730980

Computer Program for Reconstruction of Highway Accidents

Raymond R. McHenry
Calspan Corp.

Abstract

The Simulation Model of Automobile Collisions (SMAC) computer program has been developed for the purpose of achieving uniformity in the use of analytical techniques for interpretation of physical evidence in investigations of highway accidents. The comprehensive output information of the SMAC program (kinematics, tire tracks, and vehicle damage) permits extensive, detailed comparisons with physical evidence in the iterative runs used to achieve a "best fit," and the predicted vehicle responses provide a basis for relatively refined categorization of occupant exposures. The generality included in the inputs of the SMAC program permits approximation of the effects of driver control inputs, damage to vehicle running gear, and traversal of terrain zones with different friction properties.

The analytical approach is outlined, and specific assumptions are defined. Comparisons are presented between analytical predictions and results of staged collisions. In one of the presented applications to a staged collision, the initial conditions were kept unknown until completion of the reconstruction process. Results of sample applications to actual highway accidents are included. Computer graphics displays of reconstructed accidents, including rest positions, tracks, and damage, are presented.

THE DEVELOPMENT of systems, devices and structural performance standards for improved occupant protection in automobile collisions is hampered by the limited extent of applicable human tolerance information and by the relatively gross performance measures that are obtained from actual highway accidents.

NOTE: This paper is based upon research performed under Contract Nos. FH-11-7526 and DOT HS-053-1-146 with the National Highway Traffic Safety Administration, U. S. Department of Transportation. The contents of the paper reflect the views of the author, who is responsible for the facts and accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the Department of Transportation.

Yet there is no direct experimental means of generating either improved injury threshold data for living humans in the typical automobile-crash type of exposure—that is, partial or no restraint, including impact on the vehicle interior—or valid measures of the effectiveness of protective devices at hazardous exposure levels.

Experimental research with volunteers must be performed substantially below injury thresholds, and the interpretation of results obtained with cadavers, animals, and anthropomorphic dummies, in terms of corresponding results for living humans, is not a straightforward and validated procedure. Thus, a strong case exists for the performance of research directed toward greater exploitation of the extensive data generated by actual accidents.

Recognition by the National Highway Traffic Safety Administration (NHTSA) of the need to obtain refined measures of real-world collision exposures and the corresponding injury consequences is evidenced by the ongoing research efforts on improvement of accident investigation procedures (1)* and on the development of crash recorders (2). The presently described research, which is being performed under NHTSA support, is directed toward the application of computer simulation techniques to the interpretation of physical evidence in highway accidents (8,9). The objective is to develop an investigation aid that will serve to achieve uniformity, as well as significant improvements in accuracy and detail, in the interpretation of evidence in terms of occupant exposures.

Analytical reconstruction of accidents is not, of course, a new idea (3-7), nor is the use of computer simulation for this purpose new (6). Rather, the research described in this paper is unique primarily with regard to the generality of the developed computer program, the extent of included analytical details, and the concept of processing and evaluating the measured data while the investigators are at the scene, via radio contact with the reconstruction computer program.

Presently, analytical reconstruction techniques are applied in only a very limited number of accident cases. In those cases, the necessity both for selection of appropriate assumptions and approximations and for applications of judgment tend to produce a nonuniform treatment of the physical evidence. Also, the prevalent use of manual calculation procedures requires extensive simplifications in the analytical relationships, and the accuracy of such reconstruction techniques has not been realistically evaluated. The time required for manual calculations precludes complete reconstruction at the accident scene, while the evidence is intact and readily available. Rather, in cases where reconstruction calculations are planned, the investigators must attempt to recognize and measure all critical items of information prior to leaving the scene. Thus, the quality and the completeness of data taken at the scenes of accidents and the application of such data in the generally iterative and simplistic reconstruction calculations each

*Numbers in parentheses designate References at end of paper.

tend to vary with the expertise and perseverance of the individual investigators.

Application of a relatively rapid reconstruction computer program while the evidence is readily available for checking or for making additional measurements will serve to ensure that all items of data are compatible and that the definition of the event is complete. It can also serve to provide guidance to the investigators for seeking evidence of effects of damage and/or driver control inputs, in cases where such effects are indicated by the reconstruction results. An optical system has been developed within the present research program to facilitate the measurement and transmission of scene data (Appendix A).

The intended end product of the present research is an investigation aid with the minimum complexity compatible with the research objectives. The basis for the selection of approach is a belief that greater benefits will be derived from a development effort that will permit widespread, uniform applications of a relatively simplified data-processing system than from an equivalent effort applied exclusively to the advancement of accident reconstruction procedures.

Selected Analytical Approach

The general practice in automobile collision analyses is to consider the impact and the trajectory phases of the event separately (3–6). This division of the analytical task is based upon an assumption that the effects of tire forces are negligible during the existence of collision forces. While the assumption appears to be a reasonable one, its application has been found to produce significant errors in the case of moderate-speed intersection collisions in which multiple contacts frequently occur—for example, front-side followed by side-side and/or rear-side contact (8).

If secondary contacts are neglected, major errors can be produced in predictions of spin-out trajectories. On the other hand, if the tire forces are neglected throughout the time during which the collision contacts occur, significant errors can be introduced in the lateral motions of the vehicles between impacts. Thus, it is essential in a general procedure for reconstruction calculations that both the collision and tire forces be considered simultaneously. Computer routines for calculation of collision and tire forces are, therefore, combined in the Simulation Model of Automobile Collisions (SMAC) computer program.

Collision Forces

Typical impulse-momentum analyses of the collision phase (3–6) do not yield information on the magnitudes of forces and the extent of structural deformations. Therefore, prediction of the nature and extent of damage is generally not included, except for the case of full-width frontal or rear contacts (7). In the present research, it was considered to be highly desirable to devise a means of analytical generation of damage patterns for comparison with corresponding measurements at the scene. Therefore, a major effort was applied to development of an analysis that includes an approximation of vehicle crush properties in the SMAC program.

Within the research program described in Ref. 10, it was found that crush properties of the peripheral structures of automobiles could be approximated with reasonable accuracy by means of the assumption of a layer of isotropic, homogeneous material that exhibits elastic-plastic behavior. Comparisons of deformations and decelerations measured in pole impacts (11) with those that occur in full frontal contacts (7) indicate general agreement in the required properties for such an assumed peripheral layer.

In the SMAC collision calculations, the specific crush properties that are assumed do not, of course, affect the conservation of momentum. By producing a finite time duration for the application of forces, the simulated crush permits relative motions of the colliding bodies to occur during the reconstructed collision. The time-varying values for the magnitudes, positions, and orientations of collision forces that are obtained with relatively gross approximations of crush properties have been found to yield results more realistic than those of simple impulse-momentum calculations in which the effects of crush are neglected.

In the SMAC program, the original (undeformed) boundaries of the vehicles are defined in the form of rectangles. Discrete points defining the body outlines in contacted regions are generated and displaced during the impact calculations. These points serve to define the deformed boundaries. The distance between a displaced point and the initial boundary of the deflected surface is used to determine the dynamic pressure at that point during any time increment in which the point is displaced. An iterative procedure is used to adjust the displacements to achieve equal pressures from the two mutually deformed bodies at each displaced point, and a point-by-point integration of the pressure on the collision interface is used to generate the resultant collision force and a corresponding intervehicle friction force.

Since a constraint of some kind is required on the directions of deflection of the individual points, to facilitate the iterative adjustment of displacements and the determination of contact in previously damaged regions, the points are constrained to move radially toward the coordinate origins of the two deformable bodies (Fig. 1). The effects of partial recovery of deformed peripheral structure are approximated by means of a coefficient of restitution that varies as a function of the magnitude of the deflection.

The following specific analytical assumptions constitute the basis for the collision force aspect of the SMAC program:

1. The vehicles are treated as rigid bodies, each surrounded by a layer of isotropic, homogeneous material that exhibits elastic-plastic behavior.

2. The dynamic pressure in the peripheral layer increases linearly with the depth of penetration relative to the initial boundary of the deflected surface.

3. The adjustable, nonlinear coefficient of restitution varies as a function of maximum deflection.

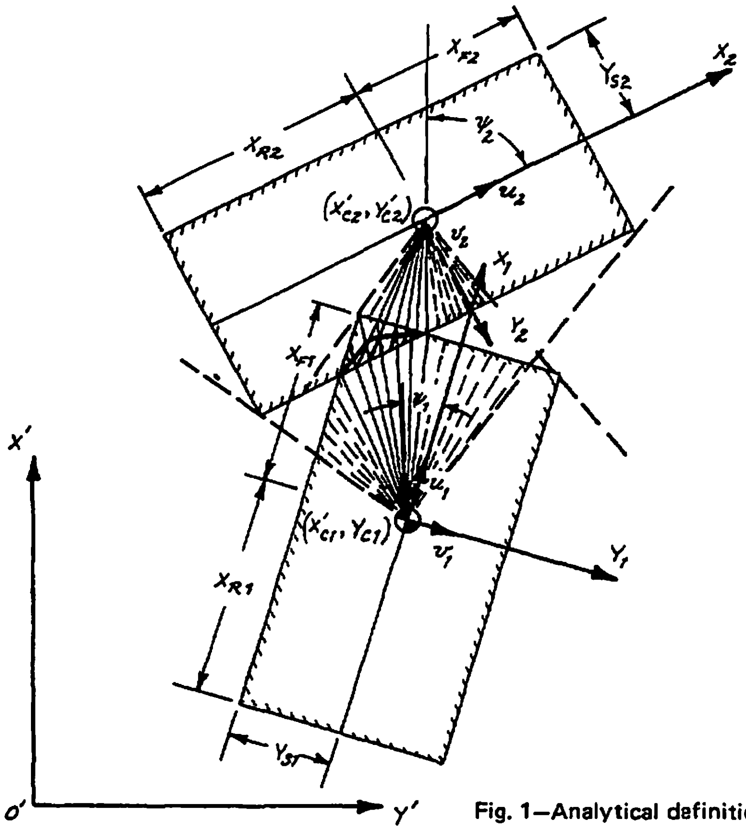


Fig. 1—Analytical definition of colliding vehicles

4. The vehicle motions are limited to a horizontal plane in which the effects of pitch and roll can be neglected.

A postprocessing routine for interpretation of damage predictions in terms of a standard collision deformation classification, or vehicle damage index (VDI), based upon SAE J224a is also included in the SMAC program.

Tire Forces

Previous methods of analysis of the tire force aspects of accident reconstruction have been highly simplified. In the more detailed approaches, the automobile has been treated as a two-wheeled vehicle, or "bicycle," in trajectory calculations (3–6). It seems obvious that the fidelity of reconstructions obtained with such simplified analytical models is quite limited. Yet, a highly detailed vehicle representation, such as that of Ref. 10, would require extensive input data and a prohibitive core capacity for most presently available time-sharing computer terminals. Therefore, in the development of the SMAC program, an attempt was made to select a compromise approach avoiding the extremes of excessive complexity and oversimplification.

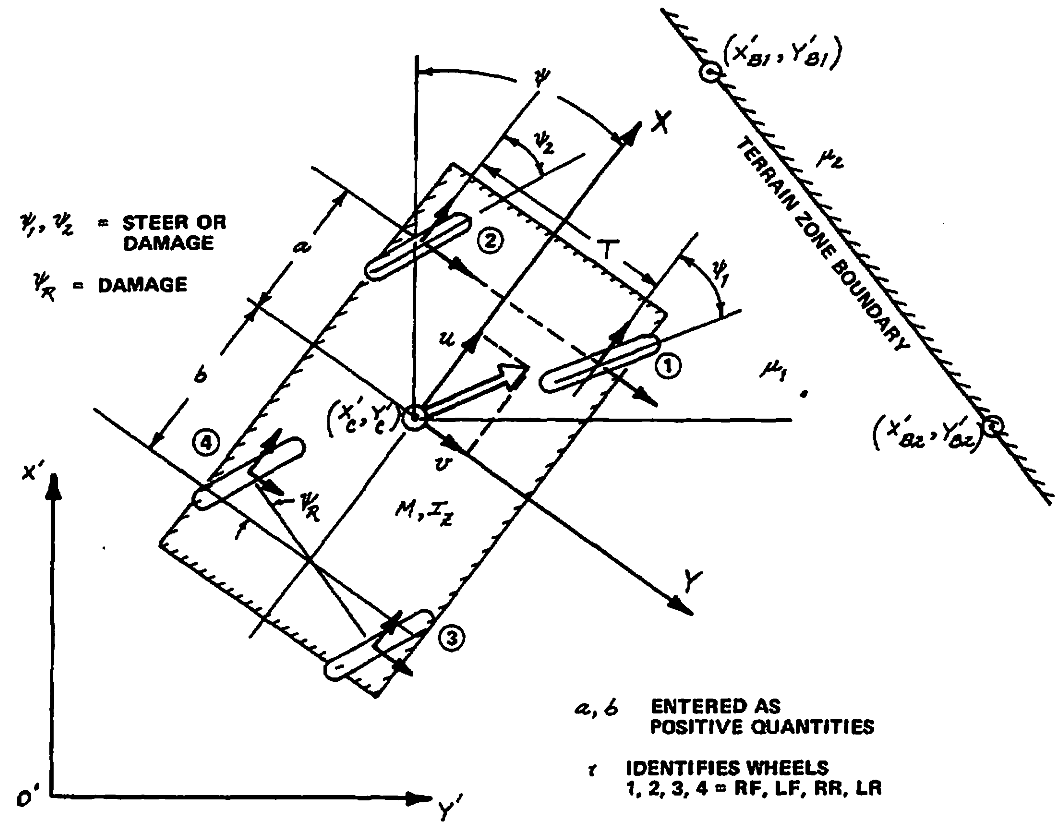


Fig. 2—Vehicle representation for trajectory calculations

The selected vehicle representation is limited to the three degrees of freedom associated with plane motions (Fig. 2). The tire side force calculations are based upon a nondimensional side force function whereby the small-angle properties of the tires become progressively "saturated" at larger angles (see Fig. 3). The "friction circle" concept is used to approximate interactions between side and circumferential (braking or tractive) tire forces. This concept (Fig. 4) is based upon the assumption that the maximum value of the resultant tire friction force is independent of its direction relative to the wheel plane. The cornering stiffnesses of the individual tires are input separately to the computer program to permit simulation of damaged or partially inflated tires. A vehicle tread dimension is included to provide realistic effects of individual tire forces (for example, locked wheels or flat tires) on yaw behavior and to permit detailed transitions across a boundary defining terrain zones with different friction coefficients.

Tabular inputs, as functions of time, are used for individual wheel torques and for steer angles of the individual front wheels and the rear axle—that is, control inputs and/or effects of damage. Provision is included for an optional linear decrement of the effective tire-ground friction coefficient with speed.

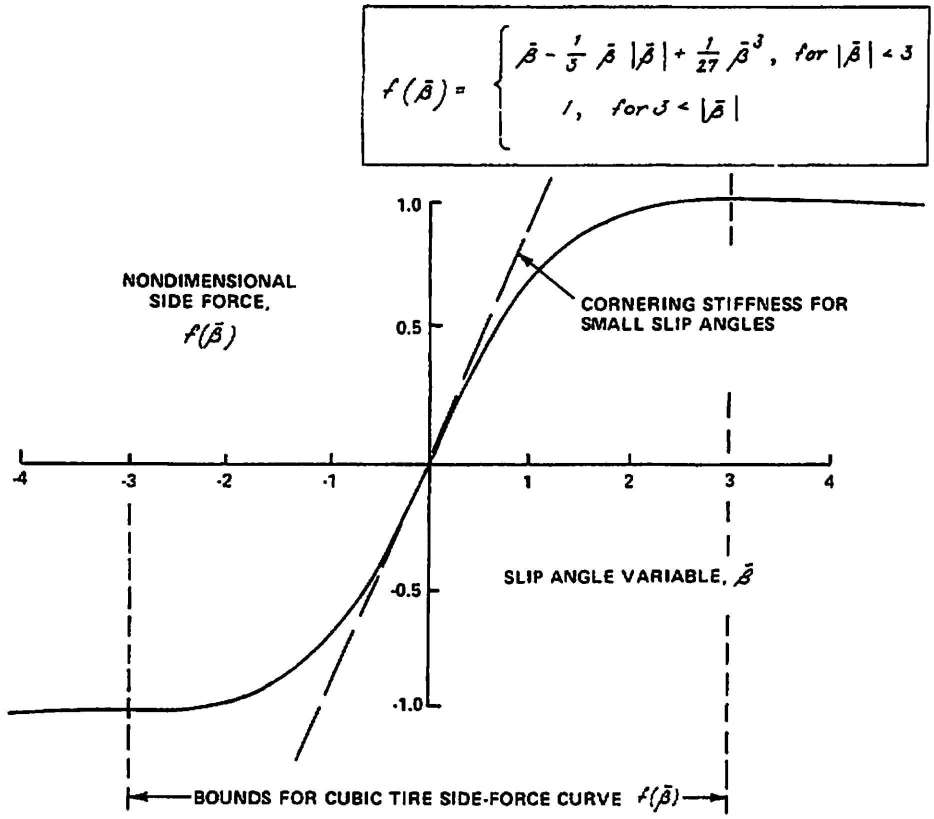


Fig. 3—Nondimensional tire side-force curve

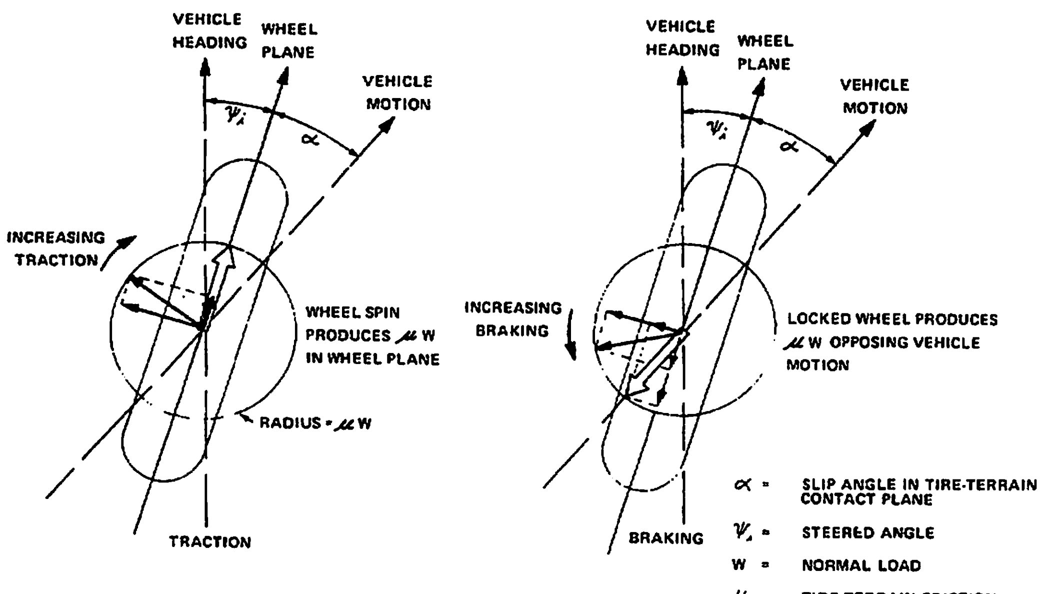
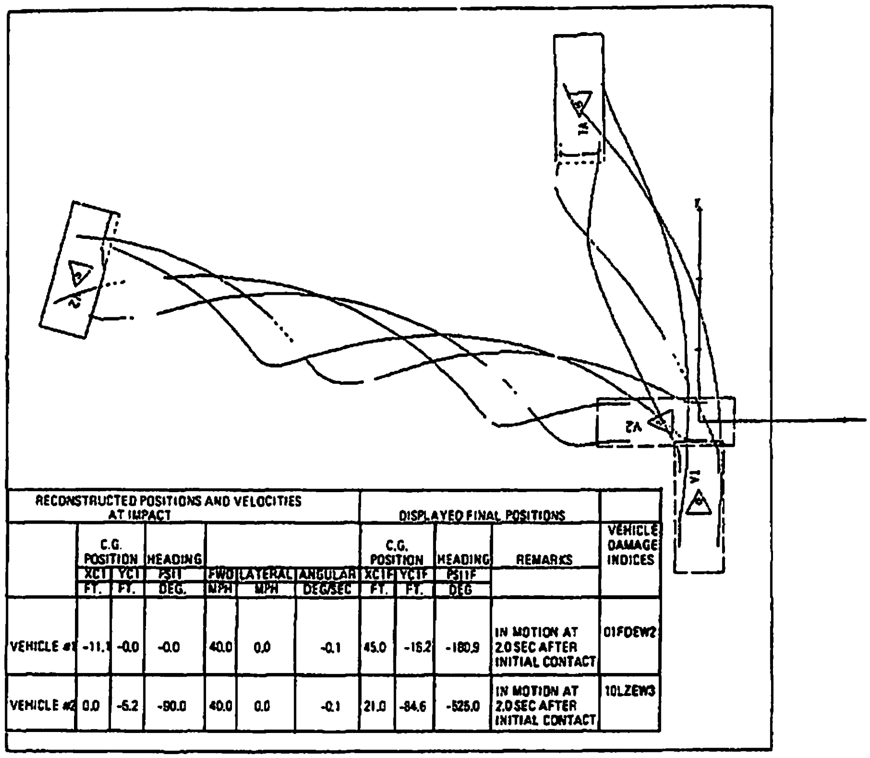


Fig. 4—Friction circle concept



RECONSTRUCTED POSITIONS AND VELOCITIES AT IMPACT								DISPLAYED FINAL POSITIONS				
	C.G. POSITION		HEADING				C.G. POSITION		HEADING	REMARKS	VEHICLE DAMAGE INDICES
	XC1 FT.	YC1 FT.	PSI1 DEG.	FWD MPH	LATERAL MPH	ANGULAR DEG/SEC	XC1F FT.	YC1F FT.	PSI1F DEG		
VEHICLE #1	-11.1	-0.0	-0.0	40.0	0.0	-0.1	45.0	-16.2	-180.9	IN MOTION AT 2.0 SEC AFTER INITIAL CONTACT	01FDEW2
VEHICLE #2	0.0	-5.2	-90.0	40.0	0.0	-0.1	21.0	-84.6	-525.0	IN MOTION AT 2.0 SEC AFTER INITIAL CONTACT	10LZEW3

Fig. 5—Graphic display of outputs of accident reconstruction collision and trajectory—rear-side impact at 40 mph

The following specific assumptions constitute the basis for the tire force aspect of the SMAC program:

1. The vehicle motions are limited to a horizontal plane in which the effects of pitch and roll can be neglected.
2. The terrain surface is flat and horizontal.
3. Effects of camber and of roll-steer of the wheels are neglected.
4. The "friction circle" concept approximates interactions between circumferential and side forces of the tires.
5. A step change in the tire-ground friction coefficient occurs at a linear boundary between two terrain zones.
6. The tire-ground friction coefficient decreases linearly with the resultant speeds of the individual wheel centers (option).

Predictions of tire tracks and skid marks are generated as a part of the output information. An index is used to indicate points at which sliding of the individual wheels occurs; that is, points at which the resultant tire force in the ground plane equals the limiting value defined by the friction circle. An auxiliary computer graphics program has been developed to display the tire tracks as well as the predicted vehicle damage. Note in Fig. 5 that broken lines are used to depict

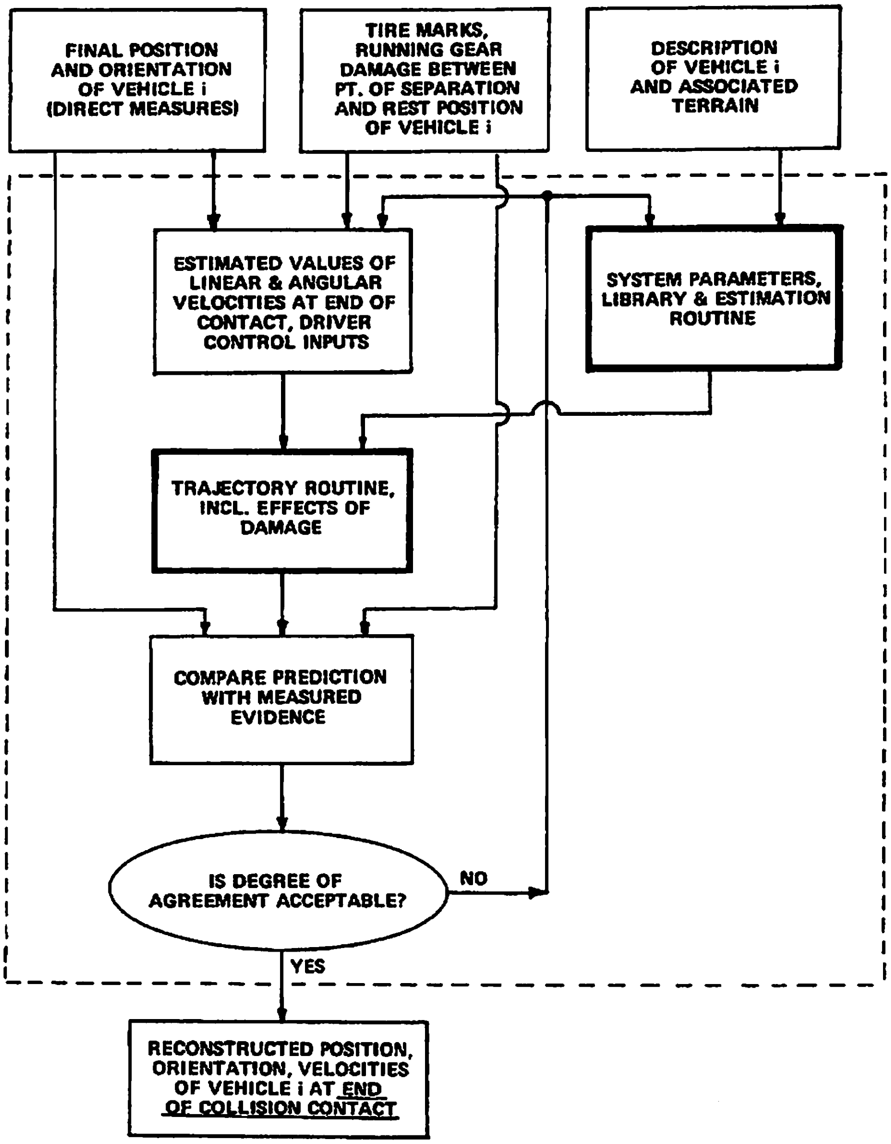


Fig. 6—Phase 1 of reconstruction—postcollision trajectories

tracks made by rolling tires, whereas solid lines are used for the tracks of sliding tires.

Operating Modes

The SMAC program can be operated in either two-vehicle or single-vehicle modes. In the two-vehicle mode of operation, a test for possible collision contact is made at the point in the program where the summations of tire forces are calculated. If contact is found to be possible, the collision routine is called, the

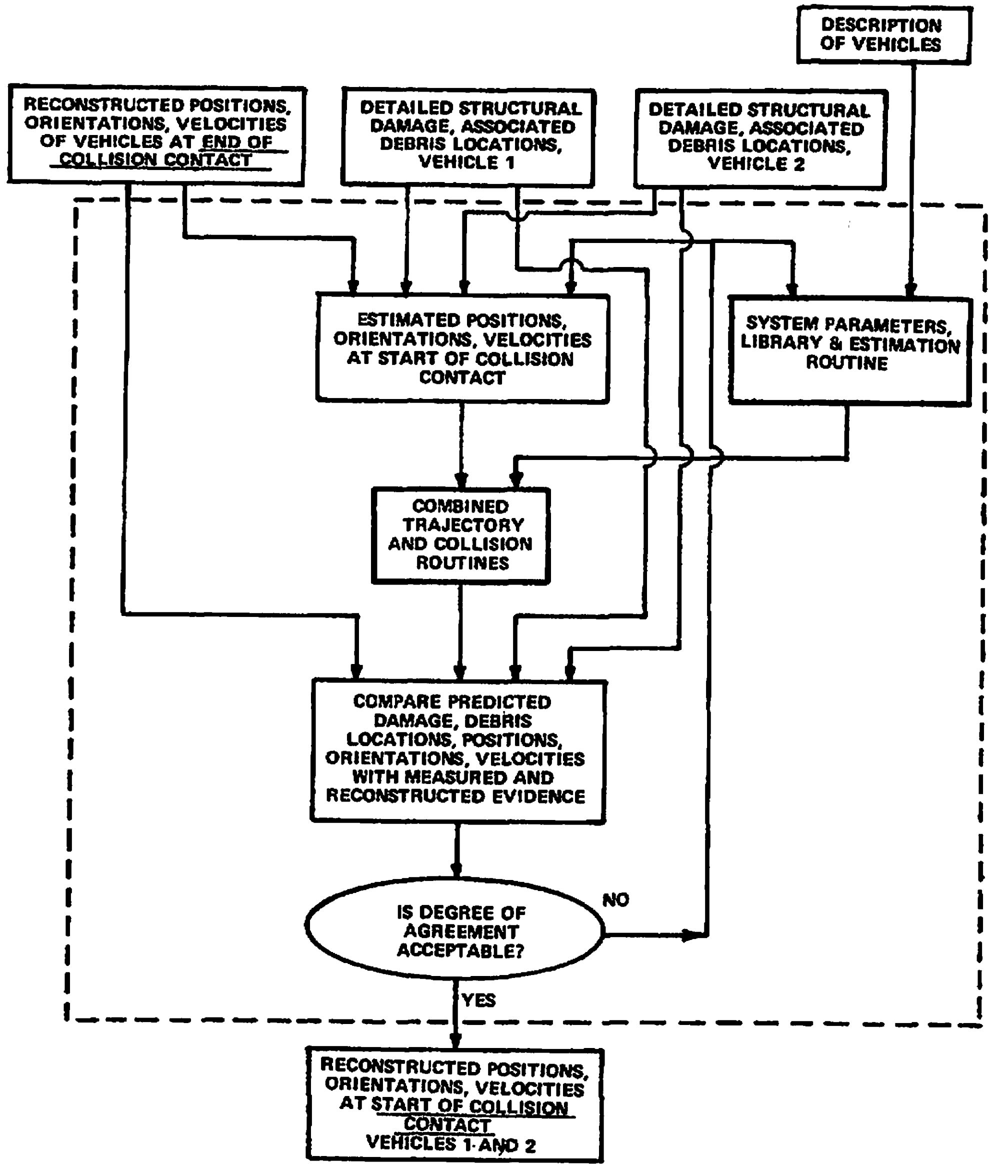


Fig. 7—Phase 2 of reconstruction—collision contact

time increment size is reduced, and any collision forces are added to the existing force summations prior to integration of the equations of motion. In single-vehicle applications, where the program is started subsequent to final separation of the colliding vehicles, the test for collision contact and the collision routine are bypassed by means of an input code.

Application Procedure

The SMAC program calculates the accident event in a step-by-step manner dur-

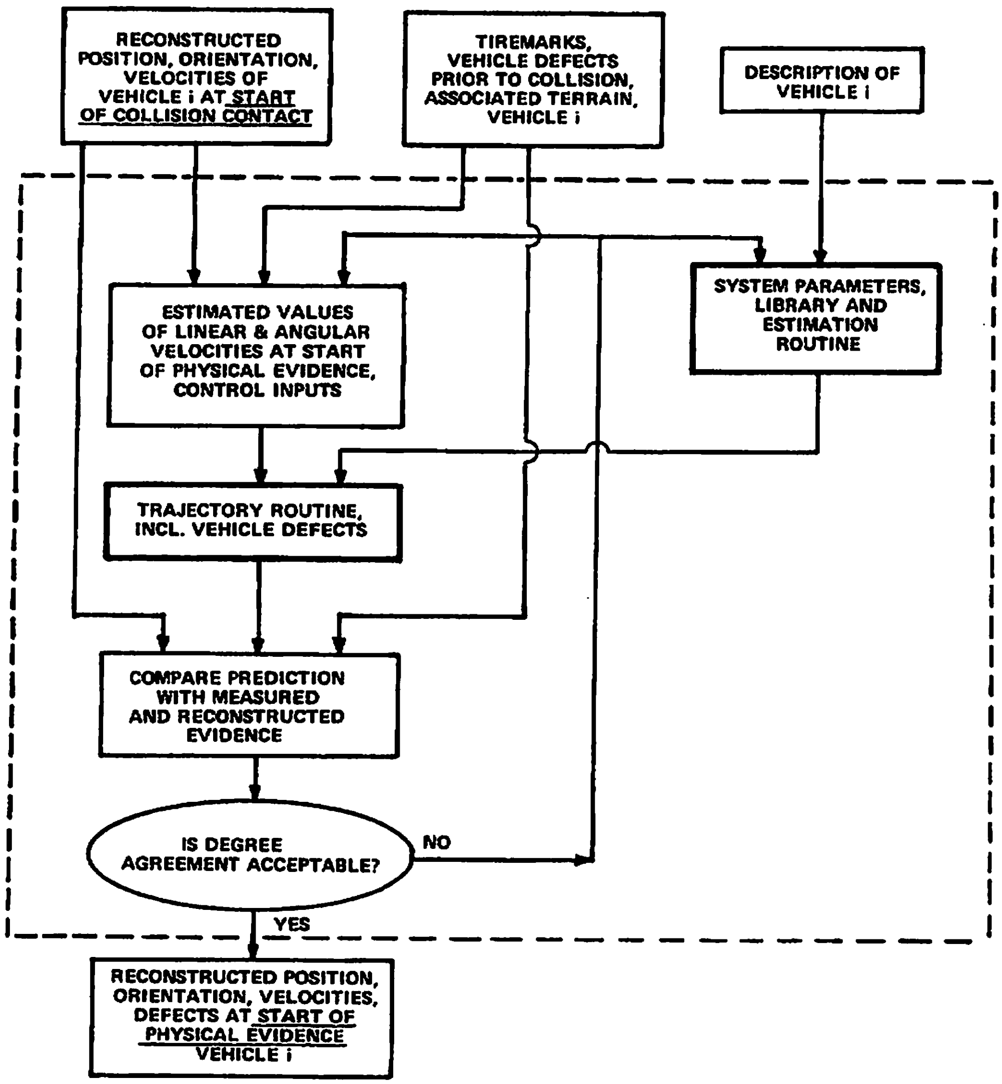


Fig. 8—Phase 3 of reconstruction—precollision trajectories

ing the selected time interval. A given run will stop on the basis either of velocity tests (both vehicles at rest) or of elapsed time (input specification). It is necessary merely to select initial conditions, time-histories of driver control inputs, and a total time interval. The vehicles can collide in any manner, within the constraints of plane motion, or can miss each other completely.

In the interest of efficiency, it is desirable to perform brief iterative runs within each of three phases of a collision event in the sequence and manner depicted in Figs. 6–8. It is planned eventually to automate the iterative aspects of the SMAC program so that the user will input only the measured evidence, and the program either will converge on a definition of the overall event that achieves an acceptable fit to the evidence or will indicate a need for checking or supplementing the measured scene data.

Discussion of Application Results

In the following paragraphs, some encouraging initial results that have been obtained with this investigation aid are presented and briefly discussed, to indicate the degree of detailed correlation that has been achieved.

Vehicle Damage Index—A postprocessing routine of the SMAC program generates predicted values for the collision deformation classification or VDI, in accordance with SAE J224a. Comparisons between analytical predictions and corresponding investigator ratings of VDI values in six staged collisions are presented in Table 1. These comparisons constitute a check of the validity of both the SMAC computer program and the VDI routine, since measured collision conditions have been used as program inputs, and the validity of the predicted VDI ratings is, of course, entirely dependent upon the accuracy of analytical predictions of damage. The experimental VDI ratings for each of the 10 vehicles involved in the staged collisions were independently generated by accident investigators.

In each run of the SMAC computer program for which results are presented, "typical" parameters other than weights were used (see Appendix B). Actual measured weights and correspondingly adjusted estimates of the complete-vehicle moments of inertia in yaw were used; that is, the radius of gyration was held constant within each vehicle category.

The only tuning adjustment that was made in vehicle parameters was in the representative value for the load-deflection characteristic of the peripheral structure (K_V), which was held constant for each vehicle category in all of the presented runs. The required value of this parameter in car-to-car and SAE barrier crashes was found to be* 50 lb/in^2 for full-size vehicles and 30 lb/in^2 for the single included case of a subcompact vehicle in order to achieve agreement with the measured extents of residual deformation in the presented collision experiments. These values were applied uniformly around the peripheries of the vehicles for which results are presented. The stiffness value of 50 lb/in^2 for full-size vehicles, which corresponds to a given vertical dimension for the contact area, agrees closely with the 12.5 *g*/ft reported by Emori (7) for full frontal contacts. In the case of the subcompact vehicle, a similar calculation yields 10.2 *g*/ft. It should be noted, however, that the presented experiments included only one subcompact vehicle and that further comparisons between predictions and experiments are necessary before a "typical" stiffness value for subcompact vehicles can be defined with confidence.

Kinematics—In the following, results of a sample "forward" reconstruction cal-

*For a 25 in vertical dimension of the contact area, 50 lb/in^2 corresponds to 2 lb/in^2 of pressure per inch of peripheral deflection.

Table 1—Predicted and Measured VDI Ratings

Collision Configuration	Velocity at Time of Impact, mph	Vehicle	Vehicle Weight, lb	Vehicle Damage Index: SMAC Prediction	Vehicle Damage Index: Investigator Rating of Actual Vehicles	CAL Full-Scale Crash Test No.
90 deg side impact	46.6	1968 Ford	3600	12FDEW2	12FDEW2	49
	0	1968 Ford	3860	03RYEW4	03RYEW4	
45 deg side impact	45.7	1968 Ford	3550	12FREE3	12FREE3	54
	0	1968 Ford	3805	02RYEW4	01RPEW3	
2 ft offset frontal	31.5	1964 Chev	3950	12FYEW5	12FYEW5	MRA 1
	30.5	1963 Chev	3080	12FYEW5	12FYEW4	
Frontal, head-on,	43.8	1968 Ford	3960	12FDEW3	12FDEW2	14
large versus small vehicle	43.8	1968 Opel	1750	12FDEW6	12FDEW6	
SAE barrier perpendicular to wall	37.9	1966 Ford	3572	12FDEW3	12FDEW3	Baseline 1
SAE barrier, oblique (ψ_0 = 20.9 deg)	40.0	1966 Ford	3630	11FDEW5	11FDEW4	Baseline 5

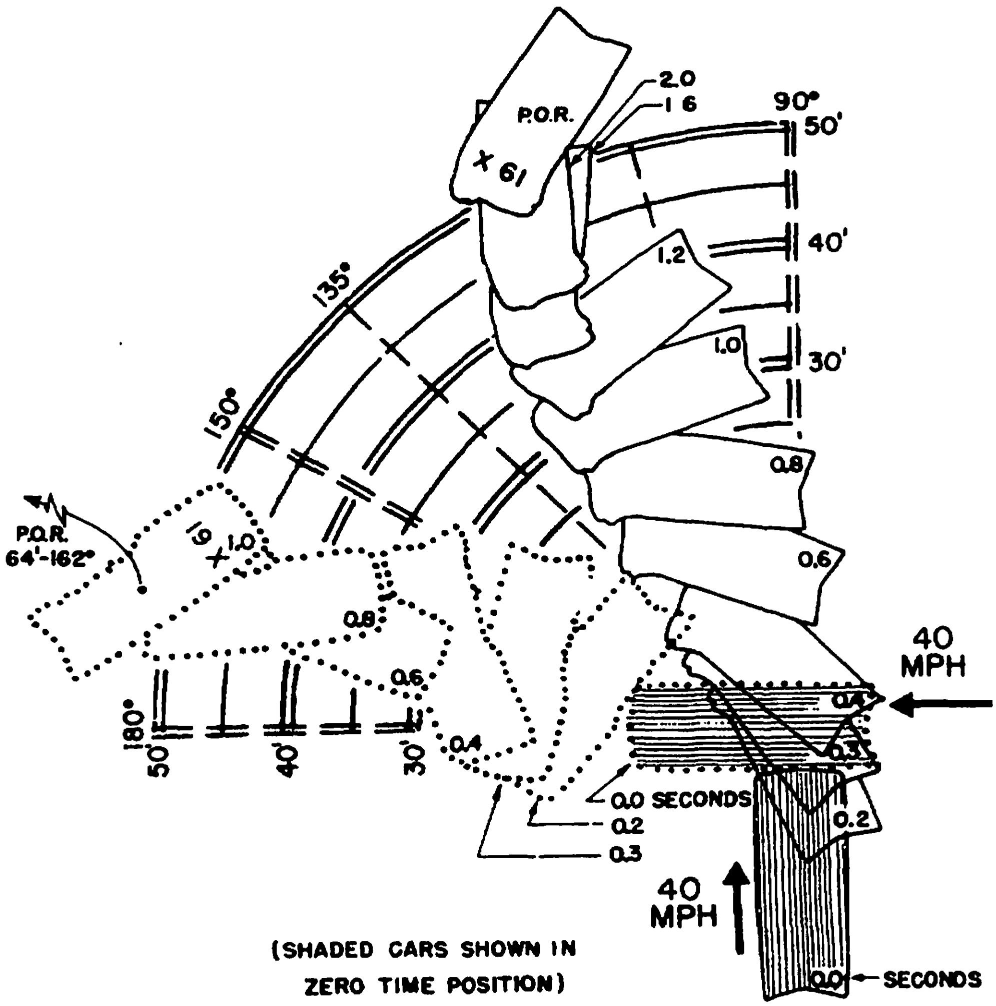


Fig. 9—Experimental data from Ref. 12—rear-side impact at 40 mph

culation (a calculation started with known velocities at impact) are compared with measured responses in an experiment reported by Severy, et al., (12).

Figs. 5 and 9, respectively, show the predicted and experimental kinematics of vehicles in an intersection type of collision for comparison. It should be noted that the predicted tire tracks and the final positions and orientations displayed in Fig. 5 include a time interval of 2.0 s after initial contact. In Fig. 9, the experimental kinematics of vehicle 2 are shown only for 1.0 s after initial contact, and vehicle 1 is shown in its rest position at an unspecified time greater than 2.0 s. A further comparison of the predicted and experimental kinematics in this case is presented in Fig. 10. While the experimental data do not include direct measures of damage, the sketches in Fig. 9 (12) do give an indication of the general locations and extent of damage, and the damage predictions in Fig. 5 permit

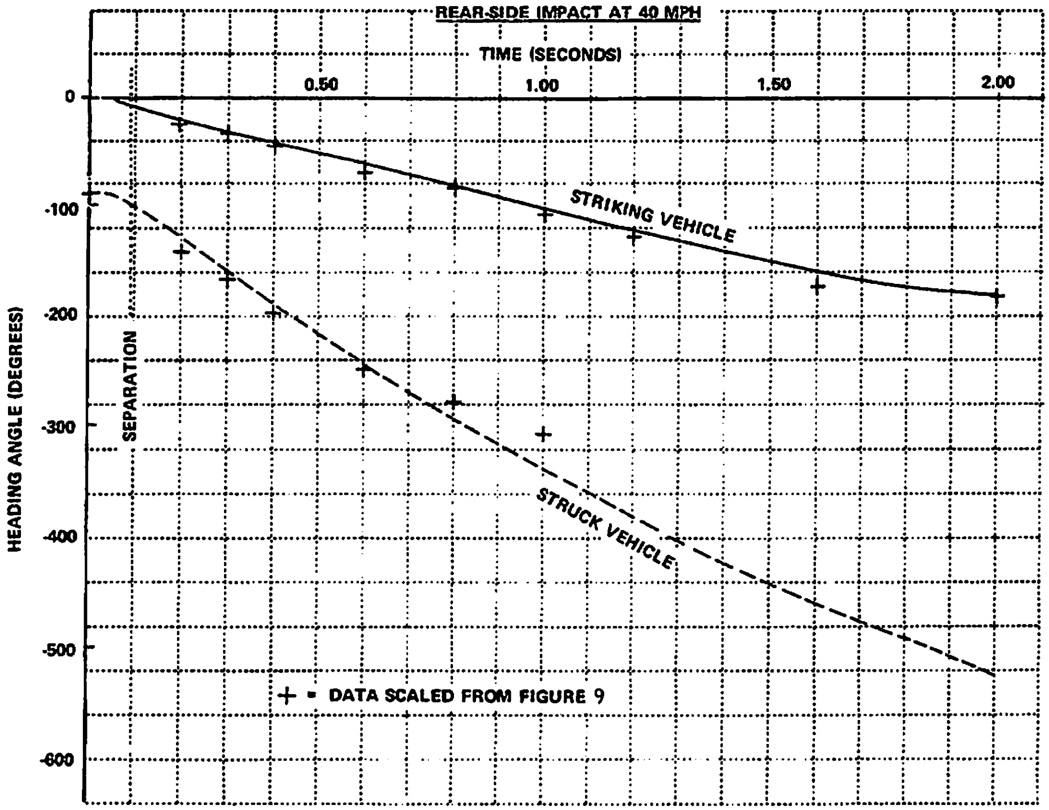


Fig. 10—Heading angles versus time

gross comparisons. The analytical predictions include complete definitions of the individual tire tracks and indications of points at which sliding of the individual wheels occurs, as depicted in the display shown in Fig. 5 (solid lines indicate sliding tires).

In general, the correlation of predicted and experimental kinematics and damage is considered to be very good. The minor discrepancies in kinematics are considered to be within the probable range of repeatability of the experiments.

Accelerations—Vehicle accelerations do not constitute a direct part of the reconstruction process. However, they do provide a primary means of refining the categorization of occupant exposures. Thus, this additional measure of validity of predictions must be recognized as being of fundamental importance.

In Table 2, predicted and measured (12) values of resultant peak accelerations are presented for six intersection type of collisions of identical vehicles. If the tire forces are assumed to be negligibly small at the moment of occurrence of the peak resultant acceleration, rigid-body behavior would require, on the basis of Newton's third law of motion, that the resultant peak accelerations of two identical vehicles be equal and opposite. In the experiments of Ref. 12, the measured values of acceleration were obtained by means of triaxial accelerometers

Table 2—Comparison of Predicted and Measured Vehicle Accelerations in 90 deg Intersection Collisions

Collision Configuration	Impact Velocity, mph	Vehicle	Measured* Resultant Peak Acceleration (Ref. 12), g	Average of Measured Peak Values of Acceleration, g	Predicted Resultant Peak Acceleration, g
Front-side	20	Striking	9	10	10.1
		Struck	11		
	40	Striking	17	17.5	17.9
		Struck	18		
Center-side	20	Striking	7	9.5	10.3
		Struck	12		
	40	Striking	16	21.5 (15)**	15.7
		Struck	27 (14)**		
Rear-side	20	Striking	6	7.5	7.8
		Struck	9		
	40	Striking	9	13	11.4
		Struck	17		

*Triaxial accelerometers mounted on vehicle frames near right center door posts (Ref. 12).
**In this case, the early, short-duration, 27 g spike is followed by a 14 g peak value that matches the timing of the peak acceleration of the striking vehicle (Fig. 10D of Ref. 12).

mounted on the vehicle frames near the right center door posts—in a position that was not directly impacted. Any motions of the accelerometer mounting point relative to the vehicle c.g. would, of course, produce deviations from equal and opposite readings. In Table 2, it may be seen that the averages of the measured peak values of accelerations for the two vehicles agree quite closely with analytical predictions.

While the simplified analytical treatment of vehicle structures in the SMAC program precludes valid predictions of details of the actual acceleration time-history waveforms, comparisons with experimental data indicate that the predicted time-histories, which resemble heavily filtered signals, correlate reasonably well with the general waveforms and durations.

In Fig. 11 predicted and measured accelerations for the struck vehicle in the 45 deg side impact experiment of Table 1 are presented for comparison. It should be noted that the areas under the predicted acceleration curves (the velocity changes that occur during the collision) result directly from application of the principle of conservation of momentum in the SMAC program; thereby, they are essentially independent of the assumed structural crush properties. The assumed crush properties do determine the durations of predicted impacts and, thereby, the extent of the generally small geometric changes that occur during collision contacts. They also influence the predicted intervehicle friction forces.

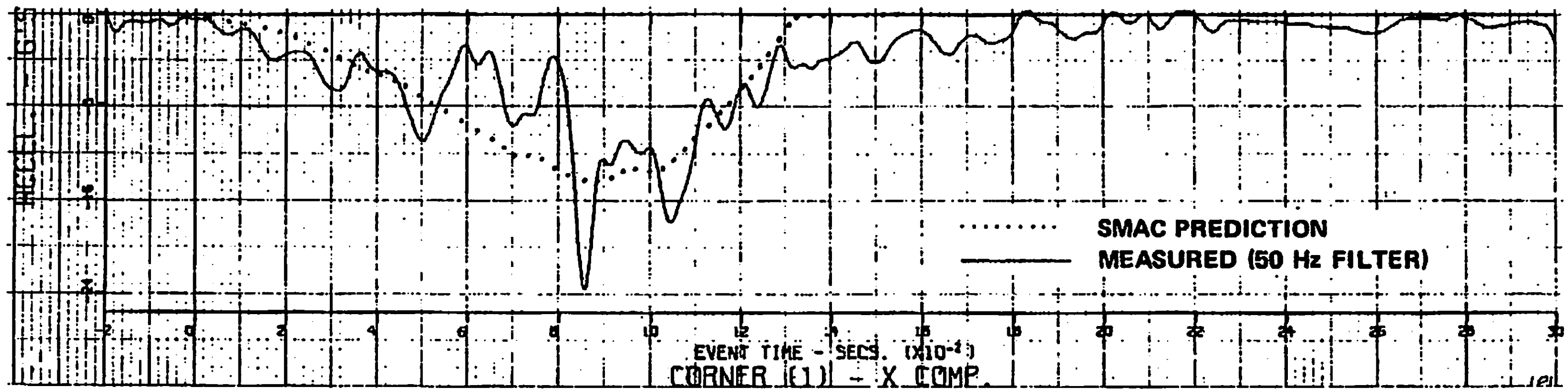


Fig. 11A—Impacting vehicle longitudinal acceleration response

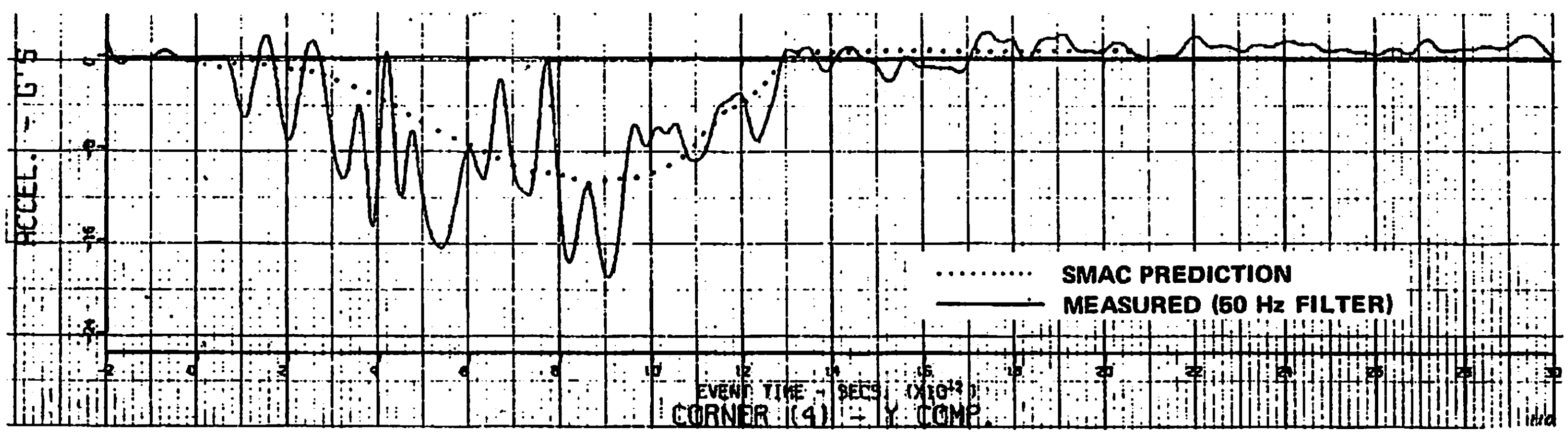
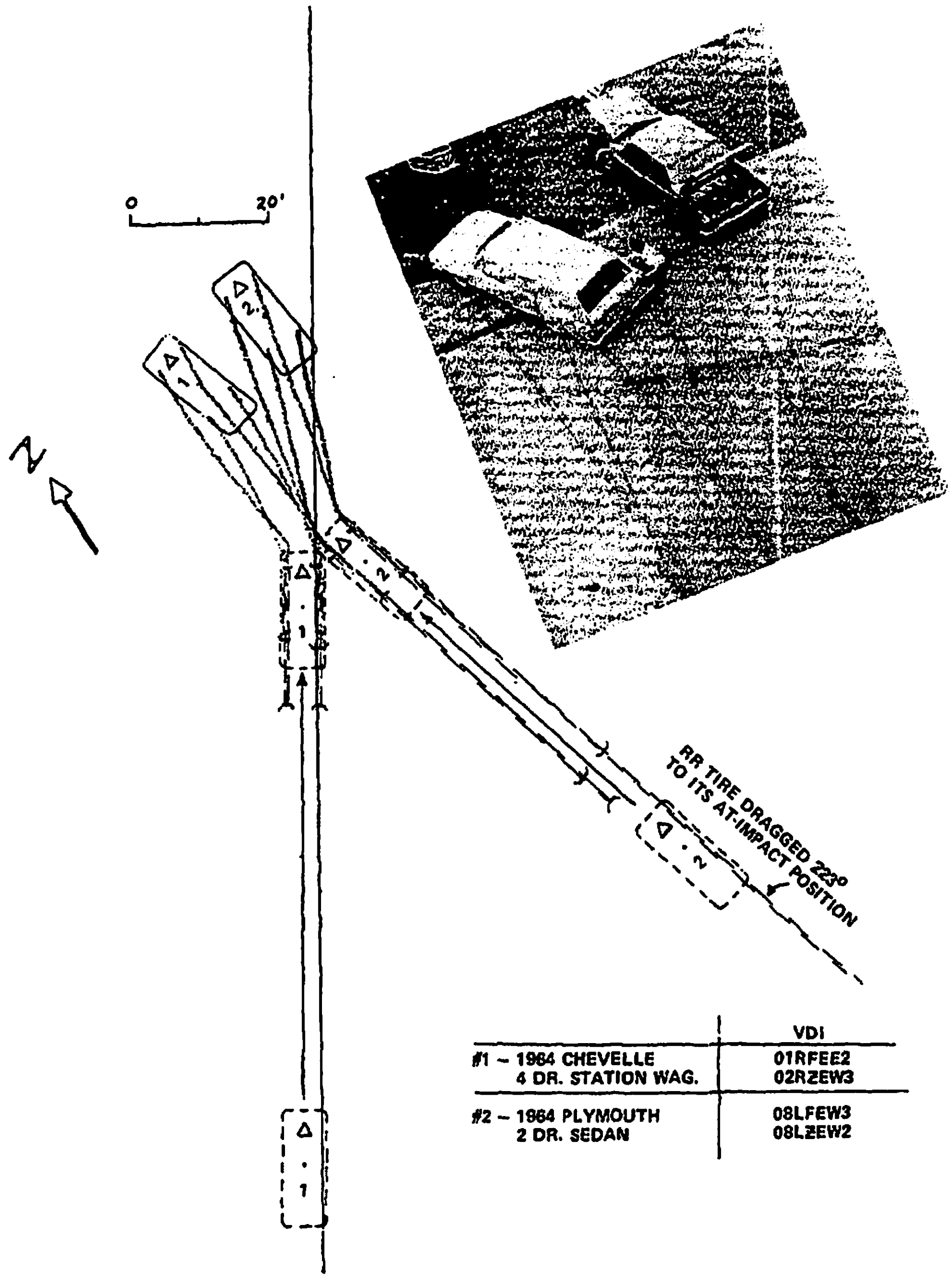
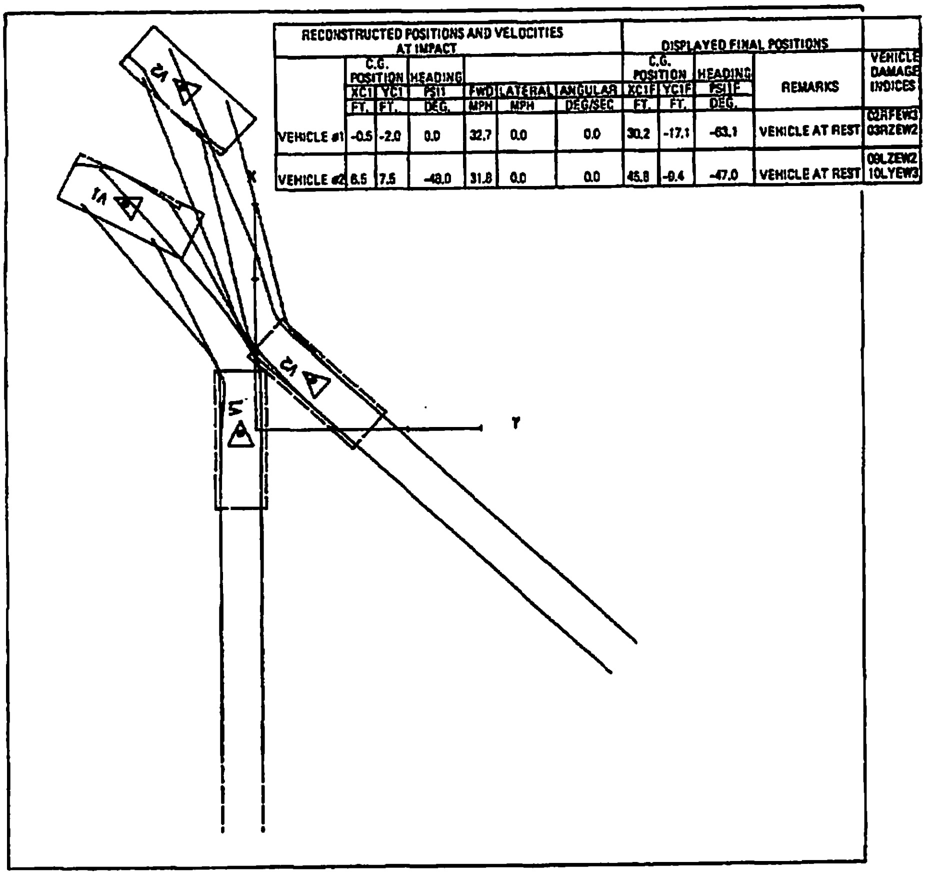


Fig. 11B—Struck vehicle lateral acceleration response



	VDI
#1 – 1964 CHEVELLE 4 DR. STATION WAG.	01RFEE2 02RZEW3
#2 – 1964 PLYMOUTH 2 DR. SEDAN	08LFEW3 08LZEW2

Fig. 12—Measured scene data test B (July 13, 1972)



	RECONSTRUCTED POSITIONS AND VELOCITIES AT IMPACT						DISPLAYED FINAL POSITIONS				
	C.G. POSITION		HEADING				C.G. POSITION		HEADING	REMARKS	VEHICLE DAMAGE INDICES
	XC1 FT.	YC1 FT.	PSI1 DEG.	FWD MPH	LATERAL MPH	ANGULAR DEG/SEC	XC1F FT.	YC1F FT.	PSI1F DEG.		
VEHICLE #1	-0.5	-2.0	0.0	32.7	0.0	0.0	30.2	-17.1	-63.1	VEHICLE AT REST	02RFEW3 03RZEW2
VEHICLE #2	6.5	7.5	-48.0	31.8	0.0	0.0	45.8	-9.4	-47.0	VEHICLE AT REST	09LZEW2 10LYEW3

AXIS INTERVALS ARE 10. FEET

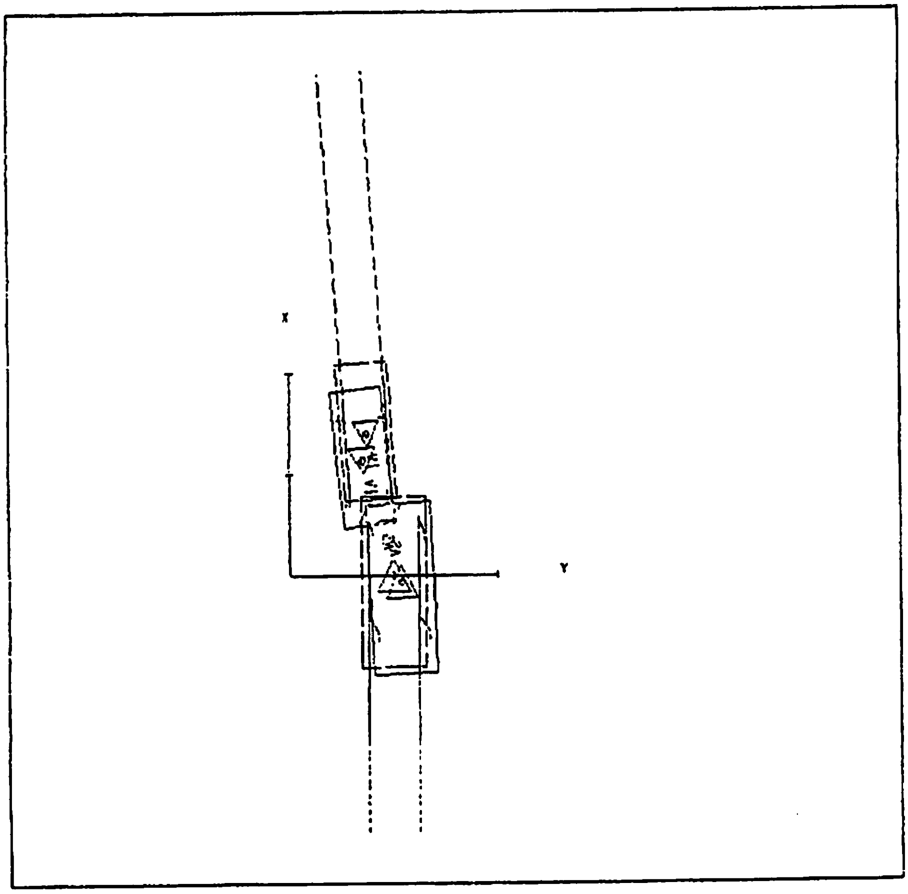
Fig. 13—Graphic display of outputs of accident reconstruction collision and trajectory—MRA test 3

The comparisons with experimental data, which include generally good correlation between the predicted and measured extents of vehicle damage, are considered to constitute evidence of the adequacy of the analytical assumptions of the SMAC program for generating realistic and reasonably accurate predictions of vehicle accelerations.

Reconstruction of Impact Conditions from Physical Evidence—A realistic evaluation of the validity and accuracy of any procedure for accident reconstruction must include applications to staged collisions for which the initial conditions are kept unknown until the reconstruction is completed. A sample application of this type was made to the staged accident depicted in Fig. 12.

After only four iterative runs of the SMAC program, a reasonably good fit to the measured evidence was achieved (Fig. 13). In this particular case, the maximum error in the reconstructed impact speeds was found to be 2.2%.

Actual Highway Accidents—The SMAC program has been applied to only a few actual highway accidents at the time of preparation of this paper. Since the



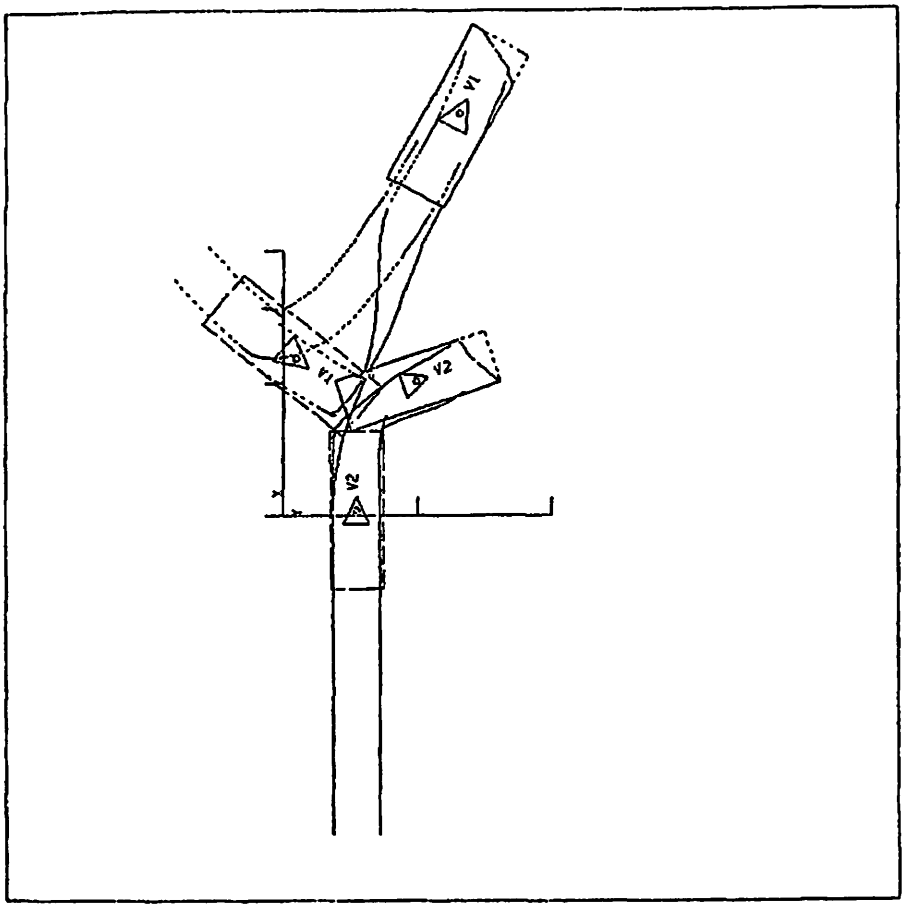
AXIS INTERVALS ARE 10. FEET

RECONSTRUCTED POSITIONS AND VELOCITIES AT IMPACT							DISPLAYED FINAL POSITIONS				
	C.G. POSITION		HEADING				C.G. POSITION		HEADING	REMARKS	VEHICLE DAMAGE INDICES
	XCI FT.	YCI FT.	PSII DEG.	FWD MPH	LATERAL MPH	ANGULAR DEG/SEC	XCIF FT.	YCIF FT.	PSIIF DEG.		
VEHICLE #1	14.0	7.4	176.0	27.1	-0.0	0.0	11.4	7.0	174.0	VEHICLE AT REST	12FYEW5
VEHICLE #2	0.0	10.0	-0.0	11.6	-0.0	-0.0	-0.6	10.8	-2.6	VEHICLE AT REST	12LFEW2

Fig. 14—Graphic display of outputs of accident reconstruction collision and trajectory—injury interpretations in Calspan case 109

actual impact conditions remain unknown in such cases, it is not possible to evaluate directly the accuracy of the results. However, the degree of confidence in the reconstruction has been found to vary with the nature and extent of the evidence and with the corresponding sensitivity of the overall fit to small changes in impact conditions.

For example, the reconstruction depicted in Fig. 14, in which there was very little movement subsequent to impact, relies heavily upon the accuracy of definition of the vehicle positions at impact relative to the final rest positions and on



AXIS INTERVALS ARE 10. FEET

RECONSTRUCTION POSITIONS AND VELOCITIES AT IMPACT							DISPLAYED FINAL POSITIONS				VEHICLES DAMAGE INDICES
	C.G. POSITION		HEADING				C.G. POSITION		HEADING	REMARKS	
	XC1 FT.	YC1 FT.	PSI1 DEG.	FWD MPH	LATERAL MPH	ANGULAR DEG/SEC	XC1F FT.	YC1F FT.	PSI1F DEG.		
VEHICLE #1	15.3	1.2	129.6	12.4	-0.9	-17.5	39.1	18.9	28.3	IN MOTION AT 3.0 SEC AFTER INITIAL CONTACT	01RFEW3
VEHICLE #2	0.5	7.0	0.0	35.6	0.0	0.0	13.0	12.7	71.6	VEHICLE AT REST	12FDEW3

Fig. 15—Graphic display of outputs of accident reconstruction collision and trajectory—CAL case 72-6B

damage measurements. In other cases, such as that depicted in Fig. 15, the longer postcollision trajectories provide additional items of evidence that are relatively sensitive to changes in impact conditions.

These initial exploratory applications have been performed with a limited number of manual adjustments of the initial conditions and without establishment of specific criteria for the fit to the physical evidence. As previously discussed, future plans include an automated procedure for adjustment of impact conditions to achieve an acceptable fit. It is also planned to include a determination of the ranges of initial conditions and driver control inputs that will satisfy the criteria for fits.

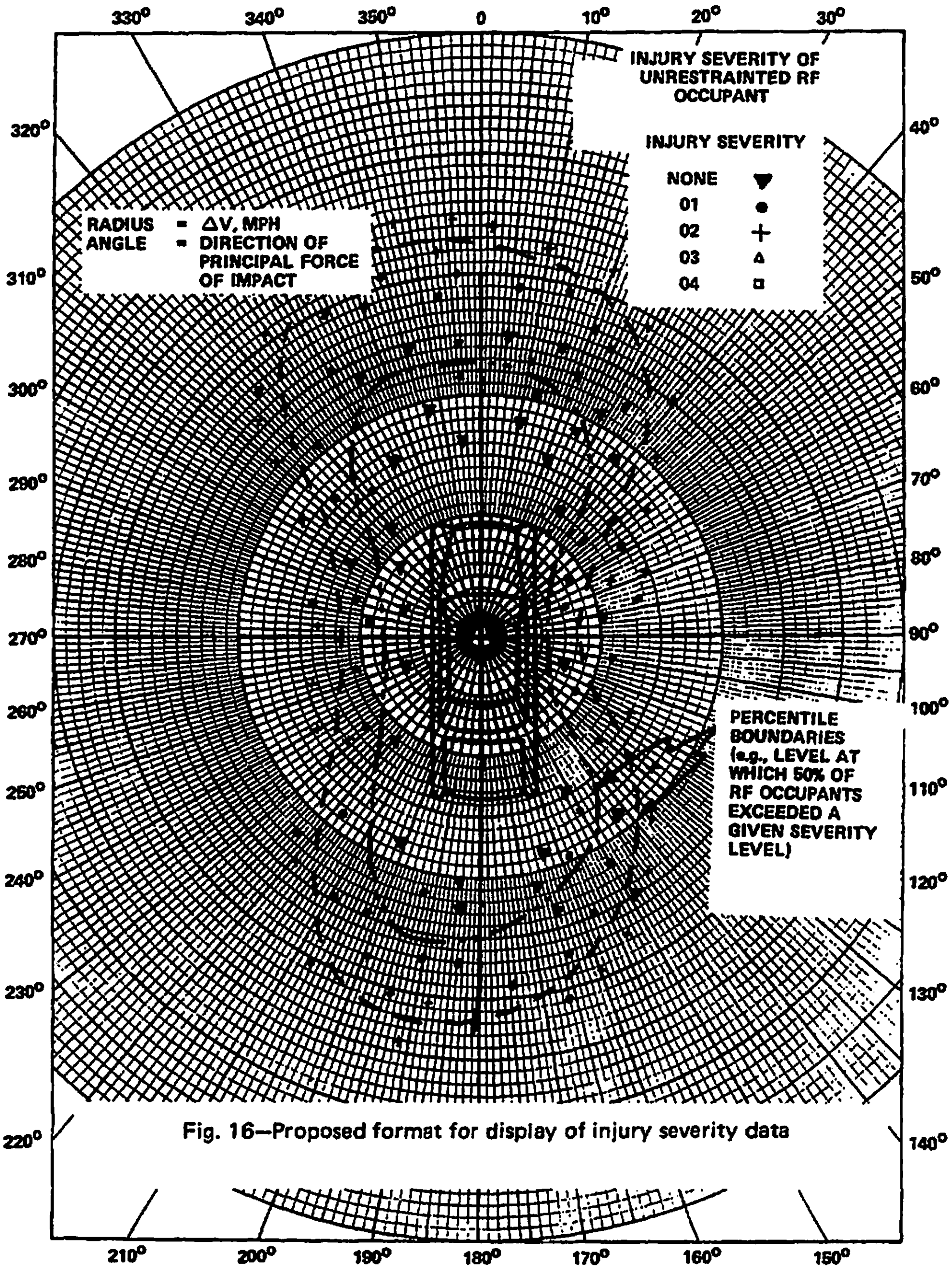


Fig. 16—Proposed format for display of injury severity data

Summary and Conclusions

The presented results of this research have established the feasibility of achieving relatively detailed definitions of occupant exposures in actual highway accidents by means of computer reconstructions. In view of the highly variable nature of physical evidence and injury mechanisms, it appears that applications will be most effective when two levels of information are sought in cases that are reconstructed in this manner.

First, injury data from all cases should be interpreted in terms of the velocity change experienced by the subject vehicle and the direction of the peak resultant acceleration. This form of definition of exposure, combined with the seated position and condition of restraint of the occupant, will permit the development of summary plots of injury severities, such as that depicted in Fig. 16. Percentile envelopes for the various injury severities, as shown in Fig. 16, can provide a means of direct comparison of vehicles and evaluation of the effectiveness of protective devices.

In cases where the nature of the physical evidence provides a relatively high degree of confidence in the detailed reconstruction and, further, where well-defined injuries have occurred, the data from the SMAC program can be input to the Calspan three-dimensional simulation of the crash victim (13) to reconstruct the internal evidence; that is, contact point locations and extents of indentations on the vehicle interior. This will provide analytical definitions of the occupant forces and accelerations corresponding to the injuries. In cases of special interest, an accelerator sled can also be used to generate a similar exposure of instrumented anthropometric dummies and thereby provide a direct means of calibration of dummy responses for injury interpretations.

Acknowledgments

The author wishes to acknowledge the contributions of the following individuals within Calspan Corp. to the research discussed in this paper: computer programming, Camille F. Bainbridge; computer-graphics displays, James P. Lynch; validation study and field testing, Donald L. Hendricks, Roger L. Orszulak, and Thomas G. Calderwood; instrumentation and collision experiments, Donald A. Alianello; scene measurement system, David J. Segal.

References

1. K. J. Tharp and J. M. Keryeski, "Techniques and Procedures for Accident Investigation." Proceedings of Collision Investigation Methodology Symposium, Warrenton, Virginia, August 24–28, 1969.

2. S. S. Teel and N. W. Lutkefedder, "Automotive Recorder Research and Its Effects on Future Vehicle Safety." Vehicle Safety Research Integration Sym-

posium, National Highway Traffic Safety Administration, Washington, D. C., May 30–31, 1973.

3. E. Marquard, "On the Mechanics of Vehicle Collisions." Automobiltechnische Zeitschrift, Vol. 64, No. 5 (May 1962), pp. 142–148.

4. E. Marquard, "Progress in the Calculations of Vehicle Collisions." Automobiltechnische Zeitschrift, Vol. 68, No. 3 (1966), pp. 74–80.

5. R. I. Emori, "Vehicle Mechanics of Intersection Collision Impact." Paper 700177 presented at SAE Automotive Engineering Congress, Detroit, January 1970.

6. F. Böhm and E. Hörz, "Non-Central Collisions of Two Rubber Tired Vehicles." Automobiltechnische Zeitschrift, Vol. 70, No. 11, pp. 385–389 and No. 12, pp. 428–432, 1968.

7. R. I. Emori, "Analytical Approach to Automobile Collisions." Paper 680016 presented at SAE Automotive Engineering Congress, Detroit, January 1968.

8. R. R. McHenry, "Development of a Computer Program to Aid the Investigation of Highway Accidents." Calspan Report No. VJ-2979-V-1, December 1971 (NTIS-PB 208537).

9. R. R. McHenry, D. J. Segal, J. P. Lynch, and P. M. Henderson, "Mathematical Reconstruction of Highway Accidents." Calspan Report No. ZM-5096-V-1, January 1973 (NTIS-PB 220150).

10. R. R. McHenry and N. J. DeLeys, "Development of Analytical Aids for Minimization of Single Vehicle Accidents." Calspan Report No. VJ-2251-V-10, July 1971 (NTIS-PB 204583).

11. R. R. McHenry, D. J. Segal, and N. J. DeLeys, "Determination of Physical Criteria for Roadside Energy Conversion Systems." Calspan Report No. VJ-2251-V-1, July 1967 (NTIS-PB 175919).

12. D. M. Severy, J. H. Mathewson, and A. W. Siegel, "Automobile Side-Impact Collisions, Series II." SAE Transactions, Vol. 67 (1959), pp. 238–264.

13. J. A. Bartz, "Development and Validation of a Computer Simulation of a Crash Victim in Three Dimensions." Paper 720961, Proceedings of Sixteenth Stapp Car Crash Conference, P-45. New York: Society of Automotive Engineers, Inc., 1972.

Appendix A
Calspan Scene Measurement System*

Optical systems offer several advantages, for purposes of measurements at accident scenes, in the form of increased accuracy and speed, reduced interference with traffic, and adaptability to a standard format for data transmission.

The Calspan data acquisition system (Fig. A-1) makes use of a transit instrumented with shaft angle encoders and a digital angle readout unit with resolution

*The described measurement system is being developed on Calspan funding as a proprietary item.

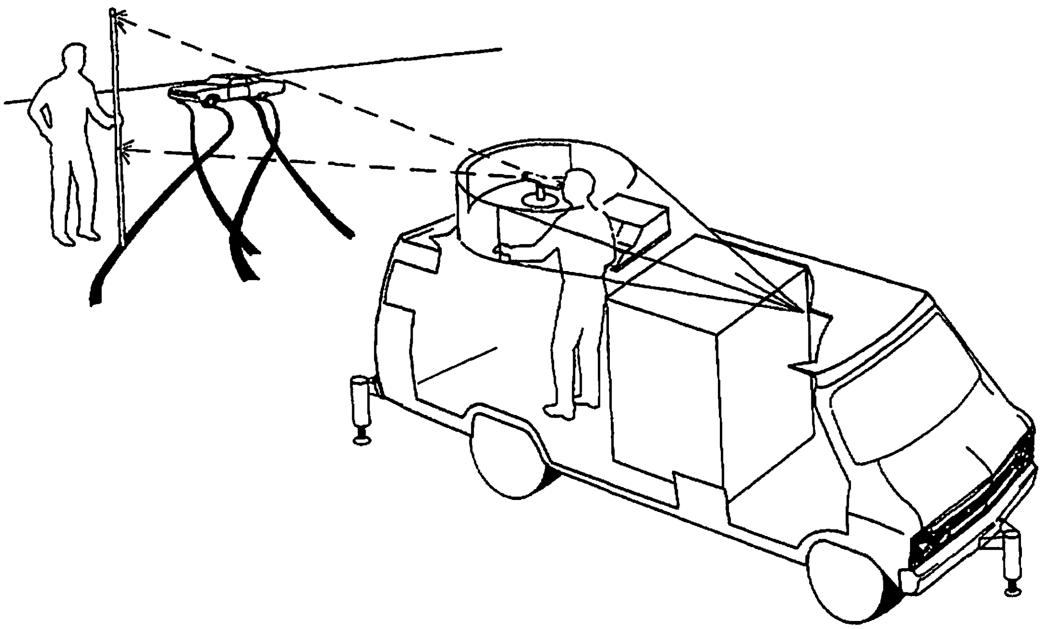


Fig. A-1—Calspan scene measurement system

of 0.01 deg. The azimuth and elevation angles of two points on a stadia rod held at a point of interest at the scene are fed directly onto an on-board minicomputer for processing. A data acquisition program resident in the on-board computer converts the transit data into rectangular coordinates in a selected reference system determined by two permanent reference points located at the accident scene. The initial two readings are used to define the selected reference coordinate system. The first reading locates the origin, and the second reading orients the direction of the positive X′ axis. In this manner, the measurements are made independent of the specific location of the transit.

A small keyboard with decimal integers permits the operator to code the dimensional information as it is recorded. A five-digit code word identifies the nature of the data that follows it (for example, tire skid mark) until a new identification code word is entered.

The accident scene measurements are then transmitted to a large-capacity base computer for reconstruction of the accident by the Calspan-developed SMAC computer program.

The van itself employs a gasoline-powered generator as a power supply for the on-board data processing equipment and for a heating/air-conditioning system. Transit sightings are made from inside the van to eliminate problems due to inclement weather. Retractable struts are employed to stabilize the vehicle against any motion during scene measurement, and the transit is mounted on a servo-driven automatic leveling system to minimize inaccuracies due to operator error.

Appendix B
Vehicle Parameters

In the interest of simplicity, the presented results obtained with the SMAC computer program have 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, and Fiat 850.
2. Compact—Maverick, Camero, Dart, and Hornet.
3. Intermediate—Chevelle, Torino, Coronet, Matador, and Skylark.
4. Full Size—Chevrolet, Galaxie, Polara, Ambassador, Monterey, LeSabre, New Yorker, Fleetwood, and Continental.

On the basis of available dimensional and shipping weight information, and with allowances made for both liquid weight and two passenger loading, the typical parameters in Table B-1 have been either directly derived or estimated from available measured values for similar vehicles.

Table B-1—Typical Dimensional and Inertial Parameters for 1971-1972 Automobiles

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

The symbols used in Table B-1 are defined as follows:

a, b = distances along vehicle fixed X-axis from total vehicle c.g. to center lines of front and rear wheels, respectively, in (both entered as positive quantities)

T = tread at front and rear wheels (average), in

k^2 = radius of gyration squared for complete vehicle in yaw, in^2

M = total vehicle mass, $lb\text{-}s^2/in$

X_F, X_R = distances along vehicle X-axis from total vehicle c.g. to boundaries of vehicle at front and rear, respectively, in (X_R is entered as negative quantity)

Y_S = distance along vehicle fixed Y-axis from total vehicle c.g. to boundary of vehicle at side (one-half of total vehicle width), in

Table B-2—Representative Values of Vehicle Parameters

Parameter	Value
$(CSTF)_{1,2}$, lb/rad	−10250.
$(CSTF)_{3,4}$, lb/rad	−10195.
C_μ	3×10^{-4}
K_V, lb/in^2	{full size = 50; subcompact = 30}
C_0	0.06423
C_1	3.5417×10^{-3}
C_2	4.7381×10^{-5}
μ	0.550
$\Delta\psi$, deg	2.00
$\Delta\rho$, in	0.20
λ, lb/in	15.0
ζ_V, in/s	5.0

For the vehicle parameters in Table B-2, 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.

The symbols used in Table B-2 are defined as follows:

$(CSTF)_i$ = cornering stiffness of tire at wheel i for small slip angles, lb/rad (entered separately to permit simulation of damaged tires)

C_μ = coefficient of linear decrement of friction with tire speed

K_V = load-deflection characteristic of peripheral vehicle structure, lb/in^2 (corresponding to given height of contact)

C_0, C_1, C_2 = constant coefficients in parabolic relationship fitted to approximate variations of "coefficient of restitution" with deflection

μ = friction coefficient for tangential forces between two interacting bodies

$\Delta\psi$ = angular interval between radial vectors in contact determination, deg

$\Delta\rho$ = increment of change of radial vector length in iterative routine for achieving equilibrium, in

λ = acceptable error in pressure balance between two bodies, lb/in (constant height of contact area is assumed) also, for solution stability, $(K_{V_1} \Delta\rho, K_{V_2} \Delta\rho) \leq \lambda$

ζ_V = minimum magnitude of relative velocity for which vehicle-to-vehicle friction forces are calculated, in/s