SHORT PAPER PCB 3-2006

IN-LINE COLLISIONS

ENGINEERING EQUATIONS, INPUT DATA AND MARC 1 APPLICATIONS

By:

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PC-BRAKE, INC.
2006

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To provide the accident reconstruction practitioner with a concise discussion of the engineering equations and limiting factors involved, evaluation of critical input data, and the analysis of actual cases by use of the MARC 1 computer software.

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We hope that our Short Papers will assist the practitioner in better understanding the limitations inherent in any derivation of engineering equations, to properly use critical input data, to more accurately and effectively formulate his or her case under consideration, to become a better prepared expert in the field of accident reconstruction, and to more effectively utilize the full potential of the MARC 1 computer program.

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Throughout the Short Papers we will extensively reference the 5th Edition of "Motor Vehicle Accident Reconstructions and Cause Analysis" by Rudolf Limpert, the "Accident Reconstruction Catalog" (ARC) CD, as well as the MARC 1 software.

IN-LINE COLLISIONS

Part Three

Frontal Two-Vehicle and Vehicle/Fixed Object Sideswipe Crashes, Test Data & Crush Energy

1. DEFINITION OF SIDE SWIPE IN-LINE COLLISION

In a sideswipe collision the approach and departure velocity vectors are approximately parallel. The velocity vectors of vehicles do change magnitude, however the direction remains unchanged. For example, if the approach angle of Vehicle 1 is 30 degrees, the departure angle is also approximately 30 degrees.

The center-of-gravities do not attain a common velocity. In two-vehicle sideswipes the contact area may be the sides, corners, top or bottom of vehicles. For example, if a car under rides the right front corner and continues under the side of a high pickup truck with both vehicles continuing in their original directions, the sideswipe analysis applies. When a vehicle glances against a guardrail, the sideswipe analysis applies. In general, collision speeds may high while the velocity change or delta-V generally is small. In full frontal collisions without sideswipe the impact speed may be small while the velocity change or delta-V is high. See ARC Sections 2.4.3, 2.4.1 (video), and 2.4.2.

2. WHAT ENGINEERING PRINCIPLES APPLY

Details are discussed in Section 33-4(c) of the Text. Equations 33-27 and 33-28 were derived from the general central oblique impact linear momentum analysis, energy balance (crush energy), and after impact run-out analysis. The approach and departure angles for each vehicle are then set equal to each other, that is, the oblique collision diagram is “collapsed” into two vehicles traveling on parallel lines in opposite directions.

After-impact decelerations and distances, crush energies, and vehicle weights are required to calculate impact velocities.

2.1. FRONTAL SIDE SWIPE MB 200D WITH MB 200D

The frontal side swipe crash test data are reported in “Computer Aided Reconstruction of Car/Car Accidents”, by Heinz Burg, published by Verlag INFORMATION Ambs GmbH, Kippenheim, Germany, 1984. The crash test discussed here is accident test No. 1.

The vehicle contact diagram generated by MARC 1 X – 9 is illustrated in Figure 1. MARC 1 X -9 is normally only used for linear and rotational momentum analysis. The run-out diagram is shown in Figure 2. Vehicle 1 (red) traveled from left to right (0 deg),

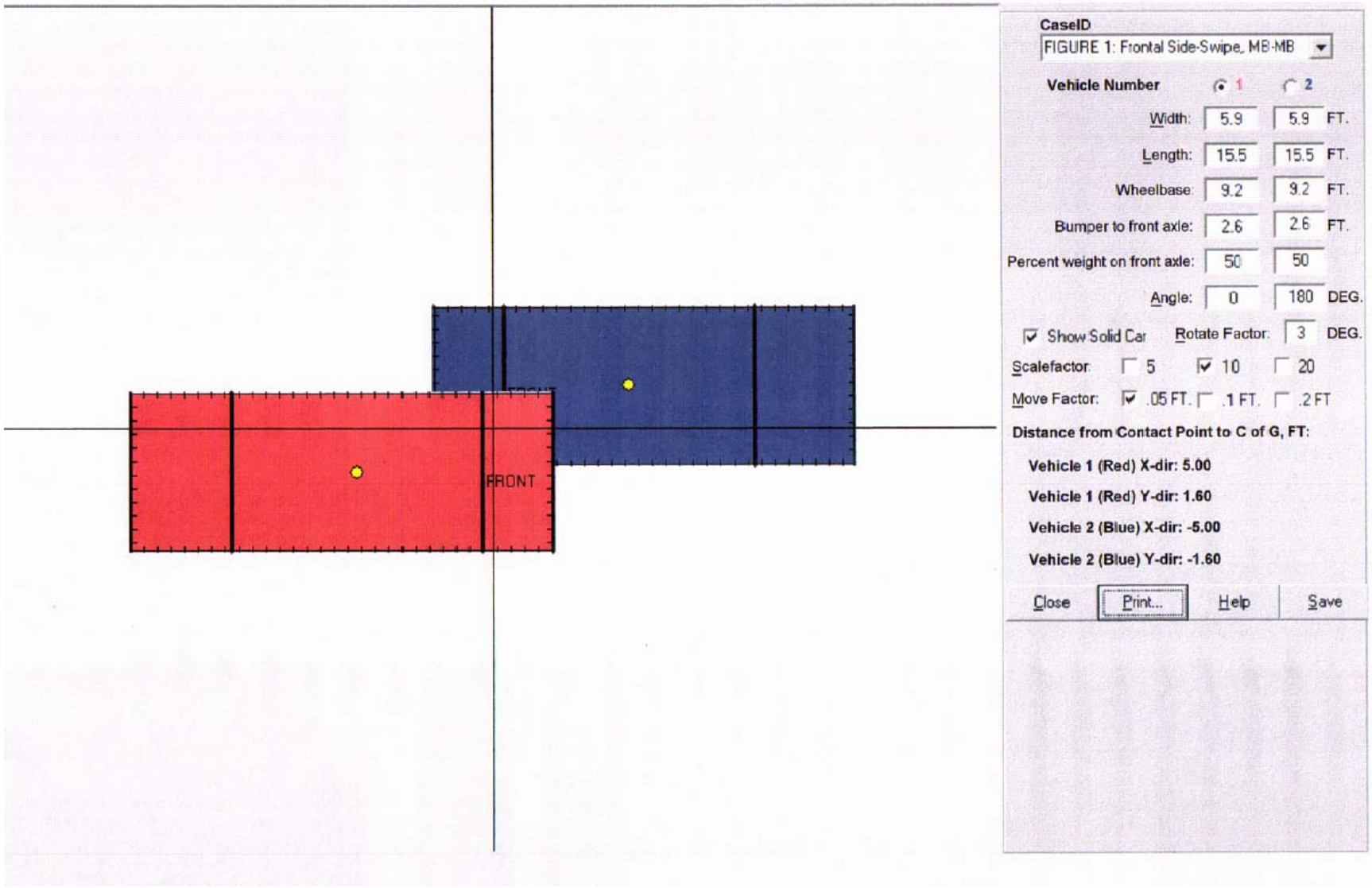
FRONT
CaseID
FIGURE 1: Frontal Side-Swipe, MB-MB
Vehicle Number 1 2
Width: 5.9 5.9 FT.
Length: 15.5 15.5 FT.
Wheelbase: 9.2 9.2 FT.
Bumper to front axle: 2.6 2.6 FT.
Percent weight on front axle: 50 50
Angle: 0 180 DEG.
Show Solid Car
Rotate Factor: 3 DEG.
Scalefactor: 5 10 20
Move Factor: .05 FT. .1 FT. .2 FT
Distance from Contact Point to C of G, FT:
Vehicle 1 (Red) X-dir: 5.00
Vehicle 1 (Red) Y-dir: 1.60
Vehicle 2 (Blue) X-dir: -5.00
Vehicle 2 (Blue) Y-dir: -1.60
Close
Print...
Help
Save

Figure 1

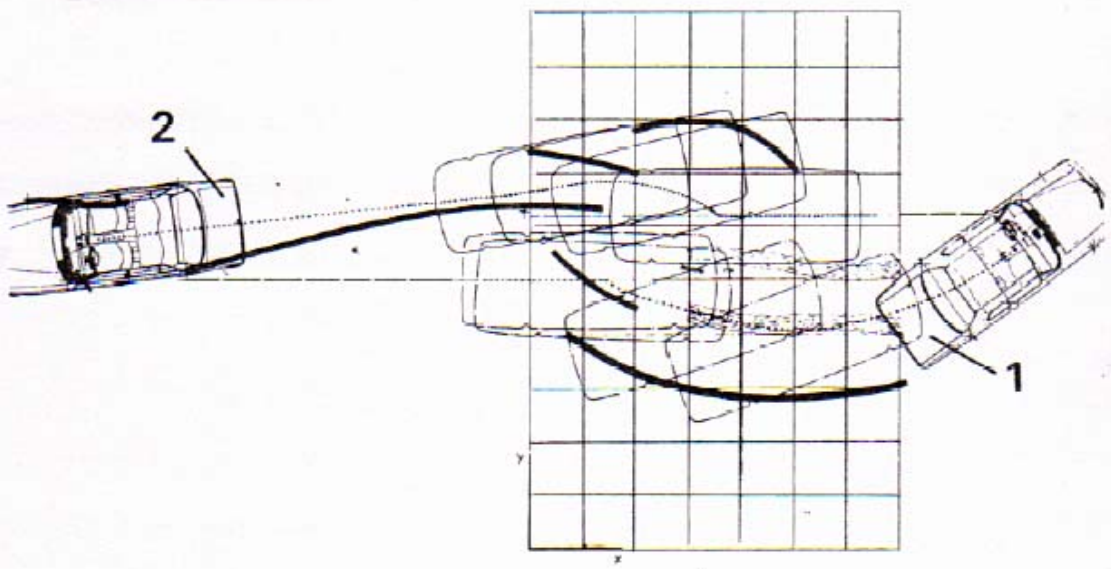

Figure 2: Vehicle Run-Out Diagram

Vehicle 2 (blue) from right to left 180 deg). As an inspection of Figure 2 reveals, both vehicles continued basically in their original directions, with minor rotations.

The test impact velocity of Vehicle 1 was 38 mph, that of Vehicle 2 was 24 mph, their weights 3418 lb and 3429 lb, respectively. The measured after-impact data are as follows: Vehicle 1: 17.4 mph, 26.5 ft, 0.39g; Vehicle 2: 5 mph, 39.4 ft, (no deceleration given). The energy equivalent velocities are EES1 = 31 +/-3 mph, EES2 = 25 +/-3 mph. The crush damages are illustrated in Figures 3, 4 and 5.

Based on the stated EES velocities, the crush energy estimates range between 89,427 and 131,860 lbft (109,617 average) for Vehicle 1, and between 55,385 to 89,715 lbft (average 71,520) for Vehicle 2.

Using the proper test data and average crush energies in MARC 1 X – 3, RUN 1 calculates the impact velocities of 36.68 mph for Vehicle 1 and 23.89 mph for Vehicle 2. The test velocities were 38 and 24 mph, respectively. Why Vehicle 2 had a relatively long run-out distance is not explained. However, since the departure velocity of Vehicle 2 was measured, it is of no consequence.

2.2. FRONTAL SIDESWIPE CHEVROLET CITATION AND TRACTOR-TRAILER

The driver of a 1983 Chevrolet Citation, after having lost control in a sweeping right-hand turn, sideswiped an oncoming 1982 Kenworth tractor-semi-trailer with its left side. Accident scene after-impact data showed that the car traveled 105 ft on asphalt, the truck 125 ft on dirt with some brakes locked.

The crash test video is shown in ARC Section 2.4.1. In the test, the tractor is stationary and anchored to the ground with the Chevrolet traveling 87.9 mph at impact. The test Chevrolet traveled approximately 350 ft after impact, including crashing into some bushes.

We will first “reconstruct” the crash test trying to obtain meaningful crush energy values. MARC 1 X-3, RUN 2 shows the crash reconstruction. Crush energy of 251,488 lbft and 10,000 lbft of secondary energy (crashing against bushes, etc.) calculate the test speed of the Citation against the stationary tractor. The crush depth measurements were chosen to approximately represent a “crush profile” along the left side of the car. Of course, the computer calculations use only the crush energy number, and not the crush measurement, in computing impact velocities. If this had not been a crash test, rather than an accident with an unknown impact velocity, crush energy ranges of +/- 20 % should be used. For example, increasing the crush width from 10 in. to 12 in. represents 301,785 lbft of crush energy and an impact velocity of 90.49 mph, while 7 in. represent 176,041 lbft and 83.51 mph.

RUN 3 shows the actual reconstruction with impact velocities of 54 mph for the Chevrolet and 34 mph for the truck. The reader is encouraged to conduct a parameter

sensitivity study to learn how reasonable variations in after-impact deceleration and crush energy affect the impact velocities of the vehicles.

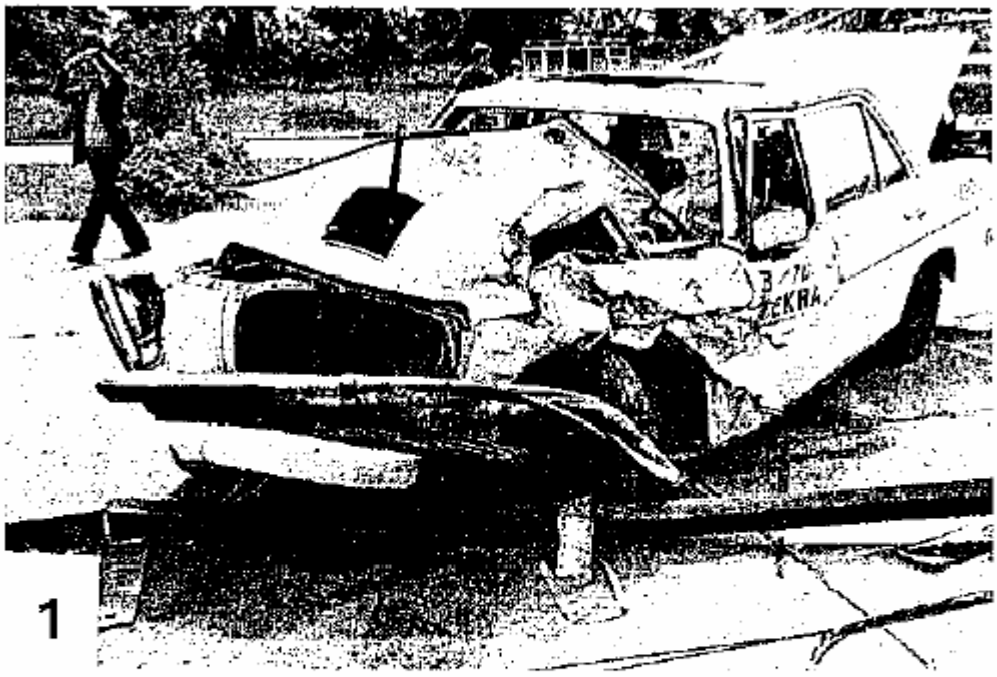

Figure 3: Vehicle 1 Damage

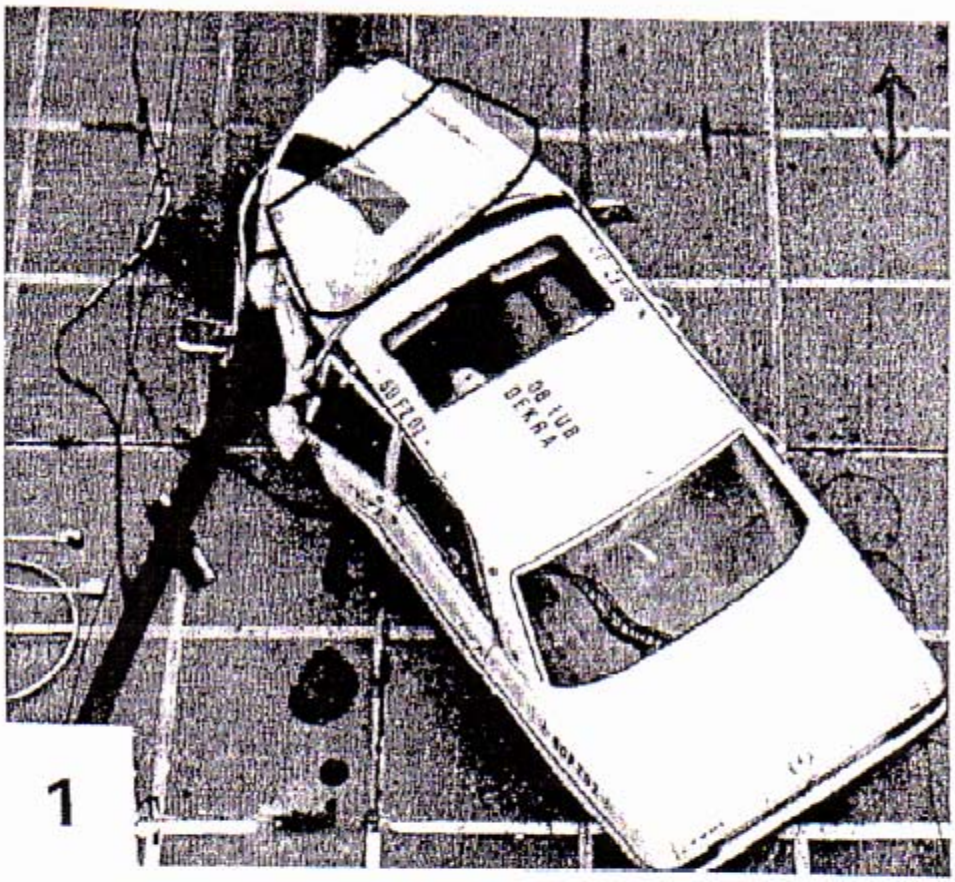

Figure 4: Vehicle 1 Damage

Figure 5: Vehicle 2 Damage

Friday, February 24, 2006

MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'X-3' RUN FOR PCB 3 - 2006, RUN 1 ********
FRONTAL SIDE-SWIPE COLLISION

Information For Vehicles		1984 MERCEDES BENZ 200	1984 MERCEDES BENZ 200
Vehicle Weight, Lbs:	===>	3418.00	3429.00
Surface #1			
Pre-Impact Braking Distance, FT:	===>	0.00	0.00
Pre-Impact Deceleration, g-UNITS:	===>	0.00	0.00
Surface #1			
Distance Traveled After Impact, FT:	===>	26.50	39.40
After-Impact Deceleration, g-UNITS:	===>	0.39	0.02
Max. Force Not Causing Damage, LBS/IN:	=>	197.00	197.00
Stiffness/Inch of Width, PSI:	===>	83.80	83.80
Force Angle Offset from Perpendicular, DEG:	===>	0.00	0.00
Width of Crush Region, IN:	===>	70.00	70.00
Number of Crush Measurements:	===>	6	6
Crush Measurement #1, IN:	===>	40.00	36.00
Crush Measurement #2, IN:	===>	32.00	22.00
Crush Measurement #3, IN:	===>	11.00	10.00
Crush Measurement #4, IN:	===>	4.00	3.00
Crush Measurement #5, IN:	===>	3.00	2.00
Crush Measurement #6, IN:	===>	1.00	0.00
Energy from Secondary Impacts, FT·LBS:	=>	0.00	0.00
Pre-Impact Speed, MPH:	===>	36.68	23.89
Speed at Impact, MPH:	===>	36.68	23.89
After-Impact Speed, MPH:	===>	17.59	4.86
Crush Energy, FT·LBS:	===>	109324.31	71641.33
EES Speed, MPH:	===>	30.94	25.01

Friday, February 24, 2006

MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'X-3' RUN FOR PCB 3 - 2006, RUN 2 ********
FRONTAL SIDE-SWIPE COLLISION

Information For Vehicles		1983 CHEVROLET CITATION	1982 KENWORTH TRACTOR
Vehicle Weight, Lbs:	===>	3100.00	999999999.
Surface #1			
Pre-Impact Braking Distance, FT:	===>	0.00	0.00
Pre-Impact Deceleration, g-UNITS:	===>	0.00	0.00
Surface #1			
Distance Traveled After Impact, FT:	===>	350.00	0.00
After-Impact Deceleration, g-UNITS:	===>	0.48	0.00
Max. Force Not Causing Damage, LBS/IN:	=>	200.00	1000.00
Stiffness/Inch of Width, PSI:	===>	70.00	500.00
Force Angle Offset from Perpendicular, DEG:	===>	0.00	0.00
Width of Crush Region, IN:	===>	10.00	15.00
Number of Crush Measurements:	===>	2	2
Crush Measurement #1, IN:	===>	90.00	5.00
Crush Measurement #2, IN:	===>	90.00	5.00
Energy from Secondary Impacts, FT·LBS:	=>	10000.00	0.00
Pre-Impact Speed, MPH:	===>	87.76	0.00
Speed at Impact, MPH:	===>	87.76	0.00
After-Impact Speed, MPH:	===>	71.60	0.00
Crush Energy, FT·LBS:	===>	251488.10	15312.50
EES Speed, MPH:	===>	49.28	0.02

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'X-3' RUN FOR PCB 3 - 2006, RUN 3 ********
FRONTAL SIDE-SWIPE COLLISION

Information For Vehicles		1983 CHEVROLET CITATION	1982 KENWORTH TRACTOR
Vehicle Weight, Lbs:	===>	3100.00	80000.00
Surface #1			
Pre-Impact Braking Distance, FT:	===>	0.00	0.00
Pre-Impact Deceleration, g-UNITS:	===>	0.00	0.00
Surface #1			
Distance Traveled After Impact, FT:	===>	105.00	125.00
After-Impact Deceleration, g-UNITS:	===>	0.45	0.30
Max. Force Not Causing Damage, LBS/IN:	=>	200.00	1000.00
Stiffness/Inch of Width, PSI:	===>	70.00	500.00
Force Angle Offset from Perpendicular, DEG:	===>	0.00	0.00
Width of Crush Region, IN:	===>	10.00	15.00
Number of Crush Measurements:	===>	2	2
Crush Measurement #1, IN:	===>	90.00	5.00
Crush Measurement #2, IN:	===>	90.00	5.00
Energy from Secondary Impacts, FT·LBS:	=>	0.00	0.00
Pre-Impact Speed, MPH:	===>	53.81	34.13
Speed at Impact, MPH:	===>	53.81	34.13
After-Impact Speed, MPH:	===>	37.61	33.51
Crush Energy, FT·LBS:	===>	251488.10	15312.50
EES Speed, MPH:	===>	49.28	2.39

3.0 SIDESWIPE WITH FIXED OBJECT

3.1 SIDESWIPE WALL IMPACT – IMPULSE ANALYSIS

The basic engineering concepts of a vehicle glancing against a wall or guardrail are discussed in Section 33-6 of the Text. Tractor-trailer wall crash tests are shown in ARC videos Sections 1.3.2 and 1.3.3. Equation 33-45 includes wall friction as well as the coefficient of restitution. The approach angle can never be equal to zero, since then there would be no impulse against the wall, and the answer would be meaningless. Expressed differently, the approach and departure velocity lines of action can never be parallel in the impulse analysis involving a rigid wall discussed in Section 33-6 of the Text.

3.2 SIDESWIPE WALL IMPACT – MARC 1 ANALYSIS

An example of a crash test with a fixed object (tractor) is shown in RUN 1 above. Vehicle 2 represents the fixed object with its weight made large, and its distance traveled after impact made small, that is, near zero.

4.0 APPLICATION

4.1 FRONTAL SIDESWIPE (UNDER-SWIPE) OF ACURA AGAINST FORD F350

A 1991 Acura Integra had veered into oncoming traffic where it impacted with a 1993 Ford F350 pulling a trailer. The vehicles approached the area of impact on nearly parallel (head-on) lines with a minor possible angular deviation.

The left front of the Acura impacted the left front of the Ford, tearing off the left front wheel of the truck, under-riding the driver's side floor area, coming in contact with the left rear dual wheels before separating from the truck. The Acura field sketch crush measurements are shown in Figure 6. The left front of the Acura was severely crushed with significant sheet metal damage along the driver's of the Acura including buckling up to the C-pillar.

The crush field sketch measurements of the Ford are shown in Figure 7.

The crush damage of both vehicles is illustrated in Figures 8 through 13.

Considering that this crash meets the requirements of a frontal sideswipe (or frontal under-swipe), we will use MARC 1 X-3 for the reconstruction of the impact speeds.

All input data are shown in the respective computer runs. The Acura after-impact deceleration was obtained from the "locked" left front tire, that of the Ford primarily

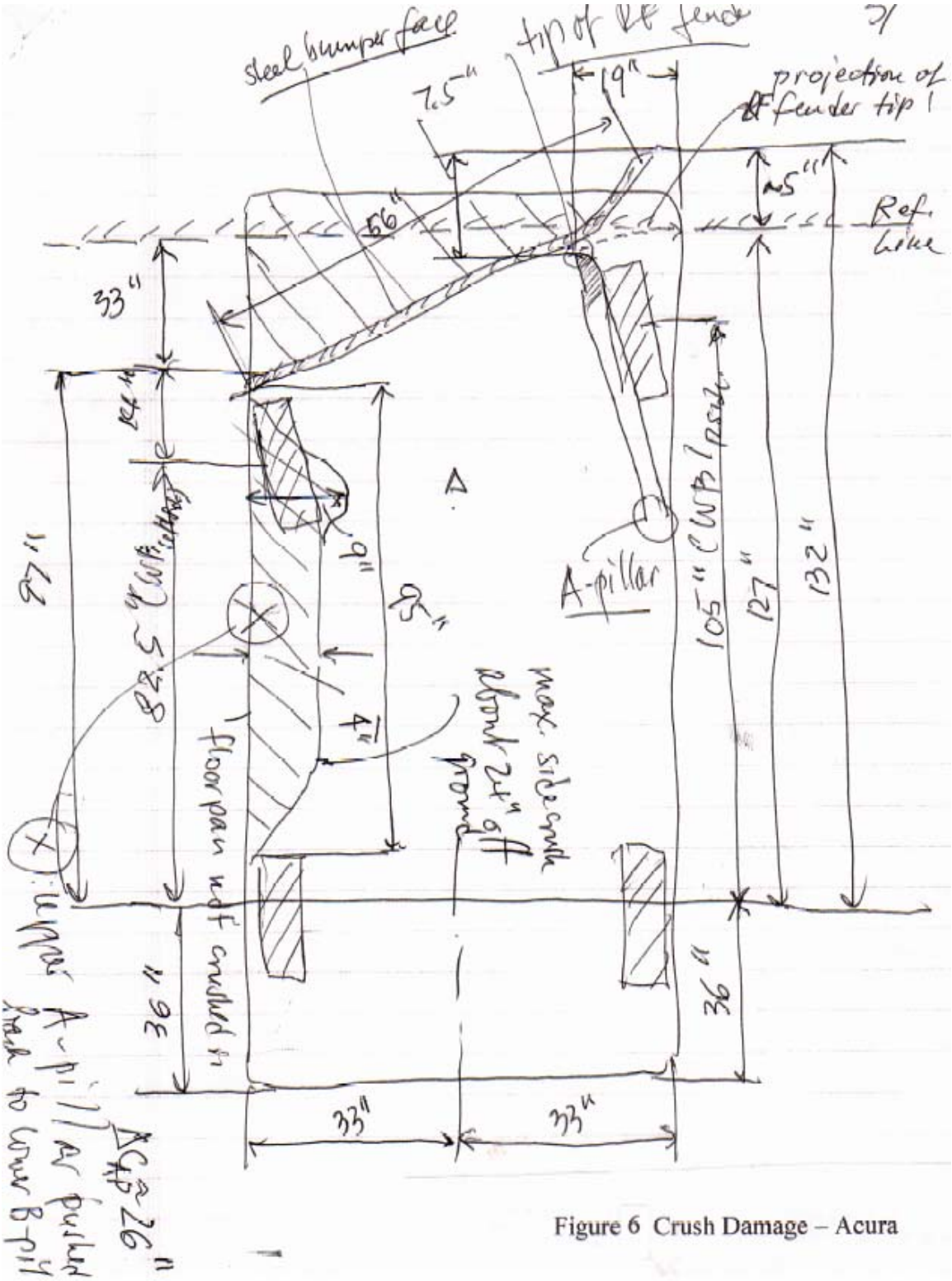

Figure 6 Crush Damage – Acura

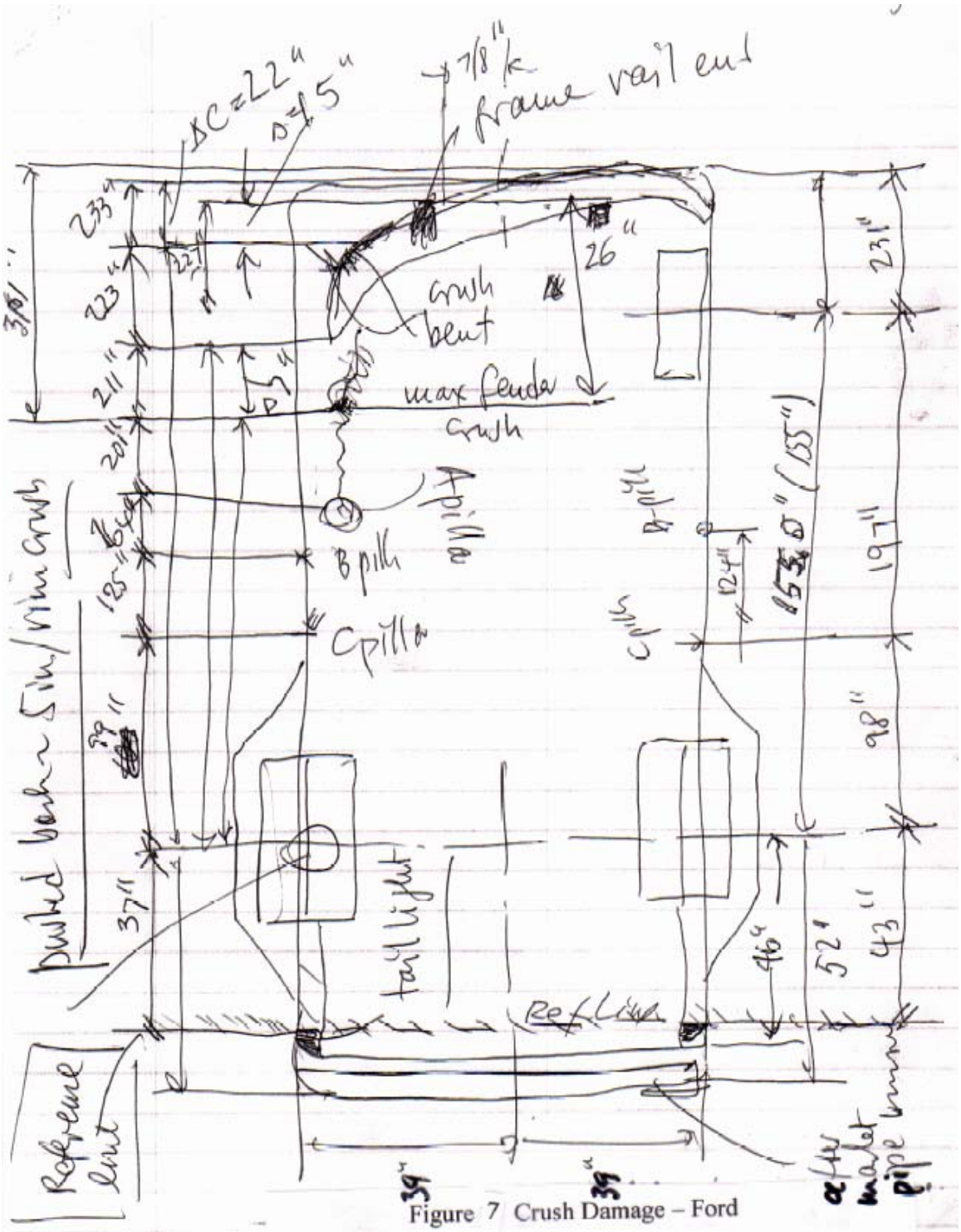

Figure 7 Crush Damage – Ford

Figure 8 Acura

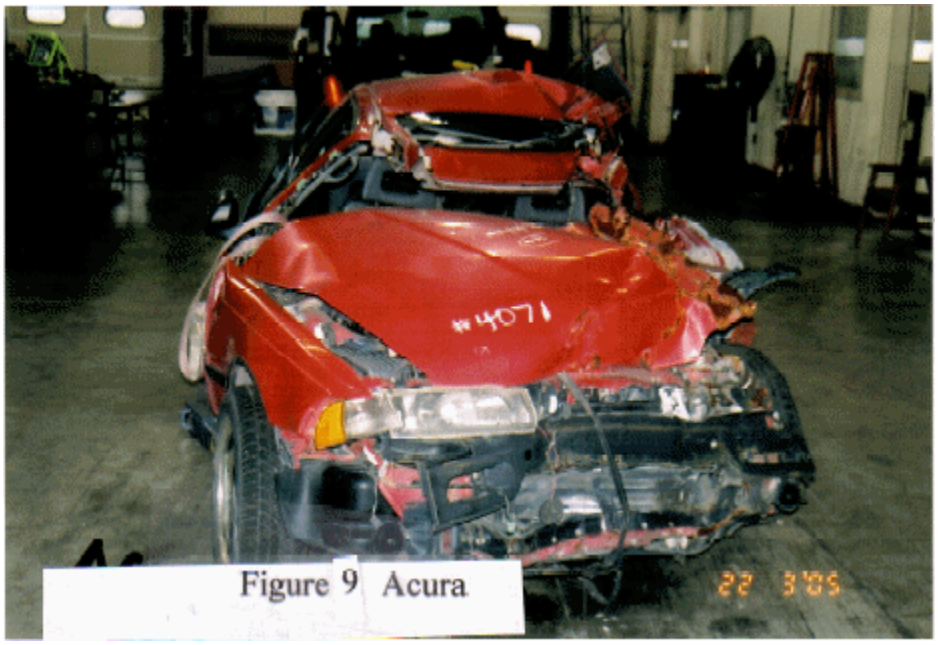

Figure 9 Acura

Figure 10 Acura

Figure 11 Ford

Figure 12 Ford

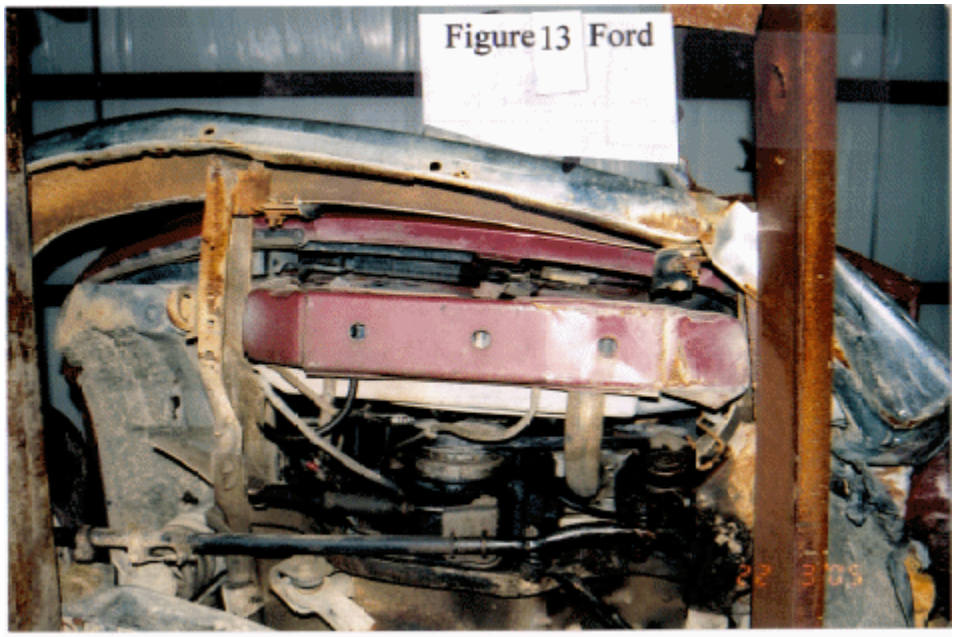

Figure 13 Ford

from its left front corner dragging on the ground without any braking by the driver and a slight down grade.

The crush depths for the Acura were obtained from the maximum left-side crush depth of approximately 40 in. (33 + 7) and 10 in. on the right side over a crush width of 56 in. These frontal crush depth measurements reflect the lowest crush energy value since no additional damage energy was included on part of the Acura in RUN 3. For the Ford a crush profile of 23 and 5 in. over a width of 30 in. was considered in RUN 3. The associated crush energy is also considered a minimum value. Inspection of RUN 3 shows impact speeds of approximately 43.7 mph and 19 mph for the Acura and Ford, respectively.

RUN 4 shows the slightly larger impact speeds based upon an increase in crush energies obtained from a force angle offset of 15 degrees.

The reader is strongly encouraged to conduct a parameter sensitivity study to determine which crash scene parameters are of major significance. This information will help the reconstructionist to better understand what input data resolution must be achieved.

Thursday, July 06, 2006

MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'X-3' RUN FOR PCB 3 - 2006, RUN 3 ********
FRONTAL SIDE-SWIPE COLLISION

Information For Vehicles		1991 ACURA INTEGRA	1993 FORD F350
Vehicle Weight, Lbs:	===>	2813.00	15055.00
NO PRE-IMPACT SURFACE INFORMATION			
Surface #1			
Distance Traveled After Impact, FT:	===>	70.00	95.00
After-Impact Deceleration, g-UNITS:	===>	0.25	0.08
Max. Force Not Causing Damage, LBS/IN:	=>	270.00	500.00
Stiffness/Inch of Width, PSI:	===>	70.00	100.00
Force Angle Offset from Perpendicular, DEG:	===>	0.00	0.00
Width of Crush Region, IN:	===>	56.00	30.00
Number of Crush Measurements:	===>	2	2
Crush Measurement #1, IN:	===>	40.00	23.00
Crush Measurement #2, IN:	===>	10.00	5.00
Energy from Secondary Impacts, FT·LBS:	=>	0.00	0.00
Pre-Impact Speed, MPH:	===>	43.70	18.97
Speed at Impact, MPH:	===>	43.70	18.97
After-Impact Speed, MPH:	===>	22.89	15.08
Crush Energy, FT·LBS:	===>	148263.33	48500.00
EES Speed, MPH:	===>	39.72	9.82

0

Thursday, July 06, 2006

MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'X-3' RUN FOR PCB 3 - 2006, RUN 4 ********
FRONTAL SIDE-SWIPE COLLISION

Information For Vehicles		1991 ACURA INTEGRA	1993 FORD F350
Vehicle Weight, Lbs:	===>	2813.00	15055.00
NO PRE-IMPACT SURFACE INFORMATION			
Surface #1			
Distance Traveled After Impact, FT:	===>	70.00	95.00
After-Impact Deceleration, g-UNITS:	===>	0.25	0.08
Max. Force Not Causing Damage, LBS/IN:	=>	270.00	500.00
Stiffness/Inch of Width, PSI:	===>	70.00	100.00
Force Angle Offset from Perpendicular, DEG:	===>	15.00	15.00
Width of Crush Region, IN:	===>	56.00	30.00
Number of Crush Measurements:	===>	2	2
Crush Measurement #1, IN:	===>	40.00	23.00
Crush Measurement #2, IN:	===>	10.00	5.00
Energy from Secondary Impacts, FT·LBS:	=>	0.00	0.00
Pre-Impact Speed, MPH:	===>	44.88	19.19
Speed at Impact, MPH:	===>	44.88	19.19
After-Impact Speed, MPH:	===>	22.89	15.08
Crush Energy, FT·LBS:	===>	158906.52	51981.61
EES Speed, MPH:	===>	41.12	10.17

0