SHORT PAPER PCB 8-2006

OBLIQUE COLLISIONS

ENGINEERING EQUATIONS, INPUT DATA AND MARC 1 APPLICATIONS

By:

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PURPOSE OF PCB SHORT PAPERS

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.

Short Papers are available free of charge and can be obtained by visiting our website at

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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.

Comments and suggestions are always invited by visiting our Discussion Forum and/or by writing to:

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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.

OBLIQUE COLLISIONS

Part Four

Linear and Rotational Momentum
Determine After-Impact Data from Known Impact Data
(The "Crash Test" on Paper)

1. DEFINITION OF LINEAR AND ROTATIONAL MOMENTUM

The basic formulation of linear and rotational momentum is discussed in Section 33-5 of the Text. The after-impact center-of-gravity velocities and angular velocities of each vehicle are calculated for known impact velocities and collision configuration by Equations 33-38 through 33-43.

2. WHAT ENGINEERING PRINCIPLES APPLY

The impulse components are calculated by Equations 33-35 and 33-36 based upon the relative velocities before as well as the center-of-gravity distances relative to the contact point (common velocity) between the vehicles.

As Example 33-6 of the Text shows, the analysis presented in Section 33-5(b) calculates the center-of-gravity velocities and angular velocities of both vehicles after impact based upon known data at the moment of impact.

For the discussion that follows we assume that the impact configuration is known. This means that the distances (or lever arms of the moment of momentum) are known from the collision diagram (MARC 1 – Y). With the masses and mass moment of inertia for both vehicles known, a-, b- and c-values are also known. See Figure 33-14 of the Text for a collision diagram example. We also assume that the approach angles are known for both vehicles.

MARC 1 – X8 computes all essential after-impact data based upon known impact velocity vectors V_{11} and V_{21}. Energy balance is included in MARC 1 – X8 to allow an accuracy check by use of the crush energies exhibited by the vehicles involved. Both oblique and in-line collision configurations can be analyzed. A common velocity must be achieved by the colliding vehicles.

MARC 1 – X8 can be used effectively to "critique" another expert's crash reconstruction by running a crash test on paper using the expert's input data.

3. NON-CENTRAL OBLIQUE IMPACT

We will analyze the crash test discussed in PCB5 – 2006, Section 4.1. The same crash test was also analyzed in PCB6 – 2006 and PCB7 – 2006. A stationary VW Derby was side-impacted by a VW Golf at 29 mph.

The vehicle contact diagram obtained from MARC 1 – Y is shown in PCB6-2006, RUN 1. All essential input data used in MARC 1 – X8, RUN 1 were already used in both previous Short Papers using linear and rotational momentum.

If no crush energy data, such as crush damage measurements and stiffness coefficients are available, MARC 1 – X8 will calculate after-impact data without performing an energy balance calculation.

Photographs of the damaged test vehicle are shown in Figures 5 and 6 of Short Paper PCB5 – 2006. An "estimated" frontal crush profile of 10 and 5 in. over a width of 45 in. for the Golf, and a side crush of 4 and 4 in. for a width of 45 in. for the Derby is shown as input data in RUN 1. The stiffness coefficients were obtained from SAE Paper 960897 for a wheelbase range of 94.8 to 101.6 in.

Inspection of RUN 1 reveals the following "29 mph crash test" data comparison obtained from the MARC 1 computer software:

	Crash Test on Paper MARC 1 – X8	Actual Crash Test
1. Impact Velocity	29 mph	29 mph
2. Departure Angle		
Golf:	96.96 deg	97 deg
Derby:	79.88 deg	80 deg
3. After-Impact Distance		
Golf:	11. 14 ft	10.2 ft
Derby:	9.66 ft	9.8 ft
4. After-Impact Rotation		
Golf:	0.12 deg	0 to 7 deg (?)
Derby:	117.10 deg	123 deg

The energy balance "error" is 3.32% indicating that the crush energy is too small by 3.32%. The results indicate excellent agreement between actual and reconstructed test data. It also indicates that the vehicle contact diagram in terms of the l_x and l_y values developed for this case is a good representation what actually happened in the crash test.

Saturday, March 18, 2006

MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'X-8' RUN FOR PCB 8 - 2006, RUN1 ********
PREDICTION OF COLLISION RESULTS
WITH CRUSH ENERGY CALCULATIONS

Information For Vehicles		1993 VW GOLF	1993 VW DERBY
Vehicle Weight, LBS:	==>	1918.00	2007.00
Vehicle Wheelbase, FT:	==>	8.12	7.70
Vehicle Length, FT:	==>	13.10	12.40
Mass Moment of Inertia, $FT\cdot LBS/SEC^2$:	==>	816.09	766.51
Approach Angle, DEG:	==>	90.00	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:	==>	0.90	0.45
After-Impact Coefficient of Rotational Friction, D'LESS:	==>	0.15	0.25
Distance from Center of Gravity to Contact Point:			
Along the X-Axis, FT:	==>	0.83	-2.75
Along the Y-Axis, FT:	==>	5.00	-2.00
Estimated Low Impact Speed, MPH:	==>	29.00	0.00
Estimated High Impact Speed, MPH:	==>	29.00	0.00
(A]Max. Force Not Causing Damage, LBS/IN:	==>	185.00	100.00
(B]Stiffness/Inch of Width, PSI:	==>	66.00	66.00
Force Angle Offset from Perpendicular, DEG:	==>	0.00	0.00
Width of Crush Region, IN:	==>	45.00	45.00
Number of Crush Measurements:	==>	2	2
Crush Measurement #1, IN:	==>	12.00	4.00
Crush Measurement #2, IN:	==>	5.00	4.00

```
******** PROGRAM 'X-8' RUN FOR PCB 8 - 2006, RUN1 ********
              PREDICTION OF COLLISION RESULTS

                                                  1993      1993
Page 2                                              VW        VW
Information For Vehicles                          GOLF     DERBY
================================================================

Specified Impact Speed, MPH:                ===>  29.00      0.00

After-Impact Velocities
      In X-Direction, MPH:                  ===>  -2.10      2.01
      In Y-Direction, MPH:                  ===>  17.22     11.25

After-Impact Direction, DEG:                ===>  96.96     79.88

After-Impact Direction of Rotation
                     V1: ===>  Counterclockwise
                     V2: ==================>           Clockwise
Angular Velocity After Impact, DEG/SEC: =>  4.52     -183.89

Rotation After Impact, DEG:                 ===>   0.12    117.10

Distance Traveled After Impact, FT:         ===>  11.14      9.66

Pre-Impact Speed, MPH:                      ===>  28.99      0.00

After-Impact Speed, MPH:                    ===>  17.34     11.42
----------------------------------------------------------------
V1/V2 IMpulse, LBS·SEC:          ===> 1044.31

Direction of Impulse, DEG:                  ===> 259.88     79.88

Delta-V Component X-Direction, MPH:         ===>  -2.10      2.01

Delta-V Component Y-Direction, MPH:         ===> -11.78     11.25

Resultant Delta-V, MPH:                     ===>  11.96     11.43

Direction of Delta-V, DEG:                  ===> 259.87     79.88
----------------------------------------------------------------

Crush Energy of Vehicle, FT·LBS:  ===>  16315.43     3764.09

Energy Equivalent Speed, MPH:     ===>      15.97        7.50
----------------------------------------------------------------

Energy of Vehicles                          Before        After
----------------------------------------------------------------
Linear Motion Energy, FT·LBS:  ===>       53830.28     28015.30

Rotational Motion Energy, FT·LBS:=>           0.00      3949.94

Energy Totals, FT·LBS:         ===>       53830.28     52044.75
----------------------------------------------------------------
Crush Energy, FT·LBS:                  =====>  20079.52

Error in Energy Balance:             =====>       3.32%
================================================================
```

A comparison between the standard linear momentum reconstructed data (PCB 5 - 2006) and MARC 1 – X8, RUN 1 indicates good agreement for the delta-V values both in terms of magnitudes and directions.

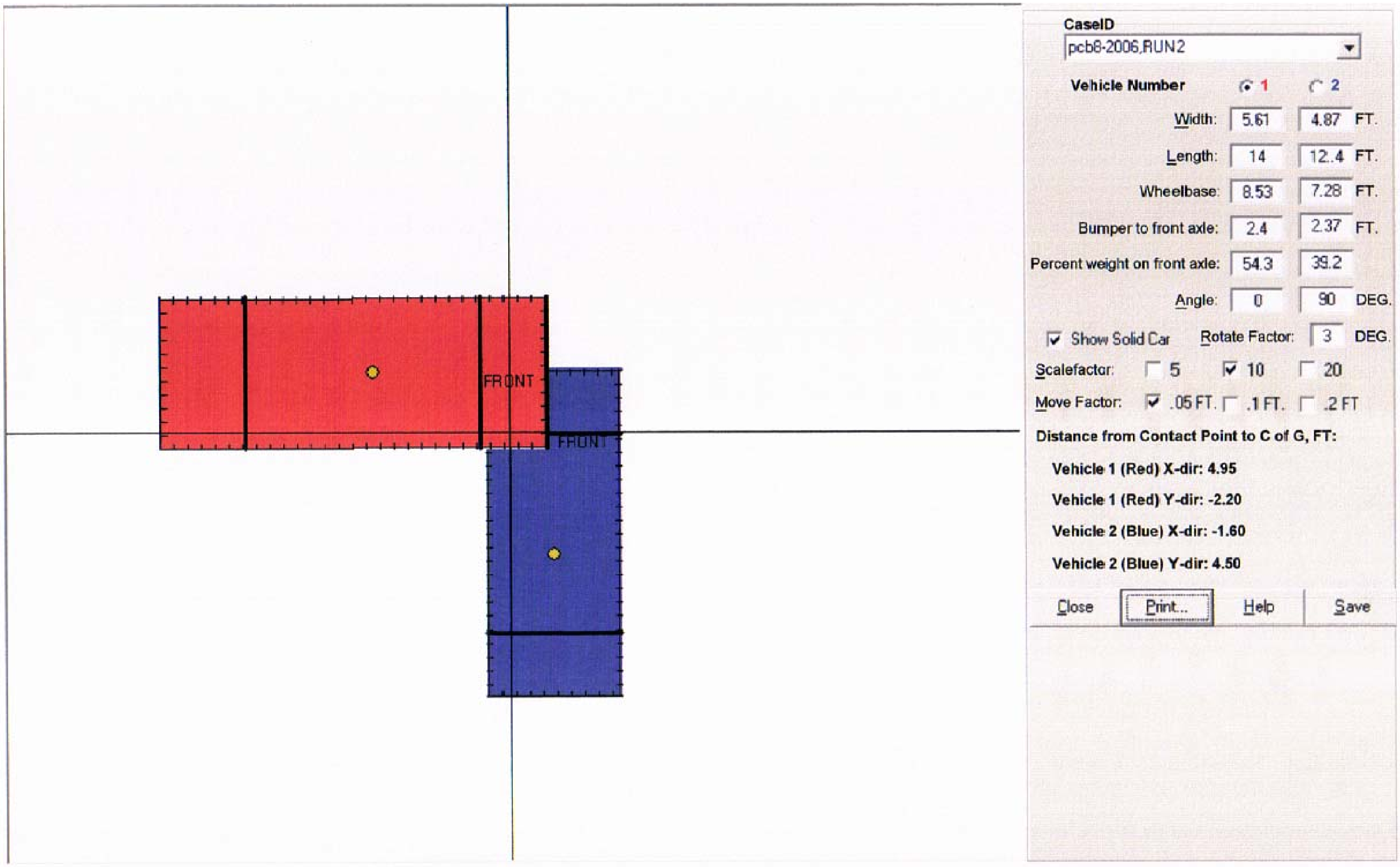
4. 0 FORD TAUNUS SIDE-IMPACTS STATIONARY SIMCA

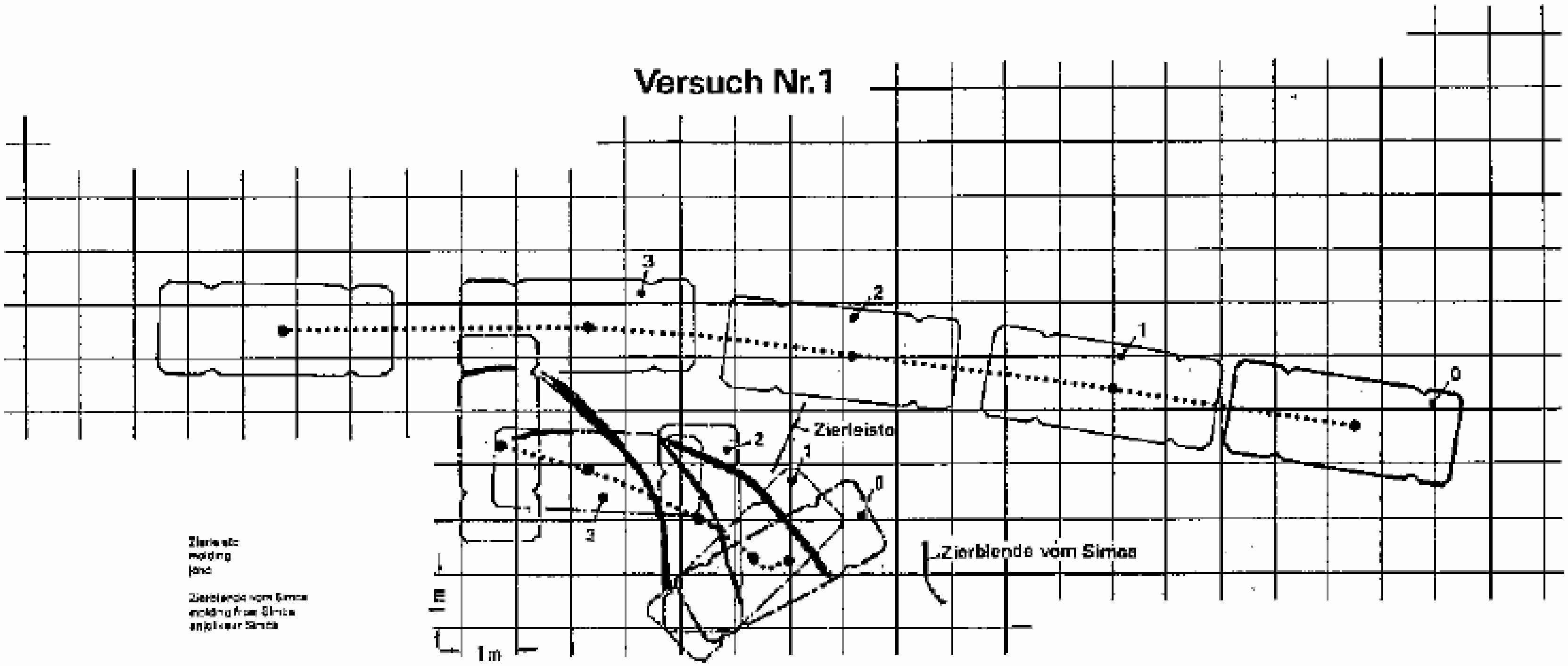
A 1980 Ford Taunus was crashed at 40 mph into the side of a stationary 1980 Simca 1000 GLS. All essential after-impact data were electronically recorded.

The MARC 1 – Y vehicle contact diagram is shown in PCB8-2006, RUN2. Vehicle dimensions were obtained from published records. The after-impact run-out diagram is shown in Figure 1.

The "Crash Test on Paper" is shown in MARC 1 – X8, RUN 2. No actual crush depth measurements were available. Crush depth in-put data were estimated from vehicle photographs. The Ford had its after-impact automatic brake-apply system fail, resulting in a run-out distance of 194 ft with a minor secondary tree impact.

	Crash Test on Paper MARC 1 – 2006, RUN 2	Actual Crash Test
1. Impact Velocity Ford	40 mph	40 mph
2. Velocity After Impact		
Ford x/y:	30.68/3.36 mph	26.1/3.73 mph
Simca x/y:	11.99/4.32 mph	11.8/4.9 mph
3. After-Impact Direction		
Ford:	6.26 deg	not measured
Simca:	340.20 deg	339 deg
4. Angular Velocity		
Ford:	-21.06 deg/sec	< 50 deg/sec
Simca:	- 338.55 deg/sec	332 deg/sec
5. Distance After Impact		
Ford:	198.3 ft	194 ft
Simca:	15.47 ft	18 ft
6. Delta – V		
Ford:	9.91 mph	11.6 mph
Simca:	12.75 mph	14.9 mph
7. Rotation After Impact		
Ford:	2.71 deg	< 10 deg
Simca:	249 deg	238 deg


FRONT
FRONT
CaseID
pcb8-2006,RUN2
Vehicle Number
1
2
Width:
5.61
4.87
FT.
Length:
14
12.4
FT.
Wheelbase:
8.53
7.28
FT.
Bumper to front axle:
2.4
2.37
FT.
Percent weight on front axle:
54.3
39.2
Angle:
0
90
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: 4.95
Vehicle 1 (Red) Y-dir: -2.20
Vehicle 2 (Blue) X-dir: -1.60
Vehicle 2 (Blue) Y-dir: 4.50
Close
Print...
Help
Save



Versuch Nr. 1

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Figure 1. After-Impact Run-Out; Ford Taunus & Simca

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                 Saturday, March 18, 2006

   MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
  ******** PROGRAM 'X-8' RUN FOR PCB 8 -2006, RUN 2 ********
              PREDICTION OF COLLISION RESULTS
              WITH CRUSH ENERGY CALCULATIONS
                                                1980        1980
                                                FORD       SIMCA
 Information For Vehicles                Taunus 2000    1000 GLS
 ===============================================================
 Vehicle Weight, LBS:                    ===> 2271.00    1764.00

 Vehicle Wheelbase, FT:                  ===>    8.53       7.28

 Vehicle Length, FT:                     ===>   14.00      12.45

 Mass Moment of Inertia, FT-LBS/SEC²:    ===> 1084.81     639.53

 Approach Angle, DEG:                    ===>    0.00      90.00

 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:    ===>    0.16       0.35

 After-Impact Coefficient of
    Rotational Friction, D'LESS:         ===>    0.20       0.40

 Distance from Center of Gravity to Contact Point:
        Along the X-Axis, FT:            ===>    4.95      -1.60
        Along the Y-Axis, FT:            ===>   -2.20       4.50

 Estimated Low Impact Speed, MPH:        ===>   40.00       0.00
 Estimated High Impact Speed, MPH:       ===>   40.00       0.00

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

(A]Max. Force Not Causing Damage, LBS/IN:===>  259.00      77.00
(B]Stiffness/Inch of Width, PSI:         ===>   43.00      37.00
 Force Angle Offset from
            Perpendicular, DEG:          ===>    0.00       0.00
 Width of Crush Region, IN:              ===>   34.00      34.00

 Number of Crush Measurements:           ===>       2          2
       Crush Measurement #1, IN:         ===>   14.00      16.00
       Crush Measurement #2, IN:         ===>    3.00       5.00


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

```
******** PROGRAM 'X-8' RUN FOR PCB 8 -2006, RUN 2 ********
              PREDICTION OF COLLISION RESULTS

                                              1980        1980
Page 2                                        FORD       SIMCA
Information For Vehicles               Taunus 2000    1000 GLS
==============================================================

Specified Impact Speed, MPH:           ===>   40.00       0.00

After-Impact Velocities
      In X-Direction, MPH:             ===>   30.68      11.99
      In Y-Direction, MPH:             ===>    3.36      -4.32

After-Impact Direction, DEG:           ===>    6.26     340.20

After-Impact Direction of Rotation
                    V1: ===>        Clockwise
                    v2: ==================>          Clockwise
Angular Velocity After Impact, DEG/SEC: => -21.06    -338.55

Rotation After Impact, DEG:            ===>    2.17     249.04

Distance Traveled After Impact, FT:    ===>  198.30      15.47

Pre-Impact Speed, MPH:                 ===>   39.98       0.00

After-Impact Speed, MPH:               ===>   30.85      12.74
--------------------------------------------------------------
V1/V2 IMpulse, LBS·SEC:         ===> 1024.09

Direction of Impulse, DEG:             ===>  160.16     340.16

Delta-V Component X-Direction, MPH:    ===>   -9.32      11.99

Delta-V Component Y-Direction, MPH:    ===>    3.36      -4.32

Resultant Delta-V, MPH:                ===>    9.91      12.75

Direction of Delta-V, DEG:             ===>  160.16     340.18
--------------------------------------------------------------

Crush Energy of Vehicle, FT·LBS:   ===>  13463.09    8825.23

Energy Equivalent Speed, MPH:      ===>     13.33      12.24
--------------------------------------------------------------

Energy of Vehicles                          Before       After
--------------------------------------------------------------
Linear Motion Energy, FT·LBS:  ===>   121260.45     81778.47

Rotational Motion Energy, FT·LBS:=>        0.00     11235.65

Energy Totals, FT·LBS:         ===>   121260.45    115302.44
--------------------------------------------------------------
Crush Energy, FT·LBS:                ====>    22288.32

Error in Energy Balance:            ====>        4.91%
==============================================================
```

Monday, March 20, 2006

MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******* PROGRAM 'X-5' RUN FOR PCB 8 - 2006 - X5, RUN3 *******
OBLIQUE COLLISION/LINEAR MOMENTUM

Information For Vehicles		1996 CHEVROLET TAHOE	1995 FORD TAURUS
Vehicle Weight, LBS:	===>	5350.00	3254.00
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:	===>	34.00	79.00
After-Impact Deceleration, g-UNITS:	===>	0.40	0.25
Amount to Vary Departure Angle, DEG:	===>	0.00	0.00
Energy from Secondary Impacts, FT·LBS.	===>	0.00	0.00

PRINT OUT 1 OF 1 PCB 8 - 2006 - X5, RUN3

Approach Angle, DEG:	===>	90.00	180.00
Departure Angle, DEG:	===>	117.00	117.00
Pre-Impact Speed, MPH:	===>	31.19	26.13
Speed at Impact, MPH:	===>	31.19	26.13
After-Impact Speed, MPH:	===>	20.20	24.34
Delta V in X-Direction, MPH:	===>	-9.17	15.08
Delta V in Y-Direction, MPH:	===>	-13.19	21.68
Delta V Resultant, MPH:	===>	16.06	26.41
Angle of Delta V, DEG:	===>	235.19	55.19

Comparison of the paper crash-test data with the measured data shows acceptable correlation. The measured data were record in form of electronic traces, making an accurate data interpretation difficult, both in terms of resolution and averaging data points.

5.0 CHEVROLET TAHOE SIDE-IMPACTS FORD TAURUS

A 1996 Chevrolet Tahoe side-impacts a 1995 Ford Taurus. The accident scene diagrams are shown in ARC "Accident Reconstruction Photos of Dr. Rudolf Limpert", photographs 254 and 255. Photographs 256 through 271 show both accident scene photographs with vehicles at their rest positions, as well as crash test photographs. The white Tahoe is the test vehicle. The subject accident Tahoe was not available for inspection.

The Tahoe traveled approximately 28 ft, the Taurus 79 ft after impact. Their departure angles were approximately 111 and 117 degrees, respectively. In the first reconstruction analysis standard linear momentum is used as shown in MARC 1 – X5, RUN 3. The impact velocities are 31 and 26 mph for the Tahoe and Taurus, respectively. If there are no tire-skid marks before impact, the approach angles are not exactly known. For example, changing the approach angles to 93 and 177 degrees, respectively changes the impact velocities to 30 and 25 mph.

The video tape of a crash test with a Tahoe traveling at 30.2 mph side-impacting a Taurus traveling at 24.3 mph is shown in ARC Section 2.3.2. The reader should carefully study the slow-motion scenes to observe where the common velocity point is located, indicated by initial vehicle motion and not by vehicle-to-vehicle contact sheet metal deformation

The vehicle contact diagram information (MARC 1 – Y) shown in PCB8-2006, RUN 3 is used in the accident reconstruction MARC 1 – X8, RUN 3 for impact velocities of 30.2 and 24.3 mph, respectively. Several of the recorded test data are shown in Figures 2 through 7.

A comparison of both the calculated and measured data indicates acceptable agreement. The reader is encouraged to conduct a parameter sensitivity study to determine which input parameters are more critical and which accident scene and vehicle crush data have a significant influence.

Inspection of the data output in MARC 1 – X8, RUN 3 shows a resultant delta-V = 19.08 mph for the Taurus. The standard linear momentum method of MARC 1 – X5, RUN 3 shows a Taurus delta-V of 26.41 mph for impact velocities of 31.19 and 26.13 mph, respectively. Of course, the delta-V calculation for the standard linear momentum method assumes a central impact, that is, the impulse forces go straight through the center-of-gravities of the vehicles. Using MARC 1 –X8 and

Monday, March 20, 2006

MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'X-8' RUN FOR PCB 8 - 2006, RUN 3 ********
PREDICTION OF COLLISION RESULTS
WITH CRUSH ENERGY CALCULATIONS

Information For Vehicles		1996 CHEVROLET TAHOE	1995 FORD TAURUS
Vehicle Weight, LBS:	===>	5350.00	3254.00
Vehicle Wheelbase, FT:	===>	9.83	8.83
Vehicle Length, FT:	===>	16.67	16.00
Mass Moment of Inertia, FT·LBS/SEC²:	===>	3506.73	1838.90
Approach Angle, DEG:	===>	90.00	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:	===>	0.40	0.23
After-Impact Coefficient of Rotational Friction, D'LESS:	===>	0.37	0.18
Distance from Center of Gravity to Contact Point:			
Along the X-Axis, FT:	===>	0.00	-2.45
Along the Y-Axis, FT:	===>	7.17	-2.27
Estimated Low Impact Speed, MPH:	===>	30.20	24.30
Estimated High Impact Speed, MPH:	===>	30.20	24.30
(A]Max. Force Not Causing Damage, LBS/IN:	===>	266.00	137.00
(B]Stiffness/Inch of Width, PSI:	===>	109.00	95.00
Force Angle Offset from Perpendicular, DEG:	===>	0.00	0.00
Width of Crush Region, IN:	===>	72.00	83.50
Number of Crush Measurements:	===>	2	4
Crush Measurement #1, IN:	===>	6.00	7.00
Crush Measurement #2, IN:	===>	12.00	14.00
Crush Measurement #3, IN:	===>	0.00	6.00
Crush Measurement #4, IN:	===>	0.00	0.00

Page 2

Information For Vehicles		1996 CHEVROLET TAHOE	1995 FORD TAURUS
Specified Impact Speed, MPH:	===>	30.00	24.00
After-Impact Velocities			
In X-Direction, MPH:	===>	-5.32	-15.56
In Y-Direction, MPH:	===>	19.88	16.96
After-Impact Direction, DEG:	===>	104.98	132.53
After-Impact Direction of Rotation			
V1: ===>		Counterclockwise	
v2: ===================>			Clockwise
Angular Velocity After Impact, DEG/SEC: =>		151.72	-100.21
Rotation After Impact, DEG:	===>	72.40	62.32
Distance Traveled After Impact, FT:	===>	35.27	76.72
Pre-Impact Speed, MPH:	===>	30.19	24.29
After-Impact Speed, MPH:	===>	20.57	23.01
V1/V2 IMpulse, LBS·SEC:	===>	2826.73	
Direction of Impulse, DEG:	===>	242.73	62.73
Delta-V Component X-Direction, MPH:	===>	-5.32	8.74
Delta-V Component Y-Direction, MPH:	===>	-10.32	16.96
Resultant Delta-V, MPH:	===>	11.61	19.08
Direction of Delta-V, DEG:	===>	242.73	62.73
Crush Energy of Vehicle, FT·LBS:	===>	43779.41	33678.38
Energy Equivalent Speed, MPH:	===>	15.66	17.61

Energy of Vehicles		Before	After
Linear Motion Energy, FT·LBS:	===>	226958.50	133174.66
Rotational Motion Energy, FT·LBS:	=>	0.00	15104.42
Energy Totals, FT·LBS:	===>	226958.50	225736.88
Crush Energy, FT·LBS:	=====>	77457.79	
Error in Energy Balance:	=====>	0.54%	

31.19 and 26.13 mph as impact velocities yields a Taurus delta-V of 19.89 mph at the vehicle's center-of-gravity.

Delta-V values at locations other than the center-of-gravity are different due to the superposition of the angular velocity. For example, the y-component of the delta-V of the Taurus at the left rear occupant location assuming a 4-foot perpendicular distance to the vehicle's center-of-gravity is computed as:

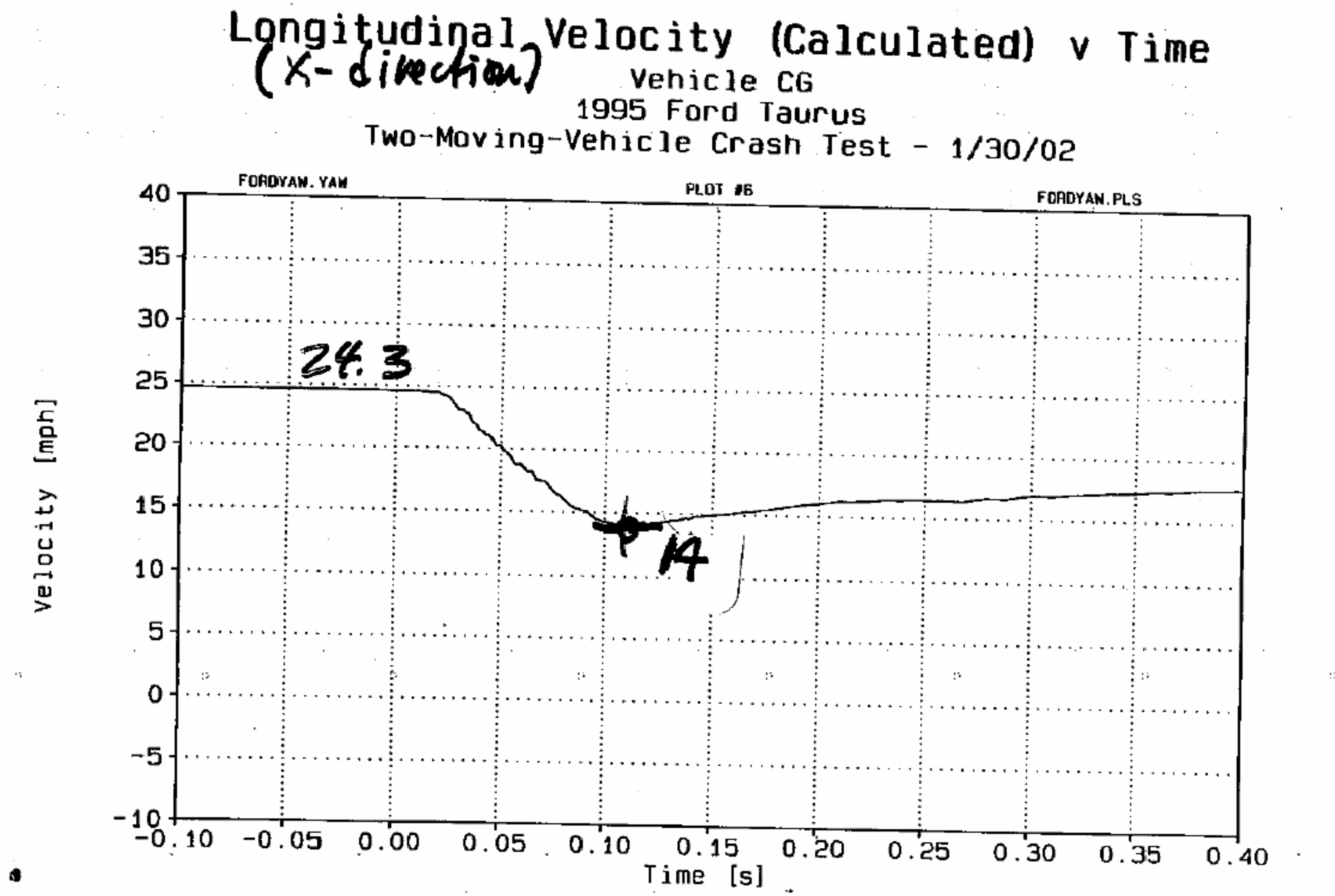
$$\text{delta-V(y)} = 16.96 - (4 \times 100.21/57.3)/(1.466) = 12.1 \text{ mph.}$$

The right rear interior door/window panel delta-V(y) would be 21.82 mph. The delta-V calculations clearly show that vehicle crashes with rotation reconstructed with the standard momentum method does not provide accurate results. This observation can be of critical importance when the "reconstructed" delta-V values are near injury producing thresh-hold levels.

	"Crash Test on Paper" MARC 1 – X8, RUN 3	Actual Crash Test
1. Impact Velocity		
Tahoe:	30.20 mph	30.20 mph
Taurus:	24.30 mph	24.30 mph
2. After-Impact Velocities:		
Tahoe x/y:	5.32/19.88 mph	6/17 mph
Taurus x/y:	15.56/16.96 mph	16/17 mph
3. Angular Velocities:		
Tahoe:	151.72 deg/sec	150 deg/sec
Taurus:	100.21 deg/sec	120 deg/sec
4. Delta-V:		
Tahoe:	11.61 mph	12 mph, left rocker pan. 17 mph, right rocker pa.
Taurus:	19.08 mph	18.6 mph, left rock. pa. 22.6 mph, right rock. pa.
5. After-Impact Distance:		
Tahoe:	35.27 ft	34 ft at acc. scene
Taurus:	76.72 ft	79 ft at acc. scene
6. Departure Angles:		
Tahoe:	104.98 deg	117 deg at acc. scene
Taurus:	132.53 deg	117 deg at acc. scene

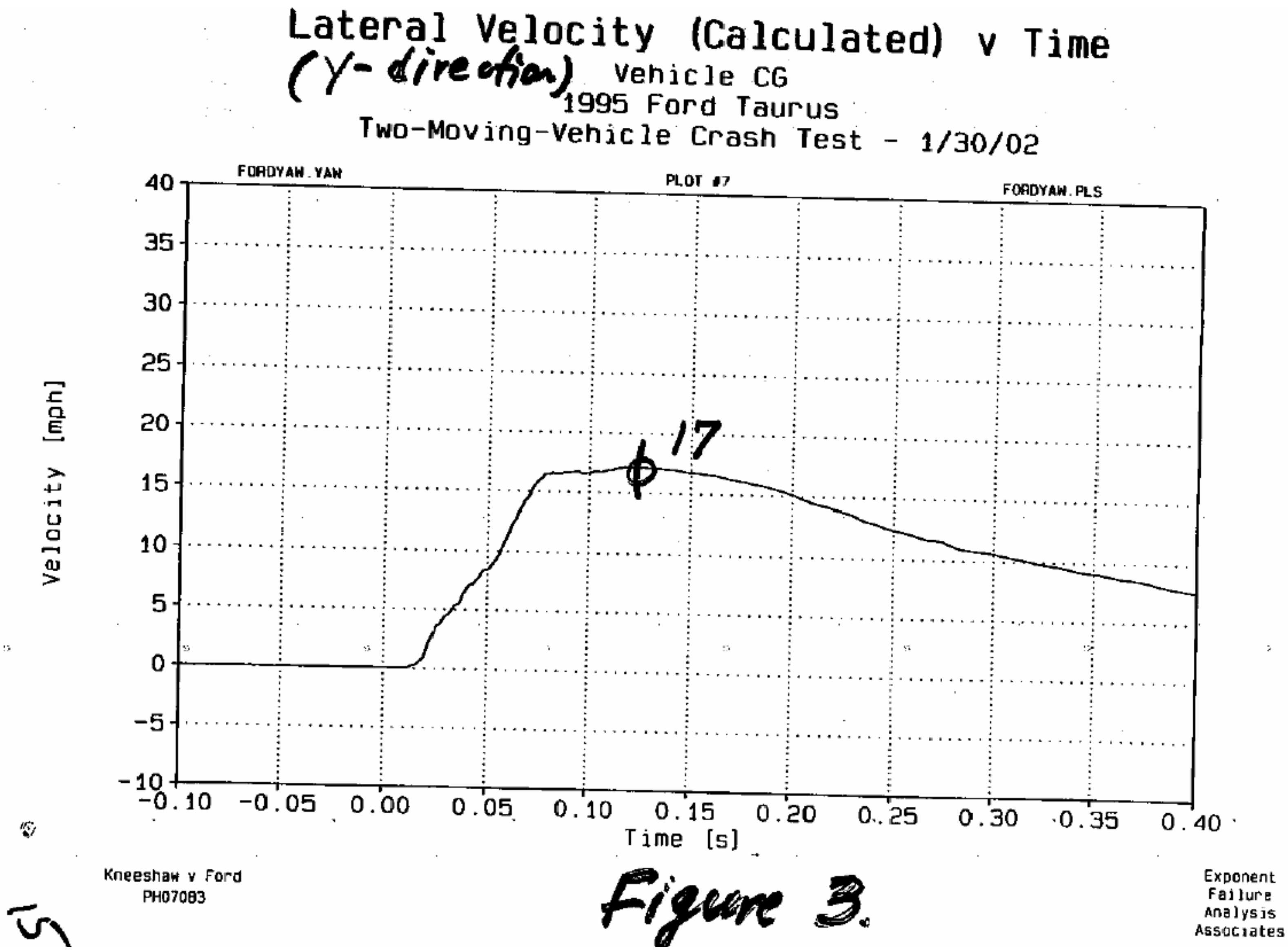
The energy balance output indicates a 0.54% error, indicating that the crush energy values are insignificantly too small. Changing, for example, the stiffness coefficient A = 95 to 98, yields an energy balance of 0.08%.

The departure angles are significantly different. During the accident while the vehicles were rotating a secondary collision occurred between the vehicles making the departure angles determined by vehicle rest positions as well as angles rotated after impact questionable.



Longitudinal Velocity (Calculated) v Time
(X-direction)
Vehicle CG
1995 Ford Taurus
Two-Moving-Vehicle Crash Test - 1/30/02
FORDYAN.YAW
PLOT #6
FORDYAN.PLS
Velocity [mph]
Time [s]
24.3
14
Kneeshaw v Ford
PH07083
Exponent
Failure
Analysis
Associates

Figure 2.



Lateral Velocity (Calculated) v Time
(Y-direction) Vehicle CG
1995 Ford Taurus
Two-Moving-Vehicle Crash Test - 1/30/02
FORDYAW.YAW
PLOT #7
FORDYAW.PLS
Velocity [mph]
40
35
30
25
20
15
10
5
0
-5
-10
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Time [s]
17
Kneeshaw v Ford
PH07083
Exponent
Failure
Analysis
Associates
5

Figure 3.

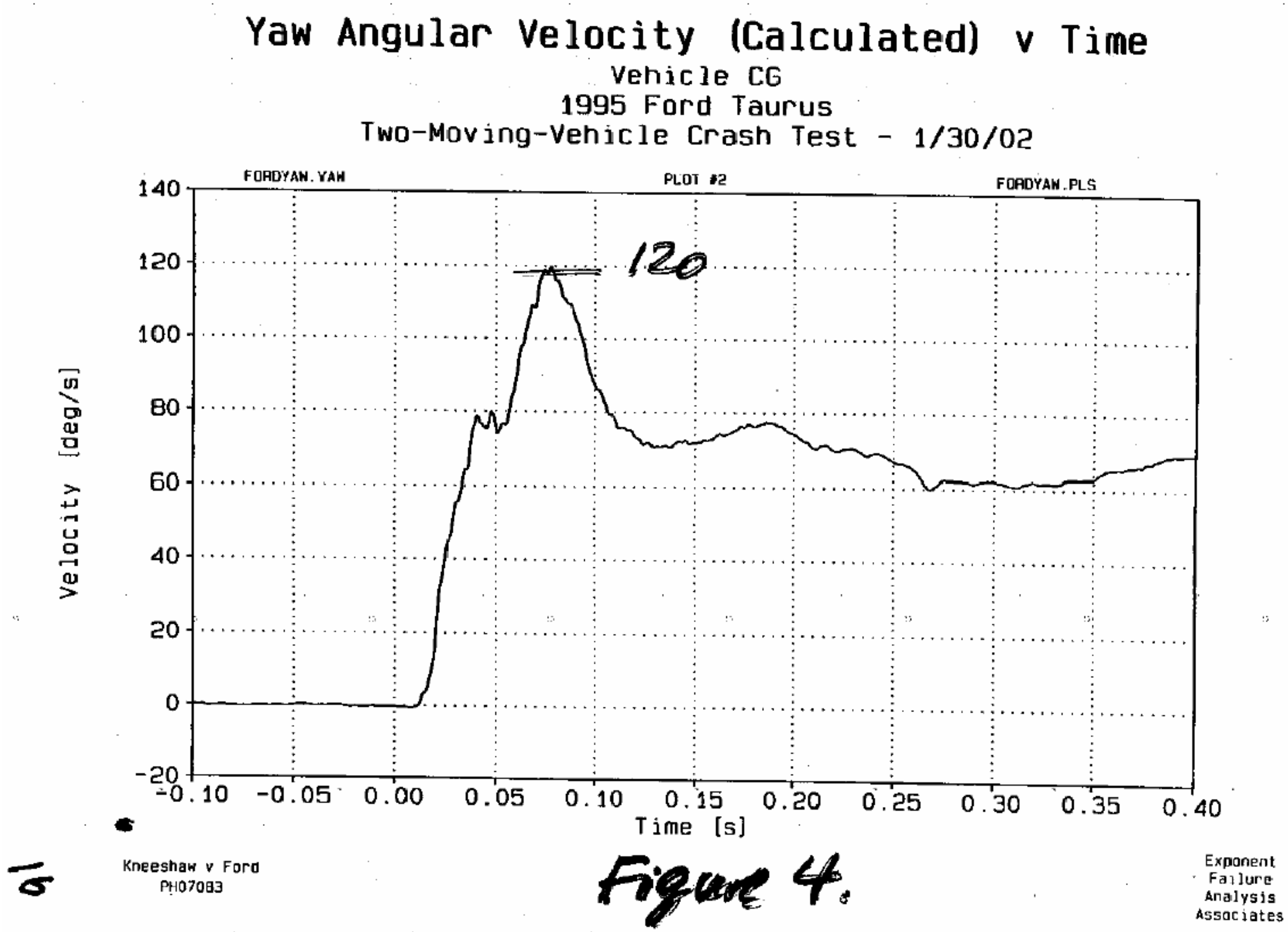
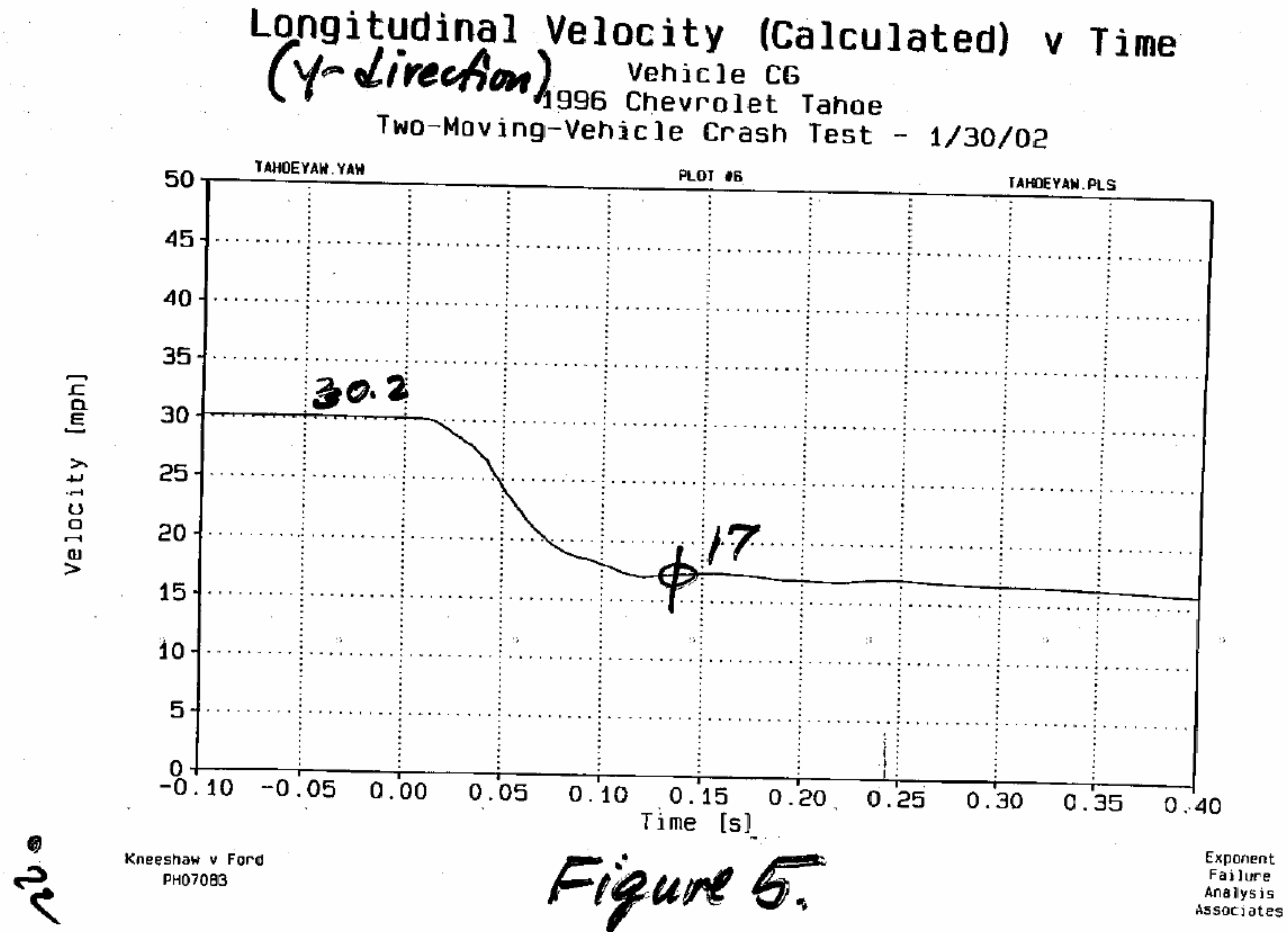

Yaw Angular Velocity (Calculated) v Time
Vehicle CG
1995 Ford Taurus
Two-Moving-Vehicle Crash Test - 1/30/02
FORDYAN.YAW
PLOT #2
FORDYAN.PLS
120
Velocity [deg/s]
140
120
100
80
60
40
20
0
-20
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Time [s]
Kneeshaw v Ford
PH07083
Exponent
Failure
Analysis
Associates

Figure 4.



Longitudinal Velocity (Calculated) v Time
(Y-direction)
Vehicle CG
1996 Chevrolet Tahoe
Two-Moving-Vehicle Crash Test - 1/30/02
TAHOEYAW.YAW
PLOT #6
TAHOEYAW.PLS
Velocity [mph]
Time [s]
30.2
17
Kneeshaw v Ford
PH07083
Exponent
Failure
Analysis
Associates

Figure 5.

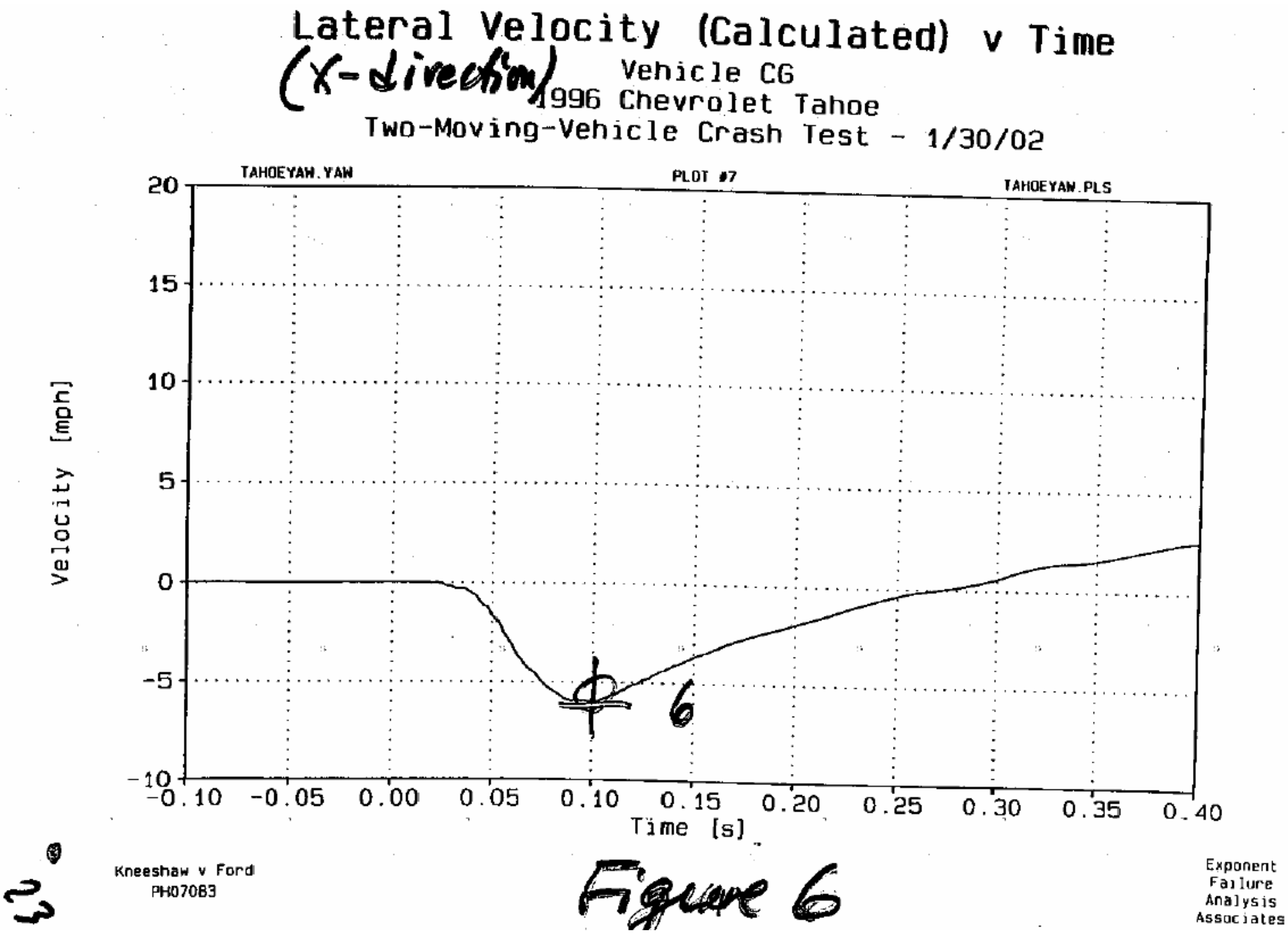

Lateral Velocity (Calculated) v Time
(X-direction)
Vehicle CG
1996 Chevrolet Tahoe
Two-Moving-Vehicle Crash Test - 1/30/02
TAHOEYAW.YAW
PLOT #7
TAHOEYAW.PLS
Velocity [mph]
20
15
10
5
0
-5
-10
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Time [s]
6
Kneeshaw v Ford
PH07083
Exponent
Failure
Analysis
Associates

Figure 6

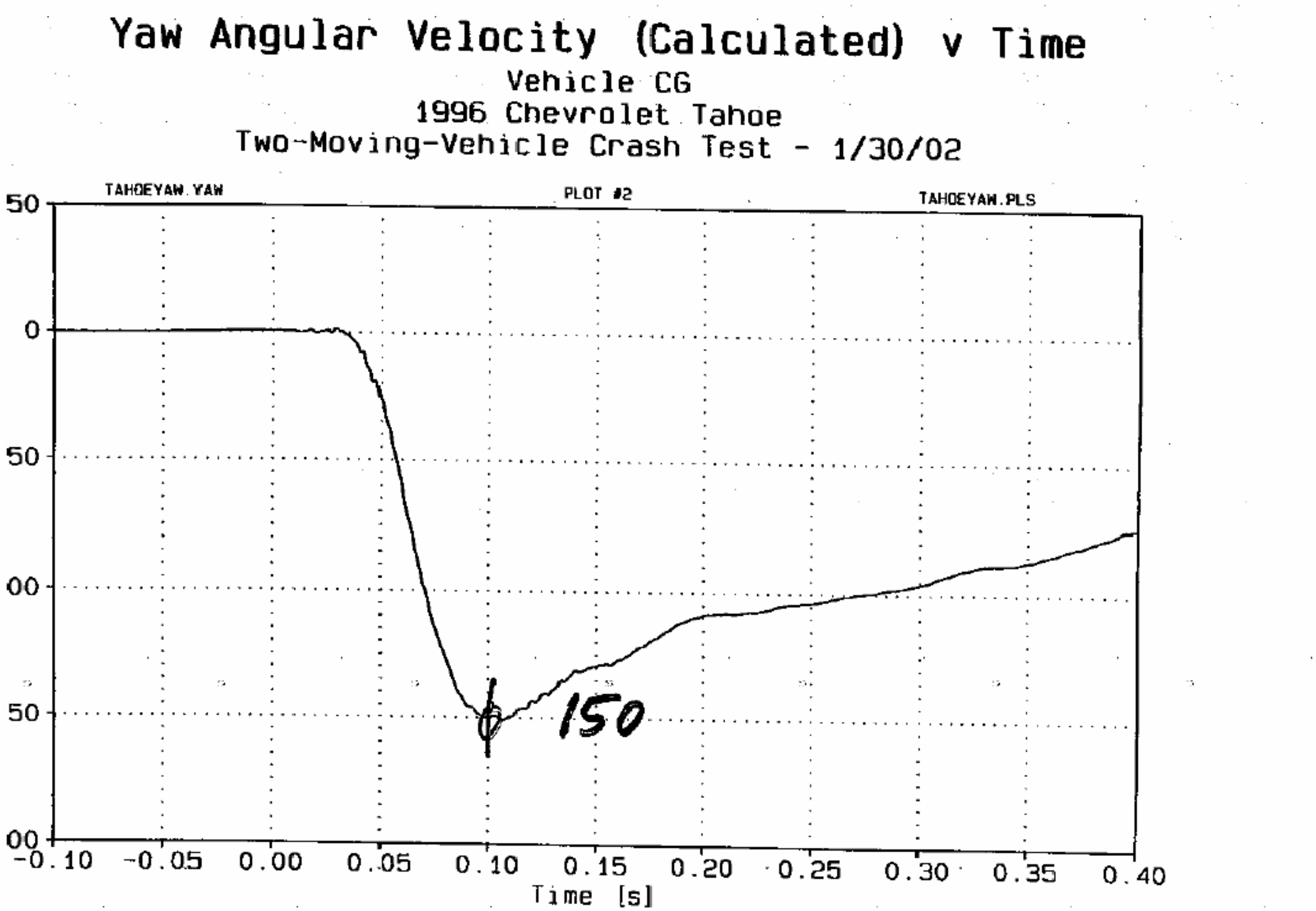

Yaw Angular Velocity (Calculated) v Time
Vehicle CG
1996 Chevrolet Tahoe
Two-Moving-Vehicle Crash Test - 1/30/02
TAHOEYAW.YAW
PLOT #2
TAHOEYAW.PLS
150
Time [s]
eshaw v Ford
PH07083
Exponent
Failure
Analysis
Associates

Figure 7.