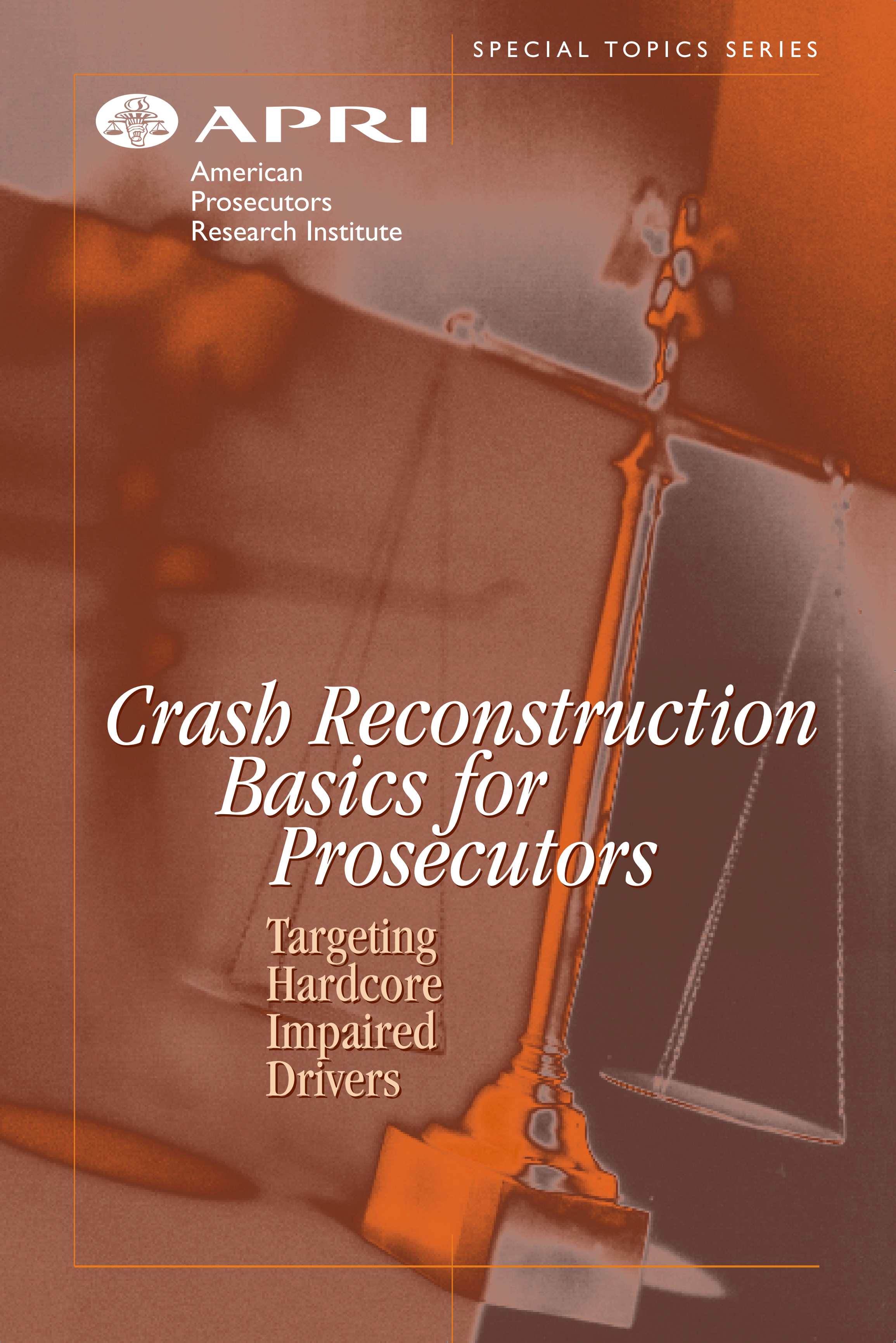

SPECIAL TOPICS SERIES

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American
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Research Institute

Crash Reconstruction Basics for Prosecutors

Targeting Hardcore Impaired Drivers

This publication was produced thanks to a charitable contribution from the Anheuser-Busch Foundation in St. Louis, Missouri. Their encouragement and support in assisting local prosecutors' fight against impaired driving is greatly appreciated. Points of view or opinions expressed are those of the authors and do not necessarily represent the official position or policies of the Anheuser-Busch Foundation, the National District Attorneys Association, the American Prosecutors Research Institute, or the U.S. Department of Transportation.

SPECIAL TOPICS SERIES

Crash Reconstruction Basics for Prosecutors

Targeting Hardcore Impaired Drivers

March 2003

American Prosecutors
Research Institute

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INTRODUCTION: MAKING TOUGH DECISIONS

Prosecutors see hardcore drunk drivers every day in court, often recognizing them from many other court appearances. As documented in the Traffic Injury Research Foundation's 2002 report *DWI System Improvements for Dealing with Hard Core Drinking Drivers: Prosecution*,* these are defendants familiar with the dark corners and back alleys of the legal system, often taking advantage of prosecutors ill-equipped with the technical skills and knowledge needed to successfully prosecute hardcore offenders. After all, impaired driving cases are some of the most difficult cases to prove. They involve scientific evidence, expert testimony, complex legal issues and jurors who typically identify with offenders. These cases require nothing less than the highest level of advocacy skills.

One of the more difficult challenges for prosecutors is evaluating fatal motor vehicle crashes. Prosecutors already know what national data reflects. Roughly 40 percent of every fatal crash report that prosecutors assess will involve impaired driving. And, grieving families, law enforcement officers and reconstructionists all look to the prosecutor's office to decide the legal ramifications of what happened: *Was this an accident or a vehicular homicide? Was this civil negligence or criminal recklessness? Was a crime even committed?* While they wait for the decision, many prosecutors are left scratching their heads trying to make sense out of a reconstructionist's report. Not only are they trying to answer, *What happened?* but prosecutors want to know *If this is what happened, how do I prove it?* Tough decisions to make, and to make those decisions, prosecutors need to be armed with the best knowledge available.

This publication serves as a primer for prosecutors on the basic science, investigative techniques and what questions to ask. Thanks to Professor John Kwasnoski, author and nationally-recognized expert on crash reconstruction, much of the mystery, myth and mathematical phobias surrounding this material will be dispelled.

* For the complete text of the report, visit www.trafficinjuryresearch.com

Never before has material like this been assembled for prosecutors, and our hope is this publication will be used by prosecutors to strengthen investigations, learn the truth and honor their calling to serve justice.

John Bobo
Director, National Traffic Law Center
American Prosecutors Research Institute
March 2003

Crash Reconstruction Basics

By John Kwasnoski
Professor Emeritus of Forensic Physics
Western New England College,
Springfield, MA,

Evaluating the Officer's Report of the Crash

After a crash, the prosecutor receives a written police report, and in many cases, a part of that report focuses on the reconstruction of the crash - the pre-impact motion of the vehicle(s), vehicle speed, etc. and the cause of the crash. At this early stage in the case after receiving the report, the prosecutor can strengthen the investigation by critically assessing the reconstruction and playing the role of the devil's advocate. At this point, challenging questions must be asked, and in some instances, additional investigation must be done to close any gaps in the state's case.

The prosecutor should be particularly sensitive to issues affecting the credibility of the potential police witness at trial. The prosecutor should look for some of the following in the officer's report of the crash:

1. Have the vehicles involved in the crash been secured? How were they transported? Are they now covered or secured indoors? If operator identification becomes an issue, certain types of forensic evidence may be compromised by weather.
   Note: a vehicle should never be released from police control unless the prosecutor knows that the defense has no further use for the vehicle and will not want to conduct any further inspection of the vehicle.
2. Are the locations of witnesses known and documented? The credibility and accuracy of a prosecution witness may be challenged by defense assertions regarding the perspective of the witness.

3. Have all aspects of the scene been photographed:
   - vehicle(s) at final rest position
   - evidence of the area of impact
   - witness perspectives
   - collision debris distribution
   - operator's view approaching crash
   - road evidence (and close-ups)
   - interiors of the vehicles
   - vehicle damage
4. Were the vehicles, bodies, or evidence moved prior to being documented?
5. Does the report include a scale drawing?
6. Was the drag factor of the road measured at the scene? This single piece of evidence is often the focus of the entire defense attack on the case since it is an integral part of many methods for estimating vehicle speed.
7. Did the investigating officer "walk the scene" to look for road defects or evidence that the road may have caused the collision? While this activity is usually part of an investigation, the police report often does not document it, and issues may surface later in the case. By including this in the report, officers show that they looked for potential exculpatory evidence as part of the routine course of the investigation, which dispels any claims of bias.
8. Has the investigator checked for recalls on *all* of the vehicles involved in the crash? This issue opens the door for claims of vehicle malfunction or defect as the cause of the crash. The prosecutor should never be blindsided by having this issue raised after a vehicle has been released or a mechanical inspection can no longer be done.
9. Have the event data recorders (EDRs) or "black boxes" been removed from the vehicles and placed into evidence? The EDRs may contain information such as the speed, use of brakes, deployment of the air bags, seat belt use, engine RPM, etc. for as much as five seconds *before* the crash. The EDR should be secured in anticipation of being able to read the computer memory at a later time. Some officers have training in how to down load the data; other agencies rely on assistance from the dealerships or car manufacturing company. (Also see pages 25 and 26.)
10. Has the clothing of all the occupants in the defendant's vehicle been secured? This may help in debunking the claims that someone else was driving.

11. Have the defendant's injuries and entire body been photographed and documented? Such injuries may help to establish that the defendant was the operator at the time of the crash.
12. Can the medical responders or hospital personnel who treated the defendant be identified?
13. Has road evidence been completely documented, including measurements and photographs clearly showing the appearance of tire marks? A common defense attack is to interpret tire marks differently to reach a different conclusion about vehicle speed. If the credibility of the state's entire case comes down to the observations the officer(s) made at the scene, the evidence should be documented as completely as possible. Debris location can be crucial in a specific instance, yet debris is often less than completely documented.
14. Are there any visibility issues, such as weather, ambient lighting, road topography, etc. that may affect the defendant's ability to avoid the collision? This can best be documented during the initial investigation, and may be compromised to some extent by trying to recreate the conditions at a later date.

Search for Gaps Through Visualization

Looking at the report with a critical eye, it is important for prosecutors to visualize the crash from the information in the report alone. By making a conscious image of the crash, second by second, the prosecutor will immediately see gaps in the paperwork. Using some model cars and recreating the vehicle motions can clarify additional investigation that may be needed - gaps in the state's case may suggest reasonable doubt later. A few extra minutes spent early in the evaluation of the case can save the prosecutor hours of work later, and strengthen the case.

Proof of Operation

Prosecutors often make the mistake of taking for granted proof of operation. After all, this element of the offense hardly seems disputable —especially after a defendant made an admission of operation and the prosecution's reconstruction is completed. But, when the speed calculations are solid as well as reconstruction proof of criminal negligence, a defendant's only defense may be that he was not the operator. This defense often surfaces after the investigation has been closed and the defendant's vehicle has been released from police control. Initially, officers should try to confirm that the defendant was the operator by documenting:

- Observations of eye witnesses who saw that the defendant was operating the vehicle, either pre-impact, post-impact or both.
- Testimony of medical or emergency personnel.
- Statements of hospital personnel who may have heard the defendant make an admission of operation. Also, check defendant's medical records for admissions.
- Forensic evidence of operation: fingerprints, hair, blood, etc.
- Matching damage to the interior of the vehicle to defendant's injuries.
- Evidence from occupant protection devices (seat belts, air bags).
- Elimination proof of other occupants.
- Evidence of contact with glass in the vehicle (either lacerations from windshield glass or "dicing" from tempered side windows)

Head strike evidence, called a "spider web" fracture, was made in this vehicle by the *driver*. Sudden rotation of the car caused by impact with a tractor-trailer spun the vehicle so quickly that the driver was thrown across the car before hitting the windshield. Without reconstructing the crash, hair evidence in the fractured glass may have suggested the head strike to be by the passenger.

If the operator identification becomes an issue, the following questions may determine whether a reconstructionist or "occupant kinematics expert" can be of assistance:

1. Is the vehicle secured and in the control of the state?
2. Are the defendant's clothing and shoes secured?
3. Is the clothing of an operator alleged by the defense secured?
4. Are there photographs of the vehicle interior?
5. Are there complete photographs of the defendant's injuries, including areas of the body that are not bruised or injured?
6. Are there autopsy or other photographs of the alleged operator's injuries?

In anticipation of such defenses the prosecutor may want to establish policies with individual departments and with area hospitals to ensure that valuable evidence is collected as a routine part of the investigation of crashes. Medical records, coroner's reports and autopsy reports may provide the basis for an expert to reach an opinion as to who was operating the vehicle at the time of the crash:

- "pattern injury" on chest from steering wheel
- head contact with A-pillar (roof supports)
- blood smears on interior of vehicle
- fingerprints on steering wheel, key, control levers, light switch, rear-view mirror and/or gear shift
- eye witnesses before or after crash
- blood spatter on driver's side of vehicle
- knee injury from contact with dash
- seat belt marks or abrasions consistent with belt use
- fabric fusion onto seat belt or dash
- forensics on deployed air bag
- abrasion from contact with head liner
- forensics from windshield *spider web* fracture
- seat position
- pedal impression on bottom of shoe
- shoe transfer onto console (left-to-right ejection)
- inability to operate manual transmission
- clothing fibers in broken parts of dash, controls
- injuries to ribs consistent with striking door panel
- lacerations on face from windshield contact
- *dicing* or multiple small cuts from side glass implosion
- teeth impressions on vinyl dash material
- damage to rear-view mirror from head impact
- "pattern injury "on leg from shift lever
- "pattern injury" on leg from door handle
- personal belongings under seat
- hair embedded in windshield
- gas purchase receipts or convenience store video
- clothing fusion onto seat
- damage to brake pedal consistent with leg injury

Note: Failure to find the indicators above should not be interpreted as proof that a particular person was not operating the vehicle. In some circumstances, evidence may not have been documented by police or identified by other witnesses. Or, the event did not generate evidence that goes to proof of operation.

The Anatomy of a Crash

A crash occurs in three chronological phases - pre-impact, impact (engagement), and post-impact. The basic events in the crash are listed below; not every crash has all of these events, and the events may occur in a different order than stated:

1. *Point of first possible perception* - the time and place where the dangerous or hazardous situation could first have been perceived.
2. *Point of actual perception* - the time and place where the first perception of danger occurs. This point may be difficult to determine with any certainty.
3. *Point of no escape* - the point and time after which the collision cannot be avoided. The relationship of the point of no escape to the point of first possible perception must be determined to answer a key question: could the crash have been avoided?
4. *Point of operator action* - the point and time where the operator initiated some action such as braking or steering to try to avoid the collision. Immediately prior to this point is the perception-reaction time of the operator, which may be a hotly disputed point in the case.
5. *Point of initial engagement* - the point where contact is first made during the crash, including the identification of the "point of impact" (POI) or "area of impact" (AOI). In pedestrian and crossing the center line cases, the POI is often disputed. This is especially true in pedestrian cases where the POI is used to estimate vehicle speed.
6. *Final rest position* (FRP) - the point where a vehicle comes to rest. The FRP, and how the vehicle got to the FRP (skidding, rolling, combination of the two) constitute what is called the post-impact trajectory of the vehicle.

Reconstruction Fundamentals

The reconstructionist's choice of methodology may be governed by the nature and completeness of the evidence at a particular crash scene. What follows is a concise overview of the various methodologies with particular emphasis on potential defense attacks on the reconstruction.

Energy Analysis

The pre-impact motion of a vehicle is characterized by what is called "kinetic energy" or motion energy, which is a mathematical description involving the vehicle's speed and weight. As a collision commences, the vehicle's kinetic energy and speed are reduced by
- energy lost to the road surface;
- energy lost during erratic motion and/or side-slipping;
- energy resulting in vehicle damage (and other vehicles or objects);
- energy transferred to property such as utility poles, fences, walls.

When the vehicle reaches its FRP, it has zero kinetic energy. The energy method of reconstructing the pre-impact speed of a vehicle includes isolating each event and identifying its energy loss, quantifying the energy loss by the equivalent speed needed to produce each loss, and then adding the equivalent speeds of all the events together using what is called "the combined speeds equation" to find the pre-impact vehicle speed. This is usually a minimum speed since some of the energy cannot be quantified.

Energy Analysis 1: Speed from Friction Marks Made by Tires
A common crash event involves losing energy (and speed) by transferring it to the road and causing a visible tire mark (skid, ABS scuff, etc.). The equivalent speed of such an event depends on road friction (drag factor), distance over which deceleration occurred, and the degree of braking, called braking efficiency (BE). These measured quantities can be used to calculate a minimum speed needed to make the tire marks by using the *speed from skid marks* equation:

$$S\ (\text{mph}) = \sqrt{\ (30\ (f)(d)(BE))\ }$$

This equation has been validated in numerous published studies[1] and is included in every basic crash reconstruction text. Some facts about the speed from skid marks equation include:
- No vehicle specific information (vehicle make, model, weight, etc.) is

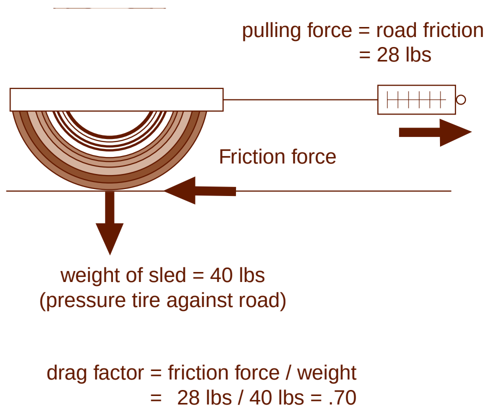
needed since the equation is derived from the basic physics of the frictional interaction of the tires with the road.
- Reasonable changes in the data produce insignificant changes in calculated speeds; the result is not sensitive to uncertainties in measured data used as input into the equation.
- The equation is widely accepted and has been judicially noticed.
- Since tire marks start after braking commences, the equation produces an *underestimate* of speed.

Measuring with the Drag Sled

The drag factor of a road surface can be measured with either a *drag sled* or accelerometer attached to a vehicle. Both of these devices produce measurements of equivalent accuracy, if used correctly, as shown in published tests.[2] The drag sled should not be used to measure the drag factor on wet roads where the weight of the car would squeegee the water out from under the tire tread. This is impossible to duplicate with a drag sled. A drag sled should also not be used on grass, as it cannot accurately produce the same friction as a full-sized vehicle, whose weight furrows the tires into the ground when it travels.

Officer pulling a drag sled and reading the pull force on the calibrated spring scale. A drag sled is basically a weighted segment of a tire, and may have many different configurations. (Photo: courtesy of Ludlow, MA Police Department).

The sled is pulled in the same direction as the vehicle motion, as close as possible to the actual tire marks, and the pull scale is read when the pull becomes smooth and free from any jerking motion. Usually multiple measurements are made over the length of the entire tire mark (*tire mark pattern*) to eliminate the suggestion of significant differences within the tire mark pattern, and investigators may use the lowest measured value for their calculations. The method for determining the drag factor is shown as follows:



The method for determining the drag factor value using the pull force and the sled weight.

A table of "typical" values for the drag factor is given below. Some defense attorneys may misstate that this is the *only possible* range of values, but actual roads often fall outside this range because of specific composition of the road surface material.

dry asphalt, cement	.60 - .80
wet asphalt, cement	.45 - .70
ice, loose snow	.10 - .25
packed snow	.30 - .55

Source: Traffic Accident Reconstruction, Vol. 2, Fricke.

Common Defense Attacks

Since the drag factor is an important part of the reconstruction methodology, defense attacks attempt to lower the value measured at the scene by investigators. Some of the more common attacks include:

CLAIM: During measurement, drag sled bounce produced an unacceptable uncertainty in the measurement.
REALITY: The drag sled scale is not read until the pull is smooth.

CLAIM: Multiple measurements were not made to reveal variations over the length of the vehicle motion.
REALITY: Without obvious visible differences in the road surface such variations usually are insignificant, but multiple measurements are always the best protection against such a claim.

CLAIM: Drag sleds are not acceptable since accelerometers have been developed.
REALITY: Drag sleds produce the same measured values as accelerometers as has been documented in side-by-side testing.[3]

CLAIM: Measured drag factor falls outside published ranges.
REALITY: This is a misinterpretation of such tables which are not intended to imply strict limits on possible drag factor values.[4]

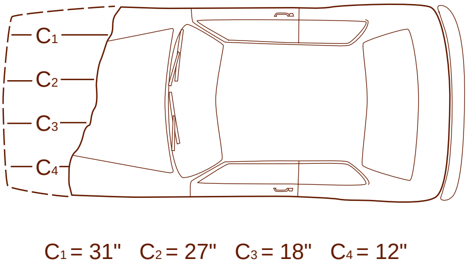
CLAIM: Drag factor is velocity-dependent and decreases at higher vehicle speeds. In other words, the defense is asserting that the officer measured the drag factor at a low speed and failed to reduce the drag factor when used in equations that yield higher speeds.
REALITY: Drag factor values at low speeds are the same as values at high speeds on dry roads, as shown by recent tests done by NY State Police and this author. Caveat: Many defense attorneys use Fricke's table on the previous page to imply that drag factors depend on speed, but Fricke's table is not supported by actual field measurements.

CLAIM: The scale used to pull the sled was not calibrated and is inaccurate.
REALITY: Maybe. Police should periodically have their scales checked against local weights & measures or in some other way to certify their accuracy.

The Truth About Braking

The length of a braking action is determined by the measurements of the tire marks on the roadway. These marks should be photographed and their specific appearance documented to avoid misinterpretation later. A good practice is to have several officers confirm the nature of the tire mark evidence, including a complete photographic record. Using a polarizing filter to reduce road glare and shooting from several angles may improve the quality of tire mark photographs. Braking efficiency is determined by weight distribution and the contribution of each wheel to the frictional slowing of the vehicle. This determination may involve mechanical inspection, tire inspection for evidence of braking or scuffing, and matching the vehicle's tires to tire marks on the road through rib pattern, track width, etc. Tire pressure, tire construction, ambient temperature, and tread depth are not significant factors on dry road surfaces.

Energy Analysis 2: Speed from Vehicle Damage/Crush Analysis
The speed (energy) required to cause permanent deformation of a vehicle can be analyzed by referring to the results of staged automobile crash tests. Manufacturers routinely conduct controlled tests to evaluate the "stiffness" of vehicles under various collision configurations (front, side, rear). These tests yield what are called *stiffness constants*, numbers that will describe mathematically how a vehicle's impact speed is related to the resulting damage. Databases of these characteristics allow the reconstructionist to determine the equivalent speed needed to cause damage if the *crush profile* or damage dimensions are measured according to a strict measurement protocol.[5] The calculation can be done by hand using an algorithm developed as part of the EDCRASH computer software,[6] or it can be done with any number of computer software packages available to reconstructionists. The calculation of crush energy (and equivalent speed) is done by modeling the damage area into *crush zones* and then determining the energy needed to cause the damage in each zone. The intrusion into each zone, called the *crush depth*, is measured by a strict protocol that is consistent with the measurements made during the original staged crash tests, as shown below. Finally, the zones are totaled, and an equivalent speed to create all the damage is determined. Due to lack of training, some law enforcement reconstructionists do not use crush analysis, but the method is generally accepted and should not be overlooked.



Measurements of the crush resulting from a frontal impact. Depth of crush in each zone is measured from the undamaged dimension of the vehicle (dashed line).

Energy Analysis 3: Speed From Utility Pole Impact
Impact speed of a vehicle that strikes a utility pole may be possible to determine either from the damage to the car or a fracture of the pole.

Research done by universities and utility companies on wooden and metal poles has resulted in a data base that relates pole failure (fracture) to vehicle speed.[7] Research on collisions into utility poles has resulted in empirical equations that relate intrusion depth to impact speed.[8] These empirical equations can be compared to determine a relatively narrow range of possible impact speeds that would have resulted in the observed damage to the vehicle.

As the basis for a separate speed determination, the damage to a pole should be photographed and measured (height above ground, pole diameter at damage point, etc), and the age of a wooden utility pole should be determined. It might also be necessary to secure a sample of the pole itself in a case where a certain type of analysis is done on the fractured or failed pole. In some cases, an impact into a tree can be mathematically analyzed using the utility pole equations, and this involves careful study of the nature of the impact to be sure it fits the criteria of the utility pole research.

Speed in a Multiple Event Collision

Once the individual events of the collision have been analyzed and equivalent speeds determined for each event, the speeds are totaled using the *combined speeds equation,* which is based on adding together the equivalent speeds of the events:

$$S = \sqrt{ (S_1^2 + S_2^2 + S_3^2 + \ldots)}$$

The reconstructionist may not include all the events. There may be a lack of empirical evidence, testing, etc. to analyze a specific event like knocking down a mailbox, running through a chain-link fence, jumping a curb, uprooting a small shrub, etc. Rather than make an assumption necessary, the reconstructionist simply acknowledges that the event has been left out of the total; therefore, the combined speeds calculation is a minimum speed estimate.

It is always better to avoid making assumptions. The credibility of the rest of the reconstruction may be compromised, opening up a defense attack that can distract from the case. The best practice is to avoid making unfounded assumptions about those events and sticking to a minimum speed estimate. The combined speeds equation is part of basic reconstruction texts and is widely accepted. Officers may refer to this method as the *conservation of energy* method because they evaluate the energy of each event and add them together.

Momentum Analysis

Another method used to determine pre-impact speed is based upon the principle of conservation of momentum. Every vehicle in motion has a property called linear momentum, which may be defined by multiplying the vehicle weight by its speed. The concept of momentum is complicated by the fact that the momentum also has a direction – the momentum of a car moving eastbound may be described as positive, while using that frame of reference, the momentum of a westbound car would be negative. Since the vehicles often move in paths that are not parallel to one another, the linear momentum analysis must employ the concepts of trigonometry to mathematically describe the motions. This generates an abundance of trigonometry symbols, angles, a zero reference direction and long calculations that may be well beyond the ability of most jurors to understand.

Momentum Analysis in a Nutshell
There are eight numbers (called variables) in the general momentum equation; any six must be known to calculate the other two. Usually, the two unknowns are the pre-impact speeds of the two vehicles. These variables include the approach and exit directions of the vehicles as well as the pre-impact and post-impact vehicle speeds.

The momentum analysis deals only with speeds immediately before impact and immediately after separation from the impact. This is independent mathematically from any energy loss or damage that occurs during the collision; therefore, the equation is a method that may be used to check other calculations. If enough information is gathered at the scene to do both energy and momentum analyses, the results should be consistent. Remember the energy-determined speed may be less because it is only a minimum speed.

The momentum equations may be sensitive to changes in input data because of the trigonometric nature of the calculations; therefore, the prosecution's reconstructionist should consider any effect of uncertainties in the data collected at the scene. Such an analysis is called a *sensitivity analysis* and should be done to reinforce the certainty of the speed calculation. A sensitivity analysis involves changing the evidence values to determine what effect it has on calculated speeds. Often, this is done to demonstrate that variations of the input variables do not have a significant impact on the determined speed.

The momentum method should *not* be used in collisions involving vehicles of great differences of weight to find the speed of the lighter vehicle (car vs. motorcycle, tractor-trailer vs. car, etc.). Uncertainties in the speed of the larger vehicle are amplified in the calculation of the smaller vehicle's speed.

Common Defense Attacks

CLAIM: Incorrect drag factor caused error in post-impact speed estimate.
REALITY: This is not a valid claim if the drag factor was measured at the scene and the officer included any defects of the rotation of the vehicle.

CLAIM: Incorrect vehicle weight was used. The defense claim will be the officer used the maximum allowed weight of the loaded vehicle (gross weight) versus the actual weight (curb weight) of the vehicle. The fact that the vehicle was not actually taken to a scale and weighed may also be an attack point since the damaged vehicle, with its specific cargo, may have changed in weight from its original specification.
REALITY: The momentum equations are not very sensitive to variations in vehicle weight –even as much as several hundred pounds. This should be shown in the sensitivity analysis.

CLAIM: Effect of post-impact vehicle rotation was not included. Defense claims the officer used full drag factor (a full drag factor means that a vehicles wheels were all locked up and skidding) in calculating post-impact speed estimate, although the vehicle did not exhibit full 100% braking. In other words, all the vehicles tires were not locked and skidding after separating from the collision.

REALITY: The prosecutor should make sure that the reconstructionist did *not* use the full drag factor if there is no evidence that all the wheels were locked up after collision. Look for locked tire evidence in the post-impact tire marks of the victim's vehicle, and tire flat spots or damage to tires causing lock-up. This can cause a significant error in the calculations.[9] Example: the medical examiner determines the victim/operator died on impact, and an investigator assumed the victim continued to brake, i.e., keep the tires locked after impact. Of course, if the victim is deceased, this would not be possible.

CLAIM: The pre-impact orientations of the vehicles, called the *approach angles*, have not been determined accurately, and assumptions have been made in determining the approach angles, which cannot be supported by evidence at the scene. The most common attack is on the approach angle of a turning vehicle.
REALITY: The orientation of the vehicle at the moment of impact should be consistent with the normal turning path and the construction of the intersection.

CLAIM: The victim's speed as determined in the equation is not consistent with eyewitness testimony.
REALITY: The calculated speed of the victim's vehicle must be consistent with the road geometry, physical limitations of the vehicle, the ability of the victim's vehicle to accelerate and the surface condition of the road. Factors to be considered include the pre-impact speed of a turning vehicle, the turning path, initial speed of the vehicle before initiating the turn, eyewitness observations, and the maximum speed at which the turn radius can be made without yawing. This serves as a flag in evaluating the case. If the calculation of the victim's speed is not consistent with the factors above, know that the same data was used to calculate the defendant's speed.

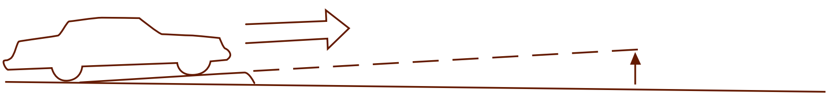
CLAIM: A lack of air bag deployment indicates a low speed for defendant's vehicle rather than the higher speed determined by the state's reconstruction expert.
REALITY: In certain collisions where impact has a significant lateral component, rather than head-on, the air bag sensors may not trigger the air bags to deploy. This does not necessarily indicate a low impact speed.

The momentum equation offers defense attorneys the possibility of constructing hypotheticals favorable to the defense. The state's expert should anticipate such an attack and consider any possible variations in the field measurements.

Note: Particular area of concern for prosecutors is the potential misuse of the full drag factor applied to post-impact vehicle motion. Often a driver is disabled by the collision and cannot apply post-impact braking action. The vehicle is moving in a combination of sliding and rolling movements, and the tire friction is really a mathematical combination of both sliding and rolling.[10] If the full drag factor is used in momentum calculations (or speed from skid marks) when there is no evidence of full braking action, the vehicle speed will be overestimated, resulting in significant errors in the momentum calculation.

Airborne Vehicles: Speed in a Vaulting Motion

When a vehicle becomes airborne, a series of equations derived from projectile motion considerations may be available to the reconstructionist. These equations may be sensitive to input data, especially the launch angle, and vertical and horizontal distances traveled by the center of mass of the vehicle must be determined. Because the airborne equations involve trigonometric functions, a small error in field data (at low launch angles) may produce a large error in the calculated speed, as shown below.



Launch angle	Calculated launch speed
5°	61.9 mph
6°	56.4 mph
7°	52.2 mph
8°	48.8 mph
9°	46.0 mph
10°	43.6 mph

Effect of launch angle estimated speed for a given distance traveled to the point of landing.

The airborne equations require careful processing of the scene to establish the data needed in the calculations. If possible, the airborne speed should be corroborated by another method.

Note: The airborne speed is an exact speed at the point where the vehicle is launched, and subsequent speeds should not be added to the airborne speed in a combined speeds calculation. However, adding equivalent speeds of events prior to the point where the vehicle was launched is perfectly acceptable in determining a speed at a previous point in the crash sequence.

Speed from Yaw Marks

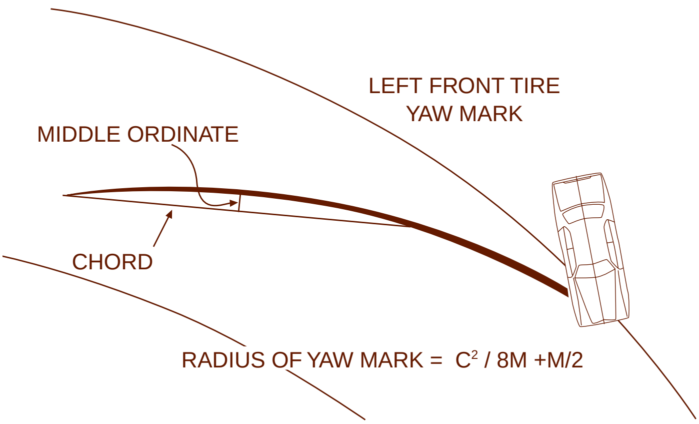
When a vehicle is in a turning motion, its speed may be too great to maintain the proposed circular path. So, the vehicle starts to slip sideways in what is called a *yawing motion*. There is not enough frictional force to provide the necessary centripetal force to keep the vehicle in its intended path. The speed at which this slipping starts is called *the critical speed for the path of the vehicle*, and it depends on the drag factor of the road (in a lateral direction) and the radius of the path of the vehicle. When side-slipping starts, the tires make what are called *yaw marks*, which may have distinct *striations* within the yaw pattern that are diagonal or even perpendicular to the overall tire mark. Usually, most visible from the outside tires, yaw marks start narrow and get wider as the yaw continues and the vehicle becomes more rotated. In a controlled turning motion, the rear wheels track inside the front wheels. In a yaw, the front and rear wheels cross over each other, resulting in a characteristic crossover point in the yaw pattern that tells the reconstructionist it is a true yaw. This crossover point may be difficult or impossible to see because of road surface effects and glare. Yaw marks are short-lived evidence and may disappear within a few days with heavy traffic on the roadway.

The yaw marks are analyzed using the speed from yaw marks equation:

$$S = \sqrt{(15\,(f)(R))}$$

The equation itself may be written in other forms to include adjustments for the effects of road crown or superelevation. The equation is derived from the basic physics of the balance between centripetal and friction forces. The speed from yaw marks equation has been validated in numerous published studies.[11] Speed estimated from this information is a speed during the yaw, not at its beginning. Thus, this is always less than the true speed of the vehicle at the start of the yawing action.

Speed at the start of the yaw is faster than the calculated speed of the yaw equation. Since the measurements do include a segment of the mark, they necessarily cannot produce a speed at the start of the mark. The yaw mark information needed to calculate speed includes the radius of the yaw mark itself, which is found using a chord and middle ordinate method, as shown below.



The radius of the yaw mark is determined by measuring a chord C and middle ordinate M on the yaw mark evidence. The curvature has been accentuated for illustration.

The drag factor should be determined *perpendicular* to the direction of the yaw mark, since frictional forces must act in that direction to provide the centripetal force needed to keep the vehicle on its path. This is different from the drag factor value used in speed from skid marks calculations, where the drag factor is measured *parallel* to the direction of travel. As an alternative, the measured drag factor can be adjusted mathematically when it is used in the speed from yaw marks equation.

Note: The difference between the two values is usually insignificant, but may not be in cases where the road has significant superelevation (road edge is higher or lower than the center of the road). The prosecutor should clarify with the police investigator that the drag factor has been determined correctly, or that a measurement of the superelevation of the road has been included in the yaw equation.

Common Defense Attacks

CLAIM: The yaw marks are not the same radius as the center of mass motion of the vehicle.
REALITY: By considering the radius of the actual yaw mark, any benefit is to the defendant.

CLAIM: Driver braking or acceleration action during the yaw affects the validity of the equation.
REALITY: If a driver brakes or accelerates during a yaw, then a reconstructionist cannot use the yaw speed equation. Evidence of such action might be seen in the appearance of the striations within the yaw pattern.

CLAIM: The tire mark evidence was actually curved ABS braking marks, not yaw marks. Therefore, the whole analysis is incorrect.
REALITY: Careful analysis of the yaw marks can prove this is not true, but it requires good photographic evidence of the entire yaw pattern and close ups of the marks as well. In a vehicle rotation, there is a distinct separation between the tire marks of the left and right tires on the same axle, but while applying ABS brakes, the tire marks stay the same distance apart—i.e., no yaw. The striations and cross-over point are also evidence of a yaw. Officers should be able to explain to the prosecutor how the two types of tire mark evidence can be distinguished.

Time-distance Analysis

During any vehicle motion, speed, position and time are mathematically interrelated. If vehicle speed is relatively constant during a particular interval, the equations are straightforward, but if vehicle acceleration is a factor, determining the specific time-distance relationship may require testing or other analysis. Time-distance analysis may be used to:

1. Evaluate operator behavior, such as:
    - Distance from impact when perception started

- Time available for evasive action
- Time needed for successful avoidance of the collision
- Response time indicative of impairment
- Assessment of inattentiveness or delay in reaction

2. Construct time lapse drawings of the crash, including information about visibility distance, pedestrian walking motion, etc.
3. Verify witness statements
4. Evaluate operator perception-reaction time (PRT)

Note: *Perception reaction time* (PRT) is the time that elapses between the the point where the operator sees the danger and when the action (braking, steering, etc.) occurs. This includes the processes of recognition and decision making; both functions are extremely sensitive to central nervous system depressants. PRT measurements cover a broad range of values that depend on the specific response task, the nature of the stimulus, the age and physical condition of the subject and many other factors. Certain numbers have been cited as benchmarks - 1.5 seconds for the 85th percentile operator PRT under most conditions,[12] and 2.5 seconds for the 90th percentile operator PRT used for road design considerations.[13] A factor affecting PRT is expectancy, which reflects the operator's expectation of what he/she will encounter. Human factors experts may propose that a defendant had a long PRT because of the unexpected nature of the dangerous situation, or a lack of prior warning of danger.

A reconstructionist should not assign a PRT value to a defendant, but rather use a range of values to reflect what might be a possible PRT. This might be done in conjunction with a toxicologist who is familiar with the literature on effects of alcohol or drugs on PRT. There is no basis for assuming the defendant had a PRT of 1.5 seconds (or any other specific value) and then proceeding with calculations about the pre-impact motion or possible evasive actions of the vehicle. If the range of values yields conflicting results with regard to criminal negligence or culpability, the prosecutor must be aware that such results are possible in the calculation. The prosecutor should ask the reconstructionist what the results are if a range of PRT values were used in the calculations. A range of values may produce inculpatory and exculpatory conclusions, which assists prosecutors in determining if they can meet their burden. A similar consideration applies to the use of pedestrian walking speeds, vehicle acceleration factors, or other data that cannot be specifically determined and about which assumptions must be made.

Speed from "Black Box" Recorder

Since the mid 1970's manufacturers have put event data recorders (EDRs) in vehicles to collect field data about crashworthiness, structural behavior of vehicle, efficacy of safety systems, etc. Recently, the ability to read the information in the event data recorder (black box) in certain vehicle models has been made commercially available.

If possible, EDRs should be secured from all vehicles involved in a crash. This may require a warrant, and the prosecutor may want to advise law enforcement officers of this new piece of potential evidence and its proper collection. Data from EDRs in many GM models from 1996 forward can be downloaded. Ford Motor Company has also installed EDRs in many models.

Note: Car makers are embracing this technology, and prosecutors should always ask if the vehicle had an EDR and whether the data can be downloaded.

The permanent EDR is triggered by an air bag sensor located in the passenger compartment of the vehicle. In crashes where the air bag did not deploy, that data may be obtained from the temporary storage cell. The information stored is from 4-5 seconds ***prior to the crash*** in either the permanent or temporary memory. Depending on the particular make and model of the vehicle, data may include:

- pre-impact speed
- deceleration rate to final rest position (helpful in occupant kinematics cases)
- use of braking prior to the crash
- use of seat belts prior to impact
- deployment of the air bag
- engine RPM

The EDR information is printed out in graphical and spread sheet forms and may require the analysis of the reconstructionist to interpret correctly. EDR information may have limited use, but when used in conjunction with a reconstruction analysis, it may provide valuable corroborative evidence.

Challenging the Defense's Expert

The level of defense attack on the prosecution's reconstruction is inversely proportional to the level of completeness of the prosecution's investigation. Errors or omissions in scene processing, examining the vehicles, taking witness statements and reconstructing the events provide attack points for the defense. While reviewing the case, the prosecutor should continually ask this question: *What do I really know for sure?* The defense may engage the services of an expert witness for trial. In anticipation of a defense expert, the prosecutor can take several steps:

1. Identify potential defenses available to the defense attorney, which might include:
   - witness accuracy
   - reconstruction inconsistent with witness statements
   - driver identification
   - reconstruction of defendant's speed
   - point of impact
   - mechanical failure/defect (suspension, steering, axle, motor mount failure, sudden tire deflation, computer fuel injection, air bag deployed, cruise control, etc.). For recall information call NHTSA's hotline 1-800-424-9393 or visit www.nhtsa.dot.gov. Also see Consumer Reports.
   - failure to hold vehicle for defense inspection
   - legal issues regarding impairment
   - physical evidence measured incorrectly
   - police measuring equipment not acceptable
   - no evasive action available to defendant
   - limited driver visibility, poor conspicuity of pedestrian
   - victim (or other vehicle) caused the crash
   - road defect, incorrect signage, road design

- vehicle identification—"hit-and-run"

2. Secure the credentials of the defense expert. This may show the "jack of all trades" expert who has very limited capacity to engage the state's expert on the technical level. The expert may never have been at an active scene, and in this case, he may have relied completely on the police investigation.
3. Ask your own expert about the defense's expert. Often the state's expert will have had prior contact with the expert or may know how to find information about the expert that can be helpful to the prosecutor.
4. Ask other prosecutors or civil attorneys about the defense expert. The prosecutor may be able to obtain evidence of prior testimony that will be invaluable at trial.
5. Contact your state prosecutors association as well as APRI's National Traffic Law Center, which maintains a database of prosecution and defense experts.

The key to handling the adverse expert is preparation. If the prosecutor can meet with the state's reconstructionist prior to discovery, the potential testimony of the defense expert may be narrowed to only a few possibilities, and the prosecutor can anticipate the defense expert's theory in many instances. Even if discovery is meager and no prior transcripts exist, if the prosecutor can take the expert's deposition or arrange an opportunity to speak with him, the state's expert should be consulted in developing the deposition and cross examination strategy. In deposition or discovery, the prosecutor should look for the following:

- Curriculum vita—publications pertinent to accident reconstruction.
- Copies of any research papers or references that expert *relied upon.* Follow up and be sure to get materials.
- Names, jurisdictions, attorneys in recent cases in which expert testified as an accident reconstruction expert.
- Details about when the expert became involved, prior work with same attorney, retainer relationship, expert's fee structure, number of hours that were already billed on the case.
- Working notes and calculations (these will show your expert exactly where the defense expert plans to go).

Get the expert to commit to the facts in the case that he/she accepts (and be specific—"what drag factor value do you accept for this roadway?," etc.). Differences in the reconstructions by the two experts may come down to "changing" the evidence. If the defense expert accepts the state's evidence in its entirety, the defense expert's calculations should not be different.

Some attacks on the defense expert may include:
• Did not personally observe evidence.
• Did not speak with police investigator.
• Did not speak with defendant.
• Did not get involved or visit the scene in a timely manner
• Does not specialize in reconstruction.
• Has not published on topics pertinent to reconstruction.
• Did not do his/her own reconstruction.
• Prepared report in response to police reconstruction.
• Submitted outrageous fee structure and amount.
• Works only for defense attorneys, never for prosecution.
• Did not have anyone check his/her work—potential for error or mistake.
• Used assumptions to make calculations and cannot verify those assumptions with evidence in the case.
• Used computer software. Get the User's Manual for the software!
• Claims to base opinion on personal testing or studies that are not published or peer reviewed.

Finally, prosecutors must consider potential attacks on the state's witnesses and challenge their own experts in anticipation of trial. It may be necessary to inoculate the state's expert against such attacks, or to admit shortcomings in the investigation that are not particularly significant to the opinions reached. Here are some potential attacks on the police officer reconstructionist:
• Cannot cite a treatise to back up testimony
• Has not done tests, published results of field studies, etc.
• Cannot derive equations used in reconstruction (this is usually not done because of potential credibility if officer can do it, but it can be

handled in redirect)
- Is not ACTAR certified, (ACTAR is the Accrediting Commission for Traffic Accident Reconstructionists). Some reconstructionists take the ACTAR test to achieve certification, but many others do not.
- Did not visit the scene in timely manner.
- Did not calibrate or check measuring equipment against a standard.
- Did not check for a recall on defendant's vehicle.
- Inspection of road for defects was not included in report.
- Performed visibility test with different vehicle –i.e., different alignment, height, model of lamps, weather, moon, etc.
- Unable to identify exact point of impact.
- Did not have all materials before reaching conclusions.
- Changed report after seeing defense expert report.
- Did not take videotape of scene.
- Never personally performed any tests that were published.
- Did not consult with anyone in this case to verify their work.
- Did not inspect the vehicle for mechanical defects.
- Lacks formal training in physics.
- Did not return in daytime to the scene of night crash to look for additional evidence.
- Did not do sensitivity analysis on the calculations.
- Failed to consider results using a different assumption (if one was used).
- Performed incomplete reconstruction of motion of victim's vehicle regarding causation.

In conclusion, prosecutors may be at a disadvantage in evaluating the case because the reconstruction of the crash involves a technical expertise that is usually beyond their training and experience. Ask the difficult, challenging, probing questions to get the best possible understanding of the technical facts of the case, and then, apply the principles of the law to those facts.

Endnotes

[1] Speed from skid mark validations studies:

a. A Comparison Study of Skid and Yaw Marks, Mary Reveley, Douglas Brown, and Dennis Gauthier, S.A.E. # 890635. Validation of both "speed from skid marks" and "critical speed" equations. For yaw calculations there was no significant difference noted in the drag factor generated by radial or bias ply tires.

b. Vehicular Deceleration and Its Relationship to Friction, Walter Reed and A. Taner Keskin, S.A.E. # 890736. Validation of the speed from skid marks calculations, but tests indicate 15% to 30% kinetic energy loss between brake application and start of visible skid marks, which *underestimates* vehicle speed based on speed from skid marks calculations by 7% to 15%.

c. Drag Sled Measurements Yield Valid Minimum Speed Estimates, J. Kwasnoski, NATARI Newsletter, 3rd Qtr., 1998. Test skids with conventional brakes showed that use of the "speed from skid marks" equation underestimates radar-measured vehicle speed, even when the longest skid mark is used as the skid length. Test skids were done at speeds of 25-46 mph on a dry, asphalt surface, and drag factor measured with an 18 lb sled.

d. Validity of Average Drag Factor Values from VC2000 Measurements, Frost, Mulverhill, and Kwasnoski, NATARI Newsletter, 4th Qtr., 2000. Field tests with the VC2000 accelerometer yielded average drag factor values that, when used with skid length measurements, underestimated actual vehicle speeds, thus validating the use of the average drag factor value from such tests.

2 Studies showing the drag sled and accelerometer produce measurements of equivalent accuracy:

a. Roadway Drag Factor Determination, Dynamic v. Static, Wakefield et.al., NATARI Newsletter, 4th Dtr, 1995. Drag sled measurements were directly compared with VC2000 determinations for three sites making measurements side-by-side. Drag sled measurements were 6%-9% lower than those made with the VC2000.

b. Drag Sleds and Drag Factors, Joseph Badger, Society of Accident Reconstructionists, Summer 2001. Fifty drag sled tests averaged within 1% of the drag factor measured with the sophisticated ASTM skid trailer.

3 See endnote above.

4 See endnote 2.a.

5 Tsumbas and Smith, "Measuring Protocol for Quantifying Vehicle Damage from an Energy Basis Point of View," S.A.E. # 880072.

6 Day, Hargens, "An Overview of the Way EDCRASH Computes Delta-V," S.A.E. # 870045.

7 James Morgan and Don Ivey, "Analysis of Utility Pole Impacts," S.A.E. # 870607

8 Utility pole studies regarding the relationship of intrusion depth to impact speed:

a. Joseph Cofone, *The Investigation of Automobile Collisions with Wooden Utility Poles and Trees*, IPTM, 1996.

b. Victor Craig, "Speed Estimation on Head-on Vehicle/pole Impacts—Update: October, 1995," Accident Reconstruction Journal, Sept/Oct, 1995.

9 Effects of post-impact vehicle rotation:

a. Kwasnoski, "Effect of Simplifying Assumptions on Speed Estimates," N.A.T.A.R.I. Newsletter, Fourth Quarter, 1994.

b. Kwasnoski, "Effect of Simplifying Assumptions on Momentum Speed Estimates," IMPACT, Autumn, 1995.

c. Kwasnoski, "Constructing Hypotheticals in Motor vehicle Homicide Cases," The Champion, November, 1992.

10 Tire Friction—mathematical combination of sliding and rolling:

a. Thomas Shelton and Victor Craig, "Translational Deceleration from Vehicle Sideslip," Accident Reconstruction Journal, Jan/Feb 1995

b. Raymond M. Brach and Russell A. Smith, "Tire Forces and Simulation of Vehicle Trajectories," Accident Reconstruction Journal, Nov/Dec 1991

c. Duane R. Meyers, "Post Impact Deceleration," Accident Reconstruction Journal, Nov/Dec 1994

d. William H. Pultar, Jr., "A Model to Determine Deceleration of Rotating Vehicles," Accident Reconstruction Journal, Nov/Dec 1990

11 Validation of speed from yaw mark studies:

a. An Analytical Assessment of the Critical Speed Formula, Raymond M. Brach, S.A.E. # 970957. Validation of the use of the "critical speed formula" by staged tests.

b. Validation of the Estimation of Speed from Critical Speed Scuffmarks, Sgt. Thomas Shelton, Accident Reconstruction Journal, Jan/Feb, 1995. Overall, the method will tend to underestimate the actual speed of the vehicle by approximately 5%. If the vehicle is being braked during sideslip, the method can significantly underestimate the actual speed of the vehicle.

c. Letter to the Editor, ARJ, Sgt. Thomas Shelton, ARJ, Sept/Oct, 1989. Result of validation tests show the critical speed formula underestimates, but never overestimated the actual vehicle speed.

d. Estimating Speed from Yaw marks—An Empirical Study, Luis Martinez, Accident Reconstruction Journal, May/June, 1993. Validation of the use of the critical speed formula from actual tests.

e. Traffic Accident Reconstruction, Lynn B. Fricke, The Traffic Institute, Northwestern University, 1990. Tests show that use of the critical speed formula underestimates actual speed by 7-12% for cars tested (standard and sport style American cars).

f. Project Y.A.M. (Yaw Analysis Methodology) Vehicle Testing and Findings, Peter Bellion, S.A.E. # 970955. In yaw tests with test vehicles the speed estimates from the "critical speed" equation were below the radar-measured speeds when the average drag factor of the road surface was used in the calculations.

12 Paul L. Olson, *Forensic Aspects of driver Perception and Response*, Lawyers & Judges Publishing Co., 1996.

13 AASHTO (American Association of State Highway and transportation Officials), *A Policy on Geometric Design of Highways and Streets*, 1984.

About the Author:

John served for 31 years as a professor of Forensic Physics at Western New England College. He is a certified police trainer in more than 20 states, and he has reconstructed over 650 crashes involving multiple and single vehicles, pedestrians, motorcycles and trains. He also teaches regularly at the Ernest F. Hollings National Advocacy Center in Columbia, South Carolina for NDAA's Lethal Weapon: DUI Homicide Course.

Notably, he was the expert in *South Carolina vs. Susan Smith*, where a mother murdered her two children by pushing a car into a lake. John participated in the re-enactment of the drowning in a submerged car, where a video was used in the sentencing phase of the trial. He also reconstructed the multiple vehicle crash in Washington, D.C., in which a Russian Embassy aide was charged with vehicular homicide (*U.S.A. vs. Makharadze).* The aide subsequently pleaded guilty after being released from diplomatic immunity.

John has co-written three best-selling books: *Investigation and Prosecution of DWI and Vehicular Homicide, Courtroom Survival*, and *The Officer's DUI Manual*, all published by LexisLaw Publishing. John has also published other trial manuals and is the creator of *Crash—The Science of Collisions*, a series of science and mathematics teaching materials focusing on crashes. The material is aimed at reducing teenage fatalities and improving science and math learning, using actual police files. For questions, you can reach John at Kwasnoski@aol.com.

Appendix: Minimum Speed From Skidmarks

Skid Length (ft.)	Drag Factor .5	.6	.7	.8	.9	1.0
20	17	18	20	21	23	24
40	24	26	28	30	32	34
60	30	32	35	37	40	42
80	34	37	40	43	46	48
100	38	42	45	48	51	54
120	42	46	50	53	56	60
140	45	50	54	57	61	64
160	48	53	57	61	65	69
180	51	56	61	65	69	73
200	54	60	64	69	73	77
250	61	67	72	77	82	86
300	67	73	79	84	90	94

Speed Estimate: A vehicle putting down 120 feet of skidmarks on a road with a drag factor of .8 would have a minimum estimated speed of 53 mph.

Breaking Distance: A vehicle moving at 40 mph on a road with a drag factor of .7 would require 80 feet of braking distance to stop.

American Prosecutors Research Institute
99 Canal Center Plaza, Suite 510
Alexandria, Virginia 22314
Phone: (703) 549-4253
Fax: (703) 836-3195
http://www.ndaa-apri.org

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