DOT HS- 800 801

PB 220 150

MATHEMATICAL RECONSTRUCTION OF HIGHWAY ACCIDENTS

Calspan Corporation
Transportation Research Department
4455 Genesee Street
Buffalo, New York 14221

Contract No. DOT-HS-053-1-146
January 1973
Intrim Technical Report

PREPARED FOR:
U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
WASHINGTON, D.C. 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/HS-800 803		[illegible]

4. Title and Subtitle	5. Report Date
Mathematical Reconstruction of Highway Accidents	January 1973
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Raymond R. McHenry, David J. Segal, James P. Lynch, Philip M. Henderson III	ZM-5096-V-1

9. Performing Organization Name and Address	10. Work Unit No.
Calspan Corporation 4455 Genesee Street Buffalo, New York 14221 (716) 632-7500	W/A N79
	11. Contract or Grant No. DOT-HS-053-1-146
	13. Type of Report and Period Covered Interim Technical Report 1/16/72 - 1/16/73
12. Sponsoring Agency Name and Address U. S. Department of Transportation National Highway Traffic Safety Administration Washington, D. C. 20590	14. Sponsoring Agency Code NHTSA

15. Supplementary Notes

16. Abstract

This report summarizes the results of the second year of a program of research directed toward the development and field testing of a computer program and associated optical measurement system to aid the investigation and reporting of highway accidents.

The overall system is aimed at providing a capability of processing and evaluating scene data, via radio contact with a remote computer, while the investigators are at the accident scene.

Included are detailed comparisons of responses and damage predicted by the developed analytical procedure with corresponding measurements from staged collisions. Field trial results with the optical measurement system are also presented.

It is concluded that the feasibility of the overall system concept has been established. Remaining difficulties with hardware, that are primarily associated with the communications link, are discussed.

17. Key Words	18. Distribution Statement
Accidents - Highway Investigation - Accidents Computer Program Accidents	Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	174	

Form DOT F 1700.7 (8-69)

FOREWORD

This report summarizes the results of the second year of a program of research directed toward the development and field testing of a computer program and associated optical measurement system to aid the investigation and reporting of highway accidents. The reported research was performed under Contract No. DOT-HS-053-1-146 with the Research Institute of the National Highway Traffic Safety Administration, U. S. Department of Transportation. The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

This report has been reviewed and is approved by:

Edwin A. Kidd

Edwin A. Kidd, Head
Transportation Research Department

ACKNOWLEDGEMENTS

The authors wish to acknowledge contributions of the following individuals, within Calspan, to the research described in this report.

- Computer Programming

  Mrs. Camille F. Bainbridge

- Validation Study and Field Testing

  Messrs. Donald L. Hendricks,
  Roger L. Orszulak, and
  Thomas G. Calderwood

- Collision Experiments

  Mr. Donald A. Alianello

SUMMARY

A computer program and an associated optical measurement system have been developed to aid the investigation of highway accidents. They are aimed at providing a capability of processing and evaluating scene data, via radio contact with a remote computer, while the investigators are at the accident scene.

Results of the second year of effort are presented and discussed. They include detailed comparisons of responses and damage predicted by the developed analytical procedure with corresponding measurements from staged collisions. Field trial results with the optical measurement system are presented.

It is concluded that the feasibility of the overall system concept has been established. Remaining difficulties with hardware, that are primarily associated with the communications link, are discussed.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

1.0 INTRODUCTION

1.1 Background

The overall objective of the reported research is to develop and field test a system for processing and evaluating highway accident data while the investigators are at the scene, via radio contact with a reconstruction computer program. The system is aimed at achieving improved quality and completeness in the reporting of physical evidence and improved uniformity in its interpretation in terms of estimation of impact conditions and categorization of occupant exposures.

Reconstruction of highway accidents is a process whereby the possible ranges of unknown variables in the sequence of events are bracketed on the basis of interpretation of the available physical evidence and, to a lesser extent, the testimony of witnesses and/or drivers. Attempts to achieve a "fit" to the overall body of evidence are made by means of iterative adjustments of the unknown variables and corresponding applications of the physical laws to individual events in the sequence.

Presently, 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.

The present research is aimed at providing a means for achieving uniform applications of analytical procedures to highway accidents and, thereby, providing a basis for refinement of the categorization of occupant exposures. It is also expected to provide improved information on the roles of vehicle and/or highway defects and of driver judgment in accident causation. Application of reconstruction calculations while the evidence is readily available for checking or for making additional measurements will serve to insure that all 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.

The intended end product of the present research is an analytical procedure with the minimum complexity compatible with the objectives. The basis for this selection of approach is the belief that greater benefits will be derived from a development effort which will permit widespread applications of a simplified data processing procedure than from an equivalent effort applied to the advancement of analytical techniques.

During the first year, an analytical approach for accident reconstruction and an optical technique for scene measurements were selected and defined (Reference 1). Initial development work within the first year yielded results that supported the feasibility of the concept. The second year effort, reported herein, has been directed toward completion of development and performance of field trials.

1.2 Organization of This Report

Conclusions and recommendations based on results of the second year efforts of this research are presented in Section 2.0. The results of the research are summarized in Section 3.0.

References are listed in Section 4.0.

Details of the analytical developments and of the optical measurement procedure are presented in Appendices 1 through 6.

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 Conclusions

2.1.1 The feasibility of rapidly processing and evaluating data transmitted from an accident scene has been established by results obtained during the second year of this research.

> The planned ultimate form of the overall system, which will make use of a single computer facility, could not be implemented during the reported second year of effort because of limitations of core storage on readily available time-sharing facilities (e.g., the Computer Search Corporation XDS Sigma-7 computer has a maximum of 80K bytes of storage available in the time-sharing mode). Because of its present core requirement (168K bytes), the Simulation Model of Automobile Collisions (SMAC) program has been operated on the Calspan computer (IBM 360/165). While future Calspan Corporation plans include the addition of facilities for transmitting and receiving data, such facilities were not available within the performance period of the presently reported research. Thus, the best approximation of the ultimate system that could be implemented included substantial time lags. It is described in the following paragraph.
>
> Measured data were transmitted to the Computer Search Sigma-7, via mobile telephone, for processing. The processed data, in addition to being transmitted back to the scene for tabular printout, were transmitted to an existing remote terminal at Calspan where they were punched on paper tape. The paper tape data were converted to IBM cards for use in producing a computer graphics display of the scene and for the development of inputs for the SMAC program.
>
> The fact that each component of the system was successfully operated is considered to have established feasibility. It is believed that the time lags can be reduced substantially by one of several possible courses of further development. For example, a minicomputer on board the investigation vehicle could serve to partially process the measurement data, for checking purposes, subsequent to which radio transmission could be made to a Calspan receiver with a tape interface on the IBM 370/165. Also, it should be noted that the SMAC core requirement can probably be reduced substantially by programming changes directed at that objective.

2.1.2 The Simulation Model of Automobile Collisions (SMAC) computer program constitutes a significant advance in the state of the art of accident reconstruction.

> The detailed correlation of output information from the SMAC program (kinematics, vehicle damage, acceleration components and tire tracks) with corresponding results of staged collisions has been demonstrated to be surprisingly good, in view of the extensive simplifying assumptions and the use of "typical" vehicle parameters (Reference 1 and Section 3.1). The program generality permits inclusion of effects of control inputs, damage to the running gear, terrain zones with different friction properties (e.g., pavement and roadside surfaces) and variation of the effective tire-terrain friction coefficient with speed. The auxiliary computer graphics routine (Section 3.3) generates pictorial displays of the reconstructed accident, including complete tire tracks for comparison with the frequently fragmentary scene data and predicted damage of the vehicles. The SMAC computer program is considered to potentially be a highly beneficial tool for categorization of occupant exposures and for investigation of causal factors in off-scene applications to adequately reported accident cases as well as in the intended on-scene applications.

2.1.3 The data acquisition system for scene measurements has been made operational and has proven to perform as intended.

> A number of remaining problem areas must be resolved before the system can be considered ready for meaningful field testing. Primary among these is the communications link between the scene and the remote computer. Also, on the basis of the limited experience gained with the system by trained accident investigators a need exists for additional measurement code categories. Particularly desirable are additional scene data codes such as lane markings, signs, signal lights, etc.

2.1.4 The use of a mobile telephone as a communications link to the computer is unacceptable as the system is currently intended to operate.

> Applications of the system have been interrupted repeatedly by disconnections from the computer that have been produced by interference signals in the mobile phone link.

2.1.5 A conventional passenger sedan is not a suitable vehicle for transporting the investigators and the optical measurement system equipment to the scenes of accidents.

> The present vehicle (1972 Chrysler, 4 door sedan) does not have sufficient space for convenient stowage of the necessary equipment. The layout of equipment that is made necessary by physical constraints of the vehicle results in an extensive amount of lost motion.

2.1.6 An auxiliary form of communications is needed between the transit/terminal operator and the investigator who holds the stadia rod.

> Long distances between the two investigators and/or heavy nearby traffic tend to make vocal communication difficult.

2.2 Recommendations

2.2.1 Development and field testing of the accident investigation system should be continued.

> In its present state of development, each component of the scene measurement and data processing system has been demonstrated to perform successfully. However, a number of frustrating problems with hardware have impeded the rate of progress toward making the overall system fully operational from the accident scene. In particular, the use of a mobile telephone for data transmission and the separate use of a time-sharing computer (conversion of transit data into scene dimension format) and a batch processing computer (reconstruction calculations) have created problems and complexity in applications of the system. The mobile phone data link, which is similar to a party-line telephone, has been used successfully for short time periods but the problems of interference signals and inadvertent disconnection during the relatively prolonged process of obtaining scene measurements have made the present mode of operation unacceptable for field applications.

Because of the need for a time-sharing computer capability for initial processing of data taken with the optical measurement system (i.e., to convert the transit data into rectangular coordinates in the selected reference system and to display it for confirmation by the transit operator) and the fact that the available time-sharing equipment has insufficient core for the developed accident reconstruction program, it is currently necessary to make use of two separate computer facilities to complete the processing of scene data. However, a number of possibilities for system modifications to alleviate communications problems and to consolidate the data processing in a single computer facility are currently being explored.

In view of the above considerations, the recommended continuation of system development and field testing would include revisions and further development of system hardware prior to initiation of field testing using police personnel. The objective of such field testing would be to investigate the training needs for use of the fully developed system and the feasibility of its adoption by police investigators.

2.2.2 Effort should be continued on the development of an automatic iteration process for the SMAC program.

An automatic iteration process with the SMAC program, to achieve a "best fit" to the physical evidence at the scene has been extensively planned but has not yet been implemented. The delay in implementation has been prompted, in part, by a desire to gain experience with manual iteration of the reconstruction calculations in applications to actual highway accidents. Also, it has been necessary to devote primary attention and efforts to the cited problems with the scene measurement system, in order that physical evidence could be generated in the format of that system. As a result, it will be necessary to apply a continuing analytical and programming effort to achieve the desired automatic reconstruction process and to incorporate analytical refinements as further experience is gained. A fully automatic iteration process is seen as an essential feature of the overall system, prior to its widespread application, in order that uniform interpretations of physical evidence can be achieved.

2.2.3 The SMAC program should be applied to adequately reported, existing accident cases to achieve improved categorization of crash victim exposures.

Acceleration data predicted by the SMAC program, such as that depicted in Figures 25 and 28, could serve as a basis for refined categorization of exposures in statistical analyses of the injury consequences of accidents. In particular, if the area under the resultant center-of-gravity acceleration curve were determined (i.e., for values greater than an arbitrarily selected threshold of, perhaps, one "g") it would provide a direct indication of the velocity change, ΔV , experienced by the passenger compartment during the collision. Such a measure would constitute a substantially more meaningful quantity than either the "impact" speed or the "travel" speed in relation to the severity of exposure of the vehicle occupants. Combination of ΔV , as herein defined, with the angular orientation of the peak resultant acceleration (currently determined in the SMAC program as a part of the VDI calculation) would permit the generation of polar plots, such as that depicted in Figure 1, in which the injury severity for a given seated position and condition of restraint could be displayed. Given a sufficient number of such data points from actual accidents, boundary curves could be developed for percentiles of the various injury severity levels.

In this manner, a basis could be provided for comparisons of collision performance between vehicles and for measures of the effectiveness of protective devices.

2.2.4 The SMAC program, in combination with accelerator sled experiments, should be applied to the calibration of anthropometric dummy responses for injury interpretations.

Interpretation of measured dummy responses in terms of the corresponding injury potential for humans constitutes a highly controversial aspect of MVSS 208. One source of difficulty is the lack of a "one to one" relationship between the dynamic responses of existing dummies and those of living humans. Another is the fact that differences exist between sensor mounting methods and positions, and resulting frequency response characteristics, in the cases of the specimens used in tests of impact tolerances (i.e., animals, cadavers, volunteers) and in anthropometric dummies.

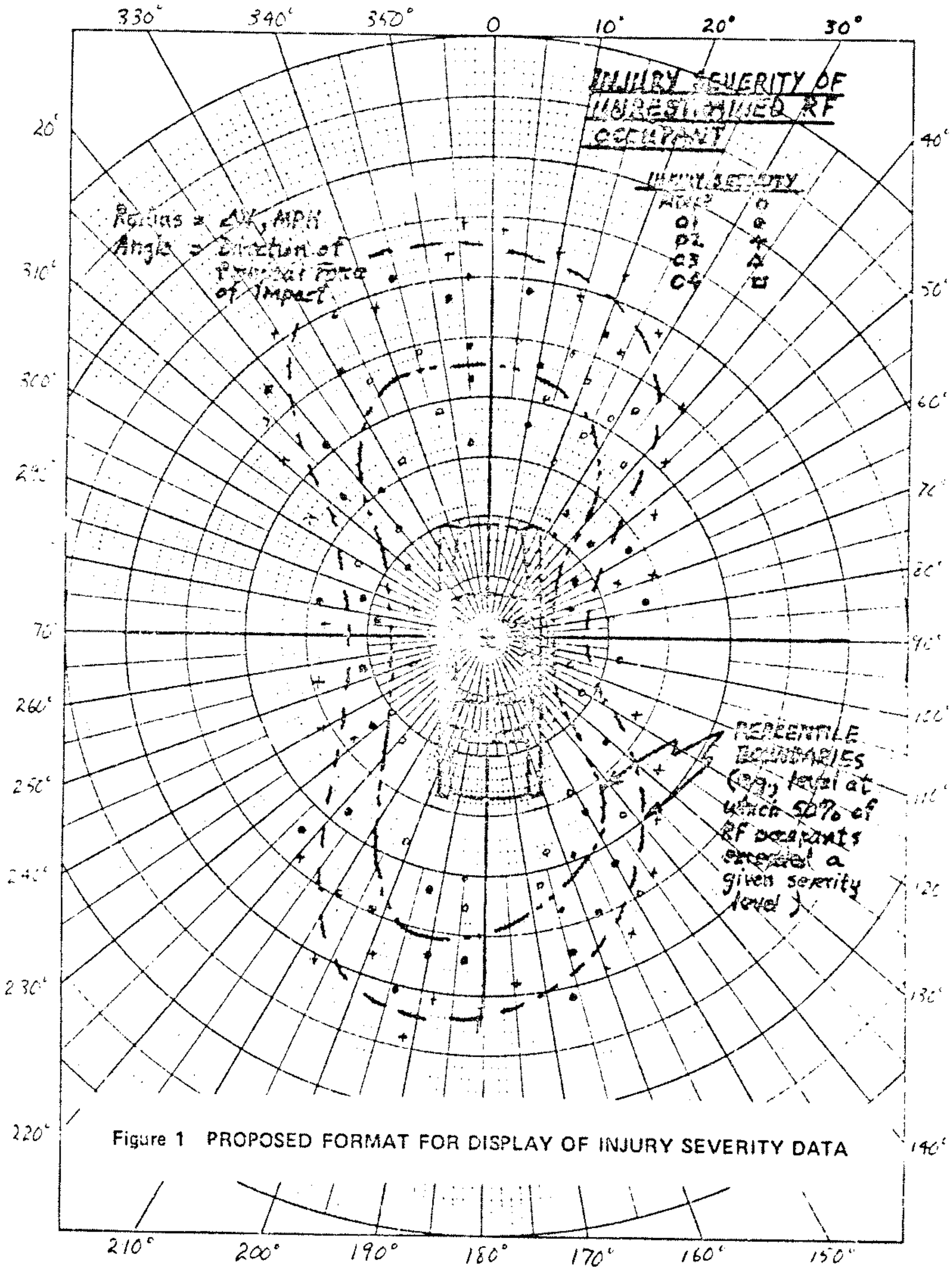


Figure 1 PROPOSED FORMAT FOR DISPLAY OF INJURY SEVERITY DATA

A long range approach to the alleviation of this problem is to strive for a test dummy which will approach a "one to one" relationship with the responses of a living human. However, it must be recognized that, despite future improvements, dummies will continue to be test devices that require calibration.

The presently recommended research task would be aimed at defining calibration factors for existing dummies, instrumented in accordance with MVSS 208, by means of direct correlation of their measured responses with injuries that have occurred in actual highway accidents. The SMAC program would be applied to reconstruct the vehicle dynamics in selected, actual injury-producing accidents. Physical simulation of the injury producing conditions, by means of an accelerator sled, would be used to determine the corresponding measured responses of existing dummies under the specific conditions of restraint. By this means, the measured dummy responses could be directly correlated with injuries to living humans.

2.2.5 Further applications of the overall system to staged collisions, in which the impact conditions are kept unknown until completion of the reconstruction, should be performed.

Applications of this type constitute the only means of achieving a realistic evaluation of the accuracy of any existing techniques for reconstruction of impact conditions, in view of the use of "typical" vehicle parameters and, frequently, of estimated tire-ground friction coefficients. In staged collisions with known impact conditions, it is obviously possible to adjust estimated parameters and, thereby, to achieve a misleading degree of agreement with the physical evidence.

2.2.6 Effort should be continued on the development of computer routines for processing indirect evidence.

The existing investigation system processes only direct physical evidence, as required to reconstruct the collision sequence. Effort has been applied to the task of expanding the data processing capabilities to include indirect supporting evidence (e.g., information about the driver, the existence and timing of traffic control signals, steering column deformation, etc.). The GM Long Form

(GM PG 2070, "Collision Performance and Injury Report") has been used as a guide in this effort. However, computer programming has not yet been initiated on this aspect of the investigation system.

3.0 DISCUSSION OF RESULTS

During this second year of the research program, effort has been concentrated on completion of development and field testing of the overall measurement and reconstruction system described in Reference 1. While the rate of progress toward a fully operational system has been somewhat slower than projected, the results obtained from trial applications of the various components of the system continue to be most encouraging. In particular, the degree of success achieved in reconstructing staged collisions and in predicting VDI (Vehicle Damage Index) ratings for given impact conditions has surpassed expectations, in view of the analytical simplifications.

The required extent of development efforts on both the SMAC program and the optical measurement system substantially exceeded original estimates and, as a result, it was necessary to curtail the levels of effort on other tasks. For this reason, the total number of accident events at which the system could be field tested within the constraints of available funding and time fell short of that envisioned in the proposal.

Results obtained in trial applications of the system clearly indicate that the overall objectives of this research are feasible. However, a number of minor difficulties with hardware remain to be overcome prior to its full implementation (see Section 3.4). Progress in field testing the accident reconstruction system at actual highway accidents and, as experience is gained, in the progressive incorporation of indirect supporting evidence was impeded by a number of frustrating minor problems with hardware. As a result, it was possible to obtain complete measurements with the optical system at the scene of only one actual highway accident. In parallel with the continuing efforts to overcome hardware problems in the optical measurement system, applications of the SMAC computer program were made to scene data obtained by conventional means from two actual accidents and graphic displays were developed for both measured and reconstructed scene data.

Specific accomplishments during the second year of the research program are discussed in the following paragraphs.

3.1 Accident Reconstruction Computer Program

A substantial amount of programming and analytical effort was found to be required to complete development of a post-processing routine for generating Vehicle Damage Indices (VDI) from predictions of damage generated by the SMAC (Simulation Model of Automobile Collisions) computer program. The routine is based on SAE Recommended Practice J224a. A significant number of changes of the VDI routine outlined in Reference 1 were found to be necessary to achieve satisfactory results. In particular, difficulties were encountered with corner damage and with damage distribution. A revised outline of the calculation procedure is presented in Appendix 1.

Analytical effort was applied to the task of developing logic to select system parameters and initial conditions for inputs to the SMAC computer program (see Appendix 2 for SMAC input format) and to automatically adjust the initial conditions in iterative attempts to achieve agreement with the physical evidence. Progress in this task was impeded by the delayed availability of VDI outputs from the reconstruction calculations, which will play an important role in the planned iterative procedure. Input parameters for four categories of automobile size are presented in Appendix 3.

Analytical and programming effort was applied to the task of generating computer graphics displays of both analytical reconstructions and measured data from the accident scene. The highly successful results of this effort are reported in Section 3.3 and Appendix 5.

3.1.1 Comparison of Analytical Predictions of Damage and Responses with Results of Staged Collisions

The reconstruction computer program was applied to eight staged collisions and two actual highway accidents for which investigator rated VDI's (Vehicle Damage Indices, SAE J224a) were available, involving a total of eighteen damaged vehicles. These trial applications to a relatively wide variety of impact conditions revealed needs for a number of program revisions both in the collision routines (Subroutines COLL and SETIND) and in the post-processing routine for generating Vehicle Damage Indices (Subroutine DAMAGE). Subsequent to each program revision, repeated runs were performed for all cases.

One result of this developmental exercise is a remarkably good correlation between analytically predicted and investigator rated VDI's. Results from the cited eight staged cases and from applications to two actual highway accidents are presented in Table 1. The presented comparisons for the eight staged collisions constitute a check of the validity of both the Simulation Model of Automobile Collisions (SMAC) computer program and the VDI routine, since measured collision conditions were used as program inputs and the validity of the predicted VDI rating is, of course, entirely dependent upon the accuracy of analytical predictions of damage.

The "investigator rated" VDI values that are presented for each of the eighteen damaged vehicles in Table 1 were independently generated by experienced members of the Calspan Accident Investigation Section. Four of the staged accidents are baseline tests that were performed within separate Calspan research programs on structural crashworthiness (Contract Nos. FH-11-7622 and FH-11-6918, References 3 and 4). Another (Calspan Test No. 14) was performed as a part of a study of underride/override of frontal structures (Contract No. FH-11-7317, Reference 5). The other three staged accidents (MRA Test Nos. 1, 2, and 3) were performed within the present research contract.

TABLE I PREDICTED AND MEASURED VDI RATINGS

Collision Configuration	Velocity At Time Of Impact	Vehicle	Vehicle Weight Lbs.	Vehicle Damage Index* SMAC Prediction	Vehicle Damage Index* Investigator Rating of Actual Vehicles	CAL Full-Scale Crash Test No.
90° Side Impact	46.6 MPH	1968 Ford	3600	12FDEW2	12FDEW2	49
	0	1968 Ford	3860	03RYEW4	03RYEW4	
45° Side Impact	45.7 MPH	1968 Ford	3550	12FREE3	12FREE3	54
	0	1968 Ford	3805	02RYEW4	01RPEW3	
2' Offset Frontal	31.5 MPH	1964 Chev	3950	12FYEW5	12FYEW5	MRA No. 1
	30.5 MPH	1963 Chev	3030	12FYEW5	12FYEW4	
Frontal, Head-On, Large vs Small Vehicle	43.8 MPH	1968 Ford	3960	12FDEW3	12FDEW2	14
	43.8 MPH	1968 Opel	1750	12FDEW6	12FDEW6	
SAE Barrier Perpendicular to Wall	37.9 MPH	1966 Ford	3572	12FDEW3	12FDEW3	Baseline No. 1
SAE Barrier, Oblique (ζ = 29.9°)	40.0 MPH	1966 Ford	3630	11FDEW5	11FDEW4	Baseline No. 3

*SAE J224a

TABLE 1 (Continued)

Collision Configuration	Velocity At Time Of Impact	Vehicle	Vehicle Weight Lbs.	Vehicle Damage Index* SMAC Prediction	Vehicle Damage Index* Investigator Rating of Actual Vehicles	Calspan Full-Scale Crash Test No.
Oblique Side Impact	27.0 MPH	1964 Plymouth 2 Dr. Sedan	3340	01RFEE1	05RFEE2	MRA Test No. 2
	26.5 MPH	1964 Chevelle 4 Dr. Station Wagon	3095	08LZEW2	11LZEW2	
Oblique Side Impact	33.0 MPH	1964 Chevelle 4 Dr. Station Wagon	3095	02RFEW3 03RZEW2	01RFEE2 02RZEW3	MRA Test No. 3
	32.5 MPH	1964 Plymouth 2 Dr. Sedan	3340	09LZEW2 10LYEW3	08LFEW3 08LZEW2	
Oblique Frontal Impact	12.4 MPH**	1971 Ford Galaxie 500	3821	01RFEW3	01FZEW2	Calspan Case No. 72-6B
	35.5 MPH**	1971 Volkswagen Microbus	2790	12FDEW3***	11FDEW7	
90° Side Impact	42.4 MPH**	1972 Chevrolet Nova	3246	01RFEW3	01FDEW2	Calspan Case No. 72-8B
	42.6 MPH**	1964 Plymouth	3610	10LYEW4	10LDEW5 02RBEW3	

*SAE J224a

**Reconstruction Values of Velocity (Actual Highway Accidents)

***Based on Passenger Car Configuration Rather Than Van

It should be noted that the analytical predictions for the first six cases in Table 1 were each run using the measured impact velocities and weights (i.e., there was no attempt to reconstruct the impact conditions from the rest positions and physical evidence). Also, since five of those six collisions were run within crashworthiness-related research programs, the reporting in those cases of rest positions and physical evidence, other than damage, was fragmentary at best. Finally, it should be recognized that the investigator-rated values for VDI's involve opinions and that they may not be exactly the same when rated by different investigators.

In each run of the SMAC computer program, for which results are presented, "typical" parameters other than weights were used (see Appendix 3). For each of the staged collisions actual measured weights and correspondingly adjusted estimates of the complete-vehicle moments of inertia in yaw were used (i.e., the radius of gyration was held constant within each vehicle category). In the two actual accident cases, estimated weights based on published data were used. In Calspan Case No. 72-6B, the estimated moment of inertia in yaw of the Volkswagen microbus was varied, as discussed in Section 3.1.3.

In the case of the first two staged impacts in Table 1 (Calspan Crash Test Nos. 49 and 54), a trailing cable on the striking vehicle was abruptly braked at approximately 0.250 seconds after contact. Inputs corresponding to locked-wheel brake forces applied by the striking vehicle subsequent to separation have, therefore, been used to generate similar decelerations of the striking vehicles after separation of the two vehicles (i.e., to prevent multiple impacts). In the computer run corresponding to the 2' offset frontal (MRA Test No. 1), the left front wheels of both vehicles were braked at t = 0.100 seconds to simulate the effects of wheel damage on the "spin-out" trajectories. Similarly, the front wheels of the Opel in the frontal, head-on (Calspan Crash Test No. 14) and of the crash vehicle in the SAE barrier perpendicular crash (Baseline No. 1) were braked at t = 0.100 seconds.

The effects of a locked wheel on "spin-out" trajectories have generally been found to be of secondary importance. However, they tend, in the case of directly involved wheels, to be in the direction of improving agreement with the experimental responses. Therefore, the assumption has been made that directly involved wheels are damaged and locked by the collision event. It should be noted that the program automatically limits the input values of braking forces to make them compatible with the wheel loadings and the specified tire-terrain friction coefficient(s).

In the case of the oblique barrier collision (Baseline No. 5), the vehicle was supported on caster wheels in the crash approach. For this reason, the simulation run includes both front wheel and rear axle steered angles and a reduced value is assumed for the effective tire-terrain friction coefficient (i.e., 0.4 is used).

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 (Appendix 3) in all of the presented runs. The value of this parameter for full-size vehicles was reduced from the 75 lb/in^2, which was found to yield reasonable results in the runs presented in Reference 1 (1960 vintage vehicles with no quantitative information available on the extent of damage), to 50 lb/in^2 in order to achieve improved agreement with the measured extents of residual deformation. It should be noted that, for a given amount of energy absorption, the extent of deflection of a linear spring varies inversely with the square root of the stiffness.

$$E = \frac{1}{2} KX^2, \quad X = \sqrt{\frac{2E}{K}}$$

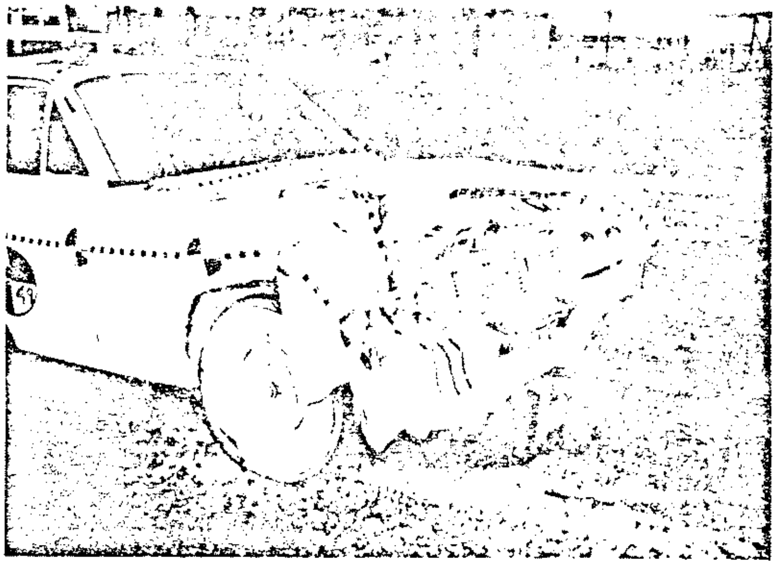
Thus, a reduction from 75 to 50 lb/in^2 would produce only a 23% increase in the deflection for equal amounts of energy absorption. Values of 50 lb/in^2 for full-size vehicles and 30 lb/in^2 for the single included sub-compact vehicle have been applied uniformly around the peripheries of the vehicles 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's per foot reported by Emori (Reference 6) for full frontal contacts. (Appendix 3, Size Category 4, Vehicle Width = 79.2 inches, (79.2)(50) = 3960 lb/in, (3960)(12) = 47,520 lbs/ft. For the full-size vehicle weights in the first six runs for which results are presented, the indicated stiffness corresponds to the range of 12.0 to 15.3 g's/foot.) In the case of the subcompact vehicle, a similar calculation yields 10.2 g's/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.

The collision cases that are included in Table 1 are discussed in greater detail in the following paragraphs.

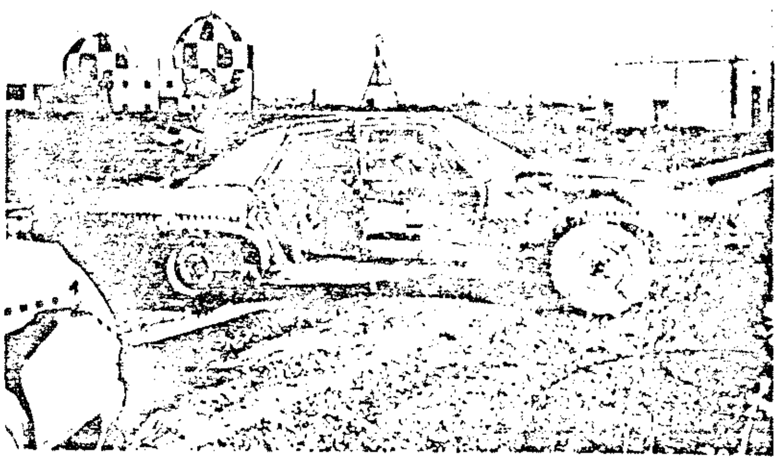
<u>90° Side Impact, Calspan Test No. 49</u>

In Table 1, it is seen that identical agreement has been achieved between the predicted and the investigator-rated VDI's for both vehicles. Photographs of the damaged vehicles are presented in Figure 2, and a computer graphics display of the corresponding SMAC prediction is presented in Figure 3. The maximum interior width reduction of the struck vehicle is given as 22.3 inches (Reference 3), and the corresponding SMAC prediction of indentation depth is 20.3 inches. Permanent deformation of the impacting vehicle was "essentially limited to the front two feet" (Reference 3). The corresponding SMAC prediction is 20.3 inches.

Additional correlation exists with other response measures including the sideward movement of the struck vehicle which is reported (Reference 3) as being "about 35 feet". The SMAC prediction for sideward movement of the center of gravity of the struck vehicle is 38.6 feet.



(a) IMPACTING VEHICLE



(b) STRUCK VEHICLE

Figure 2 VEHICLE DAMAGE IN CALSPAN TEST NO. 49, 90° SIDE IMPACT

GRAPHIC DISPLAY OF OUTPUTS OF ACCIDENT RECONSTRUCTION

COLLISION AND TRAJECTORY

CAL CRASH TEST NO. 49

JULY 6,1972

VEHICLE # 1 DATA

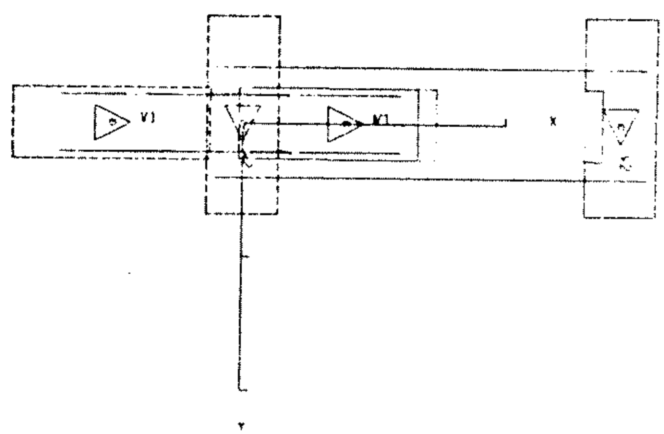
XC1'' = 9.[illegible]536 FT.

YC1'' = 0.20146 FT.

PSI1 = [illegible] DEG.

VDI = [illegible]

VEHICLE AT REST



VEHICLE # 2 DATA

XC2'' = 35.06127 FT.

YC2'' = -0.00314 FT.

PSI2 = 90.13352 DEG

VDI = [illegible]

VEHICLE AT REST

AXIS INTERVALS ARE 10. FEET

Figure 3 90° SIDE IMPACT CALSPAN TEST NO. 49

While the simplified analytical treatment of the vehicle structures in the SMAC program precludes valid predictions of details of the actual acceleration waveforms, comparisons with experimental data presented in Reference 1 and in the following paragraphs of this report indicate that the predicted peak acceleration values and the durations of predicted impacts each correlate reasonably well with measured responses. It should be noted that the areas under the predicted acceleration curves (i.e., the velocity changes that occur during the collision) result directly from application of the principle of Conservation of Momentum in the SMAC program and, therefore, 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. 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.

The peak value for the longitudinal acceleration component of the passenger compartment of the striking vehicle is reported in Reference 3 as -22 g's and the corresponding velocity change is given as 28.1 MPH. The corresponding SMAC predictions are -22.3 g's and 31.9 MPH (see Figure 4A).

Lateral acceleration responses of the struck vehicle passenger compartment were measured at several locations on the floorpan. A "zero shift" is present in each of the data channels between 0.10 and 0.20 seconds due to an instrumentation malfunction, but this period is rather late in the collision. The waveforms contain strong localized effects as a result of the extensive deformation of the floorpan. Peak lateral acceleration of the passenger compartment floorpan on the side opposite impact (relatively undeformed)

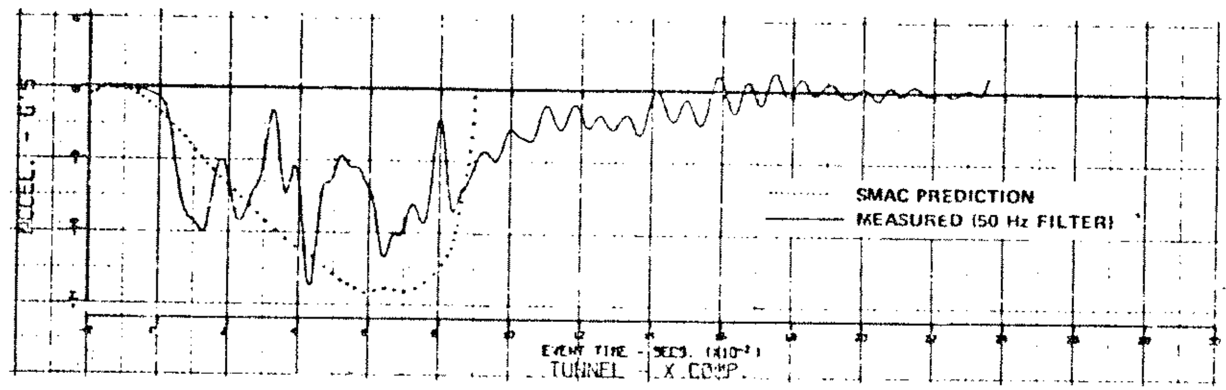


Figure 4A IMPACTING VEHICLE COMPARTMENT LONGITUDINAL ACCELERATION RESPONSES

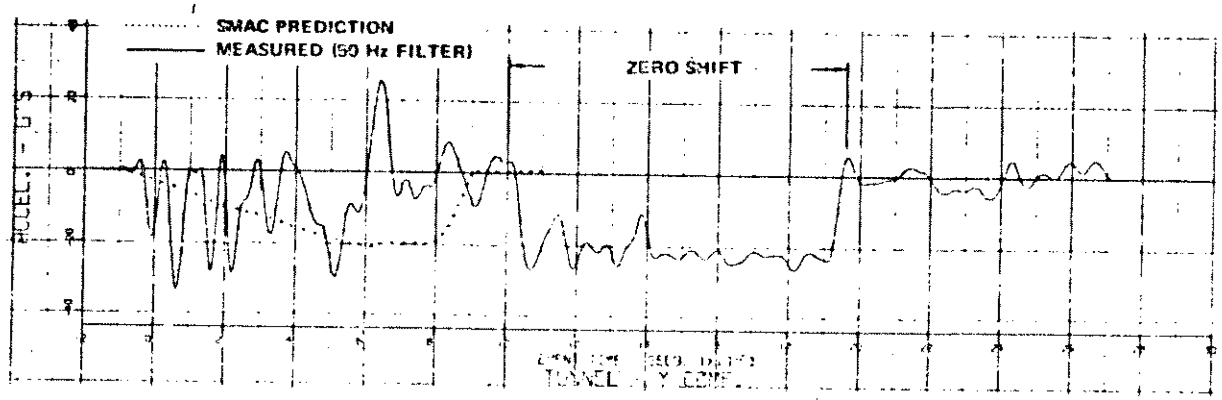


Figure 4B STRUCK VEHICLE COMPARTMENT LATERAL ACCELERATION RESPONSES is reported in Reference 3 to be about -20 g's. Figure 4B shows the measured lateral acceleration responses at the struck vehicle floorpan tunnel location and the corresponding SMAC prediction.

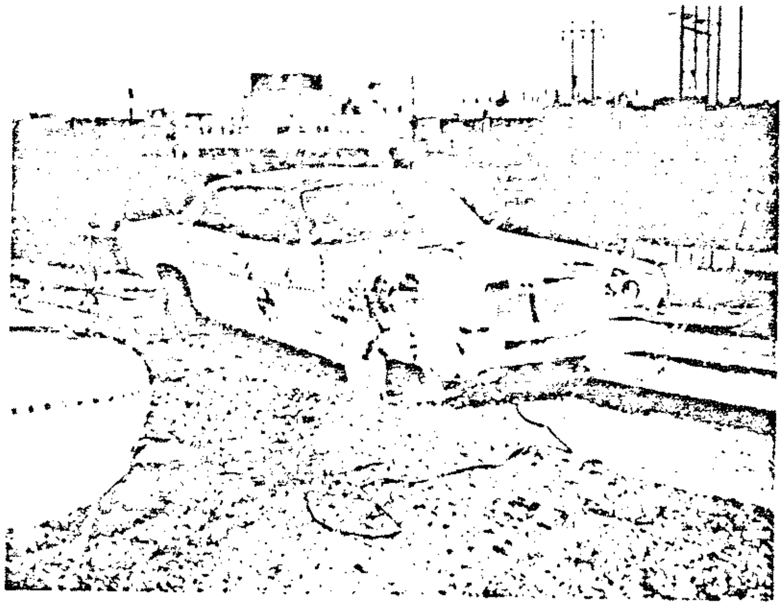
<u>45° Side Impact, Calspar Test No. 54</u>

In Table 1, it is seen that identical agreement has been achieved between the predicted and the investigator rated VDI's for the striking vehicle, but that three discrepancies exist in the VDI's for the struck vehicle. Photographs of the damaged vehicles are presented in Figure 5, and a computer graphics display of the corresponding SMAC prediction is presented in Figure 6.

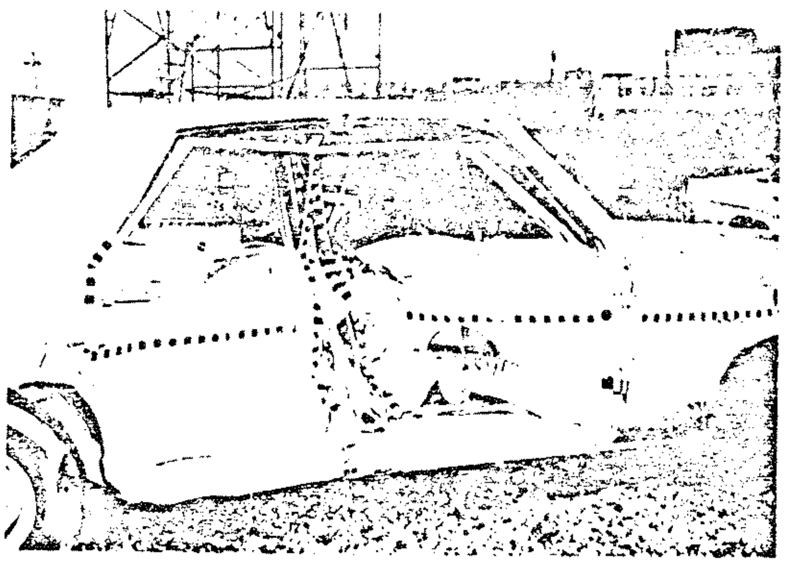
At initial contact, the direction of motion of the striking vehicle relative to the struck vehicle corresponds to a 1:30 o'clock direction for the struck vehicle. The predicted principal force occurs 0.094 seconds after initial contact, at which time the predicted relative angle has decreased by only 0.56 degrees. However, the predicted principal force, which consists of components normal and tangential (i.e., intervehicle friction) to the interface occurs at an angle of 57.9° with respect to the struck vehicle (i.e., 1:56 o'clock) and at 13.2° with respect to the striking vehicle (i.e., 12:26 o'clock). Thus, the SMAC prediction of the 2 o'clock direction for the struck vehicle appears to be correctly derived and perhaps more nearly correct than the investigator rating in this case.

The predicted Y value in Column 4 for the struck vehicle was produced by a secondary sideswipe contact in the SMAC prediction which extended the damaged region approximately fourteen inches forward of the passenger compartment area with an indentation depth of only approximately 1.5 inches.

Figure 17 VEHICLE DAMAGE IN CALSPAN BASELINE NUMBER 5 TEST, 20° OBLIQUE INTO SAE BARRIER



(a) IMPACTING VEHICLE



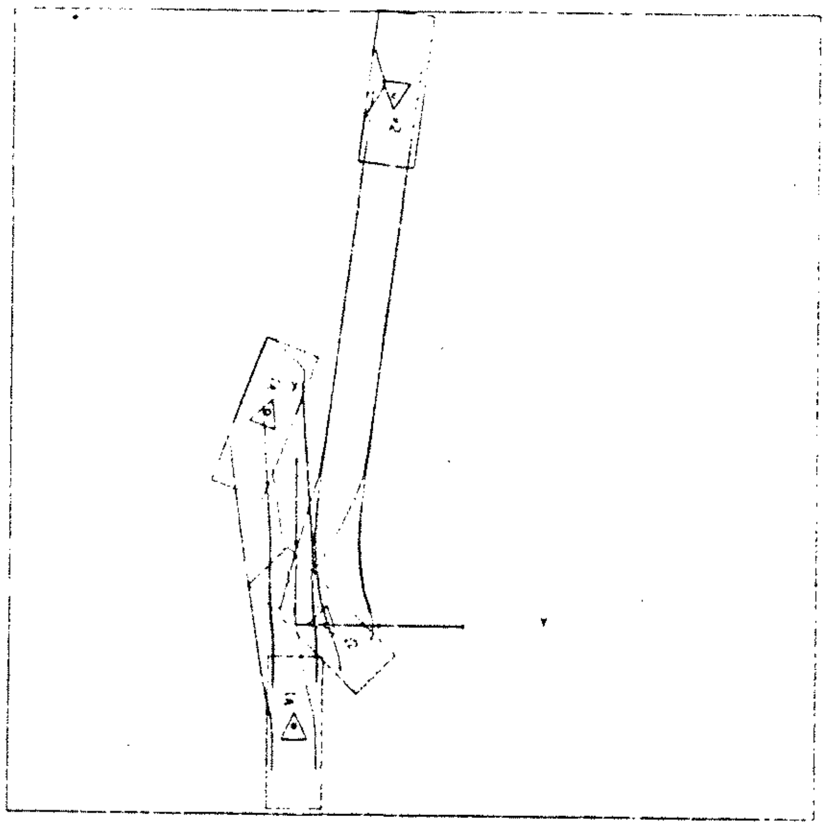
(b) STRUCK VEHICLE

Figure 5 VEHICLE DAMAGE IN CALSPAN TEST NO. 54, 45° SIDE IMPACT

GRAPHIC DISPLAY OF OUTPUTS OF ACCIDENT RECONSTRUCTION

COLLISION AND TRAJECTORY

CAL CRASH TEST NO. 59



AXIS INTERVALS ARE 10. FEET

	RECONSTRUCTED POSITIONS AND VELOCITIES AT IMPACT						DISPLAYED FINAL POSITIONS				VEHICLE DAMAGE INDEX
	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	12.2	0.0	0.0	45.[illegible]	0.0	0.0	25.6	3.6	21.0	VEHICLE AT REST	[illegible]
VEHICLE # 2	0.0	3.7	135.0	0.0	0.0	0.0	63.8	11.5	187.3	IN MOTION AT [illegible] SEC AFTER [illegible]	[illegible]

Figure 6 45° SIDE IMPACT

The predicted extent number of 4 (Column 7 of VDI) corresponds to a deflection exceeding the 3 category by only 0.92 inches. The measured maximum depth of indentation of the side of the struck vehicle is given in Reference 3 as 19 inches, whereas the corresponding SMAC prediction is 20.8 inches.

The struck vehicle is reported in Reference 3 to have been rotated "about 135° by the impact". In the predicted collision a rotation of only 60° occurred, possibly because of the cited secondary sideswipe contact in the prediction. Note that snagging on the test track guide rails may also have occurred in the test and influenced the yaw behavior of the struck vehicle during the "spin-out".

The longitudinal acceleration response of the impacting vehicle, as measured at the left front corner and digitally filtered at 50 Hz (cutoff frequency), is displayed in Figure 7A. The corresponding SMAC prediction (for longitudinal acceleration at the center of gravity) is also shown in Figure 7A.

In Figure 7B, a similar comparison is presented of the measured lateral acceleration response of the struck vehicle (left rear corner) and the corresponding SMAC prediction.

The correlation achieved in this case is considered to be very good. It is likely that small changes in the impact configuration or in vehicle dimensions and parameters could yield even closer correlation. However, the purpose of the present comparisons has been to establish the gross validity of SMAC predictions using "typical" dimensions and "representative" parameters.

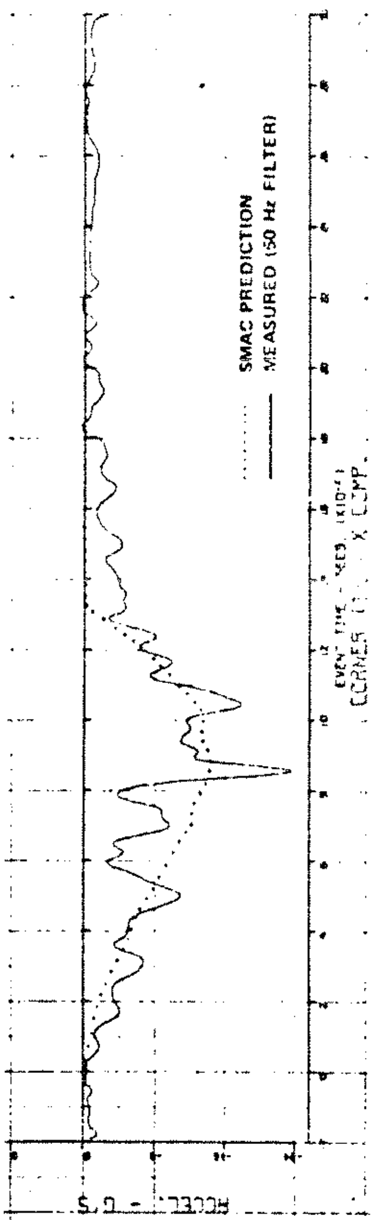


Figure 7A IMPACTING VEHICLE LONGITUDINAL ACCELERATION RESPONSE

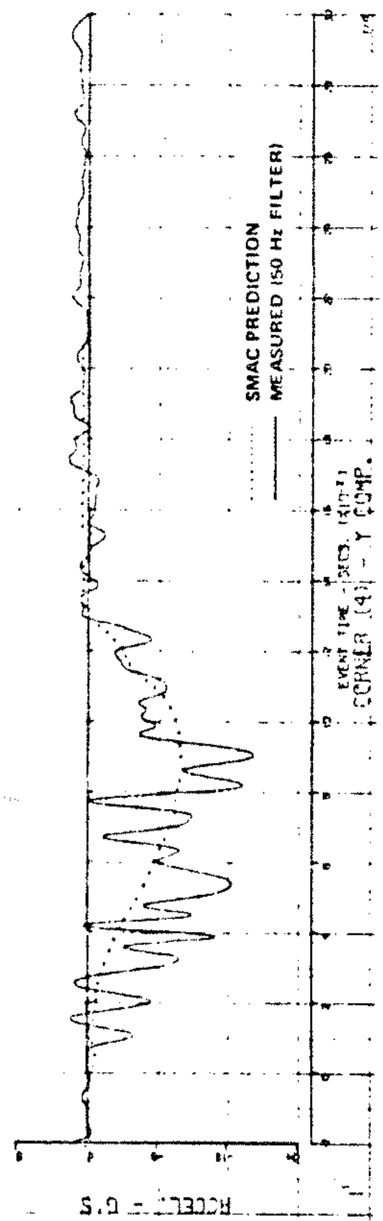


Figure 7B STRUCK VEHICLE LATERAL ACCELERATION RESPONSE

2' Offset Frontal, MRA Test No. 1

Photographs of the damaged vehicles and detailed scene data for this collision are presented in Section 3.2. A computer graphics display of the SMAC prediction is shown in Figure 8.

In Table 1, it is seen that the predicted and investigator rated VDI's for the 1964 Chevrolet are in identical agreement. For the 1963 Chevrolet, a discrepancy of one category exists in the extent of deformation (column 7) of the VDI. In view of the relatively large magnitudes of the frontal deflections the agreement is considered to be good.

The extent of yaw rotation of the vehicles in Figure 8 is less than that in the experiment (Section 3.2). This discrepancy is believed to be due, at least in part, to the neglect of pitching motions in the plane-motion SMAC simulation. A further discussion of this error source is presented in the discussion of Calspan Case No. 72-6B (Section 3.1.3).

Accelerations were measured only in the 1964 Chevrolet. Predicted and measured time-histories of the longitudinal acceleration are presented in Figure 9 for comparison. It may be seen that the general nature and amplitudes of the waveforms are in reasonably good agreement.

Frontal Head-On, Large vs. Small Vehicle, Calspan Test No. 14

This experiment was selected to test the capability of the SMAC program for treatment of collisions between vehicles of different sizes. The closing speed of approximately 88 miles/hour produced a relatively severe event. The extensive nature of the damage is shown in Figure 10. A computer graphics display of the SMAC prediction for this collision is presented in Figure 11.

GRAPHIC DISPLAY OF OUTPUTS OF ACCIDENT RECONSTRUCTION.

COLLISION AND TRAJECTORY

MRA TEST NO. 1

JUNE 30,1972

VEHICLE # 1 DATA

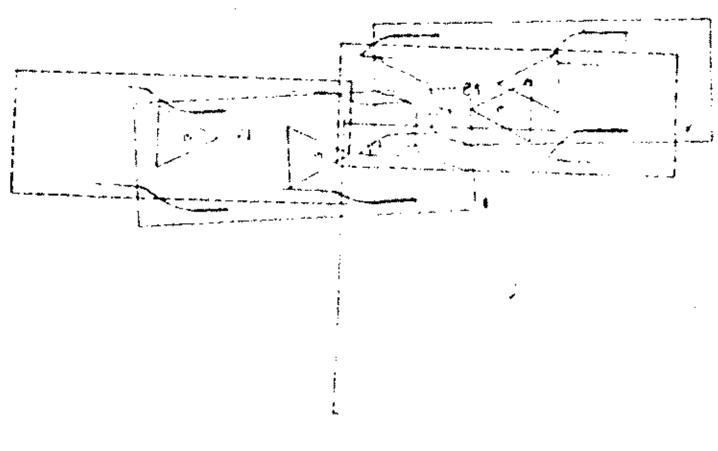
X01 = [illegible] FT.

Y01 = [illegible] FT.

PSI1 = 4.[illegible] DEG.

V11 = [illegible]

VEHICLE [illegible]



VEHICLE # 2 DATA

XC2 = [illegible] FT.

YC2 = -2.52[illegible] FT.

PSI2 = 17[illegible] DEG.

VDI = 1 2 F Y E H S

TIME = 0.[illegible] SEC.

Figure 8 2' OFFSET FRONTAL

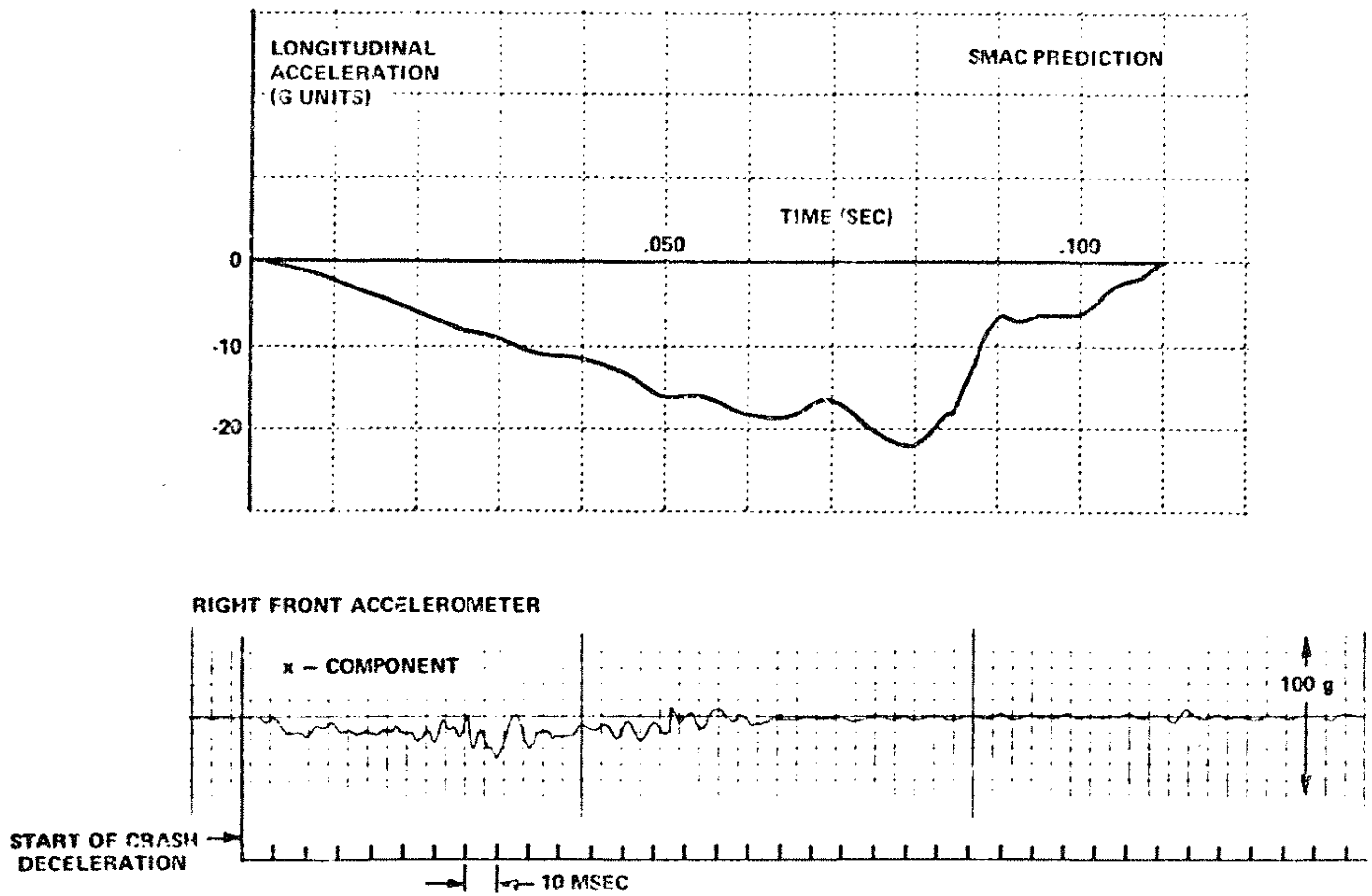


Figure 9 DATA TRACES, MRA CRASH TEST NO. 1

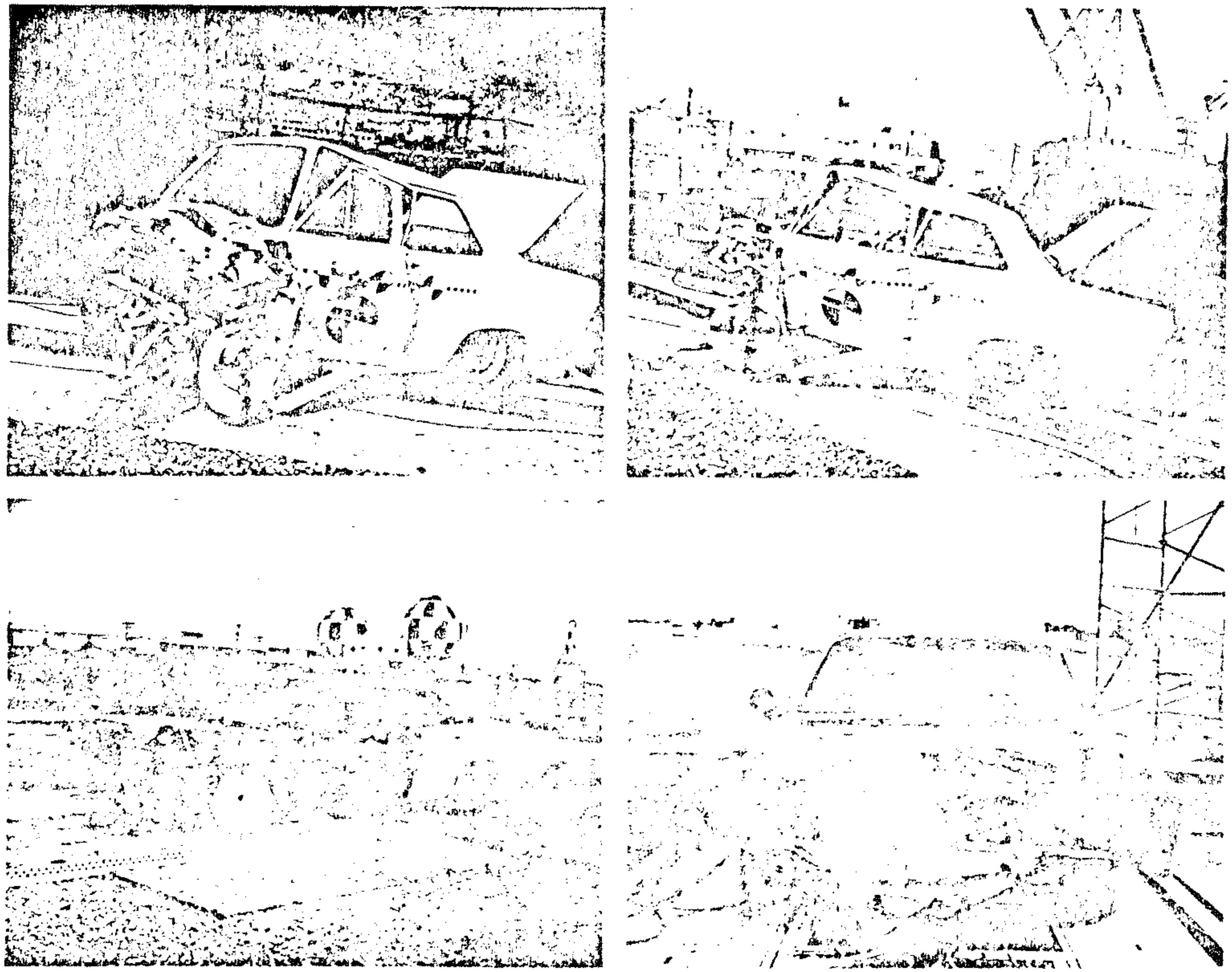
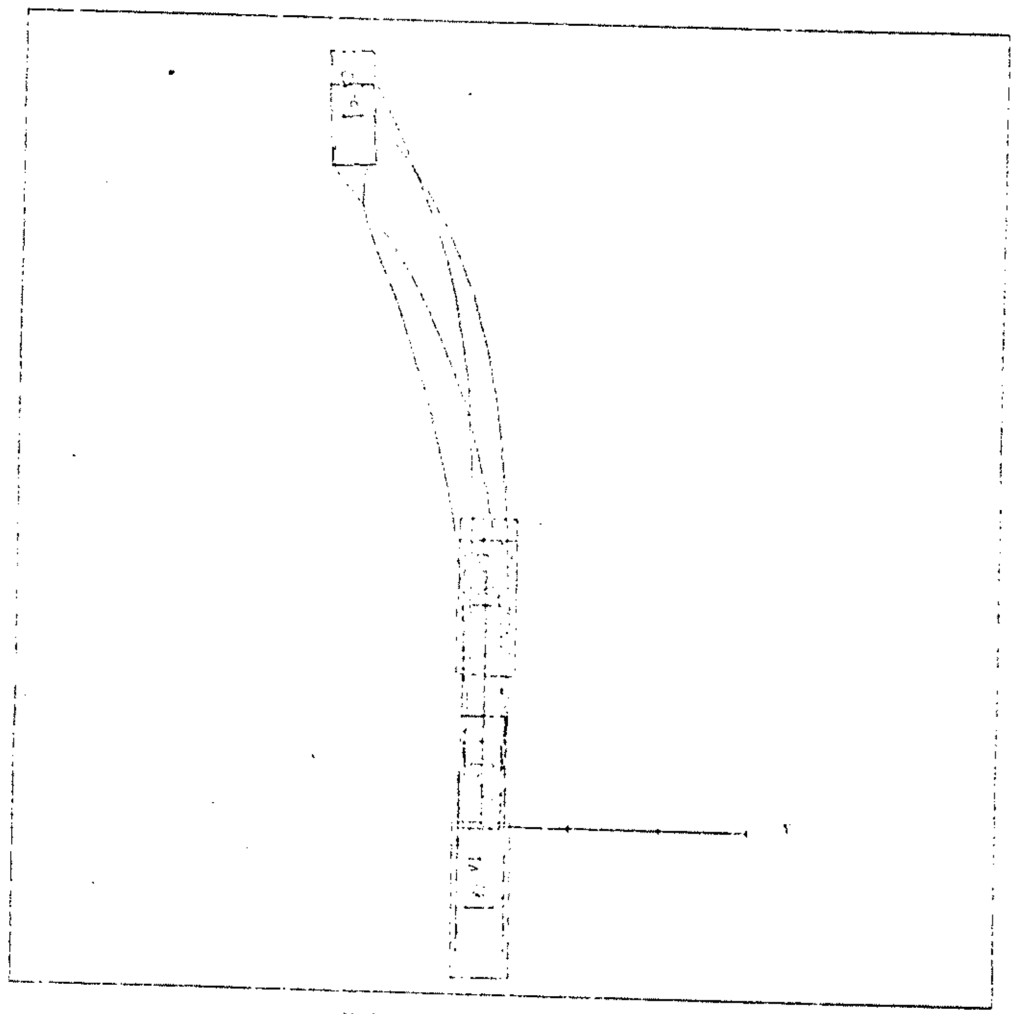


Figure 10 VEHICLE DAMAGE IN CALSPAN TEST NUMBER 14, HEAD-ON IMPACT

GRAPHIC DISPLAY OF OUTPUTS OF ACCIDENT RECONSTRUCTION

COLLISION AND TRAJECTORY

CAL CRASH TEST NO. 14



AXIS INTERVALS ARE 10. FEET

Figure 11 COMPUTER GRAPHICS FOR TEST NO. 14

	RECONSTRUCTED POSITIONS AND VELOCITIES AT IMPACT						DISPLAYED FINAL POSITIONS				VEHICLE 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	-6.0	0.0	0.0	40.6	0.0	0.0	27.7	0.1	0.2	IN MOTION AT 2.5 SEC AFTER INITIAL CONTACT	12FDEW3
VEHICLE # 2	5.9	0.0	180.0	45.3	0.0	0.0	84.1	-10.6	-2.0	IN MOTION AT 2.5 SEC AFTER INITIAL CONTACT	[illegible]

In Table 1, it may be seen that only one discrepancy exists between the predicted and investigator-rated VDI's. The predicted extent of deformation (column 7 of VDI) for the Ford is one category higher than the value assigned by the investigator.

Time-histories of longitudinal accelerations, velocities and displacements of the two vehicles as measured and reported in Reference 5 and as predicted by the SMAC program are presented in Figures 12 and 13 for comparison. It may be seen in Figures 12 and 13 that the effective coefficient of restitution generated by the SMAC program is too large in the present case. However, in view of the large extent of damage, it must be recognized that the range of validity of the simplified treatment of crush properties (Reference 1) has been exceeded in this case. In fact, the degree of correlation with the experimental data in Figures 12 and 13 must be viewed as being surprisingly good.

SAE Barrier, Perpendicular to Wall,
<u>Baseline No. 1</u>

This experiment was selected to test the capability of the SMAC program for treatment of rigid obstacles. The impact speed of 37.9 MPH produced extensive damage, as shown in Figure 14. A computer graphics display of the SMAC prediction for this collision is presented in Figure 15.

In Table 1, it may be seen that identical agreement was achieved between the predicted and investigator-rated VDI's.

In Figure 16, time-histories of longitudinal deceleration, velocity and displacement as measured and reported in Reference 4 and as predicted by the SMAC program are presented for comparison. It should be noted that the experimental time-history of velocity, which is labeled "velocity change" in Reference 4, was adjusted upward by the amount of the rebound velocity. The displayed SMAC prediction of velocity does not include such an adjustment. An initial velocity of 37.9 MPH is reported in Reference 4.

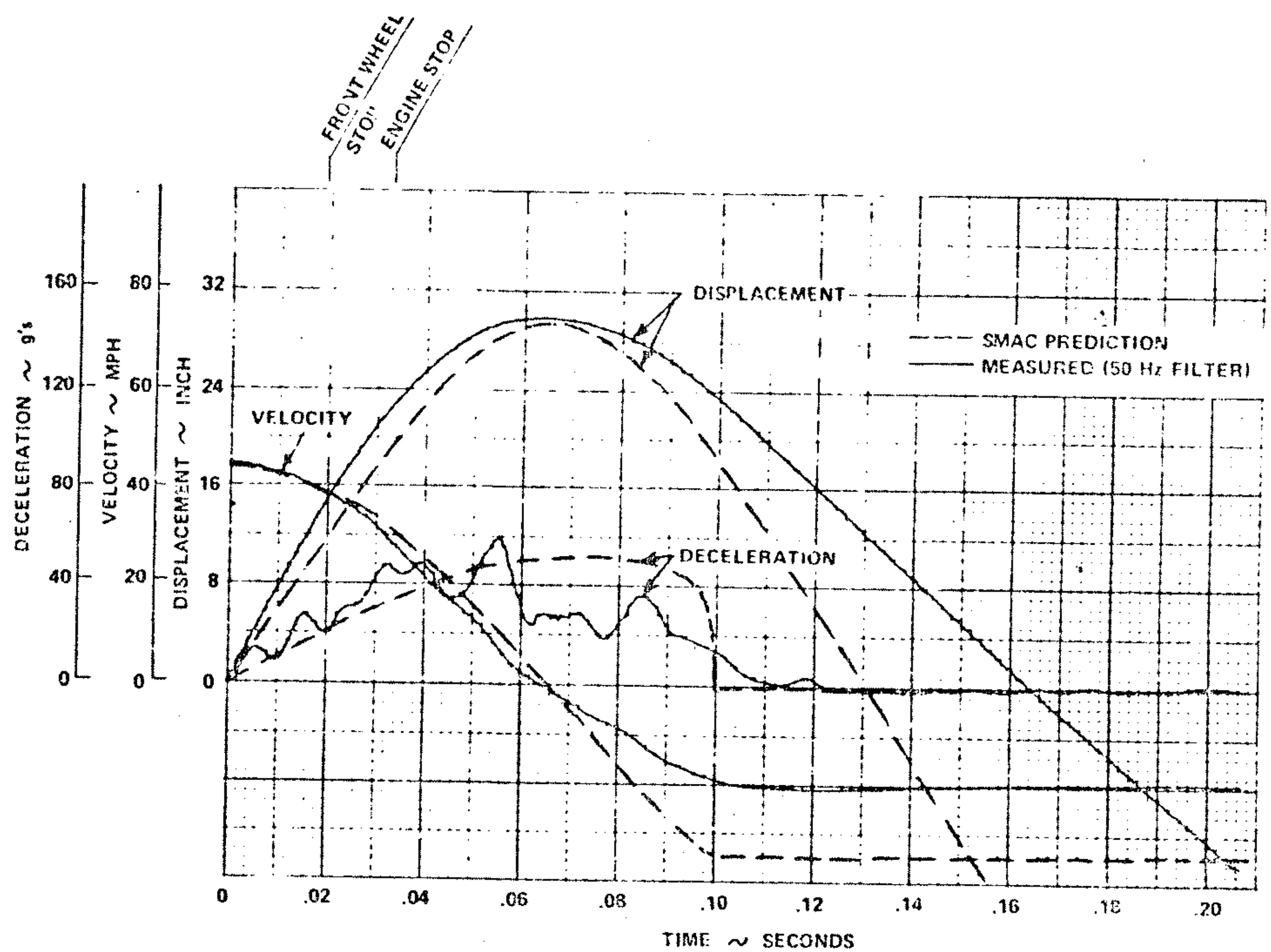


Figure 12 TEST NO. 14: OPEL COMPARTMENT LONGITUDINAL ACCELERATION DATA

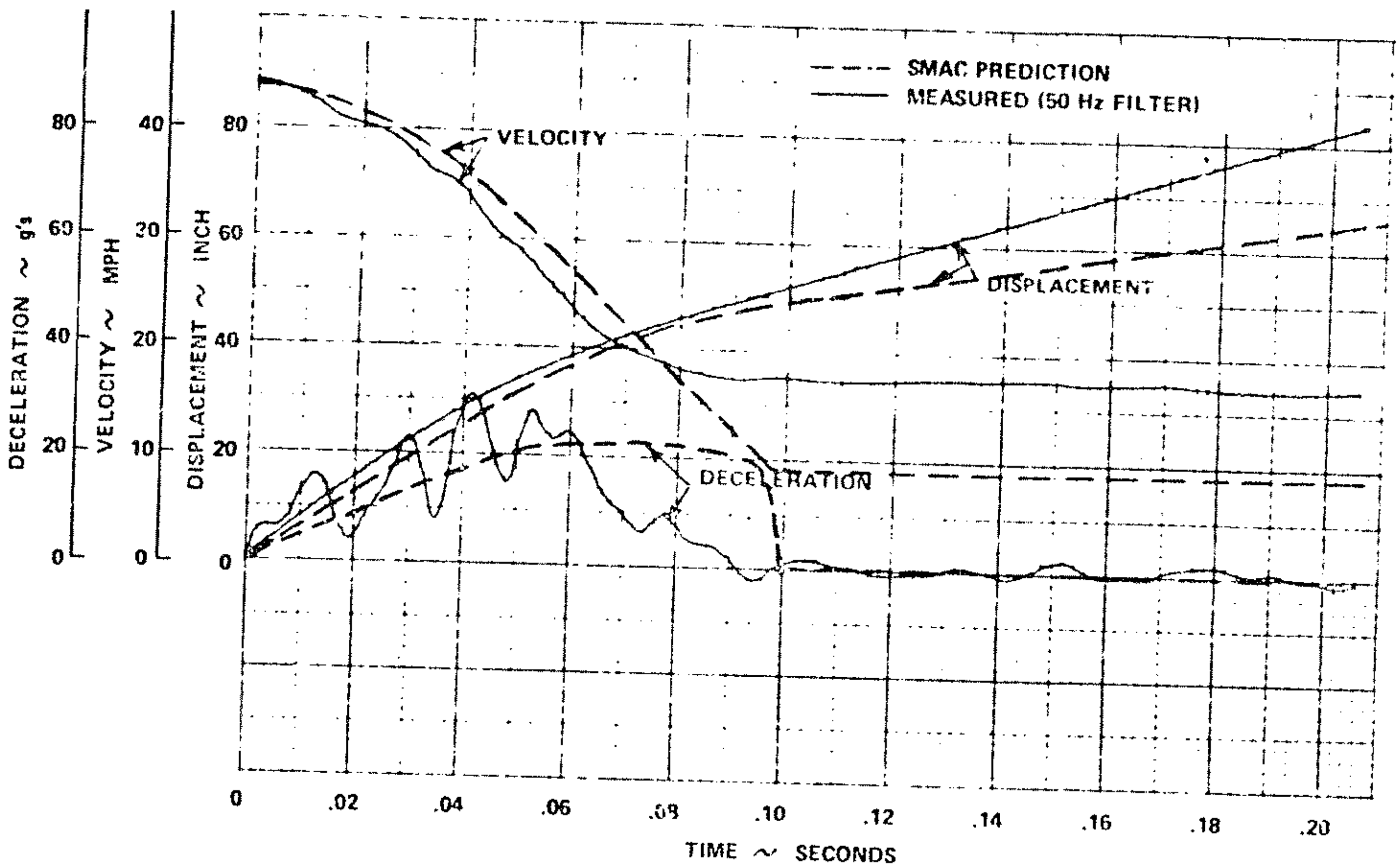


Figure 13 TEST NO. 14: FORD COMPARTMENT LONGITUDINAL ACCELERATION DATA

Figure 14 VEHICLE DAMAGE IN CALSPAN BASELINE NUMBER 1 TEST, HEAD-ON INTO SAE BARRIER

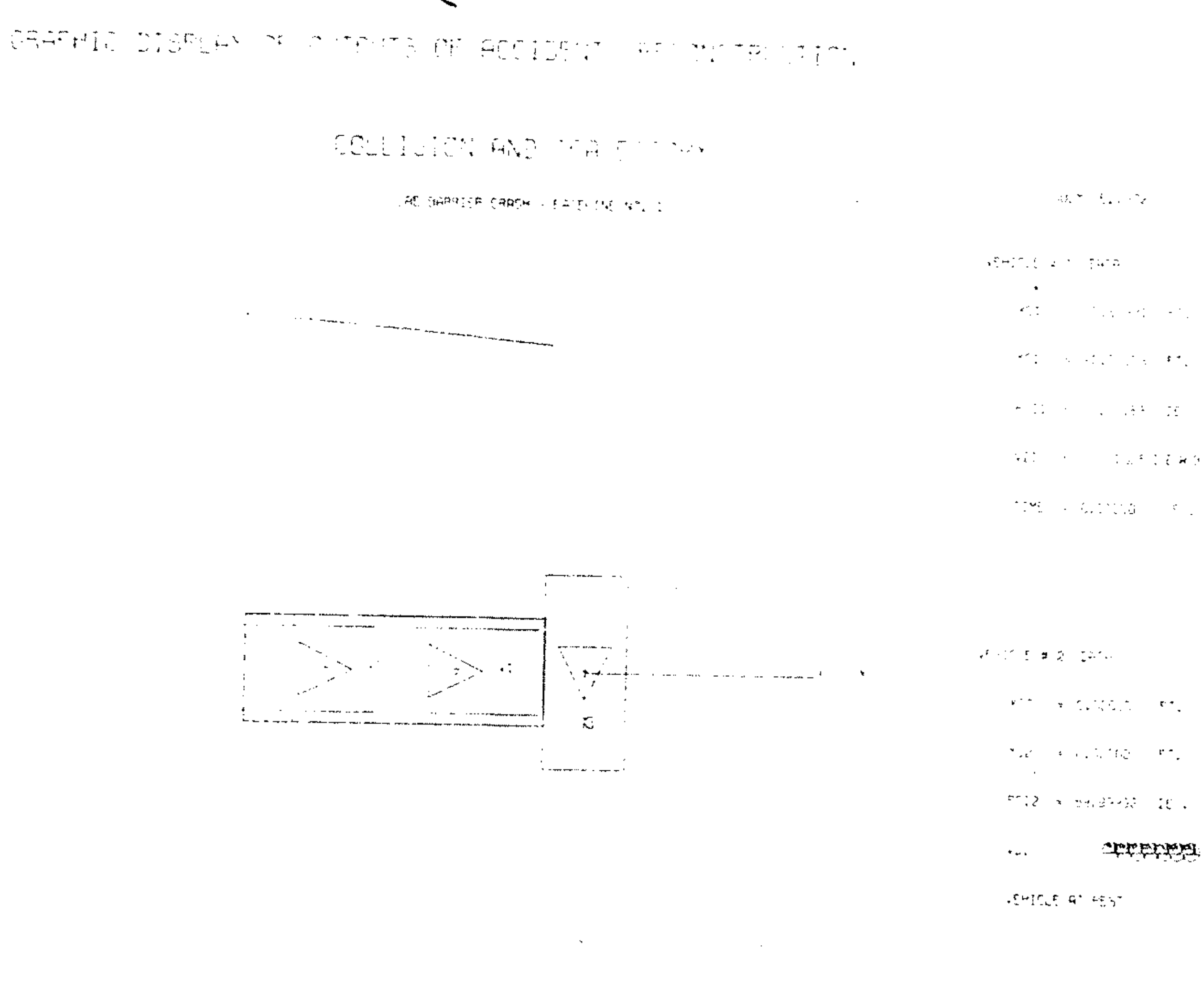


Figure 15   COMPUTER GRAPHICS OF BASELINE NO. 1

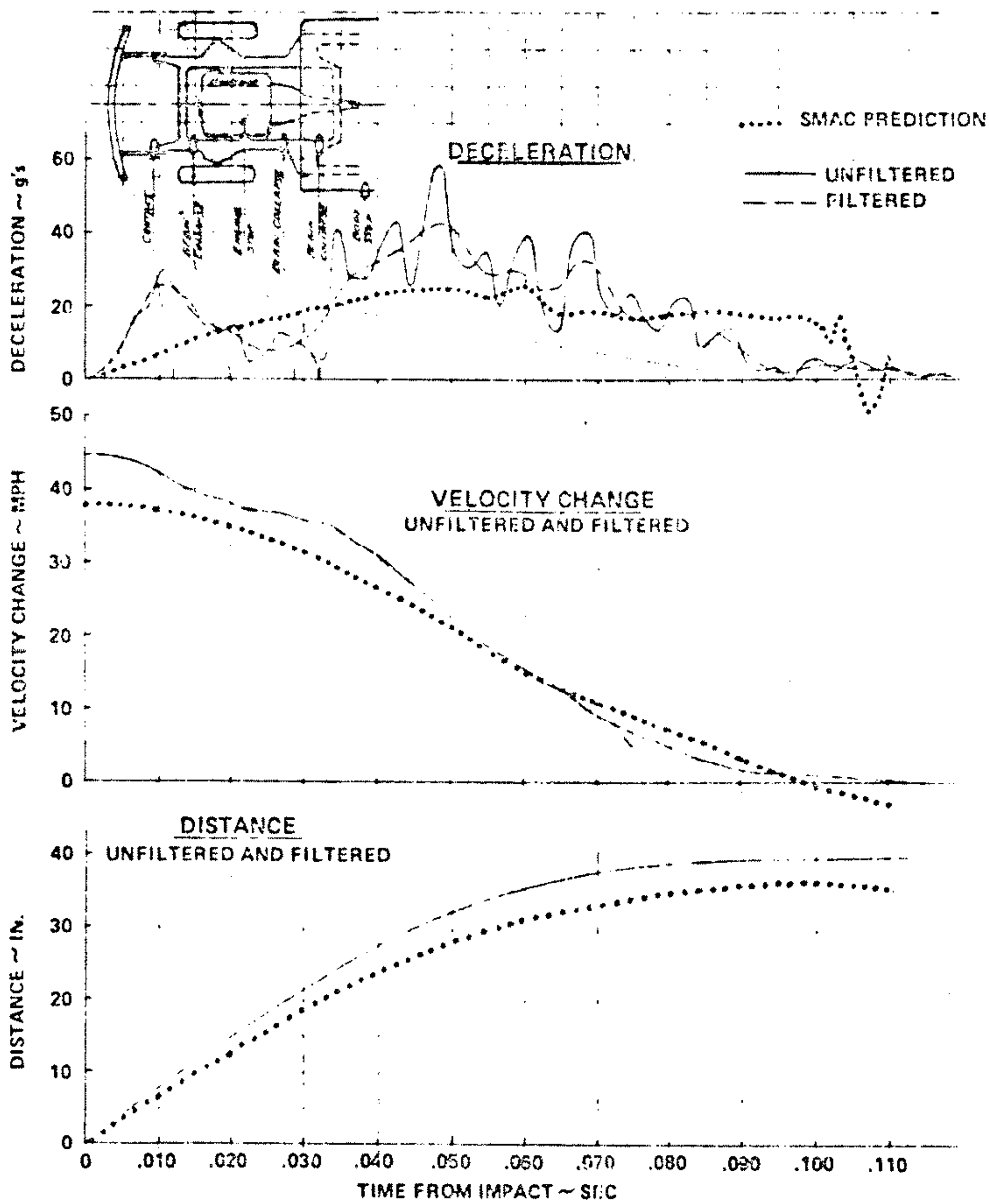


Figure 16 BASE LINE TEST NO. 1: COMPARTMENT LONGITUDINAL DATA

SAE Barrier, Oblique, Baseline No. 5

This relatively severe collision condition produced extensive damage, as shown in Figure 17. A computer graphics display of the SMAC prediction for this case is presented in Figure 18.

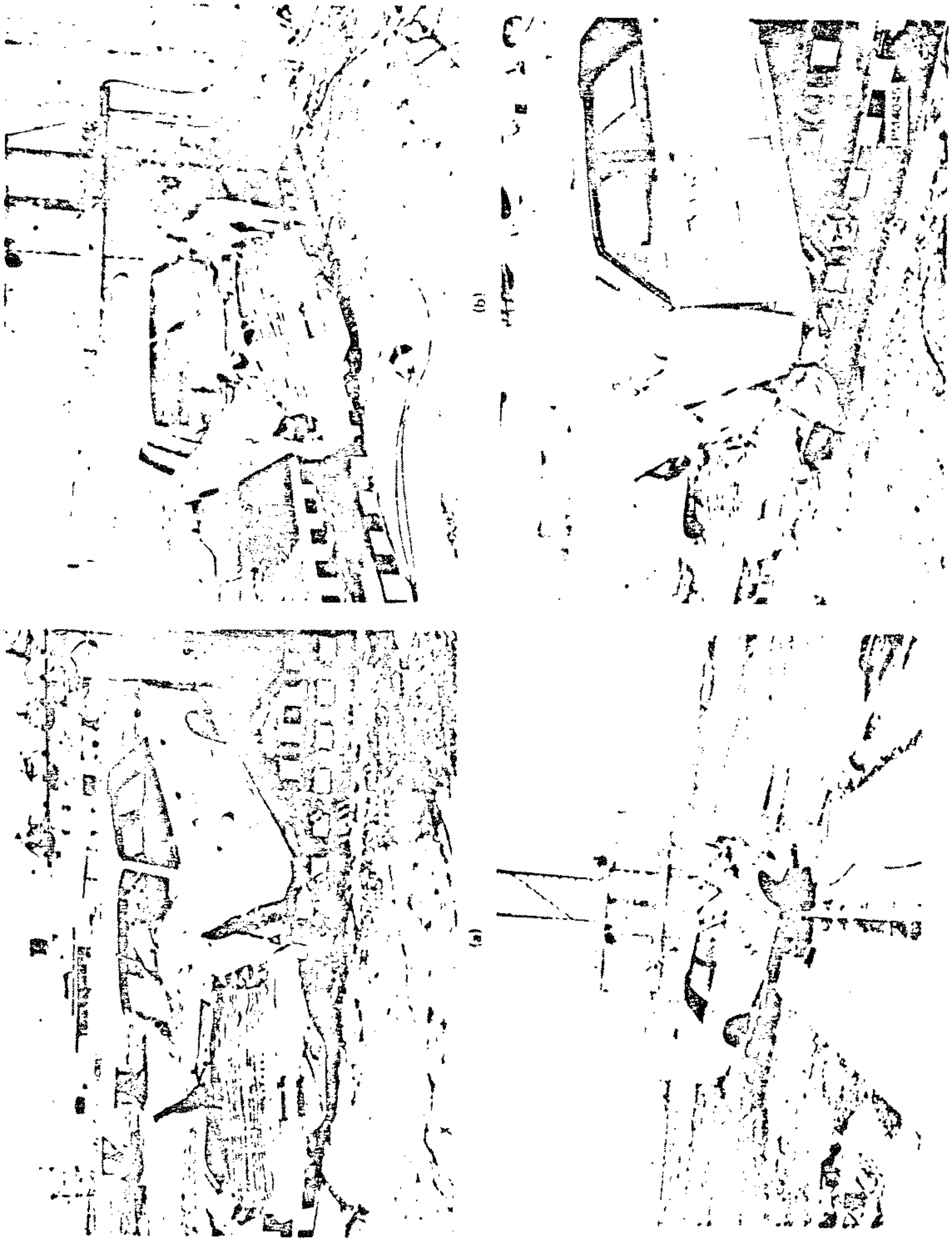
In Table 1, it is seen that the predicted and investigator rated VDI's are in agreement with the exception of the extent of deformation (column 7). In Figure 19A, the magnitude of the discrepancy is shown. It should be noted that the large deformation is beyond the range where accurate simulation results would be expected, in view of the simplified treatment of vehicle crush in the SMAC program.

In Figure 19B, it may be seen that a reasonably good approximation of the resultant compartment acceleration was achieved, despite the erroneous prediction of the extent of damage.

The remainder of the collision cases included in Table 1 are discussed in the following two sections.

3.1.2 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. In the presently reported research, two such applications were performed. It is believed that further exercises of this type, in which comparisons can be made between reconstructed and measured impact conditions subsequent to completion of a case, would be highly beneficial. Results of the two applications are discussed in the following. It should be noted that hardware difficulties with the optical measurement system (see Section 3.4) limited the available measured data for these applications.

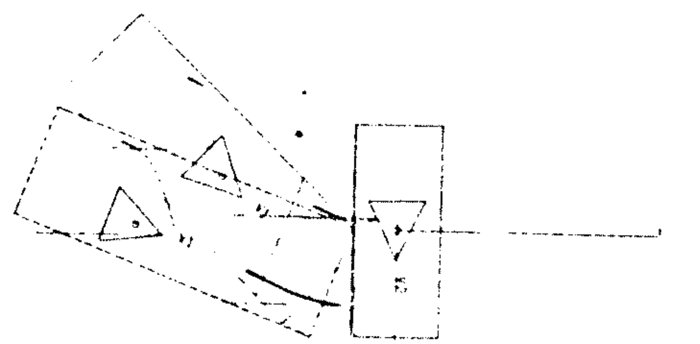


(a) (b) (c) (d)

GRAPHIC DISPLAY OF OUTPUTS OF ACCIDENT RECONSTRUCTION

COLLISION AND TRAJECTORY

SAE BARRIER CRASH - BASELINE NO. 5



TIME [illegible]

VEHICLE # 1 DATA

XC1 = -10.[illegible] FT.

YC1 = -2.[illegible] FT.

PSI1 = 44.[illegible] DEG.

VC1 [illegible]

TIME = 0.[illegible] SEC.

VEHICLE # 2 DATA

XC2 = 0.00000 FT.

YC2 = 0.00000 FT.

PSI2 = 89.99393 DEG.

VC2 = [illegible]

VEHICLE AT REST

AXIS INTERVALS ARE 10. FEET

Figure 18 COMPUTER GRAPHICS FOR BASELINE NO. 5

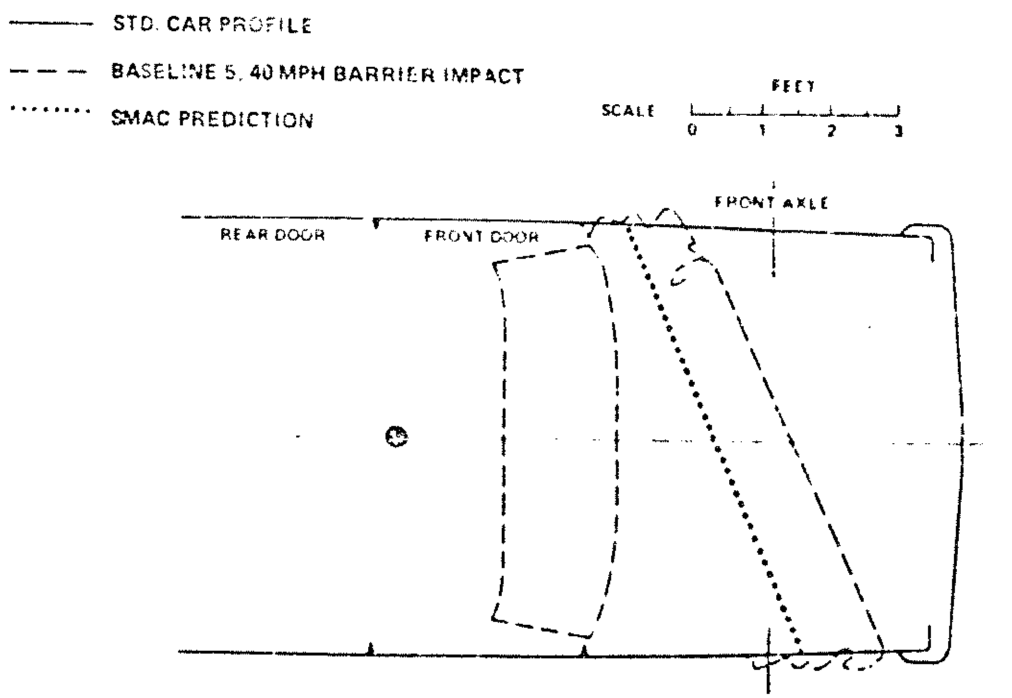


Figure 19A TOP PROFILE COMPARISON OF STD. CAR AND BASELINE 5

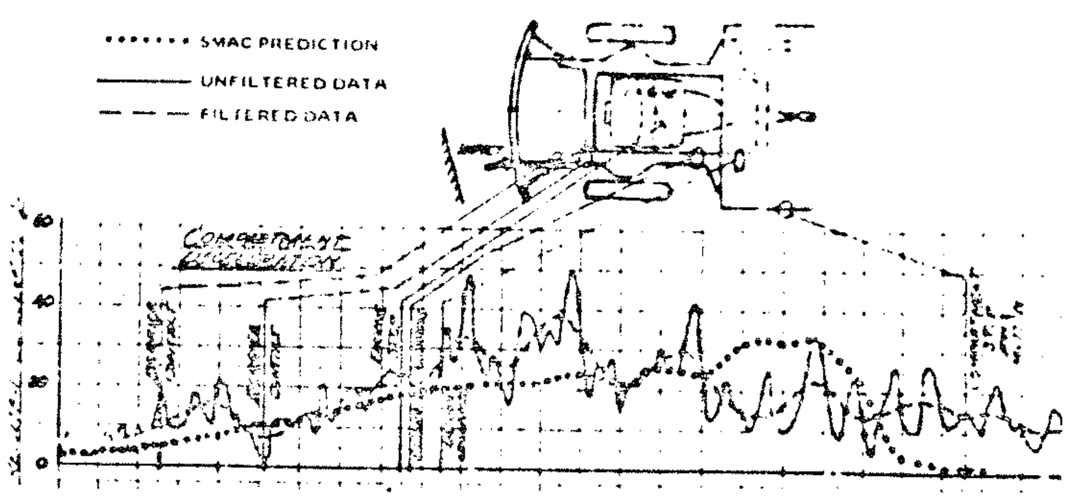


Figure 19B BASELINE TEST NO. 5: COMPARTMENT RESULTANT ACCELERATION DATA

MRA Test No. 2

A relatively large number of iterations were performed with the SMAC program in this case without achieving a highly accurate match of the rest positions and orientations. The actual vehicles were weighed during this process. Also, experimental stopping distance data were used to establish the surface friction properties. After twelve runs, the reconstruction displayed in Figure 20 was concluded to be a "best fit" (see scene data in Section 3.2). Comparison with the measured speed data yielded the following rather disappointing results:

Vehicle	Measured Speeds, MPH Travel	Measured Speeds, MPH Impact	SMAC Speeds, MPH Travel	SMAC Speeds, MPH Impact
#1	27.0	27.0	30.4 (+12.6%)	30.0 (+11.1%)
#2	29.0	26.5	25.9 (-10.7%)	23.3 (-12.1%)

Subsequent to this comparison, the measured speeds were used in the SMAC program and the predicted rest positions and orientations were found to still be a poor fit to the corresponding measurements. Variations in the interpretation of stopping distance data for surface friction properties (see Appendix 4) were tried without significant improvements.

The nature of the errors suggested an experimental problem. A detailed review of high-speed films revealed that release of the tow cable on vehicle #1 was delayed until the collision was in progress. In effect, the cable applied an impulse to vehicle #1 which violated the assumption regarding conservation of momentum.

GRAPHIC DISPLAY OF OUTPUT OF ACCIDENT RECONSTRUCTION

JULY 25, 1972

COLLISION AND TRAJECTORY

MRA TEST NO. 2

VEHICLE # 1 DATA

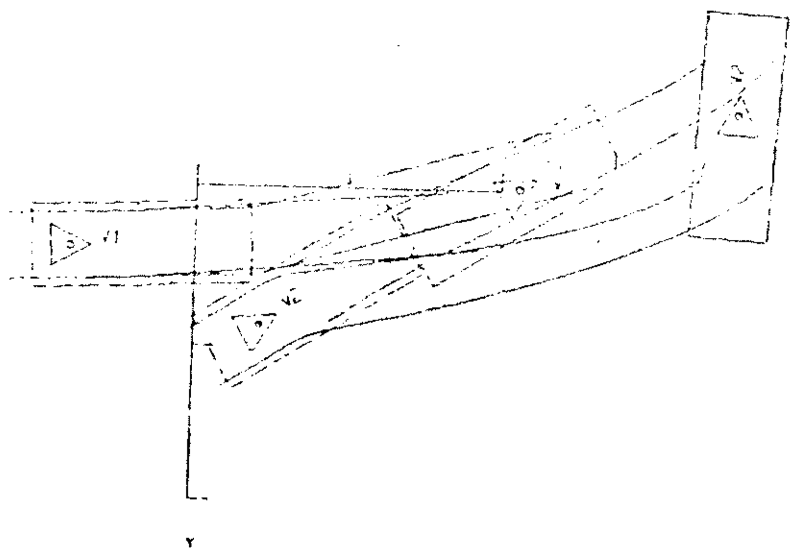
XC1" = 26.89154 FT.

YC1" = -0.14736 FT.

PSI1 = -50.22248 DEG.

VD1 = [illegible]

VEHICLE AT REST



VEHICLE # 2 DATA

XC2" = 44.76331 FT.

YC2" = -0.48026 FT.

PSI2 = -86.65182 DEG.

VD2 = [illegible]

VEHICLE AT REST

Figure 20

AXIS INTERVALS ARE 10. FEET

To confirm the theory that the inadvertent cable impulse, which left no physical evidence, was the source of the analytical discrepancies, the SMAC program was run again with the measured impact speeds and with maximum four-wheel tractive effort applied to vehicle #1 for the approximate duration of the cable pull. The results, which are displayed in Figure 21, agree much more closely with the scene data than any of the previous simulation runs. It was therefore concluded that the delayed cable release was the source of the reconstruction difficulties and that the 12% error was not a true indication of the SMAC program capabilities.

MRA Test No. 3

After only four runs of the SMAC program, a relatively good fit to the measured data was achieved (see Figure 22 and scene data in Section 3.2). While further runs could have been used to improve the fit, the desire to complete this comparison for inclusion in the Second Quarterly Progress Report led to a termination of the iteration process. The results were as follows:

Vehicle	Measured Speeds, MPH Travel	Measured Speeds, MPH Impact	SMAC Speeds, MPH Travel	SMAC Speeds, MPH Impact
#1	36.5	33.0	36.7 (+0.5%)	32.7 (-1%)
#2	36.0*	32.5	46.0 (+28%)*	31.8 (-2.2%)

* see following paragraph

With the exception of the travel speed of vehicle #2, the reconstruction accuracy in this case is excellent. Fifty foot long pre-impact skid marks were measured for vehicle #2, but the measured time-history of the speed of vehicle #2 did not indicate a corresponding deceleration. A review of high-speed motion picture films revealed that the skid marks were produced during a preceding trial run of the vehicle.

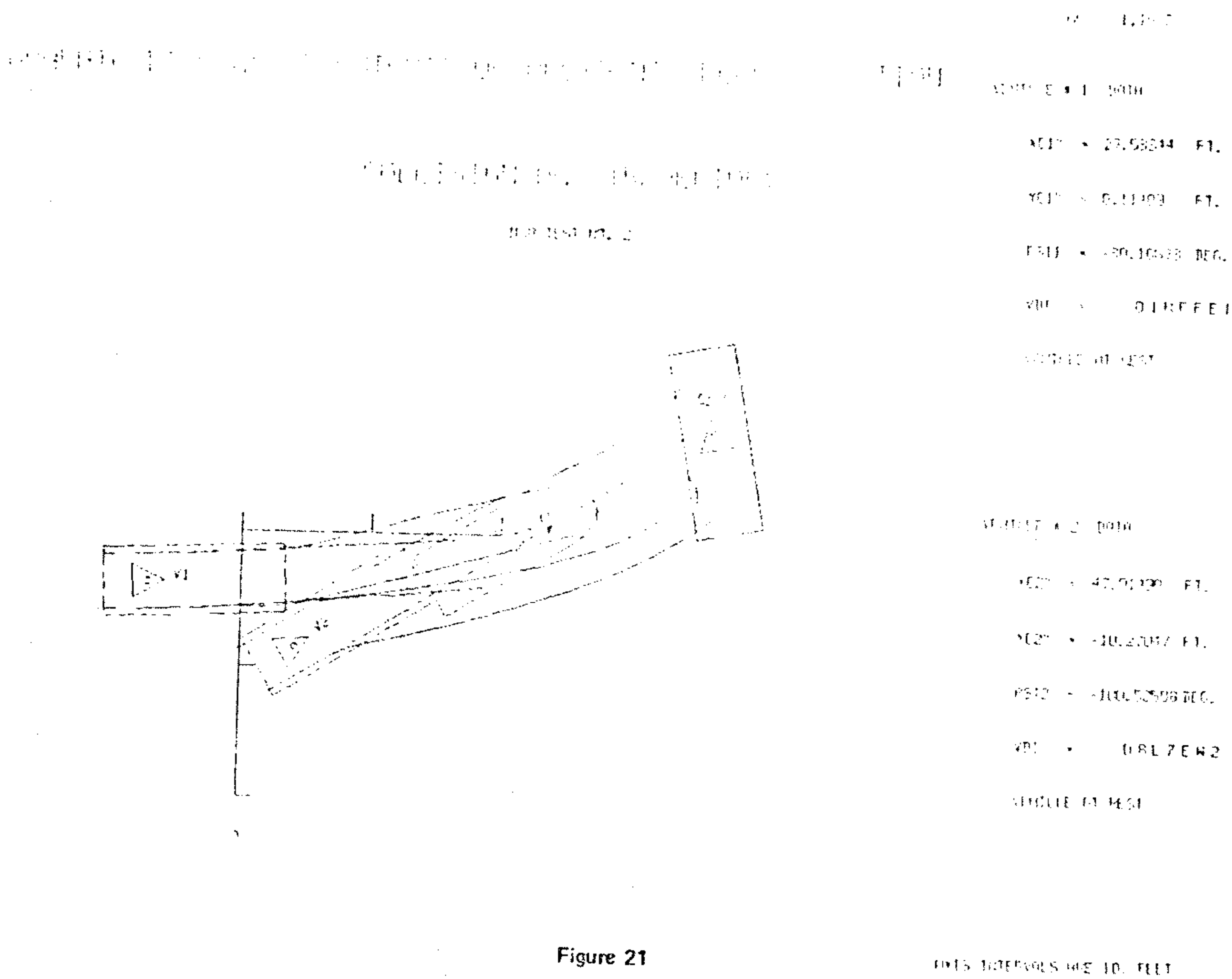


Figure 21

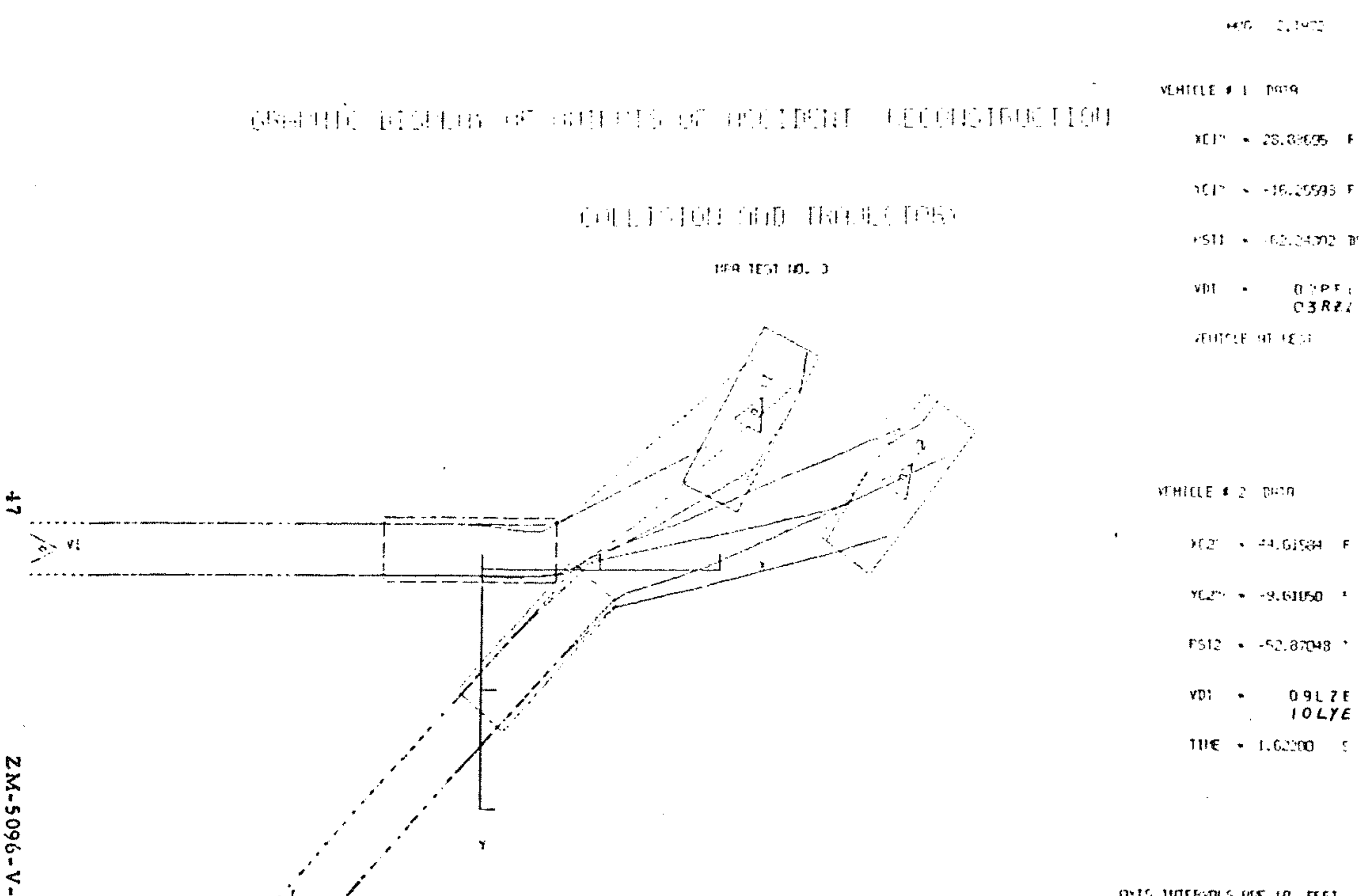

GRAPHIC DISPLAY OF RESULTS OF ACCIDENT RECONSTRUCTION
COLLISION AND TRAJECTORY
VEHICLE # 1 DATA
VEHICLE # 2 DATA
AXIS INTERVALS ARE 10. FEET

Figure 22

On the basis of the results obtained in the preceding trial applications, it is believed that ± 5% accuracy is a realistic expectation for reconstructed impact speeds in general applications (i.e., where more complicated control inputs may occur). Further exercises of this type will be necessary to establish the actual accuracy.

3.1.3 Reconstruction of Actual Highway Accidents

An automatic iteration process for the SMAC computer, to achieve a "best fit" to the physical evidence at the scene, has been extensively planned but has not yet been implemented. The delay in implementation has been prompted by a desire to gain experience with manual iteration of the reconstruction calculations in applications to actual highway accidents. Also, it has been necessary in the second year of this research to devote primary attention and efforts to the cited problems with the scene measurement system, in order that physical evidence can be generated in the format of that system. A fully automatic iteration process is seen as an essential feature of the overall system in its ultimate form, prior to widespread applications, in order that uniform interpretations of physical evidence can be achieved.

In the absence of data measured with the optical system at the scenes of actual highway accidents, the SMAC program has been applied to two cases in which the scene data were obtained by conventional means within the TLAS* research program. The results of two such applications are presented and discussed in the following paragraphs.

---

*Contract Nos. DOT-HS-053-1-277 (NHTSA) and Calspan 7202-C-129 (MVMA).

Calspan Case No. 72-6B

An accident schematic for this case is presented in Figure 23. The corresponding SMAC reconstruction is displayed in Figure 24.

In this case, a relatively large number of runs were performed in an attempt to achieve a "best fit" to the physical evidence. It was found in the SMAC runs that the predicted lateral movement of the VW Microbus was consistently greater than the corresponding measured dimension and that the predicted yaw rotation was consistently less than that measured. Because this combination of discrepancies could be produced by the use of an excessively large estimate for the yaw moment of inertia of the VW Microbus, effort was directed toward (1) refining the estimate and (2) attempting to obtain measured data from the vehicle manufacturer.

On the basis of a detailed review of available moment of inertia data for approximately ten U. S. automobiles and station wagons (including a rear engine Corvair 2 door hardtop) the value for the complete-vehicle yaw moment of inertia of the VW Microbus was estimated to lie in the range of 16,000 to 20,000 $lb\text{-}sec^2\text{-}in$ (i.e., corresponding to a radius of gyration in the range of 47.1 to 52.6 inches).

The vehicle manufacturer provided a value for the desired quantity in an unfamiliar, gravitational system of units (299.47 $Kilopond\text{-}Meter\text{-}Sec^2$). Because a straightforward conversion of the indicated value to $lb\text{-}sec^2\text{-}in$ yields a value that appears to be too large (i.e., 25,993 $lb\text{-}sec^2\text{-}in$, with a corresponding radius of gyration of 60 inches in a vehicle with a 94.5 inch wheelbase), a further request has been made either for radius of gyration information or for a conversion by VW of the previously provided quantity into $slug\text{-}ft^2$.

In the absence of definitive information regarding the actual yaw moment of inertia, exploratory runs of the SMAC program were performed using values near the lower end of the estimated range. Such runs were

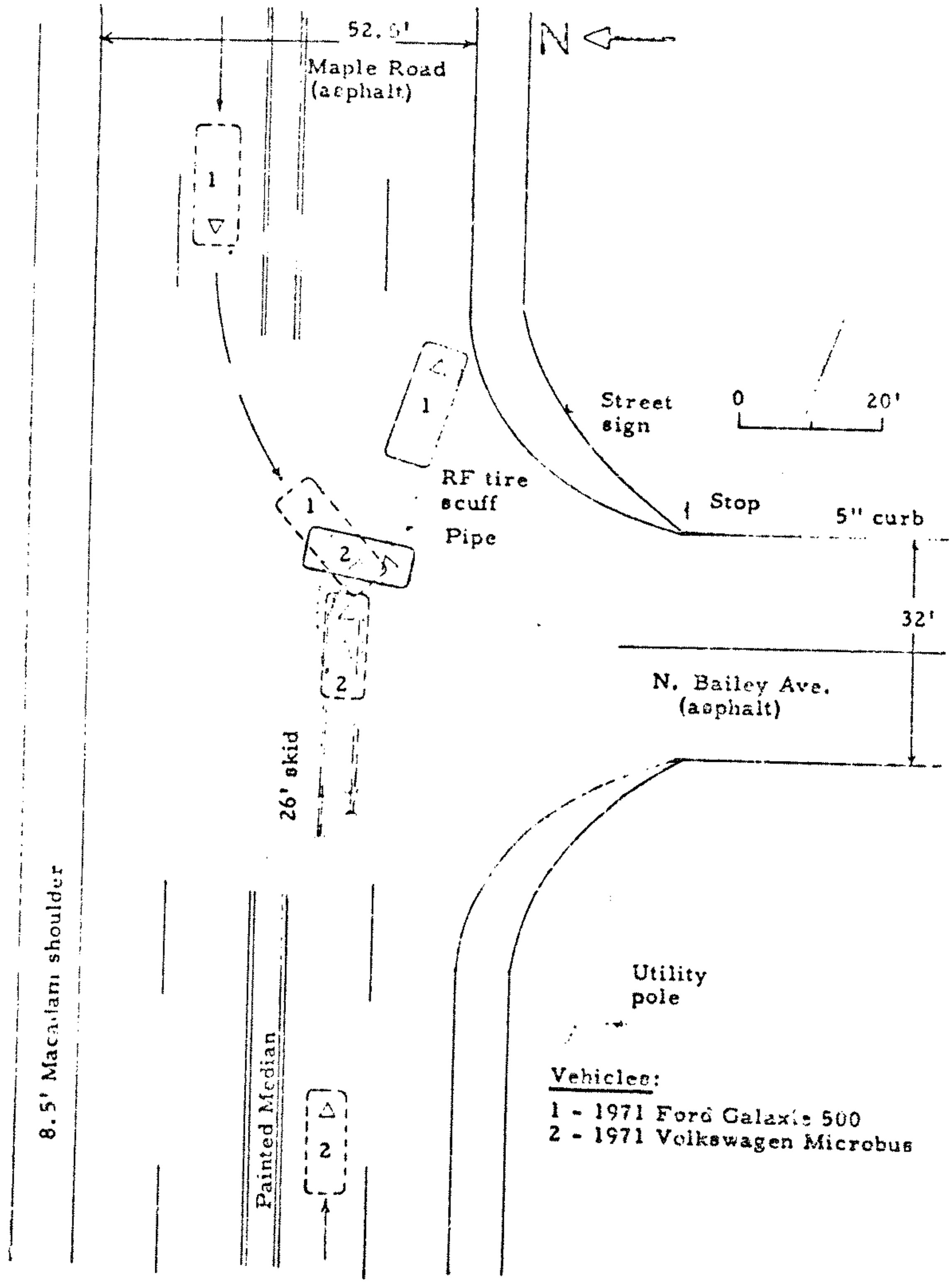
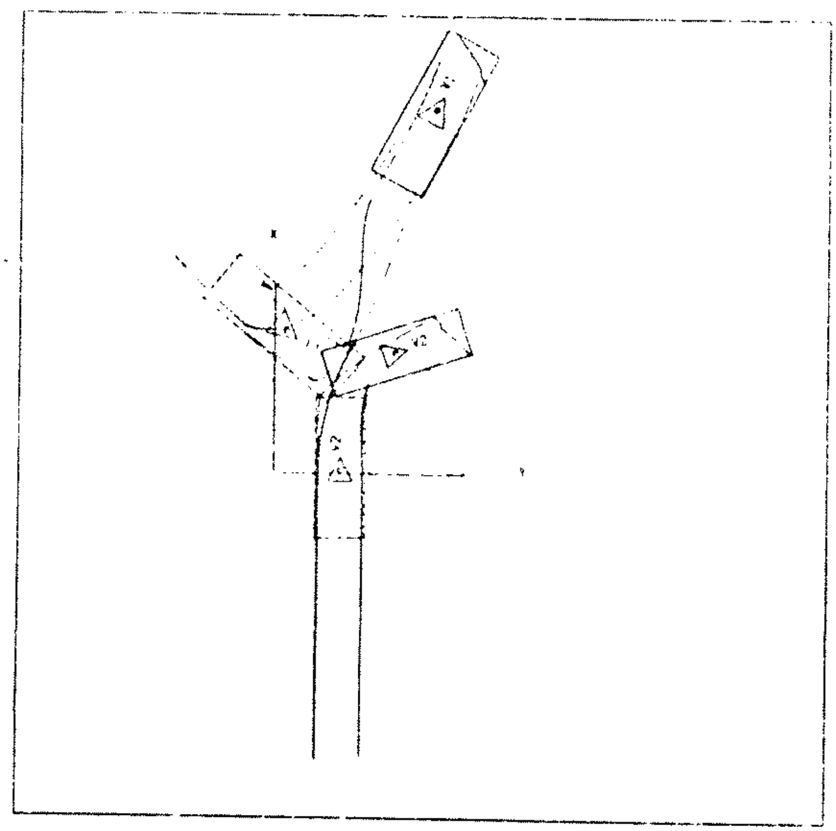


Figure 23 ACCIDENT SCHEMATIC CALSPAN CASE NO. 72-6B

GRAPHIC DISPLAY OF OUTPUTS OF ACCIDENT RECONSTRUCTION

COLLISION AND TRAJECTORY

CAL CASE NO. 72-68



AXIS INTERVALS ARE 10. FEET

	RECONSTRUCTED POSITIONS AND VELOCITIES AT IMPACT						DISPLACED FINAL POSITIONS				VEHICLE 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	-2.3	17.5	33.1	10.3	28.3	IN MOTION AT 3.0 SEC AFTER INITIAL CONTACT	01RFEW3
VEHICLE # 2	0.5	2.0	0.0	35.5	0.0	0.0	13.0	12.7	71.6	VEHICLE AT REST	12FDEW3

Figure 24

found to yield only minor improvements in the indicated prediction discrepancies.

On the basis of results obtained with the exploratory variations of the yaw moment of inertia of the VW, it is hypothesized that the remaining discrepancies between SMAC predictions and the reported behavior of the Microbus are primarily the results of forward pitching of the Microbus which is not included, of course, in the plane-motion SMAC simulation. The Microbus, which has a high floor and, consequently, a relatively high center of gravity would be expected to pitch somewhat more than a conventional sedan when contacted at an elevation corresponding to the bumper height of the Ford sedan. The investigator of this case indicates that the tire marks made by the rear wheels of the VW during the yaw rotation showed evidence of substantially reduced loading of the rear tires. Also, exploratory runs with a zone of reduced friction coefficient under the rear wheels of the VW were found to yield reductions in the indicated reconstruction discrepancies.

Therefore, it is tentatively concluded that the assumption of plane motion in the SMAC simulation program, with corresponding constant tire loadings throughout the collision and spinout, is the primary source of reconstruction discrepancies in the present case. However, since excellent agreement has been achieved in comparisons of SMAC predictions with a number of staged collisions, including intersection types (Reference 1 and Sections 3.1.1 and 3.1.2 of this report) it is further concluded that the mixture of vehicle types and the particular collision conditions in the present case have combined to amplify the errors produced by the cited analytical simplification.

The following discrepancies exist between the final reconstruction (Figure 24) and the reported scene data (Figure 23).

	Vehicle #1			Vehicle #2		
	X'	Y'	ψ	X'	Y'	ψ
Scene Data	38.4'	16.9'	20.0°	13.2'	8.4'	101°
SMAC Reconstruction	39.1'	16.9'	28.3°	13.0'	12.7'	71.6
Difference	0.7'	0.0	8.3°	0.2'	4.3'	29.4

In Figure 25, predicted time-histories of the longitudinal and lateral acceleration components of the two vehicles at their centers of gravity are displayed.

<u>Calspan Case No. 72-8B</u>

An accident schematic for this case is presented in Figure 26. The corresponding SMAC reconstruction is displayed in Figure 27.

In this case, there are the complications of ice along the side of the pavement and a secondary tree impact. The purpose of the presently reported reconstructions has been, of course, to gain experience in dealing with such complications of actual highway accidents in applications of the SMAC program.

In the final SMAC reconstruction (Figure 27), Vehicle No. 2 was run out only to the point of tree contact. An attempt to treat the tree as a vehicle (i.e., a small rectangular vehicle with a stiff structure and extremely large inertia) in a restart during the spinout of Vehicle No. 2 was abandoned because of related difficulties with the logic of the SMAC collision program.

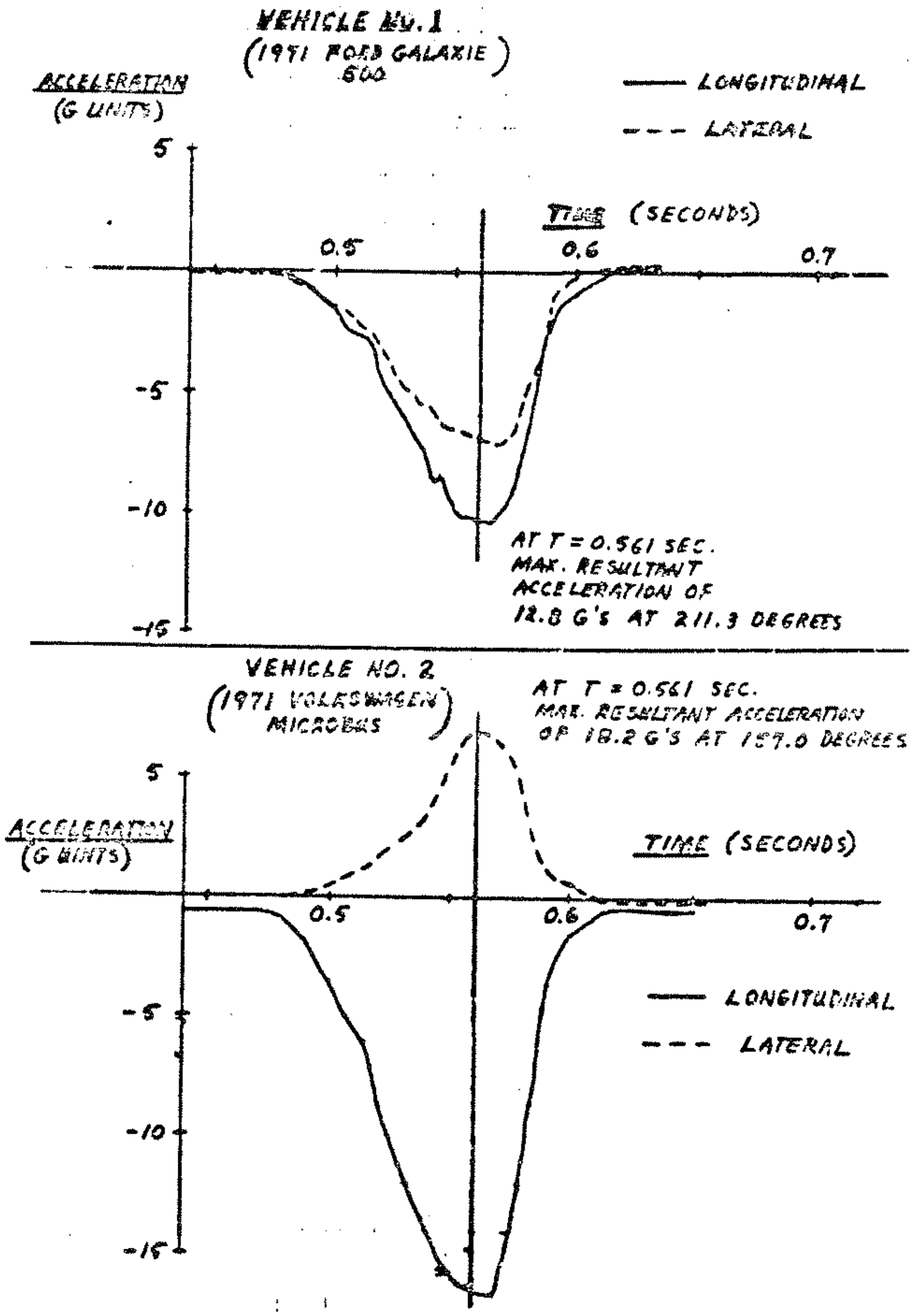


Figure 25 PREDICTED ACCELERATIONS FOR CALSPAN CASE NO. 72-6B

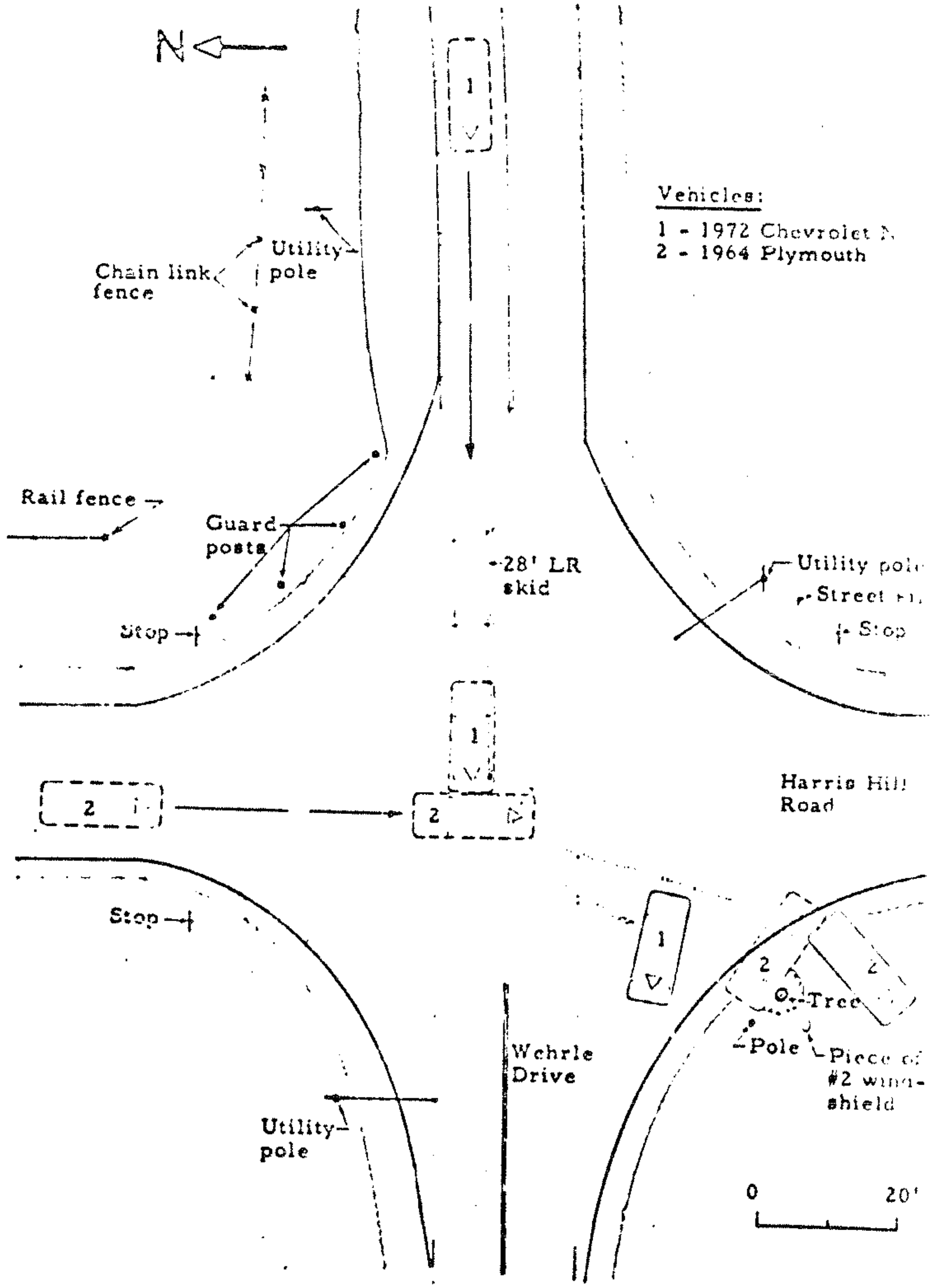
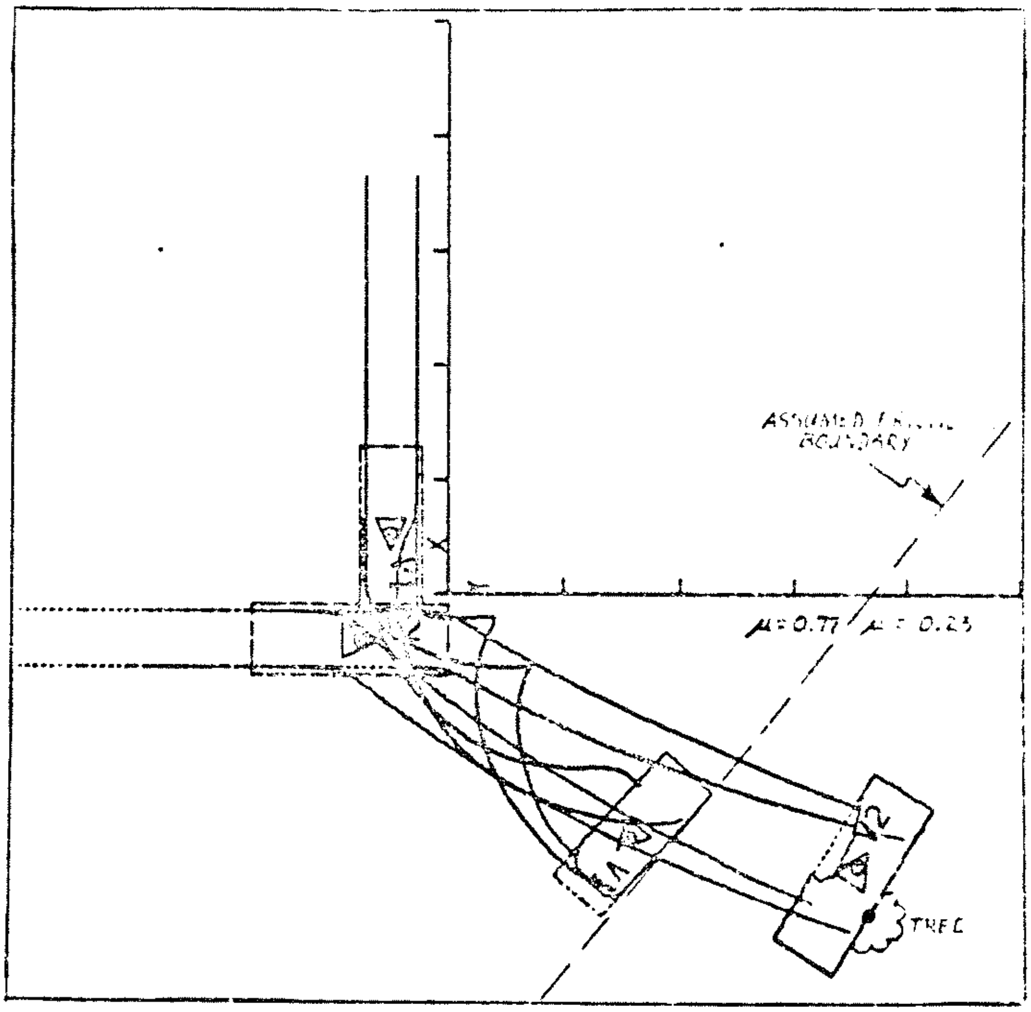


Figure 26 ACCIDENT SCHEMATIC CALSPAN CASE NO. 72-8B

GRA[illegible] DISPLAY OF OUTPUTS OF ACCIDENT [illegible]

COLLISION AND TRAJECTORY

Figure 27



AXIS INTERVALS ARE 10. FEET

	[illegible] POSITIONS AND VELOCITIES AT IMPACT						FINAL POSITIONS AND VELOCITIES				
	POSITION		HEADING	VELOCITIES			POSITION		HEADING	VELOCITY
	X (FT)	Y (FT)	(DEG)	FWD (MPH)	LATERAL (MPH)	ANGULAR (DEG/SEC)	X (FT)	Y (FT)	(DEG)	
VEHICLE # 1	[illegible].6	5.5	180.0	42.4	0.0	0.0	22.9	16.[illegible]	[illegible]	VEHICLE AT REST
VEHICLE # 2	[illegible].3	8.4	90.0	42.6	0.0	0.0	-26.0	38.6	32.9	TIME = [illegible]

The extent of yaw rotation of Vehicle No. 1 was found to be relatively sensitive to the detailed impact configuration (i.e., the vehicle positions at initial contact and the individual speeds). The final SMAC reconstruction run (Figure 26) did not place Vehicle No. 1 exactly in the reported rest position and orientation. However, further iterations were not considered to be worthwhile in view of both the generally good agreement with other aspects of the case and the fact that the pavement friction coefficient was <u>estimated</u> by the investigator. It should also be noted that Vehicle No. 1, in the displayed SMAC run, stops just short of the ice on which it would have tended to rotate further.

The following discrepancies exist between the final reconstruction (Figure 27) and the reported scene data (Figure 26).

	Vehicle #1			Vehicle #2*		
	X'	Y'	ψ	X'	Y'	ψ'
Scene Data	-23'	21.5'	-170°	-24'	38'	32°
SMAC Reconstruction	-23.0'	16.9'	-138.6°	-26.0'	38.6'	32.9°
Difference	0.0	4.6'	31.4°	2.0'	0.6'	0.9°

*At tree contact.

In Figure 28, predicted time-histories of the longitudinal and lateral acceleration components of the two vehicles, at their centers of gravity, are displayed.

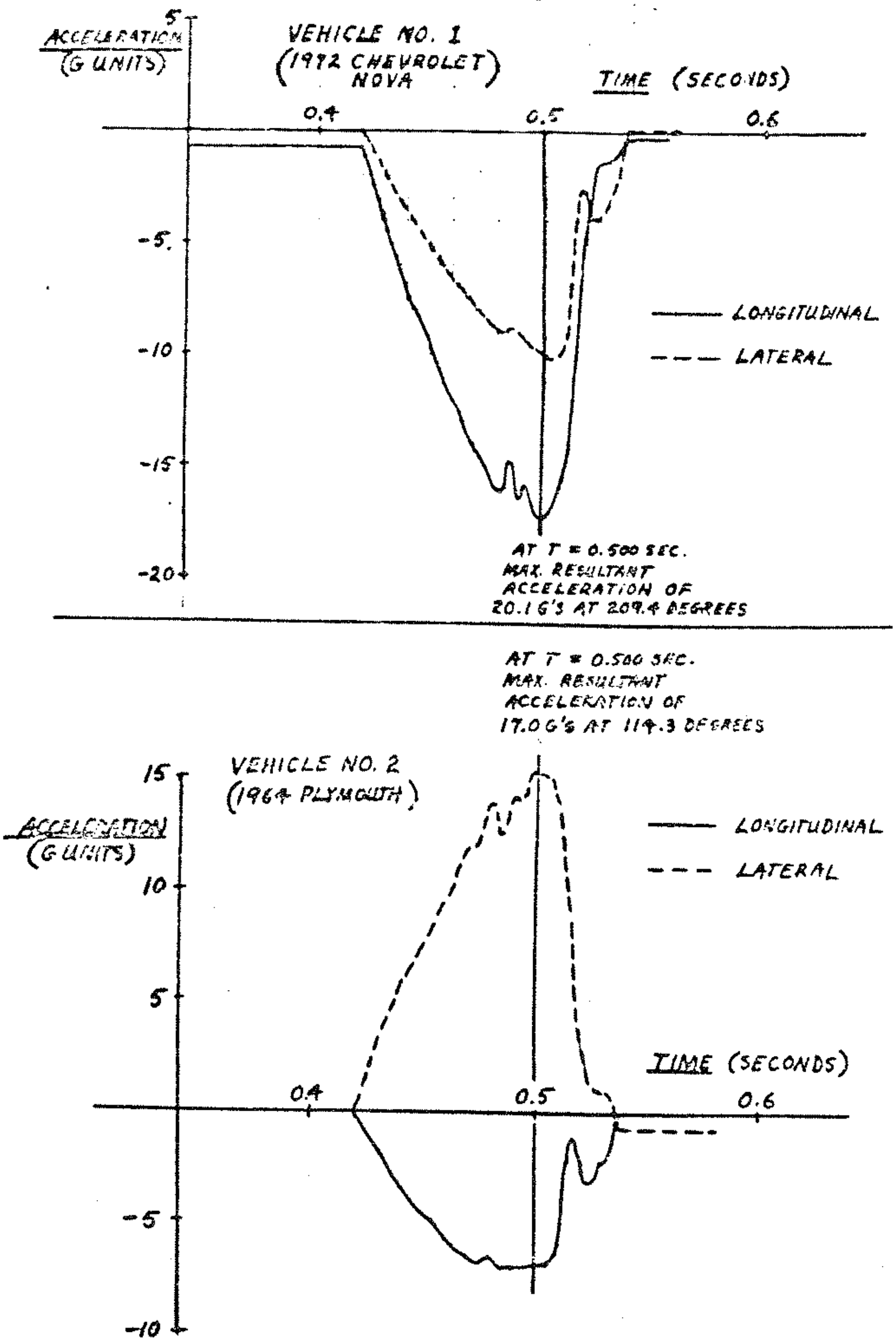


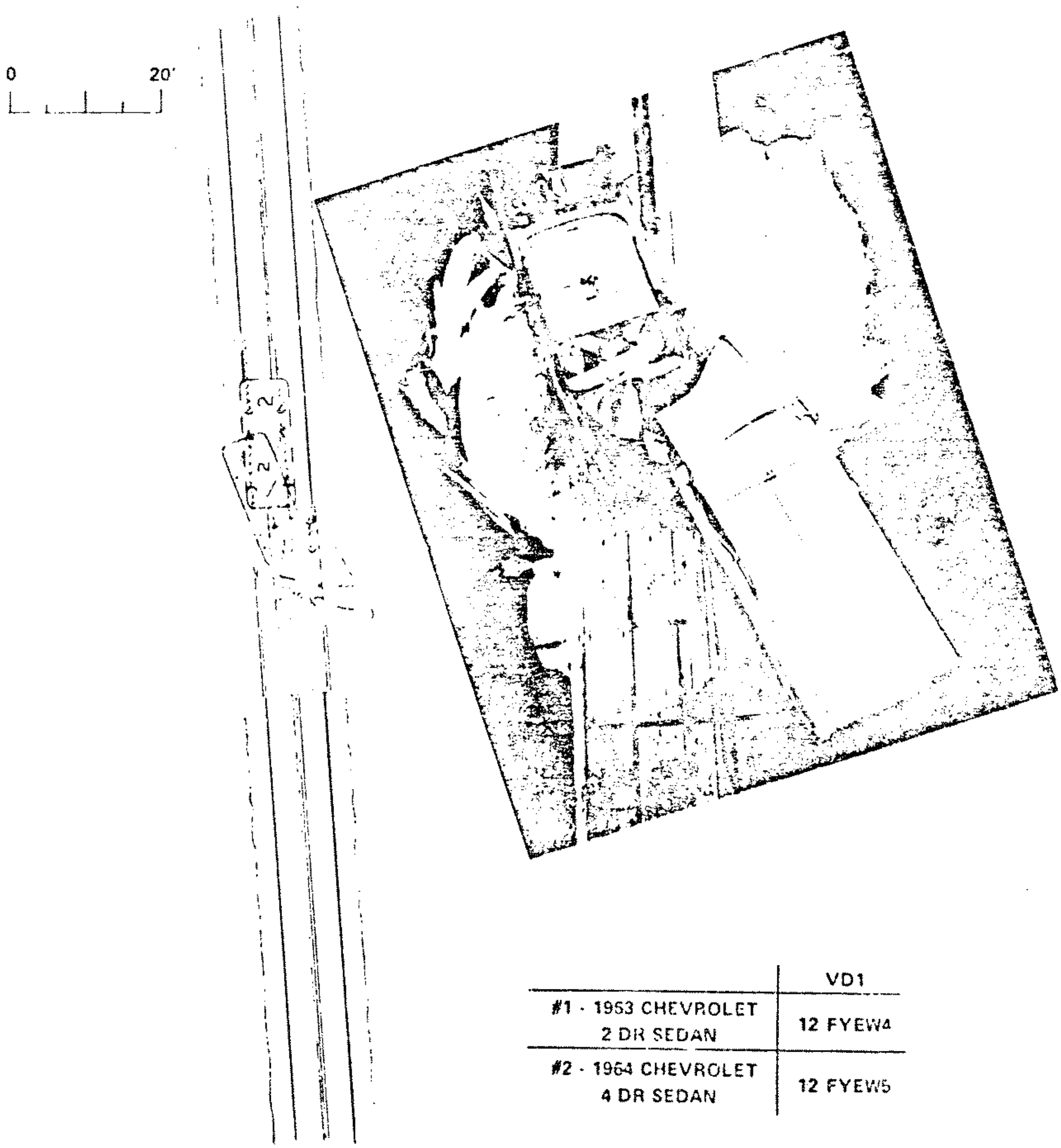
Figure 28 PREDICTED ACCELERATIONS FOR CALSPAN CASE NO. 72-8B

3.2 Staged Collisions

The initial staged accident within this research contract was performed during the first quarter of the performance period. It took the form of a head-on collision at approximately 30 MPH (60 MPH closing speed) with an offset of 2 feet between vehicle centerlines. In this initial case, an experiment with instrumented dummies was "piggybacked", and the costs of test performance were shared with NHTSA Contract No. FH-11-7592 and MVMA Contract No. Calspan 7002-C-7. Because of this fact, the approximate collision conditions were known prior to initiation of the reconstruction process. Thus, the experiment served primarily as an initial exercise for the various components of the overall system rather than as a direct evaluation of reconstruction accuracy. Scene data are shown in Figures 29 and 30 . Sand was applied to the surface in the area of the impact point in an attempt to reduce the tire-terrain friction coefficient and more clearly delineate tire evidence since the vehicles were not braked and skid marks were expected to be minimal.

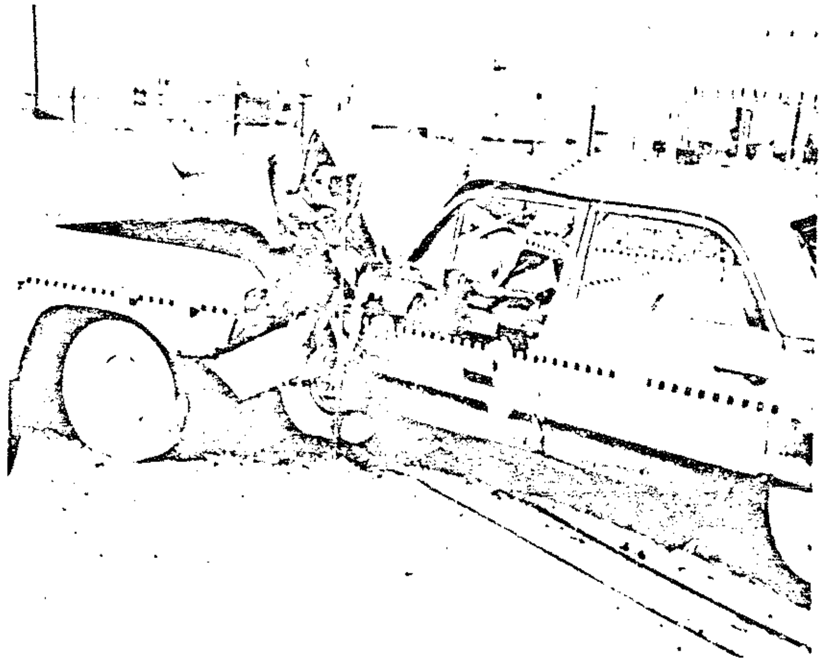
The other two staged collisions scheduled for this research program were performed during the second quarter of the research program. The objective of these two experimental crashes was to provide cases in which measured data, that were kept unknown during the reconstruction process, would be available for comparison with the final analytical results. This "closed loop" form of evaluation of reconstruction accuracy is believed to be unique. Yet, without such an evaluation, it is impossible to establish a confidence level for reconstructed impact conditions.

Scene data for the second staged collision are presented in Figures 31 and 32 . It should be noted that a delayed release of the tow cable on Vehicle #1 in this case is believed to have influenced the collision results sufficiently to preclude a highly accurate reconstruction (see Section 3.1.2).



	VD1
#1 - 1963 CHEVROLET 2 DR SEDAN	12 FYEW4
#2 - 1964 CHEVROLET 4 DR SEDAN	12 FYEW5

Figure 29 MEASURED SCENE DATA MRA TEST NO. 1



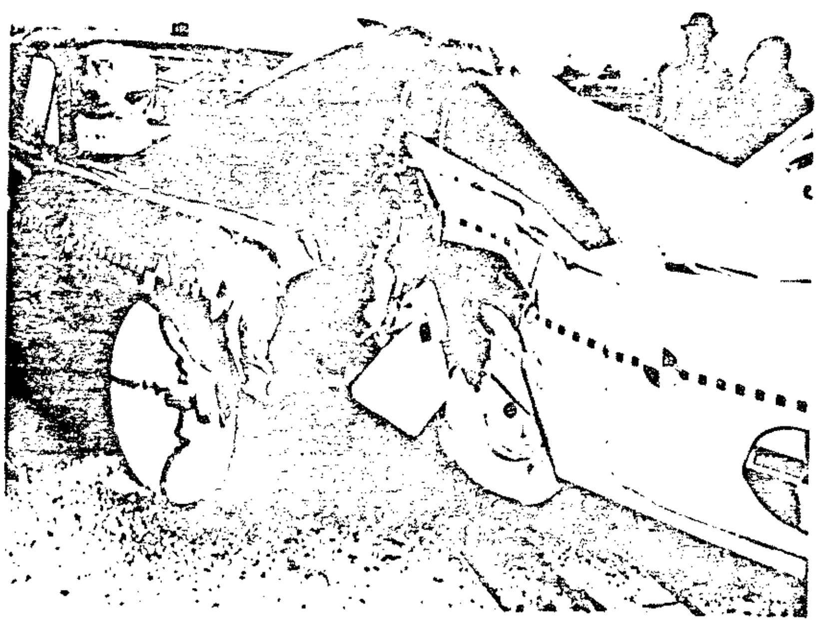
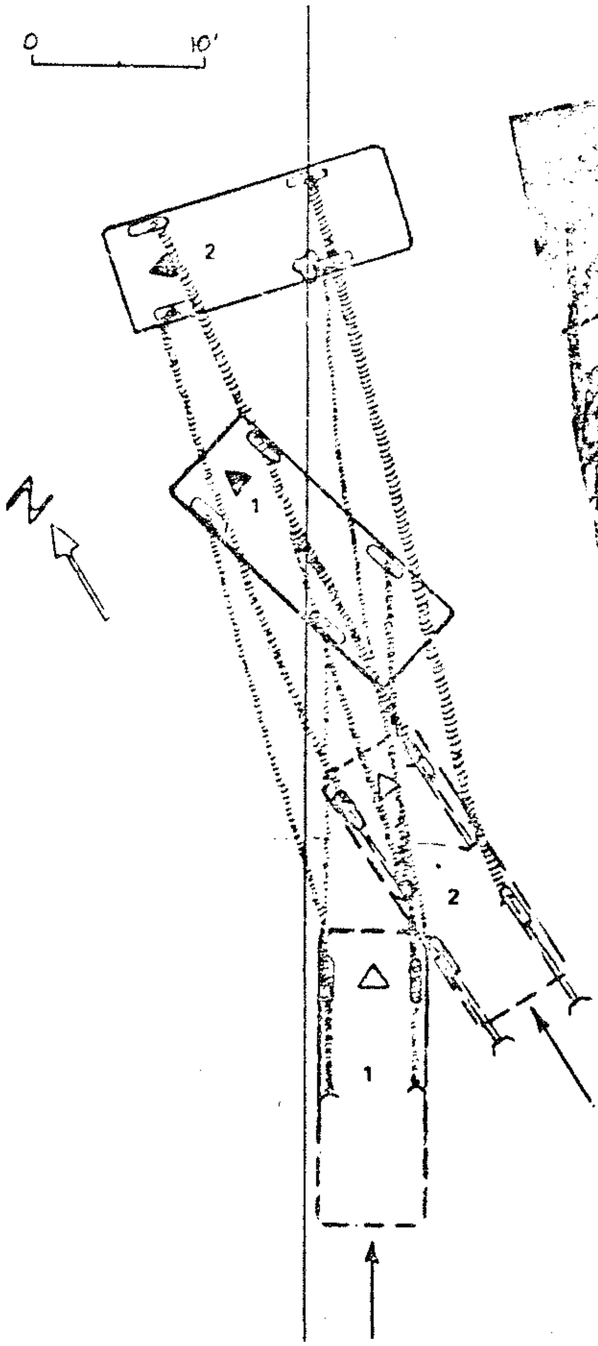
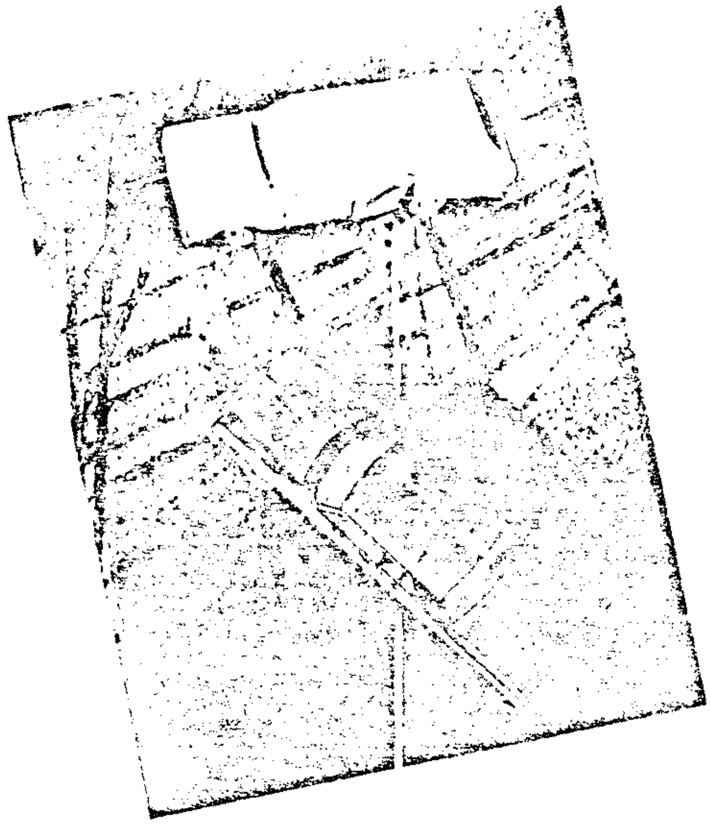


Figure 30 VEHICLE DAMAGE IN MRA TEST NO. 1, 2' OFFSET FRONTAL





	VDI
#1 -- 1964 PLYMOUTH 2 DR SEDAN	05 RFEE2
#2 – 1964 CHEVELLE 4 DR STATION WAGON	11 LZEW2

Figure 31 MEASURED SCENE DATA MRA TEST NO. 2 (12 JULY 1972)

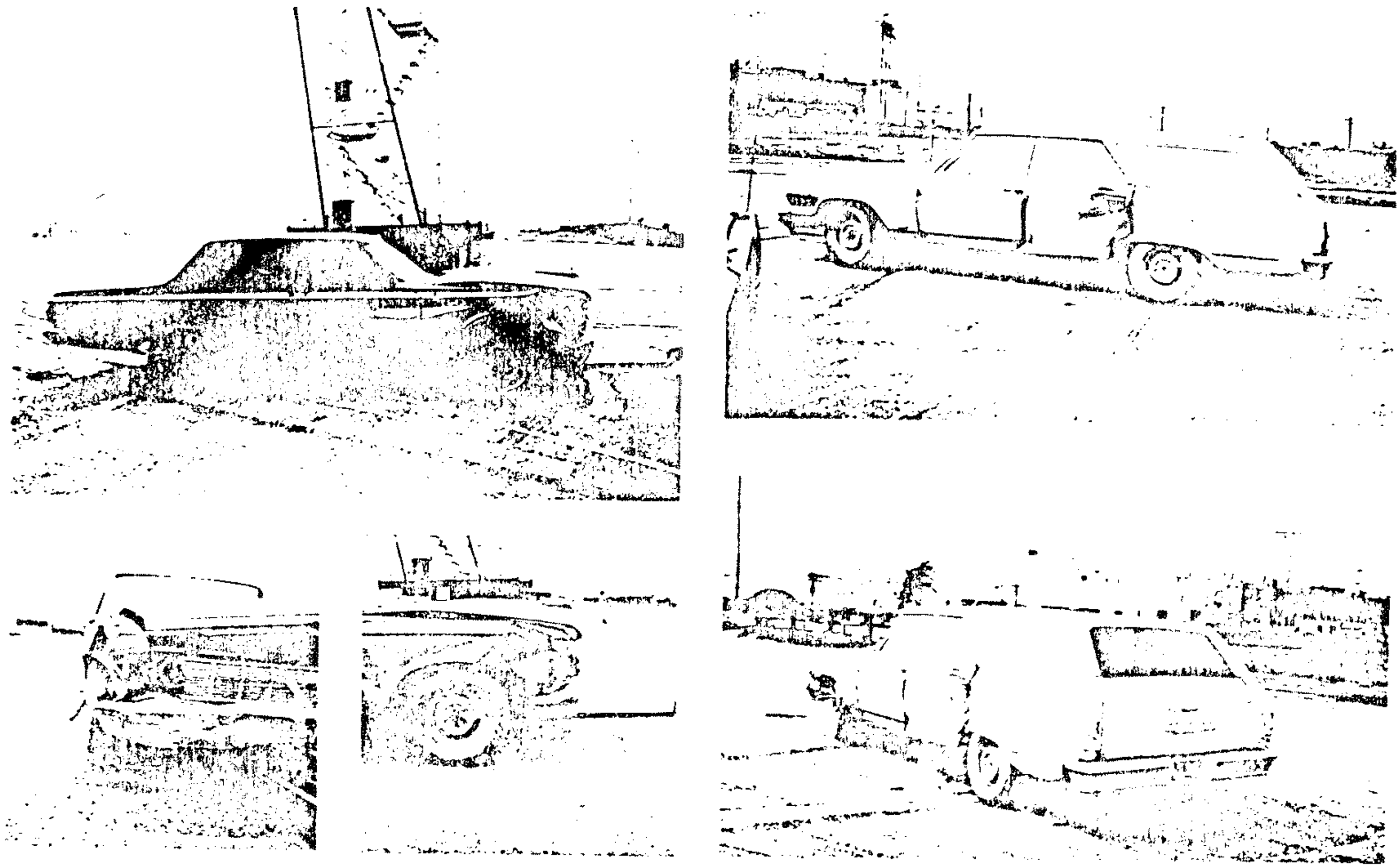
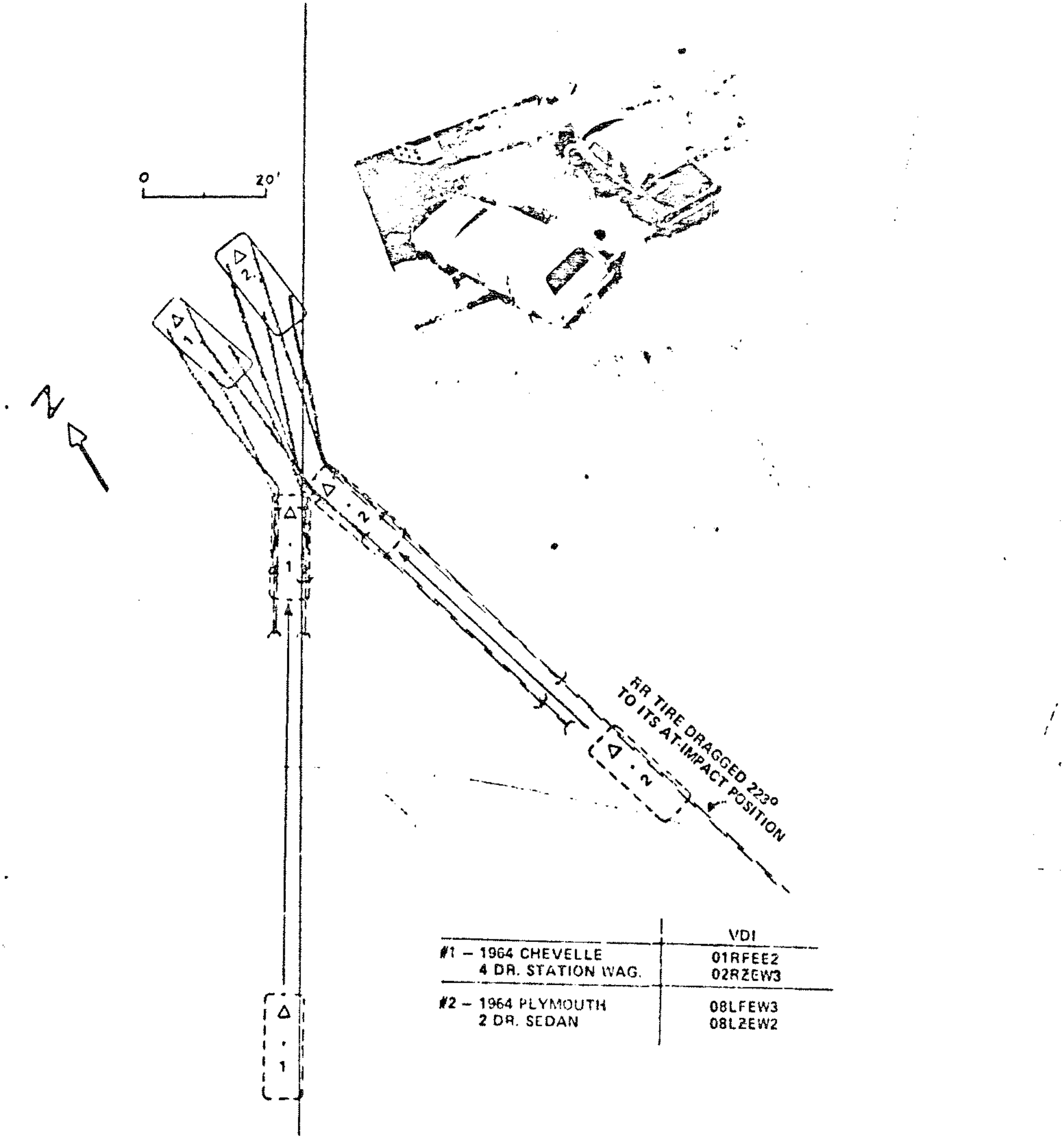


Figure 32 VEHICLE DAMAGE IN MRA TEST NO. 2

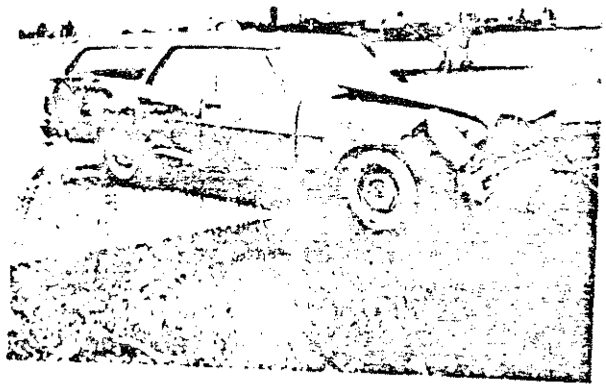
Scene data for the third staged collision are presented in Figures 33 and 34.

Results of analytical reconstructions of the three collisions are presented and discussed in Sections 3.1.1 and 3.1.2.



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

Figure 33 MEASURED SCENE DATA MRA TEST NO. 3 (13 JULY 1972)



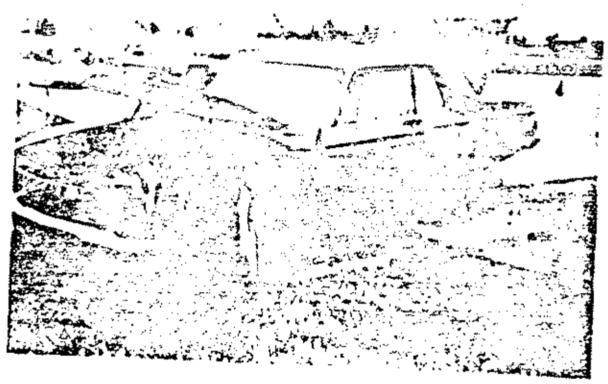


Figure 34 VEHICLE DAMAGE IN MRA TEST NO. 3

3.3 Computer Graphics Routines

3.3.1 The Need For a Graphics Display of Accident Reconstructions

Computer analysis of physical systems has until recently been directly usable only by the technically skilled. The reason is that the necessary communications medium was computer printout, whose compact tabulations and specialized codes can be deciphered only by experts. It would be unreasonable, as a part of the present research, to expect police investigators to leaf through many pages of tabular computer printout and to rapidly comprehend the results of a computer-predicted accident reconstruction. Computer graphics displays to summarize the results appear to offer a solution to this problem.

Computer graphics displays can combine pictorial and printed data. The pictorial data may be two or three dimensional, and it provides the user with rapid comprehension of physical motions, such as the dynamic interaction of two automobiles in collision. To paraphrase an old idiom, "A picture is worth a thousand pages of printout."

3.3.2 The Selected Format for Reconstruction Graphics

Figure 35 is an example of a computer graphic display of outputs of the accident reconstruction program. The important features of this display are:

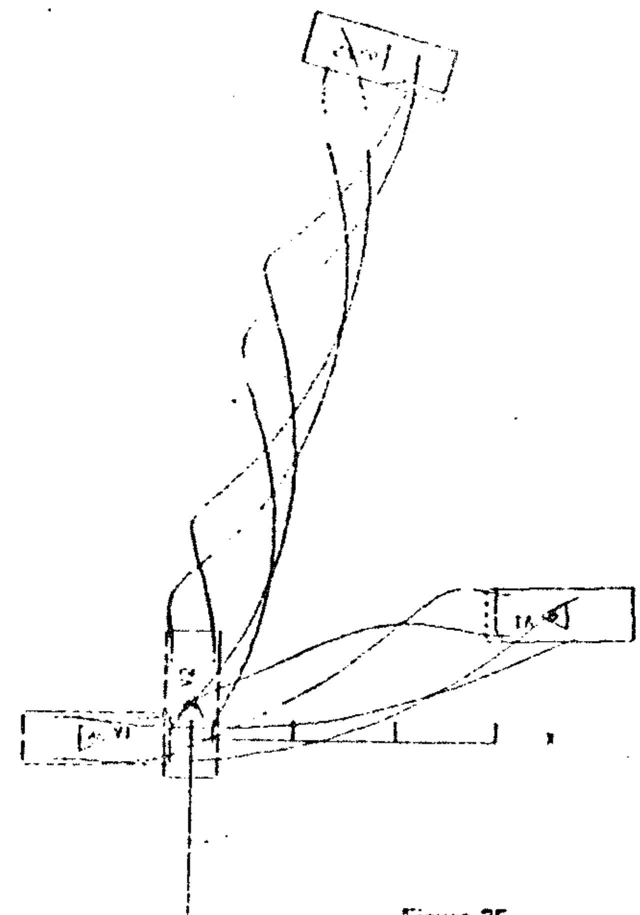
1. The title and date of the accident are displayed.

2. A set of labeled reference axes is provided.

3. The initial contact positions of each vehicle are displayed with broken lines.

GRAPHIC DISPLAY OF OUTPUTS OF ACCIDENT RECONSTRUCTION

COLLISION AND TRAJECTORY



VEHICLE # 1 DATA

XC1 = 44.30564 FT.

YC1 = -16.21791 FT.

PSI1 = -130.92506 DEG.

VDI = 01FDEW2

TIME = [illegible] SEC.

VEHICLE # 2 DATA

XC2 = 20.76723 FT.

YC2 = [illegible] FT.

PSI2 = -524.33106 DEG.

VDI = 10LZEN3

TIME = 2.00100 SEC.

ALL DISTANCES ARE IN FEET

Figure 35

4. The final computed positions of the vehicles are displayed with predicted damage indicated and with the original outlines of the vehicles indicated by dotted lines.

5. All displayed vehicles are clearly identified with the center of gravity and forward direction noted.

6. Simulated tire tracks are plotted with dashed tracks indicating rolling wheels and solid tracks indicating skidding.

7. A tabular listing is provided of the positions and orientations of the two vehicles at impact and in the final displayed positions, the predicted VDI (Vehicle Damage Index) and the elapsed time from initial contact at which the simulation halted if either vehicle had not come to rest before the end of the simulation.

8. The axis scale is indicated.

3.3.3 Description of Reconstruction Graphics Process

Reconstruction Graphic Data Tape

As a standard output of the accident reconstruction simulation program, a magnetic tape is created which contains most of the information required by the reconstruction graphics program. This information includes the initial and final positions of the vehicles, the associated tire tracks, the vehicle damage indices and definitions of the damage profiles.

A full description of the reconstruction graphic data tape is provided in Appendix 5.

Reconstruction Graphics Software

The reconstruction graphics program first reads the aforementioned tape and extracts and formats the data. A special layout subroutine takes into account the initial and final positions of the vehicles, the point of contact, and the origin of the space-fixed axis system, plus the area size into which the programmer desires to draw the picture. This layout subprogram determines the proper scale factors to be used by the plotting programs.

The reconstruction graphics program proceeds to draw the impact positions of the vehicles (i.e., at the instant of initial contact), the final positions of the vehicles (with predicted damage displayed) and the tire tracks. The vehicles are labeled and the space-fixed axes are drawn in. Finally, along the exterior of the pictorial data, the previously mentioned tabular data are plotted. The result is a concise graphic summary of the reconstructed accident.

3.3.4 Investigator Data Display

A minor modification of the above process permits the generation of graphic displays of the on-scene investigator's data. The only difference in the pictorials is that the damage is not displayed on the vehicles at their final positions, and that simulation time-out or point of rest indications are not needed. Figure 36 is an example of this type of display.

GRAPHIC DISPLAY OF ACCIDENT INVESTIGATOR DATA

COLLISION AND TRAJECTORY

VERF TEST NUMBER 2

DRY ASPHALT

FROM FILE VERFON

[illegible] INTERVALS ARE 10. FEET

VEHICLE # 1 DATA

XC1" = 0.31000 FT.

YC1" = 4.51000 FT.

PSI1 = 353.05981 DEG.

XC1' = [illegible] FT.

YC1' = [illegible] FT.

PSI1' = [illegible] DEG.

VEHICLE # 2 DATA

XC2" = 11.68000 FT.

YC2" = 7.42000 FT.

PSI2 = 324.73999 DEG.

XC2' = 47.[illegible] FT.

YC2' = [illegible] FT.

PSI2' = [illegible] DEG.

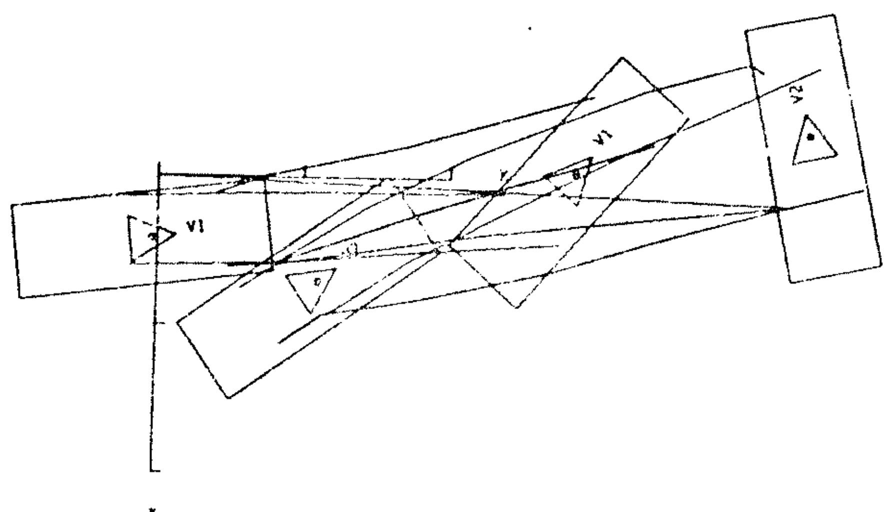


Figure 36

The accident data processing software prepares a paper tape containing the data used by the graphics program. A special interface program converts the paper tape into IBM cards for input to the graphics program. The modified version of the reconstruction display program plots the measured data with essentially the same pictorial format and scale as that previously described. Added features are the inclusion of terrain and debris data in the picture.

This investigator data display has utility in two areas. First, it augments the reconstruction display and aids the investigator running the reconstruction program in correlating his results. Second, it could be used to provide a concise visual summary for the on-scene investigator to aid him in validating his results. Also, it provides a standard format for use in reporting and documenting accidents.

3.3.5 Potential Extensions in the Application of Accident Reconstruction Graphics

The accident reconstruction graphics capability that has been developed can be expanded to add new dimensions to the total accident reconstruction effort. Recently developed low cost, terminal-type plotting devices can make instant on-scene verification of the data possible. There appears to be no better way for the accident investigator to verify his data taking efforts than this "instant graphics" approach.

The developed displays can be worked into a computer terminal interactive display system, enabling the accident reconstructor to compare his reconstructions with the investigator data, to make spot changes from the terminal, and to rapidly zero in on the optimum match of scene data.

3.3.6 Summary of Reconstruction Graphics

The two types of developed displays provide a unique enhancement of the accident reconstruction process. Since the accident reconstruction system is aimed at eventual general use by non-technical personnel, it is imperative that computer data be presented in a non-technical, easily comprehendable format. The developed graphic displays are believed to constitute a giant step in that direction.

3.4 On-Scene Data Acquisition System

3.4.1 Transit Instrument Package Development

The purpose of the Transit Instrument Package is to combine elevation and azimuth data from an instrumented surveyor's transit with a code number (entered on the control box) and format it so it can be supplied to a remote computer terminal device. This remote terminal device contains a modem which then transmits the data (and other information typed in on the terminal keyboard) to a computer via a telephone line. The remote terminal used for the initial prototype optical measurement system was an Execuport 300. Figure 37 illustrates the overall system configuration and Figure 38 presents the basic block diagram for the system.

3.4.1.1 Equipment Description

The azimuth and elevation resolvers are attached to the transit and are connected to a relay box. The relay box contains a 4 pole double throw relay which selects the resolver to be connected to the Astrosystems, Inc. Digital Angle Readout (DAR). The relay box also contains a 3 position rotary switch which can be used to select an automatic mode (i.e., the relay selects which resolver will be active), or the azimuth or elevation resolver alone. The latter two positions were intended for checkout purposes only. A LED pilot light on the relay box is lit when the relay is activated.

The selected resolver signal is then sent to the DAR. This device provides the angle information in 5 digit (degrees and hundredths of a degree) in BCD form. This data is then connected to the Digital Circuitry.

The Control Box contains five letter type thumbwheel switches, two LED pilot lights and a pushbutton switch. The thumbwheel switches are used to enter the code for each reading. The pilot lights indicate which

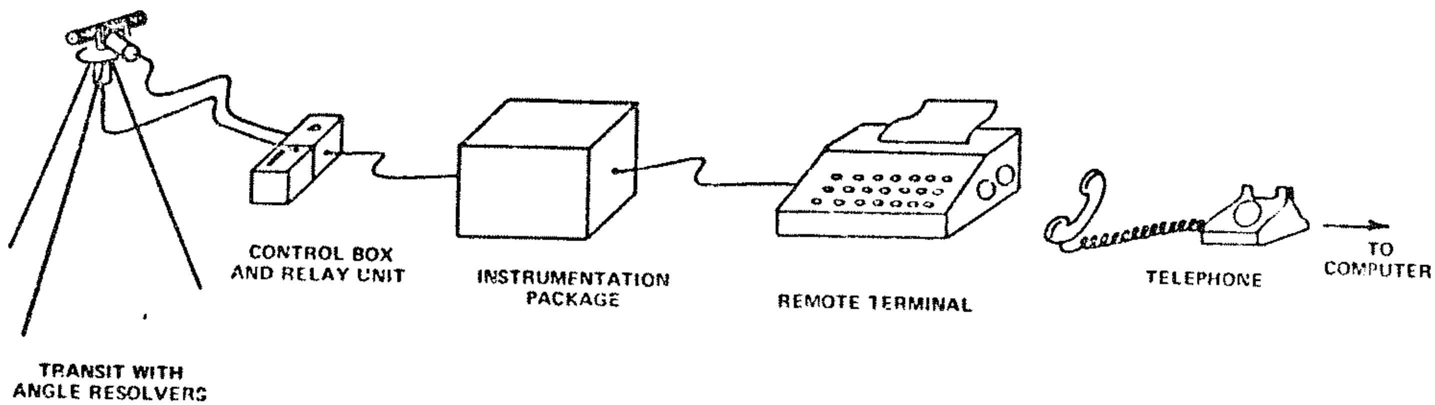
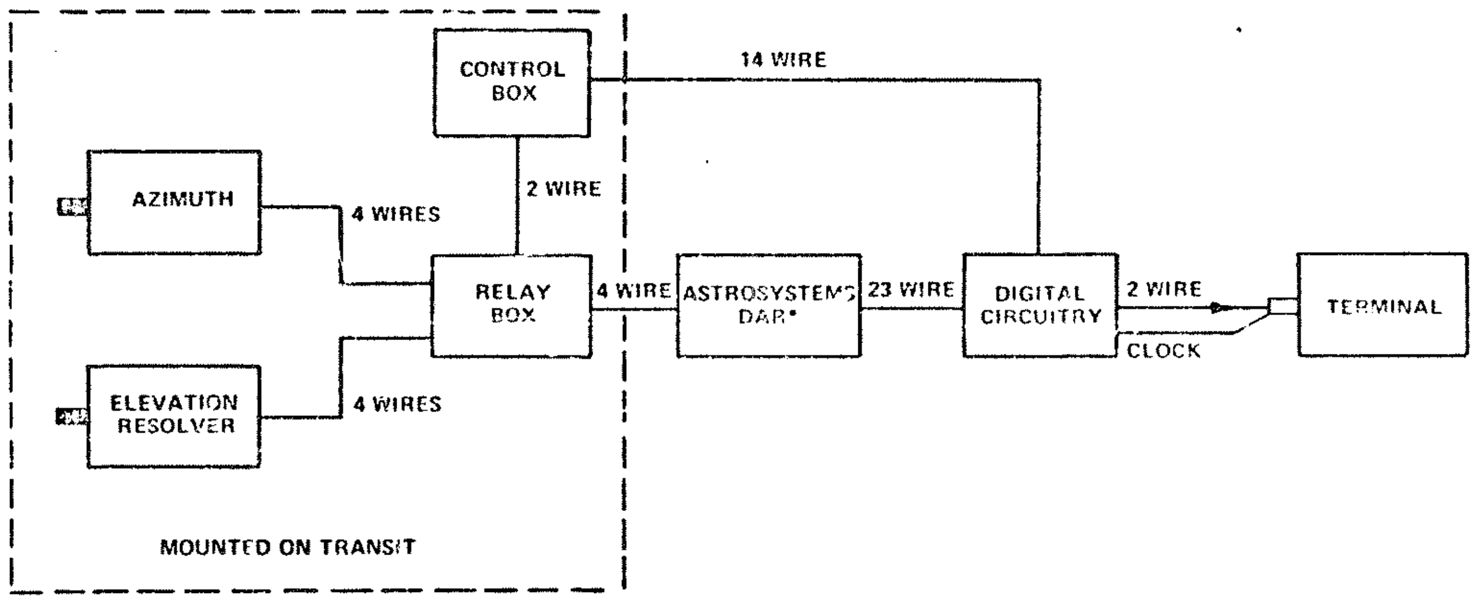


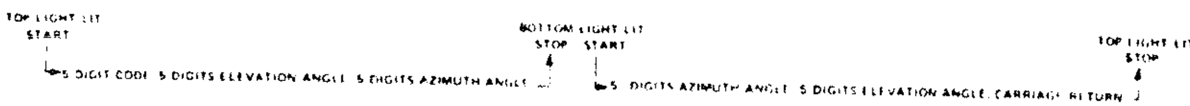
Figure 37 OPTICAL MEASUREMENT SYSTEM CONFIGURATION



*DIGITAL ANGLE RESOLVER

Figure 33 OPTICAL MEASUREMENT SYSTEM BASIC BLOCK DIAGRAM reading is to be taken next, that is, the top or bottom reading. The pushbutton is depressed to start the data entering cycle. The Control Box also contains some digital circuitry which will be discussed later. The signal which controls the relay passes through the control box.

The Digital Circuitry takes data from the DAR and the code switches and upon receipt of a start signal from the pushbutton produces the following stream of data in ASCII format to the terminal.



Notice that when the "TOP" light is lit the code data, the elevation and azimuth data for the "TOP" reading are sent. The systems then stops, lights the "BOTTOM" light and waits for the pushbutton to be depressed. When this occurs the azimuth and elevation data for the "BOTTOM" reading are entered followed by a Carriage Return and the systems stops with the "TOP" light lit awaiting a "TOP" reading and repeat of the cycle.

3.4.1.2 Detailed Description of Digital Circuitry

A block diagram for the digital circuitry is shown in Figure 39 . It should be noted that there are only four different words of data to be transmitted:

1. DAR Numbers (elevation or azimuth)
2. CODE Numbers
3. Comma
4. Carriage Return.

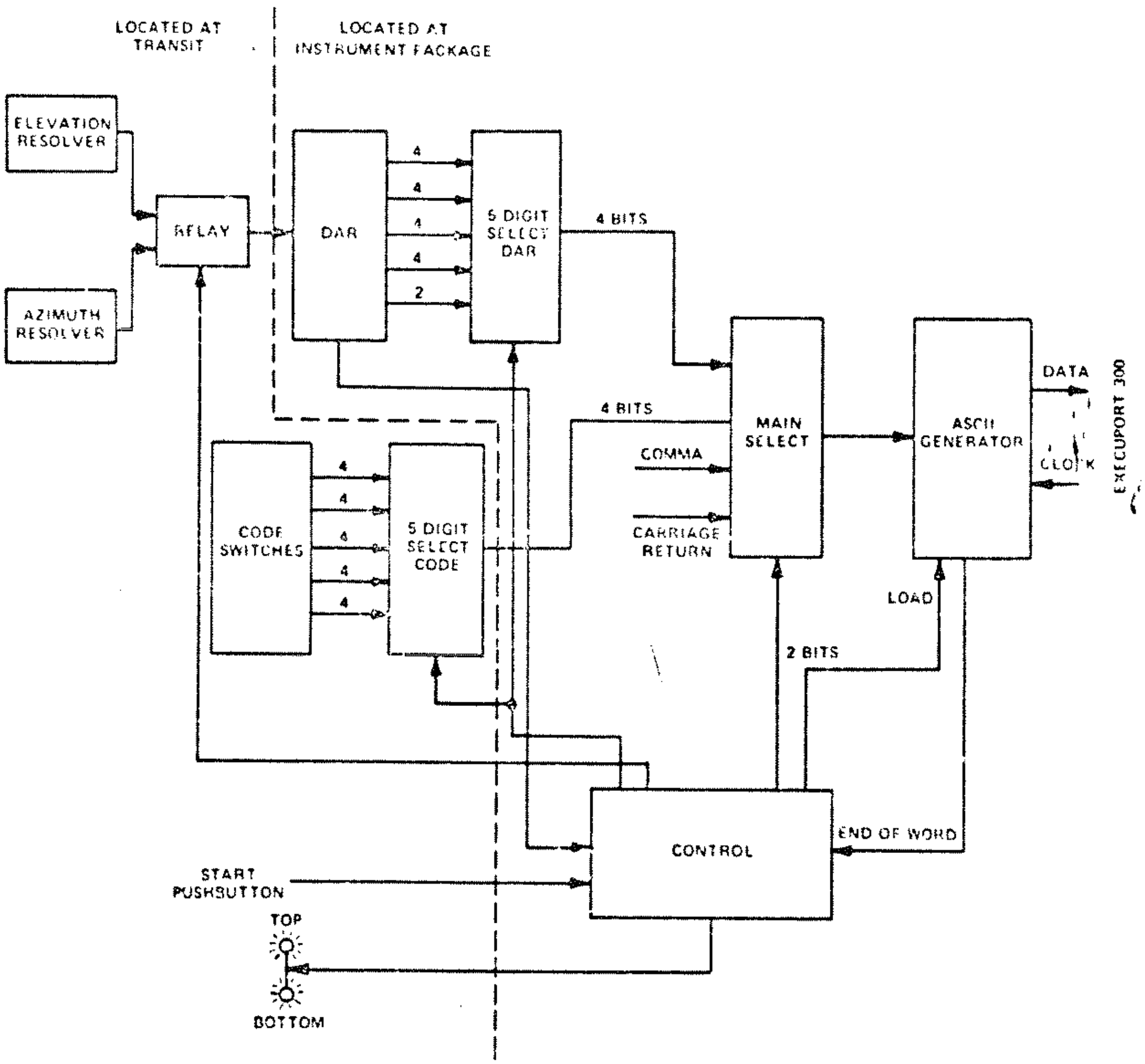


Figure 39 DETAILED DIGITAL CIRCUITRY BLOCK DIAGRAM

The appropriate data word is selected by the Main Select circuit to produce the required data format described above. The comma and carriage return are wired in data. In the ASCII format for numbers, 3 bits are constant and are wired, 1 bit is produced by a parity generator and 4 bits are the same as the BCD representation of the number.

The BCD part of the number data comes from one of two 5-digit selectors. These select which digit of Code or DAR data is to be read. While this function might have been performed by a single 10 digit selector the use of two selectors allowed the Code selector to be incorporated in the control box, thus, greatly reducing the number of wires needed between the control box and digital circuitry.

3.4.2 Data Processing

A data processing program was developed for reading, transforming and codifying transit measurements. The program is written in FORTRAN IV on an XDS Sigma-7 computer and a listing is given in Appendix 6.

The program is designed to accept a five digit code identifying the type of physical evidence for which the sighting is being made, followed by four five-digit numbers representing the elevation and azimuth (relative to the transit) of the top reference point of the stadia pole and the azimuth and elevation of the bottom reference point. The four numbers representing the angles are then changed to floating point format with two significant digits. A number of checks are made on the data to identify possible errors introduced during transmission. If errors exist, a request is made to transmit the current data point again.

If no errors are found, the transit measurements are converted into space fixed coordinates by SUBRØUTINE TRNFRM. The code corresponding to this point is then investigated and the coordinates are stored in the appropriate category of measurement.

As a back up against data loss in the event a catastrophic failure should occur somewhere in the system during the scene measurements, the transit data are also stored on a permanent disc file for later processing.

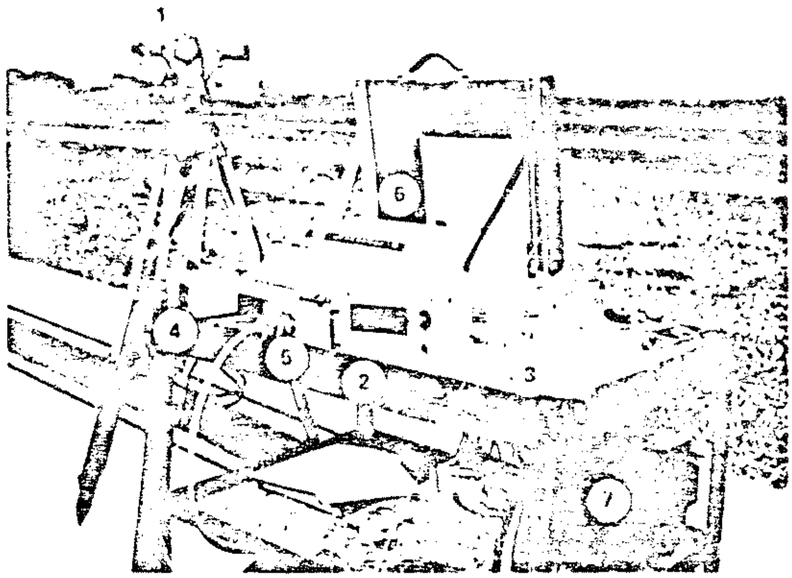
An integral part of the measurement system is a means of identifying the measurement being taken. This is accomplished by the five digit code transmitted with the transit measurements. The general categories of measurements include codes for vehicle positions, tire marks, debris, roadway layout, and axis system definition. Subcodes available include: vehicle number, wheel number, type of tire mark, and type of debris. A complete listing of currently available codes with their descriptions is given in Appendix 6. It should be noted that the data processing program and the coding format are sufficiently general to allow insertion or deletion of items as experience dictates.

A brief procedure is outlined in Appendix 6 for taking measurements with the optical system.

5.4.3 Optical Measurement System Checkout

Upon completion of the Calspan designed and built interface hardware, the optical measurement system was assembled for an initial checkout via the measurement of a full-scale accident scene staged at Calspan. Figure 40 shows the assembled system with a list of components. For this test, the communications link between the terminal and the time sharing system was accomplished with an extension telephone. In final form, however, this link is a mobile telephone unit installed in the accident investigator's vehicle.

The accident scene was investigated by a Calspan team of Tri-Level investigators and the traditional method of measurement was used (Figure 41). Subsequently, the optical measurement system was employed to measure the same scene. Two sets of measurements were taken; one being before the vehicles had been removed from the scene, as seen in Figure 42, and



1. Transit instrumented with Reeves Instrument Division, Dynamics Corporation of America, Inc. Precision Resolvers for elevation and azimuth angle detection.

2. Astrosystems Inc. Shaft Angle Encoder.

3. Calspan developed digital circuitry to convert output from Shaft Angle Encoder to ASCII and store for transmission.

4. Elevation/Azimuth relay unit.

5. Control unit.

6. Execuport 300 remote time sharing terminal.

7. 12 volt DC power supply.

Figure 40 INITIAL FORM OF OPTICAL MEASUREMENT SYSTEM

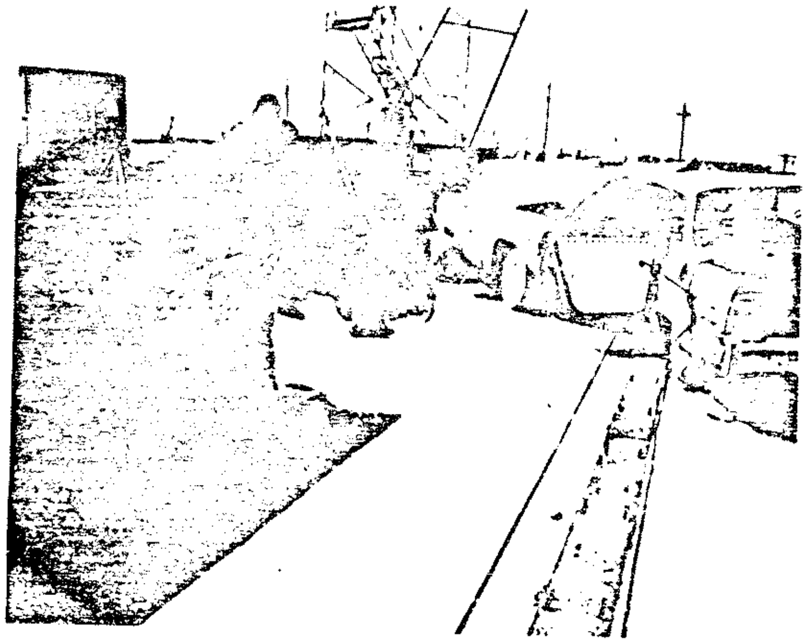


Figure 41 TRADITIONAL INVESTIGATION AND MEASUREMENT OF THE SCENE

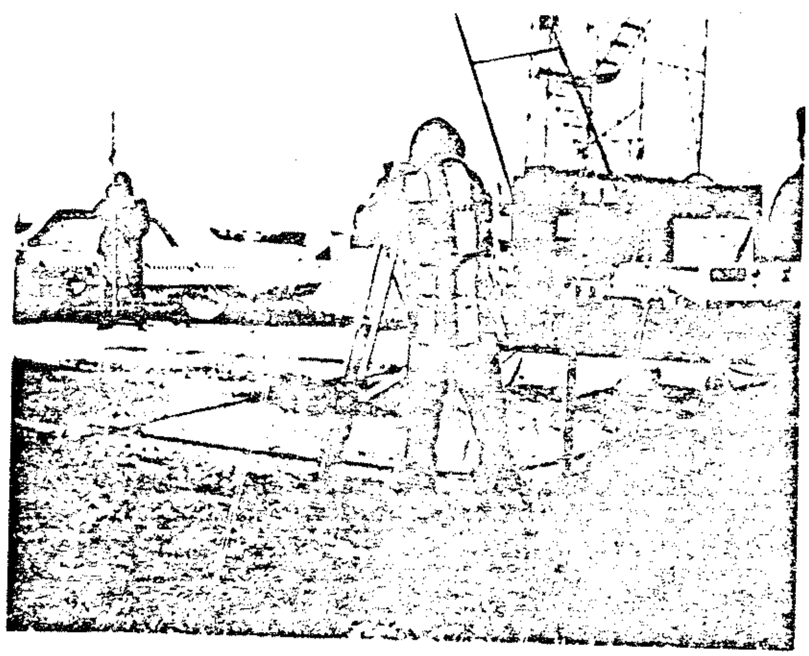


Figure 42 OPTICAL MEASUREMENT OF THE SCENE

one set afterward. The results of the two measurement sets were compared and with the exception of two points, were within expected tolerances of locating the stadia pole. A comparison of the optical system measurements and investigator's measurements is shown in Figure 43. The measurements illustrate the rest position of the tires for each vehicle and associated tire marks. The agreement appears excellent, the only obvious discrepancy being that of the left front tire marks of vehicle 1. This discrepancy probably resulted from misplacement of the stadia pole and should be easily correctable when on-scene plotting of the evidence is available.

During the second quarter, the optical measurement system equipment was installed in the 1972 Chrysler supplied for that purpose by the NHTSA. The installation is shown in Figure 44 consisting of:

1. Execuport 300 computer terminal
2. DAR and electronic interface package
3. Mobile telephone
4. Transit with angle resolvers and control boxes
5. DC to AC power inverter
6. Mobile telephone transceiver.

The equipment is shown in use at the scene of one of the staged accidents conducted within this research program in Figure 45.

Note that the Execuport 300 Computer Terminal shown in Figure 44 was borrowed for use in system development and was replaced by a Porta Com Portable Computer Terminal which was purchased during this second quarter. Installation of the Porta Com unit was delayed due to some minor interface problems between the new terminal and the electronic circuitry.

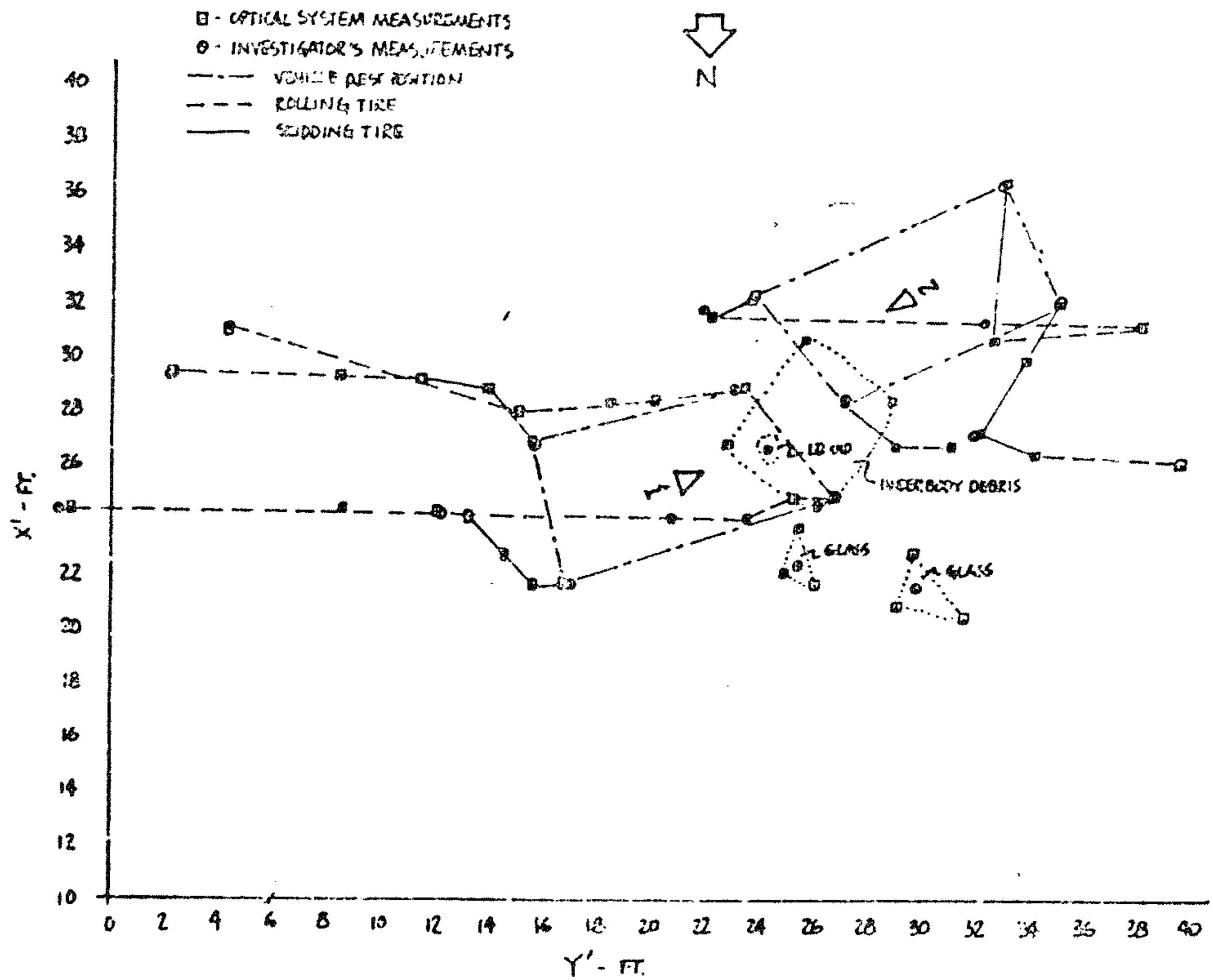


Figure 43 COMPARISON OF SCENE MEASUREMENTS

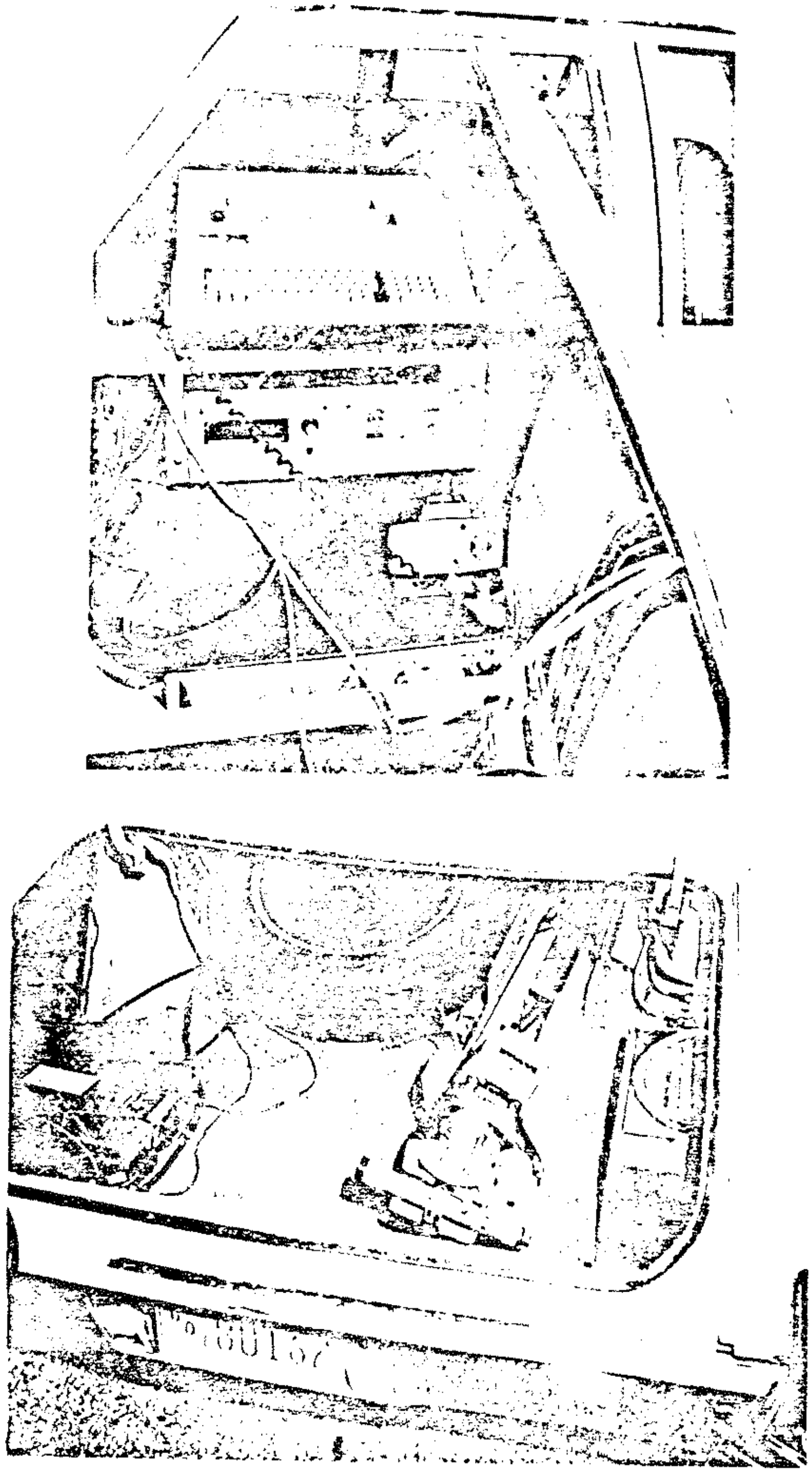


Figure 44   OPTICAL MEASUREMENT SYSTEM INSTALLATION IN VEHICLE

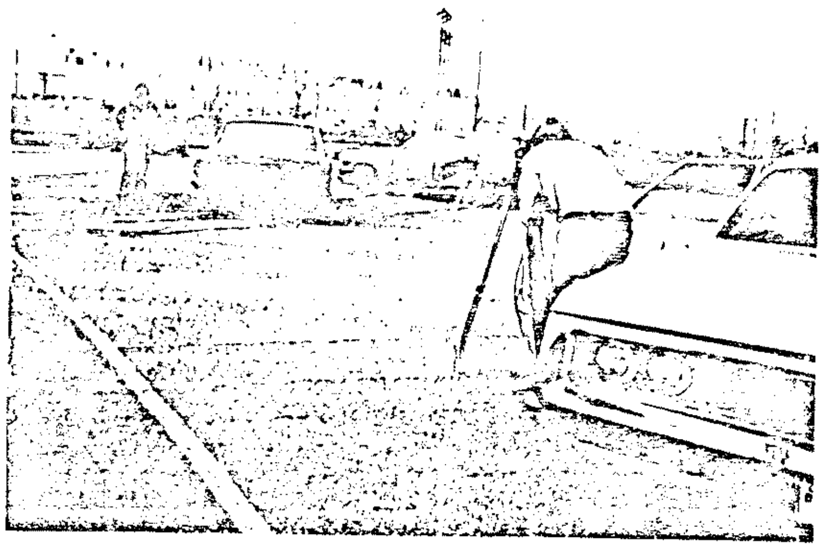


Figure 45 OPTICAL MEASUREMENT OF SCENE

During the course of prototype testing a number of equipment problems were uncovered. When installed in the vehicle it was found that the A-C equipment required more current than the vehicle alternator was capable of producing at idle. This resulted in a voltage drop to the DC to AC inverter sufficient to trip the low voltage protection breaker. It was found necessary to install a manual throttle in the vehicle to increase the engine idle speed and, thereby, prevent the excessive voltage drop.

It was also found that during use the Digital Angle Readout (DAR) would on occasion "hang up" and refuse to operate properly. Consultation with the supplier led to the identification of a defective 400 Hz oscillator as being the source of the "hang up". A new oscillator was ordered and was installed upon its arrival.

The final source of hardware difficulty in the measurement system proved to be the mobile telephone link between the computer terminal and the computer. A number of times while the system has been in use, the connection with the computer has been broken. It is suspected that the connection was broken by another mobile phone user attempting to use the channel over which the data were being transmitted.

An additional computer program was written on the time sharing system to accept data from the transit data processing program and produce a punched paper tape that can be used as an interface to the Calspan computer and plotting equipment. Thus, measured data from an accident scene, which are processed by the time sharing system, are put on paper tape for further processing by the Calspan computer center to generate a computer graphics display of the scene (see Section 3.3).

3.4.4 Field Testing of System

The accident investigation vehicle (1972 Chrysler 4 door sedan) was equipped with a two-way radio, and it was used as a "chase" vehicle in the Calspan Tri-Level Accident Study (TLAS) project* in order to permit field testing of the optical measurement system at actual accident scenes.

A number of opportunities for applications of the system were missed because of difficulties with hardware. Also, it was necessary to terminate some attempted applications. The following problems were involved.

(1) Application of the system was precluded during the early portion of the third quarter of the research program by a defective 400 Hz oscillator in the Digital Angle Readout (DAR). A replacement oscillator was obtained and installed, and the DAR now functions satisfactorily.

(2) Until quite late in the third quarter, installation in the vehicle of the "Porta Com" computer terminal purchased within this contract was held up by delays in the delivery of parts required for compatible interface circuitry. It was, therefore, necessary to borrow an "Execuport 300" computer terminal, with which the original interface was compatible, on a daily basis. On several occasions, the "Execuport 300" was not available when candidate cases were being investigated. It should be noted that the revised interface meets recently established industry standards for computer terminal peripherals and it should, therefore, be compatible with all new computer terminals.

---

*Contract Nos. DOT-HS-053-1-227 (NHTSA) and Calspan 7202-C-129 (MVMA).

(3) The investigation vehicle was disabled by electrical problems on several occasions. At the scene of one accident, the engine stalled and could not be restarted because of a "dead" battery. In an attempt to alleviate such problems, a high capacity alternator and a dual battery system were installed.

(4) Communication between the investigation vehicle and the fixed base computer has proven to be the major problem encountered during attempted system use. The mobile telephone that is currently used has caused a great deal of frustration of the system operator. Typical problems encountered include line noise, at times strong enough to make data transmission impossible, at other times only enough to mask an occasional transmitted character; random disconnects from the computer of unknown origin; and complaints from the New York Telephone Company. The mobile telephone system is in essence a party line system, and operation of the measurement equipment at an accident scene may require up to 1 1/2 hours of connection time with the time-sharing computer. This means, of course, that the mobile telephone channel being used by the measurement system operator must be totally dedicated to the system during that time period. It is suspected that some of the disconnects have been caused by other parties attempting to initiate a call on the channel in use. The telephone company has also received complaints from other subscribers in relation to the long duration lack of availability of the mobile telephone channel while the system is in operation.

As a result of the cited problems, it has been possible to obtain complete measurements with the optical system at the scene of only one actual highway accident to date. For that case, the measurement results are presented in Figure 46 . It should be noted that a total of forty (40) disconnects from the computer were encountered during the 1 1/2 hour measurement process in the displayed case.

Figure 46

GRAPHIC DISPLAY OF ACCIDENT INVESTIGATOR DATA

COLLISION AND TRAJECTORY

72-438 RT 5 8572-438 RT 5 955 FT SOUTH OF JUNB DR

MU = .7 DRY ASPHALT

1971 CHEVELLE 1971 TOYOTA

VEHICLE # 1 DATA

XC1" = 225.29998 FT.

YC1" = 7.16000 FT.

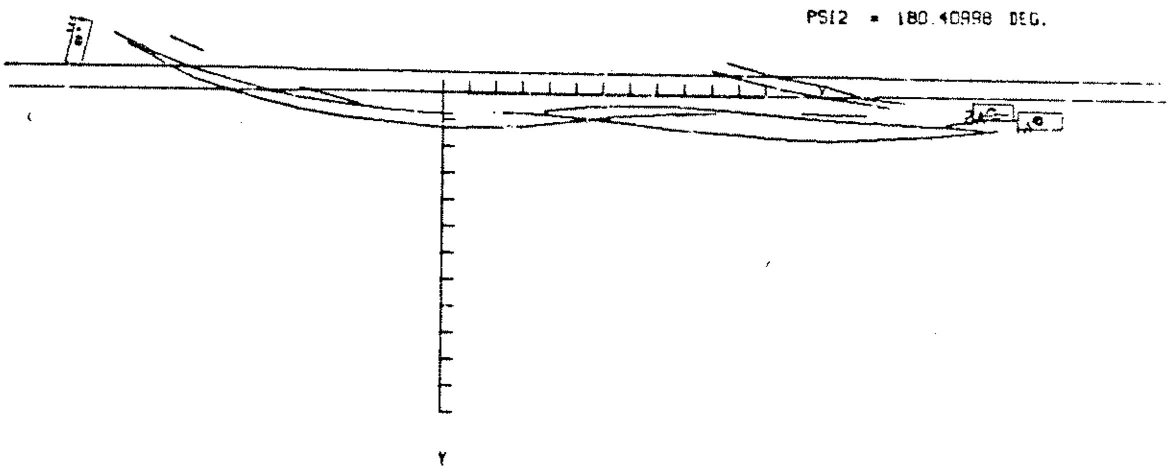
PSI1 = 179.75000 DEG.

VEHICLE # 2 DATA

XC2" = 207.01998 FT.

YC2" = 4.16000 FT.

PSI2 = 180.40998 DEG.



A dedicated radio frequency for data transmission appears to be the best solution to the indicated communications problem. This would eliminate the problems encountered with the mobile phone unit currently in use and would require no modifications of the existing data processing program. It would also leave open the possibility for complete reconstruction at the scene through the use of the remote terminal as an I/O device for the Calspan computer on which the SMAC program is run. However, because of the related need to obtain a dedicated data communications frequency (predicted to require a ninety day waiting period) and the necessary transceivers (estimated to cost $3000), exploratory tests of a "burst" transmission approach were performed, using borrowed equipment, over the existing mobile phone link.

The burst transmission approach entails operation of the measurement system in a local mode and storage of the transit data on magnetic tape. That is, instead of being transmitted to the computer, the data stream is diverted to a peripheral tape device. When the measurements have been completed, the link with the computer is made and the data transmitted from the tape. The obvious advantage of this mode of operation is that it minimizes the time during which the mobile telephone frequency is needed. The most severe potential disadvantage is that the data processing computer program may require extensive modifications to check for coding and transmission errors in a multiple record transmission mode. In addition, when measurement points are found to need retransmitting, the operators will have to locate the points in question at the scene in order to make corrections. This implies a possible necessity of marking and numbering all points that are measured. However, it is possible that an onboard computer graphics display can be used to serve as a means of checking for errors and for identification of points.

Arrangements were made with an area computer peripheral equipment vendor to borrow a remote terminal magnetic tape peripheral unit to attempt to utilize the "burst transmission" concept. Unfortunately, hardware difficulties developed during the test and consequently no firm statements regarding the compatibility of this technique with the existing system can be made at this time.

Enough experience was gained with the unit, however, to indicate that the device is compatible with the Porta Com terminal and it appears to be compatible with the interface unit. The remaining unresolved questions with this concept regard the expected decrease in the number of transmission errors and decreased frequency of disconnects, and the degree to which the data processing program will have to be modified to accept a continuous data stream. These can only be resolved through experience gained from a period of use.

The transit sighting system has proven to be sufficiently accurate for this application and while setup and sighting are somewhat time consuming, an accident scene can be measured and displayed in much less time than is required by traditional tape measurement methods.

The measurement system data processing computer program is functioning as intended; however, the limited use of the system by experienced investigators at actual accident scenes has pointed out needs for minor extensions of the program. Additional storage for tire mark evidence is considered necessary (and has been implemented to a limited extent), as well as additional identification codes for such scene descriptors as lane markings, signs, signal lights, etc. Additional built-in program checks may also be required to minimize the possibility of operator coding errors.

As the data processing computer program currently stands, it is approaching the core storage size limitations imposed by the present computer time sharing vendor. Thus, depending on the extent of changes deemed necessary, it may become necessary either to reprogram to minimize the required core storage or to investigate access to larger-capacity time sharing vendors.

In summary, the various components of the optical measurement system are operational and the overall system has been demonstrated to be capable of performing as desired but there remain a number of problem areas that must be solved before the system can be subjected to meaningful field trials and made effective for wide usage.

4.0 REFERENCES

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

2. Bartz, J. A., "A Three-Dimensional Computer Simulation of a Motor Vehicle Crash Victim," CAL Report No. VJ-2978-V-1, July 1971.

3. Greene, J. E., "Basic Research in Crashworthiness II - Side Impact Tests of Unmodified Vehicles," Calspan Report No. YB-2987-V-9, January 1973.

4. Miller, P. M. and Mayor, R. P., "Basic Research in Automobile Crashworthiness - Summary Report," CAL Report No. YB-2684-V-6, November 1969.

5. DeLeys, N. J., Segal, D. J., and Patten, J. S., "Underride/Override of Automobile Front Structures in Intervehicular Collisions, Volume 2, Car-to-Car Head-On Impacts," CAL Report No. VJ-2844-V-3, December 1971.

6. Emori, R. I., "Analytical Approach to Automobile Collisions." SAE Paper No. 680016, Automotive Engineering Congress, Detroit, January 8-12, 1968.

7. Collins, J. C. and Morris, J. L., Highway Collision Analysis, Charles C. Thomas, Publisher, Springfield, Illinois, 1967.

8. Krempel, G., "Research on Automobile Tires," Automobiltechnische Zeitschrift 69 (1967) 8.

APPENDIX 1

POST-PROCESSING OF COLLISION ROUTINE OUTPUTS TO GENERATE VEHICLE DAMAGE INDEX (VDI)

(Based on SAE J224A)

The classification system consists of seven characters, three numeric and four alphanumeric, arranged in a specific order. In the collision routine output, the classification should appear with each "DAMAGE SUMMARY" table as VDI = 0000000.

1. Direction of Principal Force at Impact

(Columns 1 and 2)

1.1 In outputs for each vehicle, scan AX_j, AY_j to find the maximum value of $[(AX_j)^2 + (AY_j)^2]$.

If more than one impact occurred (i.e., both $|AX_j|$ and $|AY_j|$ less than 1.0 g's subsequent to a maximum, followed by larger values) find the cited maximum quantity for each impact. Order multiple impacts according to the relative magnitudes of the values $[(AX_j)^2 + (AY_j)^2]$ (i.e., starting with the largest value, in order of decreasing magnitudes). Reject any points for which either $|AX_j| < 1.0$ or $|AY_j| < 1.0$.

1.2 For each maximum value determined in 1.1, let $\psi_P = \arctan AY_j/AX_j$, where $0 \leq \psi_P \leq 360°$. (Use sgn AY_j, sgn AX_j to determine quadrant.)

1.3 $N' = \dfrac{\psi_P}{30}$ rounded off to nearest integer.

1.4 $N = N' + 6$

1.5 For $N \leq 12$, proceed.
For $12 < N$, set $N = N - 12$.

1.6 For each impact, set columns 1 and 2 of classification to N (i.e., 01, 02, 03, ..., 10, 11, 12).

2. <u>Deformation Location and Classification Code</u>

(Column 3)

2.1 In the damage summary tables, determine the end points of each continuous angular range (i.e., ranges where $\Delta(\psi_{Bj}) = \Delta\psi$). Note that a continuous range across 0° will appear at the ends of the table. Designate end points as ψ_{D1} (beginning) and ψ_{D2} (end) of continuous <u>clockwise</u> sweeps, where $0 \leq \psi_{D1} \leq 360°$ and $0 \leq \psi_{D2} \leq 360°$. If, for any continuous angular range, $\psi_{D1} \equiv \psi_{D2}$, omit range from further VDI calculations.

2.2 Calculate the following 12 angles. All angles to be between zero and 360°.

ψ'_1 = arctan $0.500\, Y_S/X_F$	ψ'_7 = arctan $-0.500\, Y_S/X_R$
ψ'_2 = arctan Y_S/X_F	ψ'_8 = arctan $-\, Y_S/X_R$
ψ'_3 = arctan $2.702\, Y_S/X_F$	ψ'_9 = arctan $-1.754\, Y_S/X_R$
ψ'_4 = arctan $1.754\, Y_S/X_R$	ψ'_{10} = arctan $-2.702\, Y_S/X_F$
ψ'_5 = arctan Y_S/X_R	ψ'_{11} = arctan $-\, Y_S/X_F$
ψ'_6 = arctan $0.500\, Y_S/X_R$	ψ'_{12} = arctan $-0.500\, Y_S/X_F$

Note that the above angles lie in the following quadrants:

1st Quadrant:	ψ'_1, ψ'_2, ψ'_3
2nd Quadrant:	ψ'_4, ψ'_5, ψ'_6
3rd Quadrant:	ψ'_7, ψ'_8, ψ'_9
4th Quadrant:	ψ'_{10}, ψ'_{11}, ψ'_{12}

2.3 Adjustment of any "j" end points.* For each continuous angular range:

2.3.1 Set k = 1 $\left\{ \text{End points} = \psi'_{Dk}, X_{Dk}, Y_{Dk}, \text{ where } k = 1, 2 \right\}$

2.3.2 If ψ_{Dk} is not a "j" point, go to 2.3.7.

2.3.3 For ψ_{Dk} a "j" point and

(1) $\psi'_{11} \leq \psi_{Dk} \leq 360°$ or $0 \leq \psi_{Dk} \leq \psi'_2$, go to 2.3.4.

(2) $\psi'_5 \leq \psi_{Dk} \leq \psi'_8$, go to 2.3.5.

(3) $\psi'_2 < \psi_{Dk} < \psi'_5$ or $\psi'_8 < \psi_{Dk} < \psi'_{11}$, go to 2.3.6.

2.3.4 Set $\psi_{Dk} = \arctan \dfrac{Y_{Dk}}{X_F}$, go to 2.3.7.

2.3.5 Set $\psi_{Dk} = \arctan \dfrac{Y_{Dk}}{X_R}$, go to 2.3.7.

2.3.6 Set $\psi_{Dk} = \arctan \dfrac{Y_s}{X_{Dk}}$, go to 2.3.7.

2.3.7 For q = 1, set q = 2, return to 2.3.2.
For q = 2, proceed to 2.4.

2.4 Calculation of midpoints of ranges determined in 2.3.

(a) If range contains zero, go to 2.6.

(b) If range does not contain zero, proceed.

2.5 $\psi_M = \dfrac{\psi_{D1} + \psi_{D2}}{2}$, go to 2.7.

---

*"j" points are generated in the damaged region rather than deflected in from the periphery.

2.6 $$\psi_M = \frac{(\psi_{D1} - 360^\circ) + \psi_{D2}}{2}$$

For $\psi_M < 0$, set $\psi_M = \psi_M - 360^\circ$.

2.7 For multiple impacts (i.e., more than one value of N in 1.6, the values of N can be matched with values of ψ_M as follows:

$$\psi_M \approx 30N, \text{ find nearest values.}$$

For several values of N near one ψ_M (i.e., several impacts within one region of damage) select the N corresponding to the largest magnitude of $[(AX_j)^2 - (AY_j)^2]$.

2.8 Deformation Location

2.8.1 Non-corner damage

(1) For $\psi'_{11} \leq \psi_{D1} \leq 360^\circ$ or $0^\circ \leq \psi_{D1} \leq \psi'_2$

and

$\psi'_{11} \leq \psi_{D2} \leq 360^\circ$ or $0^\circ \leq \psi_{D2} \leq \psi'_2$,

set column 3 = F, set q = 4.2,

go to 3.1.

(2) For $\psi'_2 < \psi_{D1}$, $\psi_{D2} < \psi'_5$

set column 3 = R, set q = 4.2,

go to 3.2.

(3) For $\psi'_5 \leq \psi_{D1}$, $\psi_{D2} \leq \psi'_8$,

set column 3 = B, set q = 4.2,

go to 3.3.

(4) For $\psi'_8 < \psi_{D1}, \psi_{D2} < \psi'_{11}$, set column 3 = L, set q = 4.2, go to 3.4.

(If none of the above applies, corner damage is indicated.)

2.8.2 Corner Damage

(1) Set q = 4.1, k = 0.0.

(2) $\Delta = \psi_M - \psi_P$ (see Section 1.2 of this appendix for definition of ψ_P).

(3) $\psi_T = \psi_{D2} - \psi_M$.

(4) $-180° < \Delta, \psi_T < +180°$.

(5) For $0 \leq (|\Delta| - |\psi_T|)$, go to 2.9.2.

(6) For $|\Delta| \leq 12°$, go to 2.9.2.

2.9.1 (1) For $\psi'_{11} \leq \psi_M, \psi_P \leq 360°$, or $0 \leq \psi_M, \psi_P \leq \psi'_2$, set column 3 = F, go to 2.9.5.

(2) For $\psi'_2 < \psi_M, \psi_P < \psi'_5$, set column 3 = R, go to 2.9.5.

(3) For $\psi'_5 \leq \psi_M, \psi_P \leq \psi'_8$, set column 3 = B, go to 2.9.5.

(4) For $\psi'_8 < \psi_M, \psi_P < \psi'_{11}$, set column 3 = L, go to 2.9.5.

(5) If none of the above applies, set column 3 according to above tests of ψ_P only, set k = 1.0 sgn Δ, go to 2.9.5.

2.9.2 (1) For $\psi'_{11} \leq \psi_M \leq 360°$, or $0 \leq \psi_M \leq \psi'_2$, go to 2.9.3.

(2) For $\psi'_2 < \psi_M < \psi'_5$, set column 3 = R, to to 2.9.5.

(3) For $\psi'_5 \leq \psi_M \leq \psi'_8$, go to 2.9.4.

(4) For $\psi'_8 < \psi_M < \psi'_{11}$, set column 3 = L, go to 2.9.5.

2.9.3 (1) For $\psi'_{11} \leq \psi_M \leq 360°$ and

(a) $(Y_s + Y_{max}) \leq (X_F - X_{min})$, set column 3 = L, k = +1, go to 2.9.5.

(b) $(X_F - X_{min}) < (Y_s + Y_{max})$, set column 3 = F, go to 2.9.5.

(2) For $0 \leq \psi_M \leq \psi'_2$ and

(a) $(Y_s - Y_{min}) \leq (X_F - X_{min})$, set column 3 = R, k = -1, go to 2.9.5.

(b) $(X_F - X_{min}) < (Y_s - Y_{min})$, set column 3 = F, go to 2.9.5.

2.9.4 (1) For $\psi_M < 180°$ and

(a) $(Y_s - Y_{min}) \leq (X_{max} - X_R)$,
set column 3 = R, k = +1, go to 2.9.5.

(b) $(X_{max} - X_R) < (Y_s - Y_{min})$,
set column 3 = B, go to 2.9.5.

(2) For $180° < \psi_M$ and

(a) $(Y_s + Y_{max}) \leq (X_{max} - X_R)$,
set column 3 = L, k = -1, go to 2.9.5.

(b) $(X_{max} - X_R) < (Y_s + Y_{max})$,
set column 3 = B, go to 2.9.5.

(3) For $\psi_M = 180°$, set column 3 = B, go to 2.9.5.

2.9.5

Column 3	k	Set Column 4 To	Go To
F	-1	L	4.1
	0	-	3.1
	+1	R	4.1
R	-1	F	4.1
	0	-	3.2
	+1	B	4.1
B	-1	R	4.1
	0	-	3.3
	+1	L	4.1
L	-1	B	4.1
	0	-	3.4
	+1	F	4.1

3. Specific Horizontal Location of Deformation

(Column 4)

FRONT

3.1 For $\psi'_1 \leq \psi_{D1} < \psi'_{10}$, set column 4 = R, go to Table q.

For $\psi'_9 \leq \psi_{D1} < \psi'_{12}$, go to 3.1.1.

For $\psi'_{12} \leq \psi_{D1} \leq 360°$ or $0 \leq \psi_{D1} < \psi'_1$, go to 3.1.2.

3.1.1 For $\psi'_{12} < \psi_{D2} \leq 360°$ or $0 \leq \psi_{D2} < \psi'_1$, set column 4 = Y, go to Table q.

For $\psi'_1 < \psi_{D2} \leq \psi'_4$, set column 4 = D, go to Table q.

For $\psi'_{11} < \psi_{D2} \leq \psi'_{12}$, set column 4 = L, go to Table q.

3.1.2 For $\psi'_{12} < \psi_{D2} \leq 360°$ or $0 \leq \psi_{D2} \leq \psi'_1$, set column 4 = C, go to Table q.

For $\psi'_1 < \psi_{D2} \leq \psi'_4$, set column 4 = Z, go to Table q.

RIGHT SIDE

3.2 For $\psi'_{10} \leq \psi_{D1} \leq 360°$ or $0 \leq \psi_{D1} < \psi'_3$ } go to 3.2.1.

For $\psi'_3 \leq \psi_{D1} < \psi'_4$, go to 3.2.2.

For $\psi'_4 \leq \psi_{D1}$, set column 4 = B, go to Table q.

3.2.1 For $\psi'_2 < \psi_{D2} \leq \psi'_3$, set column 4 = F, go to Table q.

For $\psi'_3 < \psi_{D2} \leq \psi'_4$, set column 4 = Y, go to Table q.

For $\psi'_4 < \psi_{D2}$ set column 4 = D, go to Table q.

3.2.2 For $\psi'_3 < \psi_{D2} \leq \psi'_4$, set column 4 = P, go to Table q.

For $\psi'_4 < \psi_{D2}$ set column 4 = Z, go to Table q.

REAR (BACK)

3.3 For $\psi'_3 \leq \psi_{D1} < \psi'_6$, go to 3.3.1.

For $\psi'_6 \leq \psi_{D1} < \psi'_7$, go to 3.3.2.

For $\psi'_7 \leq \psi_{D1}$, set column 4 = L, go to Table q.

3.3.1 For $\psi'_5 < \psi_{D2} \leq \psi'_6$, set column 4 = R, go to Table q.

For $\psi'_6 < \psi_{D2} \leq \psi'_7$, set column 4 = Z, go to Table q.

For $\psi'_7 < \psi_{D2}$ set column 4 = D, go to Table q.

3.3.2 For $\psi'_6 < \psi_{D2} \leq \psi'_7$, set column 4 = C, go to Table q.

For $\psi'_7 < \psi_{D2}$ set column 4 = Y, go to Table q.

LEFT SIDE

3.4 For $\psi'_4 \leq \psi_{D1} < \psi'_9$, go to 3.4.1.

For $\psi'_9 \leq \psi_{D1} < \psi'_{10}$, go to 3.4.2.

For $\psi'_{10} \leq \psi_{D1}$, set column 4 = F, go to Table q.

3.4.1 For $\psi'_8 < \psi_{D2} \leq \psi'_9$, set column 4 = B, go to Table q.

For $\psi'_9 < \psi_{D2} \leq \psi_{10}$, set column 4 = Z, go to Table q.

For $\psi'_{10} < \psi_{D2} \leq 360°$ or $0 \leq \psi_{D2} < \psi'_3$ set column 4 = D, go to Table q.

3.4.2 For $\psi'_9 < \psi_{D2} \leq \psi'_{10}$, set column 4 = P, go to Table q.

For $\psi'_{10} < \psi_{D2} \leq 360°$ or $0 \leq \psi_{D2} < \psi'_3$ } set column 4 = Y, go to Table q.

4. General Type of Damage Distribution

(Column 6)

{ Note: Set Column 5 = E
Vertical Location, Not Applicable
Value E corresponds to the analytical assumptions. }

4.1 Corner Damage

{ Note: Isolated "j" points should be rejected in this calculation. }

Column 4*	Scanning Range	Scan Damage Range For	(DIS)
F	$\psi'_{11} \leq \psi_{Bi} \leq 360°$ and $0 \leq \psi_{Bi} \leq \psi'_2$	$(X)_{min}$	$X_F - X_{min}$
R	$\psi'_2 \leq \psi_{Bi} \leq \psi'_5$	$(Y)_{min}$	$Y_S - Y_{min}$
B	$\psi'_5 \leq \psi_{Bi} \leq \psi'_8$	$(X)_{max}$	$X_{max} - X_R$
L	$\psi'_8 \leq \psi_{Bi} \leq \psi'_{11}$	$(Y)_{max}$	$Y_S + Y_{max}$

	Column 6
$0 < (DIS) \leq 4.5$	S
$4.5 < (DIS) \leq 16.5$	E
$16.5 < (DIS)$	W

*For other entries in Column 4, go to 4.2.

4.2 Side or End Damage

Column 3	(DIS)
F	$(Y)\psi_{D2} - (Y)\psi_{D1}$
R	$(X)\psi_{D1} - (X)\psi_{D2}$
B	$(Y)\psi_{D1} - (Y)\psi_{D2}$
L	$(X)\psi_{D2} - (X)\psi_{D1}$

	Column 6
$0 < (DIS) \leq 16.0$	N
$16.0 < (DIS)$	W

5.0 Extent of Deformation

{Note: Isolated "j" points should be rejected in this calculation.}

Column 3	Scanning Range	Scan Damage Range For	(EXT)	Go To
F	$\psi'_{11} \leq \psi_{Bi} \leq 360°$ and $0 \leq \psi_{Bi} \leq \psi'_2$	$(X)_{min}$	$X_F - X_{min}$	5.1
R	$\psi'_2 \leq \psi_{Bi} \leq \psi'_5$	$(Y)_{min}$	$Y_S - Y_{min}$	5.2
B	$\psi'_5 \leq \psi_{Bi} \leq \psi'_8$	$(X)_{max}$	$X_{max} - X_R$	5.3
L	$\psi'_8 \leq \psi_{Bi} \leq \psi'_{11}$	$(Y)_{max}$	$Y_S + Y_{max}$	5.2

5.1 For Column 3 = F

	Column 7
$0 < (EXT) \leq 0.125\ X_F$	1
$0.125\ X_F < (EXT) \leq 0.250\ X_F$	2
$0.250\ X_F < (EXT) \leq 0.375\ X_F$	3
$0.375\ X_F < (EXT) \leq 0.500\ X_F$	4
$0.500\ X_F < (EXT) \leq 0.625\ X_F$	5
$0.625\ X_F < (EXT) \leq 0.846\ X_F$	6
$0.846\ X_F < (EXT) \leq 0.946\ X_F$	7
$0.946\ X_F < (EXT) \leq 1.046\ X_F$	8
$1.046\ X_F < (EXT)$	9

5.2 For Column 3 = R, L

	Column 7
$0 < (EXT) \leq 0.165\ Y_S$	1
$0.165\ Y_S < (EXT) \leq 0.253\ Y_S$	2
$0.253\ Y_S < (EXT) \leq 0.502\ Y_S$	3
$0.502\ Y_S < (EXT) \leq 0.751\ Y_S$	4
$0.751\ Y_S < (EXT) \leq 1.000\ Y_S$	5
$1.000\ Y_S < (EXT) \leq 1.249\ Y_S$	6
$1.249\ Y_S < (EXT) \leq 1.498\ Y_S$	7
$1.498\ Y_S < (EXT) \leq 1.747\ Y_S$	8
$1.747\ Y_S < (EXT)$	9

5.3 For Column 3 : B

	Column 7
$0 < (EXT) \leq -0.084\ X_R$	1
$-0.084\ X_R < (EXT) \leq -0.168\ X_R$	2
$-0.168\ X_R < (EXT) \leq -0.252\ X_R$	3
$-0.252\ X_R < (EXT) \leq -0.336\ X_R$	4
$-0.336\ X_R < (EXT) \leq -0.421\ X_R$	5
$-0.421\ X_R < (EXT) \leq -0.588\ X_R$	6
$-0.588\ X_R < (EXT) \leq -0.769\ X_R$	7
$-0.769\ X_R < (EXT) \leq -0.950\ X_R$	8
$-0.950\ X_R < (EXT)$	9

APPENDIX 2

SMAC INPUT FORMAT

Card No.	Program Variable	Analysis Variable	Definition	Units
1	T0	-	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
	DTPRN0	-	Output time interval	Seconds
	UVMIN	-	Vector velocity test for stop	Inches/Sec
	PSIDMN	-	Angular velocity test for stop	Degrees/Sec
	IVEH0	-	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	Inches/Sec

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

Program Variable	Analysis Variable	Definition	Units
CSTF2(1)	C_{21}	Vehicle 2, RF Tire Cornering Stiffness	Pounds/Radian
CSTF2(2)	C_{22}	Vehicle 2, LF Tire Cornering Stiffness	Pounds/Radian
CSTF2(3)	C_{23}	Vehicle 2, RR Tire Cornering Stiffness	Pounds/Radian
CSTF2(4)	C_{24}	Vehicle 2, LR Tire Cornering Stiffness	Pounds/Radian
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 $\neq$ 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 $\neq$ 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		-

INPUT DATA FORM

SIMULATION MODEL OF AUTOMOBILE COLLISIONS (SMAC)

RUN TITLE : ____________________

DATE : ____________

FIELD NUMBER

CARD NO.	1	2	3	4	5	6	7	8	9
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									

APPENDIX 3

VEHICLE 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 follow...g vehicles were included in the different categories.

1. Subcompact

Volkswagen Beetle
Toyota 1200
Datsun 1200
Vega
Pinto
Fiat 850

2. Compact

Maverick
Camero
Dar'
Ho. et

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 3-1

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	$Lb\text{-}Sec^2\text{-}in$
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

The symbols used in Table 3-1 are defined as follows:

a, b = Distances along vehicle fixed X axis from the total vehicle center of gravity to the center lines of the front and rear wheels, respectively, inches (both entered as positive quantities).

T = Tread at front and rear wheels (average), inches.

k^2 = Radius of gyration squared for complete vehicle in yaw, inches squared.

M = Total vehicle mass, $lb\text{-}sec^2/in$.

X_F, X_R = Distances along vehicle fixed X axis from the total vehicle center of gravity to the boundaries of the vehicle at the front and rear, respectively, inches (X_R is entered as a negative quantity).

Y_S = Distance along vehicle fixed Y axis from the total vehicle center of gravity to the boundary of the vehicle at the side (i.e., one-half of the total vehicle width), inches.

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.

TABLE 3-2

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}	-
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
ζ_V	5.0	In/Sec

The symbols used in Table 3-2 are defined as follows:

$(CSTF)_i$ = Cornering stiffness of the tire at wheel i for small slip angles, pounds/radian (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 a given height of contact).

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

μ = Friction coefficient for tangential forces between the two interacting bodies.

$\Delta\psi$ = Angular interval between radial vectors in contact determination, degrees.

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

λ = Acceptable error in pressure balance between the two bodies, lb/in (note that a constant height of the contact area is assumed). Also, for solution stability, ($K_{V_1}\Delta\rho$, $K_{V_2}\Delta\rho$) $\leq \lambda$.

ς_V = Minimum magnitude of relative velocity for which vehicle-to-vehicle friction forces are calculated, inches/sec.

APPENDIX 4

TIRE-GROUND FRICTION COEFFICIENT

The SMAC computer program includes a capability of simulating a linear decrement of tire-ground friction with the resultant speed of the tire in the ground plane. The existence of a decrement is indicated in literature on reconstruction (e.g., Reference 7) and an approximately linear decrement is indicated in some tire test data presented in the literature (e.g., Reference 8). This simulation option can, of course, be suppressed by setting the coefficient of the decrement, C_μ, to zero in the input data.

When this option is used, and measured stopping distance data are available from the scene, it is necessary to insure that the input values of μ_0 (tire-terrain friction coefficient at zero speed) and C_μ (coefficient of linear decrement of friction with speed) are compatible with the measured stopping distance data. For this purpose, the following relationship may be used:

$$\mu_0 = -\frac{1}{S C_\mu^2 g}\left[C_\mu V_0 + \ln(1 - C_\mu V_0)\right] \qquad (1)$$

where S = stopping distance, inches

V_0 = initial speed, inches/sec

g = 386.4 in/sec^2

Example:

S = 408 inches (34 feet)

V_0 = 492.8 inches/sec (28 MPH)

C_μ = 0.00015 (Estimated)

μ_0 = 0.82

For comparison purposes, a constant friction coefficient for the same stopping distance data would have the value:

$$\mu = \frac{V_o^2}{2gS} = \frac{242852}{315302} = 0.77 \qquad (2)$$

<u>Derivation of Equation (1):</u>

$$\mu = \mu_o (1 - C_\mu V), \text{ where } V = \text{in/sec}$$

$$\frac{dV}{dt} = -\mu g = \mu_o g (C_\mu V - 1)$$

$$\frac{dV}{(C_\mu V - 1)} = \mu_o g\, dt \,, \quad \frac{1}{C_\mu}\int_{V_o}^{V} \frac{C_\mu dV}{(C_\mu V - 1)} = \int_0^t \mu_o g\, dt$$

$$V = \frac{1}{C_\mu} - \frac{1}{C_\mu}(1 - C_\mu V_o)e^{C_\mu \mu_o g t}$$

$$S = \frac{t}{C_\mu} + \frac{1}{C_\mu \mu_o g}\left(V_o - \frac{1}{C_\mu}\right)\left(e^{C_\mu \mu_o g t} - 1\right)$$

For $V = 0$, $t = -\frac{1}{C_\mu \mu_o g} \ln (1 - C_\mu V_o) = \frac{V_o}{\mu_o g} + C_\mu S$

$$\boxed{\mu_o = -\frac{1}{C_\mu^2 S g}\left[C_\mu V_o + \ln(1 - C_\mu V_o)\right]}$$

APPENDIX 5

GRAPHICS DISPLAY PROGRAM - LOGIC DESCRIPTION

The Graphics Display program for accident reconstruction consists of a small main program with many subroutines. This appendix will describe the function and the program logic of each subroutine.

1. Accident Reconstruction Graphics Tape

The Accident Reconstruction (SMAC) program creates, together with the detailed time history of the event, a special graphics tape for use by the graphics program. This tape contains vehicle positions, speeds, orientations, tire tracks, damage tables, and titles. The tape consists of a standard IBM 370 label, an initial record containing various initial vehicle parameters, a number of time history records tabulating the tire tracks, a final record containing various final vehicle parameters, two records containing the vehicle damage indices, and sixteen records containing the vehicle damage tables. A detailed description of the graphics tape follows.

INITIAL RECORD 64 WORDS

WORDS	TYPE	SYMBOL	PURPOSE	Vehicle
1-40	A	TITLE	Title of Run	
41-43	A	DATE	Date of Run	
44	F	FVEH	# of Vehicles this Run	
45	F	XC10P	Initial X-Position	Vehicle #1
46	F	YC10P	Initial Y-Position	Vehicle #1
47	F	PSI10	Initial Yaw Angle	Vehicle #1
48	F	PSI1D0	Initial Yaw Velocity	Vehicle #1
49	F	U10	Initial U-Velocity	Vehicle #1
50	F	V10	Initial V-Velocity	Vehicle #1
51	F	XF1	Distance CG to Front	Vehicle #1
52	F	XR1	Distance CG to Rear	Vehicle #1
53	F	YS1	Distance CG to Sides	Vehicle #1
54	F	XC20P	Initial X-Position	Vehicle #2
55	F	YC20P	Initial Y-Position	Vehicle #2
56	F	PSI20	Initial Yaw Angle	Vehicle #2
57	F	PSI2D0	Initial Yaw Velocity	Vehicle #2
58	F	U20	Initial U-Velocity	Vehicle #2
59	F	V20	Initial V-Velocity	Vehicle #2
60	F	XF2	Distance CG to Front	Vehicle #2
61	F	XR2	Distance CG to Rear	Vehicle #2
62	F	YS2	Distance CG to Sides	Vehicle #2
63	F	T0	Initial Time	
64	F	DESPS0	Damage Table Angular Spacing	

TIRE TRACK RECORDS (as many as required) 27 WORDS EACH

WORDS	TYPE	SYMBOL	FUNCTION	
1	I	ITCØL	ITCØL = 1 means collision has occurred	
2	I	JYFLAG	JYFLAG = 1 means this is the last tire track record	
3	F	T	Time, Sec.	Vehicle #1
4	F	RF1SKD	1 = Roll, -1 = Skid (Right Front)	
5	F	LF1SKD	1 = Roll, -1 = Skid (Left Front)	
6	F	RR1SKD	1 = Roll, -1 = Skid (Right Rear)	
7	F	LR1SKD	1 = Roll, -1 = Skid (Left Rear)	
8	F	RF2SKD	1 = Roll, -1 = Skid (Right Front)	Vehicle #2
9	F	LF2SKD	1 = Roll, -1 = Skid (Left Front)	
10	F	RR2SKD	1 = Roll, -1 = Skid (Right Rear)	
11	F	LR2SKD	1 = Roll, -1 = Skid (Left Rear)	
12	F	V1RFX	X-Position (Right Front)	Vehicle #1
13	F	V1RFY	Y-Position (Right Front)	
14	F	V1LFX	X-Position (Left Front)	
15	F	V1LFY	Y-Position (Left Front)	
16	F	V1RRX	X-Position (Right Rear)	
17	F	V1RRY	Y-Position (Right Rear)	
18	F	V1LRX	X-Position (Left Rear)	
19	F	V1LRY	Y-Position (Left Rear)	
20	F	V2RFX	X-Position (Right Front)	Vehicle #2
21	F	V2RFY	Y-Position (Right Front)	
22	F	V2LFX	X-Position (Left Front)	
23	F	V2LFY	Y-Position (Left Front)	
24	F	V2RRX	X-Position (Right Rear)	
25	F	V2RRY	Y-Position (Right Rear)	
26	F	V2LRX	X-Position (Left Rear)	
27	F	V2LRY	Y-Position (Left Rear)	

ENDING RECORD 32 WORDS

WORDS	TYPE	SYMBOL	FUNCTION	
1	I	IRNG1	# of Damage Ranges	Vehicle #1
2	I	IK1	# of Damage Points	
3	I	JFLAG1	0 = Program Time Out 1 = P.O.R.	
4	I	NWRDB1	Not Used	
5	I	NWRDE1	Not Used	
6	F	TØV1	Elapsed Time	
7	F	XCP1	Final X-Position	
8	F	YCP1	Final Y-Position	
9	F	PSI1TM	Final Yaw Angle	
10	F	TCØL	Time of Collision	
11	F	XCT2C	Collision X-Position	
12	F	YCT1C	Collision Y-Position	
13	F	PSI1CT	Collision Yaw Angle	
14	F	U1CT	Collision U-Velocity	
15	F	V1CT	Collision V-Velocity	
16	F	PSIDCT	Collision Yaw Velocity	
17	I	IRNG2	# of Damage Ranges	
18	I	IK2	# of Damage Points	
19	I	JFLAG2	0 = Program Time Out 1 = P.O.R.	
20	I	NWRDB2	Not Used	
21	I	NWRDE2	Not Used	
22	F	TØV2	Elapsed Time	
23	F	XCP2	Final X-Position	
24	F	YCP2	Final Y-Position	
25	F	PSI2TM	Final Yaw Angle	
26	F	TCØL	Time of Collision	
27	F	XCT2C	Collision X-Position	

ENDING RECORD (continued)

WORDS	TYPE	SYMBOL	FUNCTION
28	F	YCT2C	Collision Y-Position
29	F	PSI2CT	Collision Yaw Angle
30	F	U2CT	Collision U-Velocity
31	F	V2CT	Collision V-Velocity
32	F	PS2DCT	Collision Yaw Velocity

VEHICLE DAMAGE INDEX RECORD (Vehicle #1) 70 WORDS

WORDS	TYPE	SYMBOL	FUNCTION
1-10	A	AVARN1 (1:10)	1st Character for 10 VDI's
11-20	A	AVARN1 (11:20)	2nd Character for 10 VDI's
21-30	A	AVARN1 (21:30)	3rd Character for 10 VDI's
31-40	A	AVARN1 (31:40)	4th Character for 10 VDI's
41-50	A	AVARN1 (41:50)	5th Character for 10 VDI's
51-60	A	AVARN1 (51:60)	6th Character for 10 VDI's
61-70	A	AVARN1 (61:70)	7th Character for 10 VDI's

VEHICLE DAMAGE INDEX RECORD (Vehicle #2) 70 WORDS

WORDS	TYPE	SYMBOL	FUNCTION
1-10	A	AVARN2 (1:10)	1st Character for 10 VDI's
11-20	A	AVARN2 (11:20)	2nd Character for 10 VDI's
21-30	A	AVARN2 (21:30)	3rd Character for 10 VDI's
31-40	A	AVARN2 (31:40)	4th Character for 10 VDI's
41-50	A	AVARN2 (41:50)	5th Character for 10 VDI's
51-60	A	AVARN2 (51:60)	6th Character for 10 VDI's
61-70	A	AVARN2 (61:70)	7th Character for 10 VDI's

VEHICLE DAMAGE TABLES (Polar Coordinates) 16 RECORDS OF 90 WORDS

RECORD	DESCRIPTION			
VDT #1	90 WORDS	TYPE F	1st 90 Radiuses	Vehicle #1
VDT #2	90 WORDS	TYPE F	2nd 90 Radiuses	
VDT #3	90 WORDS	TYPE F	3rd 90 Radiuses	
VDT #4	90 WORDS	TYPE F	4th 90 Radiuses	
VDT #5	90 WORDS	TYPE F	1st 90 Angles	
VDT #6	90 WORDS	TYPE F	2nd 90 Angles	
VDT #7	90 WORDS	TYPE F	3rd 90 Angles	
VDT #8	90 WORDS	TYPE F	4th 90 Angles	
VDT #9	90 WORDS	TYPE F	1st 90 Radiuses	Vehicle #2
VDT #10	90 WORDS	TYPE F	2nd 90 Radiuses	
VDT #11	90 WORDS	TYPE F	3rd 90 Radiuses	
VDT #12	90 WORDS	TYPE F	4th 90 Radiuses	
VDT #13	90 WORDS	TYPE F	1st 90 Angles	
VDT #14	90 WORDS	TYPE F	2nd 90 Angles	
VDT #15	90 WORDS	TYPE F	3rd 90 Angles	
VDT #16	90 WORDS	TYPE F	4th 90 Angles	

The last record on the tape is 90 words of -9999. To signify the end, this record is not read.

2. Data Structures and the Set-up Subroutine

All plotting data is stored in a special data structure. For any line drawing to be plotted, there will be two arrays containing the X and Y coordinates and a special identifier array specifying each line segment in the drawing in terms of the number of points and the type of line, be it solid, dashed, or phantom. Organizing all line drawing data in this way enables the same plotting techniques to be used for vehicle outlines, tracks, damage areas, etc. For example, the right front tire track of Vehicle #1 is stored in the following tables:

V1RFX	V1RFY	IV1RF
X_1	Y_1	IT
X_2	Y_2	IN
X_3	Y_3	IT
X_4	Y_4	IN
X_5	Y_5	IT
X_6	Y_6	IN
.	.	
.	.	
.	.	

(X_1, X_2, ...) are the X-coordinates of the right front tire contact point.

(Y_1, Y_2, ...) are the Y-coordinates of the right front tire contact point.

IT = {
1 - No more line segments for this line drawing.
2 - This line segment is a solid line.
3 - This line segment is a dashed line.
4 - This line segment is a phantom line.

IN = # of pairs of coordinates coming up for this line segment.

As was pointed out in the graphics tape discussion, the graphics tape supplies the X and Y coordinates of the tire contact points. However, the identifier array is not supplied. Only an array specifying if the tire is rolling or skidding is supplied. Thus, a special subroutine SETUP is provided to build the identifier array fo each tire.

```
CALL SETUP (RF1SKD, IV1RF, JTRACK)
```

where:
- RF1SKD = Array identifying if wheel is rolling or skidding.
- IV1RF = Identifier array to be built.
- JTRACK = # of entries in the RF1SKD array.

Subroutine SETUP scans down through the rolling/skidding array and builds an identifying array in the previously defined format.

3. Format and Layout of the Accident Scene

As with all mapping operations, a scale factor must be determined that converts X and Y values in the accident scene coordinate system to "plotter inches" in the plot-paper coordinate system. Also, displacements from the corner of the paper must be determined so as to properly place the accident scene origin such that all the vehicles, the collision point, and the origin are in the prescribed picture frame. A special subroutine, LAYOUT, accomplishes this.

```
CALL LAYOUT (XC10P, YC10P, XC20P, YC20P, XCP1,
             YCP1, XCP2, YCP2, XCT1C, YCT1C,
             XCT2C, YCT2C, XLONG, YLONG, SFX,
             SFY, X0, Y0)
```

where: (XC10P, YC10P, XC20P, YC20P) = Initial X and Y positions of the vehicles.

(XCP1, YCP1, XCP2, YCP2) = Final X and Y positions of the vehicles.

(XCT1C, YCT1C, XCT2C, YCT2C) = Collision X and Y positions of the vehicles.

(XLONG, YLONG) = Size of picture frame.

(SFX, SFY) = Scale factors.

(X0, Y0) = Axis offset from lower right corner of picture frame.

Subroutine LAYOUT determines the total span of points on either side of the origin and uses the maximum of the X-span or Y-span to determine the scale factor (twenty feet is added to the span to insure that the vehicle bodies fit in the picture frame). At the same time, the distance from the lower right hand corner of the rectangle formed by the X and Y spans to the origin is tabulated, and the proper offset from the lower right picture frame corner to the origin is calculated. The offset is adjusted to center the picture in both the X and Y directions.

The original intention was to provide the capability to adjust X and Y linearity through specification of XLONG and YLONG and hence SFX and SFY. However, at this stage, the graphics program assumes a square picture frame and SFX equals SFY.

4. <u>Line Drawing Routines</u>

Three similar line drawing subroutines exist to draw solid, dashed, and phantom lines.

```
      ⎧ SOLID  ⎫
CALL  ⎨ DASHED ⎬ (XDATA, YDATA, LØCATE, NUMBER, SFX, SFY)
      ⎩ PHNTOM ⎭
```

where: (XDATA, YDATA) = Arrays of X and Y coordinates.
LØCATE = Displacement into array at which to start.
NUMBER = Number of points to draw.
(SFX, SFY) = Scale factor.

The pen is moved to the location specified by the table entry at LOCATE, and a solid, dashed, or phantom line is drawn through as many points as are specified by number. X and Y coordinate data are scaled by the scale factor.

5. Track Laying Subroutine

The plotting of a long list of tire track points is accomplished by the subroutine TRACK.

CALL TRACK (XDATA, YDATA, IDATA, SFX, SFY)

where: (XDATA, YDATA) = Arrays of X and Y coordinate points.
IDATA = Identifier array built for above arrays.
(SFX, SFY) = Scale factor.

The TRACK subroutine examines pairs of entries in the IDATA array for number of points and line type and makes the appropriate call to the SOLID, DASHED, or PHNTØM routines. This process continues down through the IDATA array until an IT = 1 if found; this causes an exit from TRACK. The end result is dashed lines for rolling wheels or solid lines for skidding wheels.

6. Transformation Subroutine

Vehicles, including those with damaged areas, have line structures defined in the vehicle's own coordinate system. If they are to be placed and rotated in accident scene coordinate space, the body coordinate system has to be translated and rotated by an Euler Transform. This is accomplished by Subroutine TFØRM.

```
CALL TFØRM (XDATA, XDATAT, YDATA,
           YDATAT, N, PSI, X, Y)
```

where: (XDATA, YDATA) = Body coordinate system points.

(XDATAT, YDATAT) = Above data transformed into accident scene system.

N = # of coordinate pairs.

PSI = Yaw angle.

(X, Y) = Position in accident scene space to place the drawing.

For all N points, TFØRM does the following:

$$\begin{bmatrix} XDATAT \\ YDATAT \end{bmatrix} = \begin{bmatrix} C\emptyset S(PSI) & -SIN(PSI) \\ SIN(PSI) & C\emptyset S(PSI) \end{bmatrix} \cdot \begin{bmatrix} XDATA \\ YDATA \end{bmatrix} + \begin{bmatrix} X \\ Y \end{bmatrix}$$

7. Drawing of Vehicles at Collision

Plotting of the collision position of the vehicles is accomplished by Subroutine BCAR.

```
CALL BCAR (XF, XR, YS, XC0, YC0, PSI0, SFX, SFY)
```

where: (XF, XR, YS) = Vehicle size definition parameters.

(XC0, YC0) = Collision X and Y positions.

PSI0 = Collision yaw angle.

(SFX, SFY) = Scale factor.

Subroutine BCAR takes the size parameters and builds an XDATA and YDATA list for the vehicle outline. Subroutine TFORM is used to transform these lists into accident scene space, based on the supplied collision positions and orientations. Then the PHNTØM subroutine is called to plot the vehicle outlines. The triangular vehicle direction symbol and the vehicle identifier symbols are drawn by a special Subroutine IDENT. This subroutine executes several symbol calls to plot this data.

8. <u>Developing the Damaged Vehicle Line Structure</u>

The final batch of records on the graphics tape is the damage tables, expressed in polar coordinates. Each damaged area on the vehicle, delineated by the two intersections of the "dent" with the normal vehicle outline, will contain a set of radiuses and angles. Obviously the worst case would be a vehicle damaged all around the perimeter; the program allows up to 360 polar coordinate points to be specified. Subroutine DENTS inspects these tables and builds a plot data table in the standard format that includes the normal vehicle outline excluding the damaged areas, and damaged area, both in solid lines, and the normal vehicle outline across the damaged areas in dashed lines.

```
CALL  DENTS (DDATA, RDATA, IDATA, XDATA,
             YDATA, XF, XR, YS, DELPSØ)
```

where:	DDATA	= Polar angles of damage tables.
	RDATA	= Radii of damage tables.
	IDATA	= Plotting identifier array to be built.
	(XDATA, YDATA)	= X and Y coordinates of to be developed line structure.
	(XF, XR, YS)	= Vehicle size definition parameters.
	DELPSØ	= Angular spacing between polar coordinates.

Typically, if there is more than one damage area on a vehicle, these damage coordinates will be concatenated back-to-back in the damage table. The empty locations in the table will be filled with -1. To build the plot data table in the previously defined structure, the end points of the damaged areas must be determined. This is accomplished by comparing adjacent angle entries with the spacing DELPSØ; those whose difference is greater than DELPSØ are end points and they are loaded into a special end point table. The X and Y positions of each of these end points is determined. Using the basic vehicle dimensions, the cartesian and polar coordinates of the corners are determined. Finally, a new end point table, of the X and Y coordinates, is created so that the intersection points of the damaged areas with the vehicle outline is known.

At this point, a laborious but straightforward sorting process is performed that builds an X-Y table with association identifier array that records the perimeter of the vehicle in terms of solid lines (no damage) and dashed lines (damaged areas). The actual damage data is appended on the end of the developed tables. Thus, as in previous examples, an X-array and a Y-array of plotting points is generated with an associated identifier array showing what types and how many line segments are in the tables.

9. Drawing the Vehicle Final Positions

With the data structure filled in by the DENTS subroutine, the final positions of the vehicles may be drawn.

```
CALL ENDCAR (DDATA, RDATA, XF, XR, YS, XCP,
             YCP, PSITM, SFX, SFY)
```

where:

DDATA	=	Polar angles of damage tables.
RDATA	=	Radii of damage tables.
(XF, XR, YS)	=	Vehicle size definition parameters.
(XCP, YCP)	=	Final X and Y position of vehicle.
PSITM	=	Final yaw angle of vehicle.
(SFX, SFY)	=	Scale factor.

Subroutine ENDCAR calls DENTS to build the plot data tables, calls TFORM to translate and rotate the figure to the defined final position, then calls SOLID or DASHED to draw the figure in the same way that TRACK does. The vehicle identification marks are drawn in Subroutine IDENT.

10. Main Program

The Main Program is quite straightforward. First, the graphics tape is read all the way through and the track data is reformatted by the SETUP Subroutine. The scale factors are determined by the LAYØUT routine. All the printed data is placed on the page by numerous calls to PLOT, SYMBOL, and NUMBER, using data from the graphics tape. The collision positions of the automobiles are plotted via the BCAR routine. The tracks are laid by eight calls to the TRACK Subroutine. The final vehicle positions are plotted by calls to ENDCAR. An axis is drawn with 10 foot ticmarks, and the vehicles are identified by calls to IDENT.

Use of the Accident Reconstruction Graphics Display program is very easy - the user need only supply a graphics tape and one data card containing the variables XLONG and YLONG. XLONG and YLONG are the physical size of the picture frame of the accident scene. To plot the reconstruction on an 8 1/2" x 11" page, specify XLONG and YLONG to be six inches; this leaves ample room for the discriptive script to be plotted around the frame. At this writing, XLONG must equal YLONG.

DATA CARD FORMAT	Columns 1-8	XLONG
	Columns 9-16	YLONG

All plotting is sized to XLONG and YLONG. To produce a large blowup on a 36" plotter, merely increase XLONG and YLONG to 17".

APPENDIX 6

DATA PROCESSING PROGRAMS

A number of programs and data storage files are employed in the transit data processing software system. The basic data processing program accepts data from either the transit hardware or from a symbolic data storage file, then checks it for errors and immediately writes it to a binary file named "SAVTRN" to prevent loss of data in the event of a disconnect. The program then categorizes the data and stores it in a symbolic file, "CØUT", for later processing into the plot tape format.

In the event of a disconnect, the binary file "SAVTRN" is converted into symbolic data in a format identical to that produced by the transit hardware by the program "BINSYM", and then reread into the processing program.

The program "PLTØUT" converts the processed transit data into a format suitable for subsequent plotting of the accident scene on the Calspan plotting facility.

A block diagram of the transit data processing system is shown in Figure 6-1, and source listings of the program follow.

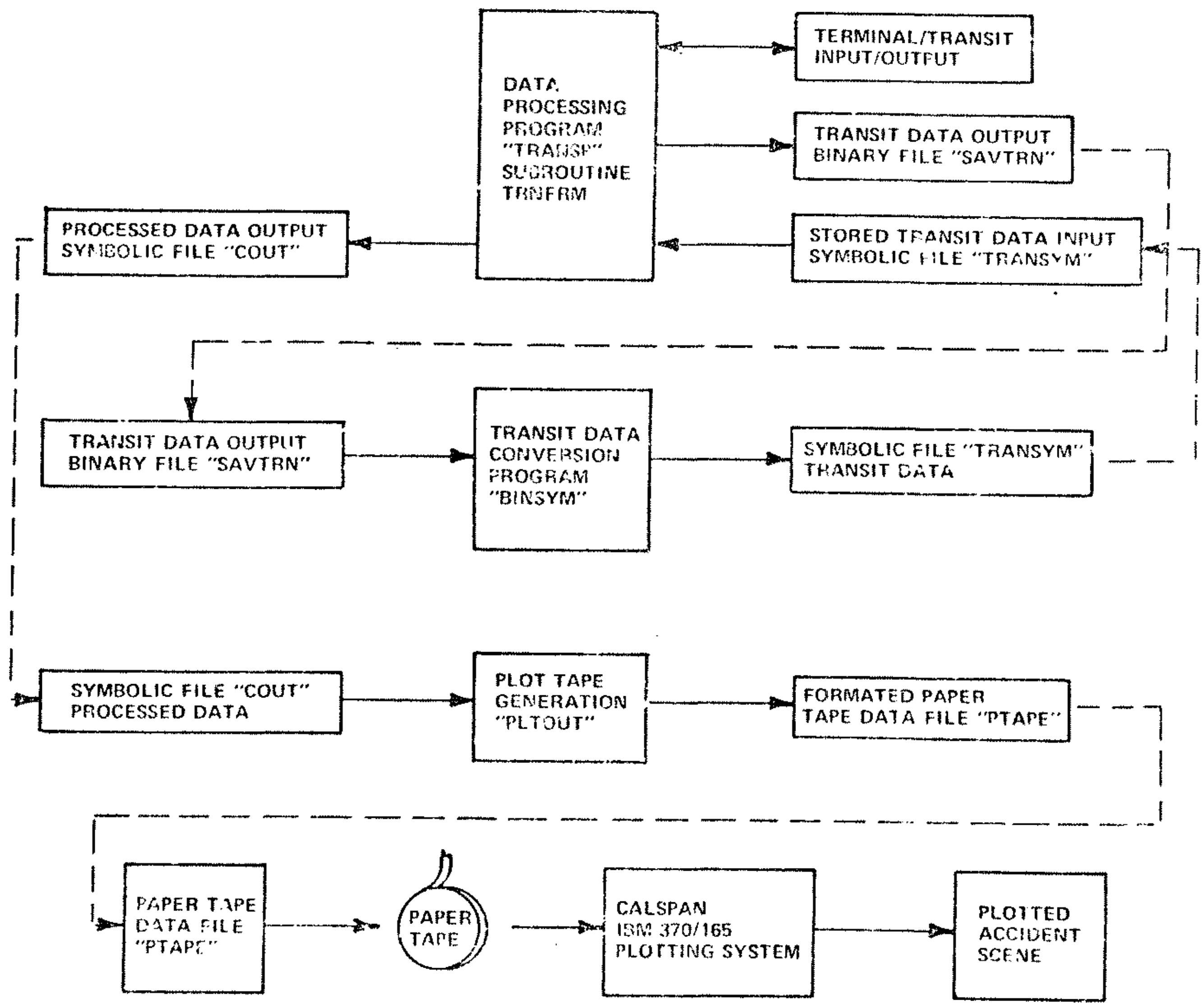


Figure 6.1 TRANSIT DATA PROCESSING SYSTEM BLOCK DIAGRAM

```
      COMMON /S/ VR(2,3,4,3),VT(2,4,3,35),P(2,3,2,25),
     1           R(3,3,4,25),TIL(36),VDI(8),AV1,AV2,SFRC(20)
      COMMON /IS/ ICNT(2,4),IT(2,4,2,35),ICODE(10),ICARD(20),
     1           ID(2,2,25),IDCT(2,2),IR(3,4,25),IRCT(3,4)
      DIMENSION DUM(1938),IDUM(854)
      EQUIVALENCE (VR(1,1,1,1),DUM(1)),(ICNT(1,1),IDUM(1))
      COMMON ET,EB,AZ,DEL,XT,YT,ZT,RT,XTO,YTO,ZTO,RTO,PSI
      DIMENSION IPTCD(5),IRHCD(5)
      DATA IPTCD/'S   ','E   ','C   ','P   ','    '/
      DATA IRHCD/'R   ','A   ','B   ','F   ','    '/
      DIMENSION COM(30)
      DATA RTS/1.0/
      DATA COMMA/','/,AMX/360./,NREC/0/
      DO 5 K=1,2176
    5 DUM(K) = 0.0
      DO 4 K=1,1014
    4 IDUM(K) = 0
      DPR = 57.2957
      CALL TOD(IMIN,IHR,IMON,IDAY,IYR)
      WRITE(1,1100) IMON,IDAY,IYR,IHR,IMIN
 1100 FORMAT(5X,'ACCIDENT RECONSTRUCTION',20X,I2,'/',I2,'/',I2,/,
     1  5X,'TRANSIT DATA PROCESSING PROGRAM',15X,I2,':',I2,//)
      WRITE(1,3001)
 3001 FORMAT(' INPUT TITLE ')
      READ(1,3002) (TTL(I),I=1,36)
 3002 FORMAT(18A4)
      WRITE(1,1101)
 1101 FORMAT(' TRANSIT DATA WILL BE STORED ON TEMPORARY STORAGE'
     1  ' FILE SAVTRN' / ' DO YOU WISH TO INPUT FROM FILE FIRST?')
      CALL YN(IOK)
      IDV = 2
      IF(IOK.EQ.0) GO TO 13
      CALL WOPENS(3,1)
      IDV = 3
      GO TO 10
   13 WRITE(1,1000)
 1000 FORMAT(//5X,'BEGIN TRANSMITTING TRANSIT DATA')
   10 CALL BUFFER IN (IDV,0,ICARD,15,J,K)
      IF(J.NE.3) GO TO 14
      WRITE(1,1300)
 1300 FORMAT(' DONE WITH FILE READ')
      IDV = 2
      GO TO 13
   14 DECODE(60,1001,ICARD,NC) I1,I2,I3,I4,I5
 1001 FORMAT(5I1)
      IF(I1.EQ.9.AND.I2.EQ.9.AND.I3.EQ.9) GO TO 999
      DECODE(60,1003,ICARD,NC) (COM(I),I=1,29)
 1003 FORMAT(30A1)
      DO 5 K=6,29,6
      IF(COM(K).EQ.COMMA) GO TO 5
```

```
      WRITE(1,1004) K
 1004 FORMAT(' TRANSMISSION ERROR -- CHARACTER ',I2,' IS NOT A COMMA',
     1 /' TRANSMIT AGAIN')
      GO TO 10
    5 CONTINUE
      DECODE(60,1002,ICARD,NC) IC,ELT,AZT,AZB,ELB
 1002 FORMAT(I6,3F6.2,F5.2)
      IF(ELT.GT.AMX.OR.ELB.GT.AMX.OR.AZT.GT.AMX.OR.AZB.GT.AMX)
     1      GO TO 6
      GO TO 7
    6 WRITE(1,1005)
 1005 FORMAT(' ERROR - ANGLE GREATER THAN 360 DEGREES-TRANSMIT AGAIN')
      GO TO 10
    7 IF(ELT.LT.110.0.AND.ELT.GT.45.0) GO TO 8
      WRITE(1,1006)
 1006 FORMAT('  CHECK TOP ELEVATION - EITHER > 110 DEG OR < 45 DEG'/
     1  '    IS THIS OK?  TYPE Y OR N')
      CALL YN(IOK)
      IF(IOK.EQ.1) GO TO 8
    9 WRITE(1,1007)
 1007 FORMAT('  TRANSMIT AGAIN')
      GO TO 10
    8 IF(ELB.LT.110.0.AND.ELB.GT.45.0) GO TO 11
      WRITE(1,1008)
 1008 FORMAT('  CHECK BOTTOM ELEVATION - EITHER >110 DEG OR <45 DEG'/
     1  '  IS THIS OK?  TYPE YES OR NO'  )
      CALL YN(IOK)
      IF(IOK.EQ.1) GO TO 11
      GO TO 9
   11 IF(ABS(AZT-AZB).LT.2.0) GO TO 12
      WRITE(1,1009)
 1009 FORMAT(' DIFFERENCE IN TOP AND BOTTOM AZIMUTH READINGS'
     1 ' IS > 2 DEG'/' IS THIS OK? TYPE Y OR N' )
      CALL YN(IOK)
      IF(IOK.EQ.0) GO TO 9
   12 CALL OPENRX(4,3,'/SAVTRN/')
      NREC = NREC+1
      IAD = 30*(NREC-1)+2
      CALL WDISC(4,1,NREC,1)
      CALL WDISC(4,IAD,COM,30)
      CALL CLOSE(4)
      ET = ELT/DPR
      EB = ELB/DPR
      AZ = .5*(AZT+AZB)/DPR
      DEL = ET-EB
      IF(I1.EQ.9) GO TO 900
      GO TO (100,200,300,400),I1
  900 GO TO(901,902,903,904),I3
  901 RTO = 5.*SIN(EB)*SIN(ET)/SIN(DEL)
      XTO = RTO*COS(AZ)
```

```
      YTO = -RTO*SIN(AZ)
      ZTO = HTLB+RTO*COS(EB)/SIN(EB)
      GO TO 10
  902 CALL TRNCRD
      Y = YT-YTO
      X = XT-XTO
      PSI = ATAN2(Y,X)
      CALL TRNFRM(XS2,YS2,ZS2)
      XT = XTO
      YT = YTO
      ZT = ZTO
      CALL SPCCRD(XS1,YS1,ZS1)
      GO TO 10
  903 WRITE(1,1021)
 1021 FORMAT(' INPUT NEW LOWER BULB HEIGHT')
      HTLBO = HTLB
      READ(1,1022) HTLB
 1022 FORMAT(F10.0)
      ZTO = ZTO-HTLBO+HTLB
      GO TO 13
  904 OUTPUT(1), 'ILLEGAL CODE - INPUT AGAIN'
      GO TO 10
  100 CALL TRNFRM(VR(I2,1,I3,I4),VR(I2,2,I3,I4),VR(I2,3,I3,I4))
      GO TO 10
  200 ICNT(I2,I3) = ICNT(I2,I3)+1
      NP = ICNT(I2,I3)
      CALL TRNFRM(VT(I2,I3,1,NP),VT(I2,I3,2,NP),VT(I2,I3,3,NP))
      IT(I2,I3,1,NP) = I4
      IT(I2,I3,2,NP) = I5
      GO TO 10
  300 IDCT(I2,I3) = IDCT(I2,I3)+1
      NDP = IDCT(I2,I3)
      CALL TRNFRM(D(I2,1,I3,NDP),D(I2,2,I3,NDP),D(I2,3,I3,NDP))
      ID(I2,I3,NDP) = I4
      GO TO 10
  400 IRCT(I2,I3) = IRCT(I2,I3)+1
      NRP = IRCT(I2,I3)
      CALL TRNFRM(R(1,I2,I3,NRP),R(2,I2,I3,NRP),R(3,I2,I3,NRP))
      IR(I2,I3,NRP) = I4
      GO TO 10
  999 WRITE(1,2001)
 2001 FORMAT(// 3X'COORDINATE SYSTEM DEFINITION POINTS :'/
     1 2X'POINT',T16,'X''',T26,'Y''',T36,'Z'''/)
      WRITE(1,2002) XS1,YS1,ZS1,XS2,YS2,ZS2
 2002 FORMAT(4X,'1',2X,3F10.2,/ 4X,'2',2X,3F10.2)
      L = 1
      WRITE(1,2004)
 2004 FORMAT(// 10X,'VEHICLE REST POSITIONS')
   15 DO 20 I=1,2
      WRITE(1,1200) I
```

```
 1200 FORMAT(/15X,'VEHICLE NO.',I3,/1X,'WHEEL/POINT',T16,'X''',T26,'Y''
     1    T36,'Z''')
      DO 20 J=1,4
      IF(VR(I,1,J,L).EQ.0.0.AND.VR(I,2,J,L).EQ.0.0) GO TO 20
      WRITE(1,2003) J,(VR(I,K,J,L),K=1,3)
 2003 FORMAT(3X,I2,4X,3F10.2)
   20 CONTINUE
      GO TO (21,22,23),L
   21 L = 2
      WRITE(1,2005)
 2005 FORMAT(//,10X,'VEHICLE IMPACT POSITIONS')
      GO TO 15
   22 L = 3
      WRITE(1,2006)
 2006 FORMAT(//10X,'VEHICLE POINTS OF IMPACT')
      GO TO 15
   23 CONTINUE
      WRITE(1,2007)
 2007 FORMAT(//25X,'TIRE MARKS')
      IND = 1
      IV = 1
      IW1 = 1
      IW2 = 2
   28 NP1 = ICNT(IV,IW1)
      NP2 = ICNT(IV,IW2)
      NPM = MAX0(NP1,NP2)
      IF(NPM.LE.0) GO TO 25
      WRITE(1,2008) IV,IW1,IW2
 2008 FORMAT(/24X,'VEHICLE NO.',I3/10X,'WHEEL NO.',I3,19X,'WHEEL'
     1    ' NO.',I3/6X,'X''',6X,'Y''',6X,'Z''',13X,'X''',6X,'Y''',
     2    6X,'Z'' )
      DO 25 N=1,NPM
      J1 = 5
      J2 = 5
      J3 = 5
      J4 = 5
      IF(N.GT.NP1) GO TO 26
      J1 =IT(IV,IW1,1,N)
      J2 = IT(IV,IW1,2,N)
   26 IF(N.GT.NP2) GO TO 27
      J3 = IT(IV,IW2,1,N)
      J4 = IT(IV,IW2,2,N)
   27 CONTINUE
      WRITE(1,2009) (VT(IV,IW1,L,N),L=1,3),IPTCD(J1),IWHCD(J2),
     1     (VT(IV,IW2,L,N),L=1,3),IPTCD(J3),IWHCD(J4)
 2009 FORMAT(2X,3F8.2,2X,A1,1X,A1,2X,3F8.2,2X,A1,1X,A1   )
   25 CONTINUE
      GO TO (30,31,32,33),IND
   30 IW1 = 3
```

```
      IN2 = 4
      IND = 2
      GO TO 28
   31 IV = 2
      IN1 = 1
      IN2 = 2
      IND = 3
      GO TO 28
   32 IN1 = 3
      IN2 = 4
      IND = 4
      GO TO 28
   33 CONTINUE
      IND = 1
      IV = 1
   34 NP1 = IDCT(IV,1)
      NP2 = IDCT(IV,2)
      NPM = MAX0(NP1,NP2)
      IF(NPM.LE.0) GO TO 38
      WRITE(1,2010) IV
 2010 FORMAT(//25X,'VEHICLE NO.',I2/15X,'DEBRIS',20X,'LIQUID'/
     1 6X,'X''',6X,'Y''',6X,'Z''',13X,'X''',6X,'Y''',6X,'Z''')
      DO 35 N=1,NPM
      J1 = 5
      J2 = 5
      IF(N.LE.NP1) J1 = ID(IV,1,N)
      IF(N.LE.NP2) J2 = ID(IV,2,N)
      WRITE(1,2011) (D(IV,L,1,N),L=1,3),IPTCD(J1),
     1     (D(IV,L,2,N),L=1,3),IPTCD(J2)
 2011 FORMAT(2X,3F8.2,3X,A1,3X,3F8.2,3X,A1  )
   35 CONTINUE
   38 GO TO (36,37),IND
   36 IV = 2
      IND = 2
      GO TO 34
   37 CONTINUE
      IND = 1
      NE = 1
      WRITE(1,2016)
 2016 FORMAT(//25X,'ROADWAY LAYOUT')
   40 NP1 = IRCT(1,NE)
      NP2 = IRCT(2,NE)
      NPM = MAX0(NP1,NP2)
      IF(NPM.LE.0) GO TO 45
      WRITE(1,2012) NE,NE
 2012 FORMAT(/10X,'ROAD EDGE',I3,14X,
     1 'SHOULDER EDGE',I3,/6X,'X''',6X,'Y''',6X,'Z''',13X,
     2 'X''',6X,'Y''',6X,'Z''')
      DO 45 N=1,NPM
      J1 = 5
```

```
      IF(N.LE.NP1) J1 = IR(1,NE,N)
      J2 = 5
      IF(N.LE.NP2) J2 = IR(2,NE,N)
      WRITE(1,2013) (R(L,1,NE,N),L=1,3),IPTCD(J1),
     1     (R(L,2,NE,N),L=1,3),IPTCD(J2)
 2013 FORMAT(2X,3F8.2,3X,A1,3X,3F8.2,3X,A1   )
   45 CONTINUE
      GO TO (41,42,43,44),IND
   41 IND = 2
      NE = 2
      GO TO 40
   42 IND=3
      NE = 3
      GO TO 40
   43 IND = 4
      NE = 4
      GO TO 40
   44 CONTINUE
      DO 50 I=1,4
      NP = IRCT(3,I)
      IF(NP.LE.0) GO TO 50
      WRITE(1,2014) NP
 2014 FORMAT(//25X,'FRICTION BOUNDARY',I4/6X,'X''',6X,'Y''',6X,'Z'''   )
      DO 49 N=1,NP
      J1 = IR(3,I,N)
      WRITE(1,2015) (R(L,3,I,N),L=1,3),IPTCD(J1)
 2015 FORMAT(2X,3F8.2,3X,A1   )
   49 CONTINUE
   50 CONTINUE
      WRITE(1,5001)
 5001 FORMAT(' INPUT VDI''S' / ' VEHICLE 1 VDI 1: ')
      READ(1,5002) (VDI(I),I=1,2)
 5002 FORMAT(2A4)
      WRITE(1,5003)
 5003 FORMAT(' VEHICLE 1 VDI 2:')
      READ(1,5002) (VDI(I),I=3,4)
      WRITE(1,5004)
 5004 FORMAT(' VEHICLE 2 VDI 1:')
      READ(1,5002) (VDI(I),I=5,6)
      WRITE(1,5005)
 5005 FORMAT(' VEHICLE 2 VDI 2:')
      READ(1,5002) (VDI(I),I=7,8)
      WRITE(1,5006)
 5006 FORMAT(' HAVE VEHICLE WEIGHTS BEEN MEASURED ?')
      CALL YN(IOK)
      IF(IOK.EQ.0) GO TO 5007
      WRITE(1,5008)
 5008 FORMAT(' INPUT WEIGHT VEHICLE 1')
      READ(1,5012) WV1
 5012 FORMAT(F6.0)
```

```
      WRITE(1,5009)
 5009 FORMAT(' INPUT WEIGHT VEHICLE 2')
      READ(1,5012) WV2
 5007 WRITE(1,5010)
 5010 FORMAT(' INPUT SURFACE FRICTION INFORMATION:')
      READ(1,5011) (SFRC(I),I=1,20)
 5011 FORMAT(20A4)
      CALL OPENS(5,2,'/COUT/')
      CALL BUFFER OUT(5,1,DUM,1938,I,N)
      CALL BUFFER OUT(5,1,IDUM,854,I,N)
      CALL CLOSE(5)
      END
```

** PAGE **	** NAME **
1	MAIN

```
      SUBROUTINE TRNFRM(XN,YN,ZN)
      COMMON ET,EB,AZ,DEL,XT,YT,ZT,RT,XTO,YTO,ZTO,RTO,PSI
      DPR = 57.2957
      JMP = 0
   10 RT = 5.*SIN(EB)*SIN(ET)/SIN(DEL)
      XT = RT*COS(AZ)
      YT = -RT*SIN(AZ)
      ZT = 1.+RT*COS(EB)/SIN(EB)
      IF(JMP.EQ.1) GO TO 90
   20 DX = XT-XTO
      DY = YT-YTO
      SP = SIN(PSI)
      CP = COS(PSI)
      XN = DX*CP+DY*SP
      YN = DY*CP-DX*SP
      ZN = ZT-ZTO
      JMP = 0
   90 RETURN
      ENTRY TRNCRD
      JMP = 1
      GO TO 10
      ENTRY SPCCRD(XN,YN,ZN)
      GO TO 20
      END
```

** PAGE **	** NAME **
1	SUBROUTINE TRNFRM(XN,YN,ZN)
1	ENTRY TRNCRD
1	ENTRY SPCCRD(XN,YN,ZN)

```
      COMMON /S/ VR(2,3,4,3),VT(2,4,3,35),D(2,3,2,25),
     1    R(3,3,4,25),TIL(36),VDI(8),RV1,RV2,SFRC(20)
      COMMON /IS/ ICNT(2,4),IT(2,4,2,35),ICODE(10),ICARD(20),
     1    ID(2,2,25),IDCT(2,2),IR(3,4,25),IRCT(3,4)
      DIMENSION ISZ(2),A(4),B(4),XP(4),YP(4),IPTT(20),TYPE(3)
      DIMENSION DUM(1908),IDUM(854)
      EQUIVALENCE (DUM(1),VR(1,1,1,1)),(IDUM(1),ICNT(1,1))
      DATA TYPE/'REST','IMPT','SEPR'/,PID2/1.5707/
      DIMENSION T(4)
      DATA A/3.72,4.39,4.78,5.04/,B/3.88,4.57,4.97,5.25/,
     1    T/4.27,4.81,5.00,5.26/
      DIMENSION XF(4),XR(4),YS(4)
      DATA IXOFF/19/
      DATA XF/6.23,7.15,7.90,8.40/, XR/-6.96,-8.34,-9.22,-9.96/,
     1    YS/2.59,2.98,3.20,3.30/
      DATA IEND/-1/
      IPI = 4.*PID2
      CALL OPENS(3,2,'/PTAPE/')
      CALL OPENS(2,1,'/COUT/')
      CALL BUFFER IN(2,1,DUM,2178,I,N)
      CALL BUFFER IN(2,1,IDUM,1014,I,N)
      CALL CLOSE(2)
      WRITE(3,7998) (TIL(I),I=1,36)
 7998 FORMAT(18A4)
      DO 500 IV=1,2
      WRITE(1,1000) IV
 1000 FORMAT(' INPUT SIZE CODE FOR VEHICLE NO.',I3)
      READ(1,1001) ISZ(IV)
 1001 FORMAT(I1)
      II = ISZ(IV)
      WRITE(3,7999) XF(II),XR(II),YS(II)
 7999 FORMAT(3F10.2)
  500 CONTINUE
      DO 501 JT=1,2
      DO 501 IV=1,2
      WRITE(1,1002) TYPE(JT),IV
 1002 FORMAT(' INPUT WHEEL NOS. TO BE USED TO CALC C.G. & PSI FOR',/
     1  3X,A4,1X,'POSITION FOR VEH NO.',I2)
      READ(1,1003) I,J
 1003 FORMAT(I2,I1)
      IF(I.GT.0) GO TO 507
      XCG = 0.
      YCG = 0.
      PSIO = 0.
      GO TO 505
  507 DO 502 K=1,4
      XP(K) = VR(IV,1,K,JT)
  502 YP(K) = VR(IV,2,K,JT)
      IF(IABS(I-J).GT.1) GO TO 550
      PSIV = ATAN2(YP(I)-YP(J),XP(I)-XP(J))-PID2
```

```
      IF(PSIV.LT.0.0) PSIV = PSIV+TPI
      PSIO = PSIV*57.3
      SP = SIN(PSIV)
      CP = COS(PSIV)
      TRK = SQRT((XP(I)-XP(J))**2+(YP(I)-YP(J))**2)
      IF(I.GT.1) GO TO 520
      X = XP(1)
      Y = YP(1)
      II = ISZ(IV)
      A1 = -A(II)
      A2 = .5*TRK
  510 XCG = X+A1*CP+A2*SP
      YCG = Y+A1*SP-A2*CP
      GO TO 505
  520 X = XP(3)
      Y = YP(3)
      II = ISZ(IV)
      A1 = B(II)
      A2 = .5*TRK
      GO TO 510
  550 PSIV = ATAN2(YP(I)-YP(J),XP(I)-XP(J))
      IF(PSIV.LT.0.0) PSIV = PSIV+TPI
      PSIO = PSIV*57.3
      SP = SIN(PSIV)
      CP = COS(PSIV)
      WBS = SQRT((XP(I)-XP(J))**2+(YP(I)-YP(J))**2)
      II = ISZ(IV)
      A1 = WBS*B(II)/(A(II)+B(II))
      A2 = T(II)*.5
      IF(I.GT.1) GO TO 560
      X = XP(3)
      Y = YP(3)
      GO TO 510
  560 X = XP(4)
      Y = YP(4)
      A2 = -A2
      GO TO 510
  505 WRITE(3,8001) IV,JT,XCG,YCG,PSIO
 8001 FORMAT(2I4,3F10.2)
  501 CONTINUE
      WRITE(3,8050) ((VR(IV,1,K,3),VR(IV,2,K,3),K=1,4),IV=1,2)
 8050 FORMAT(2F10.2)
      DO 600 IV = 1,2
      DO 600 IW=1,4
      NP = ICNT(IV,IW)
      NS = -1
      DO 605 N=1,NP
      GO TO (601,602,603,604),IT(IV,IW,1,N)
  601 IPT = 1
      GO TO 605
```

```
  602 IPT = IPT+1
      GO TO 606
  603 IPT = IPT+1
      GO TO 605
  604 IPT = 1
      GO TO 607
  606 ILCD = 2
      IF(IT(IV,IN,2,N).EQ.1) ILCD=3
  608 NS = NS+2
      IPTT(NS+1) = IPT
      IPTT(NS) = ILCD
      GO TO 605
  607 ILCD = 5
      GO TO 608
  605 CONTINUE
      IPTT(NS+2) = 1
      IPTT(NS+3) = 0
      INP = NS+3
      MNP = 0
      DO 690 M=2,INP,2
  690 MNP = MNP+IPTT(M)
      WRITE(3,8002) INP,(IPTT(M),M=1,INP)
 8002 FORMAT(10I6)
      WRITE(3,8003) (VT(IV,IN,1,M),M=1,MNP)
 8003 FORMAT(6F8.2)
      WRITE(3,8003) (VT(IV,IN,2,M),M=1,MNP)
  600 CONTINUE
      DO 700 J=1,2
      ILCD = 2
      DO 710 NE = 1,4
      NS = -1
      NP = IRCT(J,NE)
      DO 725 N=1,NP
      GO TO (721,722,723,724),IR(J,NE,N)
  721 IPT = 1
      GO TO 725
  722 IPT = IPT+1
      GOTO 726
  723 IPT = IPT+1
      GO TO 725
  724 IPT = 1
      GO TO 727
  726 NS = NS+2
      IPTT(NS+1) = IPT
      IPTT(NS) = ILCD
      GO TO 725
  727 GO TO 726
  725 CONTINUE
      IPTT(NS+2) = 1
      IPTT(NS+3) = 0
```

```
      INP = NS+3
      MNP = 0
      DO 790 M=2,INP,2
  790 MNP = MNP+IPTT(M)
      WRITE(3,8002) INP,(IPTT(M),M=1,INP)
      WRITE(3,8003) (R(1,J,NE,M),M=1,MNP)
      WRITE(3,8003) (R(2,J,NE,M),M=1,MNP)
  712 CONTINUE
  710 CONTINUE
  700 CONTINUE
      DO 800 IV = 1,2
      DO 800 J=1,2
      NP = IDCT(IV,J)
      NS = -1
      DO 835 N=1,NP
      ILCD = 5
      GO TO (831,832,833,834),ID(IV,J,N)
  831 IPT = 1
      GO TO 835
  832 IPT = IPT+1
      GO TO 836
  833 IPT = IPT+1
      GO TO 835
  834 IPT = 1
      GO TO 837
  836 NS = NS+2
      IPTT(NS+1) = IPT
      IPTT(NS) = ILCD
      GO TO 835
  837 GO TO 836
  835 CONTINUE
      IPTT(NS+2) = 1
      IPTT(NS+3) = 0
      INP = NS+3
      MNP = 0
      DO 890 M=2,INP,2
  890 MNP = MNP+IPTT(M)
      WRITE(3,8002) INP,(IPTT(M),M=1,INP)
      WRITE(3,8003) (D(IV,1,J,M),M=1,MNP)
      WRITE(3,8003) (D(IV,2,J,M),M=1,MNP)
  812 CONTINUE
  800 CONTINUE
      WRITE(3,8002) IEND
      WRITE(3,8051) (VDI(I),I=1,8)
 8051 FORMAT(2A4)
      WRITE(3,8052) WV1,WV2
 8052 FORMAT(2F10.2)
      WRITE(3,8053) (SFRC(I),I=1,20)
 8053 FORMAT(20A4)
      WRITE(3,8999) IXOFF
```

```
8999 FORMAT(A4)
     CALL CLOSE(3)
     END
```

** PAGE **	** NAME **
1	MAIN

```
      DIMENSION A(30)
      I = 0
      CALL OPENRX(2,1,'/SAVTRN/')
      CALL OPENS(3,2,'/TRANSYM/')
      CALL RDISC(2,1,IL,1)
      WRITE(1,99) IL
   99 FORMAT(I6)
      DO 50 I=1,IL
      IAD = 30*(I-1)+2
      WRITE(1,99) IAD
      CALL RDISC(2,IAD,A,30)
      WRITE(3,90) (A(J),J=1,30)
      WRITE(1,92) I,(A(J),J=1,30)
   92 FORMAT('I=',I4,2X30A1)
   90 FORMAT(30A1)
   50 CONTINUE
  100 WRITE(1,91) I
   91 FORMAT('NO. OF RECORDS =',I4)
      CALL CLOSE(2)
      CALL CLOSE(3)
      END
```

** PAGE **	** NAME **
1	MAIN

TRANSIT MEASUREMENT CODE

DIGIT 1	2	3	4	5	DESCRIPTION
9	0	1	0	0	Origin of space fixed axes
9	0	2	0	0	Point along space fixed X′ axis
9	0	3	0	0	Code to indicate change in height of lower bulb on stadia rod
9	9	9	0	0	End of data code
1	V	W	C1	0	Vehicle Position V = Vehicle No. (1, 2) W = Wheel No. (1, 2, 3, 4) C1 = Ident. Code 1 = Rest Position 2 = Point of Impact (wheel positions) Note: 2 will be used to approximate c.g. and yaw angle only. Will assume front wheels are best defined ∴ rear wheels will be used only for yaw angle 3 = Point of Impact (point of contact between vehicles)
2	V	W	C1	C2	Tire Marks V = Vehicle No. W = Wheel No. C1 = 1 — Start of Series 2 — End of Series 3 — Continuation of Series 4 — Single Point C2 = 1 — Rolling 2 — Accelerating 3 — Skidding (braking or side) 4 — Flat Tire

DIGIT 1	2	3	4	5	DESCRIPTION
3	V	C1	C2	0	Debris V = Vehicle No. C2 = 1 — Start of Series 2 — End of Series 3 — Continuation of Series 4 — Single Point C1 = 1 — Underbody Debris 2 — Liquid
4	C1	C2	C3	0	Roadway Layout C1 = 1 — Pavement Edge 2 — Shoulder Edge C2 = 1, 2 3, 4 - To assign pavement shoulder edges C1 = 3 — Other Boundary, i.e., ice or wet patch C3 = 1 — Start of Series 2 — End of Series 3 — Continuation of Series 4 — Single Point

TRANSIT MEASUREMENT PROCEDURE

Coordinate System Definition

Two points required; 1st to be origin of earth fixed axis system; 2nd lies along X' axis.

These points should be sightable from different transit locations since all evidence will probably not be visible from one location. If the transit is moved, first two points must be resighted in proper sequence.

Vehicle Positions

Rest Positions

Sight each wheel in estimated undamaged position (if necessary) with appropriate code. No particular sequence is required and wheels may be sighted from different transit locations.

Impact Positions

Sight approximate positions of front and rear wheels at impact. No particular sequence is required and sightings may take place from different transit locations.

Point(s) of Impact

Sight point or points of impact between vehicles.

Tire Marks

Current codes for tire marks include rolling, skidding, accelerating, and flat. A second code describes a measured point as the start of a series, continuation of a series, end of a series or a single point. Identification of the vehicle and tire is also included.

The procedure for recording tire marks consists first of identifying and associating marks with the tires of each vehicle and then recording a sufficient number of points along the trajectory for an adequate description. The first point recorded for a given series (for example, vehicle 1, tire 1, rolling) should be coded as the first point of a series, followed by any number of continuation points and concluding with the end of the series code. If the type of tire mark then changes (for example, from rolling to skidding) the appropriate code is changed and start, continuation and end points are recorded.

Note that the sequence of start, continuation and end points must be followed for each set of tire marks.

Debris

Current provision for coding debris include underbody debris and liquid. Debris may be located by outlining an area with a start, continuation, end sequence, locating a trajectory (of for example, trailing liquid) also with a start, continuation, end sequence or locating isolated objects with a single point code. As in the case of tire marks, the sequence of start, continuation and end must be followed if applicable.

Roadway Layout

Codes for identifying up to four sets of pavement and shoulder edges and any number of other boundaries (for example, an ice patch or standing water) are provided. Outlines of the measured areas are located with a start, continuation, and end sequence.