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March 11, 1985

Dr. Charles Y. Warner, President
Collision Safety Engineering Company
150 South Mountainway Drive
Orem, Utah 84058

Dear Chuck:

Re: SAE Paper No. 850255
"Inaccuracies in the CRASH3 Program"

Your continuing series of attacks on the CRASH and SMAC computer programs, which clearly are motivated by objectives other than the reporting of scientific research, cannot continue to go unanswered. The aggressive and overstated criticisms go far beyond the normal scope of scientific research papers and into the realm of competitive sales pitches. X

I do not feel that it is appropriate or necessary for me to respond in detail to your arguments regarding limitations on adjustments that can be made in CRASH and SMAC applications. The NHTSA objective was to develop computer aids that would serve to achieve uniform interpretations of evidence.

The incomplete states of development of some rarely applied aspects of the CRASH and SMAC computer programs reflect effects of NHTSA decisions based on priorities and budget limitations. For example, additional development of the iterative adjustment procedure for convergence of the TRAJ option of CRASH is known to be needed. Note that such development is related to computer logic rather than engineering mechanics theory.

The primary objective of this letter is to respond to your repeated references to "fundamental errors" and omissions of "complete physics" in the CRASH analysis. Rather than exert the necessary effort for a comprehensive rebuttal of your many allegations, I will limit this letter to two representative examples of errors and inaccuracies in your own use of "established physical principles and good engineering approximations" in the subject paper. Note that a critic should learn his subject matter thoroughly before attacking the work of others.

(1) On page 268, in the last paragraph of the left column, you indicate that "a restitution coefficient of 0.1 can change the energy by only one percent and affect delta-V by even less."

If you consider a simple SAE barrier crash as an example, the relationship between the impact speed-change, ΔV; the absorbed energy, E_A; and the coefficient of restitution, ϵ, can be expressed as follows (see enclosure):

$$\Delta V = -(1 + \varepsilon) \sqrt{\frac{2 E_A}{M}} \quad \text{inches/sec} \qquad (1)$$

Please note the obvious fact in equation (1) that a restitution coefficient of 0.1 directly changes ΔV (from the case of $\varepsilon = 0.00$) by 10% rather than "even less" than one percent. If one wishes to refer to an effective change in the energy term of equation (1) by placing $(1+\varepsilon)^2$ inside the square root sign, $(1.1)^2 = 1.21$. This constitutes a 21% increase in the energy term rather than your one percent value, which apparently is based on $(0.1)^2 = 0.01$.

I refer you to any physics text for the definition of the coefficient of restitution, ε, and invite a rational explanation of the cited paragraph in your paper. The paragraph has the obvious objective of dismissing the possibility of a simple and straightforward error source in order to bolster allegations of more "fundamental" error sources.

(2) On page 274, you refer to "missing terms of the energy equation" in CRASH3. On page 275, you further indicate that "five terms" are omitted in CRASH3. Clearly, you do not understand the derviation of the CRASH damage analysis in spite of the extensive published documentation of that derivation. X

Most serious researchers would probe a bit deeper into an analysis before launching a critical attack. However, you have proceeded to make a number of erroneous assertions and, further, to even suggest a plaintiff bias in the CRASH3 results (i.e., an error which acts "to increase approach velocity for the same total crush energy").

Your confusion appears to stem from your failure to recognize the fact that the changes in angular and linear velocities during a noncentral, or eccentric, impact are directly related (see sample analysis of a simple eccentric collision case in enclosure):

$$\Delta\dot{\psi} = \frac{h}{k^2} \Delta V \quad \text{radians/sec} \qquad (2)$$

where h = moment arm of resultant collision force, inches
k = radius of gyration in yaw, inches

The allegedly "missing" kinetic energy of rotation subsequent to a noncentral collision is fully included in CRASH, in the form of corresponding linear velocity terms (see enclosure). I invite you to produce a rigorous mathematical proof of your allegations regarding energy term omissions in CRASH.

In addition to your erroneous assertions, the subject paper and others in the series produced by your Collision Safety Engineering Company include a large number of factual errors, exaggerated claims and comparisons, and repeated expressions of doubts and reservations about anything that has not been developed by your own litigation consultation company.

My advice to you is to hire a competent analyst to review your own material and that of others before you launch further aggressive attacks and/or sales pitches involving theoretical aspects of engineering mechanics.

Very truly yours,

McHENRY CONSULTANTS, INC.

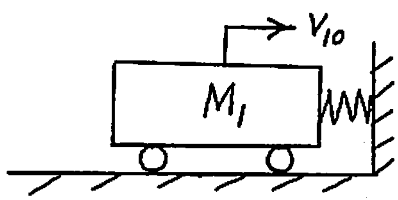
Ray McHenry

Raymond R. McHenry

RRM:cks

Enclosure

SAE Barrier Crash



Initial Kinetic Energy,

$$E_{10} = \frac{1}{2} M_1 V_{10}^2 \tag{1}$$

Absorbed Energy at end of approach period,

$$E_A = E_{10} = \frac{1}{2} M_1 V_{10}^2 \tag{2}$$

Separation Velocity,

$$V_{1f} = - \varepsilon V_{10} \tag{3}$$

Impact Speed-Change,

$$\Delta V_1 = -V_{10} + V_{1f} = -(1+\varepsilon)V_{10} \tag{4}$$

From (2),

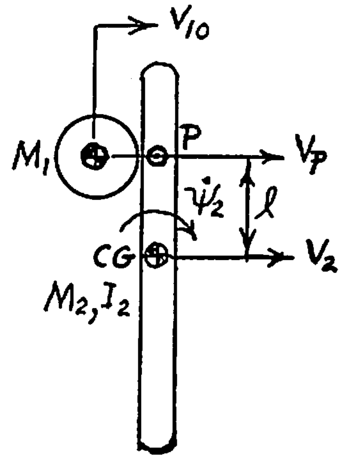
$$V_{10} = \sqrt{\frac{2 E_A}{M_1}} \tag{5}$$

From (4) and (5),

$$\Delta V_1 = -(1+\varepsilon)\sqrt{\frac{2 E_A}{M_1}} \tag{6}$$

For ε increased from 0.00 to 0.10, ΔV_1 increased by 10%. See related discussion on p. 268 of SAE #850255.

A Simple Case of Eccentric Impact



For simplicity, body 2 initially at rest.

$I_2 = M_2 k_2^2$

From conservation of linear momentum,

$$M_1 V_{10} = M_1 V_{Pf} + M_2 V_{2f} \qquad (1)$$

From impulse-momentum relationships,

$$\left.\begin{aligned} I_2 \dot{\psi}_{2f} &= \ell \int_0^t F\, dt \\ M_2 V_{2f} &= \int_0^t F\, dt \end{aligned}\right\} \quad V_{2f} = \frac{k_2^2}{\ell}\, \dot{\psi}_{2f} \qquad (2)$$

Since $V_{Pf} = V_{2f} + \ell\, \dot{\psi}_{2f}$, equation (2) permits the following definition:

$$V_{Pf} = \left(\frac{k_2^2 + \ell^2}{k_2^2} \right) V_{2f} \qquad (3)$$

By letting

$$\gamma_2 = \frac{k_2^2}{k_2^2 + \ell^2} \qquad (4)$$

and combining (1) and (3),

$$M_1V_{10} = (M_1 + \gamma_2 M_2)V_{Pf} \tag{5}$$

Solution of (5) for V_{Pf} yields

$$V_{Pf} = \frac{M_1V_{10}}{(M_1 + \gamma_2 M_2)} \tag{6}$$

The kinetic energy of the two-body system immediately prior to the collision is

$$E_o = \frac{1}{2} M_1 V_{10}^2 \tag{7}$$

The kinetic energy of the system at the end of the approach period may be expressed as

$$E_f = \frac{1}{2} M_1 V_{Pf}^2 + \frac{1}{2} M_2 V_{2f}^2 + \left[\frac{1}{2} I_2 \dot{\psi}_{2f}^2 \right] \tag{8}$$

Since $I_2 = M_2 k_2^2$ and $\dot{\psi}_{2f} = \frac{\ell}{k_2^2} V_{2f}$,

$$\frac{1}{2} I_2 \dot{\psi}_{2f}^2 = \frac{1}{2} M_2 \frac{\ell^2}{k_2^2} V_{2f}^2 \tag{9}$$

Substitution of (9) into (8) yields

$$E_f = \frac{1}{2} M_1 V_{Pf}^2 + \frac{1}{2} M_2 V_{2f}^2 \left(\frac{1}{\gamma_2}\right) \tag{10}$$

From (3), $V_{2f} = \gamma_2 V_{Pf}$ (11)

Substitution of (11) into (10) yields

$$E_f = \frac{1}{2} (M_1 + \gamma_2 M_2) V_{Pf}^2 \tag{12}$$

From (6),

$$E_f = \frac{1}{2} \frac{M_1^2 V_{10}^2}{(M_1 + \gamma_2 M_2)} \tag{13}$$

The change in kinetic energy (i.e., absorbed energy) may be obtained by subtracting (13) from (7):

$$E_A = E_o - E_f = \frac{1}{2} M_1 V_{10}^2 \left(\frac{\gamma_2 M_2}{M_1 + \gamma_2 M_2} \right) \tag{14}$$

Solution of (14) for V_{10} yields

$$V_{10} = \sqrt{\frac{2\, E_A (M_1 + \gamma_2 M_2)}{M_1 \gamma_2 M_2}} \tag{15}$$

The impact speed-change of body 1 is

$$\Delta V_1 = V_{10} - V_{Pf}$$

From equation (6),

$$\Delta V_1 = V_{10} \left(\frac{\gamma_2 M_2}{M_1 + \gamma_2 M_2} \right) \tag{16}$$

From (16) and (15),

$$\Delta V_1 = \sqrt{\frac{2\, E_A}{M_1 \left(1 + \frac{M_1}{\gamma_2 M_2} \right)}} \tag{17}$$

Since $M_1\, \Delta V_1 = M_2\, \Delta V_2$.

$$\Delta V_2 = \sqrt{\frac{2\, \gamma_2 E_A}{M_2 \left(1 + \frac{\gamma_2 M_2}{M_1} \right)}} \tag{18}$$

Equations (17) and (18) may be compared directly with equations (28) and (29) on page 9-8 of the CRASH3 User's Guide and Technical Manual, for the case of γ_1 = 1.000. Note that the kinetic energy of rotation is included at equation (8), and its effects are fully retained throughout the derivation. See related discussion on pp. 274-276 of SAE #850255.