THE SIMULATION MODEL OF AUTOMOBILE COLLISIONS (SMAC) OPERATOR'S MANUAL

Prepared by
Paul L. Solomon
Accident Investigation Division
NHTSA
October 4, 1974

CONTENTS

SECTION II

AN OVERVIEW OF OPERATING THE SMAC PROGRAM

The SMAC program user specifies values of input variables describing the vehicles, the accident scene, and some computation details.* The computer will return a printout giving position, heading, vector and angular velocity, as well as tire tracks, at regular time intervals throughtout the collision sequence. If desired, a graphic display of the simulated collision will also be created by a plotting subroutine. If the user is trying to simulate an actual collision, he will note differences between the actual and simulated collision, and modify the input data to obtain a better match.**

To clarify the data input procedure, we shall divide input data into four categories: vehicle properties (length, width, mass, etc.). calculation constants, initial conditions, and control inputs. Where particular vehicles are being simulated, most properties for any given make and model of car can be found in a reference manual (see reference 1). Otherwise, typical values such as those provided in the attached Table I may be used. Usually, values for vehicle properties are not changed in the iteration process mentioned above.

---

* We suggest using an input data form provided with the manual to record your decisions prior to transferring them on the computer (See Section III(D)).

** The art of modification is a subject in itself. One suggestion is to modify one variable at a time in order to attribute the total change from the last run to the present run to that sole modification. Understanding the theory of the SMAC program and understanding how a field investigator chooses a value for a variable will give you much insight into the modification phase of SMAC.

Calculation constants, such as the time interval used, the acceptable error in balancing collision forces, etc., are explained individually in this manual, and suggested values are given. Generally, changes in these variables will only have a secondary effect on accuracy of calculation, expense of run, or specific error messages discussed subsequently.

Often, the user will wish to simulate an accident in which only part of the information, say the final resting positions and tire tracks, is known. He will vary the input data, trying to obtain outputs corresponding to collision. The input variables of interest are the initial conditions (position, heading, velocity) and the control inputs (braking, accele-rative traction, and steering). Once the skid marks and final positions match fairly well, the user will presumably have obtained a good approximation of the initial positions, headings and velocities of the cars, if the vehicle properties used are accurate.

SECTION III

INPUT FORMAT*

A. Discussion

The first two records (e.g. cards) of a data deck for input to the SMAC program (if a data file is used, one line = one record) are heading records: these are for user convenience and contain no calculation data. Information placed in these records is printed at the top of each page of output to identify the printout. While they may be left blank, these records must not be omitted.

Next come 14 numbered records giving calculation input data. (In certain cases discussed later there will be additional, unnumbered records following records 8 and 11. These are the torque and steering tables.) The numbered records 1 through 14 are formatted 9F8.0, I8. (A remote time-share terminal user has the capability to input the input records in a free format.) Calculation data appear in the 9 floating point fields. A decimal point must appear in each floating point number. The card identification number appears, right justified, in the final integer field. After record 14 a final record, blank except for the number 9999 in columns 77-80, completes the input data. A sample computer printout of the input card images of a run follows in Section III B.

*Section III is subdivided into four parts which should be studied together. Once SMAC format is absorbed, the user is ready to learn the definitions of the input variables (i.e., Section IV).

6

B. Sample Computer Printout Of Input Card Images

```
                         SIMULATION MODEL OF AUTOMOBILE COLLISIONS (SMAC)
                                                 CASE-MO-IOU                    JAN. 1, 1974
 0.       2.       .05      .001     .01      .005     1.       2.       2.            1
 0.       0.       0.       0.       316.8    0.                                       2
 187.     0.       180.     0.       35.2     0.                                       3
 52.7     54.8     57.7     19762.5  7.5      0.       85.7     -100.    35.7          4
 49.5     53.      63.1     38032.8  10.6     0.       100.5    -119.6   39.6          5
 -10250.  -10250.  -10195.  -10195.                                                    6
 -10250.  -10250.  -10195.  -10195.                                                    7
 0.       1.2      .2       0.                                                         8
 -609.      -0.       -0.       -0.       -0.       -0.       -0.
 -609.      -0.       -0.       -0.       -0.       -0.       -0.
 -406.      -0.       -0.       -0.       -0.       -0.       -0.
 -406.      -0.       -0.       -0.       -0.       -0.       -0.
 0.       1.2      .2       0.                                                         9
 -861.      -861.     -861.     -861.     -861.     -861.     -861.
 -861.      -861.     -861.     -861.     -861.     -861.     -861.
 -574.      -574.     -574.     -574.     -574.     -574.     -574.
 -574.      -574.     -574.     -574.     -574.     -574.     -574.
 0.       .3       .1       1.                                                        10
 0.       .3       .1       1.                                                        11
 0.       70.      100.     70.      .7       .7       .0003                          12
 2.       .2       15.      5.       30.      50.      .55                            13
 .06423   3.5417-34.7381-5                                                            14
                                                                                    9999
```

C. Annotated User's Sheet

INPUT DATA FORM (SMAC)

Field Number	1	2	3	4	5	6	7	8	9	10	Comments
Col. range	1-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64	65-72	73-80	
	2 lines of 80 characters for identifying a particular run. If a line is left blank, in keeping with format, it cannot be left out.										
										1	← In col. 80
										2	← In col. 80
										3	← In col. 80
										4	← In col. 80
										5	← In col. 80
										6	← In col. 80
										7	← In col. 80
										8	← In col. 80
	7 fields that are 10 characters wide per line--a maximum of 201 fields										
										9	← In col. 80
	7 fields that are 10 characters wide per line--a maximum of 201 fields										
										10	← In cols. 79,80
	7 fields that are 10 characters wide per line--a maximum of 201 fields										
										11	← In cols. 79,80
	7 fields that are 10 characters wide per line--a maximum of 201 fields										
										12	← In cols. 79,80
										13	← In cols. 79,80
										14	← In cols. 79,80
										9999	← In cols. 77-80

DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

D. USER'S SHEET

1	2	3	4	5	6	7	8	9	10	COMMENTS
									1	
									2	
									3	
									4	
									5	
									6	
									7	
									8	
									9	
									10	
									11	
									12	
									13	
									14	
									9999	

SECTION IV
DESCRIPTION OF INPUT VARIABLES*

A. Detailed Input Variable Description

Input data variables are listed below in the following manner:

(1) A pointer denotes the card and the field position within that card (e.g., the pointer 1:3 refers to card 1, field 3).

(2) The variable name as it occurs in the program (e.g., DTTRAJ).

(3) Where applicable, a symbol is used in analysis, usually a Greek letter with appropriate subscript.

(4) An explanation of the variable is given.

(5) Where called for, suggested values are given.

(Note 0 indicates zero, Ø indicates letter "oh").

1:1 TO — The time, in seconds, at which the program starts. TO is arbitrary, and is generally chosen to be 0.0 for convenience.

1:2 TF — The time, in seconds, at which the program ends. TF-TO=total duration of the run.

1:3 DTTRAJ — The program approximates a continous, non-linear path in time and space by breaking it into small increments, taken as linear, rather than by a true line integral. DTTRAJ is the time interval of integration before, and again after, vehicle contact. This will generally be the largest time interval used (on the order of .05 seconds, smaller where forces or speeds are usually high), since changes are gradual and continous during trajectory.

[With this, and with all intervals, a smaller value will yield greater accuracy, but will also increase computer time and expense. In general, the accuracy desired will be greater when the user wishes to match a set of empirical data than when seeking to simulate a situation for heuristic purposes.]

1:4 DTCØLL — This is the interval of integration, in seconds, during the collision, where large crash forces require a small time interval (on the order of .001) to obtain a good approximation.

*It is recommended that until becoming "adequate" in the utilization of SMAC that the user rely on the detailed input variable description of Section IV(A) rather than the brief input variable description of Section IV(B).

1:5	DTCØLT		This is the interval of integration in seconds for the first 100 time increments immediately after vehicle separation. DTCØLT will generally be smaller than DTTRAJ (e.g., .01) since higher speeds and spin are often involved at this stage.
1:6	DTPRNO		The printout time interval in seconds.
1:7 1:8	UVMIN) PSIDMN)		If the absolute value of the total vector velocity in inches/second is less than UVMIN for both vehicles, and the absolute value of the angular velocity in degrees/second is less than PSIDMN for both vehicles, the run terminates. If no minimum value cut-off is desired, these can be set to 0.0. (1 mph = 17.6 inches/second)
1:9	IVEHO		Number of simulated vehicles (1. or 2.) if IVEHO = 1., program ignores inputs on records 3, 5,7,9 & 11; however, these records must be included in keeping with format.
1:10			The numerals 01, 02, - - - -, 14 go in columns 79 and 80 (see Section III(C)). This item is omitted on subsequent record explanation.
2:1	XCP10	$X'c10$	The X' coordinate, in inches, of the center of gravity of of vehicle 1, (V1). The smaller vehicle should be entered as V1 Collision forces are calculated in a clockwise sweep of V1. The force calculations are less accurate in the vicinity of a narrow intrusion; therefore, accuracy is improved when V1 is the smaller vehicle. A fixed Cartesian coordinate system is used, with the positive X' axis shown pointing upward, and the positive Y' axis to the right. Angles are measured clockwise from the positive X' axis.
2:2	YCP10	$Y'c10$	The Y'-coordinate, in inches, of the center of mass of V1. (See also comments on XCP10).
2:3	PSI10	$\psi 10$	The heading angle, in degrees of V1 measured clockwise from the positive X' axis.
2:4	PSI1DO	$\dot{\psi} 10$	The angular velocity, in degrees/second of V1. Taken to be positive when rotation is clockwise.
2:5	U10	$\psi 10$	The initial forward velocity of V1 in inches/second. The longitudinal component of the total vector velocity of V1.

2:6	V10		The initial sideway velocity of V1 in inches/second with right taken as positive.
3:1	XCP20 YCP20 PSI20 PSI20 U20 V20	X'_{c20} Y'_{c20} ψ_{20} ψ_{20} u_{20} v_{20}	Same as Card 2; except for vehicle 2.
4:1	A1	a_1	The distance in inches from the center of gravity of V1 to the midpoint between the front wheels (see Table I for typical values).
4:2	B1	a_1	The distance in inches from the center of gravity of V1 to the midpoint between the rear wheels, taken as positive (see Table I for typical values).
4:3	TR1	T_1	Average tread width in inches, i.e., distance between left and right tires, averaged over front and rear pairs (for typical values, see Table I).
4:4	FIZ1	I_{z1}	Yaw inertia, in lb-sec^2-inches, of V1. This is a measure of the torque needed to induce a given spin in V1, and depends both on the total mass of the vehicle and on how far this mass is, on the average, from the center of gravity. For typical values of mass and of k^2 ($Iz1 = k^2 \times M$), see Table I.
4:5	FMASS1	M_1	The total mass of V1, measured in lb-sec^2/inch. If vehicle weight in lbs. is known, mass in lb-sec^2/inch can be found by dividing by 386.4 (for typical values see Table I).
4:6	PSIR10	ψ_{R1}	The rear axle steer angle in degrees; angular displacement from normal orientation, with clockwise displacement taken as positive (thus for undamaged rear axle = 0.0).

4:7	XF1		Distance in inches from center of gravity of V1 to the front end of the car body. (For typical values, see Table I.)
4:8	XR1		Distance in inches from center of gravity V1 to the rear end of the car body, taken as <u>negative</u>. (For typical values, see Table I.)
4:9	YS1		Distance in inches from the center of gravity of V1 to the side of the car body; 1/2 total width. (For typical values, see Table I.)
5:1	A2	a_2)	Same as 4:1-9 except for vehicle 2.
5:2	B2	b_2)	
5:3	TR2	T_2)	
5:4	FIZ2	I_z2)	
5:5	FMASS2	M)	
5:6	PSIRSO	$\psi r2$)	
5:7	XF2	x_{F2})	
5:8	XR2	x_{R2})	
5:9	YS2	y_{S2})	
6:1	CSTF1(1)	c_{11}	Cornering stiffness for small angles, in lbs/radian, for right front tire of V1. When the tire is directed at an angle to the direction of motion, a steering force occurs in a direction perpendicular to the direction in which the tires are pointed. This force does not vary linearly with the tire slip angle, but relation is nearly linear for small slip angles. The nominal cornering stiffness is the normal force in pounds divided by the slip angle in radians for small angles. For larger angles the rate of increase of perpendicular force with increasing angle falls off as "saturation" is approached. The program handles this in a standard manner for all tires.

Typical values for cornering stiffness are -10200 lbs/radian. Cornering stiffnesses are input separately to allow the simulation of tire damage--a damaged tire which has lost its pressure will have a far lower cornering stiffness, perhaps 20 percent of that for an undamaged tire. Under-inflated tires will have somewhat lower cornering stiffnesses than the values given, but far greater than seriously damaged tires.

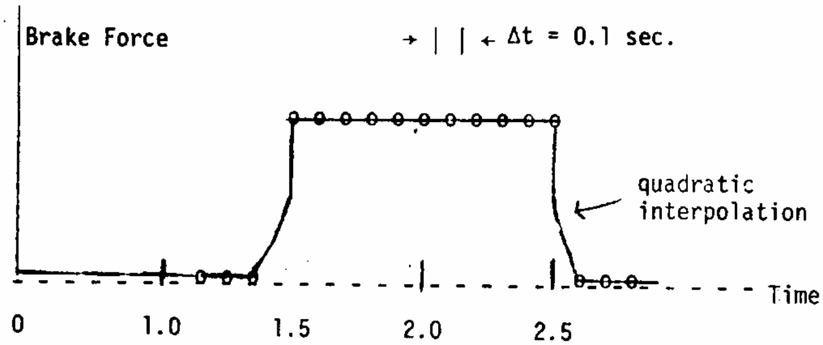
6:2	CSTF1(2)	C_{12}	Cornering stiffness, left front tire of V1, lbs/radian.
6:3	CSTF1(3)	C_{13}	Cornering stiffness, right rear tire of V1, lbs/radian.
6:4	CSTF1(4)	C_{14}	Cornering stiffness, left rear tire of V1, lbs/radian.
7:1	CSTF2(1)	C_{21}	Same as 6:1-4, except for V2.
7:2	CSTF2(2)	C_{22}	
7:3	CSTF2(3)	C_{23}	
7:4	CSTF2(4)	C_{24}	
8:1	TBTQ1		Initial time in seconds for V1's Torque (braking or accelerating) inputs. When applying torque to V1 after the run has begun (TBTQ1>TO), at least three zero inputs prior to time TBTQ1 should be inputed. This is done to accommodate quadratic interpolations which require two end points and one turning point (thus 3 points).
8:2	TETQ1		End time for torque inputs for V1 in seconds. If control inputs for torque end in the middle of a run (TETQ1<TF) input tables should end with three zero inputs to insure zero control inputs after TETQ1 (same reasoning as 8:1).
8:3	TINCQ1		Time increment for torque inputs, V1, in seconds. One value for torque is input each increment, so the size of TINCQ determines the fineness with which braking and traction can be described by the mathematical model.
8:4	NTBLQ1		If this variable is set equal to zero, the program reads the torque input tables and includes them in the calculations for the run. If any other value is entered the program ignores card #8 and there are no torque inputs for V1. For cards #8-11, when the final variable is set equal to 0.0, the card is followed by tables, each consisting of from 1 to 29 unnumbered cards, formatted (7F10.0). Each table represents the control inputs for a single wheel. Accelerative torque inputs are positive, braking inputs negative, both are in pounds. The number of entries per wheel is $\frac{\text{TETQ1 - TBTQ1}}{\text{TINCQ1}} + 1$. Entries for each wheel begin on a new card.

8:4 (Continued)

If a friction decrement with speed is used (item 12:7), at high speeds, friction and thus maximum possible tire force will be reduced. Also, if both steering and traction inputs are included for a given tire, the vector sum of these inputs cannot exceed the maximum possible force for that tire. If too large a force is entered, the program will substitute the largest possible value (i.e., a value equal to the product of the weight on that tire multiplied by the coefficient of friction).

To illustrate the torque input process, an example is in order.

Example of Torque Input. It is desired to apply the brakes of the rear wheels of a 4,000-lb vehicle (V1) strong enough to lock those wheels during the interval from 1.5 to 2.5 seconds after the program starts. Brake forces are zero at other times. (Steering inputs would be handled in the same manner as this braking example.)



Card 8	1.2	2.8	0.1	0.				
Torque Table	0.	0.	0.	0.	0.	0.	0.	)
	0.	0.	0.	0.	0.	0.	0.	) RF Wheel
	0.	0.	0.					)

(Plus 3 cards for LF wheel identical to . . . . .

8:4 (Continued)

RR Wheel	(	0.	0.	0.	-2000.	-2000.	-2000.	-2000.
	(	-2000.	-2000.	-2000.	-2000.	-2000.	-2000.	-2000.
	(	0.	0.	0.				

(Plus 3 cards for LR wheel, identical to RR wheel)

Notice that the start and end times are three time increments before and after the brake pulse, respectively, to allow for insertion of three zero force inputs as discussed under 8:1 and 8:2.

Notice that the braking force input (-2000 lbs. on each rear wheel) exceeds the maximum friction force available at that wheel (approximately 1/4 of vehicle weight x friction coefficient). This is done to insure skidding. The program will combine this force vectorially with any steering forces present, and limit the resultant to the maximum friction force.

Tables for Card 8:

(1) Traction (+) or braking (-) inputs, right front wheel, V1, in pounds force.

(2) Same, left front wheel.

(3) Same, right rear wheel.

(4) Same, left rear wheel.

9:1	TBTQ2	Same as 8:1-4 and subsequent tables, except for V2.
9:2	TETQ2	
9:3	TINCQ2	
9:4	NTBLQ2	
Tables (1-4)		
10:1	TBPSF1	Starting time for steer inputs, in seconds, V1. (See 8:1; same format as torque inputs.)
10:2	TEPSF1	End time for steer inputs, in seconds, V1 (see 8:2).
10:3	TINCP1	Time increment for steer inputs, in seconds, V1 (see 8:3).
10:4	NTBLP1	If ≠0.0, program ignores card 10 and no steering inputs are used in calculations for V1.

Steer tables are exactly like torque tables (see note on control inputs after card 8) except that values input represent tire angle, in degrees (left turn is negative, right is positive, straight ahead is 0.0 degrees). There are only 2 tables per vehicle since only front wheels are steered.

Tables for Card 10:

(1) Steer inputs, right front tire, V1, in degrees.

(2) Steer inputs, left front tire, V1, in degrees.

11:1	TBPSF2)	Same as 10:1-4 and subsequent tables, but for V2.
11:2	TEPSF2)	
11:3	TINCP2)	
11:4	NTBLP2)	
Tables (1-2))		

12:1	XBP(1)	x'_{B1}	These coordinates, in inches, define two points, $B_1 = (x'_{B1}, y'_{B1})$ and $B_2 = (x'_{B2}, y_{B2})$ in the plane of the tire forces. These 2 points determine a boundary line, dividing the plane into two zones which may be assigned different coefficients of friction. This allows the user to simulate a vehicle running onto a dirt shoulder field, etc., or any such situation which demands two adjacent areas of different frictional properties. The zone on the side of the line which contains the origin is defined as zone 1, and the other zone 2.
12:2	YBP(1)	y'_{B1}	
12:3	XBP(2)	x'_{B2}	
12:4	YBP(2)	y'_{B2}	
12:5	XMU1	μ_1	The coefficient of friction in zone 1. The coefficient can be made to vary with speed (see 12:7); it is assumed independent of other factors within a zone. Use 0.7 for dry pavement, 0.3 for wet.
12:6	XMU2	μ_2	The coefficient of friction in zone 2 (see above).
12:7	CMU	c_μ	The coefficient of linear decrement of friction with tire speed in seconds/inch. In general, the effective tire-surface friction coefficient decreases with speed and c_μ simulates this decrease. The effective friction coefficient, used in all SMAC calculations, is computed as μ effective $= \mu_0 - c_\mu \lvert v \rvert$ where μ_0 is the nominal co-effficient of friction, and is the tire speed. Thus, if no decrement is desired as speed increases, is set to 0.0. The recommended value is .0003.
13:1	DELPSO	$\Delta\psi$	The interval between radial vectors in degrees. The SMAC program calculates all collision forces in a clockwise sweep about the center of gravity of V1. The sweep is broken into increments of size (360 $\Delta\psi$ DELPSO must be an integar). Too large a value of $\Delta\psi$ will cause inaccuracies, too small a value will exceed the program's capacity. The collision interface is handled in a table of up to 100 points. If more than 100 points are required to handle the damage area, the message "ISTOP = 9" appears on the printout. The suggested value is 2. degrees, which can be increased (e.g. to 3.) if the error message "ISTOP = 9" appears.
13:2	DELRØO	$\Delta\rho$	The increment of change of the radius vector in inches. (See explanation after card 13.) A value of around .2 is recommended.

13:3	ALAMB	λ	The acceptable error in intervehicle pressure equilibrium, in pounds/inch. Choose λ greater than K_{v1} times $\Delta\rho$ and also greater than K_{v2} times $\Delta\rho$ (see explanation after card 13) e.g. for K_{v1} = 30., K_{v2} = 50., $\Delta\rho$ = .2, λ could be 12.
13:4	ZETAV	ζ_v	The minimum relative velocity for intervehicle friction, in inches/second. If, while in contact, the adjacent surfaces of the two vehicle move with respect to each other at a speed less than this, intervehicle friction is ignored. A value of around 5.0 inch/second is recommended.
13:5	AKV(1)	K_{v1}	Load-deflection characteristic, in pounds/inch^2, of V1 (see explanation after card 13). Values range from around 30. for subcompact cars to around 50. for full-sized.
13:6	AKV(2)	K_{v2}	Same as above, but for V2.
13:7	AMU	μ	This is the coefficient of friction between the two vehicles when they are in contact and the adjacent surfaces of V1 and V2 are moving with respect to each other (at a velocity greater than ζv). The force tangent to the interface opposing the relative motion = ζ times the force with which the surfaces press together. A value of about .55 is recommended.

Note on $\Delta\rho$, λ, K_{v1} and calculation of collision forces:

As the body of a car is crushed, it exerts a force proportional to that crush. The SMAC program assumes that at any point on the interface between two vehicles, the pressures exerted by the two surfaces must be essentially equal. Since the simulation is two-dimensional, units for pressure are in pounds/inch. Since the pressure is (assumed) proportional to the depth of crush, with the car body assumed to be homogeneous, the load-deflection characteristic K_v is in units of pressure/inch of crush = (pounds/inch)/inch = lbs/in.^{2}. Points displaced by crush forces are constrained to move along the radial line from the vehicle center of gravity to the initial position of the displaced point before damage occurred. The program simulates crush by adjusting each of the radii in increments of $\Delta\rho$ until the pressures exerted balance to within an allowed error of λ.

Since for solution stability there must always be a value of ρ tested for which the pressures balance to within λ, and the change in pressure per increment $\Delta\rho$ is $K_v\Delta\rho$, it is necessary that $\lambda > K_v\Delta\rho$ for both K_{v1} and K_{v2}.

The program, in seeking equilibrium, will increment ρ by Δρ up to 200 times. It this is insufficient, the message ISTOP = 7 will appear on the output, and execution will terminate. If the condition $\lambda > K_{v1}\Delta\rho$, $K_{v2}\Delta\rho$ was satisfied, then a larger value of Δρ is needed (e.g. to .3 inches) when adjusting Δρ or K_v, be sure to adjust λ also if necessary.

14:1	C0	C_0	Coefficients of assumed parabolic variation of coefficient restitution. The car body is to have some elasticity with the degree of restitution varying non-linearly with the degree of deformation. Recommended values are .06423, 3.5417×10^{-3}, and 4.7381×10^{-5}, respectively. (To fit in the field of 8 columns the latter two should be entered as 3.5417-3 and 4.7381-5, which are interpreted as scientific notation).
14:2	C1	C_1	
14:3	C2	C_2	
(15:10)			Two numerals 9999 appear in columns 77-80. Be sure all the numbered cards 1-14 have their number included, right justified, in the final integer field of each card.

B. Brief Input Variable Description

Card No.	Program Variable	Analysis Variable	Definition	Units
1	TO	-	Start time	Seconds
	TF	-	End time	Seconds
	DTTRAJ	-	Interval of integration at beginning and ending of run	Seconds
	DTCØLL	-	Interval of integration during collision contact	Seconds
	DTCØLT	-	Interval of integration for 100 time increments subsequent to separation	Seconds
	DTPRNO	-	Output time interval	Seconds
	UVMIN	-	Vector velocity test for stop	Inches/Sec
	PSIDMN	-	Angular velocity test for stop	Degrees/Sec
	IVEHO	-	Number of Simulated Vehicles (1.0 or 2.0)	-
2	XCP10	x'_{c10}	Vehicle 1, initial x'_c	Inches
	YCP10	y'_{c10}	Vehicle 1, initial y'_c	Inches
	PSI10	ψ_{10}	Vehicle 1, initial ψ	Degrees
	PSI1D0	$\dot{\psi}_{10}$	Vehicle 1, initial $\dot{\psi}$	Degrees/Sec
	U10	u_{10}	Vehicle 1, initial u	Inches/Sec
	V10	v_{10}	Vehicle 1, initial v	Inches/Sec
3	XCP20	x'_{c20}	Vehicle 2, initial x'_c	Inches
	YCP20	y'_{c20}	Vehicle 2, initial y'_c	Inches
	PSI20	ψ_{20}	Vehicle 2, initial ψ	Degrees
	PSI2D0	$\dot{\psi}_{20}$	Vehicle 2, initial $\dot{\psi}$	Degrees/Sec
	U20	u_{20}	Vehicle 2, initial u	Inches/Sec
	V20	v_{20}	Vehicle 2, initial v	

Card No.	Program Variable	Analysis Variable	Definition	Units
4	A1	a_1	Vehicle 1, CG to F. Wheel ℄ (+)	Inches
	B1	b_1	Vehicle 1, CG to R. Wheel ℄ (+)	Inches
	TR1	T_1	Vehicle 1, Average Tread	Inches
	FIZ1	I_{Z1}	Vehicle 1, Yaw Inertia	$Lb\text{-}Sec^2\text{-}In$
	FMASS1	M_1	Vehicle 1, Total Mass	$Lb\text{-}Sec^2/In.$
	PSIR10	ψ_{R1}	Vehicle 1, Rear Axle Angle (Damage)	Degrees
	XF1	X_{F1}	Vehicle 1, CG to Front (+)	Inches
	XR1	X_{R1}	Vehicle 1, CG to Rear (-)	Inches
	YS1	Y_{S1}	Vehicle 1, CG to Side (+)	Inches
5	A2	a_2	Vehicle 2, CG to F. Wheel ℄ (+)	Inches
	B2	b_2	Vehicle 2, CG to R. Wheel ℄ (+)	Inches
	TR2	T_2	Vehicle 2, Average Tread	Inches
	FIZ2	I_{Z2}	Vehicle 2, Yaw Inertia	$Lb\text{-}Sec^2/In$
	FMASS2	M_2	Vehicle 2, Total Mass	$Lb\text{-}Sec^2/In$
	PSIR20	ψ_{R2}	Vehicle 2, Rear Axle Angle (Damage)	Degrees
	XF2	X_{F2}	Vehicle 2, CG to Front (+)	Inches
	XR2	X_{R2}	Vehicle 2, CG to Rear (-)	Inches
	YS2	Y_{S2}	Vehicle 2, CG to Side (+)	Inches
6	CSTF1(1)	C_{11}	Vehicle 1, RF Tire Cornering Stiffness	Pounds/Radian
	CSTF1(2)	C_{12}	Vehicle 1, LF Tire Cornering Stiffness	Pounds/Radian
	CSTF1(3)	C_{13}	Vehicle 1, RR Tire Cornering Stiffness	Pounds/Radian
	CSTF1(4)	C_{14}	Vehicle 1, LR Tire Cornering Stiffness	Pounds/Radian

Card No.	Program Variable	Analysis Variable	Definition	Units
7	CSTF2(1)	C_{21}	Vehicle 2, RF Tire Cornering Stiffness	Pounds/Radi
	CSTF2(2)	C_{22}	Vehicle 2, LF Tire Cornering Stiffness	Pounds/Radi
	CSTF2(3)	C_{23}	Vehicle 2, RR Tire Cornering Stiffness	Pounds/Radi
	CSTF2(4)	C_{24}	Vehicle 2, LR Tire Cornering Stiffness	Pounds/Radi
8	TBTQ1	-	Initial time for torque inputs, Vehicle 1	Seconds
	TETQ1	-	Final time for torque inputs, Vehicle 1	Seconds
	TINCQ1	-	Time increment for torque inputs, Vehicle 1	Seconds
	NTBLQ1	-	If ≠ 0.0, do not read table	-

(1) Table of Traction (+) or Braking (-) Force at RF Wheel, Vehicle 1 Card format 7F10.0, use three to two hundred and one values for each wheel. The number of entries for each wheel is computed as

$$\frac{TETQ1 - TBTQ1}{TINCQ1} + 1.$$

Start the entries for each wheel on a new card. Seven entires per card.

(2) Table of Traction (+) or Braking (-) Force at LF Wheel, Vehicle 1

(3) Table of Traction (+) or Braking (-) Force at RR Wheel, Vehicle 1

(4) Table of Traction (+) or Braking (-) Force at LR Wheel, Vehicle 1

Card No.	Program Variable	Analysis Variable	Description	Units
9	TBTQ2	-	Initial time for torque inputs, Vehicle 2	Seconds
	TETQ2	-	Final time for torque inputs, Vehicle 2	Seconds
	TINCQ2	-	Time increment for torque inputs, Vehicle 2	Seconds
	NTBLQ2	-	If ≠ 0.0, do not read table	-

(1) Table of Traction (+) or Braking (-) Force at RF Wheel, Vehicle 2

(2) Table of Traction (+) or Braking (-) Force at LF Wheel, Vehicle 2

(3) Table of Traction (+) or Braking (-) Force at RR Wheel, Vehicle 2

(4) Table of Traction (+) or Braking (-) Force at LR Wheel, Vehicle 2

(Tables (2) and (3): See comments following card 8)

Card No.	Program Variable	Analysis Variable	Description	Units
10	TBPSF1	-	Initial time for steer inputs, Vehicle 1	Seconds
	TEPSF1	-	Final time for steer inputs, Vehicle 1	Seconds
	TINCP1	-	Time increments for steer inputs, Vehicle 1	Seconds
	NTBLP1	-	If ≠ 0.0, do not read table	-

(1) Steer Table (degrees) for RF Wheel, Vehicle 1

(2) Steer Table (degrees) for LF Wheel, Vehicle 1

(See comments following card 8)

Card No.	Program Variable	Analysis Variable	Description	Units
11	TBPSF2	-	Initial time for steer inputs, Vehicle 2	Seconds
	TEPSF2	-	Final time for steer inputs, Vehicle 2	Seconds
	TINCP2	-	Time increments for steer inputs, Vehicle 2	Seconds
	NTBLP2	-	If ≠ 0.0, do not read table	-

(1) Steer Table (degrees) for RF Wheel, Vehicle 2

(2) Steer Table (degrees) for LF Wheel, Vehicle 2

(See comments following card 8)

Card No.	Program Variable	Analysis Variable	Description	Units
12	XBP(1)	X'_{B1}	Points defining boundary between terrain zones	Inches
	YBP(1)	Y'_{B1}		Inches
	XBP(2)	X'_{B2}		Inches
	YBP(2)	Y'_{B2}		Inches
	XMU1	μ_1	Tire-Terrain Friction Coefficient at Zero Speed (Zone 1)	-
	XMU2	μ_2	Tire-Terrain Friction Coefficient at Zero Speed (Zone 2)	-
	CMU	C_μ	Coefficient of linear decrement of friction with tire speed	-
13	DELPS0	$\Delta\psi$	Interval between radial vectors	Degrees
	DELRØ0	$\Delta\rho$	Increment of change in radius vector	Inches
	ALAMB	λ	Acceptable error in equilibrium	Lb/Inch
	ZETAV	ζ_V	Minimum relative velocity for friction	Inches/Sec
	AKV(1)	K_{V1}	Load-deflection characteristic, Vehicle 1	Lb/In^2
	AKV(2)	K_{V2}	Load-deflection characteristic, Vehicle 2	Lb/In^2
	AMU	μ	Intervehicle friction coefficient	-

Card No.	Program Variable	Analysis Variable	Description	Units
14	C0	C_0	Coefficients of assumed parabolic variation of coefficient of restitution with deflection	-
	C1	C_1		-
	C2	C_2		-

SECTION V

OUTPUT FORMAT

A. Discussion

The output of the SMAC program is largely self-explanatory, but to prevent any initial confusion it will be briefly discussed here. The output consists of printout and an optional graphic display.

The printout first gives a line-for-line transcription of the input record. This is followed by a table of input data in which the variable name and units, as well as the input value, are printed; thus when the user wants to find a particular variable it is not necessary to identify the specific input field. Directly under this table, control inputs (from torque and steering tables) are listed.

Next comes the main body of the printout. The first page, marked page 1 in the upper right hand corner, gives the following data for vehicle 1 in labeled columns:* Coordinate position of the center of mass, the heading angle, for forward and lateral velocities, the angular velocity, the acceleration in the forward and lateral directions, and the absolute magnitude of the total acceleration.

---

* As always with the SMAC program, coordinates are in a Cartesian system with the positive x-axis at "North", positive y-axis at "East", and angles measured clockwise from the positive x-axis. For angular velocity, clockwise is positive, and for vector velocity forward and right are positive, backward and left negative. It should be noted that, although input are in inches, output are in feet.

Page 2 gives the velocity vector direction and tire tracks for vehicle 1. The velocity vector is the angle at which the car is moving with respect to its forward direction, measured clockwise from straight forward. Then the coordinate position of each tire is given for each time increment. The asterisk next to the coordinates denotes skidding tires.

Page 3 and 4 repeat this information for vehicle 2. The page after page 4, numbered page 1, begins again with vechicle 1 at the next time increment following vehicle 1's previous page 1. This 4-page pattern of vehicle 1's moving coordinate position and tire tracking (same for vehicle 2) repeats till the run ends.

At any time when the time increment changes, there is an announcement on the page prior to the first page including the new increment. The announcement includes values of the old and new increments, and the time of switchover. (For explanation of the roles of the respective Δt's, see items 1:3-5 in the preceding section.)

At the end of this main table, there are miscellaneous subroutine messages and then a damage summary. The first part of the summary is a table of displaced points--any point moved by crush forces is given in two forms, polar and cartesian. Specifically, for each vehicle ther is a table of 4 columns. The first two give radius in inches and angle in degrees (measured clockwise from front center) of each displaced point with respect to the center of gravity of the vehicle. The other two columns give x and y coordinates of the displaced points in the vehicle-fixed coordinate system (origin at center of gravity, positive x-axis through front center, positive y-axis to right).

Below the table of displaced points for each vehicle is a concise discription of the damage, given in the following form for each vehicle: the beginning and end points of the damage area in polar coordinates, the angular coordinate of the midpoint of damage, the vehicle damage index (VDI), and ΔV. ΔV is the total change in velocity (the time integral of the absolute value of the acceleration) over the period where acceleration exceeds 1 g. given in mph.

In addition to the printout, the SMAC program can create a graphic display of the simulated accident showing the position at impact, final position, damage, and tire tracks. The display consists of a heading, which includes the first two cards of input, the plot of collision, and a table of data. The plot includes labeled X' and Y' axes with a scale given at the bottom. The position of each car at impact is shown with dotted lines, and the final position with solid lines. Where damage has occurred, the solid line shows the damaged outline, with the original outline superimposed with dotted lines. Vehicles are labeled vehicle 1 and vehicle 2, and heading is given by a triangle inside each car outline, pointing in the forward direction. A small circle indicates the center of gravity. Tire tracks are also shown--solid lines where the tire is skidding, dotted lines where it is rolling.

The table appearing beneath the plot gives the following information for vehicles #1 and #2: coordinate position of the center of gravity, heading angle, forward and lateral velocity in mph and angular velocity at impact, coordinate position of center of gravity, heading angle and remarks on presence or absence of motion at end of run, and figures for vehicle damage index and ΔV (See Section V(C), page 36 for graphic display).

B. Sample Computer Printout (This output resulted from the input data shown in IIIB)

```
                         SIMULATION MODEL OF AUTOMOBILE COLLISIONS (SMAC)
                                      CAL-CASE-MU-IOU
                                       JAN. 13.1974

            INITIAL CONDITIONS                                               CALCULATION CONSTANTS
   VEHICLE NO. 1                           VEHICLE NO. 2

XC10'    =     0.0   INCHES          XC20'   =  187.000 INCHES          DELPSI   =   2.000 DEGREES
YC10'    =     8.000 INCHES          YC20'   =    0.0   INCHES          DELRHO   =   0.200 INCHES
PSI10    =     0.0   DEGREES         PSI20   =  180.000 DEGREES         LAMBDA   =  15.000 LB/IN.PRESSURE ERROR
PSI10D   =     0.0   DEG/SEC         PSI20D  =    0.0   DEG/SEC         ZETAV    =   5.000 IN/SEC.MIN.FOR FRICT
U10      =   316.800 IN/SEC          U20     =   35.200 IN/SEC
V10      =     0.0   IN/SEC          V20     =    0.0   IN/SEC

         DIMENSIONS AND INERTIAL PROPERTIES                             DEFORMABLE LAYER
A1       =    52.700 INCHES          A2      =   60.500 INCHES          KV1      =   30.000 LB/(IN**2)
B1       =    54.800 INCHES          B2      =   63.030 INCHES          KV2      =   50.000 LB/(IN**2)
TR1      =    57.700 INCHES          TR2     =   63.100 INCHES          MU.FRICT =    0.550
I1       =  19763.   LB-SEC**2-IN    I2      = 38033.  LB-SEC**2-IN     C0       =    0.064 RESTITUTION
M1       =     7.500 LB-SEC**2/IN    M2      =   10.600 LB-SEC**2/IN    C1   =  0.35417E-02   VERSUS
PSIR10   =     0.0   DEGREES         PSIR20  =    0.0   DEGREES         C2   =  0.47381E-04   DEFLECTION
XF1      =    85.700 INCHES          XF2     =  100.500 INCHES
XR1      =  -100.000 INCHES          XR2     = -119.630 INCHES
YS1      =    35.700 INCHES          YS2     =   39.630 INCHES

                                       TIRE PROPERTIES
            CORNERING STIFFNESS                                          TIRE-TERRAIN COEF AND TERRAIN ZONES
C(1)     = -10250.  LB/RAD           C(5)    = -10250.  LB/RAD          XB1' =   0.0    IN.    YB1' =  70.000 IN.
C(2)     = -10250.    ''             C(6)    = -10250.    ''            XB2' = 100.000  IN.    YB2' =  70.000 IN.
C(3)     = -10195.    ''             C(7)    = -10195.    ''            XMU1 =   0.700
C(4)     = -10195.    ''             C(8)    = -10195.    ''            XMU2 =   0.700
                                                                        CMU  =   0.30000E-03

   PSIB RANGE TESTS                   PSIBI FOR RHOBI TESTS             PROGRAM CONTROL DATA
   COLLISION CRITERIA                 COLLISION CRITERIA
PSILIM1  =  70.000 DEGREES           PSILIM5 =  10.000 DEGREES          T0       =  0.0    SEC.,BEGIN
PSILIM2  = 110.000   ''              PSILIM6 = 170.000   ''             TF       =  2.000   ''  END
PSILIM3  = 250.000   ''              PSILIM7 = 190.000   ''             DTTRAJ   =  0.050   ''  INTEG. INTVL.TRAJ
PSILIM4  = 290.000   ''              PSILIM8 = 350.000   ''             DTCOLL   =  0.001   ''  INTEG.INTVL.COLL
                                                                        DTCOLT   =  0.010   ''  INTEG.INTVL.CPOS
                                                                        DTPRNT   =  0.005   ''  PRINT INTERVAL
                                                                        UVMIN    =  1.000 IN/SEC STOPPING TEST
                                                                        PSIDOT   =  2.000DEG/SEC STOPPING TEST
                                                                        NO.OF VEHICLES = 2.
                                                                         FMOV'E =  0.(ZERO.FINAL DAMAGE TABLE TAPE
                                                                                     (NON-ZERO.DAMAGE HISTORY TAPE
                                                                                     (ALSO WRITTEN ON FORTRAN 2.
                                                                                       (TAPE IS ALWAYS FORTRAN 1)

FI(I,K),I= 1, 2),K=1,   4) STEER TABLES ALL ZERO FOR VEHICLE NO. 1
FI(I,K),I= 3, 4),K=1,   4) STEER TABLES ALL ZERO FOR VEHICLE NO. 2
```

PAGE 1

SIMULATION MODEL OF AUTOMOBILE COLLISIONS (SMAC)
CAL-CASE-MO-IDU
JAN. 13.1974
VEHICLE NO. 1

TIME	C.G. POSITION		HEADING ANGLE	VELOCITIES		ANGULAR VELOCITY	ACCELERATION		
	XCI*	YCI*	PSI1	FWD	LAT	PSI1DOT	AX1	AY1	ACC1
SEC.	FT	FT	DEG	FT/SEC	FT/SEC	DEG/SEC	G	G	G
0.0	0.0	0.67	0.0	26.40	0.0	0.0	-0.60	0.0	0.60
0.0100	0.26	0.67	0.0	26.21	0.0	0.0	-1.85	-0.02	1.85
0.0110	0.29	0.67	-0.00	26.15	-0.00	-0.03	-2.01	-0.02	2.01
0.0120	0.32	0.67	-0.00	26.08	0.00	-0.05	-2.16	-0.11	2.17
0.0130	0.34	0.67	-0.00	26.01	-0.00	-0.09	-2.31	-0.06	2.31
0.0140	0.37	0.67	-0.00	25.93	-0.00	-0.15	-2.40	-0.03	2.40
0.0150	0.39	0.67	-0.00	25.85	-0.00	-0.20	-2.54	-0.04	2.54
0.0160	0.42	0.67	-0.00	25.77	-0.00	-0.26	-2.73	-0.04	2.73
0.0170	0.44	0.67	-0.00	25.68	-0.00	-0.30	-2.92	-0.03	2.92
0.0180	0.47	0.67	-0.00	25.58	-0.01	-0.35	-3.02	-0.03	3.02
0.0190	0.50	0.67	-0.00	25.48	-0.00	-0.38	-3.27	-0.20	3.28
0.0200	0.52	0.67	-0.00	25.38	-0.01	-0.48	-3.41	-0.08	3.41
0.0210	0.55	0.67	-0.00	25.27	-0.01	-0.54	-3.52	-0.14	3.53
0.0220	0.57	0.67	-0.00	25.16	-0.01	-0.64	-3.70	-0.14	3.70
0.0230	0.60	0.67	-0.00	25.04	-0.01	-0.71	-3.82	-0.10	3.82
0.0240	0.62	0.67	-0.00	24.92	-0.01	-0.74	-3.92	-0.01	3.92
0.0250	0.65	0.67	-0.01	24.79	-0.01	-0.83	-4.04	0.09	4.05
0.0260	0.67	0.67	-0.01	24.66	-0.01	-0.93	-4.11	0.02	4.11
0.0270	0.70	0.67	-0.01	24.53	-0.01	-0.93	-4.17	-0.11	4.17
0.0280	0.72	0.67	-0.01	24.39	-0.00	-0.97	-4.28	0.04	4.28
0.0290	0.74	0.67	-0.01	24.25	-0.01	-1.08	-4.54	-0.06	4.54
0.0300	0.77	0.67	-0.01	24.10	-0.00	-1.12	-4.83	-0.06	4.83
0.0310	0.79	0.67	-0.01	23.94	-0.01	-1.25	-5.06	-0.02	5.06
0.0320	0.82	0.67	-0.01	23.78	0.00	-1.19	-5.17	0.09	5.17
0.0330	0.84	0.67	-0.01	23.61	0.00	-1.20	-5.18	-0.04	5.18
0.0340	0.86	0.67	-0.02	23.44	0.01	-1.14	-5.43	-0.08	5.43
0.0350	0.89	0.67	-0.02	23.27	0.01	-1.19	-5.51	0.06	5.52
0.0360	0.91	0.67	-0.02	23.09	0.02	-1.22	-5.66	0.01	5.66
0.0370	0.93	0.67	-0.02	22.91	0.01	-1.40	-5.68	-0.26	5.68
0.0380	0.96	0.67	-0.02	22.73	0.01	-1.62	-5.92	-0.08	5.92
0.0390	0.98	0.67	-0.02	22.54	0.01	-1.71	-6.00	-0.10	6.00
0.0400	1.00	0.67	-0.02	22.35	0.01	-1.86	-6.17	-0.22	6.17
0.0410	1.02	0.67	-0.03	22.15	0.01	-1.97	-6.23	0.16	6.23
0.0420	1.05	0.67	-0.03	21.96	0.01	-2.05	-6.36	0.34	6.37
0.0430	1.07	0.67	-0.03	21.75	0.02	-1.90	-6.45	0.47	6.47
0.0440	1.09	0.67	-0.03	21.55	0.03	-1.75	-6.57	0.33	6.58
0.0450	1.11	0.67	-0.03	21.34	0.04	-1.62	-6.68	-0.01	6.68
0.0460	1.13	0.67	-0.03	21.13	0.05	-1.60	-6.71	0.07	6.71
0.0470	1.15	0.67	-0.04	20.91	0.06	-1.51	-6.92	0.04	6.92
0.0480	1.17	0.67	-0.04	20.69	0.06	-1.65	-6.96	0.00	6.96
0.0490	1.19	0.67	-0.04	20.47	0.06	-1.64	-7.13	0.23	7.13
0.0500	1.21	0.67	-0.04	20.24	0.07	-1.61	-7.24	-0.21	7.24
0.0510	1.24	0.67	-0.04	20.01	0.08	-1.58	-7.49	0.16	7.49
0.0520	1.25	0.67	-0.04	19.78	0.09	-1.47	-7.54	0.22	7.54
0.0530	1.27	0.67	-0.05	19.54	0.09	-1.41	-7.58	0.26	7.59
0.0540	1.29	0.67	-0.05	19.30	0.10	-1.25	-7.75	0.23	7.75
0.0550	1.31	0.67	-0.05	19.05	0.11	-1.27	-7.80	-0.09	7.80
0.0560	1.33	0.67	-0.05	18.81	0.11	-1.33	-7.94	-0.07	7.94
0.0570	1.35	0.67	-0.05	18.56	0.11	-1.22	-8.00	0.19	8.00
0.0580	1.37	0.67	-0.05	18.30	0.12	-1.15	-8.08	0.17	8.09

SIMULATION MODEL OF AUTOMOBILE COLLISIONS (SMAC)
CAL-CASE-MD-10U
JAN. 13,1974

VEHICLE NO. 1
TIRE TRACKS(FT)
(*ASTERISK INDICATES SKIDDING TIRE)

TIME SEC	VELOCITY VECTOR ATAN(V1/U 1) DEG	RF X1'	Y1'	LF X2'	Y2'	RR X3'	Y3'	LR X4'	Y4'
0.0	0.0	4.4*	3.1*	4.4*	-1.7*	-4.5	3.1	-4.6	-1.7
0.010	0.0	4.7*	3.1*	4.7*	-1.7*	-4.3	3.1	-4.3	-1.7
0.011	359.999	4.7*	3.1*	4.7*	-1.7*	-4.3	3.1	-4.3	-1.7
0.012	0.000	4.7*	3.1*	4.7*	-1.7*	-4.3	3.1	-4.3	-1.7
0.013	359.999	4.7*	3.1*	4.7*	-1.7*	-4.2	3.1	-4.2	-1.7
0.014	359.995	4.8*	3.1*	4.8*	-1.7*	-4.2	3.1	-4.2	-1.7
0.015	359.993	4.8*	3.1*	4.8*	-1.7*	-4.2	3.1	-4.2	-1.7
0.016	359.991	4.8*	3.1*	4.8*	-1.7*	-4.1	3.1	-4.1	-1.7
0.017	359.990	4.8*	3.1*	4.8*	-1.7*	-4.1	3.1	-4.1	-1.7
0.018	359.988	4.9*	3.1*	4.9*	-1.7*	-4.1	3.1	-4.1	-1.7
0.019	[illegible]	4.9*	3.1*	4.9*	-1.7*	-4.1	3.1	-4.1	-1.7
0.020	359.984	4.9*	3.1*	4.9*	-1.7*	-4.0	3.1	-4.0	-1.7
0.021	359.984	4.9*	3.1*	4.9*	-1.7*	-4.0	3.1	-4.0	-1.7
0.022	359.980	5.0*	3.1*	5.0*	-1.7*	-4.0	3.1	-4.0	-1.7
0.023	359.980	5.0*	3.1*	5.0*	-1.7*	-4.0	3.1	-4.0	-1.7
0.024	359.983	5.0*	3.1*	5.0*	-1.7*	-3.9	3.1	-3.9	-1.7
0.025	359.981	5.0*	3.1*	5.0*	-1.7*	-3.9	3.1	-3.9	-1.7
0.026	359.978	5.1*	3.1*	5.1*	-1.7*	-3.9	3.1	-3.9	-1.7
0.027	359.985	5.1*	3.1*	5.1*	-1.7*	-3.9	3.1	-3.9	-1.7
0.028	359.989	5.1*	3.1*	5.1*	-1.7*	-3.8	3.1	-3.8	-1.7
0.029	359.984	5.1*	3.1*	5.1*	-1.7*	-3.8	3.1	-3.8	-1.7
0.030	359.989	5.2*	3.1*	5.2*	-1.7*	-3.8	3.1	-3.8	-1.7
0.031	359.963	5.2*	3.1*	5.2*	-1.7*	-3.8	3.1	-3.8	-1.7
0.032	0.001	5.2	3.1	5.2	-1.7	-3.7	3.1	-3.8	-1.7
0.033	0.010	5.2	3.1	5.2	-1.7	-3.7	3.1	-3.7	-1.7
0.034	0.028	5.3	3.1	5.3	-1.7	-3.7	3.1	-3.7	-1.7
0.035	0.033	5.3	3.1	5.3	-1.7	-3.7	3.1	-3.7	-1.7
0.036	0.041	5.3	3.1	5.3	-1.7	-3.7	3.1	-3.7	-1.7
0.037	0.032	5.3	3.1	5.3	-1.7	-3.6	3.1	-3.6	-1.7
0.038	0.018	5.3	3.1	5.3	-1.7	-3.6	3.1	-3.6	-1.7
0.039	0.020	5.4	3.1	5.4	-1.7	-3.6	3.1	-3.6	-1.7
0.040	0.015	5.4	3.1	5.4	-1.7	-3.6	3.1	-3.6	-1.7
0.041	0.016	5.4	3.1	5.4	-1.7	-3.5	3.1	-3.5	-1.7
0.042	0.020	5.4	3.1	5.4	-1.7	-3.5	3.1	-3.5	-1.7
0.043	0.052	5.5	3.1	5.5	-1.7	-3.5	3.1	-3.5	-1.7
0.044	0.088	5.5	3.1	5.5	-1.7	-3.5	3.1	-3.5	-1.7
0.045	0.120	5.5	3.1	5.5	-1.7	-3.5	3.1	-3.5	-1.7
0.046	0.138	5.5	3.1	5.5	-1.7	-3.4	3.1	-3.4	-1.7
0.047	0.152	5.5	3.1	5.5	-1.7	-3.4	3.1	-3.4	-1.7
0.048	0.162	5.6	3.1	5.6	-1.7	-3.4	3.1	-3.4	-1.7
0.049	0.179	5.6	3.1	5.6	-1.7	-3.4	3.1	-3.4	-1.7
0.050	0.201	5.6	3.1	5.6	-1.7	-3.4	3.1	-3.4	-1.7
0.051	0.220	5.6	3.1	5.6	-1.7	-3.3	3.1	-3.3	-1.7
0.052	0.249	5.6	3.1	5.6	-1.7	-3.3	3.1	-3.3	-1.7
0.053	0.270	5.7	3.1	5.7	-1.7	-3.3	3.1	-3.3	-1.7
0.054	0.307	5.7	3.1	5.7	-1.7	-3.3	3.1	-3.3	-1.7
0.055	0.318	5.7	3.1	5.7	-1.7	-3.3	3.1	-3.3	-1.7
0.056	0.322	5.7	3.1	5.7	-1.7	-3.2	3.1	-3.2	-1.7
0.057	0.352	5.7	3.1	5.7	-1.7	-3.2	3.1	-3.2	-1.7
[illegible]	0.370	[illegible]	3.1	[illegible]	-1.7	[illegible]	3.1	[illegible]	-1.7

SIMULATION MODEL OF AUTOMOBILE COLLISIONS (SMAC)
CAL-CASE-MO-IOU
JAN. 1J.1974
VEHICLE NO. 2

TIME SEC.	C.G. POSITION XC2' FT	YC2' FT	HEADING ANGLE PSI2 DEG	VELOCITIES FWD FT/SEC	LAT FT/SEC	ANGULAR VELOCITY PSI2DOT DEG/SEC	ACCELERATION AX2 G	AY2 G	ACC2 G
0.0	15.58	0.0	180.00	2.93	0.0	0.0	-0.63	0.0	0.63
0.0100	15.56	0.00	180.00	2.73	0.0	0.0	-1.53	-0.02	1.53
0.0110	15.55	0.00	180.00	2.68	-0.00	-0.04	-1.65	-0.02	1.65
0.0120	15.55	0.00	180.00	2.62	-0.00	-0.07	-1.75	-0.09	1.75
0.0130	15.55	0.00	180.00	2.57	-0.00	-0.11	-1.86	-0.06	1.86
0.0140	15.54	0.00	180.00	2.51	-0.00	-0.16	-1.93	-0.05	1.93
0.0150	15.54	0.00	180.00	2.44	-0.00	-0.22	-2.02	-0.06	2.02
0.0160	15.54	0.00	180.00	2.38	-0.01	-0.27	-2.16	-0.07	2.16
0.0170	15.54	0.00	180.00	2.30	-0.01	-0.32	-2.30	-0.06	2.30
0.0180	15.54	0.00	180.00	2.23	-0.01	-0.38	-2.37	-0.07	2.37
0.0190	15.53	0.00	180.00	2.15	-0.01	-0.41	-2.55	-0.19	2.56
0.0200	15.53	0.00	180.00	2.07	-0.01	-0.49	-2.65	-0.11	2.65
0.0210	15.53	0.00	180.00	1.98	-0.02	-0.53	-2.73	-0.16	2.74
0.0220	15.53	0.00	180.00	1.89	-0.02	-0.59	-2.86	-0.17	2.86
0.0230	15.52	0.00	180.00	1.80	-0.02	-0.63	-2.94	-0.14	2.95
0.0240	15.52	0.00	180.00	1.71	-0.02	-0.65	-3.02	-0.08	3.02
0.0250	15.52	0.00	179.99	1.61	-0.03	-0.69	-3.10	0.00	3.10
0.0260	15.52	0.00	179.99	1.51	-0.03	-0.74	-3.15	-0.05	3.15
0.0270	15.52	0.00	179.99	1.41	-0.03	-0.74	-3.20	-0.14	3.20
0.0280	15.52	0.00	179.99	1.31	-0.03	-0.74	-3.28	-0.04	3.28
0.0290	15.52	0.00	179.99	1.20	-0.04	-0.80	-3.46	-0.11	3.45
0.0300	15.51	0.00	179.99	1.09	-0.04	-0.80	-3.67	-0.11	3.67
0.0310	15.51	0.00	179.99	0.97	-0.04	-0.86	-3.82	-0.09	3.83
0.0320	15.51	0.00	179.99	0.84	-0.04	-0.79	-3.91	-0.03	3.91
0.0330	15.51	0.00	179.99	0.72	-0.04	-0.78	-3.92	-0.12	3.92
0.0340	15.51	0.00	179.99	0.59	-0.04	-0.71	-4.09	-0.14	4.10
0.0350	15.51	0.00	179.99	0.46	-0.04	-0.71	-4.16	-0.04	4.1[illegible]
0.0360	15.51	0.00	179.99	0.33	-0.04	-0.68	-4.25	-0.06	4.25
0.0370	15.51	0.00	179.99	0.19	-0.04	-0.71	-4.23	-0.18	4.22
0.0380	15.51	0.00	179.98	0.06	-0.05	-0.68	-3.89	-0.03	3.89
0.0390	15.51	0.00	179.98	-0.06	-0.05	-0.53	-3.80	0.06	3.8[illegible]
0.0400	15.51	0.00	179.98	-0.17	-0.04	-0.52	-3.42	-0.11	3.42
0.0410	15.51	0.00	179.98	-0.28	-0.04	-0.54	-3.44	0.12	3.44
0.0420	15.51	0.00	179.98	-0.39	-0.04	-0.57	-3.53	0.22	3.53
0.0430	15.51	0.00	179.98	-0.50	-0.03	-0.48	-3.59	0.31	3.60
0.0440	15.51	0.00	179.98	-0.62	-0.03	-0.39	-3.67	0.22	3.68
0.0450	15.51	0.00	179.98	-0.73	-0.02	-0.33	-3.75	-0.03	3.75
0.0460	15.51	0.00	179.98	-0.85	-0.02	-0.34	-3.78	0.01	3.78
0.0470	15.51	0.00	179.98	-0.97	-0.01	-0.38	-3.93	-0.03	3.93
0.0480	15.51	0.00	179.98	-1.10	-0.01	-0.43	-3.96	-0.06	3.96
0.0490	15.52	0.00	179.98	-1.22	-0.01	-0.46	-4.08	-0.04	4.08
0.0500	15.52	0.00	179.98	-1.35	-0.01	-0.46	-4.16	-0.21	4.17
0.0510	15.52	0.00	179.98	-1.48	-0.01	-0.49	-4.34	0.05	4.34
0.0520	15.52	0.00	179.98	-1.62	-0.01	-0.51	-4.38	0.10	4.38
0.0530	15.52	0.00	179.98	-1.76	-0.00	-0.54	-4.41	0.12	4.42
0.0540	15.52	0.00	179.98	-1.90	0.00	-0.50	-4.53	0.11	4.5[illegible]
0.0550	15.53	0.00	179.98	-2.04	0.00	-0.58	-4.58	-0.12	4.5[illegible]
0.0560	15.53	0.00	179.98	-2.18	0.00	-0.70	-4.68	-0.11	[illegible]
0.0570	15.53	0.00	179.98	-2.33	0.00	-0.70	-4.7[illegible]	0.08	4.7[illegible]
0.0580	15.5[illegible]	0.00	179.97	-2.48	0.01	-0.7[illegible]	-4.7[illegible]	0.07	[illegible]
0.0590	15.54	0.00	179.97	-2.6[illegible]	0.01	-0.7[illegible]	-4.[illegible]	0.11	[illegible]

SIMULATION MODEL OF AUTOMOBILE COLLISIONS (SMAC)
CAL-CASE-M1-100
JAN. 13.1974

VEHICLE NO. 2
TIRE TRACKS(FT)
(*ASTERISK INDICATES SKIDDING TIRE)

IME SEC	VELOCITY VECTOR ATAN(V2/U 2) DEG	RF X1'	Y1'	LF X2'	Y2'	RR X3'	Y3'	LR X4'	Y4'
.0	0.0	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.010	0.0	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.011	359.994	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.012	359.993	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.013	359.973	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.014	359.939	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.015	359.899	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.016	359.849	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.017	359.809	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.018	359.743	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.019	359.706	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.020	359.596	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.021	359.516	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.022	359.359	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
.023	359.283	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.024	359.196	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.025	359.027	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.026	358.849	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.027	358.754	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.028	358.603	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.029	358.297	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.030	358.046	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.031	357.546	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.032	357.352	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.033	356.846	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.034	356.350	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.5
0.035	355.130	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.036	353.055	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8*	2.6*
0.037	347.031	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8*	2.6*
0.038	322.074	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.039	216.552	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.040	193.540	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.041	188.427	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.042	186.973	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.043	183.879	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.044	182.400	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.045	181.476	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.046	181.072	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.047	180.858	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.048	180.772	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.049	180.631	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.050	180.465	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.051	180.357	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.052	180.197	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.053	180.106	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.054	179.917	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.055	179.933	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.056	179.992	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.057	179.899	10.5*	-2.6*	10.5*	2.6*	20.8	-2.6	20.8	2.6
0.058	179.840	10.5*	-2.6*	10.5*	2.6*				

SIMULATION MODEL OF AUTOMOBILE COLLISIONS (SMAC)
CAL-CASE-MO-100
JAN. 13.1974
DAMAGE SUMMARY (DISPLACED POINTS, * J POINT)

VEHICLE NO. 1
25 POINTS

	RHOB1 INCHES	PSIB1 DEG	X1 INCHES	Y1 INCHES
	73.769	0.0	73.7691	0.0
	73.820	2.000	73.7747	2.5763
	73.991	4.000	73.8011	5.1607
	74.199	6.000	73.7929	7.7559
	74.494	8.000	73.7689	10.3675
	74.925	10.000	73.7868	13.0106
	75.409	12.000	73.7598	15.6781
	76.053	14.000	73.7938	18.3908
	76.771	16.000	73.7973	21.1610
	77.552	18.000	73.7562	23.9648
	78.536	20.000	73.7996	26.8608
*	79.350	22.000	73.5718	29.7249
*	79.448	334.000	71.4071	-34.8277
	80.773	336.000	73.7895	-32.8533
	79.579	338.000	73.7839	-29.8107
	78.517	340.000	73.7822	-26.6546
	77.552	342.000	73.7563	-23.9650
	76.772	344.000	73.7976	-21.1612
	76.053	346.000	73.7937	-18.3989
	75.408	348.000	73.7598	-15.6782
	74.925	350.000	73.7871	-13.0107
	74.494	352.000	73.7689	-10.3676
	74.199	354.000	73.7927	-7.7560
	73.991	356.000	73.8007	-5.1607
	73.820	358.000	73.7749	-2.5764

VEHICLE NO. 2
20 POINTS

	RHOB2 INCHES	PSIB2 DEG	X2 INCHES	Y2 INCHES
	93.519	0.0	93.5195	0.0
	93.580	2.000	93.5232	3.2659
	93.668	4.000	93.4395	6.5339
	93.983	6.000	93.4684	9.8239
	94.413	8.000	93.4341	13.1397
	94.879	10.000	93.4375	16.4755
	95.577	12.000	93.4884	19.8716
	96.310	14.000	93.4488	23.2994
*	97.172	16.000	93.4076	26.7842
*	103.541	338.000	93.2195	-37.5632
	99.507	340.000	93.5062	-34.0336
	98.321	342.000	93.5092	-30.3831
	97.193	344.000	93.4277	-26.7901
	96.309	346.000	93.4487	-23.2994
	95.577	348.000	93.4884	-19.8717
	94.879	350.000	93.4376	-16.4757
	94.413	352.000	93.4942	-13.1399
	93.984	354.000	93.4685	-9.8241
	93.668	356.000	93.4394	-6.5340
	93.580	358.000	93.5233	-3.2660

VEHICLE NO. 1
1 RANGES

	BEGIN RHOB1 INCHES	BEGIN PSIB1 DEG		END RHOB1 INCHES	END PSIB1 DEG	MIDPOINT PSIM1 DEG	VEH.DAMAGE INDEX	VEL DELTA V MPH
*	79.45	334.00	*	79.35	22.00	356.28	12FDEW2	18.28

VEHICLE NO. 2
1 RANGES

	BEGIN RHOB2 INCHES	BEGIN PSIB2 DEG		END RHOB2 INCHES	END PSIB2 DEG	MIDPOINT PSIM2 DEG	VEH.DAMAGE INDEX	VEL DELTA MPH
*	100.54	338.00	*	97.17	16.00	355.95	12FDEW1	10.9

VEHICLE NO. 1, ELAPSED T = 2.0000 SEC

VEHICLE NO. 2, ELAPSED T = 2.0000 SEC POR

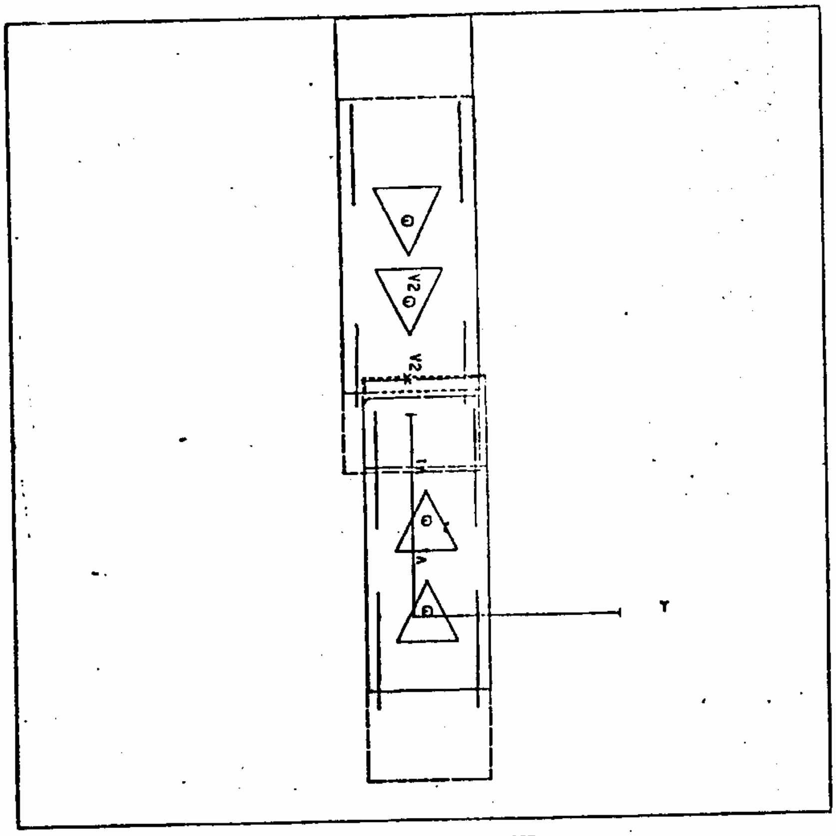
AT T= 1.2300 SEC., VEHICLE 2 MOVING SLOWLY
SPEED = 0.64651E-01 FT/SEC. PSI2D= -0.37450E 00 DEG/SEC

C. Sample Graphic Display (Derived from the input data of IIIB)

GRAPHIC DISPLAY OF OUTPUTS OF ACCIDENT RECONSTRUCTION

COLLISION AND TRAJECTORY

CASE-HO-IOU



AXIS INTERVALS ARE 10. FEET

RECONSTRUCTED POSITIONS AND VELOCITIES AT IMPACT							DISPLATED FINAL POSITIONS				VEHICLE DAMAGE INDICES.	ΔV
	C.G. POSITION		HEADING				C.G. POSITION		HEADING	REMARKS		
	XC1	YC1	PSI1	FWD	LATERAL	ANGULAR	XC1F	YC1F	PSI1F			
	FT.	FT.	DEG.	MPH	MPH	DEG/SEC	FT.	FT.	DEG.			MPH
VEHICLE • 1	0.3	0.7	0.0	17.9	0.0	0.0	4.7	0.7	-0.2	IN MOTION AT 2.0 SEC AFTER INITIAL CONTACT	12FDEW2	18.5
VEHICLE • 2	15.6	0.0	180.0	1.9	0.0	0.0	19.5	-0.0	179.6	VEHICLE AT REST	12FDEW1	11.3

SECTION VI
SUGGESTED VALUES OF PARAMETERS

In the interest of simplicity, the presented preliminary evaluation of the SMAC computer program has made use of "typical" parameters other than weights for the different categories of vehicle size rather than actual parameters for the specific vehicles. Vehicles representative of four different size categories were selected to provide a basis for "typical" parameters. The following vehicles were included in the different categories.

1. Subcompact

   Volkswagen Beetle
   Toyota 1200
   Datsun 1200
   Vega
   Pinto
   Fiat 850

2. Compact

   Maverick
   Camero
   Dart
   Hornet

3. Intermediate

   Chevelle
   Torino
   Coronet
   Matador
   Skylark

4. Full Size

   Chevrolet
   Galaxie
   Polara
   Ambassador
   Monterey
   LeSabre
   New Yorker
   Fleetwood
   Continental

On the basis of available dimensional and shipping weight information, and with allowances made for both liquid weight and two passenger loading, the following "typical" parameters have been either directly derived or estimated from available measured values for similar vehicles.

TABLE 1

TYPICAL DIMENSIONAL AND INERTIAL PARAMETERS FOR 1971-72 AUTOMOBILES

Parameter	1 Subcompact	2 Compact	3 Intermediate	4 Full Size	Units
a	44.7	52.7	57.3	60.5	Inches
b	46.6	54.8	59.7	63.0	Inches
T	51.2	57.7	60.0	63.1	Inches
k^2	1963.	2635.	2998.	3588.	Inches^2
M	5.71	8.51	9.86	12.42	$\text{Lb-Sec}^2/\text{in}$
X_F	74.7	85.7	94.8	100.5	Inches
X_R	-83.5	-100.0	-110.8	-119.6	Inches
Y_S	31.1	35.7	38.4	39.6	Inches

TABLE 2

For the following vehicle parameters, representative values have been found but no refinement has yet been attempted for the different categories of vehicle size other than the load-deflection characteristic of the peripheral structure, K_V.

REPRESENTATIVE VALUES OF VEHICLE PARAMETERS

Parameter	Value	Units
$(CSTF)_{1,2}$	-10250.	Pounds/Radian
$(CSTF)_{3,4}$	-10195.	Pounds/Radian
C_μ	3×10^{-4}	Seconds/Inch
K_V	{Full Size = 50; Subcompact = 30}	Pounds/Inch^2
C_0	0.06423	-
C_1	3.5417×10^{-3}	-
C_2	4.7381×10^{-5}	-
μ	0.550	-
$\Delta\Psi$	2.00	Degrees
$\Delta\rho$	0.20	Inches
λ	15.0	Lb/In
ξ_V	5.0	In/Sec

SECTION VII

REFERENCES

(1) Motor Vehicle Manufacture's Association (MVMA), "Accident Investigator's Manual", MVMA Detroit, Michigan. Useful for some vehicle properties.

(2) McHenry, R.R, "Development of a Computer Program to Aid the Investigation of Highway Accidents", Calspan Report No. VJ-2979-V-1, December 1971, HS 800 821. Explains theory and organization of program.

(3) McHenry, R.R., Segal, P.J., Lynch, J.P., Henderson, P.M., "Mathematical Reconstruction of Highway Accidents", Calspan Report No. ZM-5096-V-1, January 1973, HS 800 801. Gives Several case examples.

(4) McHenry, R.R., "Approximation of Impact Conditions via Computer Simulation", Proceeding International Accident Investigation Workshop, Brussels, Belgium, Pilot Study on Road Safety for the Committee on the Challenges of Modern Society, NATO, June, 1973, National Highway Traffic Safety Administrations, Washington, D.C. 20590. Provides a concise overview of SMAC.

(5) Jones, I.S., "Results of Selected Applications to Actual Highway Accidents of the SMAC Reconstruction Program" to be presented at Eighteenth Stapp Conference, Ann Arbor, Michigan, November, 1974. *Shows how the operator can obtain* a best fit to scene data.

(6) Jones, I.S., "The Application of the SMAC Accident Reconstruction Program to actual Highway Accidents". Proceedings of Eighteenth Conference of the American Association Automotive Medicine, Society of automotive Engineers, Inc., Toronto, Canada, 1974. Illustrates use of the START program to generate initial conditions for the SMAC program.