"Voodoo Physics," "Black Magic," "Sorcery," "Wizardry," and "Witchcraft" are just some of the terms of endearment that have been applied to the determination of speed from damage. The calculation of speed change, or DELTA V, from damage has been shrouded in mystery for many accident reconstructionists. How is it done? Why is it done? How does it work?

Reconstructionists routinely determine a coefficient of friction. This information is then used in various formulae to determine speeds, including speed from skidmarks. Determination of speed from damage works in much the same way. Stiffness coefficients serve in place of drag factors. Both are used in combination with distance to obtain a speed. Drag factors are used with the distance the vehicle traveled whereas stiffness coefficients are used with the deformation distance. There really is no mystery. The same diligence must be exercised in obtaining the stiffness coefficients as in determining a drag factor. Likewise, the care taken in obtaining the length of the skidmarks must also be taken in obtaining the deformation distance. The major difference is that skidmarks have only length, while deformation has both depth and width.

Delta V from damage uses the CRASH3 program formulae. CRASH3, an acronym for *Calspan Reconstruction of Accident Speeds on the Highway* -- version 3, was designed as a tool for making a standardized assessment of an accident's severity.

CRASH3 employs two separate and independent methods to estimate the speed change of a vehicle in collision -- Trajectory Analysis and Damage Analysis. Trajectory Analysis involves a work-energy relationship for the spinout and conservation of linear momentum for the collision. Damage Analysis uses detailed measurements of the structural deformation of each vehicle in order to arrive at an estimate of the energy required to produce such damage, and is the subject of this paper.

CRASH3 based software programs use algorithms based on these CRASH3 formulae and are therefore subject to the same limitations as the algorithms. Most commercial software programs allow use of actual vehicle specifications, and one allows for a different stiffness coefficient in each crush zone, data that is almost impossible to obtain without destroying an exemplar vehicle.

The use of actual vehicle specifications, coupled with the use of current exemplar-vehicle stiffness data, greatly improves the accuracy of the speed estimate. "Adjusting" for individual crush zones is an attempt to compensate for the inadequacies of the system. The "adjustment" must still be explained, and possibly defended. Utilization of additional zones over the "normal" six (6) is another attempt at increasing the accuracy of the system, but this alone rarely produces any appreciable difference in the final calculations.

CRUSH may not be pretty but it may be the only tool available that will accomplish the task.

The following excerpt is from the CRASH3 Technical Manual.

"The five basic assumptions of the CRASH3 model are restated below.

1. *The driver's control of the vehicle ceases at impact.*

2. *At some time during the interaction both vehicles achieve a common velocity at the collision interface.*

3. *The program is two-dimensional: therefore, vertical effects such as rollover, steep grades, and curb mountings cannot be modeled directly.*

4. *Vehicle properties are average properties for a vehicle class. The properties used may or may not adequately represent a particular vehicle.*

5. *Crush stiffnesses are assumed to be uniform over the side, front, or back of the vehicle.*

It is also useful at this stage to consider the intent of the CRASH3 program. Because of its availability, CRASH3 is viewed by many as a tool for accident reconstructionists involved in litigation. A vehicle collision is a very complex event and one should not expect high fidelity from a computer program filled with assumptions and simplifications. CRASH3 was designed as a research tool for identifying and establishing trends in crash severity parameters such as the change in velocity, Delta V, in highway accident data. In particular, it has been useful in measuring the speed change of vehicles during an impact: a parameter that is useful in assessing crash severity. As Section 2.5 will indicate, CRASH3 can yield completely false answers for a particular case, depending on the quality of the field data, the correspondence between the real vehicle and CRASH3's assumed vehicle, as well as the degree to which the above outlined simplifying assumptions are met. On the whole, though, CRASH3 is statistically a good predictor of trends; inferences made about a large number of accidents are very likely to be representative of collisions in the real world.

One recurring theme in this chapter will be the limitations imposed by the very sparse crash test data. Many, if not most, of CRASH3's problems can be directly attributed to insufficient data from full-scale vehicle crash tests. In addition, there will always be a need for new data as the vehicle population changes.

In summary, CRASH3 is a very useful research tool which possesses certain inherent limitations. The limitations of the program should always be rigorously observed and the final responsibility for accuracy, as with all software tools, lies with the user and not with the program developer.

The user should at this juncture recall that the CRASH3 program was not designed to be a simulation program but rather a consistent, uniform method of judging accident severity in terms of the change in velocity. CRASH3 should be statistically valid for a large number of cases; (13) it may or may not provide accurate results in a particular case.

Smith and Noga performed a linear regression analysis and developed the following regression equation.

$$DeltaV_{(TRUE)} = -0.7 + 1.1\ DeltaV_{(CRASH)} \qquad (2.126)$$

Equation (2.126) indicates that the mean value of a large number of estimates of Delta V will be approximately 10 percent lower from the true mean. Viewed for particular cases, the prediction may be in error by as much as 45 percent. This should reinforce earlier statements that CRASH3 should only be used with caution for individual accidents."

DELTA V FROM DAMAGE

What is Delta V? It is simply a change in the velocity vector. For our purposes, it is the change in the velocity vector at the center of mass of the vehicle. This change in velocity is the result of a change in speed, a change in direction, or both. A vehicle traveling at 30 mph in a northerly direction that, after impact, is traveling at 30 mph in a southerly direction, has experienced a 60 mph Delta V due to the change in direction. If a vehicle traveling 30 mph stops without changing direction, the Delta V is 30 mph. If the Delta V occurs over several seconds and is relatively small, it usually causes little or no injury. If the Delta V occurs instantaneously, or over a very small time frame compared to the change, injury or death is usually the result. Remember, it is not the fall that kills, it is the sudden stop.

Delta V may be determined graphically or mathematically using Linear Momentum and Vector Sum Analysis or by using crush damage.

Vector Sum Analysis will generate the Delta M (momentum) vectors. The length of this vector divided by the mass (weight) of the vehicle will generate Delta V. If Delta V is determined using vectors, then vector subtraction placing the tails of the approach and departure momentum vectors of the vehicle together and measuring from the head of one to the head of the other, must be used.

Delta V may also be determined mathematically using the following formula:

$\text{Delta } V_1 = \text{SQR}(V_1^2 + V_3^2 - (2 * V_1 * V_3 * \cos(B_1)))$

B_1 = DEPARTURE ANGLE 3 - 360

$\text{Delta } V_2 = \text{SQR}(V_2^2 + V_4^2 - (2 * V_2 * V_4 * \cos(B_2)))$

B_2 = DEPARTURE ANGLE 4 - APPROACH ANGLE 2

Crush damage will also help to determine Delta V. This procedure is susceptible to inaccuracies in the ability to determine accurately the Principal Direction of Force as well as the inaccuracies in precisely determining the energy involved in the deformation. Does this unacceptably flaw the methodology? Does the inability to measure the exact angles, or determine the exact departure speeds, unacceptably flaw the use of Conservation of Linear Momentum? Arguably, Linear Momentum is generally the more precise method for determining Delta V, but it may be impossible to determine the data necessary to use Linear Momentum. Within reason, Crush damage can generate Delta V to the necessary degree of accuracy.

Within reason? What is **within reason? Within reason** means measuring as accurately as possible and using the most accurate data available. It means letting the data generate the answer, not massaging the data to support predetermined answers. It means disclosing the assumptions needed in order to arrive at a solution and how those assumptions affect the solution. It means being true to the role of investigator, not assuming the role of advocate. It means **within reason**.

Very few accident reconstructionists understand Delta V from Damage. Some know the general theory, but very few could actually do it without the assistance of a computer program. If you are unable to do it, how can you explain it to a judge or jury? Most reconstructionists just plug numbers into a computer program that spits out answers, having no idea of the procedures involved. This paper is an attempt to eliminate that unacceptable situation.