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Differences Between EDCRASH and CRASH3

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ABSTRACT

Motor vehicle accident researchers have used the CRASH computer program for some time. Over the years, the code was upgraded until it reached its present and popular form, CRASH3, which runs on a mainframe computer or mini-computer with a sizeable memory capacity. A new version of the program, EDCRASH, has been developed which runs on personal computers using 128K of memory. This paper describes and compares this program with its mainframe counterpart. The program performed the same function as CRASH3, but was designed as a screen-oriented program utilizing the environment of the personal computer. Its design also allowed for file saving, graphics, routing of output, and interfacing with other accident reconstruction programs. For most accident types, the results for both programs were identical. However, for some types the results were different.

THE CRASH (CALSPAN RECONSTRUCTION of Accident Speeds on the Highway) computer program has been used as an effective tool for motor vehicle accident investigation for many years. Since its development in the early seventies [1-6]*, it has undergone many revisions and refinements. These changes have included debugging the code itself and modifications to improve its accuracy. It is doubtful that any computer program for use by accident investigators has received so much attention, undergone so thorough an evaluation, and provided so much useful data for those people who are concerned about highway accidents and their effect on our society.

*Numbers in brackets designate references at the end of the paper.

HISTORY AND PURPOSE OF CRASH

Since 1979, the National Highway Traffic Safety Administration (NHTSA) has implemented the CRASH program in a recent version, called CRASH3, for use by the National Accident Sampling System (NASS). Using a nationwide network of accident investigators, NASS has been developing a statistical database for the purpose of finding out what kind of accidents are the greatest threat to our society [7]. Automotive researchers have been able to use CRASH to provide collision dynamics for typical impact configurations in order to assess the effects upon occupant dynamics. This, in turn, aids vehicle designers who can use the results to build safer cars. Accident investigators use the program to help determine accident causation. Recently, the CRASH program has been used in the field of civil and criminal litigation, where it is an effective tool which can provide answers to technical accident-related questions.

PURPOSE OF THIS PAPER

This paper describes a recent version of the CRASH program called EDCRASH (Engineering Dynamics Corporation Reconstruction of Accident Speeds on the Highway). Its purpose is to compare EDCRASH with CRASH3, the version upon which it was based. First, similarties between the programs will be established. Then, because the major intent of this paper is to identify the differences between EDCRASH and CRASH3, those differences will be studied in the form of examples which illustrate the differences and their effect upon the results. Accident investigators familiar with CRASH3 can use this information to become familiar with EDCRASH. Others will become familiar with the general scope of either program.

OVERVIEW

The CRASH program provides a reconstruction of single- and two-vehicle accidents. The user supplies information gained from accident site and vehicle inspections. The program uses this information to determine the conditions at impact. The speed of the vehicle(s) at impact is produced only if scene data (impact/rest positions and path data) is supplied. Otherwise, the results are limited to speed change (a measure of impact severity). The program also produces intermediate results, such as separation velocities, energy absorbed by damage, and parameters associated with a trajectory simulation.

The results provide a consistent and well-validated methodology for the reconstruction of motor vehicle accidents. In addition, the program is a useful means of performing repeated analyses to test different accident scenerios (this is refered to as a "what if" analysis).

PROCEDURE

In order to provide a direct comparison between the programs, a version of CRASH3 dated December, 1981, was purchased from Mcauto (McDonnell Douglas Automation Co.) and compiled and executed on Boeing Computer Services' CDC-Cyber mainframe computer. EDCRASH, Version 2.0, dated July, 1984, provided the results on an IBM Personal Computer. Accessories included a 320K RAMdrive, IBM color/graphics adapter, and Epson MX-100 printer. Two different input data sets were supplied to each program and the results were examined. Various program options were exercised in order to evaluate conditions which led to different results. Similiarities and differences were then reported.

SIMILARITIES

EDCRASH and CRASH3 programs required the same input and yielded the same output. This was a major objective of program design, since researchers using both programs may be contributing to the same database.

Both programs were interactive. The user responded to questions (up to 50) requested at the terminal (either CRT or line printer). The input required quantitative data in three general categories. These were: (1) General Vehicle Data, (2) Accident Site Data, and (3) Vehicle Damage Data.

The General Vehicle Data defined vehicle dimensional and inertial properties and the relationship (mutual orientation) of the vehicles at impact. The Accident Site Data identified vehicle positions at impact, vehicle positions at rest, and how the vehicles moved from impact to rest (skidding, spinning, braking, and tire/ground friction). The Damage Data supplied the measured location and profile of vehicle damage.

Not all questions required answers. Some had default answers and some only provided additional detail. A list of input questions can be found in the examples cited later in this paper. A description of each of the input data questions was beyond the scope of this paper. For such a description, the reader is referred to the literature [8,9].

The output session began with a display of error messages. These messages were categorized as either informative or fatal. In the latter case, execution was terminated and output was limited to damage-based results.

The form of the output was either complete or abbreviated. The complete form displayed the impact speed and speed change for both vehicles, followed by an echo of impact and separation conditions, trajectory simulation results, summary of damage data, and vehicle dimensional and inertial properties. The abbreviated results were limited to a summary of impact speeds and speed changes, and trajectory simulation results.

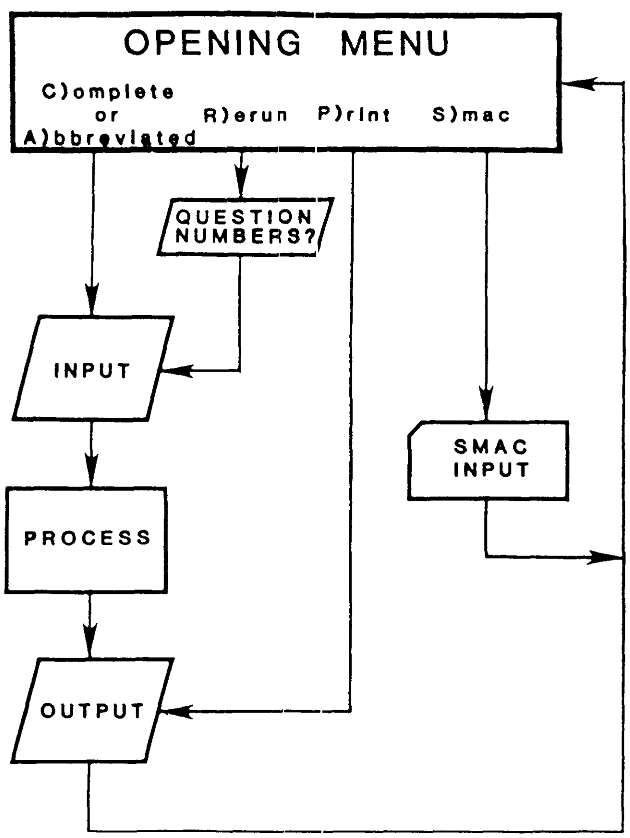

Figure 1 - Flow diagram for CRASH3

DIFFERENCES

The differences between EDCRASH and CRASH3 were found primarily in three areas: (1) User interactivity, (2) Calculations, and (3) Graphics.

User Interactivity

CRASH3 was coded in FORTRAN for use on remote input data terminals, usually connected to a mainframe computer. The terminal was a CRT or local line printer. In either case, the input questions and output results scrolled continuously, one line at a time.

EDCRASH was coded in compiled BASIC for use on the IBM PC or IBM compatible personal computer. As a result, the user interfaced with the program in a substantially different manner. This may be illustrated by inspection of flow diagrams for CRASH3 (figure 1) and EDCRASH (figure 2).

A CRASH3 session began at a menu which provided the user with a list of program options:

COMPLETE - The program ran through its entire cycle. All of the input questions and output results were presented in their most detailed formats.

ABBREVIATED - The program ran through its entire cycle. The input/output was presented in a concise format.

RERUN - The program was re-executed after changing the input for up to 12 questions (followed by processing and new results).

PRINT - Printed a Complete listing of the results.

SMAC - Generated an input data set for the SMAC (Simulation Model of Automobile Collisions [10]) program based on the CRASH3 results.

END - Returned to the computer operating system.

The user initiated a CRASH3 run by selecting the type of run to be performed. If a complete run was requested, then all questions were displayed in a long and rather detailed (complete) form. If an abbreviated form was requested, the input questions were presented in a concise form. The user's memory could be refreshed by entering a ?, which caused the complete form of the question to be displayed. When the input session was concluded, the results were processed and the output was displayed. After each execution, the program returned to the menu, allowing the user to run an abbreviated program or rerun with modified input, view the results, and follow up with input data changes and/or a complete form of the output listing. The user could then generate a SMAC input data set and exit the program. (The SMAC program can be used to test the CRASH results.)

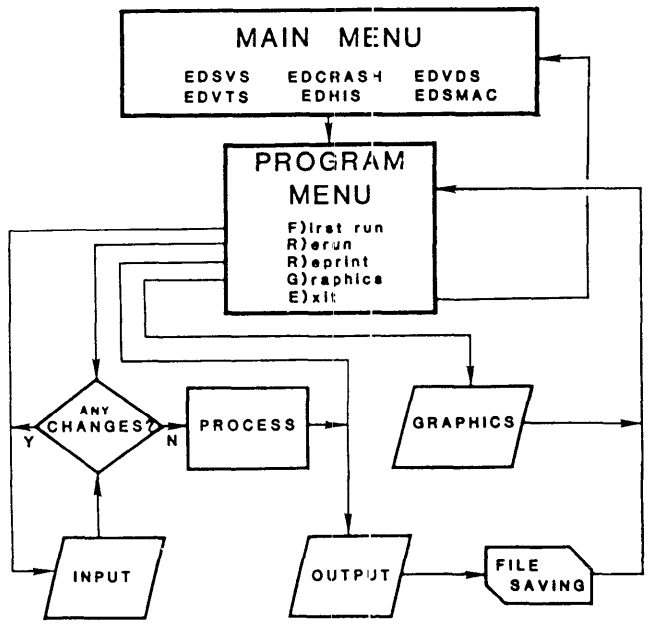

Figure 2 - Flow diagram for EDCRASH

EDCRASH was one of a series of six accident reconstruction programs, all of which were displayed on a Main Menu. Execution was initiated by selecting EDCRASH from the Main Menu. The session began with a display of the Program Menu, which provided the user with a list of options:

FIRST-RUN, INTERACTIVE SESSION - Began the question/answer session in the abbreviated format. The complete form of any question was displayed at the bottom of the screen, along with the required answer format and sample answer, if a ? was entered.

RERUN WITH INPUT FROM A PREVIOUS SESSION - Initiated the rerun option, which required the user to supply an input file (the previous file was the default file; otherwise, any previously-saved input file could be supplied). The session began by asking which section of input required review and/or changes.

OUTPUT FROM A PREVIOUS SESSION - Redisplayed the output, which required the user to supply an output file (the previous session was the default file; otherwise, any previously-saved file could be supplied). The session began by asking for the desired form of output (complete or abbreviated) and routing (screen or printer).

PICTORIAL DISPLAY OF ACCIDENT SITE - Created a pictorial representation of the accident site, which also required the user to supply an output file.

EXIT TO MAIN MENU - Returned to the Main Menu in order to execute another program or exit to the operating system.

The user initiated the analysis by selecting the type of run to be performed. However, since EDCRASH had a file-saving option, three additional options were available when initiating a session. By appropriately selecting (1) rerun with previous input, (2) reprint previous output, or (3) pictorial display of accident site, the user could rerun, re-execute, or review the results of previous sessions without re-entering the input data.

When a first-run was requested and the input session was complete, or if a rerun was requested, EDCRASH asked the user if a review of the input data, or "Any Changes?", was desired. If so, the user could scan each of the sections of data (General, Scene, Impact to rest, Tire/road, and Damage) and accept the data or change it prior to execution. Processing was initiated by a negative response to "Any Changes?". Differences in processing may be found in a later section of this paper.

At the completion of the output session, EDCRASH allowed the user to save the input and/or output files, and then returned to the Program Menu for another run.

At this point, the user could perform a new run, rerun, reprint, graph, or terminate execution. If an EDSMAC input file was desired, it was not necessary to create one, since an EDCRASH output file structure was identical to an EDSMAC input file structure.

Calculations

RICSAC data sets, used during the development of CRASH [5], were used to demonstrate the calculations. RICSAC8 was used to provide typical input and output and establish a valid basis for results. Then, RICSAC7 was used to demonstrate the effects due to some coding differences.

The RICSAC8 input data, shown in figure 3, described an impact between two Chevrolet Chevelles. Vehicle #1 struck vehicle #2 at the passenger-side door. The angle of impact was 90 degrees (perpendicular). Both vehicles responded to impact by spinning clockwise while coming to rest. In order to process the input, the CDC-Cyber required approximately 1 second; the IBM required 5.2 seconds.

```
     GENERAL INPUT DATA

 1.  Title? ............................ SAMPLE RUN  RICSAC CASE #8 11/26/80
 2.  Class/Weights ..................... 4 4479 4 471Ø
 3.  CDC/PDOF # 1? ..................... 11FDEW1 -45
 4.  CDC/PDOF # 2? ..................... Ø2RYEW2 45
 5.  Vehicle 1 & 2 Stiffness Categories  4 4

     SCENE DATA

 6.  Rest and impact? (Y or N) ....... . YES
 7.  Rest coordinates .................. -.5 12 45 6.5 21 141
 8.  Impact coordinates ................ -1Ø.9 3.2 Ø Ø 1.9 9Ø
 9.  Any slip angles? (Y or N) ......... NO
 1Ø. Slip angles 1 and 2 ............... N/A

     IMPACT TO REST PATH DATA

 11. Sustained contact? (Y or N) ....... NO
 12. Rotating skidding of #1? (Y or N) . YES
 13. Skidding stop before rest? (Y or N) NO
 14. End of skidding coordinates? ...... N/A
 15. Curved path? (Y or N) ............. NO
 16. Point on curve .................... N/A
 17. Rotation direction #1 ............. CW
 18. More than 36Ø degrees? (Y or N) ... NO
 19. Rotating skidding of #2? (Y or N) . YES
 2Ø. Skidding stop before rest? (Y or N) NO
 21. End of skidding coordinates ....... N/A
 22. Curved path? (Y or N) ............. NO
 23. Point on curve .................... N/A
 24. Rotation direction #2 ............. CW
 25. More than 36Ø degrees? (Y or N) ... NO

     TIRE/ROAD AND TRAJECTORY SIMULATION DATA

 26. Tire-ground friction coef. ........ .87
 27. Roll. resistance option (1 or 2) .  1
 28. Roll. resistances, indiv. wheels #1 .Ø1 .Ø1 .2 .2
 29. Roll. resistances, indiv. wheels #2 .Ø1 .Ø1 .2 .2
 3Ø. Decel. level #1 ................... N/A
 31. Decel. level #2 ................... N/A
 32. Trajectory simulation? (Y or N) ... NO
 33. Steer angles #1 ................... N/A
 34. Steer angles #2 ................... N/A
 35. Terrain boundary? (Y or N) ........ N/A
 36. Boundary points ................... N/A
 37. Secondary friction coef. .......... N/A

     VEHICLE DAMAGE DATA

 38. Damage dimensions? (Y or N) ....... YES
 39. Side damage width #1 .............. N/A
 4Ø. Side damage depth #1 .............. N/A
 41. Side damage midpoint offset #1 .... N/A
 42. End damage width #1 ............... 73
 43. End damage depth #1 ............... 2.7 3.6
 44. End damage midpoint offset #1 ..... Ø
 45. Side damage width #2 .............. 84.5
 46. Side damage depth #2 .............. 6.2 8.3 9.2 5.9 4.4 .8
 47. Side damage midpoint offset #2 .... 15
 48. End damage width #2 ............... N/A
 49. End damage depth #2 ............... N/A
 5Ø. End damage midpoint offset #2 ..... N/A
```

Figure 3 - RICSAC8 input data set

The computation results for CRASH3 are shown in figure 4 and the results for EDCRASH are shown in figure 5. All the results were shown (i.e., the "Complete" form was selected) in order to illustrate all the differences in output.

Neither program generated any warning messages and the results were indentical. EDCRASH reported some additional information, including Energy Absorbed by Damage, Magnitude of Principal Force, and Moment Arm of Principal Force, in the SUMMARY OF DAMAGE DATA.

After the preliminary output was reviewed, a rerun was performed and a trajectory simulation was requested. The response time for the CDC-Cyber was 4.5 seconds. The processing time for the IBM was 375.4 seconds. For purposes of brevity, only the abbreviated results were displayed.

Inspection of the output results (CRASH3, figure 6; EDCRASH, figure 7) revealed a difference in IMPACT SPEEDS AND SPEED CHANGES. The difference was due to an increase in the integration time interval. While CRASH3 used an interval of 0.025 seconds, EDCRASH used

SUMMARY OF CRASH3 RESULTS

RICSAC #8 CHEVELLE VS CHEVELLE

VEHICLE # 1

IMPACT SPEED MPH		SPEED CHANGE MPH			BASIS OF RESULTS
FWD	LAT	TOTAL	LONG.	LATERAL	
16.7	.0	12.6	-6.9	10.5	SPINOUT TRAJECTORIES AND CONSERVATION OF LINEAR MOMENTUM
					SPINOUT TRAJECTORIES AND DAMAGE
		11.8	-8.3	8.3	DAMAGE DATA ONLY

VEHICLE # 2

IMPACT SPEED MPH		SPEED CHANGE MPH			BASIS OF RESULTS
FWD	LAT	TOTAL	LONG.	LATERAL	
25.7	.0	12.0	-10.0	-6.6	SPINOUT TRAJECTORIES AND CONSERVATION OF LINEAR MOMENTUM
					SPINOUT TRAJECTORIES AND DAMAGE
		11.2	-7.9	-7.9	DAMAGE DATA ONLY

SCENE INFORMATION

	VEHICLE # 1	VEHICLE # 2
IMPACT X POSITION	-10.90 FT.	.00 FT.
IMPACT Y POSITION	3.20 FT.	1.90 FT.
IMPACT HEADING ANGLE	.00 DEG.	89.99 DEG.
REST X-POSITION	-.50 FT.	6.50 FT.
REST Y-POSITION	12.00 FT.	21.00 FT.
REST HEADING ANGLE	45.99 DEG.	140.98 DEG.
DIRECTION OF ROTATION	CW	CW
AMOUNT OF ROTATION	<360	<360

COLLISION CONDITIONS

VEHICLE # 1		VEHICLE # 2	
XC10' =	-10.9 FT.	XC20' =	.0 FT.
YC10' =	3.2 FT.	YC20' =	1.9 FT.
PSI10 =	.0 DEGREES	PSI20 =	90.0 DEGREES
PSI1D0 =	.0 DEG/SEC	PSI2D0 =	.0 DEG/SEC
BETA1 =	.0 DEGREES	BETA2 =	.0 DEGREES

SEPARATION CONDITIONS

XCS1' =	-10.9 FT.	XCS2' =	.0 FT.
YCS1' =	3.2 FT.	YCS2' =	1.9 FT.
PSIS1 =	.0 DEG	PSIS2 =	90.0 DEG
US1 =	9.8 MPH	US2 =	15.7 MPH
VS1 =	10.5 MPH	VS2 =	-6.6 MPH
PSISD1 =	59.2 DEG/SEC	PSISD2 =	54.5 DEG/SEC

Figure 4 - CRASH3 results with RICSAC8 input

IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)

	FORWARD	LATERAL
VEH#1	16.7 MPH	.0 MPH
VEH#2	25.7 MPH	.0 MPH

SPEED CHANGE (DAMAGE)

	TOTAL	LONG.	LAT.	ANG.
VEH#1	11.8 MPH	-8.3 MPH	8.3 MPH	-45.0 DEG.
VEH#2	11.2 MPH	-7.9 MPH	-7.9 MPH	45.0 DEG.

SPEED CHANGE (LINEAR MOMENTUM)

	TOTAL	LONG.	LAT.	ANG.
VEH#1	12.6 MPH	-6.9 MPH	10.5 MPH	-56.6 DEG.
VEH#2	12.0 MPH	-10.0 MPH	-6.6 MPH	33.4 DEG.

ENERGY DISSIPATED BY DAMAGE VEH#1 28479.3 FT-LB VEH#2 31220.8 FT-LB

RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
VEH#1 16.6 MPH
VEH#2 3.0 MPH
SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
VEH#1 2.0 MPH
VEH#2 -25.5 MPH
CLOSING VELOCITY (LINEAR MOMENTUM)
19.7 MPH

SUMMARY OF DAMAGE DATA (* INDICATES DEFAULT VALUE)

VEHICLE # 1			VEHICLE # 2		
TYPE	CATEGORY 4		TYPE	CATEGORY 4	
WEIGHT	4479.0 LBS.		WEIGHT	4710.0 LBS.	
CDC	12FDEW1		CDC	03RYEW2	
L	73.0 IN.		L	84.5 IN.	
C1	2.7 IN.		C1	6.2 IN.	
C2	3.6 IN.		C2	8.3 IN.	
C3	.0 IN.		C3	9.2 IN.	
C4	.0 IN.		C4	5.9 IN.	
C5	.0 IN.		C5	4.4 IN.	
C6	.0 IN.		C6	.8 IN.	
D	.0		D	15.0	
RHO	1.00	*	RHO	1.00	*
ANG	-45.0 DEG.		ANG	45.0 DEG.	
D'	1.7 IN.		D'	7.8 IN.	

DIMENSIONS AND INERTIAL PROPERTIES

A1 =	54.7 INCHES	A2 =	54.7 INCHES
B1 =	59.2 INCHES	B2 =	59.2 INCHES
TR1 =	61.8 INCHES	TR2 =	61.8 INCHES
I1 =	43364.2 LB-SEC**2-IN	I2 =	45600.7 LB-SEC**2-IN
M1 =	11.592 LB-SEC**2/IN	M2 =	12.189 LB-SEC**2/IN
XF1 =	98.8 INCHES	XF2 =	98.8 INCHES
XR1 =	-114.0 INCHES	XR2 =	-114.0 INCHES
YS1 =	38.5 INCHES	YS2 =	38.5 INCHES

ROLLING RESISTANCE

VEHICLE # 1		VEHICLE # 2	
RF	.01	RF	.01
LF	.01	LF	.01
RR	.20	RR	.20
LR	.20	LR	.20

MU---------- .87

Figure 4 (continued)

0.100 seconds, mainly to reduce processing time. This decision was supported by the fact that CRASH2 also used a 0.100 second interval. For most results, the effect of this change was less than 0.3 mph.

The RICSAC7 data, selected in order to demonstrate the effects of some minor coding errors and additional diagnostic error messages, is shown in figure 8. This data described an impact between a Chevrolet Chevelle (Vehicle #1) and a Volkswagen Rabbit (Vehicle #2). The Chevelle struck the Rabbit at the passenger-side door. The angle of impact was 120 degrees (slighlty more than perpendicular). The Rabbit responded by spinning clockwise and rolling a short distance before coming to rest. The Chevelle was redirected by the force of impact, but continued along an essentially straight course, without spinning, to its rest position.

S U M M A R Y   O F   E D C R A S H   R E S U L T S

ENGINEERING DYNAMICS CORPORATION   Date 12-06-1984   Time 11:02:44
SAMPLE RUN RICSAC CASE #8 11/26/80

WARNING MESSAGES: NO MESSAGES

VEHICLE # 1

IMPACT SPEED MPH		SPEED CHANGE MPH			BASIS OF RESULTS
FWD	LAT	TOTAL	LONG.	LATERAL	
16.7	0.0	12.6	6.9	10.5	SPINOUT TRAJECTORIES AND CONSERVATION OF LINEAR MOMENTUM
0.0	0.0	0.0	0.0	0.0	SPINOUT TRAJECTORIES AND DAMAGE
		11.8	-8.3	8.3	DAMAGE DATA ONLY

VEHICLE # 2

IMPACT SPEED MPH		SPEED CHANGE MPH			BASIS OF RESULTS
FWD	LAT	TOTAL	LONG.	LATERAL	
25.7	0.0	12.0	-10.0	-6.6	SPINOUT TRAJECTORIES AND CONSERVATION OF LINEAR MOMENTUM
0.0	0.0	0.0	0.0	0.0	SPINOUT TRAJECTORIES AND DAMAGE
		11.2	7.9	7.9	DAMAGE DATA ONLY

SCENE INFORMATION

	VEHICLE #1	VEHICLE #2
IMPACT X POSITION	10.90 FT.	0.00 FT.
IMPACT Y POSITION	3.20 FT.	1.90 FT.
IMPACT HEADING ANGLE	0.00 DEG.	89.99 DEG.
REST X POSITION	0.50 FT.	6.50 FT.
REST Y POSITION	12.00 FT.	21.00 FT.
REST HEADING ANGLE	45.99 DEG.	140.78 DEG.
DIRECTION OF ROTATION	CW	CW
AMOUNT OF ROTATION	360	360

IMPACT INFORMATION

	VEHICLE #1	VEHICLE #2
IMPACT X POSITION	10.9 FT.	0.0 FT.
IMPACT Y POSITION	3.2 FT.	1.9 FT.
IMPACT HEADING ANGLE	0.0 DEG.	90.0 DEG.
IMPACT ANGULAR ROTATION RATE	0.0 DEG/SEC	0.0 DEG/SEC
IMPACT SIDESLIP ANGLE	0.0 DEG.	0.0 DEG.
SEPARATION X POSITION	10.9 FT.	0.0 FT.
SEPARATION Y POSITION	3.2 FT.	1.9 FT.
SEPARATION HEADING ANGLE	0.0 DEG.	90.0 DEG.
SEPARATION FORWARD VELOCITY	9.8 MPH	15.7 MPH
SEPARATION LATERAL VELOCITY	10.5 MPH	6.6 MPH
SEPARATION ANGULAR ROTATION RATE	58.2 DEG/SEC	54.5 DEG/SEC

IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)

	FORWARD	LATERAL
VEH #1	16.7 MPH	0.0 MPH
VEH #2	25.7 MPH	0.0 MPH

SPEED CHANGE (DAMAGE)

	TOTAL	LONG.	LAT.	ANG.
VEH #1	11.8 MPH	-8.3 MPH	8.3 MPH	-45.0 DEG.
VEH #2	11.2 MPH	-7.9 MPH	-7.9 MPH	45.0 DEG.

SPEED CHANGE (LINEAR MOMENTUM)

	TOTAL	LONG.	LAT.	ANG.
VEH #1	12.6 MPH	6.9 MPH	10.5 MPH	-56.6 DEG.
VEH #2	12.0 MPH	10.0 MPH	6.6 MPH	33.4 DEG.

ENERGY DISSIPATED BY DAMAGE: VEH #1 38479.3 FT-LB VEH #2 31220.9 FT-LB

RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
VEH #1 15.5 MPH
VEH #2 3.0 MPH

SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
VEH #1 2.0 MPH
VEH #2 25.5 MPH

CLOSING VELOCITY (LINEAR MOMENTUM)
19.7 MPH

Figure 5 - EDCRASH results with RICSAC8 input

SUMMARY OF DAMAGE DATA
NOTE: '**' indicates default value

	VEHICLE #1	VEHICLE #2
CLASS (SIZE) CATEGORY	4	4
WEIGHT	44[illegible]9.0 LBS.	4710.0 LBS.
CDC	11FDEW1	02RYEW2
DAMAGE WIDTH	7[illegible].0 IN.	84.5 IN.
CRUSH DEPTH 1	2.[illegible] IN.	6.2 IN.
CRUSH DEPTH 2	3.6 IN.	8.3 IN.
CRUSH DEPTH 3	0.0 IN.	9.2 IN.
CRUSH DEPTH 4	0.0 IN.	5.9 IN.
CRUSH DEPTH 5	0.0 IN.	4.4 IN.
CRUSH DEPTH 6	0.0 IN.	0.8 IN.
DAMAGE MIDPOINT OFFSET	0.0 IN.	15.0 IN.
DAMAGE ENERGY	38479.3 FT.-LB.	31220.9 FT.-LB.
MAGNITUDE OF PRINCIPAL FORCE	47726.9 LB.	54794.6 LB.
DIRECTION OF PRINCIPAL FORCE	-45.0 DEG.	45.0 DEG.
MOMENT ARM OF PRINCIPAL FORCE	70.0 IN.	19.2 IN.
DAMAGE CENTROID	1.7 IN.	7.8 IN.

DIMENSIONAL, INERTIAL AND TIRE/ROAD PROPERTIES

	VEHICLE #1	VEHICLE #2
CG TO FRONT AXLE	5[illegible].7 IN.	54.7 IN.
CG TO REAR AXLE	59.2 IN.	59.2 IN.
TRACK WIDTH	61.8 IN.	61.8 IN.
YAW MOMENT OF INERTIA	4[illegible]61.[illegible] LB-SEC^2-IN	45600.7 LB-SEC^2-IN
MASS	1[illegible].6 LB-SEC^2/IN	12.2 LB-SEC^2/IN
BODY LENGTH FROM CG TO FRONT	98.8 IN.	98.8 IN.
BODY LENGTH FROM CG TO REAR	114.0 IN.	114.0 IN.
BODY WIDTH	[illegible].0 IN.	77.0 IN.

ROLLING RESISTANCE

	VEHICLE #1	VEHICLE #2
RIGHT FRONT TIRE	0.01	0.01
LEFT FRONT TIRE	0.01	0.01
RIGHT REAR TIRE	0.20	0.20
LEFT REAR TIRE	0.20	0.20
TIRE/ROAD FRICTION	0.87	0.87

Figure 5 (continued)

S U M M A R Y   O F   C R A S H 3   R E S U L T S

RICSAC #8 CHEVELLE VS CHEVELLE

IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)

	FORWARD	LATERAL
VEH#1	19.3 MPH	.0 MPH
VEH#2	21.8 MPH	.0 MPH

SPEED CHANGE (DAMAGE)

	TOTAL	LONG.	LAT.	ANG.
VEH#1	11.8 MPH	-8.3 MPH	8.3 MPH	-45.0 DEG.
VEH#2	11.2 MPH	-7.9 MPH	-7.9 MPH	45.0 DEG.

SPEED CHANGE (LINEAR MOMENTUM)

	TOTAL	LONG.	LAT.	ANG.
VEH#1	18.1 MPH	-15.9 MPH	8.5 MPH	-28.2 DEG.
VEH#2	17.2 MPH	8.1 MPH	-15.1 MPH	61.8 DEG.

ENERGY DISSIPATED BY DAMAGE VEH#1 38479.3 FT-LB VEH#2 31220.8 FT LB
SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
VEH#1 19.2 MPH
VEH#2 2.6 MPH
SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
VEH#1 2.3 MPH
VEH#2 -21.7 MPH
CLOSING VELOCITY (LINEAR MOMENTUM)
21.7 MPH

TRAJECTORY SIMULATION RESULTS

++++ VEHICLE # 1 DID NOT CONVERGE ++++
++++ VEHICLE # 2 DID NOT CONVERGE ++++

NRUNS(1) =	5	NRUNS(2) =	5
E1(1) =	.087	E2(1) =	.076
E1(2) =	.000	E2(2) =	.000
E1(3) =	.259	E2(3) =	.155
E1(4) =	.000	E2(4) =	.000
E1(5) =	.000	E2(5) =	.000
OMIN1 =	.347	OMIN2 =	.231

Figure 6 - CRASH3 results for RICSAC8 with a trajectory simulation

```
           S U M M A R Y   O F   E D C R A S H   R E S U L T S

ENGINEERING DYNAMICS CORPORATION          Date 12-06-1984  Time 11:13:14
               SAMPLE RUN  RICSAC CASE #8 11/26/80

WARNING MESSAGES:  NO MESSAGES


    IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
           FORWARD         LATERAL
VEH #1    19.1 MPH         0.0 MPH
VEH #2    22.1 MPH         0.0 MPH

    SPEED CHANGE (DAMAGE)
             TOTAL          LONG.            LAT.           ANG.
VEH #1    11.8 MPH        -8.3 MPH        8.3 MPH      -45.0 DEG.
VEH #2    11.2 MPH        -7.9 MPH        7.9 MPH       45.0 DEG.

    SPEED CHANGE (LINEAR MOMENTUM)
             TOTAL          LONG.            LAT.           ANG.
VEH #1    18.4 MPH       -15.8 MPH        8.7 MPH      -28.7 DEG.
VEH #2    17.1 MPH         8.2 MPH      -15.0 MPH       61.3 DEG.

ENERGY DISSIPATED BY DAMAGE:  VEH #1   38479.3 FT-LB  VEH #2   31220.9 FT-LB


                        RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
   VEH #1         19.0 MPH
   VEH #2          2.6 MPH

SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
   VEH #1          2.3 MPH
   VEH #2         21.9 MPH

CLOSING VELOCITY (LINEAR MOMENTUM)
                  21.6 MPH


                     TRAJECTORY SIMULATION RESULTS

****VEHICLE # 1  DID NOT CONVERGE ****
****VEHICLE # 2  DID NOT CONVERGE ****
                                              VEHICLE #1         VEHICLE #2

NUMBER OF RUNS (MAXIMUM OF 5)                  5                  5
REST POSITION X-Y ERROR ( =.10)                0.097              0.049
END OF ROTATION X-Y ERROR ( =.15)              0.000              0.000
REST POSITION HEADING ERROR ( =.10)            0.242             -0.175
END OF ROTATION HEADING ERROR ( =.15)          0.000              0.000
POINT ON CURVE X-Y ERROR ( =.15)               0.000              0.000
TOTAL WEIGHTED ERROR SUM                       0.339              0.224
```

Figure 7 - EDCRASH results for RICSAC8 with a trajectory simulation

```
     GENERAL INPUT DATA

1.  Title? ............................ RICSAC #7 CHEVELLE VS RABBIT
2.  Class/Weights ..................... 4 3700 2 1700
3.  CDC/PDOF # 1? ..................... 11FDEW1 -30
4.  CDC/PDOF # 2? ..................... 02RDEW4 30
5.  Vehicle 1 & 2 Stiffness Categories  4 2

     SCENE DATA

6.  Rest and impact? (Y or N) ......... YES
7.  Rest coordinates .................. 84.5 18.2 16.5 22.9 41.4 262
8.  Impact coordinates ................ 0 0 0 10.7 3.45 120
9.  Any slip angles? (Y or N) ......... NO
10. Slip angles 1 and 2 ............... N/A

     IMPACT-TO-REST PATH DATA

11. Sustained contact? (Y or N) ....... NO
12. Rotating skidding of #1? (Y or N) . NO
13. Skidding stop before rest? (Y or N) N/A
14. End of skidding coordinates? ...... N/A
15. Curved path? (Y or N) ............. NO
16. Point on curve .................... N/A
17. Rotation direction #1 ............. CW
18. More than 360 degrees? (Y or N) ... NO
19. Rotating skidding of #2? (Y or N) . YES
20. Skidding stop before rest? (Y or N) YES
21. End of skidding coordinates ....... 22 30 250
22. Curved path? (Y or N) ............. NO
23. Point on curve .................... N/A
24. Rotation direction #2 ............. CW
25. More than 360 degrees? (Y or N) ... NO

     TIRE/ROAD AND TRAJECTORY SIMULATION DATA

26. Tire-ground friction coef. ........ .87
27. Roll. resistance option (1 or 2) .. 1
28. Roll. resistances, indiv. wheels #1 .01 .01 .2 .2
29. Roll. resistances, indiv. wheels #2 .01 .01 1. .2
30. Decel. level #1 ................... N/A
31. Decel. level #2 ................... N/A
32. Trajectory simulation? (Y or N) ... NO
33. Steer angles #1 ................... N/A
34. Steer angles #2 ................... N/A
35. Terrain boundary? (Y or N) ........ N/A
36. Boundary points ................... N/A
37. Secondary friction coef. .......... N/A

     VEHICLE DAMAGE DATA

38. Damage dimensions? (Y or N) ....... YES
39. Side damage width #1 .............. N/A
40. Side damage depth #1 .............. N/A
41. Side damage midpoint offset #1 .... N/A
42. End damage width #1 ............... 66
43. End damage depth #1 ............... 0 1.25 2 3.75 5 6.25
44. End damage midpoint offset #1 ..... 4
45. Side damage width #2 .............. 108.5
46. Side damage depth #2 .............. 0 11 17.75 21 21.25 7.25
47. Side damage midpoint offset #2 .... -8.5
48. End damage width #2 ............... N/A
49. End damage depth #2 ............... N/A
50. End damage midpoint offset #2 ..... N/A
```

Figure 8 - RICSAC7 input data set [5]

In order to process the input for RICSAC7, the CDC-Cyber computer required approximately 1 second; the IBM PC required 3.9 seconds.

The computation results for CRASH3 are shown in figure 9 and the results for EDCRASH are shown in figure 10. The complete form of output is shown in order to illustrate all the differences.

CRASH3 did not display any warning messages. EDCRASH generated two warning messages, both informative (i.e., non-fatal). The first message (refer to figure 10) told the user of an inconsistency in the damage data: Since the damage data (user-measured and table-supplied) for each vehicle was totally independent, but the vehicles' response had to obey Newton's three laws of motion, this was a check of consistency for vehicle damage data for both vehicles. The error message generated by EDCRASH indicated the force required to cause the observed (measured) damage for each vehicle was very dissimilar (the difference was greater than 100%). The source of the error was either (1) incorrect interpretation and/or measurement of damage, or (2) inappropriate stiffness data used by the program. The cause of the error should be identified, either by close inspection of the damage measurements or the vehicle crush stiffness parameter(s).

The second warning message issued by EDCRASH informed the user that an adjustment of vehicle separation velocities was performed in order to satisfy an assumption common to both programs: The regions of each vehicle which contact one another during the collision must reach a common velocity just prior to separation. The separation velocity for each vehicle was determined independently during the post-impact phase calculations. If the input data (impact/rest/end of rotation/point on curve positions, tire-ground friction, and wheel lock-ups) were perfect - and if the 3-degree of freedom model were exact - then the velocity (speed and direction) of the regions of contact would be exactly the same for both

S U M M A R Y   O F   C R A S H 3   R E S U L T S

RICSAC #7 CHEVELLE VS RABBIT

VEHICLE # 1

IMPACT SPEED MPH		SPEED CHANGE MPH			BASIS OF RESULTS
FWD	LAT	TOTAL	LONG.	LATERAL	
26.2	.0	15.0	13.5	6.5	SPINOUT TRAJECTORIES AND CONSERVATION OF LINEAR MOMENTUM
					SPINOUT TRAJECTORIES AND DAMAGE
		19.7	-17.1	9.9	DAMAGE DATA ONLY

VEHICLE # 2

IMPACT SPEED MPH		SPEED CHANGE MPH			BASIS OF RESULTS
FWD	LAT	TOTAL	LONG.	LATERAL	
34.9	.0	32.7	27.0	-18.4	SPINOUT TRAJECTORIES AND CONSERVATION OF LINEAR MOMENTUM
					SPINOUT TRAJECTORIES AND DAMAGE
		43.0	-37.2	-21.5	DAMAGE DATA ONLY

SCENE INFORMATION

	VEHICLE # 1	VEHICLE # 2
IMPACT X POSITION	.00 FT.	10.70 FT.
IMPACT Y POSITION	.00 FT.	3.45 FT.
IMPACT HEADING ANGLE	.00 DEG.	119.99 DEG.
REST X POSITION	84.50 FT.	22.90 FT.
REST Y-POSITION	18.20 FT.	41.40 FT.
REST HEADING ANGLE	16.50 DEG.	261.97 DEG.
END-OF-ROTATION X-POSITION	.00 FT.	22.00 FT.
END-OF-ROTATION Y-POSITION	.00 FT.	30.00 FT.
END OF ROTATION HEADING ANGLE	.00 DEG.	249.97 DEG.
DIRECTION OF ROTATION	CW	CW
AMOUNT OF ROTATION	<360	<360

COLLISION CONDITIONS

```
      VEHICLE # 1                          VEHICLE # 2

XC10'    =     .0 FT.                XC20'    =    10.7 FT.
YC10'    =     .0 FT.                YC20'    =     3.4 FT.
PSI10    =     .0 DEGREES            PSI20    =   120.0 DEGREES
PSI1D0   =     .0 DEG/SEC            PSI2D0   =      .0 DEG/SEC
BETA1    =     .0 DEGREES            BETA2    =      .0 DEGREES
```

SEPARATION CONDITIONS

```
XCS1'    =     .0 FT.                XCS2'    =    10.7 FT.
YCS1'    =     .0 FT.                YCS2'    =     3.4 FT.
PSIS1    =     .0 DEG                PSIS2    =   120.0 DEG
US1      =   [illegible] MPH         US2      =     8.0 MPH
VS1      =   [illegible] MPH         VS2      =    18.4 MPH
PSISD1   =     .0 DEG/SEC            PSISD2   =   146.1 DEG/SEC
```

Figure 9 - CRASH3 results with RICSAC7 input

```
    IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
          FORWARD         LATERAL
VEH#1     26.2 MPH          .0 MPH
VEH#2     34.9 MPH          .0 MPH

    SPEED CHANGE (DAMAGE)
            TOTAL          LONG.          LAT.          ANG.
VEH#1     19.7 MPH     -17.1 MPH      9.9 MPH     -30.0 DEG.
VEH#2     43.0 MPH     -37.2 MPH    -21.5 MPH      30.0 DEG.

    SPEED CHANGE (LINEAR MOMENTUM)
            TOTAL          LONG.          LAT.          ANG.
VEH#1     15.0 MPH     -13.5 MPH      6.5 MPH     -25.6 DEG.
VEH#2     32.7 MPH     -27.0 MPH    -18.4 MPH      34.4 DEG.

ENERGY DISSIPATED BY DAMAGE  VEH#1  23188.8 FT-LB  VEH#2 196486.9 FT-LB

                     RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
   VEH#1       24.9 MPH
   VEH#2        7.3 MPH
SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
   VEH#1       -8.0 MPH
   VEH#2      -34.2 MPH
CLOSING VELOCITY (LINEAR MOMENTUM)
               32.2 MPH

SUMMARY OF DAMAGE DATA                    * INDICATES DEFAULT VALUE)

        VEHICLE # 1                             VEHICLE # 2

TYPE---------CATEGORY 4               TYPE---------CATEGORY 2
WEIGHT------   3700.0 LBS.            WEIGHT------   1700.0 LBS.
CDC-----------11FDEW1                 CDC-----------02RDEW4
L-----------     66.0 IN.             L-----------    108.5 IN.
C1----------       .0 IN.             C1----------       .0 IN.
C2----------      1.3 IN.             C2----------     11.0 IN.
C3----------      2.0 IN.             C3----------     17.8 IN.
C4----------      3.8 IN.             C4----------     21.0 IN.
C5----------      5.0 IN.             C5----------     21.3 IN.
C6----------      6.3 IN.             C6----------      7.3 IN.
D-----------      4.0                 D-----------      8.5
RHO              1.00        *        RHO              1.00        *
ANG---------     30.0 DEG.            ANG---------     30.0 DEG.
D'----------     15.6 IN.             D'----------      1.3 IN.

              DIMENSIONS AND INERTIAL PROPERTIES

A1      =     54.[illegible] INCHES           A2      =   45.3 INCHES
B1      =     57.2 INCHES                     B2      =   [illegible]
TR1     =     61.6 INCHES                     TR2     =   [illegible]
I1      =  35822.2 LB SEC**2 IN               [illegible]
M1      =   [illegible] LB SEC**2 IN          [illegible]
XF1     =   [illegible] INCHES                [illegible]
XR1     =    114.[illegible] INCHES           [illegible]
YS1     =   [illegible]                       [illegible] INCHES

                    [illegible]

      VEHICLE # 1                             VEHICLE # 2

RF                                    RF----------       .01
LF----------     [illegible]          LF----------       .01
RR----------      .20                 RR----------      1.00
LR----------      .20                 LR----------       .20

NU----------      .87
```

Figure 9 (continued)

vehicles. This velocity was computed at the damage centroid and compared for both vehicles. If the velocity difference was less than 10 percent, the average velocity was used as the common velocity. If the difference was more, then the separation velocity for one vehicle was decreased and the other was increased by 10 percent. If the resulting difference, after the adjustment, was less than 10 percent, then the observed warning message (see figure 10) was issued. If the resulting difference were still greater than 10 percent, then a fatal error message would have been issued and execution halted. The purpose of such a check was to disallow an analysis which was not within the scope of the analysis, such as a sideswipe. Both programs performed the above check. However, CRASH3 only reported the condition after two adjustments and did not

```
          S U M M A R Y    O F    E D C R A S H    R E S U L T S

ENGINEERING DYNAMICS CORPORATION          Date 12-08-1984  Time 12:32:36
                     RICSAC #7 CHEVELLE VS RABBIT

WARNING MESSAGES:

Damage-based estimates for Magnitude of Principal Force grossly violate
Newton's third law of motion.  Review the output to determine required
corrections to Damage Data and adjust as necessary.
The Magnitudes of Principal Force for Vehicles 1 and 2 should be
approximately equal.


COMMON VELOCITY WARNING -- An adjustment of vehicle separation conditions
was performed in order to be consistent with the common velocity assumption.
The adjustment does not exceed 10 percent.

                              VEHICLE # 1
 ----------------------------------------------------------------------
:    IMPACT       :                            :                       :
:     SPEED       :        SPEED CHANGE        :         BASIS         :
:      MPH        :            MPH             :          OF           :
:-----------------+----------------------------:        RESULTS        :
:  FWD   :  LAT   : TOTAL  : LONG.  : LATERAL  :                       :
:--------+--------+--------+--------+----------+-----------------------:
:        :        :        :        :          : SPINOUT TRAJECTORIES AND :
:  25.9  :   0.0  :  14.8  : -13.3  :    6.5   : CONSERVATION OF LINEAR :
:        :        :        :        :          : MOMENTUM              :
:--------+--------+--------+--------+----------+-----------------------:
:   0.0  :   0.0  :   0.0  :   0.0  :    0.0   : SPINOUT TRAJECTORIES AND :
:        :        :        :        :          : DAMAGE                :
                  +--------+--------+----------+-----------------------:
                  :  19.7  :  17.1  :    9.9   : DAMAGE DATA ONLY      :
                   ----------------------------------------------------

                              VEHICLE # 2
 ----------------------------------------------------------------------
:    IMPACT       :                            :                       :
:     SPEED       :        SPEED CHANGE        :         BASIS         :
:      MPH        :            MPH             :          OF           :
:-----------------+----------------------------:        RESULTS        :
:  FWD   :  LAT   : TOTAL  : LONG.  : LATERAL  :                       :
:--------+--------+--------+--------+----------+-----------------------:
:        :        :        :        :          : SPINOUT TRAJECTORIES AND :
:  34.7  :   0.0  :  32.1  : -26.7  :   17.9   : CONSERVATION OF LINEAR :
:        :        :        :        :          : MOMENTUM              :
:--------+--------+--------+--------+----------+-----------------------:
:   0.0  :   0.0  :   0.0  :   0.0  :    0.0   : SPINOUT TRAJECTORIES AND :
:        :        :        :        :          : DAMAGE                :
                  +--------+--------+----------+-----------------------:
                  :  43.0  :  37.2  :   21.5   : DAMAGE DATA ONLY      :
                   ----------------------------------------------------

                             SCENE INFORMATION

                                       VEHICLE #1         VEHICLE #2

IMPACT X POSITION                        0.00  FT.         10.70  FT.
IMPACT Y POSITION                        0.00  FT.          3.45  FT.
IMPACT HEADING ANGLE                     0.00  DEG.       119.99  DEG.

REST X-POSITION                         84.50  FT.         22.90  FT.
REST Y-POSITION                         18.20  FT.         41.40  FT.
REST HEADING ANGLE                      16.50  DEG.       261.97  DEG.

END OF ROTATION X POSITION               0.00  FT.         22.00  FT.
END OF ROTATION Y POSITION               0.00  FT.         30.00  FT.
END OF ROTATION HEADING ANGLE            0.00  DEG.       249.97  DEG.
DIRECTION OF ROTATION                     CW                 CW
AMOUNT OF ROTATION                       360               360

                             IMPACT INFORMATION

                                       VEHICLE #1         VEHICLE #2

IMPACT X POSITION                        0.0  FT.          10.7  FT.
IMPACT Y POSITION                        0.0  FT.           3.5  FT.
IMPACT HEADING ANGLE                     0.0  DEG.        120.0  DEG.
IMPACT ANGULAR ROTATION RATE             0.0  DEG/SEC       0.0  DEG/SEC
IMPACT SIDESLIP ANGLE                    0.0  DEG.          0.0  DEG.

SEPARATION X POSITION                    0.0  FT.          10.7  FT.
SEPARATION Y-POSITION                    0.0  FT.           3.5  FT.
SEPARATION HEADING ANGLE                 0.0  DEG.        120.0  DEG.
SEPARATION FORWARD VELOCITY             12.7  MPH           8.0  MPH
SEPARATION LATERAL VELOCITY              6.5  MPH         -17.9  MPH
SEPARATION ANGULAR ROTATION RATE         0.0  DEG/SEC     171.7  DEG/SEC

     IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
           FORWARD        LATERAL
VEH #1     25.9 MPH       0.0 MPH
VEH #2     34.7 MPH       0.0 MPH

     SPEED CHANGE (DAMAGE)
             TOTAL           LONG.           LAT.           ANG.
VEH #1     19.7 MPH      -17.1 MPH        9.9 MPH      -30.0 DEG.
VEH #2     43.0 MPH      -37.2 MPH      -21.5 MPH       30.0 DEG.

     SPEED CHANGE (LINEAR MOMENTUM)
             TOTAL           LONG.           LAT.           ANG.
VEH #1     14.8 MPH      -13.3 MPH        6.5 MPH      -26.1 DEG.
VEH #2     32.1 MPH       26.7 MPH      -17.9 MPH       33.9 DEG.

ENERGY DISSIPATED BY DAMAGE:  VEH #1   23188.8 FT-LB  VEH #2  196487.1 FT-LB
```

Figure 10 - EDCRASH results with RICSAC7 input

```
                        RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
   VEH #1         24.7 MPH
   VEH #2          7.3 MPH

SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM
   VEH #1         -8.0 MPH
   VEH #2        -33.9 MPH

CLOSING VELOCITY (LINEAR MOMENTUM)
                  31.9 MPH

                                SUMMARY OF DAMAGE DATA
                         NOTE:  '**' indicates  default value

                                      VEHICLE #1           VEHICLE #2

CLASS (SIZE) CATEGORY                    4                    2
WEIGHT                                3700.0 LBS.         1700.0 LBS.
CDC                                   11FDEW1             02RDEW4
DAMAGE WIDTH                            66.0 IN.           108.5 IN.
CRUSH DEPTH 1                            0.0 IN.             0.0 IN.
CRUSH DEPTH 2                            1.3 IN.            11.0 IN.
CRUSH DEPTH 3                            2.0 IN.            17.8 IN.
CRUSH DEPTH 4                            3.8 IN.            21.0 IN.
CRUSH DEPTH 5                            5.0 IN.            21.3 IN.
CRUSH DEPTH 6                            6.3 IN.             7.3 IN.
DAMAGE MIDPOINT OFFSET                   4.4 IN.            -8.5 IN.
DAMAGE ENERGY                        23188.8 FT. LB.    196487.1 FT.-LB.
MAGNITUDE OF PRINCIPAL FORCE         34913.4 LB.        246490.9 LB.
DIRECTION OF PRINCIPAL FORCE            30.0 DEG.           30.0 DEG.
MOMENT ARM OF PRINCIPAL FORCE           61.3 IN.            22.2 IN.
DAMAGE CENTROID                         15.5 IN.            -1.3 IN.


                   DIMENSIONAL, INERTIAL AND TIRE/ROAD PROPERTIES

                                      VEHICLE #1           VEHICLE #2

CG TO FRONT AXLE                        54.7 IN.            46.3 IN.
CG TO REAR AXLE                         59.2 IN.            50.1 IN.
TRACK WIDTH                             61.8 IN.            54.6 IN.
YAW MOMENT OF INERTIA                35822.2 LB-SEC^2-IN  12983.2 LB-SEC^2-IN
MASS                                     9.6 LB-SEC^2/IN     4.4 LB-SEC^2/IN
BODY LENGTH FROM CG TO FRONT            98.8 IN.            83.3 IN.
BODY LENGTH FROM CG TO REAR           -114.0 IN.           -91.6 IN.
BODY WIDTH                              77.0 IN.            67.2 IN.

                           ROLLING RESISTANCE

RIGHT FRONT TIRE                        0.01                0.01
LEFT FRONT TIRE                         0.01                0.01
RIGHT REAR TIRE                         0.20                1.00
LEFT REAR TIRE                          0.20                0.20
TIRE/ROAD FRICTION                      0.87                0.87
```

Figure 10 (continued)

issue a fatal error in the event the common velocity assumption was not satisfied.

The next difference between the programs was found in the IMPACT SPEEDS AND SPEED CHANGES. This difference depended on the CRASH3 code which was used and only occurred if the post-impact path for vehicle #2 had an end-of-rotation position. It was due to an error in subroutine START2, wherein the separation coordinates for vehicle #2 were incorrectly assigned the end-of-rotation coordinates rather than the impact coordinates:

```
5 XCSP=XC12
  YCSP=YC12
```

should be

```
5 XCSP=XC20
  YCSP=YC20
```

The only other difference was found in the SUMMARY OF DAMAGE DATA section of output, described earlier. Reporting the Magnitude of Principal Force was useful when an error message indicated there was a gross difference in vehicle damage data (figure 10).

After the preliminary output was reviewed, a rerun was performed and a trajectory simulation was requested. The response time for a CDC-Cyber computer was 4.5 seconds. The processing time for the IBM PC was 239.3 seconds. (Only the abbreviated results are displayed.)

```
                    S U M M A R Y    O F    C R A S H 3    R E S U L T S


RICSAC #7  CHEVELLE VS RABBIT

     IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
          FORWARD          LATERAL
VEH#1    28.6 MPH           .0 MPH
VEH#2    48.2 MPH           .0 MPH


     SPEED CHANGE (DAMAGE)
           TOTAL            LONG.           LAT.            ANG.
VEH#1    19.7 MPH       -17.1 MPH        9.9 MPH        30.0 DEG.
VEH#2    43.0 MPH        37.2 MPH       21.5 MPH        30.0 DEG.


     SPEED CHANGE (LINEAR MOMENTUM)
           TOTAL            LONG.           LAT.            ANG.
VEH#1    17.8 MPH       -15.4 MPH        9.0 MPH       -30.4 DEG.
VEH#2    38.8 MPH        33.8 MPH       19.1 MPH        29.5 DEG.

ENERGY DISSIPATED BY DAMAGE  VEH#1  23188.8 FT-LB  VEH#2 196486.9 FT-LB
SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
    VEH#1        27.3 MPH
    VEH#2        10.1 MPH
SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
    VEH#1         8.8 MPH
    VEH#2        47.1 MPH
CLOSING VELOCITY (LINEAR MOMENTUM)
                 37.4 MPH


                         TRAJECTORY SIMULATION RESULTS


**** VEHICLE # 1 DID NOT CONVERGE ****
**** VEHICLE # 2 CONVERGED O.K. ****
NRUNS(1) =        5                    NRUNS(2)  =       2
E1(1)    =     .273                    E2(1)     =    .067
E1(2)    =     .000                    E2(2)     =    .087
E1(3)    =    1.020                    E2(3)     =    .060
E1(4)    =     .000                    E2(4)     =   -.041
E1(5)    =     .000                    E2(5)     =    .000
OMIN1    =    1.292                    OMIN2     =    .171
```

Figure 11 - CRASH3 results for RICSAC7 with a trajectory simulation

Inspection of the output results (CRASH3, figure 11; EDCRASH, figure 12) again revealed a difference in IMPACT SPEEDS AND SPEED CHANGES. The difference was due to two different sources: (1) the end-of-rotation error, and (2) increasing the integration time interval from 0.025 to 0.100 seconds. Each of these differences has been described earlier. The effect of increasing the integration time step has been shown to be minor (refer to figures 6 and 7). The major cause of the difference was the end-or-rotation error, which provided the trajectory simulation a substantially different set of initial velocities (especially angular velocity; see figures 9 and 10, Separation Conditions).

```
          S U M M A R Y    O F    E D C R A S H    R E S U L T S

ENGINEERING DYNAMICS CORPORATION         Date 12-08-1984  Time 12:50:02
                     RICSAC #7 CHEVELLE VS RABBIT


WARNING MESSAGES:

Damage-based estimates for Magnitude of Principal Force grossly violate
Newton's third law of motion.  Review the output to determine required
corrections to Damage Data and adjust as necessary.
The Magnitudes of Principal Force for Vehicles 1 and 2 should be
approximately equal.


COMMON VELOCITY WARNING -- An adjustment of vehicle separation conditions
was performed in order to be consistent with the common velocity assumption.
The adjustment does not exceed 10 percent.


    IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
           FORWARD         LATERAL
VEH #1    29.5 MPH         0.0 MPH
VEH #2    53.7 MPH         0.0 MPH

    SPEED CHANGE (DAMAGE)
            TOTAL            LONG.            LAT.            ANG.
VEH #1    19.7 MPH       -17.1 MPH         9.9 MPH       -30.0 DEG.
VEH #2    43.0 MPH       -37.2 MPH       -21.5 MPH        30.0 DEG.

    SPEED CHANGE (LINEAR MOMENTUM)
            TOTAL            LONG.            LAT.            ANG.
VEH #1    19.9 MPH       -16.2 MPH        11.5 MPH       -35.5 DEG.
VEH #2    43.3 MPH        39.4 MPH       -18.0 MPH        24.5 DEG.

ENERGY DISSIPATED BY DAMAGE:  VEH #1   23188.8 FT LB  VEH #2  196487.1 FT LB


                          RELATIVE VELOCITY DATA


SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
   VEH #1          28.0 MPH
   VEH #2          11.3 MPH

SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
   VEH #1          -9.0 MPH
   VEH #2         -52.5 MPH

CLOSING VELOCITY (LINEAR MOMENTUM)
                   39.3 MPH


                          TRAJECTORY SIMULATION RESULTS


****VEHICLE # 1  DID NOT CONVERGE ****
**** VEHICLE # 2  CONVERGED OK ****

                                               VEHICLE #1          VEHICLE #2

NUMBER OF RUNS (MAXIMUM OF 5)                  5                   2
REST POSITION X-Y ERROR ( =.10)                0.265               0.093
END OF-ROTATION X-Y ERROR ( =.15)              0.000               0.115
REST POSITION HEADING ERROR ( =.10)            1.078               0.418
END-OF-ROTATION HEADING ERROR ( =.15)          0.000              -0.150
POINT-ON-CURVE X-Y ERROR ( =.15)               0.000               0.000
TOTAL WEIGHTED ERROR SUM                       1.302               0.243
```

Figure 12 - EDCRASH results for RICSAC7 with a trajectory simulation

For purposes of illustration, another rerun was performed and the trajectory simulation option was turned off. Then, the post-impact trajectory of vehicle #1 was changed so that it was curved. Both programs modelled the curved path by assuming the path was defined by a circle. The position of vehicle #1 at impact and rest defined two points on the circle, and required a third point to be supplied by the user. This point allowed the radius (which was assumed to be constant) of the path and the path length to be calculated. In addition, it allowed the separation (i.e., post-impact) angle to be based on the curved path, rather than the straight line between impact and rest positions. This feature was extremely important, since the separation angle had a great effect on separation velocity. In order to use this feature, a point on the curved path was entered:

Point on curve = 40,4

```
S U M M A R Y   O F   C R A S H 3   R E S U L T S

RICSAC #7  CHEVELLE VS RABBIT

                    SUMMARY OF RESULTS

     IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
          FORWARD         LATERAL
VEH#1    26.2 MPH          .0 MPH
VEH#2    35.0 MPH          .0 MPH

     SPEED CHANGE (DAMAGE)
          TOTAL          LONG.          LAT.          ANG.
VEH#1    19.7 MPH     -17.1 MPH      9.9 MPH    -30.0 DEG.
VEH#2    43.0 MPH     -37.2 MPH    -21.5 MPH     30.0 DEG.

     SPEED CHANGE (LINEAR MOMENTUM)
          TOTAL          LONG.          LAT.          ANG.
VEH#1    15.0 MPH     -13.5 MPH      6.5 MPH    -25.7 DEG.
VEH#2    32.7 MPH     -27.0 MPH    -18.5 MPH     34.3 DEG.

ENERGY DISSIPATED BY DAMAGE  VEH#1  23188.8 FT-LB  VEH#2 196486.9 FT-LB

                    RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
   VEH#1        25.0 MPH
   VEH#2         7.3 MPH
SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
   VEH#1        -8.1 MPH
   VEH#2        34.2 MPH
CLOSING VELOCITY (LINEAR MOMENTUM)
                32.3 MPH

                    SCENE INFORMATION

                                        VEHICLE # 1        VEHICLE # 2

IMPACT X POSITION                          .00  FT.          10.70  FT.
IMPACT Y POSITION                          .00  FT.           3.45  FT.
IMPACT HEADING ANGLE                       .00  DEG.        119.99  DEG.

REST X POSITION                          84.50  FT.          22.90  FT.
REST Y POSITION                          18.20  FT.          41.40  FT.
REST HEADING ANGLE                       16.50  DEG.        261.97  DEG.

END-OF ROTATION X POSITION                 .00  FT.          22.00  FT.
END OF ROTATION Y POSITION                 .00  FT.          30.00  FT.
END OF ROTATION HEADING ANGLE              .00  DEG.        249.97  DEG.

POINT ON CURVE X POSITION                40.00  FT.
POINT ON-CURVE Y-POSITION                 4.00  FT.

DIRECTION OF ROTATION                    CW                  CW
AMOUNT OF ROTATION                       360                 360
```

Figure 13 - CRASH3 results with point on curve

These results (CRASH3, figure 13; EDCRASH, figure 14) have been limited to the abbreviated listing plus the echo of scene data, which displays the user-entered point on curve.

Inspection of the results again revealed a difference in IMPACT SPEEDS AND SPEED CHANGES, due only to the end-of-rotation error.

In order to investigate another feature related to curved post-impact trajectories, the point on curve was changed:

Point on curve = 40,8.5

The results (CRASH3, figure 15; EDCRASH, figure 16) revealed the IMPACT SPEEDS AND SPEED CHANGES were the same as those obtained without a point on curve. This intentional result was caused by the selection of a point which was on the straight line between impact and rest positions. EDCRASH issued an informative message indicating this was the case. Note the echo of scene data did not include the user-entered point on curve. This circumstance would not lead to erroneous results.

```
S U M M A R Y   O F   E D C R A S H   R E S U L T S

ENGINEERING DYNAMICS CORPORATION        Date 12-08-1984  Time 12:55:23
                    RICSAC #7 CHEVELLE VS RABBIT

WARNING MESSAGES:

Damage-based estimates for Magnitude of Principal Force grossly violate
Newton's third law of motion.  Review the output to determine required
corrections to Damage Data and adjust as necessary.
The Magnitudes of Principal Force for Vehicles 1 and 2 should be
approximately equal.

COMMON VELOCITY WARNING -- An adjustment of vehicle separation conditions
was performed in order to be consistent with the common velocity assumption.
The adjustment does not exceed 10 percent.

     IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
          FORWARD         LATERAL
VEH #1   26.0 MPH         0.0 MPH
VEH #2   34.7 MPH         0.0 MPH

     SPEED CHANGE (DAMAGE)
          TOTAL          LONG.          LAT.          ANG.
VEH #1   19.7 MPH     -17.1 MPH      9.9 MPH    -30.0 DEG.
VEH #2   43.0 MPH     -37.2 MPH    -21.5 MPH     30.0 DEG.

     SPEED CHANGE (LINEAR MOMENTUM)
          TOTAL          LONG.          LAT.          ANG.
VEH #1   14.8 MPH     -13.3 MPH      6.5 MPH    -26.1 DEG.
VEH #2   32.2 MPH     -26.7 MPH    -17.9 MPH     33.8 DEG.

ENERGY DISSIPATED BY DAMAGE:  VEH #1   23108.8 FT-LB  VEH #2  196487.1 FT-LB

                    RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
   VEH #1        24.7 MPH
   VEH #2         7.3 MPH

SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
   VEH #1        -8.0 MPH
   VEH #2       -33.9 MPH

CLOSING VELOCITY (LINEAR MOMENTUM)
                 32.0 MPH

                    SCENE INFORMATION

                                      VEHICLE #1        VEHICLE #2

IMPACT X-POSITION                      0.00  FT.          10.70  FT.
IMPACT Y-POSITION                      0.00  FT.           3.45  FT.
IMPACT HEADING ANGLE                   0.00  DEG.        119.99  DEG.

REST X-POSITION                       84.50  FT.          22.90  FT.
REST Y-POSITION                       18.10  FT.          41.40  FT.
REST HEADING ANGLE                    16.50  DEG.        261.97  DEG.

END OF-ROTATION X POSITION             0.00  FT.          22.00  FT.
END-OF-ROTATION Y-POSITION             0.00  FT.          30.00  FT.
END-OF-ROTATION HEADING ANGLE          0.00  DEG.        249.97  DEG.
POINT ON-CURVE X-POSITION             40.00  FT.
POINT ON CURVE Y-POSITION              4.00  FT.
DIRECTION OF ROTATION                 CW                 CW
AMOUNT OF ROTATION                    360                360
```

Figure 14 - EDCRASH results with point on curve

Another condition was found which could cause misleading results, however. In order to illustrate this potential for error, the point on curve was again changed:

Point on curve = 40,85

The results (CRASH3, figure 17; EDCRASH, figure 18) revealed a significant difference for IMPACT SPEEDS AND SPEED CHANGES. The difference was caused by entering an errant point on curve (i.e., one which was too far away from the impact and rest positions to lie within the smallest possible circle drawn through the points which define the impact and rest positions). This was also the cause of the common velocity warning message issued by CRASH3 (figure 17).

```
S U M M A R Y    O F    C R A S H 3    R E S U L T S

RICSAC #7  CHEVELLE VS RABBIT

                          SUMMARY OF RESULTS

     IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
         FORWARD          LATERAL
VEH#1    26.2 MPH          .0 MPH
VEH#2    34.9 MPH          .0 MPH

     SPEED CHANGE (DAMAGE)
           TOTAL          LONG.          LAT.          ANG.
VEH#1    19.7 MPH     -17.1 MPH       9.9 MPH     -30.0 DEG.
VEH#2    43.0 MPH     -37.2 MPH      21.5 MPH      30.0 DEG.

     SPEED CHANGE (LINEAR MOMENTUM)
           TOTAL          LONG.          LAT.          ANG.
VEH#1    15.0 MPH     -13.5 MPH       6.5 MPH     -25.6 DEG.
VEH#2    32.7 MPH      27.0 MPH      18.4 MPH      34.4 DEG.

ENERGY DISSIPATED BY DAMAGE   VEH#1  23188.8 FT-LB  VEH#2 196486.9 FT-LB

                          RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
   VEH#1        24.9 MPH
   VEH#2         7.3 MPH
SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
   VEH#1         8.0 MPH
   VEH#2       -34.2 MPH
CLOSING VELOCITY (LINEAR MOMENTUM)
                32.2 MPH

                          SCENE INFORMATION

                                      VEHICLE # 1        VEHICLE # 2

IMPACT X-POSITION                      .00  FT.          10.70  FT.
IMPACT Y-POSITION                      .00  FT.           3.45  FT.
IMPACT HEADING ANGLE                   .00  DEG.        119.99  DEG.

REST X-POSITION                      84.50  FT.          22.90  FT.
REST Y-POSITION                      18.20  FT.          41.40  FT.
REST HEADING ANGLE                   16.50  DEG.        261.97  DEG.

END-OF-ROTATION X-POSITION             .00  FT.          22.00  FT.
END-OF-ROTATION Y-POSITION             .00  FT.          30.00  FT.
END-OF-ROTATION HEADING ANGLE          .00  DEG.        249.97  DEG.

DIRECTION OF ROTATION                CW                 CW
AMOUNT OF ROTATION                    360                360
```

Figure 15 - CRASH3 with a point on curve which was on a straight line between impact and rest

No other significant differences relating to the calculations were identified.

Graphics

EDCRASH produced a graphical output called a Site Drawing (figure 19). The display was limited to the vehicle outlines shown in plan view and placed at the user-entered impact and rest positions. A vehicle was also displayed at the end of rotation if one was entered. If a point on curve was entered, it was displayed only as an x-y point, since a PSI (heading angle) value was not supplied, and the orientation of the vehicle was not established.

The vehicle dimensions were based on the user-entered size (class) categories. The scale of the accident site was established from the minima and maxima of the impact and rest positions.

Output data was also displayed. This output was limited to impact speeds, and positions at impact and rest.

Additional details, including titles, headings, and other results, were added by typing the desired information onto the display.

```
S U M M A R Y    O F    E D C R A S H    R E S U L T S

ENGINEERING DYNAMICS CORPORATION          Date 12-09-1984  Time 12:17:44
                     RICSAC #7 CHEVELLE VS RABBIT

WARNING MESSAGES:

Damage-based estimates for Magnitude of Principal Force grossly violate
Newton's third law of motion.  Review the output to determine required
corrections to Damage Data and adjust as necessary.
The Magnitudes of Principal Force for Vehicles 1 and 2 should be
approximately equal.

User-entered point on curve for vehicle #1 was discarded because the
position was practically on a straight line between impact and rest.
If the post-impact path was curved and your point on curve was rejected
the results may be erroneous.  Check your data.

COMMON VELOCITY WARNING -- An adjustment of vehicle separation conditions
was performed in order to be consistent with the common velocity assumption.
The adjustment does not exceed 10 percent.

     IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
          FORWARD         LATERAL
VEH #1    25.9 MPH        0.0 MPH
VEH #2    34.7 MPH        0.0 MPH

     SPEED CHANGE (DAMAGE)
           TOTAL          LONG.          LAT.          ANG.
VEH #1    19.7 MPH     -17.1 MPH       9.9 MPH     -30.0 DEG.
VEH #2    43.0 MPH     -37.2 MPH      21.5 MPH      30.0 DEG.

     SPEED CHANGE (LINEAR MOMENTUM)
           TOTAL          LONG.          LAT.          ANG.
VEH #1    14.8 MPH     -13.3 MPH       6.5 MPH     -26.1 DEG.
VEH #2    32.1 MPH     -26.7 MPH     -17.9 MPH      33.9 DEG.

ENERGY DISSIPATED BY DAMAGE:  VEH #1   23188.8 FT-LB  VEH #2  196487.1 FT-LB

                          RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
   VEH #1        24.7 MPH
   VEH #2         7.3 MPH

SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
   VEH #1         8.0 MPH
   VEH #2       -33.9 MPH

CLOSING VELOCITY (LINEAR MOMENTUM)
                 31.9 MPH

                          SCENE INFORMATION

                                      VEHICLE #1         VEHICLE #2

IMPACT X-POSITION                     0.00  FT.          10.70  FT.
IMPACT Y-POSITION                     0.00  FT.           3.45  FT.
IMPACT HEADING ANGLE                  0.00  DEG.        119.99  DEG.

REST X-POSITION                      84.50  FT.          22.90  FT.
REST Y-POSITION                      18.20  FT.          41.40  FT.
REST HEADING ANGLE                   16.50  DEG.        261.97  DEG.

END-OF-ROTATION X-POSITION            0.00  FT.          22.00  FT.
END-OF-ROTATION Y-POSITION            0.00  FT.          30.00  FT.
END-OF-ROTATION HEADING ANGLE         0.00  DEG.        249.97  DEG.
DIRECTION OF ROTATION                CW                 CW
AMOUNT OF ROTATION                    360                360
```

Figure 16 - EDCRASH with a point on curve which was on a straight line between impact and rest

CONCLUSIONS

1. The CRASH program, either EDCRASH or CRASH3, represented an effective means of reconstruction for most single- and two-vehicle accidents.

2. EDCRASH and CRASH3 required the same input data.

3. EDCRASH produced additional output when compared to CRASH3, including the Magnitude of Principal Force and Graphics.

4. The major difference between EDCRASH and CRASH3 was user-interactivity. This was the result of substantial differences in program design.

```
S U M M A R Y   O F   C R A S H 3   R E S U L T S

***WARNING***   SEPARATION VELOCITIES ALONG DOPF ARE
          NOT COMPATIBLE, ACCORDING TO ASSUMPTION OF A
          COMMON VELOCITY AT THE DAMAGE AREA CENTROIDS.

RICSAC #7  CHEVELLE VS RABBIT

                     SUMMARY OF RESULTS

   IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
        FORWARD        LATERAL
VEH#1   35.7 MPH        .0 MPH
VEH#2   43.9 MPH        .0 MPH

   SPEED CHANGE (DAMAGE)
          TOTAL        LONG.        LAT.        ANG.
VEH#1   19.7 MPH    -17.1 MPH     9.9 MPH    -30.0 DEG.
VEH#2   43.0 MPH    -37.2 MPH   -21.5 MPH     30.0 DEG.

   SPEED CHANGE (LINEAR MOMENTUM)
          TOTAL        LONG.        LAT.        ANG.
VEH#1   18.8 MPH     15.8 MPH    10.2 MPH    -32.9 DEG.
VEH#2   40.9 MPH     36.4 MPH   -18.6 MPH     27.1 DEG.

ENERGY DISSIPATED BY DAMAGE  VEH#1  23188.8 FT-LB  VEH#2 196486.9 FT LB

                     RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
   VEH#1       33.9 MPH
   VEH#2        9.2 MPH
SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
   VEH#1       10.9 MPH
   VEH#2       42.9 MPH
CLOSING VELOCITY (LINEAR MOMENTUM)
               43.1 MPH
                     SCENE INFORMATION

                               VEHICLE # 1       VEHICLE # 2

IMPACT X POSITION                  .00  FT.       10.70  FT.
IMPACT Y POSITION                  .00  FT.        3.45  FT.
IMPACT HEADING ANGLE               .00  DEG.     119.99  DEG.

REST X POSITION                  84.50  FT.       22.90  FT.
REST Y POSITION                  18.20  FT.       41.40  FT.
REST HEADING ANGLE               16.50  DEG.     261.97  DEG.

END-OF-ROTATION X POSITION         .00  FT.       22.00  FT.
END OF ROTATION Y POSITION         .00  FT.       30.00  FT.
END OF ROTATION HEADING ANGLE      .00  DEG.     249.97  DEG.

POINT ON CURVE X-POSITION        40.00  FT.
POINT ON CURVE Y-POSITION        85.00  FT.

DIRECTION OF ROTATION            CW                CW
AMOUNT OF ROTATION               <360              <360
```

Figure 17 - CRASH3 with errant point on curve

5. A difference in processing time was identified. The difference was not significant unless a trajectory simulation was requested, wherein a CDC-Cyber mainframe (CRASH3) required 4.5 seconds compared to about 5 minutes for EDCRASH. Without a trajectory simulation, CRASH3 required approximately 1 second while EDCRASH required about 5 seconds.

6. EDCRASH and CRASH3 produced different results when the post-impact path for vehicle #2 had an end of rotation. This was the result of an error found in CRASH3.

7. EDCRASH and CRASH3 usually produced slightly different results when a trajectory simulation was requested. This was primarily the result of the end-of-rotation error (above).

8. EDCRASH and CRASH3 handled the case of a post-impact point on curve differently. EDCRASH performed an additional validity check to help insure valid data and corresponding results.

9. EDCRASH generated additional warning messages, both informative and fatal, resulting from validity checks for damage data and common

```
S U M M A R Y   O F   E D C R A S H   R E S U L T S

ENGINEERING DYNAMICS CORPORATION        Date 12-09-1984  Time 12:20:26
                   RICSAC #7 CHEVELLE VS RABBIT

WARNING MESSAGES:

Damage based estimates for Magnitude of Principal Force grossly violate
Newton's third law of motion.  Review the output to determine required
corrections to Damage Data and adjust as necessary.
The Magnitudes of Principal Force for Vehicles 1 and 2 should be
approximately equal.

User-entered point on curve for vehicle #1 was discarded because the
position was too far away from other path coordinates to make sense.
If the post-impact path was curved and your point on curve was rejected
the results may be erroneous.  Check your data.

COMMON VELOCITY WARNING -- An adjustment of vehicle separation conditions
was performed in order to be consistent with the common velocity assumption.
The adjustment does not exceed 10 percent.

   IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)
        FORWARD        LATERAL
VEH #1  25.9 MPH       0.0 MPH
VEH #2  34.7 MPH       0.0 MPH

   SPEED CHANGE (DAMAGE)
          TOTAL        LONG.        LAT.        ANG.
VEH #1  19.7 MPH    -17.1 MPH     9.9 MPH    -30.0 DEG.
VEH #2  43.0 MPH    -37.2 MPH    21.5 MPH     30.0 DEG.

   SPEED CHANGE (LINEAR MOMENTUM)
          TOTAL        LONG.        LAT.        ANG.
VEH #1  14.8 MPH    -13.3 MPH     6.5 MPH    -26.1 DEG.
VEH #2  32.1 MPH    -26.7 MPH    17.9 MPH     33.9 DEG.

ENERGY DISSIPATED BY DAMAGE:  VEH #1  23188.8 FT-LB  VEH #2  196487.1 FT LB

                     RELATIVE VELOCITY DATA

SPEED ALONG LINE THRU CGS (LINEAR MOMENTUM)
   VEH #1       24.7 MPH
   VEH #2        7.3 MPH

SPEED ORTHOG. TO CG LINE (LINEAR MOMENTUM)
   VEH #1        8.0 MPH
   VEH #2       33.9 MPH

CLOSING VELOCITY (LINEAR MOMENTUM)
                31.9 MPH

                     SCENE INFORMATION

                               VEHICLE #1        VEHICLE #2

IMPACT X-POSITION                 0.00  FT.       10.70  FT.
IMPACT Y-POSITION                 0.00  FT.        3.45  FT.
IMPACT HEADING ANGLE              0.00  DEG.     119.99  DEG.

REST X-POSITION                  84.50  FT.       22.90  FT.
REST Y-POSITION                  18.20  FT.       41.40  FT.
REST HEADING ANGLE               16.50  DEG.     261.97  DEG.

END-OF ROTATION X POSITION        0.00  FT.       22.00  FT.
END OF ROTATION Y POSITION        0.00  FT.       30.00  FT.
END OF-ROTATION HEADING ANGLE     0.00  DEG.     249.97  DEG.
DIRECTION OF ROTATION            CW                CW
AMOUNT OF ROTATION               360              < 360
```

Figure 18 - EDCRASH with errant point on curve

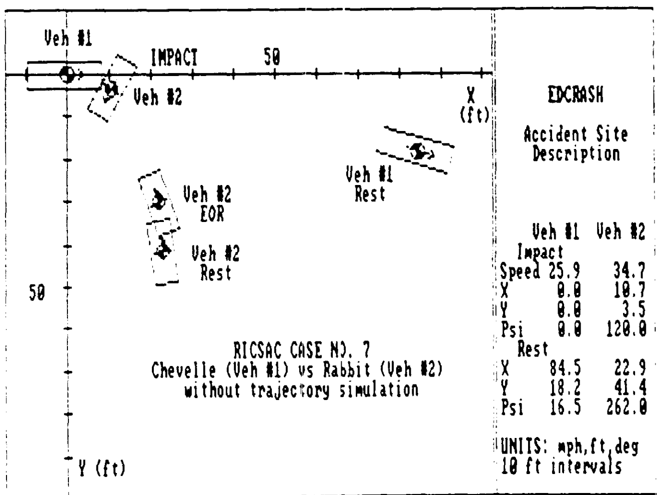

Figure 19 - EDCRASH Site Drawing

velocity to insure valid data and corresponding results.

10. EDCRASH produced a graphics display of the results.

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