The Expert AutoStats®
SPEED FROM CRUSH FORMULA

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A rapid approach to the evaluation or estimation of the speed component involved in crushing a vehicle is given on the third page of the EXPERT AUTOSTATS(R)[1] long-form printout. The formula is:

$$V = \sqrt{30 * d * CF}$$

where:

V is the speed equivalent of the energy spent in crushing a vehicle. The speed is in Miles per Hour (MPH);
d is the Maximum Crush Depth, in Feet.
CF is the Crush Factor.

30 is the same conversion factor that is found in the "traditional Speed from Skid" formula, and it converts the formula from feet/second to MPH. (The metric equivalent works when the units are Kg and Meters).

This Crush Factor is analogous to the "drag factor" or coefficient of friction value used in the speed from skid calculation. CF is the EXPERT AUTOSTATS(R) Crush Factor: The first approximation values suggested are 21 for Front Crush, 27 for Side Crush, and 17-27 for Rear Crush.

d is the Total Crush to Both Vehicles when the target vehicle has 0 OR less Velocity in the direction of movement of the "Bullet" vehicle. It is the maximum crush to a single vehicle when the collision vehicles have opposing speeds.

This V is the speed equivalent of the work done to collapse the vehicle or vehicles. One must add (Vector Addition!) the pre-and post-impact speed (or Work or Kinetic Energy components) for each vehicle.

VALIDATION PROCESS:

The initial derivation and validation came from our working over 100 vehicle accidents, ranging from hoods or fenders dented by pedestrians to head-on crashes at greater than 60 mph for each vehicle!. This work was done in the early and mid-1980's.

In the discussion on braking, J. Stannard Baker in his text on accident investigation provided a table which contained a value of f = 20 for a car into a fixed barrier [2]. Because of the differences in materials and construction of vehicles from the 1930's to the 1960's upon which Baker's value was based, we decided to re-evaluate this number.

Once it was determined that the calculation was valid in principle, and gave speeds in the same range as calculated independently by other methods, we researched the literature for data which gave both the crush profile and the maximum depth of the crush AND impact speed. The EDC publication "VEHICLE CRUSH STIFFNESS COEFFICIENTS" [3] gave all of the desired data. We "back calculated" the impact speed using our Crush Factor and the Maximum Depth of Crush reported. We then compared our resultant speed with the Delta V reported for a particular vehicle test.

We also made use of the many NHTSA Barrier crash studies which Victor Craig periodically published in the Accident Reconstruction Journal [4].

This formula and recommended CF values for front and side impacts have also been compared against crash data presented by others at over 60 seminars on accident reconstruction over the past 10 years.

This has now been tested and substantiated by over 100 former "non-believer" reconstructionists around the country.!

In all cases, the results using this formula and CF values were within the acceptable limits of error considering the uncertainty in both the speed and crush measurements reported for a given test.

The greatest variation is found in the rear-end collision trunk crushing. This is true regardless of the method used to calculate the speed from rear crushing, SO BE CAUTIOUS!!! Some vehicles are as strong in the trunk as they are in the front engine compartment, while others make aluminum foil seem strong!. Also, data on rear-end collisions generally present a Delta V value which includes both the speed dissipation during the crush plus the speed dissipation from point of contact to point of rest of the "target" vehicle. This, of course, is much larger than just the crush speed component!

REPRESENTATIVE VALIDATION DATA ANALYSIS:

Table I. Test data and the calculated impact speed for three frontal collisions and one rear impacts where both the impact and rebound speeds were known [5].

Vehicle	Weight	W.B.	F/R	V_{impact}	$V_{rebound}$	V_{crush}	$Crush_{Max}$	CF	V_{calc}	Error
1981 Escort 2dr	3039	94.5	F	30.3	5.6	29.78	18.4 in.	21	31.08	+1.3
1981 Escort 2dr	–	94.5	F	35.2	5.25	34.8	22.9 in.	21	34.6	-0.2
1982 Escort 4dr	2584	94.5	F	34.52	14.39	31.38	24.1 in.	21	35.5	+4.12
							* 19.0 in.	21	31.58	+0.2
1981 Mercury Lynx	2439	94.6	R	27.07	20.4	17.79	11.2 in.	9	15.87	-1.92
								*# 21	24.2	-2.87
								*# 27	27.49	+0.42

NOTES: * This is for the grill/hood crush, without the 5 inch bumper.
*# These values are compared with the Impact Speed, including the "rebound", or after impact, speed of the Lynx from the collision.

Table II - Test Data and the Calculated Impact Speed for Frontal Collisions (Data obtained from the EDC Publication[3])

Year	Make/Model	Body Style	Weight (pounds)	Wheelbase (Inches)	Maximum Crush (Inches)	CF	(R)ecorded Delta-V (Impact) Speed (MPH)	CF (C)alculated Impact Speed (MPH)	Calculated Speed: Speed Difference (C - R) (MPH)	Calculated Speed: (-) Speed Difference (MPH)	Calculated Speed: (+) Speed Difference (MPH)	(EDC) A&B Calculated Impact Speed	Calculated Speed: Speed Difference (EDC - R) (MPH)	Calculated Speed: (-) Speed Difference (MPH)	Calculated Speed: (+) Speed Difference (MPH)
1976	VW Rabbit	Sedan	1920	94.5	6.6	21	15.0	18.6	3.6		3.6	15.2	0.2		0.2
1976	VW Rabbit	Sedan	2285	94.5	21.3	21	29.4	33.4	4.0		4.0	29.4	0.0		0.0
1978	Chevrolet Blazer K5 4WD	Utility	5761	100.8	17.3	21	29.5	30.1	0.6		0.6	29.5	0.0		0.0
1979	Subaru Brat 4WD	MPV	2866	96.5	21.3	21	29.6	33.4	3.8		3.8	29.6	0.0		0.0
1973	VW Super Beetle	Sedan	2034	95.3	9.1	21	19.9	21.9	2.0		2.0	15.7	-4.2	-4.2	
1980	Ford Bronco 4WD	Utility	4864	105	20.5	21	31.8	32.8	1.0		1.0	29.6	-2.2	-2.2	
1980	Ford F350	Flatbed	5914	104.5	22.0	21	33.1	34.0	0.9		0.9	30.6	-2.5	-2.5	
1982	Chevrolet LUV	Pickup	3198	108	18.4	21	29.4	31.1	1.7		1.7	29.7	0.3		0.3
1982	Chevrolet Sport Van	Van - Full Size	3647	110.5	12.0	21	29.4	25.1	-4.3	-4.3		29.4	0.0		0.0
1982	Chrysler LeBaron	Coupe	3000	99.9	23.3	21	35.3	35.0	-0.3	-0.3		35.3	0.0		0.0
1982	Nissan Sentra	Sedan	1957	94.5	17.0	21	29.4	29.9	0.5		0.5	29.4	0.0		0.0
1984	Dodge Caravan	Van - Mini	3791	122.1	24.7	21	35.9	36.0	0.1		0.1	35.4	-0.5	-0.5	
1984	Jeep CJ-7 4WD	Utility	3180	93.5	21.1	21	35.1	33.3	-1.8	-1.8		34.9	-0.2	-0.2	

Calculated Speed: Speed Difference (C - R) (MPH)	Calculated Speed: (-) Speed Difference (MPH)	Calculated Speed: (+) Speed Difference (MPH)		Calculated Speed: Speed Difference (EDC - R) (MPH)	Calculated Speed: (-) Speed Difference (MPH)	Calculated Speed: (+) Speed Difference (MPH)
13.0	3.0	10.0	Number of tests	13.0	5.0	8.0
0.1	-0.3	0.1	Minimum Difference	0.0	-0.2	0.0
0.9	-2.1	1.8	Average Difference	-0.7	-1.9	0.1
0.9	-0.5	1.4	Mean Difference	-0.7	-0.7	0.0
0.9	-1.8	1.3	Median Difference	0.0	-2.2	0.0
-4.3	-4.3	4.0	Maximum Difference	-4.2	-4.2	0.3
2.2	1.6	1.4	Population SD +/-	1.3	1.5	0.1
2.3	2.0	1.5	Sample SD +/-	1.4	1.6	0.1

DISCUSSION:

Campbell proposed a similar relationship in his 1974 SAE paper [6]. He proposed the formula $V = b1*x + b0$, where b0 is the no damage speed.

Our research has shown that the newest vehicles do not vary significantly from those of the 1940-1980 vintage. Using the CF equation will sometimes result in a rather large variant from the reported data, but this is more often due to the rebound speed and distance, or in rear and side collisions, the speed after impact and distance from POI to POR which is unreported. In all cases where all of the necessary data is available, this formula produces results as least as good as the more complex A-B-G equation approach. This is not unexpected since the A-B-G equations were developed from Campbell's work, and more terms were added to improve the curve-fit of the data.

The Advantages of This Method of evaluating the "Crush Speed":

1. This formula is familiar to everyone who has tried to do a speed from skid calculation. The only difference is a relative large number for the Crush Factor, rather than the decimal value for friction (resistance to movement).

2. If necessary, one can perform the calculation in your head while on the witness stand, or in deposition. A calculator does make life easier, but you can "ballpark" the square root in your head.

3. If required, this formula can be derived while on the witness stand without references.

4. You don't have to rely on trying to get the NHTSA data, or to remember 3 constants and a rather lengthy formula that you may have to derive when you are cross-examined!

5. The values obtained are as reliable as the depth of crush measured after the crash is over and the dust has settled.

LITERATURE CITED

1. Expert AutoStats computer program, 4N6XPRT SYSTEMS, La Mesa, CA. 91941

2. Baker, J. Stannard, "Traffic Accident Investigation Manual", 1975, The Traffic Institute, Northwestern University.

3. Hargens, Randall and Day, Terry, "VEHICLE CRUSH STIFFNESS COEFFICIENTS ...", EDC Library Ref. No. 1042, Engineering Dynamics Corporation, Lake Oswego, OR , 1987

4. Accident Reconstruction Journal, P.O. Box 234, Waldorf, MD 20604.

5. "BH2VJ Crash Testing Project Seminar Notes: August 12-14, 1992", BH2VK Engineering, Somis, CA, 1992.

6. Campbell, K. L., "Energy Basis for Collision Severity", SAE 740565, Society of Automotive Engineers, 1974.

Derivation of the Crush Factor (CF) :

1. F = M*A = (WT/32.2)*(v/T)   and   A = Mu*g = Mu*32.2
   where M = Mass, A = Acceleration in feet/sec/sec, Mu = Friction factor, F = Force (in Pounds), and v = speed in Ft/Sec

2. KE = F*d = (½)*M* v^2 = M*A*d
   where d = Distance moved

3. M*A*d = (½)*Mv^2
   and Mass 'cancels' on both sides.

4. $v^2 = 2*A*d = 2*Mu*32.2*d$
   where v in Ft/Sec and d in Ft

5. v = $\sqrt{64.4 * Mu * d}$ (in Ft/Sec)

6. To convert from Ft/Sec (v) to Mi/Hr (V):
   K = 3600 Sec/Hr * 1/5280 Mi/Ft   in Sec*Mi/Hr*Ft
   K = 0.6818 and K^2 = 0.46488
   $K^2 * 64.4 = 29.94$ which rounds to 30 Mi^2/Hr^2

   V = $\sqrt{K * Mu * d}$ where V is Mi/Hr

   V = $\sqrt{30 * Mu * d}$ where V is Mi/Hr

This is recognized as the 'Speed From Skid' formula, where Mu is the sliding friction factor usually having a value of 1.0 or less, and the braking efficiency is 1 (100%).

7. The Speed From Crush is then obtained by the formula:

   $$V = \sqrt{30 * CMu * d} = \sqrt{30 * CF * d}$$

   where V is Mi/Hr, CMu is the Crush {Friction} Factor **CF**, and d is in **feet**

8. CF is determined experimentally from crashes where both speed {V} and crush distance {d} are known:

   $CF = V^2/(30*d)$ where **d is in feet**