FRONTAL OFF-SET COLLISION

MARC1 SOLUTIONS

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Short Paper PCB2 – 2014

www.pcbrakeinc.com

1.0. Introduction

A crash-test-on- paper is an analysis using the forward method where impact conditions are specified and essential after-impact parameters are calculated. It is extremely helpful when exploring the theoretical and practical boundaries of a collision. MARC1 provides simple and effective tools to quickly switch from the forward method to the backwards method when investigating a particular crash. Conducting and analyzing a crash-test-on-paper is used to determine parameters such as crush energy, run-out dynamics, rotational dynamics, spin angle, and others. An accuracy check of another expert's reconstruction can be done quickly. Detailed parameter evaluations are very helpful in understanding critical elements of vehicle crashes. Effective cross examination questions can be formulated when the questioning attorney knows the correct answers well in advance of the witness. One important consideration for a crash-test-on-paper is that the analysis is reasonably simple while all critical elements are examined. An important aspect of this approach is that when two or more independent methods are used, data accuracy is ensured. On the other hand, critical formulation errors are discovered and corrected prior to formulating opinions.

Several popular accident reconstruction programs use the forward method where conditions at impact are specified and the calculated results are compared with post-crash accident scene data. This is usually done since deriving the governing equations y = f(x) for the backwards method is an algebraically involved task. When calculated and measured after-impact data are in reasonable agreement, reconstruction correctness has been achieved. However, this conclusion is only valid when after-impact scene and vehicle data are not contaminated by expert ignorance.

2.0. Frontal Off-Set In-line Collision Analysis

2.1. Crash Test Nr. 8, Unfallversuche; Verlag INFORMATION Ambs, 1982

We will "reconstruct" a old German crash test using MARC1 software. We want to explore the boundaries of the crash test by running our own crash-test-on-paper.

A 1972 Toyota Corolla KE 20 was travelling left-to-right under 0 degrees (east) at 53.7 mph, a 1971 Datsun 1800 L was stationary pointing right-to-left under 180 degrees (west) . The off-set was approximately 60 %.

The "accident scene" diagram is shown in Figure 1. Vehicle 1 (Toyota) travelled from left to right, Vehicle 2 (Datsun) from right to left. The general information shown in Figure 1 is what an investigating officer or reonstruction expert may see when at the scene of an inline collision. A scene diagram similar to Figure 1frequently is the basic information from which to start a reconstruction. As Figure 1 reveals, the center-of-gravity of each vehicle is primarily travelling in the zero-degree or easterly direction after impact. The Toyota rotated clockwise.

It is of critical importance that all scene data are presented and documented in a scaled diagram. Most frequently, computer-generated diagrams are used. One important factor of scene data documentation is that all data and measurements required for a speed reconstruction analysis are provided in numerical format. For an officer or expert to determine the length of a tire mark by measuring it in a scaled drawing such as Figure 1 is not acceptable. While at the scene all critical data required for reconstruction must be measured or scanned so that they are available for analysis. Identifying and documenting unique scene data is critical for an accurate data collection.

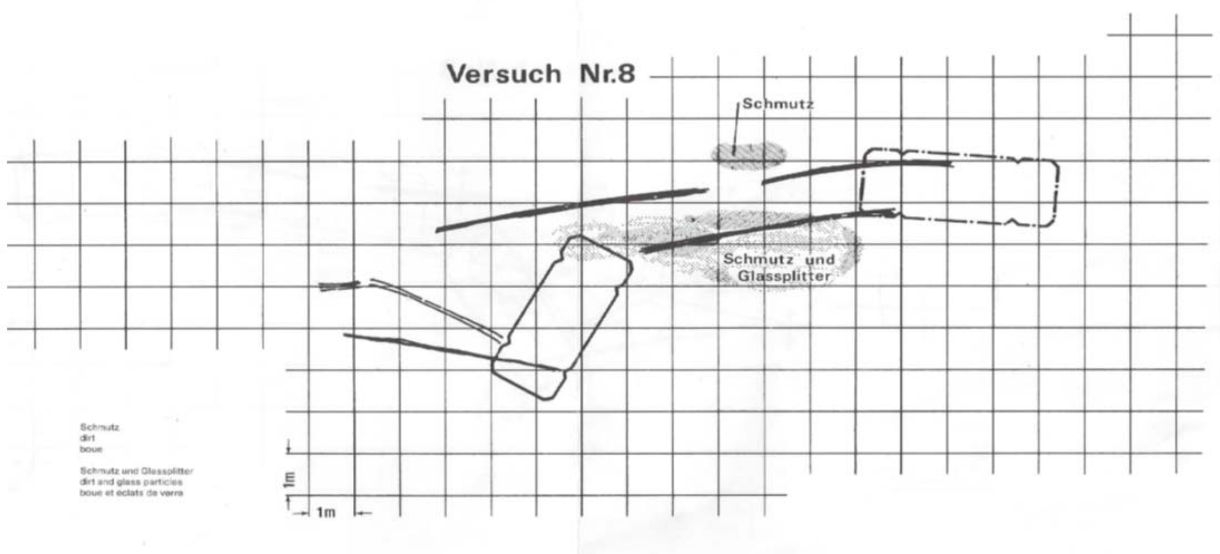

Figure 1. Post Test Crash Scene Data - "Accident Scene Diagram"

The accident collision and run-out diagram is shown in Figure 2. The test report states that the velocity of the Datsun (V2) was zero at the moment of the collision.

Figure 2 shows the correct interpretation of the scene data in terms of placing vehicles at initial approach and when moving to their respective rest positions. The test report does not provide crush depth data, except to state that the energy equivalent speeds are the following Toyota; EES_1 = 31.07 mph, Datsun EES_2 = 25.48 mph. The photographs provided with the report do not allow any crush depth analysis. We make the assumption that the crash was plastic with the coefficient of restitution e = 0. The information exhibited by Figures 1 and 2 does not tell us how fast either vehicle was traveling or that the Datsun was stopped when impacted. We only know that from the test report.

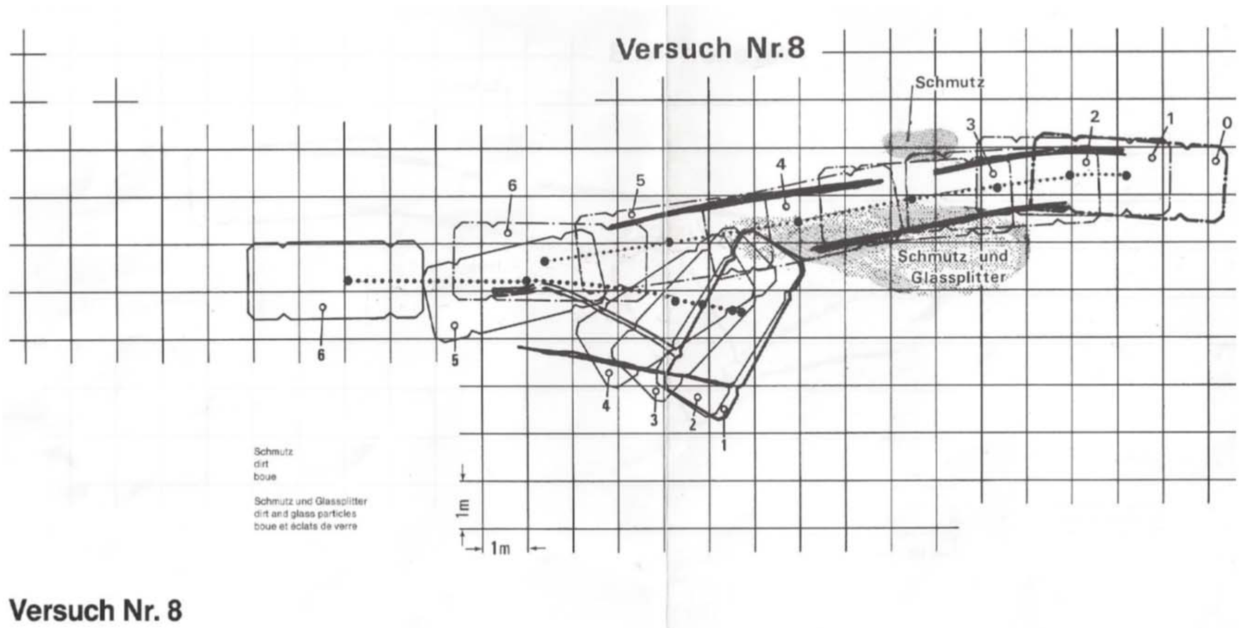

Figure 2. Accident Scene Diagram with Vehicle Run-out Dynamics.

2.2. "Scene Data" Information

Inspection of Figure 2 reveals the after impact run-out path of each vehicle. Each diagram square represents 1 by 1 meter area. The Toyota (V1) travelled approximately 28.5 ft, the Datsun (V2) approximately 43 ft after impact. Post-crash V1 rotated approximately 55 degrees, V2 1 degree. V1 shows rear tire scuff marks, V2 significant front tire scuff marks (test report says the Datsun was in 2nd gear).

In an inline collision the after-impact speeds of both cars must be calculated from scene evidence. Depending upon sheet metal/fender damage, a proper post-crash drag factor analysis can be performed. Close inspection of Figure 2 and the tire markings tells us that the Datsun is probably the vehicle with the more accurate post-crash data. Figure 1 shows after-impact tire skid marks of the Datsun, probably primarily from the front tires as the vehicles travels backwards.

MARC1 – E4 is used to compute the after-impact drag factor when some tires are wedged sufficiently so that the tire(s) cannot rotate, some have engine drag and/or rolling resistance. Since the Datsun travelled backwards after impact, the static axle loads are reversed front-to-rear. The Datsun is a rear-wheel drive car. Using a retarding coefficient of 0.2 for the "front" wheels in A4, and 0.8 for the right "rear" and 0.80 for the left "rear", yields an after-impact drag factor of 0.454g.

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                 Saturday, September 20, 2014

    MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
    ********* PROGRAM 'E-4' RUN FOR PCB 2 - 2014 *********
               DECELERATION OF TWO-AXLE VEHICLES
Information For Vehicle                         1971 DATSUN 1800
==============================================================
Vehicle Weight, LBS:                              ===>  2271.00
Static Front Axle Load, LBS:                      ===>  1081.00
Static Rear Axle Load, LBS:                       ===>  1190.00
Vehicle Wheelbase, FT:                            ===>     8.59
Vehicle Center of Gravity Height, FT:             ===>     1.90

Retarding Coefficient of . . .
    Right Front Wheel, D'Less:                    ===>    0.200
    Left Front Wheel,D'Less:                      ===>    0.200
    Right Rear Wheel, D'Less:                     ===>    0.800
    Left Rear Wheel, D'Less:                      ===>    0.800
==============================================================
Trial 1 . . .External Retarding Forces. . .
    Right Front Wheel, LBS:                       ===>   108.10
    Left Front Wheel, LBS:                        ===>   108.10
    Right Rear Wheel, LBS:                        ===>   476.00
    Left Rear Wheel, LBS:                         ===>   476.00
 Total Retarding Force, LBS:                      ===>  1168.20
 Vehicle Deceleration for First Trial, G-UNITS: ===>      0.514
==============================================================
Trial 2 . . .External Retarding Forces. . .
    Right Front Wheel, LBS:                       ===>   133.94
    Left Front Wheel, LBS:                        ===>   133.94
    Right Rear Wheel, LBS:                        ===>   372.64
    Left Rear Wheel, LBS:                         ===>   372.64
 Total Retarding Force, LBS:                      ===>  1013.17
 Vehicle Deceleration for Second Trial, G-UNITS:===>      0.446
==============================================================
Trial 3 . . .External Retarding Forces. . .
    Right Front Wheel, LBS:                       ===>   130.51
    Left Front Wheel, LBS:                        ===>   130.51
    Right Rear Wheel, LBS:                        ===>   386.36
    Left Rear Wheel, LBS:                         ===>   386.36
 Total Retarding Force, LBS:                      ===>  1033.74
 Vehicle Deceleration for Third Trial, G-UNITS: ===>      0.455
==============================================================
Trial 4 . . .External Retarding Forces. . .
    Right Front Wheel, LBS:                       ===>   130.97
    Left Front Wheel, LBS:                        ===>   130.97
    Right Rear Wheel, LBS:                        ===>   384.54
    Left Rear Wheel, LBS:                         ===>   384.54
 Total Retarding Force, LBS:                      ===>  1031.01
 Vehicle Deceleration for Fourth Trial, G-UNITS:===>      0.454
==============================================================
   Datsun is RWD using 0.2 on leading rear wheels. Heavy marks
   most likely from crush damage to trailing front wheels,
   hence 0.8.
```

The probable after-impact speed V_{22} of the Datsun is computed easily from run-out distance and drag factor, yielding:

$$V_{22} = [(30)(43)(0.454)]^{1/2} = 24.2 \text{ mph}$$

Assuming a plastic collision (e=0) makes the after-impact speed of the Toyota equal to 24.2 mph. The after-impact drag factor of the Toyota is:

$$a_{12} = (24.2)^2/[(30)(28.5)] = 0.68g$$

Although this number appears larger than expected, the smaller Toyota probably was smashed down as it separated from the Datsun.

2.3. Vehicle and Test Report Data

When reconstructing an accident, all input data required for a proper reconstruction should be as accurate as possible. Check the input data used against as many other sources as possible. I have read many experts reports with glaring mistakes, easily avoidable. In one of my cases the plaintiff's expert did not recognize that metric units were used on a drawing showing a highway re-construction zone. Instead of using a curve radius of 608 meters or 1994 feet, he used 602 feet. No wonder he opined that the truck-trailer rolled based on a loading defect.

All data required for a reconstruction are provided in the test report.

Test Report Vehicle and Test Data

	Toyota Corolla	Datsun1800L	Units
Weight	1863	2271	lb
Wheel base	7.66	8.59	ft
Over-all length	12.9	14.25	ft
FOH	2.26	2.36	ft
Mass-moment-of-inertia	726	1097	$lbftsec^2$
Percent on Front Axle	52	52.4	%
EES	31.07	25.48	mph
Test Speed	53.6	0	mph
Angular velocity	57 - 80	0	deg/sec

2.4. “Accident Scene” and Crash Data Analysis

Inspection of Figures 1 and 2 shows basically an in-line collision with the center-of-gravity of each vehicle travelling in nearly parallel lines similar to their approach direction lines of travel. V1 rotates approximately 55 degrees after impact. We first investigate the crash test in more detail by running our own crash-test-on-paper using MARC1-W2. The test report shows that the crash test was run with the Toyota impact speed equal to 53.60 mph. The Datsun was stationary.

In a purely plastic impact (e = 0) we should expect the after impact velocities of each vehicle to be equal. See Section 33.01[5] through [7] for details on the physics equations underlying inline collisions and Module W2.

One additional piece of important information calculated by W2 is the total crush energy of 98,123 lbft expanded in the crash. Without further vehicle damage analysis, we cannot state how much of this crush energy is from the Toyota, and how much from the Datsun. If we knew the A and B-stiffness coefficients and crush depth data, this question could be easily answered.

MARC1-W2 also shows that the calculated after-impact speeds are 24.16 mph. In Section 2.2 we determined after-impact speeds of 24 mph based upon the accident scene tire markings and post-crash distances travelled. If we had not known the test speed of 53.6 mph, we could have iterated the impact speed of the Toyota in W2 until the “crash-test-on-paper calculated an after-impact speed of 24 mph.

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
********** PROGRAM 'W-2' RUN FOR PCB 2- 2014 **********
TWO VEHICLE IN-LINE COLLISION

Information For Vehicles	1972 TOYOTA Corolla KE 20	1971 DATSUN 1800 L
Before Impact Speed of Vehicle, MPH:===>	53.60	0.00
Vehicle Weight, LBS: ===>	1863.00	2271.00
Coefficient of Restitution, D'LESS: ===>	0.00	
After Impact Speed of Vehicle, MPH: ===>	24.16	24.16

Delta-V for Vehicle 1, MPH: ===>	-29.44
Delta-V for Vehicle 2, MPH ===>	24.16
Crush Energy, FT·LBS: ===>	98123.08

2.5. Treat Crash Test as Head-on Inline Collision Reconstruction

MARC1-X1 applies. The software treats the crash as a plastic collision (e = 0). The rotational after-impact energy of the Toyota is computed with MARC1-A4. The test report indicates a measured after-impact angular velocity of the Toyota of 69 deg/sec.

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                    Saturday, September 20, 2014

      MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
  ******* PROGRAM 'A-4' RUN FOR PCB 2-2014 Section 2.5  *******
                       POST-IMPACT ROTATION

  Information For Vehicle 1                  1972 TOYOTA Corolla
  ==========================================================
  Vehicle Weight, LBS:                           ===>    1863.00
  Vehicle Length, FT:                            ===>      12.90
  Vehicle Wheelbase, FT:                         ===>       7.66
  Rotational Coefficient of Friction, D'LESS:    ===>       0.15
  After-Impact Angle Rotated, DEG:               ===>      55.00
  Mass-Moment of Inertia, FT·LBS·SEC·SEC:        ===>     736.36
  Angular Velocity, RAD/SEC:                     ===>       1.67
  Rotational Energy, FT·LBS:                     ===>    1027.80
  Time to Rotate After Impact, SEC:              ===>       1.15
  ==========================================================
```

MARC1-A4 predicts an after-impact rotational velocity of 1.67 rad/sec. The rotational energy is 1028 lbft, most likely indicating an insignificant number. We can compare it to the after-impact linear kinetic energy of the Toyota to see that it is not a critical factor. After-impact kinetic energy of V1:

$$E_{k12} = (1863)[(24.16)(1.466)]^2/[(2)(32.2)] = 36{,}290 \text{ lbft}$$

MARC1-X1 requires the crush energy sustained by each car. The test report indicates energy equivalent speeds of EES_1= 31.07 mph and EES_2 = 25.96 mph. Since we have no other information on CDC and crush depth measurements, we have to select reasonable crush depth measurements and A- and B-stiffness coefficients to obtain a total crush energy of 98,123 lbft.

Using MARC1-X1 with the appropriate input data is shown in the printout. Inspection shows a predicted impact speed of 53 mph for the Toyota and basically a stationary Datsun at impact. We should expect that since the crash is basically an inline collision. The crush energy used in MARC1-X1 is calculated from the stiffness coefficients and crush depth data. The values used in the X1 run yield individual crush energies of 52,388 lbft for the Toyota and 46,055 lbft for the Datsun, and hence, a total crush energy of 98,443lbft.

MARC1-X1 software predicts a Toyota impact speed of 53.53 mph with the Datsun basically stationary. The crush energies shown as EES-values are 29 and 24.65 mph, respectively, that is, slightly lower than stated in the test report.

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   MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
   ********** PROGRAM 'X-1' RUN FOR PCB 2- 2014 **********
                      HEAD-ON COLLISION

                                             1972        1971
                                           TOYOTA      DATSUN
Information For Vehicles                Corolla  KE 20     1800 L
=============================================================
Vehicle Weight, Lbs:                   ===>   1863        2271

NO PRE-IMPACT SURFACE DATA

Surface #1
Distance Traveled After Impact, FT:    ===>  28.50       43.00
After-Impact Deceleration,  g-UNITS:   ===>   0.67        0.45

Max. Force Not Causing Damage, LBS/IN:===> 259.00      300.00
Stiffness/Inch of Width, PSI:          ===>  43.00       56.00
Force Angle Offset from
            Perpendicular, DEG:        ===>   0.00        0.00
Width of Crush Region, IN:             ===>  60.00       60.00

Number of Crush Measurements:          ===>      2           2
      Crush Measurement #1, IN:        ===>  24.00       18.00
      Crush Measurement #2, IN:        ===>   7.00        7.00

Secondary Impact Energy, FT·LBS:       ===>
=============================================================

Pre-Impact Speed, MPH:            ===>       53.53        0.13
Speed at Impact, MPH:             ===>       53.53        0.13
After-Impact Speed, MPH:          ===>       23.91       24.17
EES Speed, MPH:                   ===>       29.01       24.64
Crush Energy, FT·LBS:             ===>       52388       46055
=============================================================
```

MARC1-X1 In-line Collision

2.6. Using Combined Linear-and-Rotational Momentum

MARC1-X8 applies. Inherent in the underlying equations is a plastic impact, that is, e = 0. The analysis requires an accurate positioning of the vehicle when the contact point between vehicles has reached a common velocity. MARC1-Z1 applies. The CDCs (Collision Deformation Classification) of each vehicle could be used to place the vehicles according to recorded deformation and crush depth measurements. Figure 3 shows the vehicle location according to the test report.

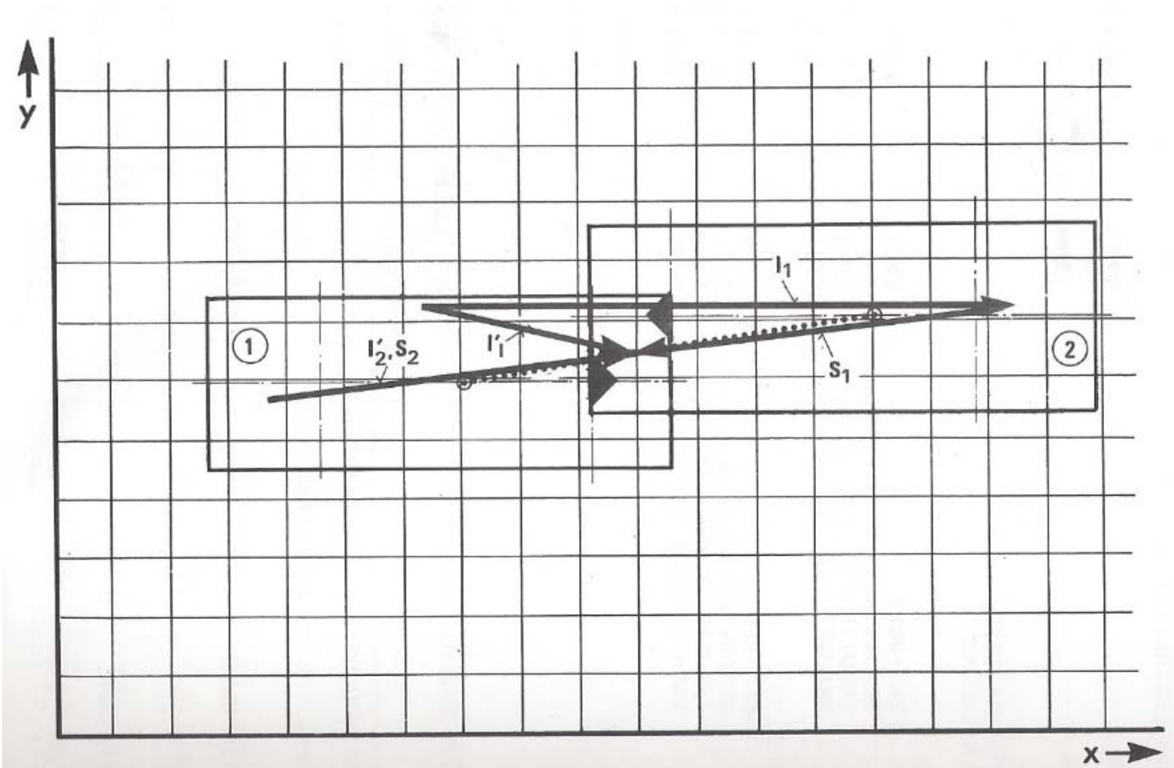

Figure 3. Vehicle-to-vehicle Contact Diagram from Test Report.

The vectors S_1 and S_2 (equal and opposite) are the test report impulse of 13,349 (kg)(m/sec) or (Newtonsec) equal 2,999 lbsec. The impulse angle is -173.9 deg (test report).

The vehicle contact diagram (MARC1-Z1) shown in Figure 4 shows my location of the vehicles at impact based on photographs, Figure 3, and a 60% overlap frontal crash. Each marking on the outline of the vehicles represents 6 inches of distance. The red car is the Toyota the blue the Datsun.

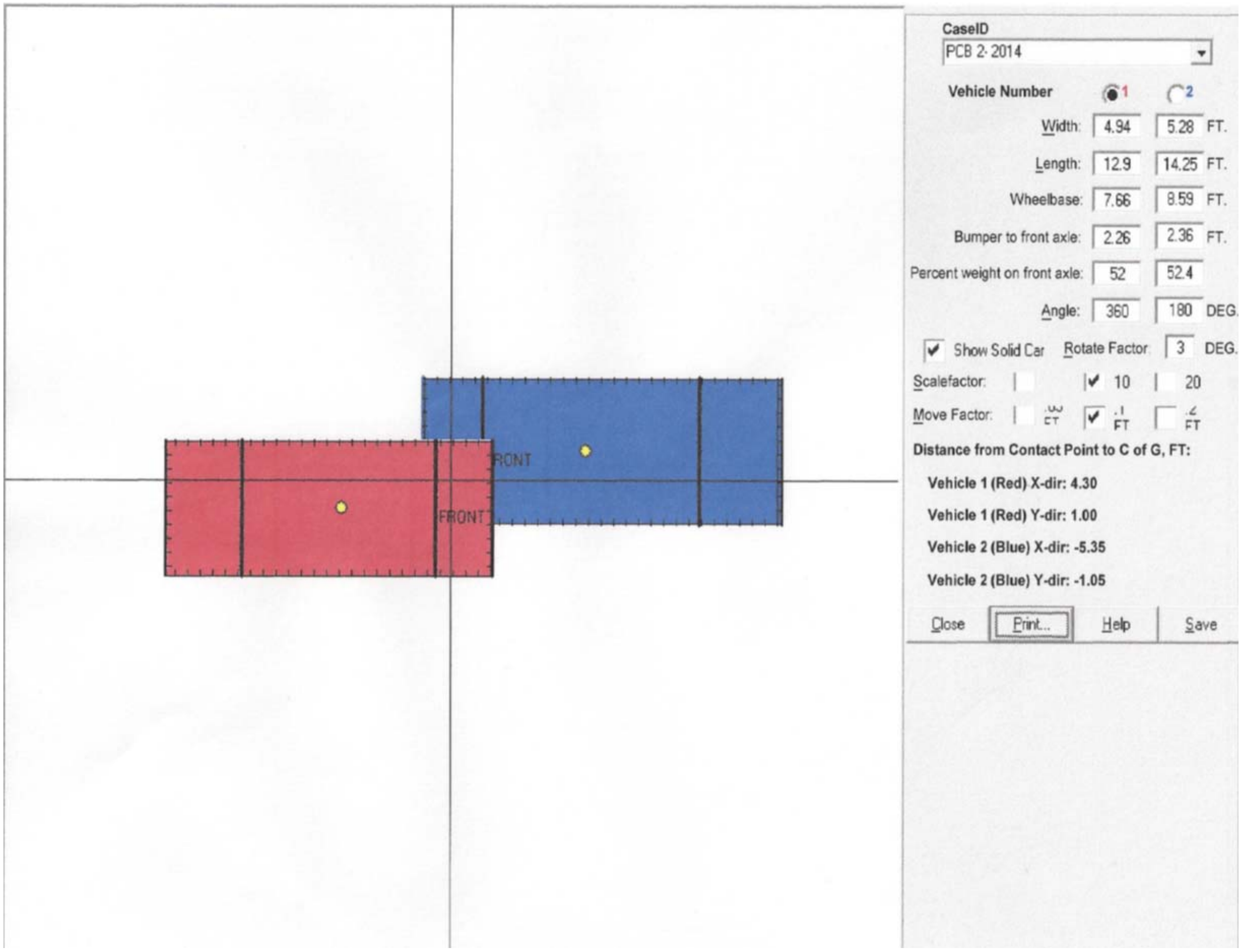

Figure 4. MARC1-Z1 Vehicle Contact Diagram.

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
* PROGRAM 'X-8' RUN FOR Shortpaper PCB 2 - 2014 - Crash Tests on Paper *
PREDICTION OF COLLISION RESULTS
WITH CRUSH ENERGY CALCULATIONS

```
                                                  1972         1971
                                                TOYOTA       DATSUN
Information For Vehicles                  Corolla KE 20      1800 L
===================================================================
Vehicle Weight, LBS:                       ===>    1863         2271

Vehicle Wheelbase, FT:                     ===>    7.66         8.59

Vehicle Length, FT:                        ===>   12.90        14.25

Mass Moment of Inertia, FT·LBS·SEC²:       ===>     726         1097

Approach Angle, DEG:                       ===>    0.00       180.00

Initial Angular Velocity, DEG/SEC:         ===>    0.00         0.00

Surface #1
Pre-Impact Braking Distance, FT:           ===>    0.00         0.00
Pre-Impact Deceleration,  g-UNITS:         ===>    0.00         0.00

Surface #2
Pre-Impact Braking Distance, FT:           ===>    0.00         0.00
Pre-Impact Deceleration,  g-UNITS:         ===>    0.00         0.00

After-Impact Deceleration,  g-UNITS:       ===>    0.67         0.45

After-Impact Coefficient of
   Rotational Friction, D'LESS:            ===>    0.15         0.50

Distance from Center of Gravity to Contact Point:
       Along the X-Axis, FT:               ===>    4.75        -5.35
       Along the Y-Axis, FT:               ===>    1.00        -1.00

Estimated Low Impact Speed, MPH:           ===>   53.53         0.00
Estimated High Impact Speed, MPH:          ===>   53.53         0.00

-------------------------------------------------------------------

(A]Max. Force Not Causing Damage, LBS/IN:===>   259.00       300.00
(B]Stiffness/Inch of Width, PSI:           ===>   43.00        56.00
   Force Angle Offset from
            Perpendicular, DEG:            ===>    0.00         0.00
   Width of Crush Region, IN:              ===>   60.00        60.00

   Number of Crush Measurements:           ===>       2            2
         Crush Measurement #1, IN:         ===>   24.00        18.00
         Crush Measurement #2, IN:         ===>    7.00         7.00


===================================================================
```

PREDICTION OF COLLISION RESULTS

Page 2 Information For Vehicles		1972 TOYOTA Corolla KE 20	1971 DATSUN 1800 L
Specified Impact Speed, MPH:	===>	53.53	0.00
After-Impact Velocities			
In X-Direction, MPH:	===>	24.87	23.51
In Y-Direction, MPH:	===>	-3.69	3.03
After-Impact Direction, DEG:	===>	351.59	7.34
After-Impact Direction of Rotation			
V1: ===>		Counterclockwise	
v2: ===================>			Counterclockwise
Angular Velocity After Impact, DEG/SEC: =>		74.44	39.45
Rotation After Impact, DEG:	===>	32.80	3.05
Distance Traveled After Impact, FT:	===>	31.42	41.59
Pre-Impact Speed, MPH:	===>	53.50	0.00
After-Impact Speed, MPH:	===>	25.13	23.70
V1/V2 Impulse, LBS·SEC:	===> 2451.14		
Direction of Impulse, DEG:	===>	187.34	7.34
Delta-V Component X-Direction, MPH:	===>	-28.66	23.51
Delta-V Component Y-Direction, MPH:	===>	-3.69	3.03
Resultant Delta-V, MPH:	===>	28.90	23.71
Direction of Delta-V, DEG:	===>	187.34	7.34
Crush Energy of Vehicle, FT·LBS:	===>	52388.39	46054.52
Energy Equivalent Speed, MPH:	===>	29.03	24.65

Energy of Vehicles		Before	After
Linear Motion Energy, FT·LBS:	===>	178151.47	81889.17
Rotational Motion Energy, FT·LBS:	=>	0.00	872.66
Energy Totals, FT·LBS:	===>	178151.47	181204.75
Crush Energy, FT·LBS:	=====>	98442.92	
Error in Energy Balance:	=====>	-1.71%	

2.7. Test Report Data and MARC1-X8 Comparison.

Comparing the test report data with the MARC1-X8 printout shows the following. It should be remembered that X8 is a crash-test-on paper. Once the impact configuration (Figure 4) and impact velocities are specified, X8 computes the dynamic motion parameters immediately after impact. The distances travelled after impact as well as the angles rotated are a direct function of the after-impact drag factors specified by the reconstructionist.

The ‘Error in Energy Balance” of -1.71% likewise is influenced by the crush energies, and hence, empirical data subject to interpretation. A negative value means that the crush energies are slightly too large. The critical input data in an offset inline collision is the exact (lateral) offset distance. In Figure 4 the lateral (y-distances) are 1.00 and 1.05 ft. The input data in MARC1-X8 are equal to 1.00 ft for both cars.

Test Report and MARC1-X8 Comparison

	Test Report		MARC1-X8		Units
	Toyota	Datsun	Toyota	Datsun	
Test Speed	53.6	0	53.6	0	mph
EES	31.07	25.48	29.03	24.65	mph
Post Impact Speed	20.63	26.57	25.13	23.70	mph
Post-Impact Distance	28.5	42.6	31.42	41.59	ft
Departure Angle	348.5	7.0	351.59	7.34	deg
Delta-V	35.3	28.96	28.90	23.71	mph
Delta-V Direction			187.35	7.35	deg
Angular Velocity	69	29	74.44	39.45	deg/sec
Rotation after Impact	55	4	32.80	3.05	deg
Angular Acceleration	630	229			deg/sec^2
Impulse	2999		2630		lbsec
Impulse Angle	173.9		187.34		deg

The test-report measured Toyota post impact velocity traces in the x-direction V_{12x} = 20.3 mph and in the y-direction V_{12y} = 3.7 mph. MARC1-X8 calculates V_{12x} = 24.07 mph and V_{12y} = -3.69 mph. The Datsun measured post impact velocities are: V_{22x} = 26.4 mph and V_{22y} = 3.0 mph while MARC1-X8 computes V_{22x} = 23.51 mph and V_{22y} = 3.03 mph.

Using the test-report after impact velocities yields a coefficient of restitution of (Eq. 33-11):

$$e_x = (26.4 - 20.3)/(53.6 - 0) = 0.11.$$

I do not think that most experts would be able to assign a coefficient of restitution of 0.11 to their reconstruction from vehicle damage inspection alone. However, running a crash test on paper with MARC1-W2 using e = 0.11 yields the same after-impact speeds for the Toyota and Datsun as reported.

Friday, September 26, 2014

MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
********** PROGRAM 'W-2' RUN FOR PCB 2- 2014 **********
TWO VEHICLE IN-LINE COLLISION

Information For Vehicles	Corolla	1972 TOYOTA KE 20	1971 DATSUN 1800 L
Before Impact Speed of Vehicle, MPH:	===>	53.60	0.00
Vehicle Weight, LBS:	===>	1863.00	2271.00
Coefficient of Restitution, D'LESS:	===>	0.11	
After Impact Speed of Vehicle, MPH:	===>	20.92	26.81

Delta-V for Vehicle 1, MPH:	===>	-32.68
Delta-V for Vehicle 2, MPH	===>	26.81
Crush Energy, FT·LBS:	===>	96935.79