path with constant speed will have a changing velocity due to the body's changing direction.[21] This change in velocity over time is called centripetal acceleration.[22] Centripetal acceleration has a radial direction toward the center of the circular movement and is given by the following equation:

$$a = \frac{v^2}{R} \qquad \text{(Equation 1)}$$

In this equation,

a = acceleration,

v = velocity (ft/sec), and

R = radius of motion (ft).[23]

According to Newton's Second Law of Motion, the acceleration with which an object moves is directly proportional to the magnitude of the force applied to the object and inversely proportional to the mass of the object. Therefore, the following equation is true:

$$F = \frac{Wa}{g} \qquad \text{(Equation 2)}$$

In this equation,

F = force (ft-lbs.),

m = mass (W/g),

W = weight of body (lbs), and

g = acceleration of gravity (ft/sec^2).[24]

We can now substitute Equation 1 for a in Equation 2 to derive the following equation:

$$F = \frac{Wv^2}{gR} \qquad \textit{(Equation 3)}$$

The lateral force on a vehicle moving on a pavement surface is produced by the frictional force between the tires and the roadway as follows:

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[20] Handling, *supra* note 18, at § 11:6.

[21] BASICS, *supra* note 7, at 21.

[22] BASICS, *supra* note 7, at 21.

[23] BASICS, *supra* note 7, at 21.

[24] BASICS, *supra* note 7, at 21.

$$F = fw \qquad \text{(Equation 4)}$$

In this equation, f = friction demand between the tires roadway (Drag Factor).[25]

Substituting Equation 4 for F in Equation 3 yields the next step in the derivation:

$$FW = \frac{Wv^2}{gR} \qquad \text{(Equation 5)}$$

The next step is:

$$fw = \frac{Wv^2}{gR} \rightarrow v^2 = fgR \rightarrow v = \sqrt{fgR}$$

Now, accounting for roadway curves superelevation, *e,* this equation becomes:

$$v = \sqrt{gR(e+f)}$$

In this equation,
g = 32.174 ft/sec^2 (acceleration of gravity)
e + f are dimensionless numbers (units)
R = radius of curvature (radial motion) in units of ft.
Thus,

$v = \sqrt{(32.174\, ft/s^2)R(ft)(e+f)}$, with [v] = ft/s

For [v] = mph, we use the conversion factor 1 mph = 1.47 ft/s. Hence,

$$v = \sqrt{(32.174\, ft/s^2)R(ft)(\frac{1\, mph}{1.47 ft/s})^2(e+f)} =$$

$$\sqrt{(14.9)R(e+f)}\, mph$$

$v = \sqrt{15R(e+f)}\, mph$, with R measured in units of ft and e+f both dimensionless.

Yaw marks are analyzed to estimate the speed by utilizing a variation of the Critical Speed Formula.[26] This formula estimates the speed during the middle of the yaw and not during its beginning.[27] Therefore, as Part VI stresses, the speed estimate will always be

[25]BASICS, *supra* note 7, at 21.

[26]BASICS, *supra* note 7, at 21.

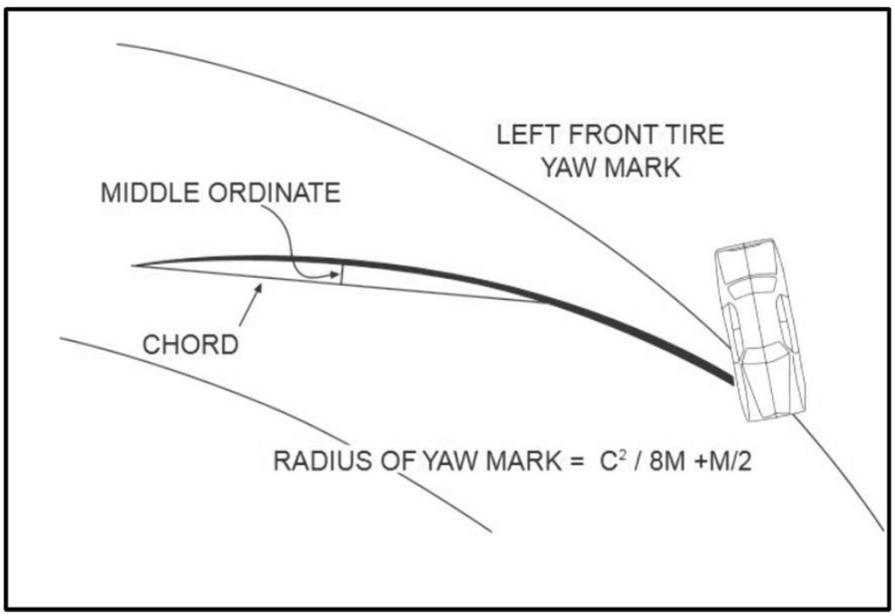
[27]BASICS, *supra* note 7, at 22.

lower than the speed of the vehicle immediately before the start of the yawing action.[28]

B. <u>The *R* in the Critical Speed Formula: The Radius of the Yaw Mark</u>

In order to apply the Critical Speed Formula, an expert must find the radius (R) of the yaw mark.[29] To find the radius of the mark, the expert must determine the chord and the middle ordinate of the mark, as shown in Figure 2.[30]

Figure 2: Chord and Middle Ordinate[31]



[28]Basics, *supra* note 7, at 22.

[29]Basics, *supra* note 7, at 22.

[30]Basics, *supra* note 7, at 22.

[31]Basics, *supra* note 7, at 22.

In Figure 2, the radius of the yaw mark is determined by measuring a chord "C" and middle ordinate "M" on the yaw mark.[32] The radius of a yaw mark is found by the equation:

$$R = \frac{C^2}{8m} + \frac{m}{2}.$$

In this equation,

R = radius of the curve,

C = chord, and

m = middle ordinate.[33]

Alternatively, the equation to find the radius of a yaw mark may include variables to account for the size of the vehicle.[34]

C. The *f* in the Critical Speed Formula: The Drag Factor

To apply the formula, the expert must also find the Drag Factor (f) of the vehicle to the road.[35] The Drag Factor is of the utmost importance in this type of litigation, and at trial the attorney opposing the expert often attacks the expert's assumption about the Drag Factor to decrease the weight of the expert's testimony in the jurors' minds.[36] In order to determine the drag factor of a vehicle, the expert may need to find the vehicle's tires' friction coefficients (μ) individually.[37] The friction coefficient is the deceleration coefficient for a vehicle's individual tires sliding across a surface.[38] The friction coefficient and drag factors are ratios of the tangential force (parallel to the surface), applied to an object sliding across a surface to the normal force (perpendicular to the surface), on the object.[39] The friction coefficient and the drag factor are the same coefficient *if and only if* all four tires on a vehicle are locked and sliding on a level surface.[40]

The determination of the vehicle's individual tire friction coefficients can have a major impact on the final speed estimate of the

[32] BASICS, *supra* note 7, at 22.

[33] BASICS, *supra* note 7, at 22.

[34] *See* GIANNELLI ET AL., *supra* note 5, at 27.

[35] GIANNELLI ET AL., *supra* note 5, at 21.

[36] GIANNELLI ET AL., *supra* note 5, at 13.

[37] Gary E. Kilpatrick, The Physics of Collision (Apr. 2017) (inactive web-article on file with authors).

[38] Kilpatrick, *supra* note 37.

[39] Lynn B. Fricke & J. Stannard Baker, *Drag Factor and Coefficient of Friction in Traffic Accident Reconstruction*, *in* TRAFFIC ACCIDENT INVESTIGATION MANUAL, 1, 3 (11th ed. 2011).

[40] Kilpatrick, *supra* note 37.

expert.[41] When a vehicle yaws after a collision, the drag forces generated by each tire and axle can vary greatly.[42] Also, when a vehicle slides from one surface to another such as sliding from asphalt to dirt or grass, the drag forces can change substantially. Therefore, the drag factor should be determined for each surface involved in the yawing action. Finally, when some but not all of a vehicle's tires lock in a slide, the individual tires will have substantially different Friction Coefficients. The expert must account for these disparities to accurately determine Drag Factor to input to the formula.

The Drag factor is given by:

$f_{RD} = ((f_f — x_f(f_f — f_r))/((1 — z(f_f — f_r))$.

In this equation,

x_f = the width of the axles, and

z = the distance between the front and rear tires.[43]

The Drag Factor of a vehicle sliding on an inclined surface is given by:

$f_{RD} = (\mu + G)/SRT(1 — G^2)$.

Here, G = the grade of the surface.[44]

D. <u>The Impact of e in the Critical Speed Formula: Superelevation</u>

Superelevation is the vertical distance between the heights of the inner and outer edges of a roadway.[45] The Critical Speed Formula will not always be written to explicitly take account for superelvation.[46] Nevertheless, the superelevation can affect the accuracy of an expert's determination. Consequently, the expert should account for superelevation, *e*, either in the Critical Speed Formula itself or in determining the vehicle's Drag Factor, *f*.[47] Once the expert has found the superelevation, he or she will have all the information needed to apply the Critical Speed Formula. Additionally, the drag factor for a vehicle skidding due to the driver's application of the brakes may be translated to the drag factor for yawing vehicle.[48] Typically the difference will be insignificant.[49] However, when the superelevation is

[41] Kilpatrick, *supra* note 37.

[42] Kilpatrick, *supra* note 37.

[43] Kilpatrick, *supra* note 37.

[44] Kilpatrick, *supra* note 37.

[45] *Superelevation Definition*, MERRIAM-WEBSTER DICTIONARY, https://www.merriam-webster.com/dictionary/superelevation (last visited March 3, 2019).

[46] BASICS, *supra* note 7, at 21.

[47] BASICS, *supra* note 7, at 23.

[48] BASICS, *supra* note 7, at 22.

[49] BASICS, *supra* note 7, at 22.

substantial, the difference in the drag factors can be substantial and ought to be accounted for.[50]

II. THE COLLECTION OF THE PHYSICAL EVIDENCE NEEDED TO CORRECTLY APPLY THE CRITICAL SPEED FORMULA

To apply the Critical Speed Formula, the expert needs to collect or have access to information from the scene. For instance, the expert must have information about the mark itself as well as the factors influencing the vehicle's drag factor and friction coefficients because all those considerations affect the computation of the critical speed. The collection process must be both thorough and meticulous, since it has a direct impact on the accuracy of the expert's final opinion.

A. Collecting Evidence from the Scene of the Incident: In General

It is certainly preferable if the expert personally makes the measurements and collects the other relevant data at the scene. Whenever possible, the expert himself or herself should collect and record evidence from the scene.[51] The expert ought to visit the scene as quickly as possible. Unfortunately, yaw marks tend to be short lived and susceptible to later traffic on the roadway.[52] In particular for our purposes, in order to evaluate a yaw mark, the expert must have an accurate measurement of the arc of the mark itself.[53] Typically, the arc tapers toward the end.[54] Accident reconstructionists ordinarily treat the tapered mark as a portion of a circle.[55]

Often an expert will not be retained until long after the accident occurred.[56] In that event, the expert has to rely on information collected by the accident investigators such as the police who responded to the accident scene. Videotape, photographs, scaled diagrams, and drawings of the scene can be useful memorials of data from the scene of the incident.[57] Ideally, the responding officer will obtain and carefully record as much information from the scene

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[50] BASICS, *supra* note 7, at 22.

[51] BASICS, *supra* note 7, at 22.

[52] Glennon, *supra* note 8.

[53] 9 AM. JUR. 3d *Proof of Facts* 115 (1990 & 2018 Supp.).

[54] 9 AM. JUR. 3d, *supra* note 53, at 115.

[55] 9 AM. JUR. 3d, *supra* note 53, at 115.

[56] Mayor & Imwinkelried, *supra* note 19, at 452.

[57] CRASHWORTHINESS LITIGATION, *supra* note 6, at § 9:6.

as possible.[58] This information should include location, time of the incident, weather and visibility conditions, and traffic congestion.[59]

In many instances, this information is recorded in a police report about the accident. The accuracy of the report is paramount because the expert must rely on the police report's account of what the parties and witnesses saw.[60] Unfortunately, in many cases, these reports are incomplete and of little assistance to the expert.[61] As a practical matter, the quality of the report is often directly proportional to the seriousness of the accident.[62] Fatal accidents typically produce much better reports than those resulting from mere fender benders.[63] In short, the quality of the expert's analysis often depends on the seriousness of the incident and the amount of time elapsing between the time of the incident and the beginning of the expert's analysis.

B. Collecting Evidence About the Drag Factor in Particular.

An expert can employ several different methods to find the appropriate Drag Factor and Friction Coefficients. Those methods include (1) performing a test-skid of the accident vehicle; (2) sliding an individual tire; (3) using existing highway department skid numbers for the road in question; and (4) looking up friction coefficient in a table and applying the appropriate adjustments for the case at hand.

1. Performing a Test-Skid the Accident Vehicle

The ideal method of determining the Drag Factor and Friction Coefficients is to use the very vehicle involved in the incident in the area of the incident under similar weather conditions.[64] The next best option is to employ a similar, exemplar vehicle. The use of the very vehicle is appropriate only if the vehicle is not too severely damaged from the collision.[65] If possible, the test ought to be conducted at the location of the incident under similar roadway conditions.[66] If that location is too dangerous or unavailable, a similar, nearby location

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[58] TEX. ASS'N POLICE EXPLORERS, TRAFFIC ACCIDENT RECONSTRUCTION, 1, 1 (2017), *available at* http://www.co.wise.tx.us/constable/downloads/traffic%20accident%20investigation.pdf [hereinafter "ACCIDENT RECONSTRUCTION"].

[59] ACCIDENT RECONSTRUCTION, *supra* note 58, at 1.

[60] ACCIDENT RECONSTRUCTION, *supra* note 58, at 3.

[61] ACCIDENT RECONSTRUCTION, *supra* note 58, at 11–12.

[62] ACCIDENT RECONSTRUCTION, *supra* note 58, at 11–12 (instructing the investigator to collect more detailed data in the case of a serious accident).

[63] ACCIDENT RECONSTRUCTION, *supra* note 58, at 11–12.

[64] Fricke & Baker, *supra* note 39, at 10.

[65] Fricke & Baker, *supra* note 39, at 10.

[66] Fricke & Baker, *supra* note 39, at 10.

can be used.[67] The vehicle should be driven at a high speed that is still reasonably safe.[68] Then the expert must brake very hard and measure the length of the skid mark.[69] Alternative tests can be conducted by completing a yawing action. However, conducting a yaw test may prove difficult on a public road. Hence, if the expert chooses to test the drag factor by locking up the brakes, he or she should mathematically adjust for a yawing action and consider superelevation when necessary.[70] This test should be repeated several times to ensure consistent, repeatable results.[71] Finally, the expert ought to account for possible speedometer error.[72] This can be done through various methods such as timing a measured mile at a constant rate of speed.[73]

2. Sliding an Individual Tire

Another popular method is sliding a single test tire from the vehicle involved in the incident.[74] Typically the tire will be filled with concrete and pulled by a trailer.[75] However, this method has been sharply criticized because in this condition the load on the tire is considerably less than what would be normal for the same tire under the weight of a full vehicle.[76] It is generally accepted that a tire deteriorates faster as the load increases and that at skidding speeds, the tire will be heated to increased friction.[77] Consequently, the friction data collected by this method will be higher than the true friction coefficient.[78] Commercial testing sled manufacturers frequently provide suggested reduction factors that can be applied.[79] However, because of the various weaknesses of this method, using the vehicle involved in the accident or an exemplar vehicle, the first option, is considered a superior method.[80]

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[67] Fricke & Baker, *supra* note 39, at 10.

[68] Fricke & Baker, *supra* note 39, at 10.

[69] Fricke & Baker, *supra* note 39, at 10.

[70] BASICS, *supra* note 7, at 22.

[71] BASICS, *supra* note 7, at 22.

[72] BASICS, *supra* note 7, at 22.

[73] BASICS, *supra* note 7, at 22.

[74] BASICS, *supra* note 7, at 11.

[75] BASICS, *supra* note 7, at 11.

[76] BASICS, *supra* note 7, at 11.

[77] BASICS, *supra* note 7, at 12.

[78] BASICS, *supra* note 7, at 12.

[79] Fricke & Baker, *supra* note 39, at 12.

[80] Fricke & Baker, *supra* note 39, at 12.

3. Using Existing Highway Department Skid Numbers for the Road in Question

State highway departments regularly test roads for friction coefficients.[81] These published friction coefficients are usually meant to represent the coefficients for a normal passenger car.

There are several criticisms of reliance on highway department skid numbers. First, in an Ohio study, the highway department Friction Coefficients were compared to formally computed Friction Coefficients.[82] In the study, three trucks and three cars were tested with a variety of tires and loads on three different types of pavement.[83] The vehicles were tested at speeds ranging from 10 miles per hour to 60 miles per hour.[84] The study concluded that at lower speeds, the highway department coefficients were much lower than the actual Friction Coefficients.[85] A second criticism is that the standard test tires used by the state highway departments do not have the typical characteristics of a normal passenger car.[86] The test tires have been found to give lower friction values.[87] Third, highway department figures may be dated because the surface conditions might have changed.[88] Finally, highway department coefficients may not reflect the load in the subject vehicle.[89] Therefore, again, using the involved vehicle or a similar, exemplar vehicle, the first option, is preferable.

4. Looking Up Friction Coefficient in a Table and Apply the Appropriate Adjustments to for the Case at Hand[90]

If tests cannot be conducted for an accident, the expert may find it necessary to look up the coefficient in a table providing a range of typical values for the subject surface. The range can vary greatly; the figure provides only an average Friction Coefficient of the entire skid.[91] Most importantly, the data is not specific to the accident that the expert is trying to reconstruct. Therefore, this method suffers from lack of accuracy and is markedly inferior to the first option.

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[81] Fricke & Baker, *supra* note 39, at 12.

[82] W. R. Garrott, D. A. Guenther, R. Houk, J. Lin, & M. Martin, *Improvement of Methods for Determining Pre-Crash Parameters from Skid Marks*, NHTSA Tech. Rep. DOT HS 806-063 (1981), *available at* https://babel.hathitrust.org/cgi/pt?id=mdp.39015075561632.

[83] Garrott et al., *supra* note 82, at 72–84.

[84] Garrott et al., *supra* note 82, at 72–84.

[85] Garrott et al., *supra* note 82, at 72–84.

[86] Fricke & Baker, *supra* note 39, at 13.

[87] Fricke & Baker, *supra* note 39, at 13.

[88] Fricke & Baker, *supra* note 39, at 13.

[89] Fricke & Baker, *supra* note 39, at 13.

[90] Fricke & Baker, *supra* note 39, at 9.

[91] Fricke & Baker, *supra* note 39, at 13.

III. THE LAW GOVERNING THE ADMISSIBILITY OF THE EXPERT TESTIMONY: THE WITNESS'S QUALIFICATIONS AS AN EXPERT

Parts I and II reviewed the science underlying yaw mark analysis. This part turns to the governing law. Under Federal Rule of Evidence 702, a witness may qualify as an "expert by knowledge, skill, experience, training or education." Under Rule 702(a), the standard applied by a ruling judge on the admissibility of expert testimony is whether the expert's testimony will help the trier of fact: Does the witness possess knowledge or skill superior to that of the lay jurors such that the witness can draw an inference completely beyond their competence or at least much more reliably than the jurors could?[92]

A. Expertise Acquired by Formal Education or Training

There is consensus that a witness readily qualifies as an accident reconstruction expert if the witness possesses formal education training in highly pertinent subjects such as physics, mechanics, and the laws of motion.[93] Thus, a witness may qualify as an expert if he or she had earned a relevant academic degree, or has at least graduated from a specialized accident reconstruction course.[94]

B. Expertise Acquired by Practical Experience

A point of sharp disagreement among courts is whether witnesses such as traffic investigators with experience but without formal training may testify on matters of accident reconstruction.[95] In the recent past, the trend has been to allow police officers with practical experience and generalized training to testify on some accident reconstruction questions, including speed estimates based on skid marks.[96] In reality, courts have permitted officers with no formal training to testify on issues that are fully explicable only through physics.[97] However, while allowing such testimony, these courts often stress that the

[92] GIANNELLI ET AL., *supra* note 5, at § 27; 1 C. MCCORMICK, EVIDENCE § 13 (7th ed. 2013).

[93] GIANNELLI ET AL., *supra* note 5, at § 27; *Com. v. Serge*, 2003 PA Super 470, 837 A.2d 1255 (2003), decision aff'd, 586 Pa. 671, 896 A.2d 1170 (2006).

[94] GIANNELLI ET AL., *supra* note 5, at § 27.

[95] GIANNELLI ET AL., *supra* note 5, at § 27; JOHN A. TARANTINO, STRATEGIC USE OF SCIENTIFIC EVIDENCE 558 (1988); *see also Scott v. Yates*, 71 Ohio St. 3d 219, 1994-Ohio-462, 643 N.E.2d 105 (1994).

[96] GIANNELLI ET AL., *supra* note 5, at § 27.02; *Kelsay v. Consolidated Rail Corp.*, 749 F.2d 437, 16 Fed. R. Evid. Serv. 1296 (7th Cir. 1984); *Trailways, Inc. v. Clark*, 794 S.W.2d 479 (Tex. App. Corpus Christi 1990), writ denied, (Dec. 31, 1990).

[97] *Roberts v. Grafe Auto Co., Inc.*, 701 So. 2d 1093 (Miss. 1997) (ruling a police officer was qualified as an accident reconstruction expert based on training and investigation for testimony that defective tire contributed to accident); *State v. Goode*, 305 S.C. 176, 406 S.E.2d 391 (Ct. App. 1991) (holding trial court did not err in qualifying officer as an expert who testified that gouge marks in victim's lane indicated where the collision occurred).

witness's testimony must be strictly confined to his or her area of expertise.[98]

In *Trailways, Inc. v. Clark*, the court held that an officer was qualified to testify, based on skid marks, that a bus had been traveling over 102 kph while the bus was navigating a turn.[99] In ruling the officer qualified, the court cited several factors, including, *inter alia,* the officer's practical experience investigating accidents as well as the officer's attendance at several update courses on traffic accidents and a 12-day engineering course.[100] Unfortunately, it is unclear from the opinion what specific training the officer received at these courses. Today many courts would treat that gap in the record as fatal to the witness's claim to be an expert. A trial judge should demand that the witness's proponent elicit details about the content of such training courses. Unless an officer is taught and proficient in skid mark or yaw mark analysis, such as how to accurately determine the drag factor of a vehicle on a specific surface, the officer should not be allowed to testify to a speed estimate based upon skid marks or yaw marks.

More specifically, a trial judge should reject an opinion by any investigator who in conclusory fashion claims to be an expert based solely on practical experience. Without more, there is no showing of a feedback loop ensuring the reliability of the investigator's opinion. A traffic collision investigator could investigate hundreds of collisions and make loosely base speed estimates on the skid and yaw marks at the scene. When the jurors hear testimony about the witness's investigation of "hundreds" of collisions, they may well be impressed by the witness's background. However, unless the expert's earlier conclusions were confirmed by subsequent formal analyses, such as Yaw Mark Speed Analysis, the witness may simply have been repeating the same mistake over and over again. Hence, standing alone, testimony about an investigator's "extensive practical experience" investigating accidents should not qualify the investigator as an expert on accident reconstruction, much less on the specific topic of estimating speed through yaw mark analysis.

IV. THE LAW GOVERNING THE ADMISSIBILITY OF THE EXPERT WITNESS: THE EXPERT'S MAJOR PREMISE

There are many ways of using a witness who happens to be an expert. To begin with, if the witness happens to have personal knowledge of any relevant facts, under Rule 602 the witness may testify about those facts, just as any lay witness could. The witness's possession of a Ph.D. does not preclude him or her from testifying

[98] GIANNELLI ET AL., *supra* note 5, at § 27.02.

[99] *Trailways, Inc.*, 794 S.W.2d at 482.

[100] *Trailways, Inc.*, 794 S.W.2d at 482–83.

to facts they know firsthand. Moreover, if the witness has sufficient personal knowledge to establish the foundation for a lay opinion, under Rule 701 the witness may testify to a lay opinion, just as any lay witness could. Moreover, if the witness qualifies under the standards discussed in Part III, the expert could give the jury a general lecture or exposition about a scientific theory or technique. Federal Rule of Evidence 702 permits an expert to testify to "an opinion or otherwise." The Advisory Committee Note to Rule 702 explains that the drafters added "or otherwise" to signal that an expert may testify about a general scientific technique or theory without purporting to apply the technique or theory to the specific facts of the case.

However, in the vast majority of cases, the expert's proponent wants the expert to do more. The proponent wants the expert to derive an opinion about the significance of some case-specific fact or facts by applying the technique or theory to evaluate the fact or facts. In the typical case, after the witness qualifies as an expert, the witness's testimony is syllogistic in structure: The technique or theory is the major premise, the case-specific information serves as the minor premise, and the expert arrives at the conclusion or opinion by applying the major premise to the minor premise.

In federal practice, Rules 201 and 702(c) govern the expert's major premise. As the Supreme Court recognized in *Daubert*, some "theories that are so firmly established as to have attained the status of scientific law, such as the laws of thermodynamics, properly are subject to judicial notice under Federal Rule of Evidence 201."[101] Judicial notice obviates the need for live testimony and a formal Rule 702(c) foundation for very well-established propositions. Newton's Laws and principles are undeniably sound.[102] It is well-settled that these laws and principles are so extensively validated and accepted that the judge may judicially notice their validity under Federal Rule of Evidence 201(b)(2).[103] The judge will simply instruct the jury to accept the truth of these propositions even though they will not hear any live testimony about the validation of the propositions. Under Rule 201(f), in civil cases the judge's instruction binds the jurors.

The proponent of Yaw Speed Mark Analysis will typically have little difficulty convincing the trial judge that the Critical Speed Formula and similar formulae pass muster. Many of these formulae

[101] *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. 579, 593, 113 S. Ct. 2786, 125 L. Ed. 2d 469, 27 U.S.P.Q.2d 1200, Prod. Liab. Rep. (CCH) P 13494, 37 Fed. R. Evid. Serv. 1, 23 Envtl. L. Rep. 20979 (1993).

[102] Mayor & Imwinkelried, *supra* note 19, at 444–45.

[103] Mayor & Imwinkelried, *supra* note 19, at 444–45.

are direct derivatives of Newton's laws of motion.[104] Consequently, these formulae are judicially noticeable. If the formula is not itself noticeable or directly, mathematically derivable from a noticeable formula, the proponent will have to present live testimony to satisfy *Daubert*'s reliability/validation standard. The proponent would need to elicit testimony about:

- the size of the date set in any empirical validating study;
- the composition of the study;
- the test conditions; and
- the specific findings in the study, such as the percentage of false positives and negatives.

The bottom line is that the proponent must marshal enough empirical data and reasoning to persuade the trial judge by a preponderance of the evidence that by using the particular technique or formula the expert is relying on, the expert can accurately draw the specific type of inference that the expert proposes testifying to. As a general proposition, the courts have been very receptive to testimony about the accident reconstruction methodologies for estimating speed, including skid and yaw mark analysis.[105]

V. The Law Governing the Expert Testimony: the Expert's Minor Premise

In Yaw Mark Speed analysis, the expert's minor premise is the expert's information about the case-specific facts that the expert will use the technique or theory to evaluate. While Rule 702(c) governs the types of techniques or theories that the expert may employ, Rule 703 governs the types of sources of information that the expert may draw on in order to learn the case-specific facts. Simply stated, under Rule 703 the expert may rely on: (a) personal knowledge; (b) hypothesized facts if other witnesses provide admissible evidence of the facts; or (c) the contents of secondhand, out-of-court reports if it is the customary, reasonable practice in the expert's specialty to rely on such sources.

Rule 703 limits the types or quality of sources that the expert can rely on to acquire the case-specific information. Rule 702(b) adds that the expert must base his or her opinion on "sufficient facts or data." To reliably apply the Critical Speed Formula, the expert must possess or acquire sufficient information to make several determinations, including which car left the mark in question; whether the mark

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[104] Handling, *supra* note 18, at § 11:6.

[105] Mayor & Imwinkelried, *supra* note 19, at 444–45; *see also Brimmer v. Melendez*, 2008 WL 90058, at *2 (N.J. Super. Ct. App. Div. 2008) (noting the general acceptance of skid mark analysis). *See also* Imwinkelried, The Best Insurance Against Miscarriages of Justice Caused by Junk Science: An Admissibility Test that Is Scientifically and Legally Sound, 81 Albany L.Rev. 851, 857-56 (2017/2018).

is a yaw mark; what is the general condition of the mark; and what is the pertinent drag factor.

A. Attributing the Mark to a Particular Car

The threshold question is which car left or created the mark. That determination can be difficult. There are two dimensions to the question: Was the mark left at the time of the accident, and was the mark left by the car in question? Even if the investigators arrive immediately after an accident, there is the possibility that the mark was pre-existing. If the investigators arrive a substantial period of time after the accident, there is a further possibility that the mark was left by vehicles that passed the scene after the incident but before the investigator's arrival. It is ideal if the mark terminates at the wheel of the car in question and the investigators can match the tire tread to the any tread design in the yaw mark and the mark is darker in color than any other nearby highway marks.

B. Determining Whether the Mark Is a Yaw Mark

Yaw marks are analyzed differently than other types of highway marks such as skids.[106] Therefore, in order for an expert to accurately find the speed at which the vehicle was traveling, the expert must correctly characterize the marks at the scene. This can be challenging in cases in which there are multiple marks.[107] To accurately characterize yaw marks, the expert must find a crossover point where the vehicle's front tires shift from tracking inside the rear tires to tracking outside the rear tires in the yaw pattern.[108] Failure to correctly characterize the marks may lead to the inadmissibility of an expert's testimony or the admission of an inaccurate opinion.

C. Determining the Condition of the Yaw Mark

Even if the investigator finds and identifies a yaw mark, its condition may be too poor to permit an analysis; or its condition may mislead an expert into forming an incorrect opinion. Yaw marks are susceptible to degradation by weather, sunlight, and traffic which may cause them to become obscured.[109] The sooner a yaw mark is properly documented after an accident, the more likely that the expert's analysis of the mark will yield an accurate speed estimate.[110] Even when the indications of contamination do not lead the judge to

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[106] GRAY BEAUCHAMP, DETERMINING VEHICLE STEERING AND BRAKING FROM YAW MARK STRIATIONS (Soc'y of Auto. Eng'r 2009); Mayor & Imwinkelried, *supra* note 19, at 450–52.

[107] Mayor & Imwinkelried, *supra* note 19, at 447–52.

[108] BASICS, *supra* note 7, at 21.

[109] Mayor & Imwinkelried, *supra* note 19, at 451–53; DONALD E. STRUBLE, AUTOMOTIVE ACCIDENT RECONSTRUCTION: PRACTICES AND PRINCIPLES 16, 87–88 (2013).

[110] STRUBLE, *supra* note 109, at 86–88.

altogether bar the expert's opinion, evidence of contamination can be the basis a convincing attack on the weight of the opinion.[111]

D. Determining the Drag Factor

Assume that the expert has correctly determined that a mark is a yaw mark left by a particular vehicle. As we saw in Part I, even then the expert needs accurate information about the drag factor to properly assess the significance of the yaw mark.

Part II explained that there are four methods of determining drag factor: using the crash vehicle itself or a similar vehicle, testing a single tire from the crash vehicle, utilizing highway department figures, and relying on the drag factor in a table.[112] Using the crash vehicle or an exemplar vehicle is widely regarded as the best practice.[113] However, the use of any of these methods can present problems that, at the very least, may give rise to weight attacks.

The central challenge is accounting for the differences between the test conditions and the conditions when the actual vehicle left the mark. In *Thorpe v. Commonwealth*, an expert claimed that for purposes of a yaw mark analysis, he could find the drag factor of a certain stretch of road without accounting for the size and weight of the subject vehicle.[114] However, the court held that the testimony was inadmissible due to the expert's failure to account for the actual dimensions of the crash vehicle.[115] In a drag factor determination, even a small error in accounting for the crash vehicle can diminish the weight of an expert's testimony. More egregious errors such as a complete failure to account for the weight of the vehicle may result in the inadmissibility of the testimony.

VI. THE LAW GOVERNING THE EXPERT TESTIMONY: THE LIMITATIONS OF THE EXPERT'S FINAL CONCLUSION

A. The Tendency to Underestimate the Vehicle's Actual Speed

As we have seen, determining a vehicle's speed from the Critical Speed Formula is frequently used and can be a very helpful tool in accident reconstruction.[116] The formula can enable an expert to form an opinion estimating the vehicle's speed. However, there are limitations to the expert's opinion. To begin with, Critical Speed Formula

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[111] STRUBLE, *supra* note 109, at 86–88.

[112] Fricke & Baker, *supra* note 39, at 10.

[113] Fricke & Baker, *supra* note 39, at 10.

[114] *Thorpe v. Commonwealth*, 223 Va. 609, 292 S.E.2d 323, 325 (1982).

[115] *Thorpe*, 292 S.E.2d at 325–26.

[116] BASICS, *supra* note 7, at 21; Charles P. Dickerson, Mark W. Arndt, Stephen M. Arndt, & Gregory A. Mowry, *Evaluation of Vehicle Velocity Predictions Using the Critical Speed Formula* [S.A.E. Tech. Paper # 950137, at 81–82 (1995), *available at*

calculates the speed of a vehicle mid yaw rather than at the beginning of the action. Therefore, the Critical Speed Formula often underestimates the speed of a yawing vehicle. One study found that the method tends to underestimate the actual speed of the vehicle by approximately 5%.[117] Several studies point to the conclusion that the Critical Speed Formula underestimates, but never overestimates, the actual speed of the vehicle.[118] Northwestern University conducted a study of the Critical Speed Formula in which they used standard and sport style American cars.[119] The study found that the Critical Speed Formula underestimates the actual speed of vehicles by 7 to 12% for the cars tested.[120] Another study reported that the yaw tests the vehicle's speed from the Critical Speed Formula were below the radar measured speeds when the average drag factor of the road surface was used in the calculation.[121]

The California Highway Patrol undertook an analytical assessment of the Critical Speed Formula. They conducted 94 experiments where the speed of yawing vehicles was measured by radar and also computed by the Critical Speed Formula.[122] Seventy vehicles were evaluated while coasting, 16 while accelerating, and eight while the vehicles were braking.[123] The tests were conducted at speeds ranging from 53 miles per hour to 96 miles per hour.[124] The study found that the error estimation using the Critical Speed Formula has a normal distribution with a standard deviation of 5.75%.[125] Critical speed established by this procedure was within ± 2(5.75%) of the average error values listed above roughly 95% of the time.[126] Additionally, the study found that the accuracy of the

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http://www.transport-safety.com/docs/1995_VehicleVelocityPredictionsUsingCriticalSpeedFormula.pdf; Glennon, *supra* note 8.

[117] Thomas Shelton, *Validation of the Estimation of Speed from Critical Speed Scuffmarks*, 7 ACCIDENT RECONSTRUCTION J. 37 (1995).

[118] Shelton, *supra* note 117, at 37–40.

[119] LYNN B. FRICKE, 2 TRAFFIC ACCIDENT RECONSTRUCTION 72: 44–49 (1990).

[120] FRICKE, *supra* note 119, at 72: 44–49.

[121] Peter Bellion, *Project Y.A.M. (Yaw Analysis Methodology) Vehicle Testing and Findings*, S.A.E. Tech. Paper # 970955 (1997), *available at* 106 J. PASSENGER CARS 1626 (1997).

[122] Shelton, *supra* note 117, at 37–40.

[123] Shelton, *supra* note 117, at 37–40.

[124] Shelton, *supra* note 117, at 37–40.

[125] Shelton, *supra* note 117, at 37–40.

[126] Shelton, *supra* note 117, at 37–40.

Critical Speed Formula tends to decrease the more the vehicle is braked.[127]

Ironically, precisely because the Critical Speed Formula tends to underestimate the actual speed of the vehicle, the formula can be a potent tool for a prosecutor or plaintiff. Ordinarily, the prosecutor or and civil plaintiff wants to show that the defendant of a vehicle was driving at a negligently or recklessly high speed. Again, the use of the Critical Speed Formula ordinarily yields an opinion underestimating the actual speed. If the Critical Speed Formula yields a finding that suggests criminal or civil negligence, the true speed was likely even higher.

B. Other Limitations of the Expert's Final Opinion

The application of Yaw Mark Speed Analysis in a given case can entail small measurement errors that, in turn, produce substantial accuracy error.[128] Normally yaw mark speed analysis assumes the roadway curve as the critical path taken by the vehicle.[129] However, studies consistently show that drivers steer instantaneous path radii that are sharper than the roadway curve.[130] It has been asserted that the most likely scenario is that a driver's inattention causes a driver to drive straight for too long and then turn sharply to correct the vehicle's orientation to the roadway.[131] Several well respected accident reconstruction texts endorse the plausibility of this scenario.[132] However, skeptics have countered that this scenario cannot withstand close scrutiny.[133] The skeptics argue that the formula explains the dynamics of a steady-state point mass object and should not be applied to tire marks associated with a vehicle rotating out of control.[134] The chord is treated as offset in order to measure a circular curve which is traveling downstream.[135] Because the offset method is translated from a spiraling curve, even a small error can produce substantial error in estimating the loss-of-control speed.[136]

[127] Shelton, *supra* note 117, at 37–40.

[128] Glennon, *supra* note 8.

[129] Glennon, *supra* note 8.

[130] Glennon, *supra* note 8; John C. Glennon & Graeme D. Weaver, *The Relationship of Vehicle Paths to Highway Curve Design*, Tex. Transp. Instit. Res. Rep. No. 134-5 iii-v, 3, 30 (1971).

[131] Glennon & Weaver, *supra* note 130, at 33, 38–39.

[132] Glennon & Weaver, *supra* note 130, at 33, 38–39.

[133] Glennon & Weaver, *supra* note 130, at 3, 39.

[134] Glennon & Weaver, *supra* note 130, at 3, 39.

[135] Glennon & Weaver, *supra* note 130, at v, 37–38.

[136] Glennon & Weaver, *supra* note 130, at v, 37–38.

VII. CONCLUSION

Typically the proponent of Yaw Mark Speed Analysis will have little difficulty qualifying a witness who has an educational background or at least formal training in the relevant science. If the proponent intends to use formal analysis such as the Critical Speed Formula, it is ideal if the expert has an extensive background in physics.

Once the witness has been qualified, he or she will usually have little difficulty validating his or her major premise. If the expert relies on the Critical Speed Formula, the expert can readily demonstrate that the formula is derivable from Newton's Laws, which are judicially noticeable under Federal Rule of Evidence 201(b). Even if the judge balks at judicial notice, there has been such extensive empirical validation of most of the commonly used formulae that it will be a straightforward matter to lay a foundation satisfying Federal Rule 702(c) and *Daubert.*

However, at trial the minor premise frequently becomes the major point of contention. As we have seen, to apply the Critical Speed Formula, the expert needs sufficient information about a number of topics, including which car left the mark, whether the mark is a yaw mark, the measurements of various facets of the mark, and the drag factor. Rule 703 allows the expert to acquire the information from a variety of types of sources. However, when the expert relies on secondhand reports about the case-specific facts, as is often the case when the expert is retained long after the accident, the expert must be prepared to testify that it is the reasonable, customary practice of his or her specialty to consider out-of-court reports from such sources. Moreover, Rule 702(b) requires that the expert possess "sufficient" information about these topics. Even assuming arguendo that the expert's minor premise information satisfies both Rules 702(b) and 703, though, the opponent is free to attack the reliability and weight of that information. While in many cases the opponent virtually concedes the validity of the Critical Speed Formula, the expert's major premise, the battle is often waged over the reliability of the minor premise in the expert's syllogism. As is so often true in the law, the facts prove to be outcome determinative.

Appendix: Sample Foundation For Introducing Scientific Evidence On Determining Critical Speed From Yaw Marks

First the proponent will need to qualify a witness as an expert based on formal training in highly pertinent subjects such as physics, mechanics, or the laws of motion.

The expert will then explain the Major premise by showing the Critical Speed Formula and its grounding and derivation through Newton's Laws.

The Expert will then explain his or her minor premise. Here the expert will explain how he or she applied the facts of the case and how he or she evaluated the facts in order to arrive at his or her opinion. In many cases this involves qualifying another witness such as the accident investigator who recorded necessary information such as the shape and size of yaw marks, the vehicle weight, tread, tire inflation, and anything relating to friction coefficients and drag factor. However, some jurisdictions allow the expert to rely upon facts he or she observed and reported from the investigating officer or his or her report.

A. The Expert's Qualifications

Q: What is your current occupation?

A: I am a Physics Professor at UC Davis.

Q: What courses do you teach?

A: I teach several courses in Physics, Aerospace Engineering and Mechanical Engineering. Specifically, I teach Computational Methods of Mathematical Physics, Thermodynamics and Statistical Mechanics, and Analytical Mechanics.

Q: What degrees do you hold?

A: I have a B.S. in Mechanical Engineering from UC Davis, a M.S. in Applied Mathematics, and a Ph.D. in Aerospace Engineering from UC Davis.

Q: Do you have any formal training related to accident reconstruction?

A: Yes, I have also attended a specialized accident reconstruction course at Northwestern University.

Q: How many classroom hours did this course require?

A: 120 hours.

Q: How often have you testified in court?

A: 10 times.

Q: How many times were you permitted to give expert testimony?

A: Every time.

Q: What subjects did you testify about?

A: Mostly accident reconstruction as well as few defective design cases.

Q: How many times did you testify about accident reconstruction?

A: Eight times.

Q: What is the extent of your research in the field of Accident Reconstruction?

A: Verification of the Critical Speed Formula.

Q: Have you published any articles on Accident Reconstruction?

A: Yes.

Q: How many?

A: 10.

Q: Where were these articles published?

A: The Society of International Engineers Monthly Journal.

Q: What professional organizations do you belong to?

A: The Society of International Engineering.

B. The Major Premise

Q: What is a yaw mark?

A: The physical mark on the roadway caused by a wheel rolling on its longitudinal axis while simultaneously slipping on its lateral axis.

Q: What is Yaw Mark Speed Analysis?

A: Yaw Mark Speed Analysis is method of accident reconstruction that applies the Critical Speed Formula In order to determine the minimum speed that a vehicle must have been traveling prior to entering into a yawing action.

Q: What is the Critical Speed Formula Based on?

A: The Critical Speed Formula is derived from Newton's Laws.

C. The Minor Premise

Q: Where were you on January 1, 2017?

A: My office at UC Davis.

Q: What happened that day?

A: I received a case file, investigation report, and photos regarding a traffic collision in West Sacramento. I also spoke with the investigating officer.

Q: Who was involved in the collision?

A: Mr. Richardson and Mr. Peterson.

Q: How do you know the materials you received were for the collision involving Mr. Richardson and Mr. Peterson?

A: The materials were labelled as such and the files and investigation reports described the location and collision described by the investigating officer.

Q: What did you discuss with the investigating officer?

A: I wanted to verify the conditions of the vehicle, location of the incident, and the weather the day of the incident. I also wanted to inquire as to how the yaw marks described in the file were measured and photographed.

Q: What did the officer say?

A: The officer indicated that an LTI Laser with a polarizer was used to assist in determining the visual skid length, the condition of the tires, roadway, and vehicles were all recorded in the reports.

D. The Opinion

Q: Do you have an opinion as to how fast the Defendant was driving?

A: The Defendant driving over 50 mph while attempting to navigate the turn.

E. Explanation of Opinion

Q: How did you arrive at this opinion?

A: I applied the Critical Speed Formula to the instant case.

Q: What is the Critical Speed Formula?

A: The Critical Speed Formula is an equation derived from Newton's Laws. I determines the maximum speed that a vehicle could navigate a turn without the tires breaking free and the vehicle spinning out of control. This is done by determining the total friction on the vehicle's tires compared to the centripetal force pulling the vehicle laterally.

Q: How certain are you of this opinion?

A: The variables applied and their accuracy for the Critical Speed Formula are not exact. However, the Critical Speed Formula underestimates the true speed of the vehicle because it calculates the speed of the vehicle midway through the yawing action and not exactly when the vehicle begins to slide. Therefore, I said the vehicle was likely travelling over 50 mph as opposed to saying the vehicle was traveling exactly 50 mph.