TEST YOUR SKILL

MARC1 SOLUTIONS

Accident Reconstruction Journal

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1.0 Introduction

We thought it might be helpful for the MARC1 user and ARJ readers to see Victor Craig's problems solved with the MARC1 software modules. Vic provides excellent detailed long-hand mathematical solutions to each problem. Using MARC 1 is not intended to suggest to readers that long-hand solution practice is not necessary. The ability to carry out manual calculations establishes the expertise required of experts throughout their career. Using MARC1 software is intended to be a companion tool, to allow quick and efficient parameter evaluations, as well as to provide many more insights easily available with MARC1.

Let us say from the outset, the solutions in ARJ 22/6 are correct. At times we will comment to help readers visualize additional important elements of the reconstruction involved.

2.0. MARC1 Solutions

2.1. Problem #1

It is a straight-forward motion/deceleration problem. Since MARC1 – A1 also computes the kinetic energy of the truck, we assumed a weight of 48,000 lb for the dump truck. The drag factor of 0.51g is that of a good air brake system on a dry road.

The MARC1 – A1 data printout below shows the velocity of the truck as a function for each tenth of a second (0.1 sec). The stopping time is 5.98 sec. Inspection of the printout reveals, for example, that after four seconds of braking the truck has traveled 261.51 ft with a travel speed of 22.19 mph at that moment. The kinetic energy of the truck at the beginning of braking is 7,190,728.91 lbft.

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'A-1' RUN FOR ARJ 22/6 - Prob. 1 ********
MOTION ANALYSIS FOR VEHICLE COMING TO A COMPLETE STOP

Information For Vehicle 1		0
Vehicle Weight, LBS:	===>	48000.00
After-Impact Speed, MPH:	===>	67.00
After-Impact Deceleration, g-UNITS:	===>	0.51
Distance Traveled After Impact, FT:	===>	293.74
Post-Crash Time, SEC:	===>	5.98

Data Printout For Intervals Using After Impact Speed

TIME AFTER IMPACT		DISTANCE TRAVELED		SPEED	
00.0	SEC	0.00	FT	67.00	MPH
00.1	SEC	9.74	FT	65.88	MPH
00.2	SEC	19.32	FT	64.76	MPH
00.3	SEC	28.73	FT	63.64	MPH
00.4	SEC	37.98	FT	62.52	MPH
00.5	SEC	47.06	FT	61.40	MPH
00.6	SEC	55.98	FT	60.28	MPH
00.7	SEC	64.73	FT	59.16	MPH
00.8	SEC	73.32	FT	58.04	MPH
00.9	SEC	81.75	FT	56.92	MPH
01.0	SEC	90.01	FT	55.80	MPH
01.1	SEC	98.11	FT	54.68	MPH
01.2	SEC	106.04	FT	53.56	MPH
01.3	SEC	113.81	FT	52.44	MPH
01.4	SEC	121.42	FT	51.32	MPH
01.5	SEC	128.86	FT	50.20	MPH
01.6	SEC	136.14	FT	49.08	MPH
01.7	SEC	143.25	FT	47.96	MPH
01.8	SEC	150.20	FT	46.84	MPH
01.9	SEC	156.98	FT	45.72	MPH
02.0	SEC	163.60	FT	44.60	MPH
02.1	SEC	170.06	FT	43.48	MPH
02.2	SEC	176.35	FT	42.36	MPH
02.3	SEC	182.47	FT	41.24	MPH
02.4	SEC	188.44	FT	40.12	MPH
02.5	SEC	194.24	FT	39.00	MPH
02.6	SEC	199.87	FT	37.88	MPH
02.7	SEC	205.34	FT	36.75	MPH
02.8	SEC	210.65	FT	35.63	MPH
02.9	SEC	215.79	FT	34.51	MPH
03.0	SEC	220.77	FT	33.39	MPH
03.1	SEC	225.58	FT	32.27	MPH
03.2	SEC	230.23	FT	31.15	MPH
03.3	SEC	234.71	FT	30.03	MPH
03.4	SEC	239.04	FT	28.91	MPH
03.5	SEC	243.19	FT	27.79	MPH
03.6	SEC	247.18	FT	26.67	MPH
03.7	SEC	251.01	FT	25.55	MPH
03.8	SEC	254.68	FT	24.43	MPH
03.9	SEC	258.18	FT	23.31	MPH
04.0	SEC	261.51	FT	22.19	MPH
04.1	SEC	264.68	FT	21.07	MPH
04.2	SEC	267.69	FT	19.95	MPH
04.3	SEC	270.53	FT	18.83	MPH
04.4	SEC	273.21	FT	17.71	MPH
04.5	SEC	275.73	FT	16.59	MPH
04.6	SEC	278.08	FT	15.47	MPH
04.7	SEC	280.26	FT	14.35	MPH
04.8	SEC	282.28	FT	13.23	MPH
04.9	SEC	284.14	FT	12.11	MPH
05.0	SEC	285.84	FT	10.99	MPH
05.1	SEC	287.36	FT	9.87	MPH
05.2	SEC	288.73	FT	8.75	MPH
05.3	SEC	289.93	FT	7.63	MPH
05.4	SEC	290.97	FT	6.51	MPH
05.5	SEC	291.84	FT	5.39	MPH
05.6	SEC	292.55	FT	4.27	MPH
05.7	SEC	293.09	FT	3.15	MPH
05.8	SEC	293.47	FT	2.03	MPH
05.9	SEC	293.68	FT	0.91	MPH
06.0	SEC	293.74	FT	0.00	MPH

Energy from Deceleration, FT-LBS: ===> 7190728.91

ARC1 – A1 : ARJ 22/6 – Prob. 1.

2.2. Problem #2

The problem is a relative motion problem since two vehicles approach each other in the same traffic lane. When the vehicles are 850 feet apart, the common clock begins to tick.

The MARC1 – B2 printout is shown below. The output table shows the distances traveled and velocities in one-tenth of a second time intervals. Impact occurs after a time of 4.33 seconds has elapsed. Further review of the table shows, after three seconds V1 has traveled 277 ft, V2 312 ft. the distance between them is 260.67 ft.

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'B-1' RUN FOR ARJ 22/6 - Prob. 2 ********
BOTH VEHICLES AT CONSTANT SPEEDS

Information For Vehicles		1982 DODGE Pickup Truck	2000 FORD Pickup Truck
Vehicle Weight, LBS:	===>	4800.00	5790.00
Pre-Impact Travel Speed, MPH:	===>	63.00	71.00

Total Time Until Impact, SEC:	===>	4.33
Travel Distance Between Vehicles, FT:	===>	850.00

Elapsed Time		Distance Traveled V1		Distance Traveled V2		Distance Between Vehicles	
0.00	SEC	0.00	FT	0.00	FT	850.00	FT
0.10	SEC	9.24	FT	10.41	FT	830.36	FT
0.20	SEC	18.47	FT	20.82	FT	810.71	FT
0.30	SEC	27.71	FT	31.23	FT	791.07	FT
0.40	SEC	36.94	FT	41.63	FT	771.42	FT
0.50	SEC	46.18	FT	52.04	FT	751.78	FT
0.60	SEC	55.41	FT	62.45	FT	732.13	FT
0.70	SEC	64.65	FT	72.86	FT	712.49	FT
0.80	SEC	73.89	FT	83.27	FT	692.84	FT
0.90	SEC	83.12	FT	93.68	FT	673.20	FT
1.00	SEC	92.36	FT	104.09	FT	653.56	FT
1.10	SEC	101.59	FT	114.49	FT	633.91	FT
1.20	SEC	110.83	FT	124.90	FT	614.27	FT
1.30	SEC	120.07	FT	135.31	FT	594.62	FT
1.40	SEC	129.30	FT	145.72	FT	574.98	FT
1.50	SEC	138.54	FT	156.13	FT	555.33	FT
1.60	SEC	147.77	FT	166.54	FT	535.69	FT
1.70	SEC	157.01	FT	176.95	FT	516.05	FT
1.80	SEC	166.24	FT	187.35	FT	496.40	FT
1.90	SEC	175.48	FT	197.76	FT	476.76	FT
2.00	SEC	184.72	FT	208.17	FT	457.11	FT
2.10	SEC	193.95	FT	218.58	FT	437.47	FT
2.20	SEC	203.19	FT	228.99	FT	417.82	FT
2.30	SEC	212.42	FT	239.40	FT	398.18	FT
2.40	SEC	221.66	FT	249.81	FT	378.53	FT
2.50	SEC	230.90	FT	260.22	FT	358.89	FT
2.60	SEC	240.13	FT	270.62	FT	339.25	FT
2.70	SEC	249.37	FT	281.03	FT	319.60	FT
2.80	SEC	258.60	FT	291.44	FT	299.96	FT
2.90	SEC	267.84	FT	301.85	FT	280.31	FT
3.00	SEC	277.07	FT	312.26	FT	260.67	FT
3.10	SEC	286.31	FT	322.67	FT	241.02	FT
3.20	SEC	295.55	FT	333.08	FT	221.38	FT
3.30	SEC	304.78	FT	343.48	FT	201.73	FT
3.40	SEC	314.02	FT	353.89	FT	182.09	FT
3.50	SEC	323.25	FT	364.30	FT	162.45	FT
3.60	SEC	332.49	FT	374.71	FT	142.80	FT
3.70	SEC	341.72	FT	385.12	FT	123.16	FT
3.80	SEC	350.96	FT	395.53	FT	103.51	FT
3.90	SEC	360.20	FT	405.94	FT	83.87	FT
4.00	SEC	369.43	FT	416.34	FT	64.22	FT
4.10	SEC	378.67	FT	426.75	FT	44.58	FT
4.20	SEC	387.90	FT	437.16	FT	24.94	FT
4.30	SEC	397.14	FT	447.57	FT	5.29	FT
4.33	SEC	399.63	FT	450.37	FT	0.00	FT

Kinetic Energy of Vehicle 1, FT-LBS:	===>	635776.41
Kinetic Energy of Vehicle 2, FT-LBS:	===>	974041.22

MARC1 – B2: ARJ 22/6; Prob. 2

2.3. Problem #3

This is a straight-forward motion/acceleration problem. Inspection of the MARC1 – J2 output below shows that the bus accelerated to a speed of 12.19 mph. We could also have used MARC1 – E1 which calculates speed from distance and deceleration.

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'J-2' RUN FOR ARJ 22/6 - Prob. 3 ********
COMBINED SPEEDS FROM DIFFERENT SURFACES

Information For Computing Vehicle Final Speed

Vehicle Initial Speed, MPH:	===>	0.00
Number of Different Accel/Decel Surfaces	===>	1.00
Accel/Decel Distance for Surface 1, FT:	===>	33.00
Accel(+)/Decel(-) for Surface 1, g-UNITS:	===>	0.15
Secondary Energy [Out -]/[In +], FT-LBS:	===>	0.00
Vehicle Weight, LBS:	===>	0.00
Final or Combined Speed from 1 Surface(s), MPH:	===>	12.19

MARC1 – J2: ARJ 22/6; Prob. 3

2.4. Problem #4

This is a straight-forward motion problem with a motorcycle traveling over different lengths of surfaces with different drag factors. The MARC1 – J2 data printout is shown below. Now let us assume that the motorcycle after sliding the last segment of 107 ft did not come to rest and impacted a stationary pickup truck pushing it a certain distance indicating a secondary energy of 24000 lbft. Also assuming a motorcycle weight of 470 lb, calculation now yields a travel speed of 69 mph (instead of 56 mph) (see example two below).

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'J-2' RUN FOR ARJ 22/6 - Prob. 4 ********
COMBINED SPEEDS FROM DIFFERENT SURFACES

Information For Computing Vehicle Final Speed

Vehicle Initial Speed, MPH:	===>	0.00
Number of Different Accel/Decel Surfaces	===>	3.00
Accel/Decel Distance for Surface 1, FT:	===>	80.00
Accel(+)/Decel(-) for Surface 1, g-UNITS:	===>	0.35
Accel/Decel Distance for Surface 2, FT:	===>	21.00
Accel(+)/Decel(-)for Surface 2, g-UNITS:	===>	0.88
Accel/Decel Distance for Surface 3, FT:	===>	107.00
Accel(+)/Decel(-)for Surface 3, g-UNITS:	===>	0.54
Secondary Energy [Out -]/[In +], FT-LBS:	===>	0.00
Vehicle Weight, LBS:	===>	0.00
Final or Combined Speed from 3 Surface(s), MPH:	===>	55.93

Example two with secondary impact energy:

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'J-2' RUN FOR ARJ 22/6 - Prob. 4 ********
COMBINED SPEEDS FROM DIFFERENT SURFACES

Information For Computing Vehicle Final Speed

Vehicle Initial Speed, MPH:	===>	0.00
Number of Different Accel/Decel Surfaces	===>	3.00
Accel/Decel Distance for Surface 1, FT:	===>	80.00
Accel(+)/Decel(-) for Surface 1, g-UNITS:	===>	0.35
Accel/Decel Distance for Surface 2, FT:	===>	21.00
Accel(+)/Decel(-)for Surface 2, g-UNITS:	===>	0.88
Accel/Decel Distance for Surface 3, FT:	===>	107.00
Accel(+)/Decel(-)for Surface 3, g-UNITS:	===>	0.54
Secondary Energy [Out -]/[In +], FT-LBS:	===>	26000.00
Vehicle Weight, LBS:	===>	470.00
Final or Combined Speed from 3 Surface(s), MPH:	===>	69.16

MARC1 – J2: ARJ 22/6; Prob. 4

2.5. Problem #5

This is a straight-forward motion problem involving vault speed analysis. The MARC1 – L1 printout is shown below. The speed required to depart under an angle of 4 degrees (7%) upward and land 70 ft horizontally from takeoff-point is 86.54 mph. For a Camaro weight of 3680 lb the crush energy at 86.54 mph is 919,767 lbft. A detailed vault analysis including pitching motion can be done with MARC1 –L2.

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'L1' RUN FOR ARJ 22/6 - Prob. 5 ********
VAULT/FALL MOTION

Information For Vehicle

Horizontal Flight Distance, FT:	===>	70.00
Vertical Distance Change, FT:	===>	0.00
Take-Off Angle, DEG:	===>	4.00
Take-Off Angle, PERCENT:	===>	7.00
Vehicle Weight, LBS:	===>	3680.00
Vehicle Speed for Vaulting, MPH:	===>	86.54
Airborne Time, SEC:	===>	0.00
Vertical Velocity at Impact, FT/SEC:	===>	0.00
MPH:	===>	0.00
Resultant Velocity at Impact, FT/SEC:	===>	126.87
MPH:	===>	86.54
Impact Angle, DEG::	===>	0.00
Impact Energy, FT-LBS:	===>	919767.44

MARC1 – L1: ARJ 22/6; Prob. 5

2.6. Problem #6

This is an engine-transmission-final drive-tire radius problem. As it is usually done, we assume that the driven tires are not slipping. The two MARC1 – M3 data printouts are shown for an engine speed of 800 and 2100 RPM. If the driven tires were slipping, the engine speed is not fully transmitted to the driven tires. With 100% slip to vehicle does not move at all.

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'M-3' RUN FOR ARJ 22/6 - Prob. 6 ********
VEHICLE SPEED FROM ENGINE RPM

Information For Vehicle		0
Engine Speed, RPM:	===>	800.00
Transmission Ratio, D'LESS:	===>	2.27
Final Gear Ratio, D'LESS:	===>	5.60
Effective Tire Radius, IN:	===>	22.00
Tire Slip (0 to 1.0), D'LESS:	===>	0.00
Maximum Vehicle Speed, MPH:	===>	8.24

MARC1 – M3: ARJ 22/6; Prob. 6 – 800 RPM

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'M-3' RUN FOR ARJ 22/6 - Prob. 6 ********
VEHICLE SPEED FROM ENGINE RPM

Information For Vehicle		0
Engine Speed, RPM:	===>	2100.00
Transmission Ratio, D'LESS:	===>	2.27
Final Gear Ratio, D'LESS:	===>	5.60
Effective Tire Radius, IN:	===>	22.00
Tire Slip (0 to 1.0), D'LESS:	===>	0.00
Maximum Vehicle Speed, MPH:	===>	21.63

MARC1 – M3: ARJ 22/6; Prob. 6 – 2100 RPM

2.7. Problem #7

This is a speed-from yaw marks motion problem. The reader is reminded that the yaw marks must have been caused by a steering input by the driver, and not, for example by rear tire tread separation, by bumping by another vehicle, or by premature rear brake lockup.

We first compute the tire mark radius from MARC1 – M3. The data output is shown below indicating a right front tire mark radius of 292.68 ft.

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'U-1' RUN FOR ARJ 22/6 - Prob. 7a ********
CURVE RADIUS/SPEED FROM YAW MARKS

Data Printout For Curve Radius Determination

Curve Chord Length, FT:	===>	60.00
Road Middle Coordinate, FT:	===>	1.54
Curve Radius, FT:	===>	292.68

MARC1 – U1: ARJ 22/6; Prob. 7a

Since the speed from yaw marks applies to the center-of-gravity, we have adjusted the cg-radius by 3 ft to 289.68 ft. MARC1 – U3 data output below shows a speed of 60.88 ft.

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'U-3' RUN FOR ARJ 22/6 - Prob. 7b ********
CURVE RADIUS/SPEED FROM YAW MARKS

Data Printout For Speed in a Curve

Level Side Friction Coefficient, D'LESS:	===>	0.82
Lateral Road Slope, DEG:	===>	1.15
Curve/Yaw Radius of C of G of Vehicle, FT:	===>	289.68
Speed from Curve/Yaw Measurements, MPH:	===>	60.88

The radius of the right front tire is 292.68 ft. The curve radius of the car's center-of-gravity is 292.68 - 3 = 289.68 ft. Using 292.68 ft yields 61.2 mph.

MARC1 – U3: ARJ 22/6; Prob. 7b

2.8. Problem #8

This is a straight-forward intersection collision problem. MARC1-X5 uses the polar coordinate system where east is 0 degrees, north 90 degrees, west 180 degrees, and south is 270 degrees, and 360 degrees is the same as 0 degrees, namely east (sin0 = sin360 = 0; cos 0 = cos 360 = 1).

The MARC1 – X5 data output is shown below. It computes the same speeds as ARJ, as well as many other very useful data such as delta-Vs at the center-of-gravity of the vehicles, the impulse at the crash point (common velocity), direction of principal force (same as impulse direction or delta-V direction) and crush energy. Since linear momentum does not calculate rotational after-impact dynamics, the crush energy value of 86,569 ftlb assumes rotational energies after impact as zero. However, if the accident scene investigation indicates some vehicle spinning after impact, the actual crush energy shown may be lower by the amount of rotational energies after impact. Standard linear momentum does not know anything about rotational dynamics!

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
******** PROGRAM 'X-5' RUN FOR ARJ22/6 - Prob. 8 ********
OBLIQUE COLLISION/LINEAR MOMENTUM

Information For Vehicles		1982 DODGE Pickup Truck	1985 CHEVROLET unk
Vehicle Weight, LBS:	===>	4050	3930
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:	===>	20.00	26.00
After-Impact Deceleration, g-UNITS:	===>	0.52	0.43
Amount to Vary Departure Angle, DEG:	===>	0.00	0.00
Energy from Secondary Impacts, FT·LBS.	===>		

MARC 1 uses the polar coordinate system for velocity directions. EAST is 0 deg, NORTH is 90 deg, WEST is 180 deg, SOUTH is 270 deg, and 360 deg is the same as 0 deg. The crush energy calculated assumes there is no rotation after impact. Linear momentum does not address rotional impact dynamics.

PRINT OUT 1 OF 1 ARJ22/6 - Prob. 8

Approach Angle, DEG:	===>	0.00	270.00
Departure Angle, DEG:	===>	305.00	297.00
Pre-Impact Speed, MPH:	===>	18.20	31.24
Speed at Impact, MPH:	===>	18.20	31.24
After-Impact Speed, MPH:	===>	17.66	18.31
Delta V in X-Direction, MPH:	===>	-8.07	8.32
Delta V in Y-Direction, MPH:	===>	-14.47	14.92
Delta V Resultant, MPH:	===>	16.57	17.08
Angle of Delta V, DEG:	===>	240.85	60.85
V1/V2 Impulse, LBS*SEC:	===>	3055.75	
Total Crush Energy FT*LBS:	===>	86569.20	

Using the sketch shown in the TEST YOUR SKILL section for problem 8 as a guide to locate vehicles at impact, and running a crash-test-on-paper with MARC1 –X8 (which includes linear and rotational momentum) yields a total rotational after-impact energy of both V1 and V2of approximately 15,773 lbft. V1 will rotate 109 degrees, V2 only 32 degrees after impact.

The crush energies in terms of A and B-stiffness values and crush depths are all estimated assumed values. However, they seemed to be in harmony with the “reconstruction” since the energy balance error is only 0.34% as an inspection of the last calculated date output shows.

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MOTOR VEHICLE ACCIDENT RECONSTRUCTION AND CAUSE ANALYSIS
*** PROGRAM 'X-8' RUN FOR ARJ 22/6 -Crash Test On Paper - Prob. 8 ***
PREDICTION OF COLLISION RESULTS
WITH CRUSH ENERGY CALCULATIONS

		0	0
Information For Vehicles			
Vehicle Weight, LBS:	===>	4050	3930
Vehicle Wheelbase, FT:	===>	10.00	10.00
Vehicle Length, FT:	===>	16.00	16.00
Mass Moment of Inertia, FT·LBS·SEC²:	===>	2592	2515
Approach Angle, DEG:	===>	0.00	270.00
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:	===>	0.52	0.43
After-Impact Coefficient of Rotational Friction, D'LESS:	===>	0.35	0.20
Distance from Center of Gravity to Contact Point:			
Along the X-Axis, FT:	===>	-3.00	0.00
Along the Y-Axis, FT:	===>	3.00	-6.00
Estimated Low Impact Speed, MPH:	===>	18.20	31.24
Estimated High Impact Speed, MPH:	===>	18.20	31.24
(A]Max. Force Not Causing Damage, LBS/IN:	===>	200.00	200.00
(B]Stiffness/Inch of Width, PSI:	===>	50.00	50.00
Force Angle Offset from Perpendicular, DEG:	===>	0.00	0.00
Width of Crush Region, IN:	===>	43.00	43.00
Number of Crush Measurements:	===>	2	2
Crush Measurement #1, IN:	===>	14.00	14.00
Crush Measurement #2, IN:	===>	14.00	14.00

PREDICTION OF COLLISION RESULTS

```
                                                  0         0
Page 2
Information For Vehicles
============================================================

Specified Impact Speed, MPH:           ===>   18.00     31.00

After-Impact Velocities
      In X-Direction, MPH:             ===>   15.18      3.11
      In Y-Direction, MPH:             ===>  -12.13    -18.74

After-Impact Direction, DEG:           ===>  321.39    279.45

After-Impact Direction of Rotation
                    V1: ===>  Counterclockwise
                    v2: ==================>  Counterclockwise
Angular Velocity After Impact, DEG/SEC: =>  185.26     76.22

Rotation After Impact, DEG:            ===>  109.54     32.45

Distance Traveled After Impact, FT:    ===>   24.17     27.96

Pre-Impact Speed, MPH:                 ===>   18.20     31.20

After-Impact Speed, MPH:               ===>   19.42     18.99
------------------------------------------------------------
V1/V2 Impulse, LBS·SEC:         ===> 2304.47

Direction of Impulse, DEG:             ===>  256.00     76.00

Delta-V Component X-Direction, MPH:    ===>   -3.02      3.13

Delta-V Component Y-Direction, MPH:    ===>  -12.13     12.50

Resultant Delta-V, MPH:                ===>   12.50     12.88

Direction of Delta-V, DEG:             ===>  256.00     75.96
------------------------------------------------------------

Crush Energy of Vehicle, FT·LBS:  ===>    29025.00  29025.00

Energy Equivalent Speed, MPH:     ===>       14.65     14.88
------------------------------------------------------------

Energy of Vehicles                            Before     After
------------------------------------------------------------
Linear Motion Energy, FT·LBS:  ===>   172765.34    98362.13

Rotational Motion Energy, FT·LBS:=>        0.00    15773.29

Energy Totals, FT·LBS:         ===>   172765.34   172185.42
------------------------------------------------------------
Crush Energy, FT·LBS:                 =====>     58050.00

Error in Energy Balance:              =====>         0.34%
============================================================
```

"Crash Test on Paper" MARC1 – X8: ARJ 22/6; Prob. 8