March 1983

DOT HS-806-446

U.S. Department of Transportation
National Highway Traffic Safety Administration

Update of Crash II Computer Model Damage Tables—Volume I

Vehicle Research and Test Center
National Highway Traffic Safety Administration
P.O. Box 37
East Liberty, Ohio 43311

Technical Report Documentation Page

1. Report No. DOT HS-806 446	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle UPDATE OF CRASH II COMPUTER MODEL DAMAGE TABLES Vol. I		5. Report Date MARCH 1983
		6. Performing Organization Code NRD-22
7. Author(s) M.W. Monk, D.A. Guenther		8. Performing Organization Report No. SRL-16
9. Performing Organization Name and Address Vehicle Research and Test Center National Highway Traffic Safety Administration P.O. Box 37 East Liberty, Ohio 43311		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration Washington, D.C. 20590		13. Type of Report and Period Covered FINAL Oct. 1979 - March 1983
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A study was conducted to investigate simple updates and improvements for the CRASH II computer model. The main emphasis was to use a number of recent Agency crash tests and also data provided by the Motor Vehicle Manufacturers Association to derive improved stiffness coefficients for the model. Using the newly derived coefficients, improved reconstruction capability was demonstrated for the frontal and rear collision modes. The rear mode results were noted to be a marked improvement. It was found that nearly all of the side collision mode data that is available involves structurally modified vehicles and is not useful for deriving stiffness coefficients for baseline vehicles.

In addition to passenger car data, stiffness coefficients were also derived for vans, pickups and 4x4's. Reconstruction results obtained from the new coefficients are presented and discussed.

Other model improvements that were investigated include a new analytical approach for reconstructing highly oblique collisions and the assumption of other than linear stiffness properties for vehicles. The results of these attempted model improvements are discussed.

17. Key Words Accident reconstruction CRASH II computer model Vehicle stiffness parameters		18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

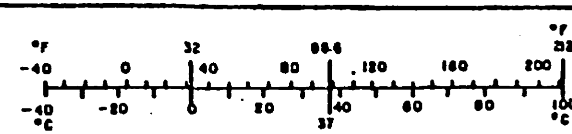


TABLE OF CONTENTS

	Page
LIST OF FIGURES	iv
LIST OF TABLES	v
INTRODUCTION	1
Background	1
Damage Algorithm and Assumptions	1
Items Addressed in SRL Study	2
UPDATE OF STIFFNESS PARAMETER TABLES	2
CRASH Model Use of Stiffness Parameters	2
CRUSH Model Approach	4
Laboratory Collision Data	6
New Stiffness Derivation	15
Validation of the New Stiffness Values	27
Discussion of Stiffness Values	30
ANALYSIS OF LINEAR FORCE DEFLECTION	33
Background	33
Selected Laboratory Collision Analysis	35
ANALYSIS OF OBLIQUE-FORCE ENERGY CORRECTION FACTOR	46
Laboratory Test Data	50
Observations from Test Data	54
Discussion, Conclusions and Recommendations Regarding the Energy Correction Factor	56
CONCLUSIONS AND RECOMMENDATIONS	60
REFERENCES	61

APPENDIX A Relationship Between Crush, Stiffness and Delta-V in the CRASH & CRUSH Models

APPENDIX B Solution Procedure of the CRUSH Program

APPENDIX C SRL Version of CRUSH

APPENDIX D Staged Collision Data

APPENDIX E CRUSH vs. Delta-V Curves for Passenger Cars

APPENDIX F Validation (Level I and Level II)

APPENDIX G Procedure for Obtaining Instrumentation Force Direction

LIST OF FIGURES

Figure No.		Page No.
1	Assumed Form of Crush Resistance	3
2	SRL CRUSH Runs for 1978 Monza	20
3	SAS CRUSH Run for Rear Sub-Compact Collisions	21
4	CRUSH vs. Delta-V Curve	22
5	Algorithm for A and B Values	23
6	Extrapolated Force vs. CRUSH Curve	34
7	Citation CRUSH Response	36
8	Torino CRUSH Response	42
9	Force Components of a Side Collision	46
10	Energy Correction Factor vs. Angle	48
11	Velocity Polygon for 60^{0} Side Oblique Impact	52
12	Laboratory Derived Energy Correction Factors	57

LIST OF TABLES

Table No.		Page No.
1	Crush Coefficients Prior to SRL Study	5
2	Computer Run of CRUSH from Reference 1	7
3	SRL Computer Run of CRUSH on McAuto System	8
4	Crush Results by the McAuto System vs. Results from Reference 1 Prior to SRL Modification of McAuto	9
5	Crush Results by the SRL Program vs. Results from Reference 1 After Program Modification of McAuto	10
6	Passenger Cars Used for Front Stiffness Values	12
7	Passenger Cars Used for Rear Stiffness Values	13
8	Passenger Cars Used for Side Stiffness Values	14
9	Vans Used for Stiffness Value Derivation	16
10	Pickups Used for Stiffness Value Derivation	17
11	4x4's Used for Stiffness Value Derivation	18
12	Crush Coefficients Based on CRUSH Program for Passenger Cars	25
13	Crush Coefficients Based on CRUSH Program for Vans, Pickups, & 4x4's	26
14	Level-I Validation of Rear Stiffness Parameters, Subcompact Vehicles	28
15	Level-II Validation of Rear Stiffness Parameters, Subcompact Vehicles	29
16	Averaged (Old & New) Passenger Car Frontal Stiffness Values	32
17	Citation Barrier Test Reconstructions	38

LIST OF TABLES (Cont.)

Table No.		Page No.
18	Comparison Between Hand Calculation Method and Conventional (CRUSH & CRASH) Method	40
19	Torino Static CRUSH & Dynamic CRUSH Measurements	43
20	Torino Accelerometer Static & Dynamic CRUSH Measurements	44
21	Reconstruction Results by Linear and Bi-Linear Methods	44
22	Laboratory Tests Used for Energy Correction Factor Analysis	51

ACKNOWLEDGMENTS

The views and findings of this report are those of the authors and do not necessarily reflect the policy of the NHTSA. The authors gratefully acknowledge the helpful suggestions of Mr. Tom Noga of the National Center for Statistics and Analysis who was also the focal point for the collection of the staged collision data used in this study. The authors also express gratitude to the Motor Vehicle Manufacturer's Association for their contribution of side impact collision data used in this study. The following students from the Ohio State University participated in the various project elements: Mike Pereira, Jahan Bayat-Mokhtari and Chien-Ann Hou. Gratitude is also expressed to Reva Blaker, Susan Weiser, and Judy Weiser for the preparation of the manuscript.

INTRODUCTION

Background - The CRASH* computer program was developed to provide uniformity and improved accuracy of highway accident reconstruction. The model accepts as input the physical evidence such as vehicle(s) size(s) and inertial parameters, the scene trajectory information and the damage measurements of the vehicle(s). In the absence of scene documentation, the reconstruction is based solely upon damage information. In the absence of damage measurements, the reconstruction is based upon the Vehicle Damage Index (VDI) of the involved vehicle(s). The primary outputs from the model are the vector change(s) in velocity of the vehicle(s) resulting from the collision and (when scene measurements are available) the impact speed(s).

Damage Algorithm and Assumptions - The algorithm of the CRASH computer model which utilizes the damage information to compute the delta-V vectors is the DAMAGE algorithm. In the formulation of the algorithm, the following assumptions are made:

- that the vehicle exhibits a linear force vs. deflection property,
- that at a given location, the stiffness is the same in any direction of deformation,
- that the collision deformation is plastic and no slippage occurs.

The actual stiffness properties are derived from staged collision data and are stored within the algorithm as a table of values. The table is subdivided by vehicle size and area of damage. At the time of initiation of this project, the stiffness values stored in the model were those derived by McHenry(1)**in 1977. Most of the data were from vehicles whose model years were in the early 1970's. Very little data were available for the rear collision mode during the McHenry update.

* Calspan Reconstruction of Accident Speeds on the Highway

** Numbers in raised parenthesis indicate references at the end of the paper.

Items Addressed in SRL Study - The primary focus of this study was the updating of the stiffness values stored within the DAMAGE algorithm. Since the rear stiffness values were based on such sparse data, special effort was put forth to locate and verify crush data for the rear damage area. Frontal data were included but were analyzed in light of the existing values which had been verified by considerable experience. Side data were needed but very little were found.

The model assumptions were also examined in the study to determine if simple improvements could be made within the scope of the project. The benefit of assuming a bilinear force vs. deflection representation, rather than a linear, was examined and specific examples shown.

The physical limitations of other assumptions associated with oblique-angle collision reconstructions were identified and discussed.

UPDATE OF STIFFNESS PARAMETER TABLES

CRASH Model Use of Stiffness Parameters - The basic approach of correlating vehicle damage to collision energy was presented by K.L. Campbell at the 3rd International Conference on Occupant Protection[2]. The extension of the empirical relationships begun by Campbell formed the basis for the CRASH model DAMAGE algorithm. In the model, the force resulting from collision deformation is assumed to be a function of the three variables shown in Figure 1. The variable "A" represents the force (per unit of damage length or width) required to initiate permanent deformation. "B" represents the stiffness (per unit of damage length or width) and "C" is the amount of structural crush. The relationship between delta-V, crush and the stiffness parameters is contained in Appendix A of this report and is reproduced from Reference 1, pages 36 through 44. A more complete derivation can be found in Reference 3, pages 50 through 57. It is noted that the delta-V is also linearly

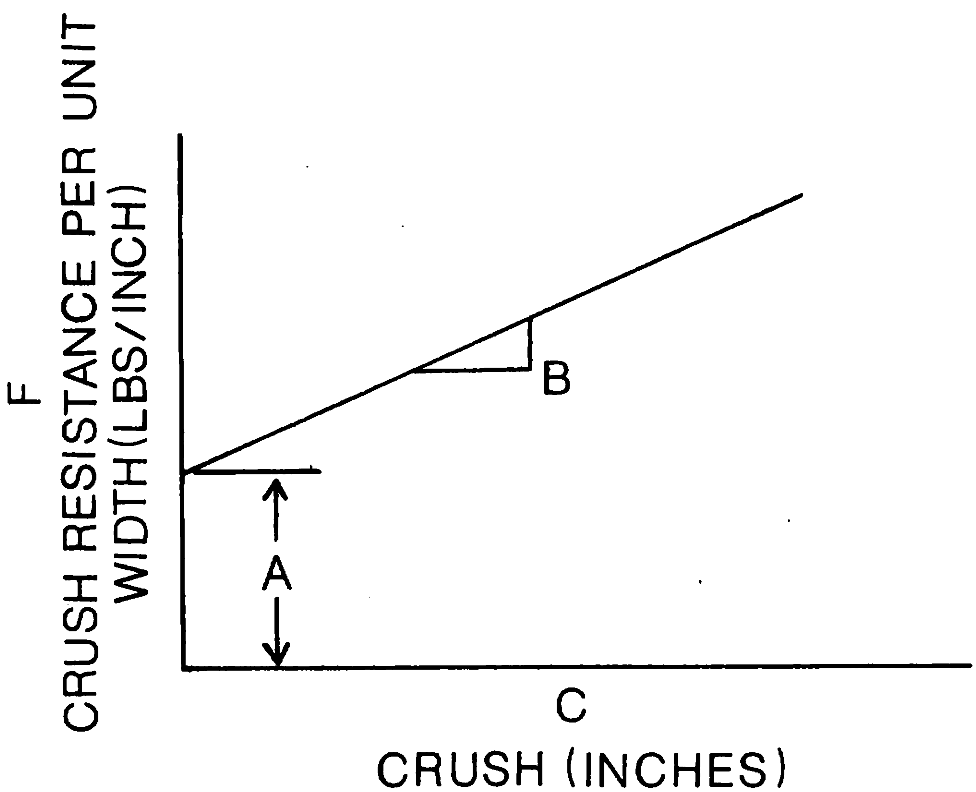


FIGURE 1

Assumed Form of Crush Resistance

related to crush, and that another parameter "G" is derived as a constant of integration. In the model, the constants A, B, and G are stored as a table of values. Separate values are stored for each vehicle size (mini through large) and for each general area (front, rear, side).

Table I shows the tabular values as derived under the work of Reference 1. The units for the values are defined in Appendix A. The procedure for CRASH reconstruction is summarized as follows:

1) The reconstructionist enters the vehicle category, inertial parameters (if known) and the measured damage information (crush depths, damage length, location, and force direction) for each involved vehicle.
2) Based upon the size category and damage area input to the computer, the computer retrieves the appropriate stiffness and inertial parameters (A, B & G).
3) The equations are solved.
4) The delta-V vectors are output along with other computed information.

CRUSH Model Approach - It was decided, due to the large number of staged collision tests available, to use an automated approach for analyzing the tests. The CRUSH model was selected. The following is intended to briefly describe the conceptual approach of the model.

The CRUSH model was formulated as part of the study of Reference 1. In concept, it is an inversion of the process of the CRASH model. Whereas the CRASH model starts from known damage measurements and known stiffness parameters and then computes delta-V's, the CRUSH model starts from known delta-V's and known damage measurements and then computes stiffness values. At least two separate staged collisions are needed for each set of stiffness values (an infinite combination of A, B and G's will satisfy the damage and energy criteria of one test). More reliable stiffness values are obtained if the laboratory tests were conducted at widely differing speeds.

TABLE 1

Crush Coefficients Prior to SRL Study

		1 MINICAR	2 SUBCOMPACT	3 COMPACT	4 INTERMEDIATE	5 FULL SIZE	6 LARGE
	A	85.4	94.89	154.6	233.7	307.5	307.5
F	B	64.0	71.11	69.57	49.9	36.89	36.89
	G	57.0	63.31	171.78	547.3	1281.1	1281.1
	A	77.2	140.4	173.3	143.0	176.5	176.5
R,L	B	36.7	66.7	57.1	50.4	47.1	47.1
	G	81.3	147.8	263.2	202.7	330.8	330.8
	A	65.98	65.98	78.18	85.51	93.28	93.28
B	B	13.20	13.20	15.64	17.11	18.66	18.66
	G	164.97	164.97	195.45	213.78	233.21	233.21

Each test must have only one vehicle with unknown stiffness values. Thus, either car to barrier collisions are used or the stiffness values of one car (for car-to-car) are assumed.

The exact coding of the CRUSH model is sophisticated, and contains over 4000 fortran statements. A procedural summary of the program is contained in Appendix B as taken from Reference 1. It is noted from this summary that this procedure was written for obtaining stiffness values from two staged collisions. The procedure is similar for obtaining stiffness values from several staged collisions.

In the SRL study, the CRUSH model was reviewed and a version that was available on the McAuto time share system was accessed for check-out runs. Input for an individual run made by McHenry was reproduced with the McAuto version and the results were found to agree. Tables 2 and 3 are the McHenry and SRL runs respectively. The output from the individual run is in the form of alpha and beta parameters. The alpha and beta values from multiple runs are then used for calculations of the A, B, and G parameters. The SRL was not able to reproduce the McHenry values of A, B, and G using the McAuto version of CRUSH. It was found that the program called a linear fit subroutine in line 6530 of the code. This was believed to be in error and was changed to a non-linear fit subroutine from the SAS library. When the change was made the results from the McHenry run were reproduced. Tables 4 and 5 show the SRL runs before and after the correction of line 6530. The model was then assumed to be free from coding errors and ready for use in test data analysis. One further change was made to the model to allow input data to be entered in response to questions (interactively) rather than read from a fixed-format file. The SRL version of CRUSH is contained in Appendix C.

Laboratory Collision Data - Data from several NHTSA test programs were assembled for use in updating the stiffness parameters. The bulk of the effort of collecting useable data was accomplished by the Accident Investigation Division of the National Center for Statistics and Analysis. These data were made available to the SRL for this study.

TABLE 2

Computer Run of CRUSH from Reference 1

```
                    ++++ INTERMEDIATE RESULTS ++++
FRONTAL SAE BARRIER CRASH AT 7.9 MPH, INTERMEDIATE VEHICLE, 12/8/76
                    (Ref. 7)
                                                                        INTERMEDIATE FRONTAL
VEHICLE TYPES :       4    8
VEHICLE WEIGHTS:      4550.001000000.00
VEHICLE DAMAGE INDICES: 12FDEW1     12FDEW1
COLLISION SPEEDS:        132.00       0.0                         (-5.0%)
A(2),B(2),G(2):           0.0        0.0         0.0
DIRECTION OF PRINCIPAL FORCE:         360.00     360.00                                              D     D
V1 DAMAGE DATA:      79.80           2.00       2.00       0.0       0.0       0.0       0.0   0.0   0.
V2 DAMAGE DATA:      0.0             0.0        0.0        0.0       0.0       0.0       0.0   0.0   0.
GAM(1:2):       1.00       1.00
ENERGY(2):       0.0
DELV1:    131.40
SUMENG:    102122.12
ENERGY(1):   102122.12
ALPHA1,BETA1:          159.60       159.60
17. IS A SECOND CRASH TEST AVAILABLE? (YES OR NO)
Y                   ++++ INTERMEDIATE RESULTS ++++
HEAD-ON FRONTAL, IDENTICAL INTERMEDIATE VEHICLES, CLOSING AT 87.4 MPH, 12/8/76
```

TABLE 3

SRL Computer Run of CRUSH on McAuto System

```
 ==== INPUT DATA AND CRUSH ROUTINE RESULTS ====

 TEST NUMBER 600
VEHICLE TYPES :      4    8
VEHICLE WEIGHTS:    4550.001000000.00
VEHICLE DAMAGE INDICES: 12FDEW1    12FDEW1
COLLISION SPEEDS:      132.00       0.00
A(2),B(2),G(2):          0.00        0.00        0.00
DIRECTION OF PRINCIPAL FORCE:      360.00     360.00
V1 DAMAGE DATA:     79.80            2.00        2.00        0.00        0.00
    0.00        .00
V2 DAMAGE DATA:      0.00            0.00        0.00        0.00        0.00
    0.00        0.00
GAM(1:2):        1.00       1.00
ENERGY(2):        0.00
DELV1:    131.40
SUMENG:    102122.16
ENERGY(1):  102122.16
ALPHA1,BETA1:          159.60       159.60
```

TABLE 4

CRUSH Results By the McAuto System
vs.
Results From Reference 1*
Prior to SRL Modification of McAuto

McAuto	From Reference 1
A = 989.75	A = 254.96
B = 27.24	B = 48.27
G = 0.00	G = 673.23

*Based on identical input data and without changing line 06530 in CRUSH

TABLE 5

CRUSH Results By the SRL Program
vs.
Results From Reference 1*
After Program Modification of McAuto

McAuto	From Reference 1
A = 254.96	A = 254.96
B = 48.27	B = 48.27
G = 673.23	G = 673.23

*Based on identical input data and changing line 06530 in CRUSH

As the various test reports were received, they were first examined to determine if the data were suitable for the study. Tests involving vehicles which were structurally modified were not included in the study. In addition, tests with inadequate damage measurements were not included. The remaining tests were separated into the 18 categories of Table 1. Appendix D contains a list of all of the contracts and contractors from which crash test data were received. Tables 6, 7 and 8 contain lists of the vehicles which were included in each size category for the frontal, rear, and side damage locations. The vehicles were categorized according to the wheel base dimension rather than the weight. Those vehicles which were not felt to be characteristic of the wheel-base category were placed in the category judged most appropriate and are footnoted.

In order to be acceptable, the tests were required to contain all the measurements used as input to the CRUSH model. The data required are:

vehicle size category
vehicle weight
vehicle damage index
impact speed
damage width
damage depths at 2, 4, or 6 equally spaced points
distance from vehicle center of gravity (c.g.) to damage center

Most of the tests were conducted for research purposes other than accident reconstruction; therefore, the measurements taken were not precisely as required by the model. Where possible, measurements and sketches were used to derive the data for the model. In many instances, the information was insufficient and the test was not used. Appendix D also shows the tests that were reviewed but were not used as data for the model.

A number of staged collisions have been conducted using vans, pickup trucks and 4x4's as test vehicles. The data available to the SRL had sufficient numbers of these tests to enable creation of separate categories for the

TABLE 6

Passenger Cars Used for Front Stiffness Values

Mini 80 - 94.8"	Subcompact 94.8 - 101.6"	Compact 101.6 - 110.4"	Intermediate 110.4 - 117.5"	Full 117.5 - 123.2"
78 Volkswagen Rabbit (9)*	79 Chevrolet Monza (10)	80 AMC Concord (22)	78 Chrysler LeBaron (41)	78 Ford LTD II Brougham (54)
75 Honda Civic (3)CVCC (1-3)	79 Toyota Celica (11)	78 AMC Concord (23)	79 Buick Riviera (42)	79 Oldsmobile 98 Regency (55)
79 Honda Civic CVCC (5)	78 AMC Gremlin (13)	78 Peugeot 604SL (24)	79 Mercury Marquis (43)	79 Ford LTD (56)
79 Chevrolet Chevette (6)	78 Mazda RX-4 (14)	79 Chevrolet Malibu (25)	78 Dodge Magnum XE (44)	73 MVMA Data 40.7 mph
79 Volkswagen Rabbit (7)	78 Dodge Challenger (15)	78 Mercury Monarch (26)	78 Dodge Monaco (45)	73 MVMA Data 30.5 mph
78 Chevrolet Chevette (8)	78 Dodge Omni** (16)	78 Mercury Zephyr (27)	79 Chrysler LeBaron (46)	73 MVMA Data 60.2 mph
79 Datsun 210 (4)	79 Plymouth Horizon** (17)	79 Ford Fairmont (28)	79 Plymouth Volare (47)	75 MVMA Data 31.1 mph
	79 Saab 900 AL (20)	79 Ford (2)Granada (29,30)	79 Dodge Magnum Tudor (49)	76 MVMA Data 31.0 mph
	77 Pontiac Sunbird (21)	79 Pontiac Firebird (31)	79 Chevrolet Impala (50)	73 MVMA Data 40.3mph
	79 Ford Fiesta (18)	78 Toyota Cressida (32)	77 Ford LTD (51)	
	79 Mercury Bobcat (12)	78 Datsun 810 (Sta wgn)(33)	77 Chrysler Cordoba (52)	
	79 Toyota Corolla (19)	75 Volvo (2)244 (38,39)	78 Chevrolet Nova (53)	
	MVMA (8)Supplied Data	74 Volvo 244 (36)	76 MVMA Supplied Data	
		79 Volvo 244 DL (34)	79 Chrysler LeBaron (48)	
		75 Volvo (2)244 DL (35,37)		
		78 Buick Century Custom (40)		

*Numbers in parenthesis indicate the line number in Appendix D which contains the contract information
**New CRASH run only, no other documentation

TABLE 7

Passenger Cars Used for Rear Stiffness Values

Mini 80 - 94.8"	Subcompact 94.8 - 101.6"	Compact 101.6 - 110.4"	Intermediate 110.4 - 117.5"	Full 117.5 - 123.2"
79 Triumph Spitfire (57)*	77 MVMA Supplied Data	78 Ford Fairmont (83)	77 Oldsmobile Cutlass Supreme(87)	79 Checker Taxicab (95)
77 Chevrolet Chevette (59)	78 Chevrolet Monza (71)	79 Mercury Monarch (80)	78 Dodge Diplomat (86)	75 MVMA (2)Supplied Data
79 Plymouth Arrow (58)	78 Pontiac Sunbird (72)	79 Mercury (2)Zephyr (81,82)	78 Buick Regal** (88)	76 MVMA Supplied Data
79 MG Midget (60)	78 Plymouth Sapporo (75)	80 AMC Concord (84)	77 MVMA Supplied Data	
	78 Saab 99GL (76)	79 Volvo (85)	79 Buick Riviera Type S(93)	
	78 Mazda Cosmo (77)		79 Ford LTD (92)	
	78 Buick Opel (78)		79 Ford Thunderbird (91)	
	78 Datsun 510 (79)		79 Cadillac Seville (90)	
	72 Ford Pinto*** (21.47mph) (69)		77 Pontiac Ventura (89)	
	72 Chevrolet Vega (21.38mph) (70)		78 Pontiac Phoenix (94)	
	76 Ford Pinto Wgn (35.18mph) (61)			
	72 Ford Pinto Wgn*** (35.57mph) (67)			
	76 Ford Pinto (30.31mph) (63)			
	76 Ford Pinto*** (35.30mph) (64)			
	74 Ford Pinto (29.89mph) (65)			
	74 Ford Pinto (35.32mph) (66)			
	71 Chevrolet Vega (34.78mph) (73)			
	71 Ford Pinto (29.91mph) (67)			
	72 Ford Pinto (35.27mph) (68)			
	71 Chevrolet Vega (40.74mph) (74)			

*Numbers in parenthesis indicate the line number in Appendix D which contains the contract information
**New CRASH run only, no other documentation
***The Pinto is actually a mini-car by wheel base

TABLE 8

Passenger Cars Used for Side Stiffness Values

Mini 80 - 94.8"	Subcompact 94.8 - 101.6"	Compact 101.6 - 110.4"	Intermediate 110.4 - 117.5"	Full 117.5 - 123.2"
See McHenry Ref. No. 1	RICSAC DATA	RICSAC DATA	RICSAC DATA	RICSAC DATA

stiffness parameters of these vehicles. Tables 9, 10 and 11 present the specific vehicles used for the van, pickup and 4x4 categories respectively. Data were not available for analysis of the side stiffness values for any of these vehicles, and were also not available for the rear stiffness values of 4x4's. Though not complete, the data were felt to be significant because of the increasing number of highway accidents involving these vehicle types and the need for reconstructions of such accidents. Additional subdivision of these vehicles by size, etc. was felt desirable but not possible from the data available.

New Stiffness Derivation - The vehicles shown on Tables 6 through 11 were used to derive the updated stiffness parameters for the various categories that they represent. The derivation procedure will be presented here and the validation procedure will be presented in the following section. The derivation procedure was as follows:

1) Utilize the CRUSH model to get preliminary stiffness values for each category (i.e., run CRUSH with each staged collision in the category).
2) Perform hypothetical CRASH reconstructions of a high speed collision and a low speed collision with the new stiffness values (i.e., plot the crush depth vs. delta-V line that results from the derived coefficients).
3) Adjust the derived coefficients in the range outside of the available test data to yield acceptable reconstruction results.

The procedure will be illustrated by deriving the rear stiffness values for sub-compact vehicles. Table 7 shows that 20 laboratory collisions were performed for this category. Data was extracted from each of the laboratory tests and input to the CRUSH program. Figure 2 shows a CRUSH input session and resulting output. Note that the output is in the form of Alpha and Beta parameters with their associated damage length and energy. After all 20 collisions had been run, the 4 parameters from each run were input to the NLIN subroutine of the Statistical Analysis System to determine the optimum solution to the three equations shown in Figure 3. The output parameters are

TABLE 9

Vans Used for Stiffness Value Derivation

Front		Rear	
79 Ford Econoline E150* (2)	(99,100)	78 Chevrolet C10 Van	(108)
79 Dodge B200 (4)	(101,102,103,104)	78 Dodge B100	(109)
78 Ford Econoline E150	(105)		

*Numbers in parenthesis indicate the line number in Appendix D which contains the contract information

TABLE 10

Pickups Used for Stiffness Value Derivation

Front		Rear	
78 Ford Custom Styleside F250 P.U.	(114)*	78 Datsun P.U.	(115)
78 Chevrolet Luv P.U.	(113)	78 Ford F-100 1/2 Ton P.U.	(116)
78 Ford Custom Styleside F150 P.U.	(112)	78 Dodge D-100 P.U.	(117)
78 Chevrolet El Camino P.U.	(111)	78 Ford Ranchero 1/2 Ton P.U.	(118)
78 Ford Courier P.U.	(110)	78 Toyota SR5 Hilux Long Bed P.U.	(119)
		78 GMC 1500 P.U.	(120)

*Numbers in parenthesis indicate the line number in Appendix D which contains the contract information

TABLE 11

4x4's Used for Stiffness Value Derivation

Front	
78 Subaru Brat	(122)
78 Datsun F-10	(121)
78 AMC Jeep CJ5	(96)

noted in Figure 3 as the values Ahat = 78.07 and Bhat = 0.459. The preliminary values are suspicious, due to the very low predicted slope, Bhat. A likely cause of the problem could be that the laboratory collisions were tightly grouped around crush depths of 12 to 15 inches. Thus, the predicted values of A and B (which at this point are the preliminary values Ahat, Bhat) may provide useful CRASH predictions at crush depths of 12 - 15 inches, but be unacceptable outside that range.

The second step in the parameter derivation is to perform two hypothetical CRASH model reconstructions using the preliminary values, Ahat and Bhat. To accomplish this, the sub-compact rear stiffness values in the CRASH model were replaced with the preliminary values. A vehicle which had a weight and width equal to the average of the 20 laboratory cases was assumed. Two impacts were reconstructed in which full rear crush to the vehicle occurred from hitting a fixed rigid barrier. Crush depths of 32 inches and 8 inches were assumed. The resulting delta-V values were 17.4 and 15.3. These values, when plotted allow a crush vs. delta-V line to be drawn (see Figure 4). The delta-V values outside of the range of the laboratory data are suspect. Particularly, the intercept value is not reasonable, and the adjustment procedure is required.

The adjustment procedure of step 3 utilizes the crush vs. delta-V plot of Figure 4. For any straight line relating delta-V and crush, there exists a unique combination of A and B which coincide with the line. A simple algorithm was written for the computer which would enable the derivation of A and B values for a desired crush vs. delta-V characteristic. The algorithm listing is shown in Figure 5. The required input are two points on a line of crush and delta-V.

```
1978 CHEVROLET MONZA

SIZE CATEGORY VEHICLE NO. 1?
2

SIZE CATEGORY VEHICLE NO. 2?
7

WEIGHT OF VEHICLE NO. 1?
3490

WEIGHT OF VEHICLE NO. 2?
4000

VEHICLE DAMAGE INDICE NO. 1?
06BDAW9

VEHICLE DAMAGE INDICE NO. 2?


IMPACT SPEED VEHICLE NO. 1?, [MPH]
0

IMPACT SPEED VEHICLE NO.2?, [MPH]
29.21

DIRECTION OF PRINCIPAL FORCE FOR VEHICLE NO. 1?
180

DIRECTION OF PRINCIPAL FORCE FOR VEHICLE NO. 2?
360

DAMAGE WIDTH FOR VEHICLE NO. 1?
52

NUMBER OF DAMAGE DEPTH PROFILES FOR VEHICLE NO. 1?
MUST BE 2, 4, OR 6.
4

DAMAGE DEPTH PROFILE FOR VEHICLE NO. 1?
14.4,11.3,11.3,15.4

DAMAGE MIDPOINT OFFSET FOR VEHICLE NO. 1?
0

DAMAGE WIDTH FOR VEHICLE NO. 2?
0

NUMBER OF DAMAGE DEPTH PROFILES FOR VEHICLE NO. 2?
MUST BE 2, 4, OR 6.
2

DAMAGE DEPTH PROFILE FOR VEHICLE NO. 2?
0,0

DAMAGE MIDPOINT OFFSET FOR VEHICLE NO. 2?
0


**** INPUT DATA AND CRUSH ROUTINE RESULTS ****
```

```
1978 CHEVROLET MONZA
VEHICLE TYPES :      2    7
VEHICLE WEIGHTS:     3490.00   4000.00
VEHICLE DAMAGE INDICES: 06BDAW9
COLLISION SPEEDS:         0.00    514.10
A(2),B(2),G(2):          0.00        0.00     514.10
DIRECTION OF PRINCIPAL FORCE:      180.00     360.00
V1 DAMAGE DATA:     52.00            14.40      11.30      11.30      15.4
0      0.00
    0.00        0.27
V2 DAMAGE DATA:      0.00            0.00       0.00       0.00       0.0
0      0.00
    0.00        0.00
GAM(1:2):        1.00       0.73
ENERGY(2):        0.71
DELV1:   233.48
SUMENG:   542060.38
ENERGY(1):  542059.69
ALPHA1,BETA1:          650.00     4101.38

DO YOU WANT THIS DATA ENTERED INTO YOUR DATA SET

TO CALCULATE A AND B VALUES. IF YES TYPE 1, IF NO TYPE 0
1

RUN AGAIN? IF YES TYPE 1, IF NO TYPE 0.
1

TITLE?
```

FIGURE 2

SRL CRUSH Run for 1978 Monza

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   17:01 MONDAY, APRIL 5, 1982

NOTE: THE JOB GUENTHER HAS BEEN RUN UNDER RELEASE 79.5 OF SAS AT OHIO STATE UNIVERSITY (00416)

```
DATA ONE;
INPUT E ALPHA BETA L;
CARDS;
PROC NLIN;
PARMS A= 200 TO 300 BY 10   B= 40 TO 60  BY 5;
MODEL E=A*ALPHA+B*BETA+A*A*L/(2*B);
DER.A=ALPHA+A*L/B;
DER.B=BETA-A*A*L/(2*B*B);
OUTPUT OUT=TWO PARMS=AHAT BHAT;
PROC PRINT;
```

NOTE: SAS INSTITUTE INC
SAS CIRCLE
BOX 8000
CARY, N.C. 27511

OBS	E	ALPHA	BETA	L	AHAT	BHAT
1	647820	1060.04	8587.5	65.8	78.0695	0.459085
2	597981	1031.74	8164.7	65.3	78.0695	0.459085
3	569751	1093.05	9483.4	63.0	78.0695	0.459085
4	590559	1541.94	19270.3	62.0	78.0695	0.459085
5	591170	836.15	5694.1	61.8	78.0695	0.459085
6	597472	712.22	3814.1	66.5	78.0695	0.459085
7	533087	920.53	6637.5	64.0	78.0695	0.459085
8	635488	845.46	5582.8	66.0	78.0695	0.459085
9	637406	787.50	4969.0	63.0	78.0695	0.459085
10	464955	987.62	7011.7	69.6	78.0695	0.459085
11	575605	1333.69	12895.3	69.9	78.0695	0.459085
12	379441	982.09	6919.6	69.8	78.0695	0.459085
13	418686	907.20	6102.1	67.5	78.0695	0.459085
14	396503	624.91	2802.8	69.9	78.0695	0.459085
15	554189	985.54	7010.9	69.6	78.0695	0.459085
16	269374	1002.24	7232.4	69.6	78.0695	0.459085
17	605404	1036.13	7843.8	68.8	78.0695	0.459085
18	446636	1205.02	10371.4	70.1	78.0695	0.459085
19	564224	392.70	2531.4	65.6	78.0695	0.459085
20	399707	858.70	5644.7	65.6	78.0695	0.459085

FIGURE 3

SAS CRUSH Run for Rear Sub-Compact Collisions

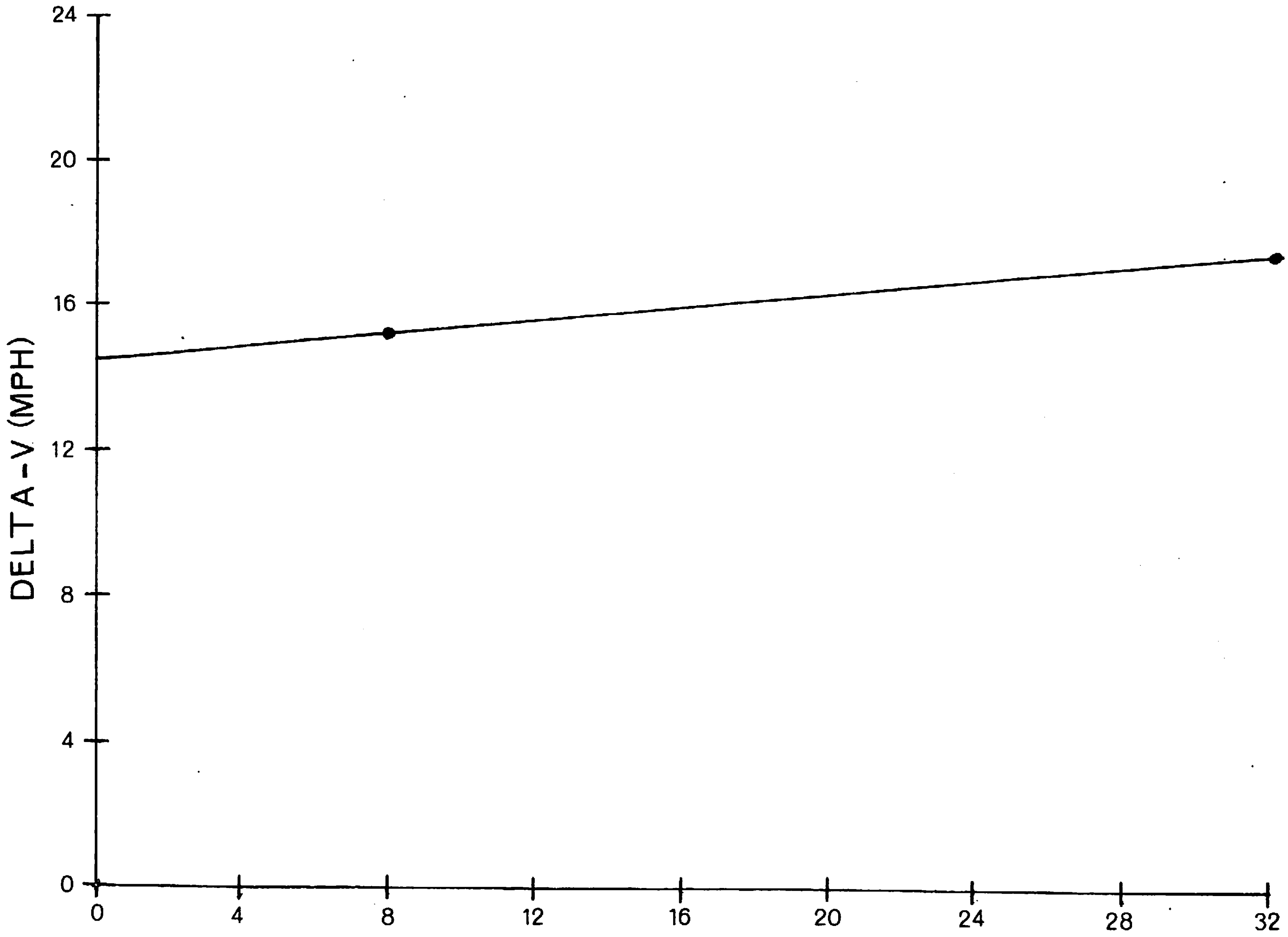


FIGURE 4
CRUSH vs. Delta-V Curve

```
C
C
C  THIS ROUTINE CONVERTS DELTA V VS. CRUSH CURVES TO F/L VS. CRUSH CURVES
C
C
       WRITE(5,10)
10     FORMAT(/////,' INPUT "1" TO INPUT TEST WEIGHT',/,
     1 'INPUT "2" TO CALCULATE TEST WEIGHT FROM DATA')
       READ(5,*)IND
       IF (IND.EQ.1) GO TO 50
       WRITE(5,15)
15     FORMAT(' HOW MANY TEST WEIGHTS DO YOU WISH TO AVERAGE?',$)
       READ(5,*)MW
       TESTW = 0
       DO 40 I=1,MW
       WRITE(5,20)I
20     FORMAT(' INPUT TEST WEIGHT NO. ',I2,' ',$)
       READ(5,*)TW
       TESTW=TESTW+TW
40     CONTINUE
       AVRW=TESTW/MW
       GO TO 100
50     WRITE(5,55)
55     FORMAT(' INPUT AVERAGE TEST WEIGHT (LBS) ',$)
       READ(5,*)AVRW
100    WRITE(5,110)AVRW
110    FORMAT(//,'AVERAGE TEST WEIGHT IS ',F10.4)
C
C
C CALCULATE AVERAGE TEST MASS
C
C
       AVRM=AVRW/32.2/12
C
C
C DETERMINE AVERAGE TEST CRUSH LENGTH
C
C
       WRITE(5,120)
120    FORMAT(////,' INPUT "1" TO INPUT AVERAGE CRUSH LENGTH',/,
     1 ' INPUT "2" TO CALCULATE LENGTH FROM DATA')
       READ(5,*)IND
       IF (IND.EQ.1) GO TO 150
       WRITE(5,115)
115    FORMAT(' HOW MANY LENGTHS DO YOU WISH TO AVERAGE?',$)
       READ(5,*)ML
       TESTL = 0
       DO 140 I=1,ML
       WRITE(5,125)I
125    FORMAT(' INPUT LENGTH NO ',I2,' ',$)
       READ (5,*)TL
       TESTL=TESTL+TL
140    CONTINUE
       AVRL=TESTL/ML
       GO TO 200
150    WRITE(5,155)
155    FORMAT(' INPUT AVERAGE CRUSH LENGTH ',$)
       READ(5,*)AVRL
200    WRITE(5,210)AVRL
210    FORMAT(///,' AVERAGE CRUSH LENGTH IS ',F10.4)
C
C
C DETERMINE SLOPE AND INTERCEPT OF DELTA V VS. CRUSH CURVE
C
C
C
       WRITE(5,300)
300    FORMAT(///,' INPUT DELTA V AT 12 IN. CRUSH [MPH] ',$)
       READ(5,*)V1
       WRITE(5,310)
310    FORMAT(///,' INPUT DELTA V AT 0 IN. CRUSH [MPH] ',$)
       READ(5,*)V0
       YINT=V0*17.6
       SL=(V1-V0)*17.6/12
C
C
C CALCULATE A,B,G
C
C
       A=YINT*SL*AVRM/AVRL
       B=SL**2*AVRM/AVRL
       G=A**2/(2*B)
C
C PRINT RESULTS
C
       WRITE(5,400)A,B,G
400    FORMAT(//,' A= ',F10.4,//,' B= ',F10.4,//,' G= ',F10.4)
       STOP
       END
```

FIGURE 5 - Algorithm for A and B Values

For the adjustment of the Ahat and Bhat values, it was assumed that the value of delta-V at 12 inches of crush was good and that a 5 mph delta-V could be sustained with no permanent crush to the rear of the vehicle. These two points yielded adjusted values of:

$$A = 169.37$$
$$B = 29.92$$
$$G = 479.35$$

This completed the procedure for obtaining rear stiffness values of sub-compact vehicles. A similar procedure was followed for all of the passenger car as well as the light truck categories. In some instances, the adjustment procedure of step 3 was not required.

The individual CRUSH computer runs for all passenger car and light truck laboratory tests are contained in Volume II of this report. The Volume is indexed to allow each category to be located and the parameter derivation traced.

A visual presentation of the passenger car results is shown in Appendix E. Each figure shows the crush vs. delta-V result of the old stiffness values, the unadjusted new values and where adjustment was necessary, the adjusted new values. An additional line is shown for the frontal stiffness parameters of Appendix E. This represents the average of the old and the new (or new adjusted) stiffness values. The reason for averaging is discussed in a later section of this paper, "Discussion of Stiffness Values". The final stiffness values are shown in Tables 12 and 13.

The process selected for parameter derivation in this study is not claimed to yield optimum results. Two additional methods for derivation are known but were not used in this study. The first is to utilize a standard optimization routine that hunts for A and B values which best reconstruct the test cases. The second method also utilizes the CRUSH model approach but bypasses the adjustment process by entering "dummy" crash test results at speeds outside the narrow range of most crash test data. The second method was used by

TABLE 12

Crush Coefficients Based on
CRUSH Program

		Minicar	Subcompact	Compact	Intermediate	Full/Large
	A =	294.8	363.6	415.4	440.23	368.19
Front	B =	43.5	36.4	41.5	34.85	38.84
	G =	998.9	1817.9	2077.0	2280.3	1745.3
	A =	77.2	258.4	35.7	342.4	218.0
Side	B =	36.7	28.0	72.8	44.3	41.7
	G =	81.3	1160.8	8.8	1324.3	570.3
	A =	365.7	390.5	410.6	356.6	296.8
Rear	B =	38.1	40.7	93.6	12.8	70.1
	G =	1755.4	1874.4	1930.9	4986.0	628.1

TABLE 13

Stiffness Values for Vans, Pickups and 4x4's

		VANS	PICKUPS	4x4's
FRONTAL	A	383	480	390
	B	126	50	32
	G	580	2315	2255
REAR	A	300	346	320*
	B	55	25	20*
	G	818	2373	2560*

*Estimated, no data to verify

Jones[4] in a similar study of European vehicles. The first is judged to be sensitive to clustered data just like the method that was chosen.

Validation of the New Stiffness Values - There were two levels of validation recognized as possible to check the newly derived parameters. The first level was that of reconstructing the staged collisions which were used as model input to derive the parameters. Such reconstructions were performed with both models (the CRASH model containing the old stiffness values and the CRASH model containing the new stiffness values). The second level of validation was to reconstruct staged collisions which were not used to derive the stiffness parameters. This was recognized as a much better check of the model accuracy, however, such a validation was only possible for a few categories as will be discussed.

The first level of validation was performed as follows:

1) If less than 10 collisions were used to derive stiffness values, all were reconstructed in the validation process.
2) If more than 10 collisions were used, 10 were randomly selected and reconstructed.

The validation of the rear stiffness values for subcompact vehicles will be shown to illustrate the procedure. As shown earlier, a total of 20 staged collisions were used in the derivation of the parameters. A random selection process yielded 10 cases which were reconstructed with the old and the new parameters. Table 14 shows the results of the two reconstructions for each of the 10 collisions. The new coefficients were found to yield more accurate reconstructions, as was expected, for the subset of data used.

Two additional subcompact rear-end collisions were performed at Calspan Corporation[5] using fairly recent model cars. In each impact, a 1974 Ford Pinto was impacted in a 10 degree rear offset configuration by a 1974 Ford Torino. Again, the reconstructions were performed using the old and new models. Table 15 shows the results of the reconstructions. The new parameters showed improvement.

TABLE 14

Level I Validation of Rear Stiffness Parameters, Subcompact Vehicles

NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Parameters Delta-V1	Old Parameters Delta-V2	New Parameters Delta-V1	New Parameters Delta-V2
NHTSA-8-0323 74 Pinto	18.3400	11.5400	13.9000	8.7000	20.2000	12.7000
NHTSA-8-0323 74 Pinto	21.9500	13.3700	19.1000	11.6000	27.1000	16.5000
NHTSA-8-0323 71 Vega	22.2500	12.5300	18.7000	10.5000	26.2000	14.8000
NHTSA-8-0323 71 Pinto	19.3800	10.5300	14.6000	7.9000	23.5000	12.8000
NHTSA-8-0323 71 Vega	26.1200	14.6100	21.1000	11.8000	29.4000	16.4000
77 MVMA	15.9200	14.4800	8.2000	7.4000	16.8000	15.2000
77 MVMA	15.6000	13.6100	6.4000	5.6000	13.5000	11.8000
77 MVMA	15.7700	13.5500	6.7000	5.7000	14.2000	12.2000
77 MVMA	16.8000	13.0000	8.5000	6.6000	17.6000	13.6000
77 MVMA	16.2900	12.7100	7.8000	6.1000	16.4000	12.8000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 111.4500

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 39.0100

10 RUNS WERE MADE IN CALCULATING THESE VALUES

TABLE 15

Level II Validation of Rear Stiffness Parameters, Subcompact Vehicles

	Actual		Old Parameters		New Parameters	
	delta-v1	delta-v2	delta-v1	delta-v2	delta-v1	delta-v2
RICSAC[4] Test #3	9.5	15.8	3.1	4.9	5.4	8.6
RICSAC TEST #4	15.1	23.6	9.1	14.1	17.0	26.5

A similar approach was followed for the other categories. Appendix F contains the results of each type of validation (level I and, when possible, level II) for all of the passenger car and light truck stiffness categories. In many instances, only a level I validation was performed due to the lack of separate, late model collision data with which to perform the level II validation.

Discussion of Stiffness Values - Based upon the quantity and quality of the data available, the frontal and rear passenger car stiffness values were judged to be quite reliable. It was understood that the values were representative of the average stiffness of the vehicles tested. No effort was put forth in this study to identify "outriggers" (vehicles which have individual stiffness values that vary greatly from the size category to which they belong) or to compute stiffness values for individual vehicle models. Both would be reasonable topics for another study. The frontal values were found to be relatively close to those computed earlier in Reference 1. If the differences in frontal stiffness values were judged to result from vehicle fleet differences, then it would make sense to compute an average or weighted average of the old and the new values. If the differences were judged to result from an increase of data, then it would be reasonable to discard the former values and use the new values. The judgement was made that the differences were fleet differences and that the old values should be averaged with the new. To accomplish the averaging, the crush vs. delta-V plots (Appendix E) were used. A line was placed mid-way between the old and the new (or adjusted new) lines on each plot. The A, B and G values which correspond to the mid-line were then computed. Table 16 presents the averaged frontal stiffness values of the "old" and "new" vehicle fleets.

NOTE: The averaged stiffness values shown in Table 16 were implemented in the "Crash III" version under the direction of the NCSA in Washington, D.C. in January, 1982.

The rear stiffness values for passenger cars were found to be more noticeably different from the old values. The earlier values were based upon very little actual data, so the new values were judged to be an improvement. The earlier values were replaced by the new values. (See p. E-15) X

The side impact test data were lacking in quantity and were of somewhat questionable quality. Data were only available for three passenger car categories. The bulk of the data was extracted under the RICSAC[5] study and the actual test reports were not available. Some additional data were from testing with the barrier specified in Federal Motor Vehicle Safety Standard 208 and the loading is not representative of a car-to-car impact. It was judged that the old side stiffness values should be retained until more or better data become available.

TABLE 16

Averaged (Old & New) Passenger Car
Frontal Stiffness Values

Frontal Impact	1 (Mini)	2 (Subcompact)	3 (Compact)	4 (Intermediate)	5 (Full/Large)
A	301.54	259.38	317.35	355.88	325.18
B	47.04	43.23	55.94	33.78	37.03
G	966.74	778.13	900.11	1874.9	1427.61

NOTE: The averaged stiffness values were implemented in the "Crash III" version under the direction of the NCSA in Washington, D.C. in January, 1982.

ANALYSIS OF LINEAR FORCE DEFLECTION ASSUMPTION

Background - It was previously pointed out that the CRASH model was formulated with an assumed straight-line relationship between vehicle crush and force (see Figure 1). It was noted that a value "A" was derived to denote the level of force at which permanent crush was initiated. The value "B" was used to denote the slope of the line. Both values were derived as "unit-length" values, i.e., force per unit of crush length and stiffness per unit of crush length. One further relationship, not previously pointed out, is the physical meaning of the "G" value. If the line shown on Figure 1 were extended until it intersects the abscissa (see Figure 6), the area enclosed by the abscissa, the ordinate and the force line has the value "G". Expressed mathematically in terms of A and B:

$$G = \frac{A^2}{2B}$$

SRL's understanding is that it was derived to represent the elastic energy of crushing the unit of vehicle surface. For the front or rear surface it could conceptually be thought of as the energy per unit vehicle width absorbed by the energy absorbing bumper system before any permanent deformation was caused. A vehicle impacting a fixed barrier at a speed at which its kinetic energy was equal to the product of G and the vehicle width would bottom out the energy absorbing bumper but cause no permanent crush. No physical evidence is known to justify the assumption that the elastic stiffness is equal to the plastic stiffness of a vehicle surface. Since that assumption was not the topic of this study element, it was left to future analysis.

The pages cited in Appendix A give an overview of the derivation of the energy resulting from a collision and the formulation of delta-V. The formulation becomes much more complex if other than straight-line properties are assumed for the force vs. deflection. All of the equations that lead to the computation of delta-V from crush measurements would need to be rederived if other than a linear force vs. deflection is assumed. It was not the intent of this element to derive a new model, but rather to investigate the

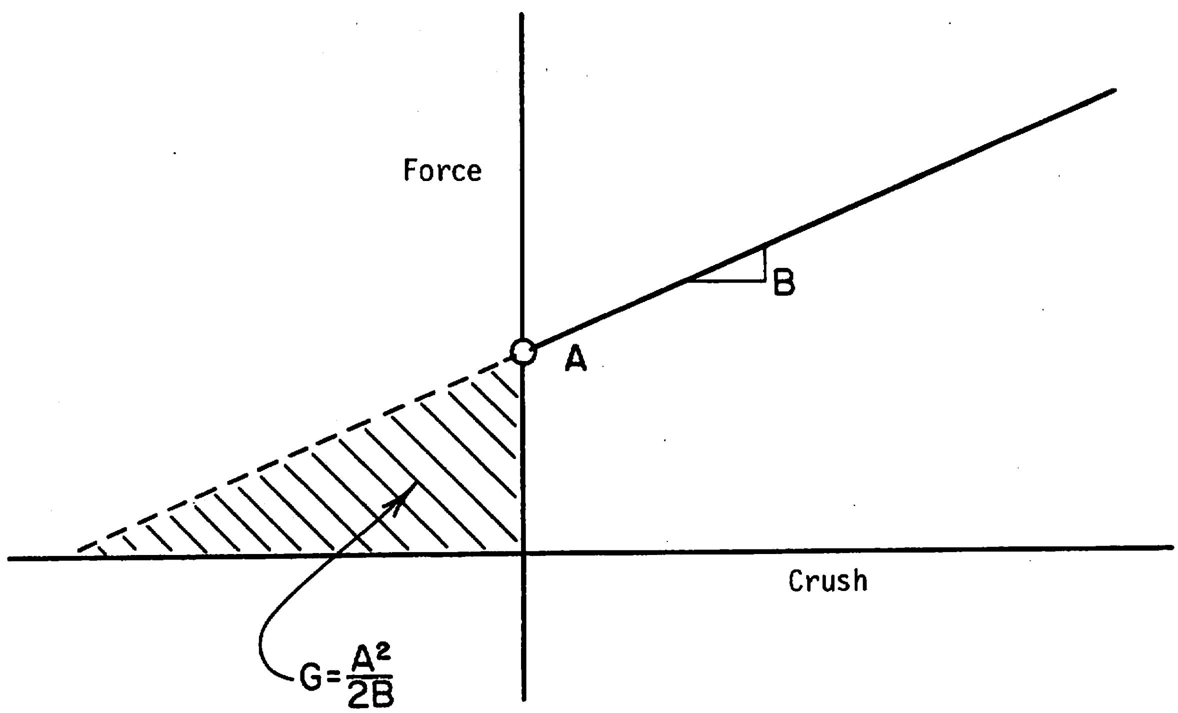


FIGURE 6
Extrapolated Force vs. CRUSH Curve

benefit that might be expected from a more complicated force vs. deflection relationship.

Selected Laboratory Collision Analysis - It was decided to select two series of vehicle crashes for analysis:

(1) Chevrolet Citation/barrier collisions at three different impact speeds. Selected for analysis because the force vs. deflection curves derived from the accelerometer data were observed to be nearly linear, matching the linearity assumption of CRASH.

(2) Ford Torino/barrier collisions at five different impact speeds. Selected for analysis because the force vs. deflection curves derived from accelerometer data were observed to be bi-linear, violating the linearity assumption of CRASH.

Because a range of speeds were used in the collision testing of each vehicle, it was possible to compute stiffness values for each vehicle individually.

Chevrolet Citation - Figure 7 presents information relating to the Citation crashes. The actual force vs. deflection plots (derived from the accelerometer traces) are shown for the 35, 40, and 48 mph impact speeds. A straight line has been placed over these showing the regression fit to the traces. This straight line represents the actual linear force vs. deflection characteristics as approximated from the accelerometer data.

The CRUSH model was run with the three Citation tests as input. The following frontal stiffness parameters were derived:

A = 515.7		
B = 15.9	CRUSH Model Derived Parameters	
G = 8372.8		

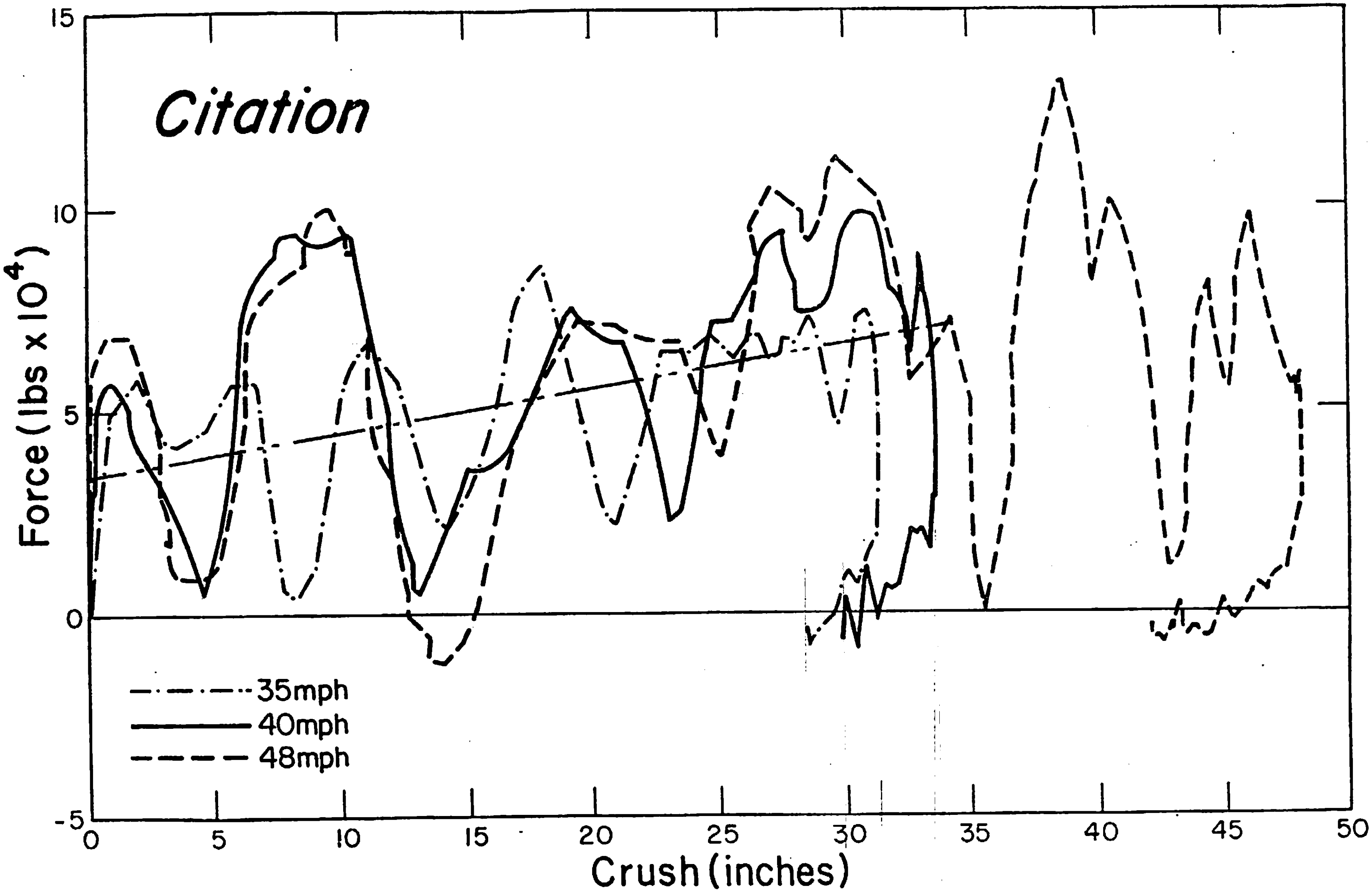


FIGURE 7
Citation CRUSH Response

The frontal stiffness values which correspond to the straight-line fit of the accelerometer data were:

A =	585.7	
B =	11.9	Accelerometer Derived Parameters
G =	14459.3	

It was noted in this excercise that the stiffness values derived by CRUSH are not necessarily the actual stiffness values of a vehicle or class of vehicles, i.e., they do not match the experimentally derived force vs. deflection. The reason for this is most likely due to the fact that the equations in the model define assumed relationships between crush and energy. The use of static crush, rather than dynamic crush, exaggerates the stiffness value "B". The two independent sets of stiffness values were then used to reconstruct the three Citation collisions. The results are shown on Table 17. It was noted that the actual vehicle stiffness values did not produce reconstructions which were as accurate as the CRUSH derived coefficients. An analysis of the two sets of parameters revealed that actual stiffness values were penalized by the "G" value which resulted from the assumed formulation. The actual intercept (A) was larger and the actual slope (B) was less, both having the effect of making the area under the tail of the curve larger. It became apparent that a separate approach was needed by which delta-v values predicted from accelerometer derived stiffness data could be compared with the traditional CRASH values shown in the middle column of Table 17. The approach selected was to use dynamic crush and to simply calculate the area under the force vs. deflection line. The following steps were used in this formulation:

1) The accelerometer time history was processed to derive the cross plot of force and deflection (at 15 Hz).
2) A straight line was fit (by least squares regression techniques) to the accelerometer derived force vs. deflection curve. For bi-linear curves the process was the same, except that two lines were fit.

TABLE 17

Citation Barrier Test Reconstructions

Actual Delta-v	CRASH II With CRUSH Derived Coefficients	CRASH II with Accelerometer Derived Coefficients
35.0	34.7	39.4
39.9	39.7	43.9
48.0	47.8	51.0

3) The dynamic crush was determined by dividing the static crush by the average ratio of static to dynamic for the test series. (Note: The dynamic crush had been measured in the laboratory tests but is not available in highway accidents. It was decided to maintain techniques which could be transferred to highway accidents, so the dynamic crush was computed from the static crush.)
4) The area was found under line number 1 (see Figure 8)
5) The area was found under line number 2 (if the curve was bi-linear).
6) The energy was then computed: $E = [Area_1 + Area_2]$
7) The delta-V was computed: Delta-V = SQRT[2XE/M]

A comparison of the two reconstruction methodologies was conducted as follows:

1) The three Citation collisions (all of which had near linear force vs. deflection characteristics) were reconstructed by the new approach using an assumed linear force vs. deflection.
2) The results were compared with those obtained from the conventional approach (Table 17, middle column).

Table 18 shows this comparison.

In the process of working with the force-crush curves, inconsistencies were observed between reported static crushes (used in the conventional approach) and static crushes determined from the acceleration responses (used in the acceleration-data approach).

Consequently, the SRL reviewed the crash test films and found agreement between static crushes obtained from accelerometer data and film analysis. This indicated that the reported static crushes (measured post-tests) were probably not measured in a manner compatible with this type of modeling. In spite of this apparent difference, excellent correlation was seen in Table 17 between actual delta-V's and delta-V's obtained by the conventional approach. The reason for this is simply that the reported static crushes were used to generate the CRUSH coefficients (A, B, and G) describing the curve which

TABLE 18

Comparison Between Hand Calculation
Method and Conventional (CRUSH & CRASH) Method - Citation

Actual Delta-v	Conventional Method	Hand Calculated from Accelerometer Data
35.0	34.7	34.7
39.9	39.7	36.5
48.0	47.8	47.6

best fit the three data points. In "reconstructing" the delta-V's, the same reported crush values were used. The correlation seen was, therefore, not an indication that the force-crush curve described by A, B and G represents the physical properties of the vehicle (it would not have the proper slope or intercept for the Citation), but it was an indication of the validity of the linearity assumption for the Citation (if nonlinear, agreement would not be possible for all three points).

The conclusions for the Citation analysis were:

1) The straight line approximation fitted the data very well.
2) Hand calculations of energy under the straight line fit through the force vs. deflection data also yield good results, provided the static crush measurements are accurate.

Ford Torino - Figure 8 shows the force-deflection curves of five tests with the Torino at speeds from 15 to 40 mph. The data (shown filtered at 60 Hz) was filtered to 15 Hz to smooth the curve. The digital data points were input to a standard regression routine and the straight line best representing the first portion of data was computed. The point of intersection of the two straight lines was selected "by eye". A computer routine could probably have been written to optimize a bilinear curve to data points but this was not done. The resulting bilinear curve is judged to be a good, though not an optimum, representation of the data. It was also judged adequate to conduct this level of investigation of the curve shape. Following the formulation based on accelerometer data, the energy and delta-V at each level of dynamic crush were computed by hand. In addition, the 5 data sets of static crush and actual delta-V were input to the CRUSH model and the linear stiffness values for the CRASH II model were computed by the conventional approach. The five cases were then reconstructed with CRASH II. The results are intended to provide a reasonable comparison of the two methods -- linear and bi-linear formulation.

Problems were encountered in this analysis and, as with the Citation, data inconsistencies were noted. The degree to which these problems biased the

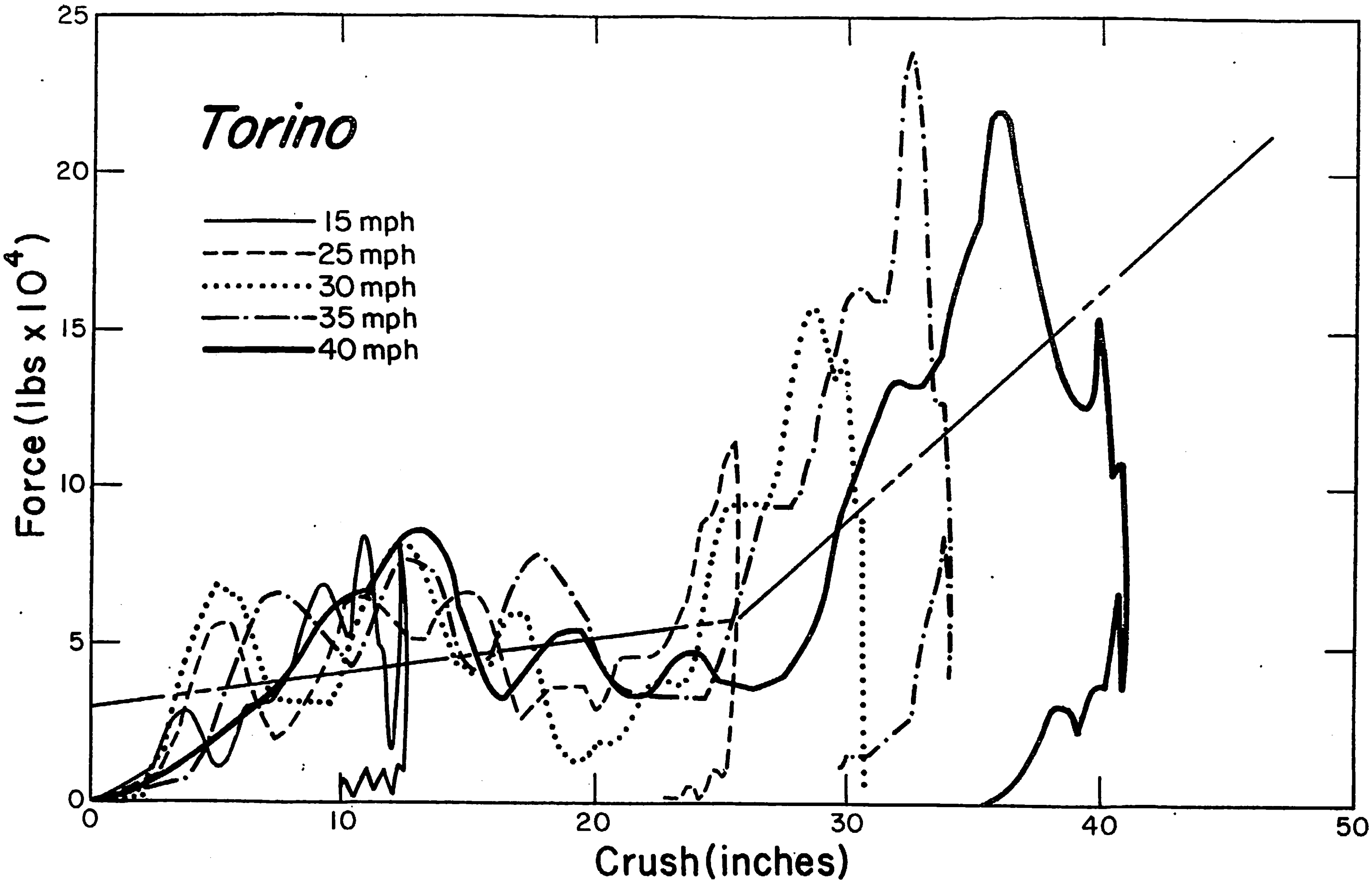


FIGURE 8

Torino CRUSH Response

results to favor one formulation or the other was not determined. The static crush measurements again appeared to be out of line with the dynamic data. The test films were not available to determine which was correct. Table 19 shows the average static crushes recorded by the contractor from post-test measurements. Also shown are the dynamic crushes derived from the accelerometer data.

TABLE 19 -- Torino Static CRUSH and Dynamic CRUSH Measurements

Test Speed (mph)	Post Test Static Crush (in)	Accelerometer Dynamic Crush (in)	Ratio of Static/Dynamic
14.8	7.	12.5	.56
25.5	17.7	25.6	.69
30.4	19.5	30.6	.64
35.2	25.5	34.	.75
40.5	30.6	41.	.75

The ratio of static over dynamic crush is generally expected to range from .8 to .9 (based on scores of laboratory dynamic tests). The above ratios of .56 to .75 are not realistic. The same problem was encountered with the Citation data and the film analysis indicated the accelerometer data to be accurate. Therefore, the static crush measurements were taken from the curves on Figure 8, defining the crush at which the force level returns to zero as the static crush. Table 20 presents this data.

TABLE 20 -- Torino Accelerometer Static & Dynamic Crush Measurements (From Figure 8)

Test Speed (mph)	Accelerometer Static Crush (in)	Accelerometer Dynamic Crush (in)	Ratio of Static/Dynamic
14.8	10.	12.5	.8
25.5	23.	25.6	.9
30.4	--.	30.6	.--
35.2	29.	34.	.85
40.5	35.5	41.	.87

The average ratio by this method was .85.

The static crush was divided by .85 in each case to obtain dynamic crush. The dynamic crush was used to perform hand calculations of energy under the bi-linear curve. The results are presented in Table 21.

TABLE 21 -- Reconstruction Results by Linear and Bi-linear Methods

Actual Impact Velocity	Crash II Linear	Hand Calculated Bi-Linear
14.8	16.6	14.3
25.5	26.9	24.7
30.4	--.--*	--.--*
35.2	34.	32.4
40.5	41.3	41.1

* The accelerometer trace was not integrated to the rebound stage for this test on Figure 8 -- no static crush was determined.

The parameter values used for the above table were as follows:

Linear		Bi-Linear	
A =	449.6	A =	406.
B =	46.5	B1 =	11.1
G =	2173.5	B2 =	104.7

One observation from this presentation is that the straight line approach of the CRASH II model fits these data very well even though the actual force-deflection appears bi-linear. The sum of the squares of the differences was 8.9 for the bi-linear and 7.3 for the linear. The bi-linear was not better than the linear. This was not interpreted to mean that a bi-linear curve could not be optimized which would give better overall results than the linear. It did indicate the surprising accuracy of the linear approach when a wide spread of velocity data is available for a vehicle or class of vehicles. This was evidenced from both the Citation and Torino analyses. It suggested that very little benefit can be gained by formulating a more complicated curve fit approach through the kind of data presently available.

The conclusions from the Torino analysis were:

1) The linear assumption of the CRASH model appeared reasonable for these four Torino collisions.
2) Hand calculations of energy under the bi-linear fit of the data also yielded good reconstructions.
3) Based on the Torino collisions, there did not appear to be a need to formulate a more complicated model. The need was rather to obtain the same quality and quantity of data for all vehicles or vehicle classes, as were available for the Citation and Torino.

It should further be pointed out that in both the Citation and Torino analyses, lower speed collisions were not focused on. It may well be that in the 5 to 20 mph range of speeds, a bilinear formulation would render a more accurate presentation of actual collisions. Data were not available for these vehicles in that range of speeds. In addition, the interest in such low speed collisions is not as high among most accident researchers. The conclusions presented though, only pertain to the speed ranges analyzed.

ANALYSIS OF OBLIQUE-FORCE ENERGY CORRECTION FACTOR

In the Crash II model, absorbed energy in angled collisions is calculated as:

$$E = (1 + \tan^2 \alpha)\ f(A, B, C_N, L_N) \qquad \text{eq. 1}$$

where   is the angle between the direction of force and a line normal to the side of the vehicle being impacted. Derivation of the $(1 + \tan^2 \alpha)$ term apparently results from an assumption that the resultant force (F_R) per unit length along the struck side of the vehicle is a function of normal depth of penetration (C_N) and the impact angle (α) as follows:

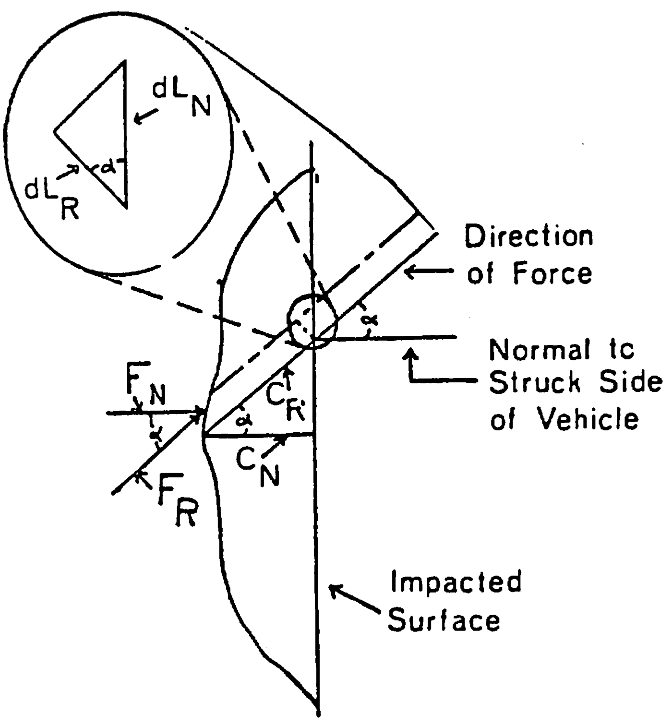


FIGURE 9

Force Components of a Side Collision

$$F_N = A + BC_N$$

$$F_R = \frac{F_N}{\cos \alpha} + \frac{A + BC_N}{\cos \alpha} \qquad \text{eq. 2}$$

By this assumption, the tangential force component (F_T) is given by

$$F_T = F_N \tan \alpha$$

The value of F_T increases without limit as α approaches 90^o. This leads to the $1 + \tan^2 \alpha$ correction factor as follows:

$$E = \int_0^{L_N} \int_0^{C_R} F_R\, dC_R\, dL_N$$

$$E = \int_0^{L_N} \int_0^{C_R} \left(\frac{A + BC_N}{\cos \alpha} \right) dC_R\, dL_N \qquad \text{eq. 3}$$

$$C_N = C_R \cos\alpha \qquad \text{eq. 4}$$

$$E = \int_0^{L_N} \int_0^{C_R} \left(\frac{A}{\cos\alpha} + BC_R \right) dC_R dL_N$$

$$E = \int_0^{L_N} \left(\frac{AC_R}{\cos\alpha} + \frac{B}{2} C^2_R \right) dL_N$$

$$E = \int_0^{L_N} \left(\frac{A}{\cos\alpha} \left(\frac{C_N}{\cos\alpha} \right) + \frac{B}{2} \frac{C^2_N}{\cos^2\alpha} \right) dL_N$$

$$E = \frac{1}{\cos^2\alpha} \int_0^{L_N} \left(AC_N + \frac{B}{2} C^2_N \right) dL_N$$

But since $\frac{1}{\cos^2\alpha} = 1 + \tan^2\alpha$

$$E = (1 + \tan^2\alpha)\, f(A, B, C_N, L_N) \qquad \text{eq. 5}$$

as in equation 1.

Figure 10 shows the function $(1 + \tan^2\alpha)$ plotted for correction factor angles ranging from zero to 75 degrees. The present version of the CRASH model (CRASH II) limits this energy correction factor to the functional value at $\pm$75 degrees, i.e. the correction factor is less than or equal to 14.9. It is noted that the function is fairly flat over the range of correction factor angles of zero (normal to surface) to 30 degrees. The energy correction factor is 1.0 at 0 degrees, 1.33 at 30 degrees, 2.0 at 45 degrees, 4.0 at 60 degrees and 14.9 at 75 degrees. The extreme sensitivity and high values for the correction factor at angles above 30^{o} suggest that the assumptions break down at high impact angles.

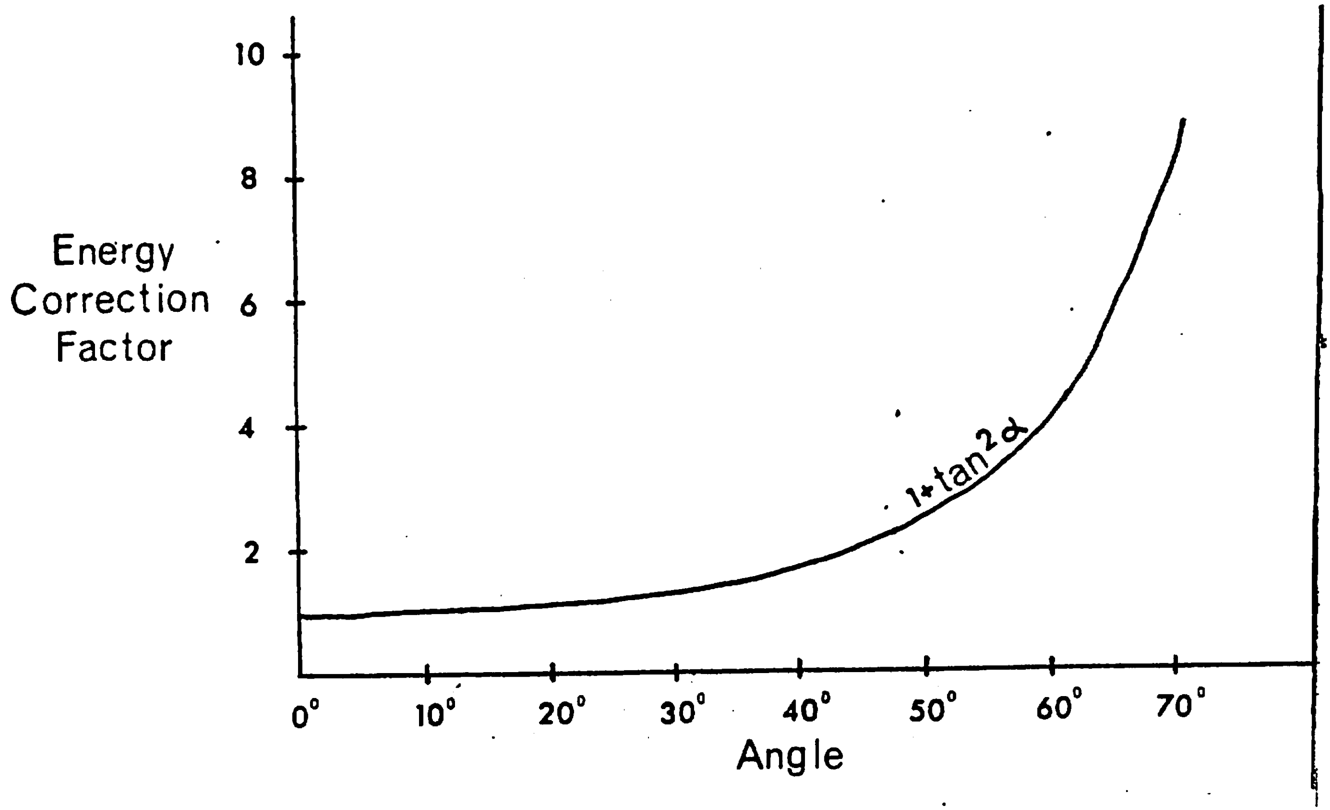


FIGURE 10 - Energy Correction Factor vs. Angle

Alternatively, it could be assumed that the vehicle is isotropic and that the resultant force-vs-deflection characteristic (F_R) is a function of (1) the width of the deflected area normal to the direction of deflection, and (2) the depth of penetration normal to the impacted side of the vehicle. These assumptions yield a correction factor of 1 for all force direction angles, as follows:

$$F_R = A + BC_N \quad \text{eq. 6}$$

$$L_R = \cos\alpha \; L_N : dL_R = \cos\alpha \; dL_N \text{ (see Figure 9)} \quad \text{eq. 7}$$

$$E = \int_0^{L_R} \int_0^{C_R} F_R dC_R dL_R \quad \text{eq. 8}$$

$$E = \int_0^{L_R} \int_0^{C_R} (A + BC_N) \; dC_R dL_R$$

From Eq. 4

$$E = \int_0^{L_R} \int_0^{C_R} (A + B \cos\alpha\, C_R)\, dC_R\, dL_R \qquad \text{eq. 9}$$

$$E = \int_0^{L_R} \left(AC_R + \frac{B \cos\alpha\, C^2_R}{2} \right) dL_R$$

From Eq. 4 and Eq. 7

$$E = \int_0^{L_R} \left(\frac{AC_N}{\cos\alpha} + \frac{B\cos\alpha}{2} \frac{C^2_N}{\cos^2\alpha} \right) \cos\alpha\, dL_N$$

$$E = \int_0^{L_R} \left(AC_N + \frac{BC^2_N}{2} \right) dL_N \qquad \text{eq. 10}$$

The integral in eq. 10 is over the entire damage area. The value of the integral outside the damage area is 0 since c_N is 0. Thus the limit can be extended from L_R to $L_R/\cos\alpha$ without affecting the value of the integral. Then by direct substitution from eq. 7

$$E = \int_0^{L_R/\cos\alpha} \left(AC_N + \frac{BC^2_N}{2} \right) dL_N = \int_0^{L_N} \left(AC_N + \frac{BC^2_N}{2} \right) dL_N \qquad \text{eq. 11}$$

This relationship is independent of α, indicating a correction factor of 1 for all impact angles.

In the next section, the two correction factor formulations will be compared to the available experimental data.

Laboratory Test Data - In order to check out the above derivations, it would be ideal to have a body of data for collisions in which the relative velocity angle was varied. This could be accomplished by conducting a series of side impacts with identical cars, and varying the impact angle and speed ratios to get relative velocity angles from near zero to near 90 degrees. Such data would allow thorough analysis of the relationship between the force angle and the relative velocity angle as well as the relationship between force angle and crush energy.

Table 22 shows a tabulation of a few tests for which the necessary information was obtainable. The table contains data from 11 tests performed by three contractors under separate contracts. The first two contracts in column A were conducted specifically for the purpose of furthering accident investigation capabilities. The third contract was a side impact safety research effort in which data useful for accident investigation was also extracted.

The direction of the relative velocity vector (with respect to the struck vehicle) is shown in column E. The relative velocity is defined as the vector difference between the striking and struck vehicle velocity vectors. Both the magnitude and orientation of the impact speeds are necessary to compute the relative velocity direction. An example is shown in Figure 11 for Case Number 9. The relative velocity direction is the direction that the bullet vehicle appears to be traveling as viewed by an occupant of the struck vehicle. If the vehicle were actually homogeneous or isotropic, the force direction would be the same as the relative velocity direction.

Column F presents the clock direction of force assigned by the contractor or a trained accident investigator. All of the CDC's were assigned by trained accident investigators (trained in accordance with the National Crash Severity Study and/or National Accident Sampling System protocol) except those of the

TABLE 22

Laboratory Tests Used for Energy Correction Factor Analysis

	A	B	C	D	E	F	G	H	I	J	K	L
	Contractor/ Contract No.	Test No.	Impact Angle	Impact Speeds (mph)	Relative Velocity Angle	Investigator/ Contractor Force Direction	Reconstructionist Force Direction	Instrumentation Force Direction(*)	Instrumentation Correction Factor	Total Kenetic Energy Loss Ft-Lb	CRASHII Energy - No Correction Factor Ft-Lb	Laboratory Correction Factor J/K
1.	Calspan Corp. DOT-HS-7-01511	1	60°	19.8/ 19.8	30	01 o'clock	30	40	2.4	63,034	60,795	1.0
2.	Calspan Corp. DOT-HS-7-01511	2	60°	31.5/ 31.5	30	02 o'clock	60	35**	3.0	162,640	150,840	1.1
3.	Calspan Corp. DOT-HS-7-01511	6	60°	21.5/ 21.5	30	02 o'clock	60	42	2.2	62,590	66,556	.94
4.	Calspan Corp. DOT-HS-7-01511	7	60°	29.1/ 29.1	30	02 o'clock	60	54	1.5	108,849	107,044	1.0
5.	Calspan Corp. DOT-HS-7-01511	8	90°	20.8/ 20.8	45	03 o'clock	45	60	1.3	62,725	24,931	2.5
6.	Calspan Corp. DOT-HS-7-01511	9	90°	21.2/ 21.2	45	02 o'clock	25	45	2.0	38,584	17,907	2.1
7.	Calspan Corp. DOT-HS-7-01511	10	90°	33.3/ 33.3	45	01 o'clock	25	50	1.7	91,601	23,754	3.8
8.	Texas Instruments Institute DOT-HS-01262 & DOT-HS-01656	2	90°	25.6/ 26.5	-45	09 o'clock	--	-60	1.3	76,175	60,801	1.25
9.	Texas Instruments Institute DOT-HS-01262 & DOT-HS-01656	3	60°	38.5/ 26.5	-36	11 o'clock	--	-52	1.6	114,871	178,649	.64
10.	Dynamic Science Inc. DOT-HS-9-02177	8330-4	60°	30.2/ 15.4	-40	11 o'clock	-42	-65***	1.2	33,419	36,650	.91
11.	Dynamic Science Inc. DOT-HS-9-02177	8329-1	90°	40.8/ 20.8	-63	10 o'clock	-54	-75***	1.1	64,368	103,044	.62

*See Appendix G for procedure
**Incomplete instrumentation history; done by film analysis by personnel within the National Center for Statics and Analysis
***Taken directly from Contract Progress Reports

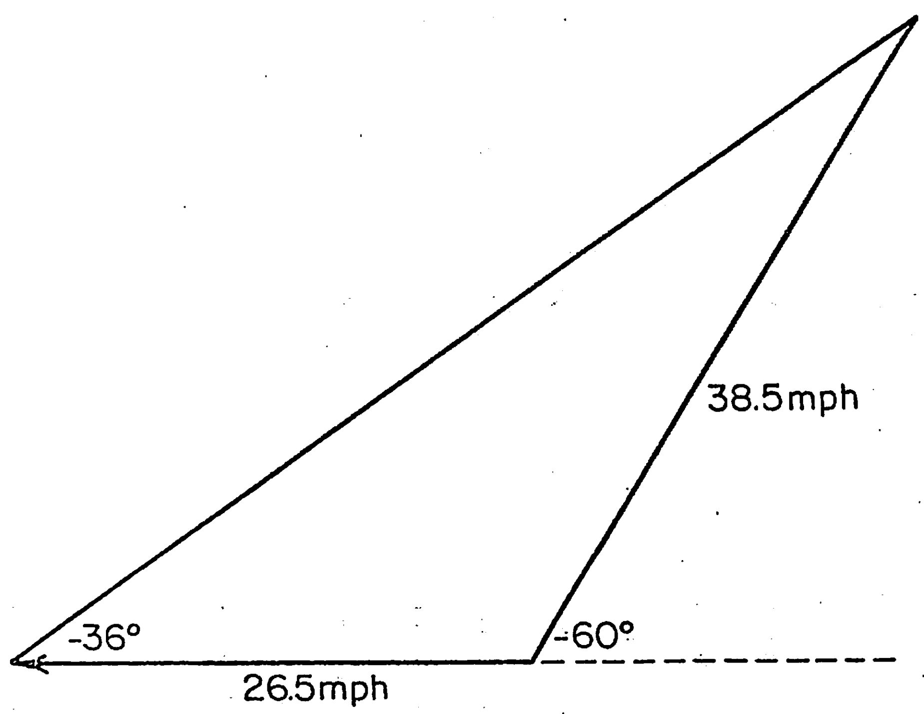


FIGURE 11
Velocity Polygon for 60° Side Oblique Impact

two Texas Transportation Institute (TTI) tests which were assigned by the contractor.

Column G presents the force angle used for the CRASH II model reconstruction of the test. These are also assigned by trained reconstructionists. No CRASH II reconstructions were performed in the TTI study.

Column H presents an estimate of the average force direction on the side struck car over the impact event, as derived from the vehicle accelerometer data. Since the estimate is somewhat subjective and is sensitive to the methodology chosen, the approach used and results obtained are summarized in Appendix G. It is noted here though that the average force angle over a time period varies with time - nearly always starting out close to the normal for the early part of the event and moving toward a direction tangent to the surface later in the event. This is important for two reasons: 1) the time of separation is often subjective and will affect the average force direction and 2) the average force direction over the collision event should not be (but often is) used to estimate trajectory of a near side occupant, since the time intervals of consideration are different. This is more clearly noted by noting the change in average force direction from about 50 msec. (near side occupant contact) to 150 msec. (approximate time of vehicle separation).

Column I presents the correction factor computed in the model if the present function is retained and the instrumentation derived average force direction is used.

Column J presents the kinetic energy lost in the impact during the collision event. This was determined from the impact velocities and the separation velocities (rotational as well as translational). The translational separation velocities were estimated by subtracting the delta-V's from the impact velocities. The rotational separation velocities were taken from the contract test report except for the two Dynamic Science tests which were estimated on the basis of total angular displacement during spin out.

The energy loss was computed as follows:

Kinetic Energy Loss = Translational Energy Loss - Rotational Energy Gain

Translational Energy Loss = Initial Translational Energy - Final Translational Energy

Initial Translational Energy = $1/2\ M1 * V1^2 + 1/2\ M2 * V2^2$

where: M1, M2 are vehicle masses
V1, V2 are impact speeds

Final Translational Energy = $1/2\ M1\ (V1 - D1)^2 + 1/2\ M2\ (V2 - D2)^2$

where: D1, D2 are translational delta-V's

Rotational Energy Gain = $1/2\ I1 * W1^2 + 1/2\ I2 * W2^2$

where: I1, I2 are inertia values for yaw
W1, W2 are rotational velocities

It is assumed that the kinetic energy loss is absorbed in vehicle crush.

Column K presents the crush energy estimated by the CRASH II model without any correction factor applied. In other words, based upon the damage profiles of the vehicles, and assuming that the crush was normal to the surface, the crush energy was estimated by the CRASH II model.

Column L presents the ratio of the measured kinetic energy lost to the estimated crush energy. These could be called laboratory-test-derived correction factors, to the degree that the test velocity data is accurate and the stiffness values of the CRASH II model (and all model assumptions) are valid.

Observations from Test Data - Some tentative and general observations are possible from the data of Table 22. The relative velocity angles of column E range from 30 degrees to 63 degrees. The clock increments of force direction in column F encompassed the relative velocity direction about half of the time. Tests 1 and 2 of the RICSAC series (rows 1 and 2 in the table) which were identical in configuration and vehicles (only the impact speeds were changed) were coded with differing force directions. This was also the case for tests 9 and 10 (rows 6 and 7).

The measured force directions of column H were compared with those of column F, and generally did not fall within the clock increment of the investigator assigned force direction. The measured force direction generally tended to be 10 to 15 degrees toward the normal from the relative velocity direction. This could indicate that some amount of longitudinal slipping occurs between the vehicles, limiting the longitudinal force on the side struck vehicle.

It is known that considerable attention is given to training investigators in coding force directions. Like many parameters in accident investigation, however, the force direction remains a fairly subjective rather than a scientific measurement. Evidence of this is seen in columns E, F and H. This was further observed in a random selection of 50 National Crash Severity Study cases (see Appendix C of Reference 6 for selection details). The investigator coded force directions were found to have been edited and changed by the Quality Control contractor in approximately 30 percent of the cases. This observation is not intended to be critical of a host of careful investigators but rather suggests caution in coupling such a sensitive parameter as the correction factor with such a difficult measurement as force direction. Further reason for uncoupling the two parameters will be shown in discussing the results in column L.

Column G is not very pertinent to this topic except to illustrate that delta-V reconstructions are sometimes "enhanced" by entering force directions outside of the clock increment of force coded by the investigator.

Column L shows the various correction factors which are necessary to make the CRASH II computed energy agree with the measured change in kinetic energy. The values of column L are plotted as a function of the measured force direction in Figure 12. The present model correction function is shown on the same graph. There is judged to be little observable correlation between the correction factor and the force direction.

Closer examination of column L shows that only three tests indicated correction factors higher than 2.0. Two of the three tests were conducted by impacting a Ford Torino in the front axle with a Honda Civic. What is suggested is that the stiffness values of the model are inadequate for the Honda-to-Torino collision configuration, perhaps because of striking the front axle (a hard spot).

The question arises as to whether this only occurs when hard spots (the front axle) are struck. These tests alone are probably not sufficient to answer the question. Two tests were conducted at 90 degrees with Chevrolet Chevelles impacted in the front axle by Chevrolet Chevelles and are related to this question. These tests are identified as numbers 5 and 8 on Table 22. Test 5 had impact speeds of 20.8 mph for each vehicle and test 8 had impact speeds of 25.6 and 26.5 mph respectively. The lower speed test resulted in essentially no damage to the striking vehicle and required a correction factor of 2.5 to make the energies balance. The higher speed test (only 4 or 5 mph higher) resulted in 13 inches crush to the striking vehicle and had a correction factor of 1.25. Thus, all other factors being equal, the correction factor for the Chevelle tests seems related to speed - perhaps indicating that the stiffness problem is more that of the front of the Chevelle rather than the hard spot around the axle on the side of the vehicle.

Excepting test nos. 5 through 7, which required high correction factors that do not appear to correlate with force angle, the average corrections factor shown on Table 22 is .93 with a standard deviation of .21. This suggests that for many crash configurations, a correction factor of 1 would provide fairly good results. This is consistent with the isotrophic behavior assumption suggested earlier.

Discussion, Conclusions and Recommendations Regarding the Energy Correction Factor

In the eleven laboratory tests examined, the investigator coded force direction was not always consistent with the relative velocity angle nor with the

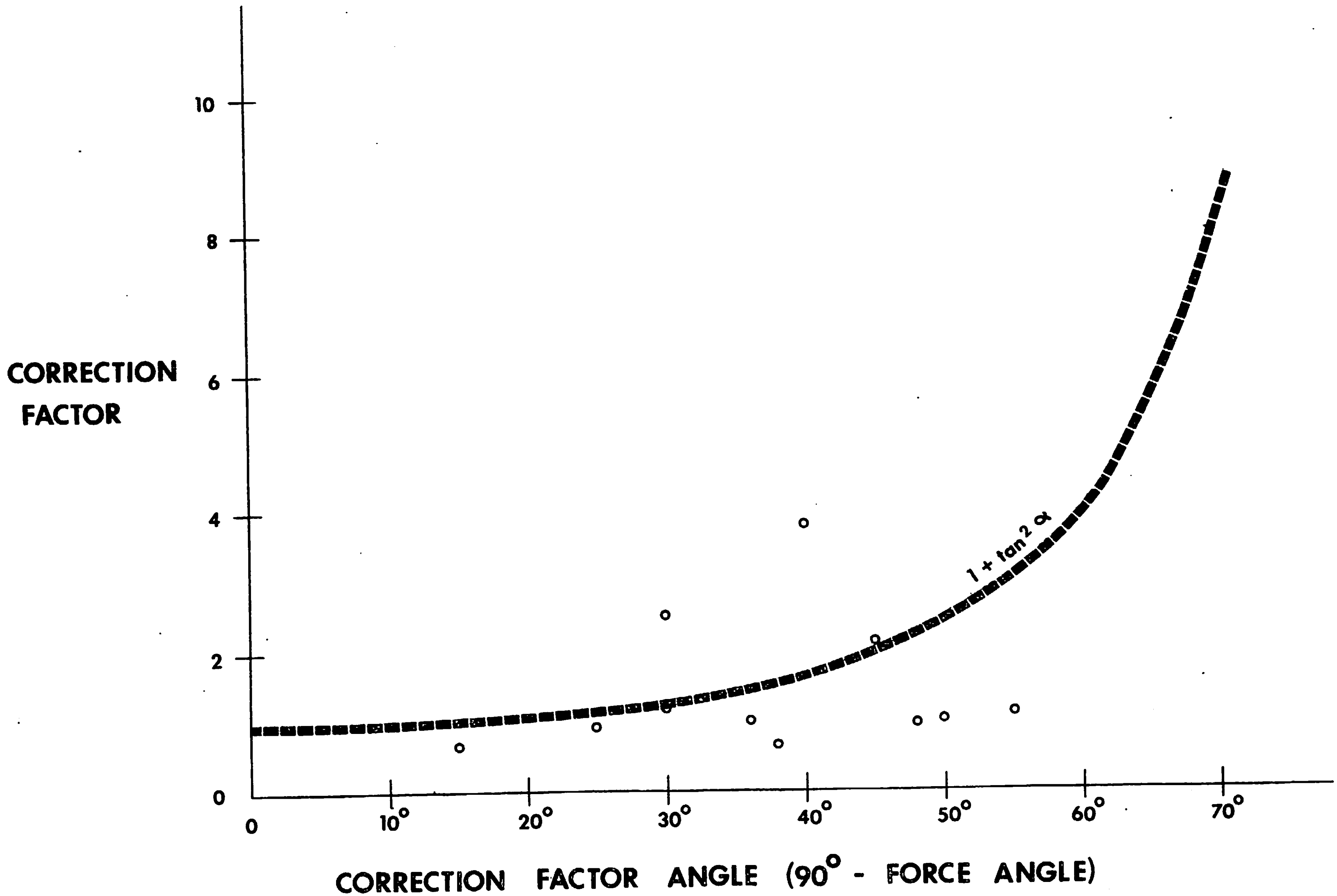


FIGURE 12

Laboratory Derived Energy Correction Factors instrumentation derived force direction. At the same time, the laboratory derived correction factors did not seem to be related to the investigator force direction, relative velocity direction or the instrumentation derived force direction. For eight of the eleven tests, the average correction factor was .93. The very fact that the laboratory correction factor averaged less than 1.0 for these eight tests suggests that the side stiffness values of the model may be too high for most crash configurations. In four tests, higher correction factors were derived, but it was suggested that this may be due to the stiff front axle area struck or to the vehicle stiffness characteristics in general. The higher correction factors do not appear to correlate with force angle.

In the bulk of the tests, intervehicular slipping does appear to be limiting the longitudinal forces applied and energy dissipated. This suggests that a correction factor of 1 would be appropriate in many cases. This may ultimately lead to the model being reformulated to reflect the proper amount of intervehicular friction. The SRL analysis is the basis for the following conclusions:

- the side stiffness values of the model are too high for most of the vehicles of Table 22

- the laboratory derived energy correction factors are not necessarily related to force directions on the vehicle

- the energy correction factor is usually around a value of .93.

Based upon these conclusions, the following recommendations are offered:

- Implement an intermediate fix to the CRASH II model to alleviate correction factor inaccuracies. Alternative fixes might be:

  1) Remove the present function and use the model without a correction factor.

  or

2) Retain the present function, but limit the maximum value of the correction factor to 2.0.

Initiate side impact tests both to further refine the stiffness values of axle and compartment areas, and to verify correction factor findings.

CONCLUSIONS AND RECOMMENDATIONS

From this study, the following has been concluded:

* The front and rear passenger car stiffness values were judged to be quite reliable based upon the quantity and quality of the data available. Front stiffness parameters were derived from averaging the old values with the new. The rear stiffness values were noticeably different from the old values, which were based upon very little actual data. The earlier values were replaced by the new values. Due to the fact that side impact test data were lacking in quantity and were of somewhat questionable quality, it was judged that the old side stiffness values should be retained until more or better data became available.

* For the present level of sophistication of data collection, the linear force vs. deflection assumption of the CRASH II model is adequate.

* The present model assumptions and related formulation are not adequate for oblique force collisions. It is recommended that a study should be initiated to obtain data for a better representation. A temporary fix was proposed to reduce errors in the interim.

* It is recommended that side impact tests to refine the stiffness values and further verify correction factor finding be initiated.

REFERENCES

1. McHenry, R.R., "Yielding Barrier Test Data Base - Refinement of Damage Data Tables in the CRASH Program", Report No. DOT-HS-802-265.

2. Campbell, K.L., "Energy Basis for Collision Severity", SAE Paper No. 740565, Proceedings of the 3rd International Conference on Occupant Protection, Troy, Michigan, July 10-12, 1974.

3. McHenry, R.R., "User's Manual for the CRASH Computer Program", Calspan Report No. ZQ-5708-V-3, January 1976, Contract No. DOT-HS-5-01124.

4. Jones, I.S., Jennings, P.W., "The Development and Evaluation of the CRASH II Program for use under European Conditions", SAE Paper No. 810473, 1981.

5. Shoemaker, N.E., "Research Input for Computer Simulation of Automobile Collisions, Volume IV", Report No. DOT-HS-7-01511.

6. Monthly Progress Report of Project No. SRL-15, "Accident Data Analysis - All Modes", January 1981.

7. James, M.E., Jr., Ross, H.E., Jr., "Improvement of Accident Simulation Model", Report No. DOT-HS-803-620.

8. McHenry, R.R., Lynch, J.P., Segal, D.J., "Research Input for Computer Simulation of Automobile Collisions - Interim Report", Report No. DOT-HS-805-046, June 1977.

9. Monthly Progress Report No. 9 of Contract No. DOT-HS-9-02177, "Counter Measures for Side Impact", February 1980.

APPENDIX A

Relationship Between Crush, Stiffness and Delta-v in the CRASH and CRUSH models

APPENDIX

ANALYTICAL BASIS OF THE CRUSH PROGRAM

The following basic relationship is assumed to exist between absorbed energy and residual damage (see damage dimension format in Figure 1-1).

$$E = A\alpha + B\beta + GL \quad \text{inch lbs} \qquad (1)$$

where α = Plan view direct-contact damage area, in^2 (a uniform vertical damage profile is assumed)

β = First moment of the plan view direct-contact damage area about the line defining the original (undeformed) surface, in^3

L = Length of direct contact damage area, inches

A = lb/in
B = lb/in^2
G = lb

(A, B, G: Fitted empirical coefficients)

Equation (1) corresponds to a linear relationship between crush resistance per unit width and residual deformation.

$$F = A + BC \quad \text{lbs/inch} \qquad (2)$$

The relationship defined by equation (2) is depicted in Figure 1-2.

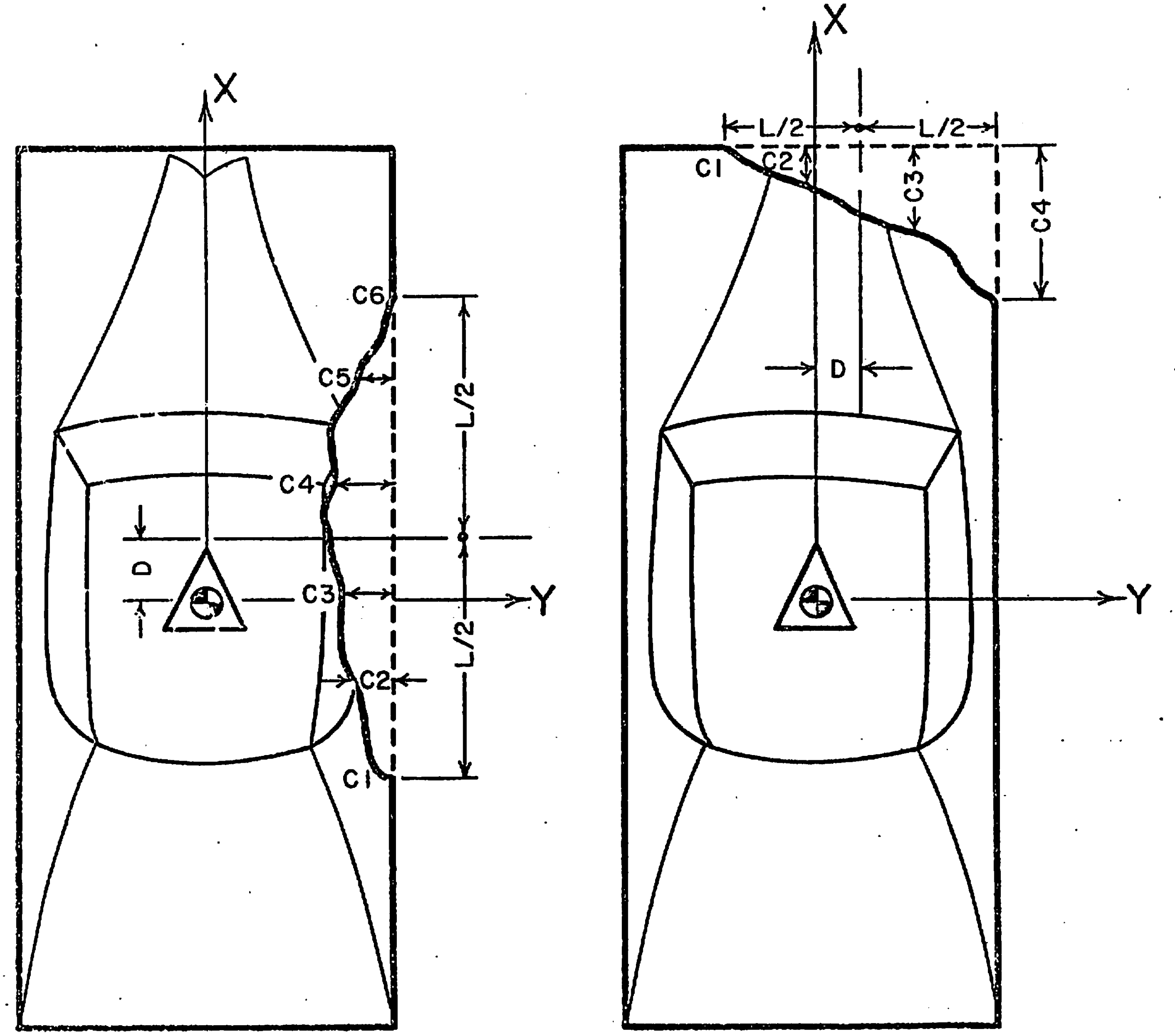


FIGURE 1-I

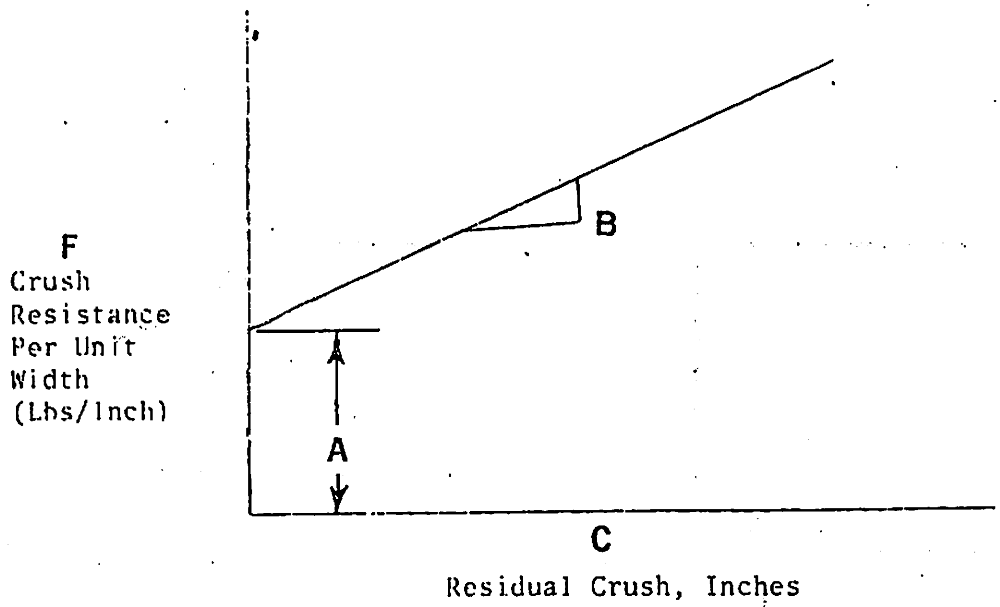


Figure 1-2 ASSUMED FORM OF CRUSH RESISTANCE

ZR-5954-V-1

The energy absorbed by the vehicle crush may be obtained by double integration of equation (2).

$$E = \int_0^L \int_0^C (A + Bc)\, dc\, d\ell \tag{3}$$

where C = Residual crush, inches

L = Length of direct contact damage area, inches

Integration of (3) yields

$$E = \int_0^L \left(AC + B\frac{C^2}{2} + G\right) d\ell \tag{4}$$

where G = Constant of integration

If the linear slope, B, is assumed to exist in the non-damage range of applied force, the constant of integration, G, is equal to the work done in reaching force value A. Thus, an elastic deflection equal to A/B and involving an energy absorption of $A^2/2B$ per unit width will exist at C = 0. Therefore, $G = A^2/2B$.

Integration of equation (4) yields

$$E = A\int_0^L C\,d\ell + B\int_0^L \frac{C^2}{2}\,d\ell + \frac{A^2}{2B}\,L \tag{5}$$

Since $\alpha = \int_0^L C\,d\ell$

and $\beta = \int_0^L \frac{C^2}{2}\,d\ell$,

equation (5) may be expressed

$$E = A\alpha + B\beta + \frac{A^2}{2B} L \qquad (6)$$

Frontal Impacts

For the case of symmetrical, full-frontal impacts, equation (5) becomes

$$E = \left(\frac{BL}{2}\right) C^2 + (AL)\ C + \frac{A^2 L}{2B} \qquad (7)$$

Equating the absorbed energy to the dissipated kinetic energy of the subject vehicle (see Reference 12 for a discussion of energy relationships),

$$\frac{1}{2} M\ (\Delta V)^2 = E \qquad (8)$$

$$(\Delta V)^2 = \left(\frac{BL}{M}\right) C^2 + \left(\frac{2AL}{M}\right) C + \frac{A^2 L}{MB} \qquad (9)$$

Equation (9) may be restated

$$\Delta V = \sqrt{\frac{BL}{M}}\ \left(C + \frac{A}{B}\right) \qquad (10)$$

Therefore, in this special case (i.e., symmetrical, full-frontal) the impact speed change (ΔV) is a linear function of the residual crush (C) and has an intercept at $A\sqrt{\frac{L}{BM}}$. The relationship is depicted in Figure 1-3.

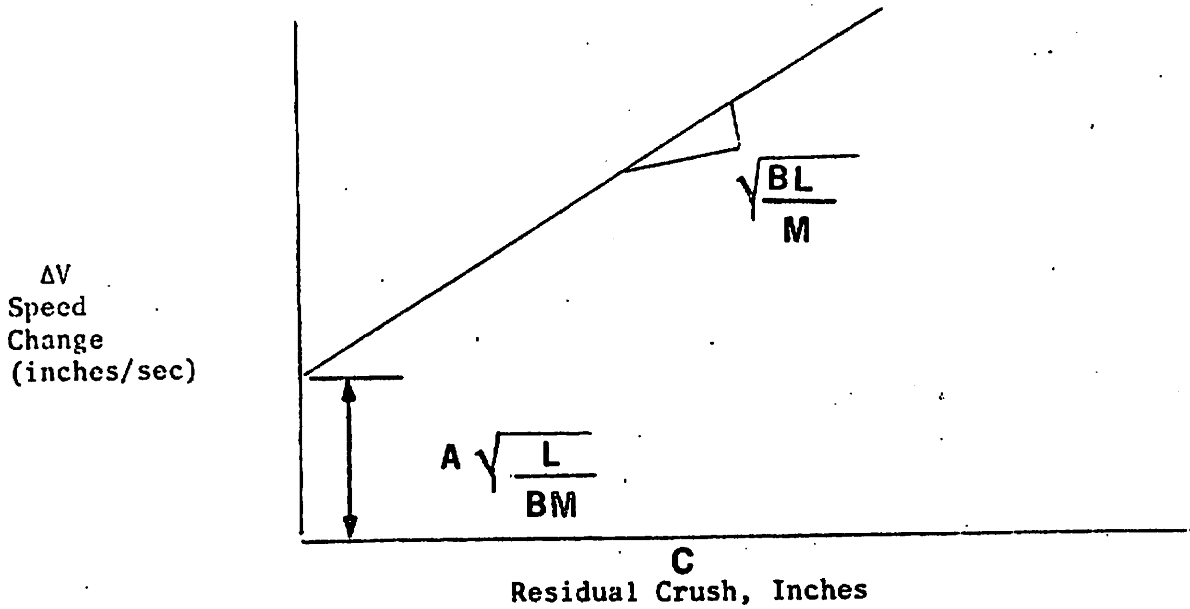


Figure 1-3 SPEED CHANGE VS. RESIDUAL CRUSH IN FULL FRONTAL SYMMETRICAL IMPACTS

Campbell (Reference 4) has used the symbols b_0 and b_1 for the intercept and slope of Figure 1-3, and he has presented some representative values. It is of interest to relate his variables to A, B and G.

$$b_0 = A \sqrt{\frac{L}{BM_s}} \quad \text{inches/sec} \tag{11}$$

$$b_1 = \sqrt{\frac{BL}{M_s}} \quad \text{in/sec/in} \tag{12}$$

where M_s = Standard test mass, lb sec^2/in.

Solution of (11) and (12) for A and B yield

$$A = \frac{b_0 b_1 M_s}{L} \quad \text{lb/inch} \tag{13}$$

$$B = \frac{b_1^2 M_s}{L} \quad \text{lb/in}^2 \tag{14}$$

$$G = \frac{A^2}{2B} = \frac{b_0^2 M_s}{2L} \quad \text{lb} \tag{15}$$

Application of equations (13), (14) and (15) to the frontal barrier test data presented by Campbell (Reference 4) yields the results presented in Table 1-1.

<u>Side Impacts</u>

In the case of side impacts, determination of the energy absorption by vehicle crush is somewhat more complicated. First, the "effective mass" at the point where a common velocity is reached must be determined from the impact configuration and the inertial properties of the two colliding bodies. Note that the present version of CRASH includes the assumption that the common velocity is reached at the centroid of the damaged area (Reference 13).

Table 1-1 Frontal Barrier Test Data
(Based on Reference 4)

	Std. Wgt. (Lbs)	Width (In)	b_0 MPH	b_1 MPH/In	A Lb/Inch	B Lb/In^2	G Lb.
71-72 Std. Full Size	4500	79.2	6.85	0.88	274.6	35.27	1068.6
73-74 Std. Full Size	4500	79.2	7.5	0.90	307.5	36.89	1281.1
73-74 Intermediate	4000	76.8	7.5	0.90	281.8	33.82	1174.3
71-74 Compact	3400	71.4	3.0	1.35	154.6	69.57	171.78
71-74 Subcompact	2500	62.2	3.0	1.35	130.5	58.72	144.94

Next, energy absorption produced by a tangential component of the collision force must be subtracted from the total, since the fitted empirical crush characteristics apply only to the intervehicle force component perpendicular to the involved side or end (Reference 14).

If two data sets (E_1, α_1, β_1, L_1; E_2, α_2, β_2, L_2) are available, equation (6) can be solved for B.

$$B = \frac{A\ (L_1\alpha_2 - L_2\alpha_1) + E_1L_2 - E_2L_1}{(L_2\beta_1 - L_1\beta_2)} \tag{16}$$

Substitution of (16) in (6), with (6) containing data set (E_1, α_1, β_1, L_1), yields

$$A = -\frac{K_2}{2K_1} + \frac{1}{2}\sqrt{\left(\frac{K_2}{K_1}\right)^2 - \frac{4K_3}{K_1}} \tag{17}$$

where

$$K_1 = [\alpha_1(L_2\beta_1 - L_1\beta_2) + \beta_1\ (L_1\alpha_2 - L_2\alpha_1)]\ [L_1\alpha_2 - L_2\alpha_1] + \frac{L_1}{2}\ (L_2\beta_1 - L_1\beta_2)^2 \tag{18}$$

$$K_2 = [\alpha_1(L_2\beta_1 - L_1\beta_2) + 2\beta_1\ (L_1\alpha_2 - L_2\alpha_1)]\ [E_1L_2 - E_2L_1] - E_1\ (L_1\alpha_2 - L_2\alpha_1)\ (L_2\beta_1 - L_1\beta_2) \tag{19}$$

$$K_3 = (E_1L_2 - E_2L_1)\ [\beta_1(E_1L_2 - E_2L_1) - E_1(L_2\beta_1 - L_1\beta_2)] \tag{20}$$

APPENDIX B

Solution Procedure of the CRUSH Program

Solution Procedure of CRUSH Program

{ Two tests required for nonzero intercept in force-deflection plot. For single test, zero-zero intercept will be assumed. }

1. TEST #1

Enter size categories for both vehicles.

(Vehicle #1 - subject vehicle
Vehicle #2 - other vehicle in staged collision)

1. Minicar	5. Full size
2. Subcompact	6. Large
3. Compact	7. Rigid
4. Intermediate	8. Barrier

2. Enter test weights of Vehicle #1 and Vehicle #2.

3. Enter VDI's of Vehicles #1 and #2.

4. Enter collision speeds of Vehicle #1 and Vehicle #2.

{ Enter in MPH, convert to in/sec
Speed = 17.6 x MPH in/sec }

5. Enter A, B, G for Vehicle #2.

6. Enter directions of principal impact forces, if known more accurately than VDI clock directions.

7. Enter damage dimensions for Vehicle #1.

L_1, D_1, C_{11}, C_{12}, C_{13}.....C_{16}

ZR-5954-V-1

8. Enter damage dimensions for Vehicle #2.

L_2, D_2, C_{21}, C_{22}, C_{23}.....C_{26}

9. Calculate γ_1, γ_2

$\left\{ \begin{array}{l} X_F,\ X_R,\ Y_s,\ \text{RSQ from Table 1-2} \\ \text{See DAMAGE routine of CRASH} \end{array} \right\}$

10. $$\Delta V_1 = \left(\frac{\gamma_1 \gamma_2 M_2}{\gamma_1 M_1 + \gamma_2 M_2} \right) (V_1 \cos ANG1 + V_2 \cos ANG2)$$

11. $$\Sigma E = \frac{M_1 \left(1 + {}^{\gamma_1 M_1}/_{\gamma_2 M_2}\right)}{2\gamma_1} (\Delta V_1)^2$$

12. $$E_2 = (1 + \tan^2 \alpha_2)\ f\ (A,B,G,C,L)$$

(See DAMAGE routine)

13. $$E_1 = \Sigma E - E_2,\ E'_1 = E_1/(1 + \tan^2 \alpha_1)$$

where E'_1 = absorbed energy of subject vehicle corresponding to the intervehicle force component perpendicular to the involved side or end.

14. Calculate α_1, β_1, as follows.

ZR-5954-V-1

Table 1-2

	1	2	3	4	5	6	7
	MINICAR	SUBCOMPACT	COMPACT	INTERMEDIATE	FULL SIZE	LARGE	RIG
M	5.70	7.90	9.18	10.99	12.59	13.74	10
XF	76.0	83.3	89.8	98.8	101.8	104.2	84
XR	-83.8	-91.6	-106.4	-114.0	-121.9	-125.2	-96
YS	30.4	33.6	36.3	38.5	39.9	39.9	39
RSQ	2006.	2951.	3324.	3741.	4040.	4229.	402

15. Is this the second crash test?

If yes, set $E'_{12} = E'_1$

$\alpha_{12} = \alpha_1$

$\beta_{12} = \beta_1$

$L_{12} = L_1$

and go to (19).

16. If only one crash test is available for the subject vehicle, set $E'_{12} = 0$

$\alpha_{12} = 0$

$\beta_{12} = 0$

$L_{12} = L_{11}$

and go to (19).

17. If results of two crash tests are available, set $E'_{11} = E'_1$

$\alpha_{11} = \alpha_1$

$\beta_{11} = \beta_1$

$L_{11} = L_1$

Save E'_{11}, α_{11}, β_{11}, L_{11}, clear the rest and proceed.

18. TEST #2, Return to (1).

19. $$K_1 = [\alpha'_{11}(L_{12}\beta_{11}-L_{11}\beta_{12}) + \beta_{11}(L_{11}\alpha_{12}-L_{12}\alpha_{11})]\ [L_{11}\alpha_{12}\alpha_{11}] + \frac{L_{11}}{2}(L_{12}\beta_{11}-L_{11}\beta_{12})^2$$

$$K_2 = [\alpha_{11}(L_{12}\beta_{11}-L_{11}\beta_{12}) + 2\beta_{11}(L_{11}\alpha_{12}-L_{12}\alpha_{11})]\ [E'_{11}L_{12}-E'_{12}L_{11}] - E'_{11}(L_{11}\alpha_{12}-L_{12}\alpha_{11})(L_{12}\beta_{11}-L_{11}\beta_{12})$$

$$K_3 = (E'_{11}L_{12}-E'_{12}L_{11})\ [\beta_{11}(E'_{11}L_{12}-E'_{12}L_{11}) - E'_{11}(L_{12}\beta_{11}-L_{11}\beta_{12})]$$

20. $$A = -\frac{K_2}{2K_1} + \frac{1}{2}\sqrt{\left(\frac{K_2}{K_1}\right)^2 - \frac{4K_3}{K_1}} \quad \text{lb/in}$$

$$B = \frac{A(L_{11}\alpha_{12}-L_{12}\alpha_{11}) + E'_{11}L_{12}-E'_{12}L_{11}}{(L_{12}\beta_{11} - L_{11}\beta_{12})} \quad \text{lb/in}^2$$

$$G = \frac{A^2}{2B} \quad \text{lb}$$

α_1 = Damage area, in^2

β_1 = 1st moment of damage area, in^3

L_1 = Length of indentation, inches

<u>6 Points</u>

$$\alpha_1 = \frac{L_1}{10} (C_1 + 2C_2 + 2C_3 + 2C_4 + 2C_5 + C_6)$$

$$\beta_1 = \frac{L_1}{30} (C_1^2 + 2C_2^2 + 2C_3^2 + 2C_4^2 + 2C_5^2 + C_6^2$$
$$+ C_1C_2 + C_2C_3 + C_3C_4 + C_4C_5 + C_5C_6$$

<u>4 Points</u>

$$\alpha_1 = \frac{L_1}{6} (C_1 + 2C_2 + 2C_3 + C_4)$$

$$\beta_1 = \frac{L_1}{18} (C_1^2 + 2C_2^2 + 2C_3^2 + C_4^2 + C_1C_2 + C_2C_3 + C_3C_4)$$

<u>2 Points</u>

$$\alpha_1 = \frac{L_1}{2} (C_1 + C_2)$$

$$\beta_1 = \frac{L_1}{6} (C_1^2 + C_1C_2 + C_2^2)$$

APPENDIX C

SRL Version of CRUSH

```
C*                                                                        *
C*                     C R U S H        S U B P R O G R A M               *
C*----------------------------------------------------------------------*
C*                                                                        *
C*   PURPOSE:  READ CASE FROM STAGED COLLISION DATA BANK                  *
C*             USING SUBSET FROM DAMAGE ROUTINE FROM CRASH2, DETERMINE    *
C*             THE ENERGY, ALPHA, BETA,DAMAGE WIDTH,SIZE AND IMPACT       *
C*             CONFIGURATION                                              *
C*----------------------------------------------------------------------*
C*  PROCEDURE: ENTER VEHICLE SIZES, WEIGHTS, VEHICLE DAMAGE INDICES,      *
C*             COLLISION SPEEDS, DIRECTIONS OF PRINCIPAL IMPACT FORCES,   *
C*             DAMAGE MEASUREMENTS, AND CONSTANTS A, B, AND G FOR         *
C*             VEHICLE # 2. (VEHICLE #2 IS ALWAYS A KNOWN QUANTITY)       *
C*             USING SECTIONS OF CRASH2 DAMAGE SUBROUTINE, CALCULATE      *
C*             THE DISSIPATED ENERGY OF VEHICLE # 2 AND THE CONSTANTS     *
C*             IDENTIFYING THE EFFECTIVE MASS AT THE CENTROIDS, GAM(1)    *
C*             AND GAM(2). THE SPEED CHANGE FOR VEHICLE # 1 IS FOUND      *
C*             AND THE SUM OF THE DISSIPATED ENERGIES. FINALLY, THE       *
C*             DISSIPATED ENERGY FOR VEHICLE # 1 IS CALCULATED AND THE    *
C*             DAMAGE AREA AND FIRST MOMENT IS FOUND. THUS, FOR THE       *
C*             FIRST CRASH TEST, THE DISSIPATED ENERGY, DAMAGE AREA,      *
C*             FIRST MOMENT OF THAT AREA, AND THE WIDTH OF THE AREA       *
C*             IS CALCULATED AND RETAINED. (ENERGY1,ALPHA1,BETA1,L1 )     *
C*----------------------------------------------------------------------*
C*                                                                        *
C*                                                                        *
C*----------------------------------------------------------------------*
C*  VARIABLES: TITLE(30)------ USER SUPPLIED TITLE                        *
C*             QMARK---------- QUESTION MARK /'?    '/                    *
C*             BSPACE--------- BACKSPACE /'$    '/                        *
C*             BLANK---------- SPACE CHARACTER /'     '/                  *
C*             JV1,JV2-------- VEHICLE TYPES                              *
C*             JTYP(2)-------- VEHICLE TYPES                              *
C*             ICODE---------- RETURN CODE                                *
C*             W(2)----------- VEHICLE WEIGHTS                            *
C*             JWSET(2)------- WEIGHT ENTRY FLAGS                         *
C*             FMASS1,FMASS2-- VEHICLE MASSES                             *
C*             FIZ1,FIZ2------ VEHICLE INERTIAS                           *
C*             JVDI(2,7)------ VEHICLE DAMAGE INDEX                       *
C*             LVDI(7)-------- VEHICLE DAMAGE INDEX                       *
C*             V1,V2---------- IMPACT VELOCITIES                          *
C*             ANG(2)--------- DIRECTION OF PRINCIPAL IMPACT FORCE        *
C*             JASET(2)------- ANG ENTRY FLAG                             *
C*             A(8,3)--------- CRUSH STIFFNESS CONSTANT                   *
C*             B(8,3)--------- CRUSH STIFFNESS CONSTANT                   *
C*             G(8,3)--------- CRUSH STIFFNESS CONSTANT                   *
C*             LL(2),L(2)----- DAMAGE WIDTH                               *
C*             JLSET(2)------- WIDTH ENTRY FLAG                           *
C*             CC(2,6),C(2,6)- DEPTH PROFILE                              *
C*             JCSET(2)------- PROFILE ENTRY FLAG                         *
C*             DD(2),D(2)----- MOMENT ARM                                 *
C*             JDSET(2)------- MOMENT ARM ENTRY FLAG                      *
C*             XF(8),XFF------ CG-TO-FRONT DISTANCE                       *
C*             XR(8),XRR------ CG-TO-REAR DISTANCE                        *
C*             YS(8),YSS------ CG-TO-SIDE DISTANCE                        *
C*             RSQ(8)--------- RADIUS OF GYRATION                         *
C*             ENERGY(2)------ DISSIPATED ENERGY                          *
C*             GAM(2)--------- EFFECTIVE MASS ADJUSTMENT                  *
C*                                                                        *
```

```
C*                                                                        *
C************************************************************************
```

```
      COMMON /CRASH/  TITLE(80),W(2),LW(2,4),LL(2),CC(2,6),DD(2),ANG(2),
     *                RHO(2),XBP(2),YBP(2),STEER(2,4),L(2),C(2,6),D(2),
     *                CSTF(2,4),AKV(2),E1(5),E2(5),ENERGY(2),
     *                XCR1,YCR1,PSIR1,XCR2,YCR2,PSIR2,
     *                XC10,YC10,PSI10,XC20,YC20,PSI20,
     *                XC11,YC11,PSI11,XC12,YC12,PSI12,
     *                XC21,YC21,XC22,YC22,
     *                DELVR1,DELVR2,DELVX1,DELVX2,DELVY1,DELVY2,
     *                U1OMPH,V1OMPH,U2OMPH,V2OMPH,
     *                US1MPH,VS1MPH,US2MPH,VS2MPH,
     *                S1,T1,S2,T2,S3,T3,S4,T4,S5,T5,S6,T6,
     *                XCSP1F,YCSP1F,XCSP2E,YCSP2E,PSISD1,PSISD2,
     *                MU,MU2,CMU,OMIN1,OMIN2,
     *                A1,A2,B1,B2,TR1,TR2,FIZ1,FIZ2,FMASS1,FMASS2,
     *                XF1,XF2,XR1,XR2,YS1,YS2,XFB,XRB,YSB,
     *                JSSET(2),JSKID(2),JTYP(2),JVDI(2,7),
     *                IFLAG(2),JIND(2),JWSET(2),JLSET(2),JCSET(2),
     *                JDSET(2),JASET(2),JRSET(2),JCURV(2),IRI(2),
     *                JERR(2),NRUNS(2),
     *                JBSET,IND,IDAM,JSPIN,JTRAJ,MENU,ISTOP
      DIMENSION DEFL(2),GAM(2),A(2),B(2),G(2)
      DIMENSION  LINE(80)
      DIMENSION H(2),KK(2),ITABLE(10,2),LVDI(7),VALUE(12)
      DIMENSION XF(8),XR(8),YS(8),MASS(8),RSO(8),DA1(8),DB1(8),DTR1(8),
     1          WGT(8),WBASE(8),TOTLEN(8),TOTWID(8),DCSTF(2,8),DAKV(8)
      DIMENSION  AAAA(8,3),  BBBB(8,3),   GGGG(8,3)
      REAL     LW,L,LL,MU,MU2,KK,MASS
      REAL      L1,L2,K1,K2,K3
      REAL     LENGTH
      INTEGER     TITLE, AZAPL,BZAPL,BZAPH,AZAPH
C
C     LOAD UP THE TABLES
C
C
C     LOAD UP THE TABLES
C
      DATA AAAA/85.4,94.89,154.6,233.7,307.5,307.5,0.0,0.0,
     1        77.2,140.4,173.3,143.0,176.5,176.5,0.0,0.0,
     2        65.98,65.93,78.18,85.51,93.28,93.28,0.0,0.0/
      DATA BBBB/64.0,71.11,69.57,49.9,36.89,36.89,0.0,0.0,
     1        36.7,66.7,57.1,50.4,47.1,47.1,0.0,0.0,
     2        13.2,13.2,15.64,17.11,18.66,18.66,0.0,0.0/
      DATA GGGG/57.0,63.31,171.78,547.3,1281.1,1281.1,0.0,0.0,
     1        81.3,147.8,263.2,202.7,330.8,330.8,0.0,0.0,
     2        164.97,164.97,195.45,213.78,233.21,233.21,0.0,0.0/
      DATA  ITABLE/'0   ', '1   ', '2   ', '3   ', '4   ', '5   ',
     *             '6   ', '7   ', '8   ', '9   ',
     *             0,1,2,3,4,5,6,7,8,9/
      DATA BLANK/'    '/,  QMARK/'?   '/,  BSPACE/'$   '/
      DATA  JCHARF/'F   '/,  JCHARB/'B   '/,  JCHARD/'D   '/,
     *      JCHARP/'P   '/,  JCHARZ/'Z   '/,  JCHARY/'Y   '/,
     *      JCHARC/'C   '/,  JCHARR/'R   '/,  JCHARL/'L   '/,
     *      JCHARN/'N   '/
      DATA  JBLNK/'    '/
C
C     INITIALIZE VEHICLE PARAMETER TABLES
C
      DATA XF/75.0, 33.3, 89.8, 98.8, 101.8, 104.2, 84.0, 50.0/
      DATA XR/-83.8, -91.6, -105.4, -114.0, -121.9, -125.2, -96.0, -50./
      DATA YS/33.4, 33.5, 36.3, 38.5, 39.9, 39.9, 39.0, 50.0/
      DATA MASS/5.7, 7.9, 9.18, 10.99, 12.59, 13.74, 10.35, 1000000./
      [illegible] 2335., 2981., 3???., 3751., 4040., 4233., 4029., 1000000./
```

```
      DATA DA1/45.1, 45.3, 51.3, 54.7, 58.1, 60.1, 54., 50.0/
      DATA DB1/48.1, 50.1, 55.5, 59.2, 63.0, 65.1, 66.0, 50.0/
      DATA DTR1/51.1, 54.6, 58.9, 61.8, 63.7, 63.6, 60.0, 50.0/
      DATA WGT/2202., 3053., 3547., 4247., 4865., 5309., 4000.,1000000./
      DATA WBASE/93.2, 96.4, 106.8, 113.9, 121.1, 125.2, 120., 50.0/
      DATA TOTLEN/159.9, 174.9, 196.2, 212.8, 223.7, 229.4, 209.2, 50./
      DATA TOTWID/60.8, 67.2, 72.6, 77.0, 79.8, 79.8, 78., 50.0/
      DATA DCSTF/-5374., -5039., -7500., -6931., -8714., -8055.,
     1           -10434., -9641., -11964., -11033., -13051., -12049.,
     2           -1000000., -1000000., -1000000., -1000000./
      DATA DAKV/59., 59., 70., 51., 56., 56., 56., 56./
C
C   SET THE COLLISION COUNTER TO ZERO
C
  100 NCRASH = 0
C
C   INITIALIZE SOME DATA
C
      OPEN (UNIT=1,NAME='SY:CRUSH1.DAT')
      WRITE(1,300)
  300 FORMAT(' DATA ONE;',/,' INPUT E ALPHA BETA L;',/,' CARDS;')
  400 A(1) = 0.0
      B(1) = 0.0
      G(1) = 0.0
      A(2) = 0.0
      B(2) = 0.0
      G(2) = 0.0
      DO   420   J = 1,2
      GAM(J) = 1.0
      ENERGY(J) = 0.0
      KK(J) = 0.0
      L(J) = 0.0
      LL(J) = 0.0
      D(J) = 0.0
      DD(J) = 0.0
      DO   410   K = 1,6
      C(J,K) = 0.0
      CC(J,K) = 0.0
  410 CONTINUE
  420 CONTINUE
C
C
C
C
C
C  $$$$ INPUT SUBSECTION $$$$
C
C
C
C
  501 FORMAT(80A1)
      WRITE(5,502)
  502 FORMAT(' TITLE?')
      READ(5,501)LINE
  510 DO   520   J=1,80
      IF   (LINE(J) .NE. JBLNK)   GO TO 550
  520 CONTINUE
      GO TO 8500
C
C   LOAD TITLE INTO TITLE ARRAY
C
      [illegible]
```

```
      TITLE(J) = LINE(J)
  560 CONTINUE
      NCRASH = NCRASH + 1
C
C
C
C   EXTRACT THE VEHICLE TYPES
      WRITE(5,600)
  600 FORMAT('0SIZE CATEGORY VEHICLE NO. 1?')
      READ(5,501)LINE
C
  610 CALL READ2(LINE,RESULT,1,4,JCODE)
      JTYP(1) = IFIX(RESULT)
      WRITE(5,602)
  602 FORMAT('0SIZE CATEGORY VEHICLE NO. 2?')
      READ(5,501)LINE
      CALL READ2(LINE,RESULT,1,4,JCODE)
      JTYP(2) = IFIX(RESULT)
C
C   EXTRACT THE WEIGHTS
C
      WRITE(5,621)
  621 FORMAT('0WEIGHT OF VEHICLE NO. 1?')
      READ(5,501)LINE
  620 CALL READ2(LINE,RESULT,1,8,JCODE)
      IF  (JCODE .EQ. 0)  GO TO 624
  622 W(1) = RESULT
      FMASS1 = W(1)/386.4
      FIZ1 = ((MASS(JTYP(1))*RSQ(JTYP(1)))*FMASS1)/MASS(JTYP(1))
      JWSET(1) = 1
      GO TO 630
  624 W(1) = WGT(JTYP(1))
      FIZ1 = MASS(JTYP(1))*RSQ(JTYP(1))
      FMASS1 = MASS(JTYP(1))
      JWSET(1) = 0
  630 WRITE(5,631)
  631 FORMAT('0WEIGHT OF VEHICLE NO. 2?')
      READ(5,501)LINE
      CALL READ2(LINE,RESULT,1,8,JCODE)
      IF  (JCODE .EQ. 0)  GO TO 634
  632 W(2) = RESULT
      FMASS2 = W(2)/386.4
      FIZ2 = ((MASS(JTYP(2))*RSQ(JTYP(2)))*FMASS2)/MASS(JTYP(2))
      JWSET(2) = 1
      GO TO 640
  634 W(2) = WGT(JTYP(2))
      FIZ2 = MASS(JTYP(2))*RSQ(JTYP(2))
      FMASS2 = MASS(JTYP(2))
      JWSET(2) = 0
C
C   EXTRACT THE VDI'S
C
  640 WRITE(5,641)
  641 FORMAT('0VEHICLE DAMAGE INDICE NO. 1?')
      READ(5,501)LINE
      DO  644  J=1,7
      JVDI(1,J) = LINE(J)
  644 CONTINUE
      WRITE(5,642)
  642 FORMAT('0VEHICLE DAMAGE INDICE NO. 2?')
      READ(5,501)LINE
```

```
      JVDI(2,J)=LINE(J)
  646 CONTINUE
C
C   EXTRACT THE SPEEDS
C
      WRITE(5,649)
  649 FORMAT('0IMPACT SPEED VEHICLE NO. 1?, @MPH|')
      READ(5,501)LINE
  650 CALL READ2(LINE,V1,1,8,JCODE)
      WRITE(5,651)
  651 FORMAT('0IMPACT SPEED VEHICLE NO.2?, @MPH|')
      READ(5,501)LINE
  655 CALL READ2(LINE,V2,1,8,JCODE)
      V1 = V1*17.6
      V2 = V2*17.6
C
C   EXTRACT THE DIRECTIONS OF PRINCIPAL FORCE
C
      WRITE(5,659)
  659 FORMAT('0DIRECTION OF PRINCIPAL FORCE FOR VEHICLE NO. 1?')
      READ(5,501)LINE
  660 CALL READ2(LINE,RESULT,1,8,JCODE)
      IF  (JCODE .EQ. 0)   GO TO 665
  664 ANG(1) = RESULT
      JASET(1) = 1
      GO TO 670
  665 JASET(1) = 0
  669 FORMAT('0DIRECTION OF PRINCIPAL FORCE FOR VEHICLE NO. 2?')
  670 WRITE(5,669)
      READ(5,501)LINE
      CALL READ2(LINE,RESULT,1,8,JCODE)
      IF  (JCODE .EQ. 0)   GO TO 676
  674 ANG(2) = RESULT
      JASET(2) = 1
      GO TO 700
  676 JASET(2) = 0
  700 CONTINUE
C
C   EXTRACT THE DAMAGE WIDTH FOR V1
C
      WRITE(5,709)
  709 FORMAT('0DAMAGE WIDTH FOR VEHICLE NO. 1?')
      READ(5,501)LINE
  710 CALL READ2(LINE,RESULT,1,8,JCODE)
      IF  (JCODE .NE. 0)   GO TO 714
  712 JLSET(1) = 0
      GO TO 720
  714 JLSET(1) = 1
      LL(1) = RESULT
  720 CONTINUE
C
C   EXTRACT THE DAMAGE DEPTH PROFILE FOR V1
C
      WRITE(5,716)
  716 FORMAT('0NUMBER OF DAMAGE DEPTH PROFILES FOR VEHICLE NO. 1?',
     1/,' MUST BE 2, 4, OR 6.')
      READ(5,*)JCODE
      WRITE(5,715)
  715 FORMAT('0DAMAGE DEPTH PROFILE FOR VEHICLE NO. 1?')
      READ(5,*)(CC(1,LO), LO=1,JCODE)
  724 JCSET(1) = JCODE
```

```
C     EXTRACT THE DAMAGE MIDPOINT OFFSET FOR V1
C
      WRITE(5,726)
  726 FORMAT('0DAMAGE MIDPOINT OFFSET FOR VEHICLE NO. 1?')
      READ(5,501)LINE
  730 CALL READ2(LINE,RESULT,1,8,JCODE)
      IF  (JCODE .NE. 0)  GO TO 734
  732 JOSET(1) = 0
      GO TO 800
  734 JOSET(1) = 1
      DD(1) = RESULT
  800 CONTINUE
C
C     EXTRACT THE DAMAGE WIDTH FOR V2
C
      WRITE(5,808)
  808 FORMAT('0DAMAGE WIDTH FOR VEHICLE NO. 2?')
      READ(5,501)LINE
  810 CALL READ2(LINE,RESULT,1,8,JCODE)
      IF  (JCODE .NE. 0) GO TO 814
  812 JLSET(2) = 0
      GO TO 820
  814 JLSET(2) = 1
      LL(2) = RESULT
  820 CONTINUE
C
C     EXTRACT THE DAMAGE PROFILE FOR V2
C
      WRITE(5,816)
  816 FORMAT('0NUMBER OF DAMAGE DEPTH PROFILES FOR VEHICLE NO. 2?'
     1,/,' MUST BE 2, 4, OR 6.')
      READ(5,*)JCODE
      WRITE(5,818)
  818 FORMAT('0DAMAGE DEPTH PROFILE FOR VEHICLE NO. 2?')
      READ(5,*)(CC(2,LC), LC=1,JCODE)
  824 JCSET(2) = JCODE
C
C     EXTRACT THE DAMAGE MIDPOINT OFFSET FOR V2
C
      WRITE(5,826)
  826 FORMAT('0DAMAGE MIDPOINT OFFSET FOR VEHICLE NO. 2?')
      READ(5,501)LINE
  830 CALL READ2(LINE,RESULT,1,8,JCODE)
      IF  (JCODE .NE. 0)  GO TO 834
  832 JOSET(2) = 0
      GO TO 900
  834 JOSET(2) = 1
      DD(2) = RESULT
C
C     THAT'S IT
C
  900 CONTINUE
C
C     SOLVE FOR GAM(1), GAM(2), AND ENERGY(2)
C
 1900 DO    2500    I=1,2
 1910 IF    (JASET(I) .EQ. 1)    GO TO 1925
 1915 DO    1920    JPL = 1,10
      IF    (JVDI(I,1) .EQ. ITABLE(JPL,1))    NUM1 = ITABLE(JPL,2)
      IF    (JVDI(I,2) .EQ. ITABLE(JPL,1))    NUM2 = ITABLE(JPL,2)
 1920 CONTINUE
```

```
      ANG(I) = FLOAT(NN)
      GO TO 1928
 1925 NN = IFIX(ANG(I))
 1928 CONTINUE
      J = JTYP(I)
      IF (J .EQ. 3)   GO TO 2500
      XFF = XF(J)
      XRR = XR(J)
      YSS = YS(J)
C
C   REPLACE D(I),L(I),C(I,1),C(I,2),C(I,3),AND C(I,4) WITH ANY DIRECT
C   USER ENTRIES
C
 1930 IF   (JDSET(I))    1935,1935,1931
 1931 D(I) = DD(I)
 1935 IF   (JLSET(I))    1940,1940,1936
 1936 L(I) = LL(I)
 1940 IF   (JCSET(I))    1950,1950,1941
 1941 C(I,1) = CC(I,1)
      C(I,2) = CC(I,2)
      C(I,3) = CC(I,3)
      C(I,4) = CC(I,4)
      C(I,5) = CC(I,5)
      C(I,6) = CC(I,6)
C
C   SET UP J  (1=FRONT, 2=SIDE, 3=REAR)
C
 1950 IF   (JVDI(I,3) .EQ. JCHARF)    J = 1
      IF   (JVDI(I,3) .EQ. JCHARR)    J = 2
      IF   (JVDI(I,3) .EQ. JCHARL)    J = 2
      IF   (JVDI(I,3) .EQ. JCHARB)    J = 3
C
C   GET A,B,G FOR VEHICLE # 2
C
 1955 A(2) = AAAA(JTYP(2),J)
      B(2) = BBBB(JTYP(2),J)
      G(2) = GGGG(JTYP(2),J)
C
C   FORSTALL ANY DIVIDE BY ZERO DIAGNOSTICS BY MAKING ANY ZERO DAMAGE
C   MEASUREMENTS EQUAL TO .00001
C
 1953 IF   ((ABS(D(I)) - .001) .LT. 0.)   D(I) = .0001
      IF   ((ABS(L(I)) - .001) .LT. 0.)   L(I) = .0001
      IF   ((ABS(C(I,1)) - .001) .LT. 0.)   C(I,1) = .0001
      IF   ((ABS(C(I,2)) - .001) .LT. 0.)   C(I,2) = .0001
      IF   ((ABS(C(I,3)) - .001) .LT. 0.)   C(I,3) = .0001
      IF   ((ABS(C(I,4)) - .001) .LT. 0.)   C(I,4) = .0001
      IF   ((ABS(C(I,5)) - .001) .LT. 0.)   C(I,5) = .0001
      IF   ((ABS(C(I,6)) - .001) .LT. 0.)   C(I,6) = .0001
C
C   CALCULATE THE ENERGY DISSIPATED
C   NOTE: SINCE 2,4, OR 6 DEPTH PROFILE POINTS ARE PERMITTED,
C         THREE FORMS OF THE ENERGY CALCULATION ARE NECESSARY.
C         FLAG JCSET(I) INDICATES THE # OF DEPTH PROFILE ENTRIES.
C         TEMP3,TEMP4,TEMP5,TEMP6 ALL ADJUST THE D-VALUE FOR CENTROID.
C
      K=JTYP(I)
      JJJ = JCSET(I)
      IF   (JCSET(I) .EQ. 0)   JJJ=4
      IF   (JJJ .EQ. 2)   GO TO 1960
      IF   (JJJ .EQ. 4)   GO TO 1970
      [illegible]
```

```
 1960 TEMP1 =   A(I)*(C(I,1)+C(I,2))/2.
      TEMP2 =   B(I)*(C(I,1)*C(I,1)+C(I,1)*C(I,2)+C(I,2)*C(I,2))/6.
      TEMP3 = C(I,2)-C(I,1)
      TEMP4 = C(I,1)+C(I,2)
      TEMP5 = (L(I)/6.)*(TEMP3/TEMP4)
      TEMP6 =-(C(I,1)*C(I,1)+C(I,1)*C(I,2)+C(I,2)*C(I,2))/
     1          (3.*(C(I,1)+C(I,2)))
      ENERGY(I) = L(I)*(TEMP1 + TEMP2 + G(I))
      GO TO 2000
 1970 TEMP1 =   A(I)*(C(I,1)+2.*C(I,2)+2.*C(I,3)+C(I,4))/2.
      TEMP2 =   B(I)*(C(I,1)*C(I,1)+2.*C(I,2)*C(I,2)+2.*C(I,3)*C(I,3)
     1+C(I,4)*C(I,4)+C(I,1)*C(I,2)+C(I,2)*C(I,3)+C(I,3)*C(I,4))/6.
      TEMP3 = -7.*C(I,1)-6.*C(I,2)+6.*C(I,3)+7.*C(I,4)
      TEMP4 = C(I,1)+2.*C(I,2)+2.*C(I,3)+C(I,4)
      TEMP5 = (L(I)/13.)*(TEMP3/TEMP4)
      TEMP6 = (C(I,1)*C(I,1)+2.*C(I,2)*C(I,2)+2.*C(I,3)*C(I,3)+
     1           C(I,4)*C(I,4)+C(I,1)*C(I,2)+C(I,2)*C(I,3)+C(I,3)*C(I,4))/
     2          (3.*(C(I,1)+2.*C(I,2)+2.*C(I,3)+C(I,4)))
      ENERGY(I) = (L(I)/3.)*(TEMP1 + TEMP2 + 3.*G(I))
      GO TO 2000
 1980 TEMP1 =   A(I)*(C(I,1)+2.*C(I,2)+2.*C(I,3)+2.*C(I,4)+2.*C(I,5)
     1+C(I,6))/2.
      TEMP2 =   B(I)*(C(I,1)*C(I,1)+2.*C(I,2)*C(I,2)+2.*C(I,3)*C(I,3)
     1+2.*C(I,4)*C(I,4)+2.*C(I,5)*C(I,5)+C(I,6)*C(I,6)+C(I,1)*C(I,2)
     2+C(I,2)*C(I,3)+C(I,3)*C(I,4)+C(I,4)*C(I,5)+C(I,5)*C(I,6))/6.
      TEMP3 = -13.*C(I,1)-18.*C(I,2)-6.*C(I,3)+6.*C(I,4)+18.*C(I,5)+
     1        13.*C(I,6)
      TEMP4 = C(I,1)+2.*C(I,2)+2.*C(I,3)+2.*C(I,4)+2.*C(I,5)+C(I,6)
      TEMP5 = (L(I)/30.)*(TEMP3/TEMP4)
      TEMP6 =-(C(I,1)*C(I,1)+2.*C(I,2)*C(I,2)+2.*C(I,3)*C(I,3)+2.*C(I,4)
     1          *C(I,4)+2.*C(I,5)*C(I,5)+C(I,6)*C(I,6)+C(I,1)*C(I,2)+
     2          C(I,2)*C(I,3)+C(I,3)*C(I,4)+C(I,4)*C(I,5)+C(I,5)*C(I,6))/
     3          (3.*(C(I,1)+2.*C(I,2)+2.*C(I,3)+2.*C(I,4)+2.*C(I,5)+
     4          C(I,6)))
      ENERGY(I) = (L(I)/5.)*(TEMP1 + TEMP2 + 5.*G(I))
C
C   NN IS THE INTEGER EQUIVALENT OF THE CLOCK DIRECTION
C   ANG(2) IS THE FLOATING-POINT VERSION OF THE CLOCK DIRECTION
C   IF USER ENTERED THE DIRECTION OF PRINCIPAL FORCE, USE THAT.
C
 2000 D(I) = D(I) + TEMP5
C
C   CHECK IF IT'S A FRONT OR REAR COLLISION
C
 2010 IF   ((J .EQ. 1)  .OR.  (J .EQ. 3))   GO TO 2100
 2020 IF   ((NN .EQ. 90)  .OR.  (NN .EQ. 270))   GO TO 2025
      GO TO 2030
C
C   FOR PERPENDICULAR SIDE COLLISIONS , H = D. (FORCE POINTS THRU C.G.)
C
 2025 H(I) = D(I)
      TEMP2 = 0.0
      GO TO 2400
C
C   FOR NON-PERPENDICULAR SIDE COLLISIONS, H IS CALCULATED AS FOLLOWS:
C
 2030 TEMP1 = Y33 - TEMP6
 2035 IF   (JVDI(I,3) .EQ. JCHARL)   GO TO 2060
 2040 TEMP2 = (90.-ANG(I))/57.3
      GO TO 2060
 2050 TEMP2 = (ANG(I)-270.)/57.3
 [illegible] TEMP[illegible] = [illegible](TEMP[illegible],D(I) + TEMP2)
```

```
      H(I) = SQRT(D(I)**2 + TEMP1**2)*TEMP3
      GO TO 2400
 2100 IF  ((NN .EQ. 360)  .OR.  (NN .EQ. 180))   GO TO 2110
      GO TO 2120
C
C   FOR STRAIGHT-ON FRONT OR REAR IMPACTS, H = ENTERED MOMENT ARM
C
 2110 H(I) = D(I)
      TEMP2 = 0.0
      GO TO 2400
C
C   FOR OFFSET FRONT/REAR IMPACTS, H IS CALCULATED AS FOLLOWS
C
 2120 IF   (J .EQ. 1)   GO TO 2140
      TEMP1 = XRR - TEMP6
      TEMP2 = (ANG(I)-180.)/57.3
      GO TO 2160
 2140 TEMP1 = XFF - TEMP6
      IF   (NN .GT. 270)   GO TO 2150
      TEMP2 = -ANG(I)/57.3
      GO TO 2160
 2150 TEMP2 = (360.-ANG(I))/57.3
 2160 H(I) = D(I)*COS(TEMP2) + TEMP1*SIN(TEMP2)
 2400 IF   (ABS(TEMP2) .GE. 1.3)   GO TO 2402
C
C   CALCULATE CORRECTION FACTOR AND GAMMA
C
 2401 KK(I) = 1. + TAN(TEMP2)*TAN(TEMP2)
      GO TO 2410
 2402 KK(I) = 13.7
 2410 ENERGY(I) = ENERGY(I)*KK(I)
 2405 GAM(I) = RSQ(JTYP(I))/(RSQ(JTYP(I)) + H(I)*H(I))
 2500 CONTINUE
C
C   CALCULATE DELTA-V FOR VEHICLE # 1
C
 3000 TEMP1 = (GAM(2)*FMASS2)/(GAM(1)*FMASS1 + GAM(2)*FMASS2)
      TEMP2 = V1*COS(ANG(1)*.01745) + V2*COS(ANG(2)*.01745)
      DELV1 = TEMP1*TEMP2*GAM(1)
C
C   CALCULATE THE TOTAL ENERGY DISSAPATION
C
 3200 TEMP1 = 1.0 + (GAM(1)*FMASS1)/(GAM(2)*FMASS2)
      SUMENG = (FMASS1*TEMP1*DELV1*DELV1)/(2.*GAM(1))
C
C   CALCULATE THE ENERGY DISSAPATED BY VEHICLE # 2
C
 3300 ENERGY(1) = SUMENG - ENERGY(2)
      ENGY1 = ENERGY(1)
      ENERGY(1) = (ENERGY(1))/KK(1)
C
C   CALCULATE THE DAMAGE AREA AND FIRST MOMENT OF THE AREA
C
 6000 JJJ = JCSET(1)
      IF   (JCSET(1) .EQ. 0)   JJJ=4
      IF   (JJJ .EQ. 2)   GO TO 6100
      IF   (JJJ .EQ. 4)   GO TO 6200
      IF   (JJJ .EQ. 6)   GO TO 6300
C
C   TWO POINTS
C
```


```
 [illegible]
```

```
      BETA1  = (L(1)/6.)*(C(1,1)*C(1,1)+C(1,1)*C(1,2)+C(1,2)*C(1,2))
      GO TO 6400
C
C   FOUR POINTS
C
 6200 ALPHA1 = (L(1)/6.)*(C(1,1)+2.*C(1,2)+2.*C(1,3)+C(1,4))
      BETA1  = (L(1)/18.)*(C(1,1)*C(1,1)+2.*C(1,2)*C(1,2)+2.*C(1,3)*
     1         C(1,3)+C(1,4)*C(1,4)+C(1,1)*C(1,2)+C(1,2)*C(1,3)+
     2         C(1,3)*C(1,4))
      GO TO 6400
C
C   SIX POINTS
C
 6300 ALPHA1 = (L(1)/10.)*(C(1,1)+2.*C(1,2)+2.*C(1,3)+2.*C(1,4)+
     1         2.*C(1,5)+C(1,6))
      BETA1  = (L(1)/30.)*(C(1,1)*C(1,1)+2.*C(1,2)*C(1,2)+2.*C(1,3)*
     1         C(1,3)+2.*C(1,4)*C(1,4)+2.*C(1,5)*C(1,5)+C(1,6)*C(1,6)+
     2         C(1,1)*C(1,2)+C(1,2)*C(1,3)+C(1,3)*C(1,4)+C(1,4)*C(1,5)+
     3         C(1,5)*C(1,6))
 6400 CONTINUE
C
C   PRINT THE INPUT DATA AND THE CRUSH INTERMEDIATE RESULTS
C
 9000 WRITE(5,9001)  (TITLE(J),J=1,40)
 9001 FORMAT(' ',/////,' ',' ==== INPUT DATA AND CRUSH ROUTINE RESULTS =
     *===',//,' ',40A1)
C
      WRITE(5,9010) JTYP(1),JTYP(2)
 9010 FORMAT(' ','VEHICLE TYPES : ',2I5)
C
      WRITE(5,9020) W(1),W(2)
 9020 FORMAT(' ','VEHICLE WEIGHTS: ',2F10.2)
C
      WRITE(5,9030) (JVDI(1,N),N=1,7),(JVDI(2,M),M=1,7)
 9030 FORMAT(' ','VEHICLE DAMAGE INDICES: ',7A1,4X,7A1)
C
      WRITE(5,9040) V1,V2
 9040 FORMAT(' ','COLLISION SPEEDS: ',2F10.2)
C
      WRITE(5,9050) A(2),B(2),G(2)
 9050 FORMAT(' ','A(2),B(2),G(2):  ',3F10.2)
C
      WRITE(5,9060) ANG(1),ANG(2)
 9060 FORMAT(' ','DIRECTION OF PRINCIPAL FORCE: ',2F10.2)
C
      WRITE(5,9070) L(1),(C(1,N),N=1,6),D(1)
 9070 FORMAT(' ','V1 DAMAGE DATA: ',F8.2,4X,6F10.2,4X,F8.2)
C
      WRITE(5,9080) L(2),(C(2,N),N=1,6),D(2)
 9080 FORMAT(' ','V2 DAMAGE DATA: ',F8.2,4X,6F10.2,4X,F8.2)
C
      WRITE(5,9090) GAM(1),GAM(2)
 9090 FORMAT(' ','GAM(1:2): ',2F10.2)
C
      WRITE(5,9100) ENERGY(2)
 9100 FORMAT(' ','ENERGY(2): ',F10.2)
C
      WRITE(5,9110)  DELV1
 9110 FORMAT(' ','DELV1: ',F8.2)
C
      WRITE(5,9120) SUMENS
[illegible]
```

```
C
      WRITE(5,9130) ENGY1
 9130 FORMAT(' ','ENERGY(1): ',F10.2)
C
      WRITE(5,9140) ALPHA1,BETA1
 9140 FORMAT(' ','ALPHA1,BETA1:   ',2F12.2)
 8000 CONTINUE
      WRITE(5,8005)
 8005 FORMAT('0DO YOU WANT THIS DATA ENTERED INTO YOUR DATA SET',/,
     1'0TO CALCULATE A AND B VALUES. IF YES TYPE 1, IF NO TYPE 0')
      READ(5,*)QUEST
      IF(QUEST.EQ.0)GO TO 8014
      WRITE(1,8010)ENGY1,ALPHA1,BETA1,L(1)
 8010 FORMAT(' ',4F16.2)
 8014 WRITE(5,8015)
 8015 FORMAT('0RUN AGAIN? IF YES TYPE 1, IF NO TYPE 0.')
      READ(5,*)DECIDE
      IF(DECIDE.EQ.0)GO TO 8500
      GO TO 400
 8500 CONTINUE
      WRITE(5,8550)
 8550 FORMAT('0YOU MUST NOW INPUT THE PARAMETER LIST FOR A AND B
     1VALUES.',/,'0THIS WILL PUT A RANGE AROUND A GUESS VALUE OF
     2A AND B.',/,'0MAKE SURE TO SELECT A RANGE THAT WILL ENCOMPASS
     3 THE ACTUAL',/,'0VALUE YOU ARE SEEKING. NOW ENTER LOW RANGE
     4 VALUE OF A, HIGH',/,'0RANGE VALUE OF A, LOW RANGE VALUE OF B,
     5 HIGH RANGE VALUE',/,'0OF B. SEPARATE WITH COMMAS AND ENTER IN
     6 INTEGER FORM.',/,'0EXAMPLE: FOR A GUESS VALUE OF A=250 AND B=49,
     7',/,'0ENTER: 200,300,40,60')
      READ(5,*)AZAPL,AZAPH,BZAPL,BZAPH
      WRITE(1,8600)AZAPL,AZAPH,BZAPL,BZAPH
 8600 FORMAT(' PROC NLIN;',/,' PARMS A=',I4,' TO ',I4,' BY 10
     1  B=',I4,' TO ',I4,' BY 5;',/,' MODEL E=A*ALPHA+B*BETA+A*A
     2*L/(2*B);',/,' DER.A=ALPHA+A*L/B;',/,' DER.B=BETA-A*A*L/(2*
     3B*B);',/,' OUTPUT OUT=TWO PARMS=AHAT BHAT;',/,' PROC PRINT;')
      CLOSE(UNIT=1)
      WRITE(5,8700)
 8700 FORMAT('0BE SURE TO: LIST CRUSH1.DAT, BEFORE YOU SUBMIT IT.',/
     1,'0IF YOU WANT TO EDIT IT TYPE: EDIT CRUSH1.DAT, IN ORDER TO',/
     2,'0ADD DATA. CHECK DIR TO MAKE SURE SAS.JCL IS PRESENT.',/,'0
     3TYPE: JOB SAS CRUSH1.DAT , PICK UP ANSWERS IN RL 2113.')
      STOP
      END
      SUBROUTINE READ2(LINE,RESULT,JSTART,JEND,ICODE)
C
C**************************************************************************
C*                                                                *OPTION*
C*                                                                ********
C*                                                                -CRASH2A-*
C*                                                                        *
C*                SUBROUTINE  READ2(LINE,RESULT,JSTART,JEND,ICODE)        *
C*                                                                        *
C*                                                                        *
C*  PURPOSE: PERMITS IDIOT-PROOF READING OF A FIELD OF NUMERIC DATA.      *
C*           IF REGULAR FORTRAN NUMERIC I/O IS USED, THE USER MAY         *
C*           INADVERTANTLY MAKE A SPELLING ERROR AND CAUSE THE FORTRAN    *
C*           I/O PROCESSOR TO TERMINATE THE RUN WITH A DIAGNOSTIC.        *
C*           TO CIRCUMVENT THIS, SUBROUTINE READ2 SCANS A FIELD OF        *
C*           CHARACTERS AND CONSTRUCTS THE DESIRED NUMERIC ITEM.          *
C*           IF AN ERROR IS MADE, A RETURN CODE IS SET.                   *
C*                                                                        *
```

```
C*                         DATA PREVIOUSLY READ IN.                              *
C*                                                                               *
C*          RESULT-------- THE ANSWER IN FLOATING POINT.                         *
C*                                                                               *
C*          JSTART-------- POSITION AT WHICH THE FIELD STARTS.                   *
C*                                                                               *
C*          JEND---------- POSITION AT WHICH THE FIELD ENDS.                     *
C*                                                                               *
C*          ICODE--------- RETURN CODE  -999 = ERROR                             *
C*                                         0 = FIELD IS EMPTY                    *
C*                                         1 = VALID RESULT                      *
C*                                                                               *
C*  CONVENTIONS: ANY VALID INTEGER OR FLOATING POINT NUMBER MAY BE               *
C*               ENTERED IN THE FIELD.                                           *
C*               EMBEDDED BLANKS, INCOMPLETE NUMBERS, AND ILLEGAL                *
C*               CHARACTERS WILL CAUSE AN ERROR RETURN CODE.                     *
C*                                                                               *
C*               EXAMPLES OF VALID NUMBERS:  1527                                *
C*                                           -1527.31                            *
C*                                           -1527.31E-3                         *
C*                                           -.312E5                             *
C*                                                                               *
C*  SYMBOLS: SX-------- SIGN OF FRACTIONAL PART                                  *
C*           SE-------- SIGN OF EXPONENTIAL PART                                 *
C*           X--------- FINAL FRACTIONAL PART                                    *
C*           EX-------- FINAL EXPONENTIAL PART                                   *
C*           NEX------- # OF DECIMAL PLACES IN FRACTIONAL PART                   *
C*           JPLUSF---- + SIGN FLAG (FRACTIONAL)      0 = LEGAL                  *
C*                                                    1 = NOT ALLOWED            *
C*           JMINF----- - SIGN FLAG (FRACTIONAL)      0 = LEGAL                  *
C*                                                    1 = NOT ALLOWED            *
C*           JPLUSE---- + SIGN FLAG (EXPONENTIAL)     0 = LEGAL                  *
C*                                                    1 = NOT ALLOWED            *
C*           JMINE----- - SIGN FLAG (EXPONENTIAL)     0 = LEGAL                  *
C*                                                    1 = NOT ALLOWED            *
C*           JPOINT---- DECIMAL POINT FLAG  0 = NO POINT FOUND                   *
C*                                          1 = DECIMAL POINT FOUND              *
C*           JEXP------ EXPONENT FLAG  0 = NO EXPONENT                           *
C*                                     1 = EXPONENT FOUND                        *
C*           JDIGIT---- DIGIT FLAG  0 = NO DIGITS FOUND                          *
C*                                  1 = FRACTIONAL DIGITS FOUND                  *
C*                                  2 = EXPONENTIAL DIGITS FOUND                 *
C*           JDONE----- FIELD COMPLETION FLAG 0 = FIELD NOT FINISHED             *
C*                                            1 = NUMBER DONE                    *
C*           ICODE----- SUBROUTINE RETURN CODE (SEE PARAMETER LIST)              *
C*           JCHAR----- SCALAR VERSION OF CURRENT CHARACTER                      *
C*           LINE(80)-- 80A1 FIELD OF CHARACTERS                                 *
C*           ITABLE(10,2)- LOOKUP TABLE  CHARACTER-TO-NUMERALS                   *
C*           IDIGIT---- NUMERIC EQUIVALENT OF CHARACTER                          *
C*           J--------- FIELD POSITION COUNTER                                   *
C*           IBLNK----- BLANK CHARACTER                                          *
C*           IPLUS----- PLUS CHARACTER                                           *
C*           IMINUS---- MINUS CHARACTER                                          *
C*           IDECPT---- DECIMAL POINT CHARACTER                                  *
C*           IEXP------ EXPONENT MARK 'E'                                        *
C*           IEXPD----- EXPONENT MARK 'D'                                        *
C*           RESULT---- FLOATING POINT RESULT                                    *
C*                                                                               *
C*                                                                               *
C*                                                                               *
C*    SPECIAL THANKS TO GENE BUTLER FOR ASSISTANCE ON THIS                       *
C     SUBROUTINE.                                                                *
```

```
C*                                                                      *
C*                                                                      *
C***********************************************************************
C
C
C
      DIMENSION LINE(80),ITABLE(10,2)
      REAL      RESULT,SX
      INTEGER   LINE,ITABLE,SE,X,EX,NEX,JPLUSF,JMINF,JPLUSE,JMINE,
     1          JDIGIT,JDONE,ICODE,JCHAR,IDIGIT,J,IBLNK,IPLUS,IMINUS,
     2          IDECPT,IEXP,IEXPD,JPOINT,JEXP
      DATA  IBLNK/'    '/,  IPLUS/'+   '/,  IMINUS/'-   '/,
     1      IDECPT/'.   '/,  IEXP/'E   '/,  IEXPD/'D   '/
      DATA  ITABLE/'0   ','1   ','2   ','3   ','4   ','5   ','6   ',
     1             '7   ','8   ','9   ',
     2             0,1,2,3,4,5,6,7,8,9/
C
C-----INITIALIZE ALL DATA
C
   10 ICODE = 0
      JPLUSF = 0
      JPLUSE = 0
      JMINF = 0
      JMINE = 0
      JPOINT = 0
      JEXP = 0
      JDIGIT = 0
      JDONE = 0
      SE = 1
      NEX = 0
      X = 0
      EX = 0
      J = 1
      SX = 1.0
      RESULT = 0.0
C
C   FETCH THE NEXT CHARACTER
C
  100 JCHAR = LINE(JSTART+J-1)
C
C   IS THE CHARACTER A BLANK ?
C
C NOTE: BLANKS ARE IGNORED TILL THE NUMBER STARTS.
C       AFTER THAT, THE APPEARANCE OF A BLANK WILL END THE FIELD.
C
  200 IF   (JCHAR .NE. IBLNK)   GO TO 300
      IF   ((JPLUSF .EQ. 0) .AND. (JMINF .EQ. 0) .AND. (JPLUSE .EQ. 0)
     1 .AND. (JMINE .EQ. 0) .AND. (JPOINT .EQ. 0) .AND. (JEXP .EQ. 0)
     2 .AND. (JDIGIT .EQ. 0))   GO TO 1000
      JDONE = 1
      GO TO 1000
C
C   IS THE CHARACTER A PLUS SIGN?
C
C NOTE: IF THE FIELD IS FINISHED, A PLUS SIGN WILL SET AN ERROR CODE.
C       IF  (JPLUSF,JMINF,JEXP = 0)     THIS IS THE FRACTION SIGN
C       IF (JPLUSE,JMINE = 0, JEXP = 1)  THIS IS THE EXPONENT SIGN
C       ANYTHING ELSE WILL CAUSE AN ERROR.
C
  300 IF   (JCHAR .NE. IPLUS)  GO TO 400
      IF   (JDONE .EQ. 1)   GO TO 315
     1 ((JPLUSE .EQ. 0) .AND. (JMINE .EQ. 0) .AND. (JEXP .EQ. 0))
```

```
     1      GO TO 340
        IF    ((JPLUSE .EQ. 0) .AND. (JMINE .EQ. 0) .AND. (JEXP .EQ. 1))
     1      GO TO 360
  315 ICODE = -999
      RETURN
  340 SX = 1.0
      JPLUSF = 1
      GO TO 1000
  360 SE = 1
      JPLUSE = 1
      GO TO 1000
C
C   IS THE CHARACTER A MINUS SIGN?
C
C NOTE: IF THE FIELD IS FINISHED, A MINUS SIGN WILL CAUSE AN ERROR.
C        IF  (JPLUSF,JMINF,JEXP = 0)    THIS IS THE FRACTION SIGN
C        IF (JPLUSE,JMINE = 0, JEXP = 1)  THIS IS THE EXPONENT SIGN
C        ANYTHING ELSE IS AN ERROR.
C
  400 IF  (JCHAR .NE. IMINUS)  GO TO 500
      IF  (JDONE .EQ. 1)  GO TO 415
      IF   ((JPLUSF .EQ. 0) .AND. (JMINF .EQ. 0) .AND. (JEXP .EQ. 0))
     1     GO TO 440
      IF   ((JPLUSE .EQ. 0) .AND. (JMINE .EQ. 0) .AND. (JEXP .EQ. 1))
     1     GO TO 460
  415 ICODE = -999
      RETURN
  440 SX = -1.0
      JMINF = 1
      GO TO 1000
  460 SE = -1
      JMINE = 1
      GO TO 1000
C
C   IS THE CHARACTER A DECIMAL POINT
C
C NOTE: IF FIELD IS FINISHED, A DECIMAL POINT WILL CAUSE AN ERROR.
C       DECIMAL POINTS ARE ONLY ALLOWED IN THE FRACTIONAL PART.
C
  500 IF  (JCHAR .NE. IDECPT)  GO TO 600
      IF  (JDONE .EQ. 1)  GO TO 515
      IF  ((JPOINT .EQ. 0) .AND. (JEXP .EQ. 0))  GO TO 520
  515 ICODE = -999
      RETURN
  520 JPOINT = 1
      JPLUSF = 1
      JMINF = 1
      GO TO 1000
C
C   IS THE CHARACTER AN 'E' OR A 'D'?
C
C NOTE: IF THE FIELD IS FINISHED, AN EXPONENT WILL CAUSE AN ERROR.
C       ONLY ONE EXPONENT MARK IS ALLOWED.
C
  600 IF  ((JCHAR .NE. IEXP) .AND. (JCHAR .NE. IEXPD))  GO TO 700
      IF  (JDONE .EQ. 1)  GO TO 615
      IF  (JEXP .EQ. 0)  GO TO 620
  615 ICODE = -999
      RETURN
  620 JEXP = 1
      JPOINT = 1
      JPLUSF = 1
```

```
      JMINF = 1
      GO TO 1000
C
C   IS THE CHARACTER A VALID NUMERAL?
C
C NOTE: IF THE FIELD IS FINISHED, A NUMERAL WILL CAUSE AN ERROR.
C         USE THE LOOKUP-TABLE TO GET THE NUMERIC EQUIVALENT.
C
  700 DO 707 JPL=1,10
      IF  (JCHAR .EQ. ITABLE(JPL,1))  GO TO 720
  707 CONTINUE
  710 ICODE = -999
      RETURN
  720 IDIGIT = ITABLE(JPL,2)
      IF  (JDONE .EQ. 1)  GO TO 710
      IF  (JEXP .EQ. 1)  GO TO 780
C
C   IF WE'RE DOING THE FRACTIONAL PART, GET THE RUNNING ANSWER.
C
  750 X = X*10 + IDIGIT
      NEX = NEX + JPOINT
      JDIGIT = 1
      JPLUSF = 1
      JMINF = 1
      GO TO 1000
C
C   IF WE'RE DOING THE EXPONENTIAL PART, GET THE RUNNING EXPONENT.
C
  780 EX = EX*10 + IDIGIT
      JDIGIT = 2
      JPLUSE = 1
      JMINE = 1
      GO TO 1000
C
C   SEE IF THE END-OF-THE-FIELD HAS BEEN REACHED?
C
 1000 IF   ((JSTART+J-1) .EQ. JEND)   GO TO 1500
      J = J + 1
      GO TO 100
C
C   END-OF-FIELD HAS BEEN REACHED.
C
C NOTE: CHECK IF ENTIRE FIELD WAS COMPLETELY BLANK.
C         CHECK IF ANY DIGITS AT ALL WERE ENCOUNTERED
C         CHECK IF THE EXPONENTIAL PART HAD ANY DIGITS.
C
 1500 IF   ((JPLUSF .EQ. 0) .AND. (JMINF .EQ. 0) .AND. (JPLUSE .EQ. 0)
     1 .AND. (JMINE .EQ. 0) .AND. (JPOINT .EQ. 0) .AND. (JEXP .EQ. 0)
     2 .AND. (JDIGIT .EQ. 0))   GO TO 1600
 1510 IF  (JDIGIT .LT. 1)  GO TO 1530
 1520 IF   ((JEXP .EQ. 1) .AND. (JDIGIT .NE. 2))  GO TO 1530
      GO TO 2000
 1530 ICODE = -999
      RETURN
C
C   HANDLE BLANK FIELD HERE.
C
 1600 ICODE = 0
      RETURN
C
C   WORK OUT NUMERICAL RESULT HERE
C
```

```
2000 RESULT = SX*FLOAT(X)*10.0**(SE*EX-NEX)
     ICODE = 1
     RETURN
     END
```

APPENDIX D

This appendix contains an individual listing of all staged collisions for which delta-v and residual damage information was examined

MINI - FRONTAL

#	YEAR	VEHICLE	TEST	SUPPLIER
1	1975	Honda Civic CVCC-to NHTSA Test Device	DOT-HS-7-01758 31.12 mph, frontal	DSI
2	1975	Ford Torino-to- 1975 Honda CVCC	DOT-HS-5-01099 29.2 mph, front-to-front	Calspan
3	1975	Honda Civic CVCC-to- NHTSA Test Device	DOT-HS-01758 40.83 mph, frontal	DSI
4	1979	Datsun 210 2dr.-to- Fixed Barrier	DOT-HS-6-01478 35.2 mph, frontal	DSI
5	1979	Honda Civic 2dr.-to- Fixed Barrier	DOT-HS-8-01938 34.75 mph, frontal	Calspan
6	1979	Chevrolet Chevette-to- Fixed Barrier	DOT-HS-8-01938 34.8 mph, frontal	Calspan
7	1979	VW Rabbit-to- Fixed Barrier	DOT-HS-8-01938 34.8 mph, frontal	Calspan
8	1978	Chevrolet Chevette-to- Fixed Barrier	DOT-HS-6-01477 29.375 mph, frontal	AETL
9	1978	VW Rabbit-to- Fixed Barrier	DOT-HS-6-01478 29.58 mph, frontal	DSI

SUBCOMPACT - FRONTAL

#	YEAR	VEHICLE	TEST	SUPPLIER
10	1979	Chevrolet Monza-to-Fixed Barrier	DOT-HS-8-01938 35.06 mph, frontal	Calspan
11	1979	Toyota Celica Liftbk to-Fixed Barrier	DOT-HS-8-01938 34.8 mph, frontal	Calspan
12	1979	Mercury Bobcat-to-Fixed Barrier	DOT-HS-6-01478 35.05 mph, frontal	DSI
13	1978	AMC Gremlin-to-Fixed Barrier	DOT-HS-6-01477 29.72 mph, frontal	AETL
14	1978	Mazda RX-4-to-Fixed Barrier	DOT-HS-6-01478 30.04 mph, frontal	DSI
15	1978	Dodge Challenger-to-Fixed Barrier	DOT-HS-6-01477 29.285 mph, frontal	DSI
16	1978	Dodge Omni 4dr-to-Fixed Barrier	DOT-HS-6-01477 29.77 mph, frontal	AETL
17	1979	Plymouth Horizon-to-Fixed Barrier	DOT-HS-6-01478 34.86 mph, frontal	DSI
18	1979	Ford Fiesta-to-Fixed Barrier	NHTSA 790547 34.94 mph, frontal	M.S.E.C.*
19	1979	Toyota Corolla-to-Fixed Barrier	NHTSA 790549 34.95 mph, frontal	M.S.E.C.
20	1979	Saab 900GL-to-Fixed Barrier	NHTSA 790548 29.28 mph, frontal	M.S.E.C.
21	1977	Pontiac Sunbird-to-Fixed Barrier	DOT-HS-6-01478 29.52 mph, frontal	DSI

*Mobility Systems Equipment Company

COMPACT - FRONTAL

#	YEAR	VEHICLE	TEST	SUPPLIER
22	1980	AMC Concord-to-Fixed Barrier	DOT-HS-8-01938 34.7 mph, frontal	Calspan
23	1978	AMC Concord-to-Fixed Barrier	DOT-HS-6-01477 29.67 mph, frontal	AETL
24	1978	Peugeot 604SL-to-Fixed Barrier	DOT-HS-6-01477 29.4 mph, frontal	AETL
25	1979	Chevrolet Malibu-to-Fixed Barrier	DOT-HS-8-01938 35.4 mph, frontal	Calspan
26	1978	Mercury Monarch-to-Fixed Barrier	DOT-HS-6-01477 29.03 mph, frontal	AETL
27	1978	Mercury Zephyr-to-Fixed Barrier	DOT-HS-6-01477 29.67 mph, frontal	AETL
28	1979	Ford Fairmont-to-Fixed Barrier	DOT-HS-8-01938 35.4 mph, frontal	Calspan
29	1979	Ford Granada-to-Fixed Barrier	DOT-HS-8-01938 34.6 mph, frontal	Calspan
30	1979	Ford Granada-to-Fixed Barrier	DOT-HS-8-01938 34.57 mph, frontal	Calspan
31	1979	Pontiac Firebird-to-Fixed Barrier	DOT-HS-6-01478 35.24 mph, frontal	DSI
32	1978	Toyota Cressida-to-Fixed Barrier	DOT-HS-6-01478 29.61 mph, frontal	DSI
33	1978	Datsun 810-to Fixed Barrier	DOT-HS-6-01477 30.045 mph, frontal	AETL
34	1979	Volvo 244DL-to-Fixed Barrier	NHTSA 790550 34.98 mph, frontal	M.S.E.C.
35	1975	Volvo 244DL-to-Fixed Barrier	DOT-HS-7-01758 45.11 mph, frontal	DSI
36	1974	Volvo 244-to-Volvo 244	DOT-HS-7-01542 30.1 mph, front-to-front	DSI
37	1975	Volvo 244DL-to-NHTSA Moving Device	DOT-HS-7-01758 30.69 mph, front-to-front	DSI
38	1975	Volvo 244-to-Volvo 244	DOT-HS-7-01542 30.2 mph, front-to-front	DSI
39	1975	Volvo 244-to-Volvo 244	DOT-HS-7-01542 30.3 mph, front-to-front	DSI
40	1978	Buick Century Custom-to-Fixed Barrier	DOT-HS-6-01477 29.84 mph, frontal	AETL

INTERMEDIATE - FRONTAL

#	YEAR	VEHICLE	TEST	SUPPLIER
41	1978	Chrysler LeBaron-to-Fixed Barrier	DOT-HS-6-01477 29.67 mph, frontal	AETL
42	1979	Buick Riviera-to-Fixed Barrier	DOT-HS-6-01478 35.33 mph, frontal	DSI
43	1979	Mercury Marquis-to-Fixed Barrier	DOT-HS-6-01478 35.42 mph, frontal	DSI
44	1978	Dodge Magnum XE-to-Fixed Barrier	DOT-HS-6-01477 29.87 mph, frontal	AETL
45	1978	Dodge Monaco-to-Fixed Barrier	DOT-HS-6-01478 29.34 mph, frontal	DSI
46	1979	Chrysler LeBaron-to-Fixed Barrier	DOT-HS-8-01938 35.04 mph, frontal	CATC
47	1979	Plymouth Volare-to-Fixed Barrier	DOT-HS-8-01938 34.98 mph, frontal	CATC
48	1979	Chrysler LeBaron-to-Fixed Barrier	DOT-HS-8-01938 35.04 mph, frontal	CATC
49	1979	Dodge Magnum Tudor-to-Fixed Barrier	NHTSA 308-23-464 35.3 mph, frontal	Calspan
50	1979	Chevrolet Impala-to-Fixed Barrier	DOT-HS-6-01478 35.17 mph, frontal	DSI
51	1977	Ford LTD-to-Fixed Barrier	DOT-HS-6-01478 29.36 mph, frontal	DSI
52	1977	Chrysler Cordoba-to-Fixed Barrier	DOT-HS-6-01478 29.22 mph, frontal	DSI
53	1978	Chevrolet Nova-to-Fixed Barrier	DOT-HS-6-01478 29.65 mph, frontal	AETL

FULL - FRONTAL

#	YEAR	VEHICLE	TEST	SUPPLIER
54	1978	Ford LTDII Brougham-to-Fixed Barrier	DOT-HS-6-01477 29.72 mph, frontal	AETL
55	1979	Oldsmobile Regency-to-Fixed Barrier	DOT-HS-6-01478 34.99 mph, frontal	DSI
56	1979	Ford LTD-to-Fixed Barrier	DOT-HS-8-01938 35.35 mph, frontal	CATC

MINI - REAR

#	YEAR	VEHICLE	TEST	SUPPLIER
57	1979	Triumph Spitfire-to-Moving Barrier	DOT-HS-6-01477 29.63 mph, rear impact	NHTSA 790537 AETL
58	1979	Plymouth Arrow-to-Moving Barrier	DOT-HS-6-01477 29.76 mph, rear impact	NHTSA 790543 AETL
59	1977	Chevrolet Chevette-to-Fixed Barrier	DOT-HS-6-01478 29.32 mph, rear impact	DSI
60	1979	MG Midget-to-Moving Barrier	DOT-HS-6-01477 29.66 mph, rear impact	NHTSA 790536 AETL

SUBCOMPACT - REAR

#	YEAR	VEHICLE	TEST	SUPPLIER
61	1976	Ford Pinto Wagon-to- 1971 Chevrolet Impala	NHTSA-8-0323 35.18 mph, rear-to-front	DSI
62	1972	Ford Pinto Wagon-to- 1971 Chevrolet Impala	NHTSA-8-0323 35.57 mph, rear-to-front	DSI
63	1976	Ford Pinto Wagon-to- 1971 Chevrolet Impala	NHTSA-8-0323 30.31 mph, rear-to-front	DSI
64	1976	Ford Pinto Wagon-to- 1971 Chevrolet Impala	NHTSA-8-0323 35.30 mph, rear-to-front	DSI
65	1974	Ford Pinto-to- 1971 Chevrolet Impala	NHTSA-8-0323 29.89 mph, rear-to-front	DSI
66	1974	Ford Pinto-to- 1971 Chevrolet Impala	NHTSA-8-0323 35.32 mph, rear-to-front	DSI
67	1971	Ford Pinto-to- 1971 Chevrolet Impala	NHTSA-8-0323 29.91 mph, rear-to-front	DSI
68	1972	Ford Pinto-to- 1971 Chevrolet Impala	NHTSA-8-0323 35.27 mph, rear-to-front	DSI
69	1972	Ford Pinto-to- Fixed Barrier	NHTSA-8-0323 21.47 mph, rear impact	DSI
70	1972	Chevrolet Vega-to- Fixed Barrier	NHTSA-8-0323 21.38 mph, rear impact	DSI
71	1978	Chevrolet Monza-to- Moving Barrier	DOT-HS-6-01478 29.21 mph, rear impact	DSI
72	1978	Pontiac Sunbird Moving Barrier	DOT-HS-6-01478 29.32 mph, rear impact	DSI
73	1971	Chevrolet Vega-to- 1971 Chevrolet Impala	NHTSA-8-0323 34.78 mph, rear-to-front	DSI
74	1971	Chevrolet Vega-to- 1971 Chevrolet Impala	NHTSA-8-0323 40.74 mph, rear-to-front	DSI
75	1978	Plymouth Sapporo-to- Moving Barrier	DOT-HS-6-01478 29.80 mph, rear impact	DSI
76	1978	Saab 99GL-to- Moving Barrier	DOT-HS-6-01478 29.29 mph, rear impact	DSI
77	1978	Mazda Cosmo-to- Moving Barrier	DOT-HS-6-01478 29.00 mph, rear impact	DSI
78	1978	Buick Opel-to- Moving Barrier	DOT-HS-6-01478 30.27 mph, rear impact	DSI
79	1978	Datsun 510-to- Moving Barrier	DOT-HS-6-01478 29.52 mph, rear impact	DSI

COMPACT - REAR

#	YEAR	VEHICLE	TEST	SUPPLIER
80	1979	Mercury Monarch-to-Fixed Barrier	DOT-HS-8-01938 35.09 mph, rear impact	Calspan
81	1979	Mercury Zephyr-to-Fixed Barrier	DOT-HS-8-01938 35.2 mph, rear impact	Calspan
82	1979	Mercury Zephyr-to-Fixed Barrier	DOT-HS-8-01938 35.3 mph, rear impact	Calspan
83	1978	Ford Fairmont-to-Moving Barrier	DOT-HS-6-01478 29.49 mph, rear impact	DSI
84	1980	AMC Concord-to-Fixed Barrier	DOT-HS-8-01938 34.97 mph, rear impact	Calspan
85	1979	Volvo 4dr Sedan-to-Fixed Barrier	DOT-HS-8-01938 34.55 mph, rear impact	Calspan

INTERMEDIATE - REAR

#	YEAR	VEHICLE	TEST	SUPPLIER
86	1978	Dodge Diplomat-to-Moving Barrier	DOT-HS-6-01478 29.73 mph, rear impact	DSI
87	1977	Oldsmobile Cutlass Supr.-to-Fixed Barrier	DOT-HS-6-01478 28.98 mph, rear impact	DSI
88	1978	Buick Regal-to-Moving Barrier	DOT-HS-6-01478 29.90 mph, rear impact	DSI
89	1977	Pontiac Ventura-to-Fixed Barrier	DOT-HS-6-01478 29.30 mph, rear impact	DSI
90	1979	Cadillac Seville-to-Moving Barrier	DOT-HS-6-01477 29.57 mph, rear impact	AETL
91	1979	Ford Thunderbird-to-Moving Barrier	DOT-HS-6-01477 35.19 mph, rear impact	AETL
92	1979	Ford LTD Landau-to-Moving Barrier	DOT-HS-6-01477 35.03 mph, rear impact	AETL
93	1979	Buick Riviera S-to-Moving Barrier	DOT-HS-6-01477 34.81 mph, rear impact	AETL
94	1978	Pontiac Phoenix-to-Moving Barrier	DOT-HS-6-01478 28.81 mph, rear impact	DSI

FULL - REAR

#	YEAR	VEHICLE	TEST	SUPPLIER
95	1979	Checker Taxi-Cab-to-Moving Barrier	DOT-HS-6-01477 29.67 mph, rear impact	AETL (NHTSA 790545)

VANS - FRONTAL

#	YEAR	VEHICLE	TEST	SUPPLIER
97	1978	Ford P500 Van-to-Fixed Barrier	DOT-HS-6-01477 29.385 mph, frontal	AETL
98	1978	GMC Vandura G1500-to-Fixed Barrier	DOT-HS-6-01477 29.525 mph, frontal	AETL
99	1979	Ford Econoline E150-to-Fixed Barrier	DOT-HS-8-01942 15.25 mph, frontal	DSI
100	1979	Ford Econoline E150-to-Fixed Barrier	DOT-HS-8-01942 30.02 mph, frontal	DSI
101	1979	Dodge B200 Van-to-Fixed Barrier	DOT-HS-8-01942 15.28 mph, frontal	DSI
102	1979	Dodge B200 Van-to-Fixed Barrier	DOT-HS-8-01942 30.22 mph, frontal	DSI
103	1979	Dodge B200 Van-to-Fixed Barrier	DOT-HS-8-01942 25.17 mph, frontal	DSI
104	1979	Dodge B200 Van-to-1979 Chevrolet Impala	DOT-HS-8-01942 30.8 mph, front-to-front	DSI
105	1978	Ford Econoline E150-1979 Chevrolet Impala	DOT-HS-8-01942 31.8 mph, front-to-front	DSI
106	1978	GMC G35 Magnavaro-to-Fixed Barrier	DOT-HS-6-01477 29.225 mph, frontal	AETL
107	1978	Chevrolet G20-to-Fixed Barrier	DOT-HS-6-01477 29.41 mph, frontal	AETL

VANS - REAR

#	YEAR	VEHICLE	TEST	SUPPLIER
108	1978	Chevrolet G-10 Van-to-Moving Barrier	DOT-HS-6-01478 29.18 mph, rear impact	DSI
109	1978	Dodge B100-to Moving Barrier	DOT-HS-6-01478 29.2 mph, rear impact	DSI

PICKUP - FRONTAL

#	YEAR	VEHICLE	TEST	SUPPLIER
110	1978	Ford Courier P.U.-to-Fixed Barrier	DOT-HS-6-01477 29.73 mph, frontal	AETL
111	1978	Chevrolet El Camino-to-Fixed Barrier	DOT-HS-6-01477 29.755 mph, frontal	AETL
112	1978	Ford Custom Styleside F150-to-Fixed Barrier	DOT-HS-6-01477 29.16 mph, frontal	AETL
113	1978	Chevrolet Luv, P.U. to-Fixed Barrier	DOT-HS-6-01477 29.735 mph, frontal	AETL
114	1978	Ford Custom Styleside F250-to-Fixed Barrier	DOT-HS-6-01477 29.85 mph, frontal	AETL

PICKUP - REAR

#	YEAR	VEHICLE	TEST	SUPPLIER
115	1978	Datsun P.U.-to-Moving Barrier	DOT-HS-6-01478 29.4 mph, rear impact	DSI
116	1978	Ford F-100 1/2 Ton-to-Moving Barrier	DOT-HS-6-01478 29.66 mph, rear impact	DSI
117	1978	Dodge D-100 P.U.-to-Moving Barrier	DOT-HS-6-01478 29.43 mph, rear impact	DSI
118	1978	Ford Ranchero 1/2 Ton to-Moving Barrier	DOT-HS-6001478 29.11 mph, rear impact	DSI
119	1978	Toyota SR5 Long Bed P.U. SR5 Hilux-to-Moving Barrier	DOT-HS-6-01477 29.67 mph, rear impact	AETL
120	1978	GMC 1500 P.U.-to-Moving Barrier	DOT-HS-6-01478 29.18 mph, rear impact	DSI

4X4 - FRONTAL

#	YEAR	VEHICLE	TEST	SUPPLIER
121	1978	Datsun F-10-to-Fixed Barrier	DOT-HS-6-01478 29.8 mph, frontal	DSI
122	1978	Subaru Brat Fixed Barrier	DOT-HS-6-01478 29.56 mph, frontal	DSI

The following tests were not run as part of the CRUSH program in order to obtain A, B, and G values for the reasons stated:

1. Dynamic Science Incorporated
   Contract DOT HS-5-01104
   "Impact Test of Compact Vehicle With Modified Side Structure, 35 mph, 60° Impact, Torino to Volare, Test No. 7."

   1975 Ford Torino
   1976 Plymouth Volare

   Reason: Modification of R.F. Door

2. Dynamic Science Incorporated
   Contract DOT HS-5-01104
   "Impact Test of Compact Vehicle with Modified Side Structure, 35 mph, 60° Impact. Torino to Volare, Test No. 6"

   1975 Ford Torino
   1976 Plymouth Volare

   Reason: Modification of R.F. Door

3. Dynamic Science Incorporated
   Contract DOT HS-5-01104
   "Impact Test of Compact Vehicle with Modified Side Structure, 35 mph, 60° Impact. Torino to Volare Side (Right), Test No. 5."

   1975 Ford Torino
   1976 Plymouth Volare

   Reason: Modification of R.F. Door

4. Dynamic Science Incorporated
   Contract DOT HS-5-01104
   "Impact Test of Compact Vehicle with Modified Side Structure, 25 mph, 60° Impact. Torino to Volare, Test No. 3."

   1975 Ford Torino
   1976 Plymouth Volare

   Reason: Modification of R.F. Door

5. Dynamic Science Incorporated
   Contract DOT HS-5-01104
   "Impact Test of Compact Vehicle with Modified Side Structure, 35 mph, 60° Impact. Impala to Volare, Test No. 10."

   1978 Chevrolet Impala
   1976 Plymouth Volare

   Reason: Modification of R.F. Door

6. Dynamic Science Incorporated
Contract DOT HS-5-01104
"Impact Test of Compact Vehicle with Modified Side Structure, 25 mph, 60° Impact. Impala to Volare, Test No. 10."

1978 Chevrolet Impala
1976 Plymouth Volare

Reason: Modification of R.F. Door

7. Dynamic Science Incorporated
Contract: DOT HS-6-01307
Vehicle Integration of Advanced restraint Systems. Volume II: Phase A. Test No. 10, Torino to Volvo, 30° Right Oblique."

1975 Ford Torino
1976 Volvo 244

Reason: A & B Pillar Modifications in Volvo

8. Dynamic Science Incorporated
Contract: DOT HS-6-01307
Vehicle Integration and Evaluation of Advanced Restraint Systems. Volume II: Phase B. Test No. 14, Torino to Volvo, 30° Right Oblique."

1975 Ford Torino
1976 Volvo 244

Reason: A & B Pillar Modifications in Volvo

9. Dynamic Science Incorporated
Contract: DOT HS-6-01307
Vehicle Integration and Evaluation of Advanced Restraint Systems. Volume II: Phase B. Test No. 12, Torino to Volvo, 30° Right Oblique."

1975 Ford Torino
1976 Volvo 244

Reason: Modifications of dash, A & B Pillar in Volvo

10. Dynamic Science Incorporated
Contract: DOT HS-5-01104
"Impact Test of Compact Vehicle with Modified Side Structure, 35 mph, 90° Impact, Torino to Volare,

1975 Ford Torino
1976 Plymouth Volare

Reason: Modification of L.F. Door

21. Approved Engineering Test Laboratories
Contract: DOT HS-6-01477
"Occupant Response and Vehicle Acceleration in a 30 mph Left Oblique Impact Test."

1978 Buick Skyhawk "5" -- 2 door coupe -- Rigid Barrier

Reason: Impossible to obtain damage length from available data

22. Dynamic Science Incorporated
Contract: DOT HS-5-01104
"Baseline Test of Compact Vehicle Side Structure, 25 mph, 60° Impact, Torino to Volare Test No. 2."

1975 Ford Torino
1976 Plymouth Volare

Reason: Impossible to obtain damage dimensions for striking vehicle from available data

23. Calspan Corporation
Contract: DOT HS-5-01099
"Car-to-Car Side Impact Crush and Crush Testing Test Report Test No. 1"

1978 Ford Torino
1975 Plymouth Fury

Reason: Intrusion

24. Calspan Corporation
Contract: DOT HS-5-01099
"Car-to-Car Side Impact Crush and Crash Testing Test Report Test No. 5"

1975 Plymouth Fury
1975 Plymouth Fury

Reason: Damage dimension

25. AETL
Contract: DOT HS-6-01477
"Car-to-Car"

1978 Buick Skyhawk "S"

Reason: Not sufficient impact direction data

26. AETL
Contract: DOT HS-6-01477

1978 Fiat 131-5 MIRAFIONI

Reason: Impossible to determine exact crush of oblique test

27. Calspan Corporation
Contract: DOT HS-5-D1099
"Car-to-Car Front-to-Side"

1975 Ford Torino
1975 Plymouth Fury

Reason: Striking vehicle damage profile

28. Calspan Corporation
"Baseline Crash Test No. 4"

1978 Chevrolet Impala
1976 Volkswagen Rabbit

Reason: No striking vehicle measurements

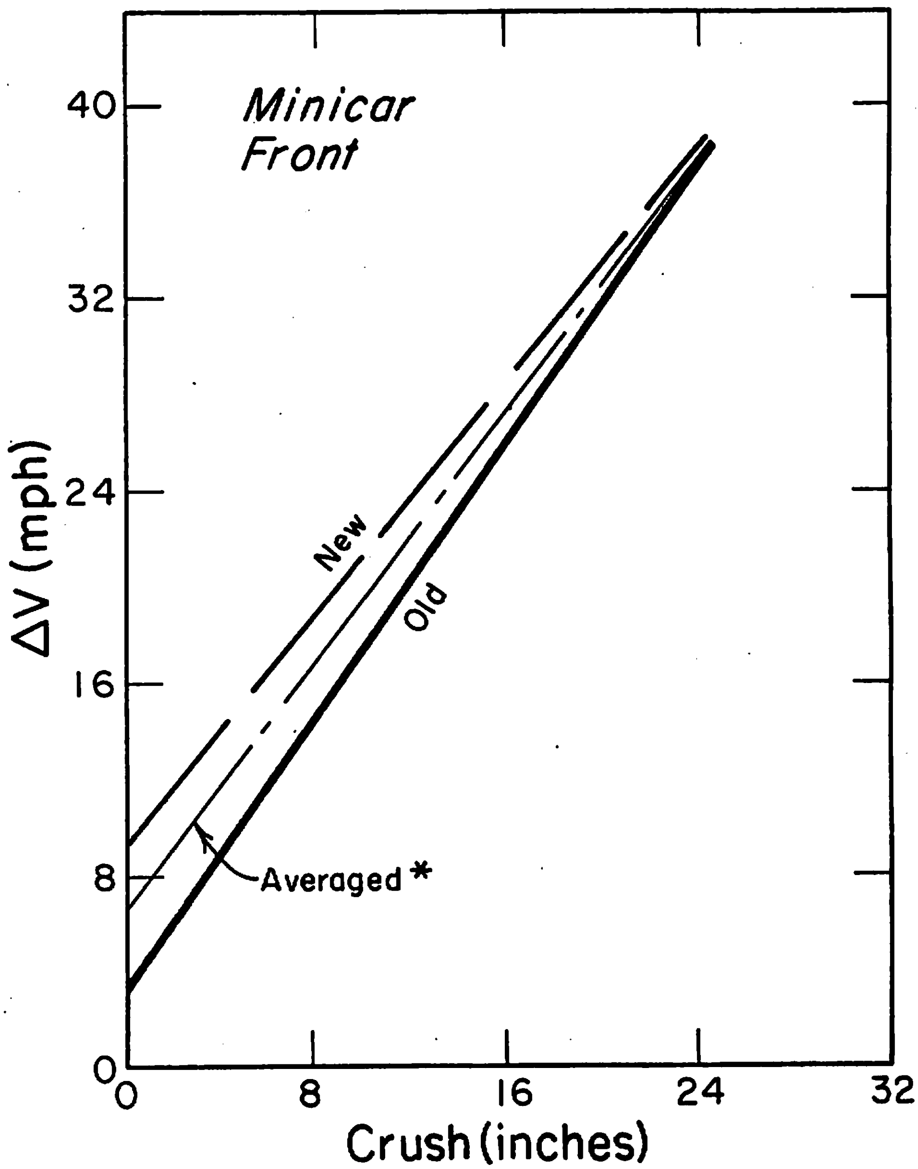
29. Calspan Corporation
"Baseline Crash Test No. 6"

1978 Chevrolet Impala
1976 Volkswagen Rabbit

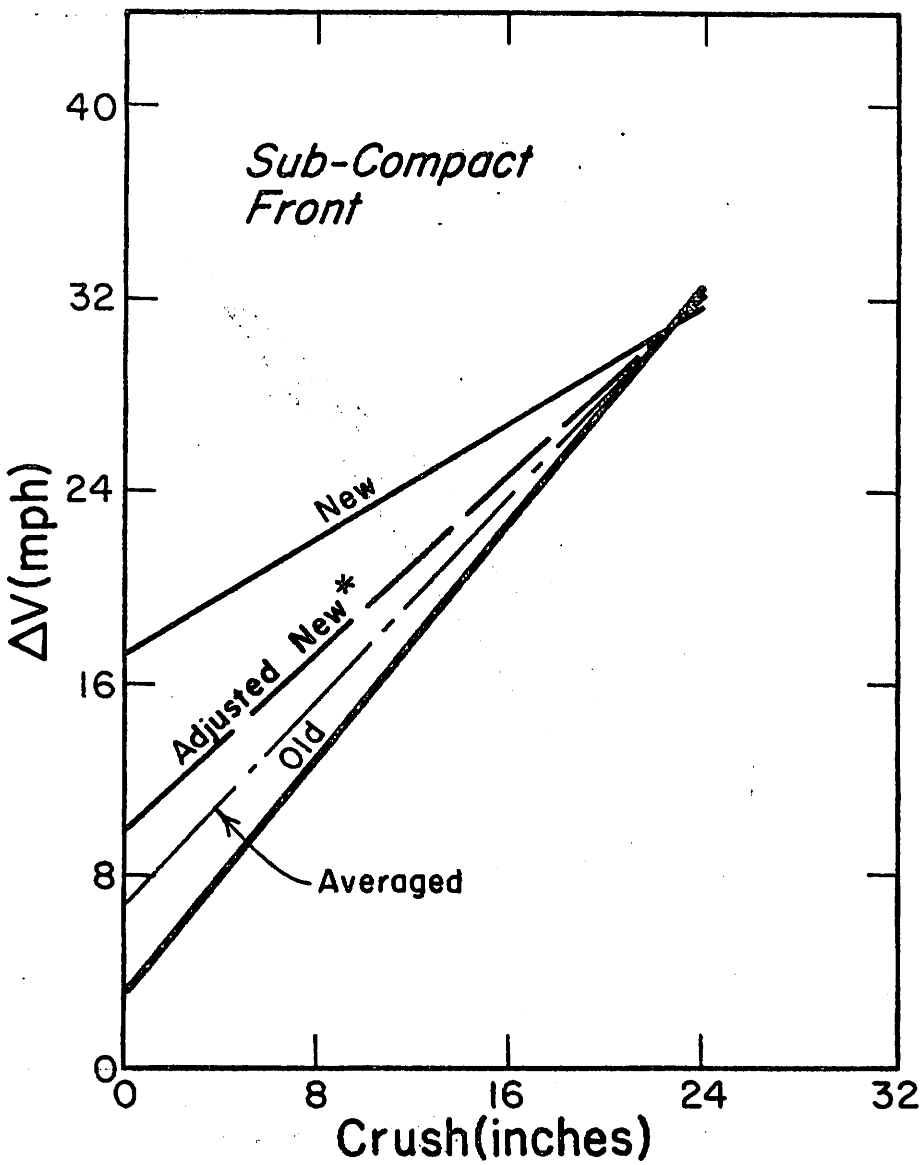
Reason: No striking vehicle measurements

APPENDIX E

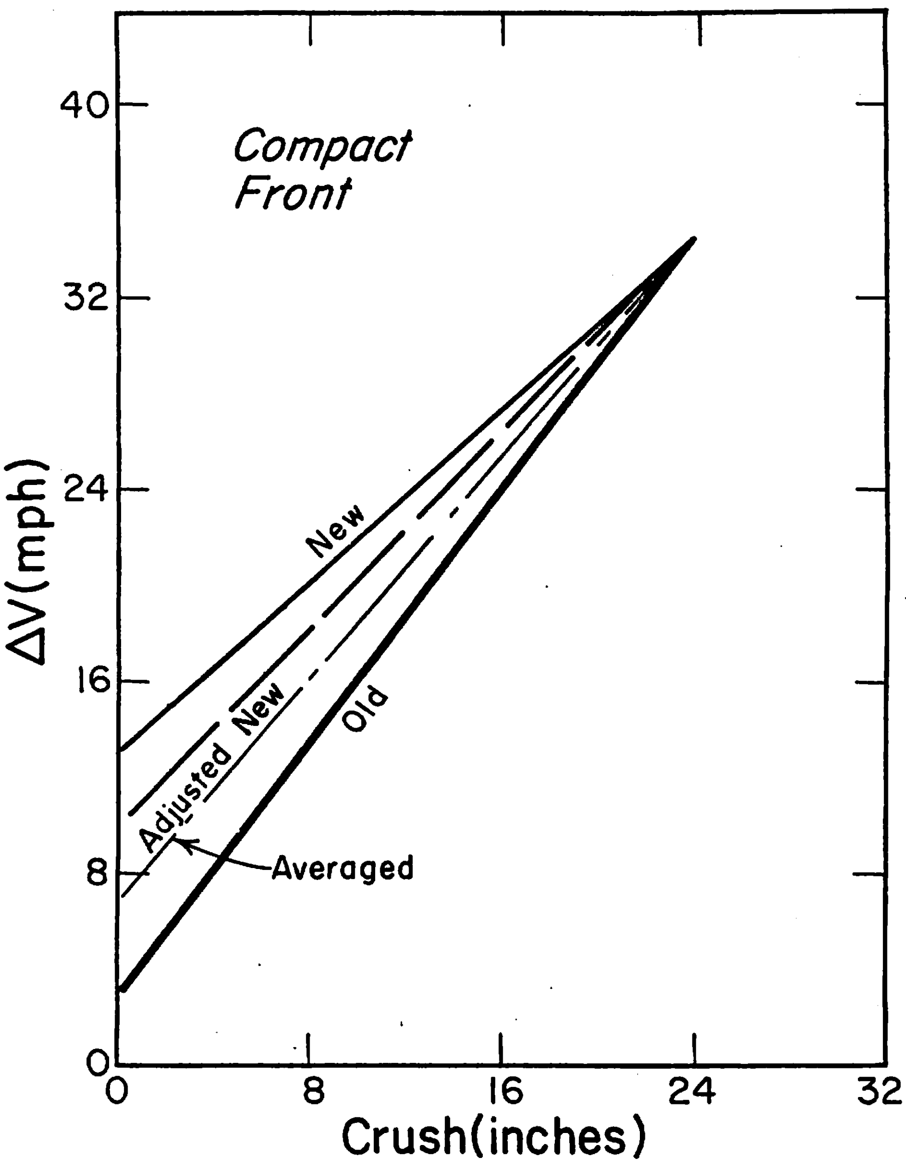
Crush vs. Delta-V Graphs for Passenger Cars, Vans, Pickups, and 4 x 4's

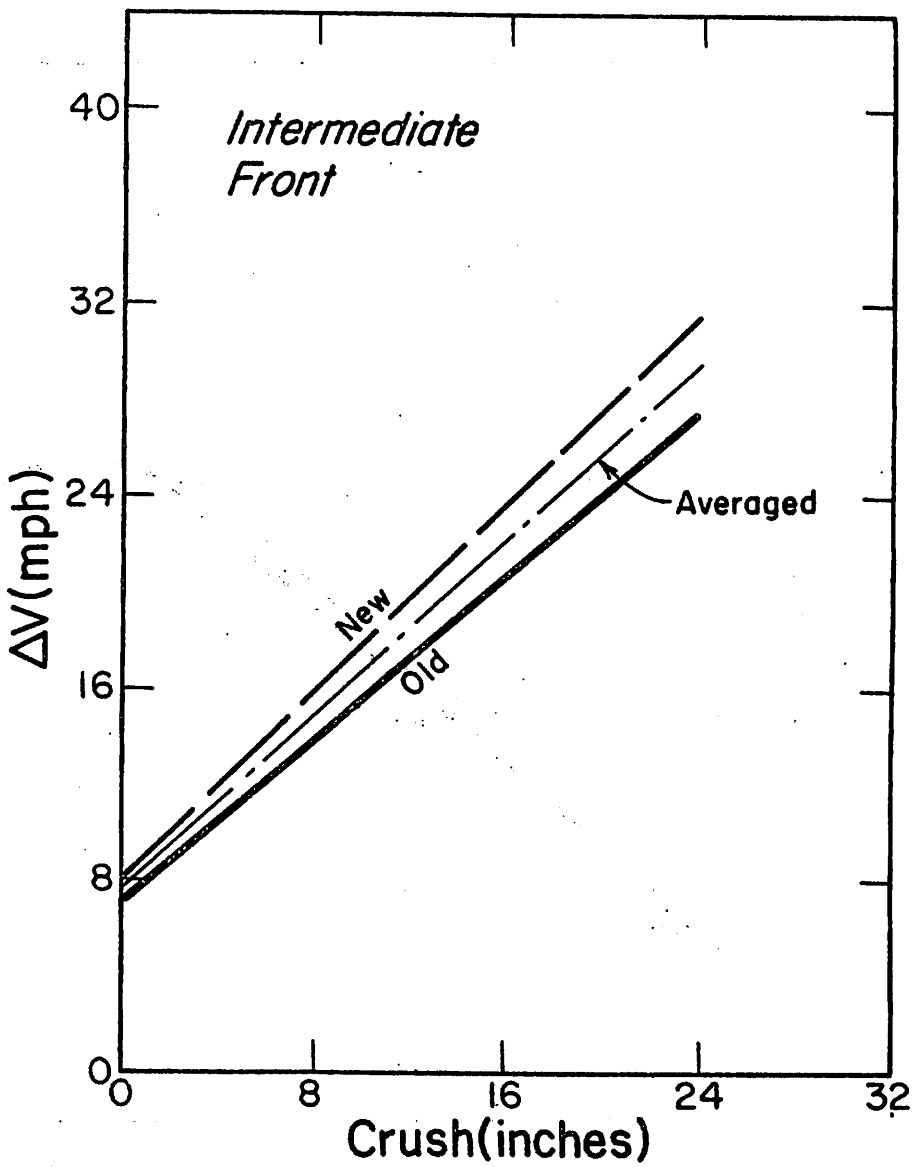


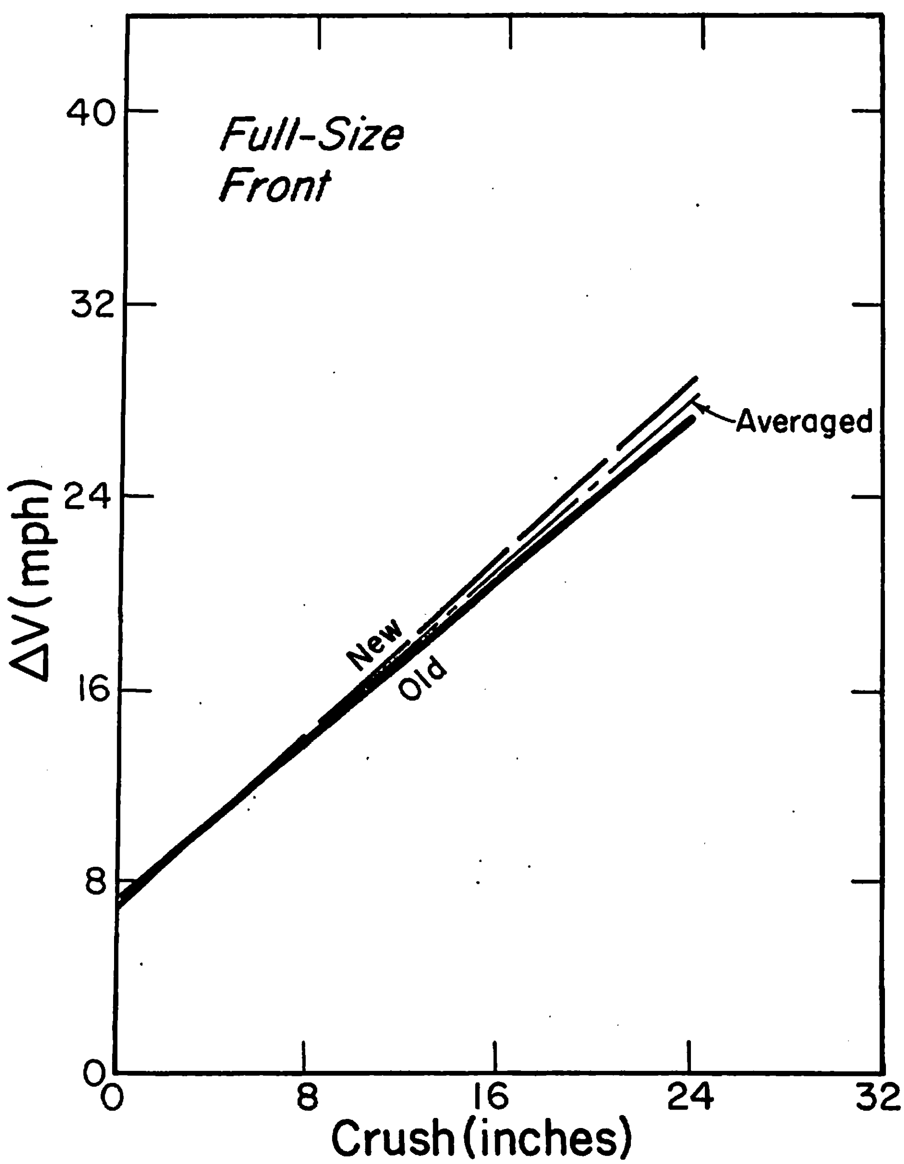
*See text for discussion of averaging.

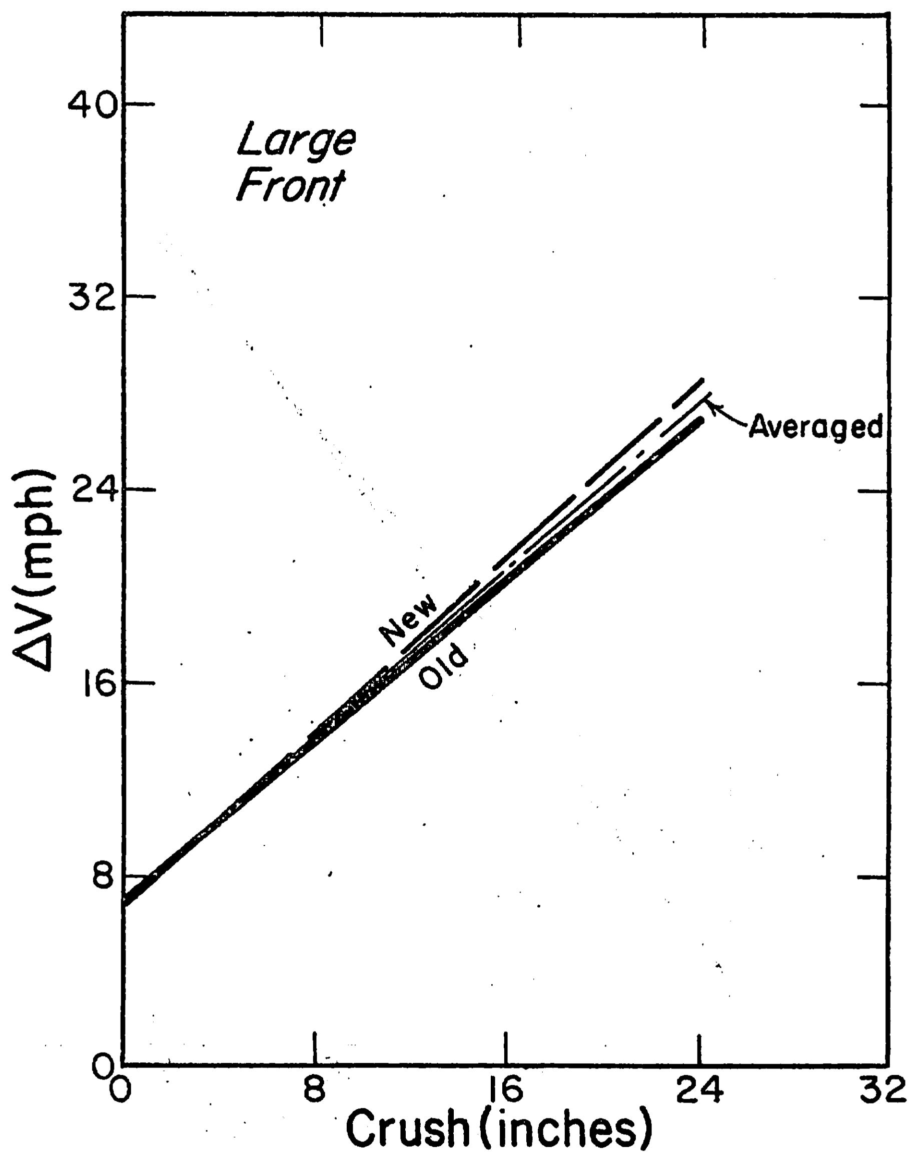


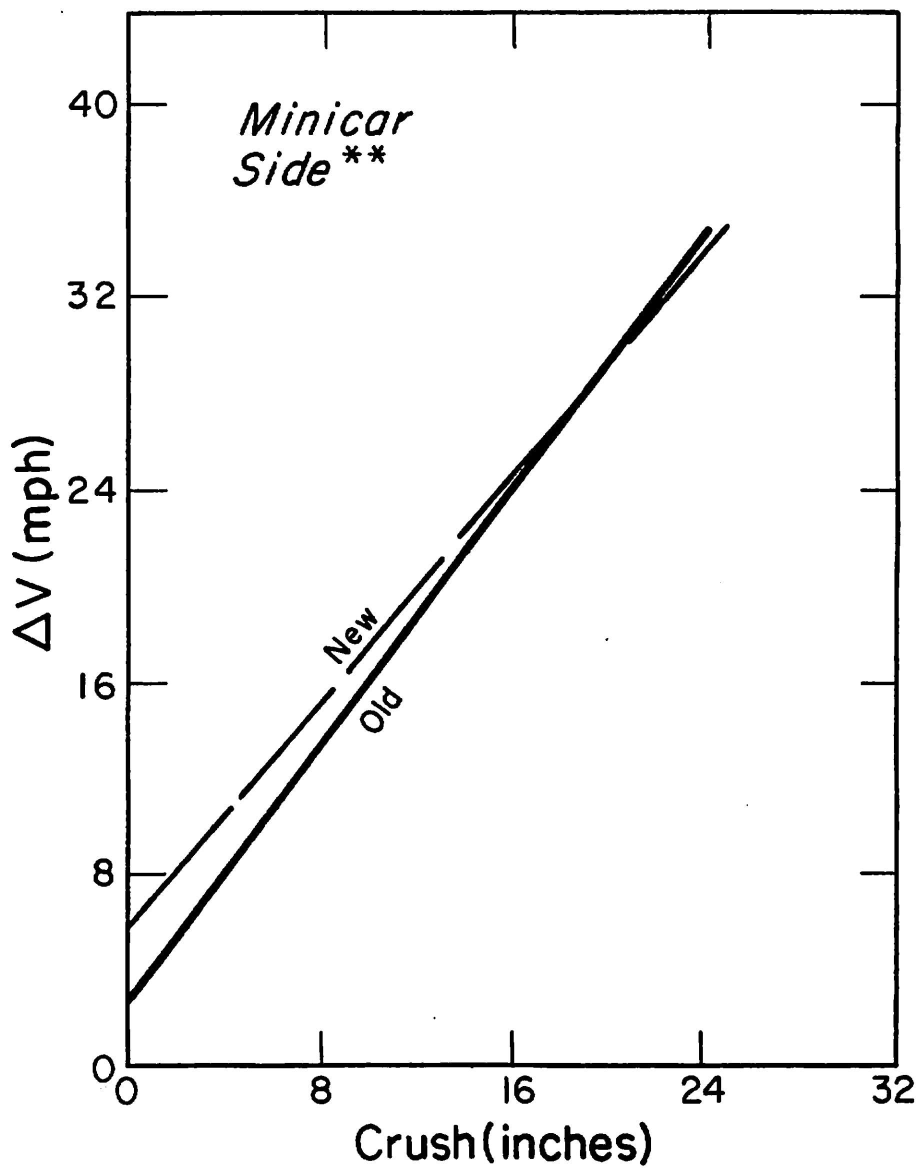
* See text for adjustment procedure.


Compact
Front
ΔV(mph)
Crush(inches)
New
Adjusted New
Old
Averaged
0
8
16
24
32
40

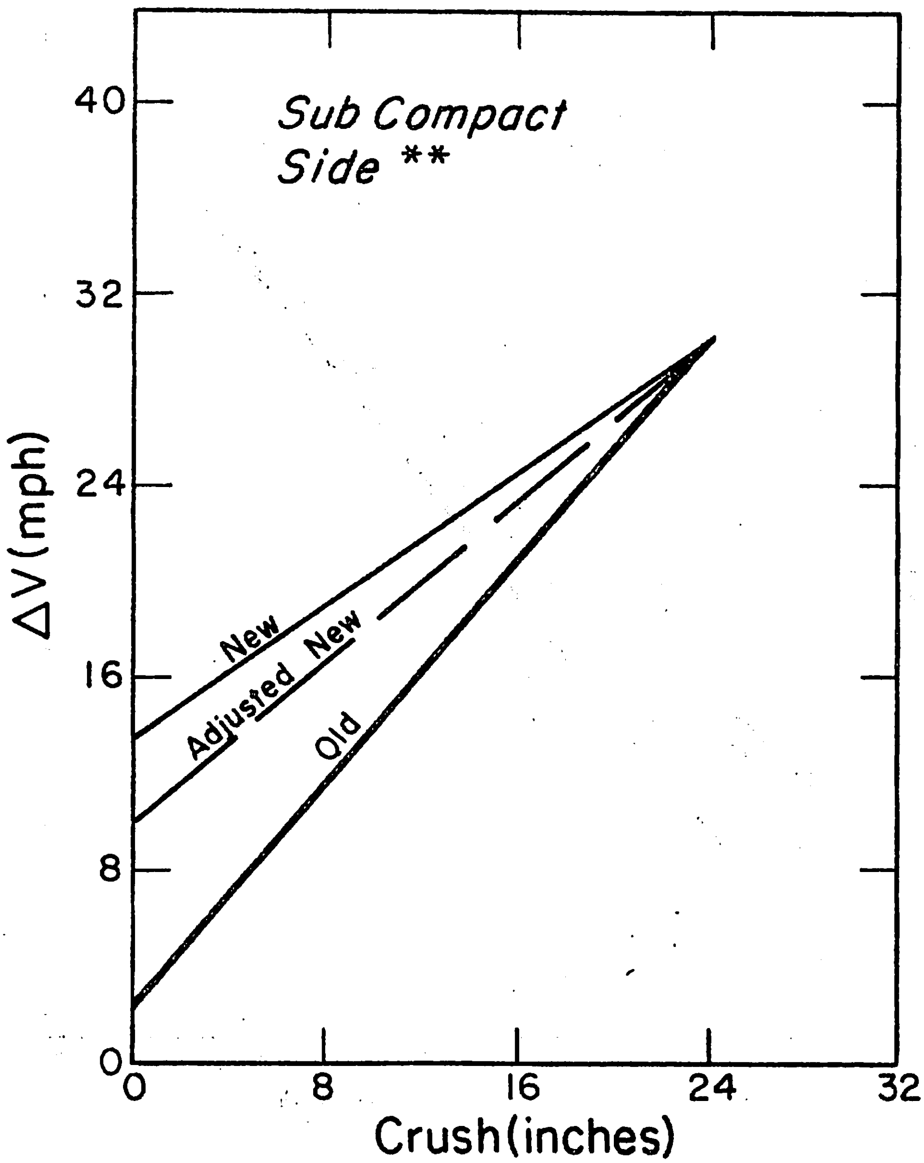

Intermediate
Front
ΔV(mph)
40
32
24
16
8
0
New
Old
Averaged
0
8
16
24
32
Crush(inches)


Full-Size
Front
40
32
24
16
8
0
ΔV (mph)
New
Old
Averaged
0
8
16
24
32
Crush (inches)

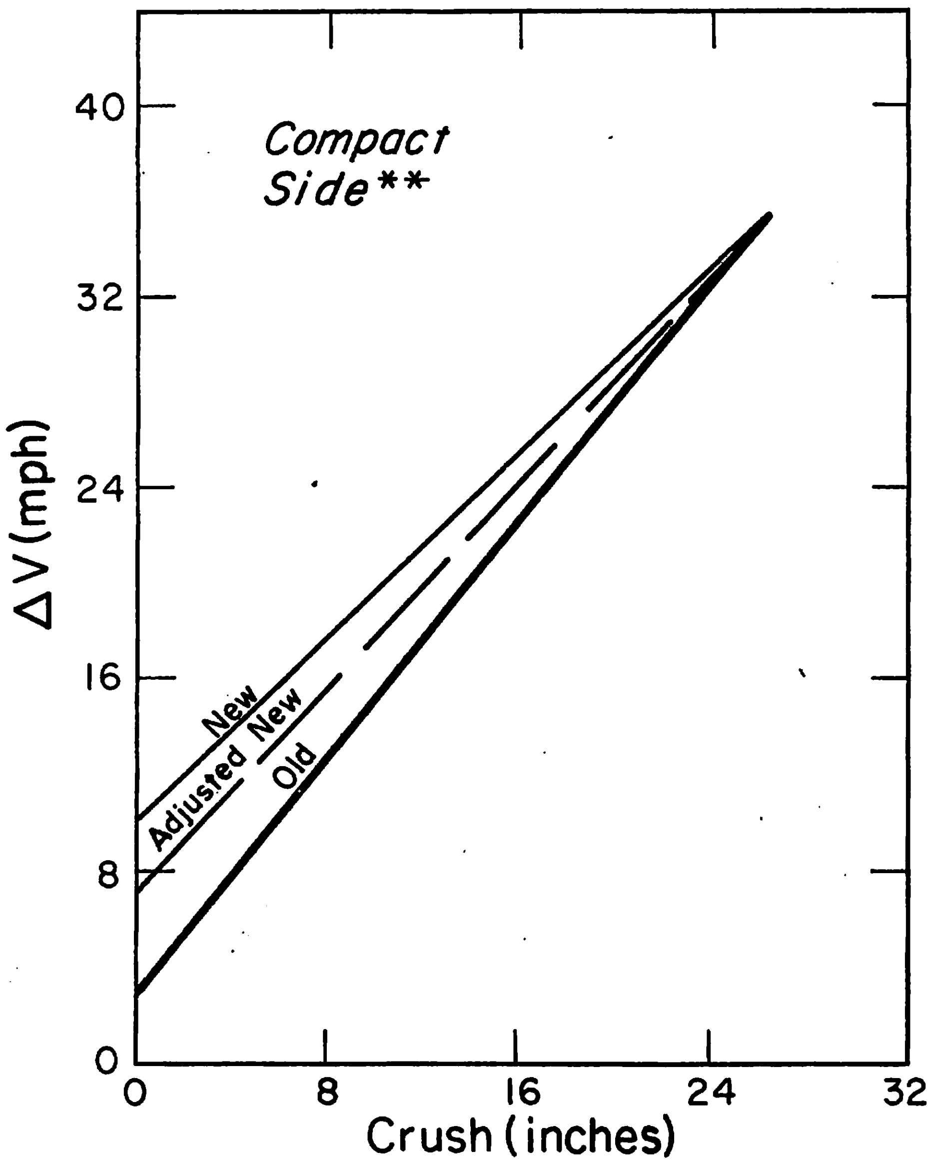

Large
Front
Averaged
New
Old
ΔV(mph)
Crush(inches)
0
8
16
24
32
40



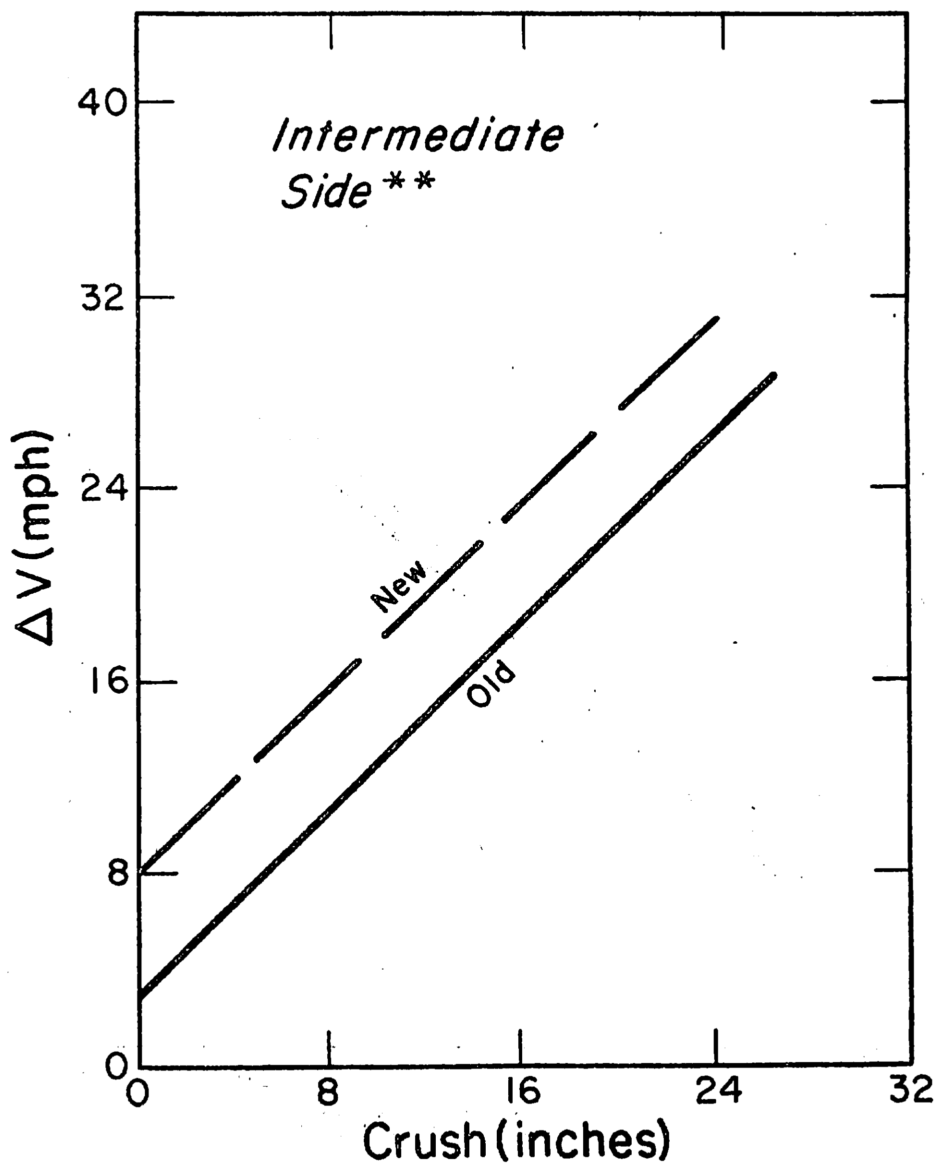
**Side values are considered tententative due to sparsity of data.



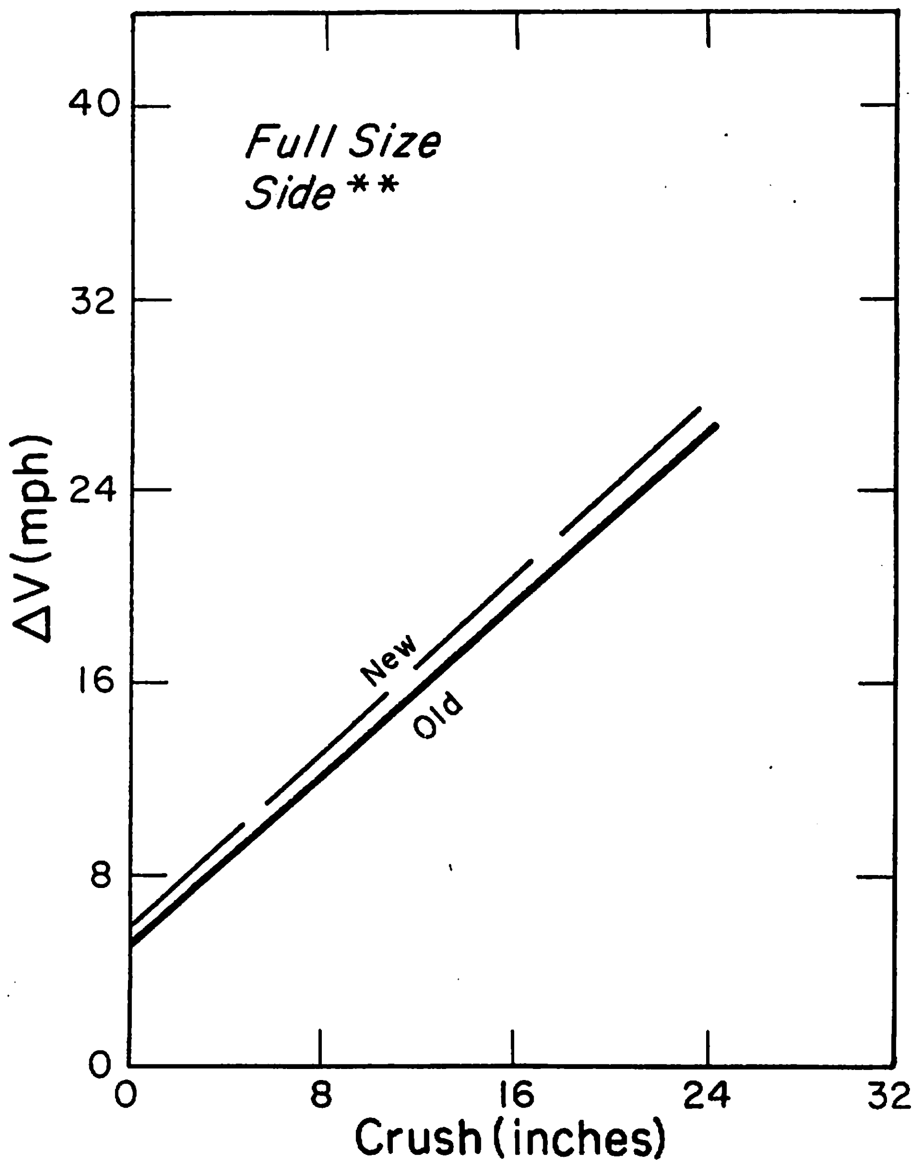
** Side values are considered tentative due to the sparsity of data.



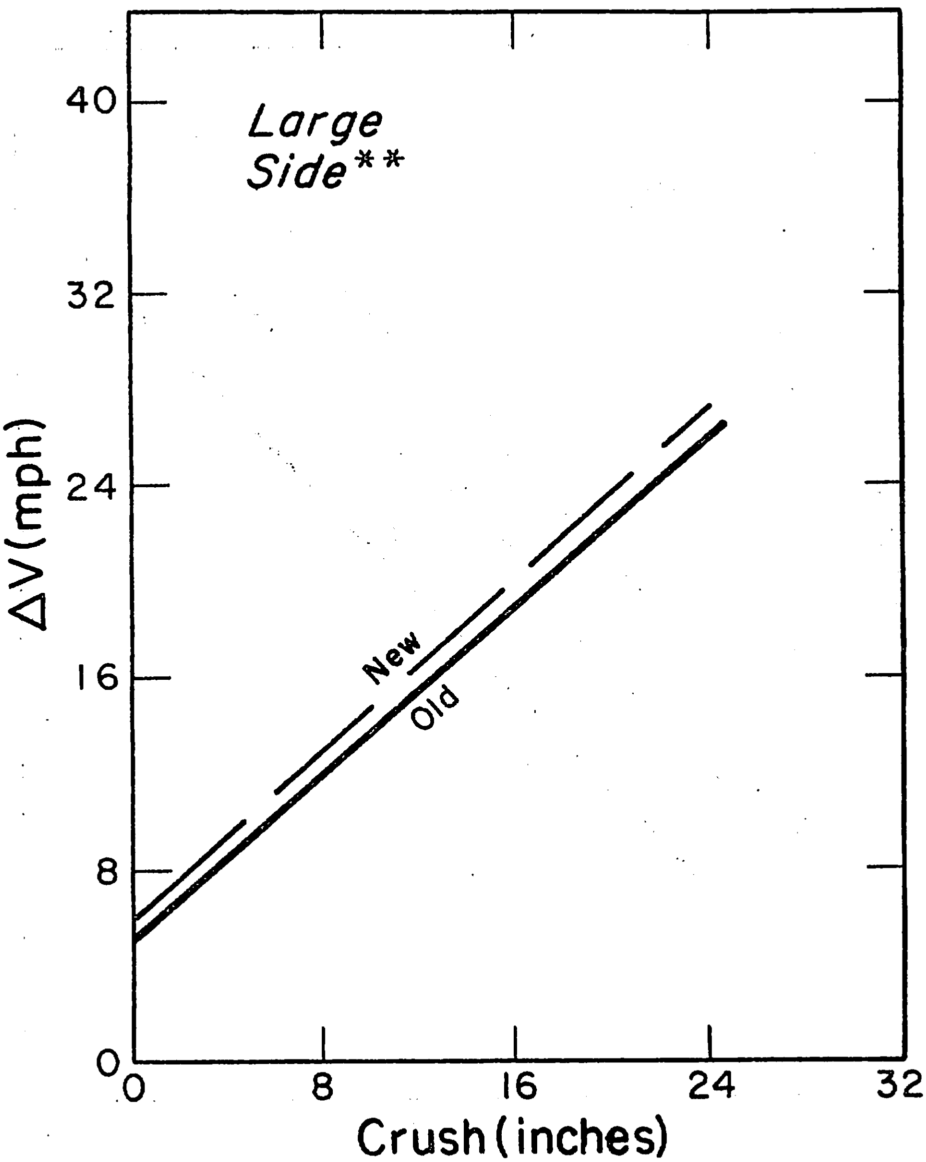
**Side values are considered tentative due to the sparcity of data.



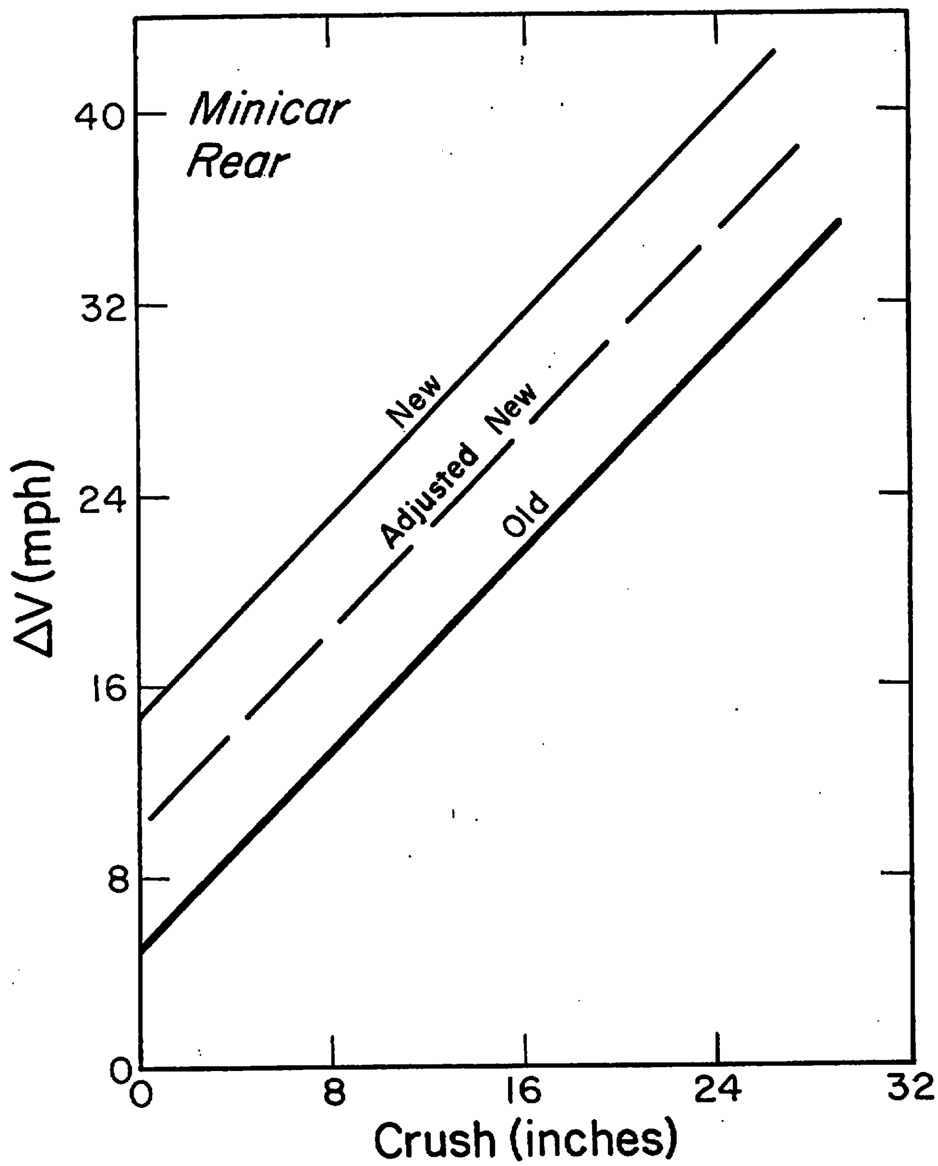
** Side values are considered tentative due to the sparsity of data.

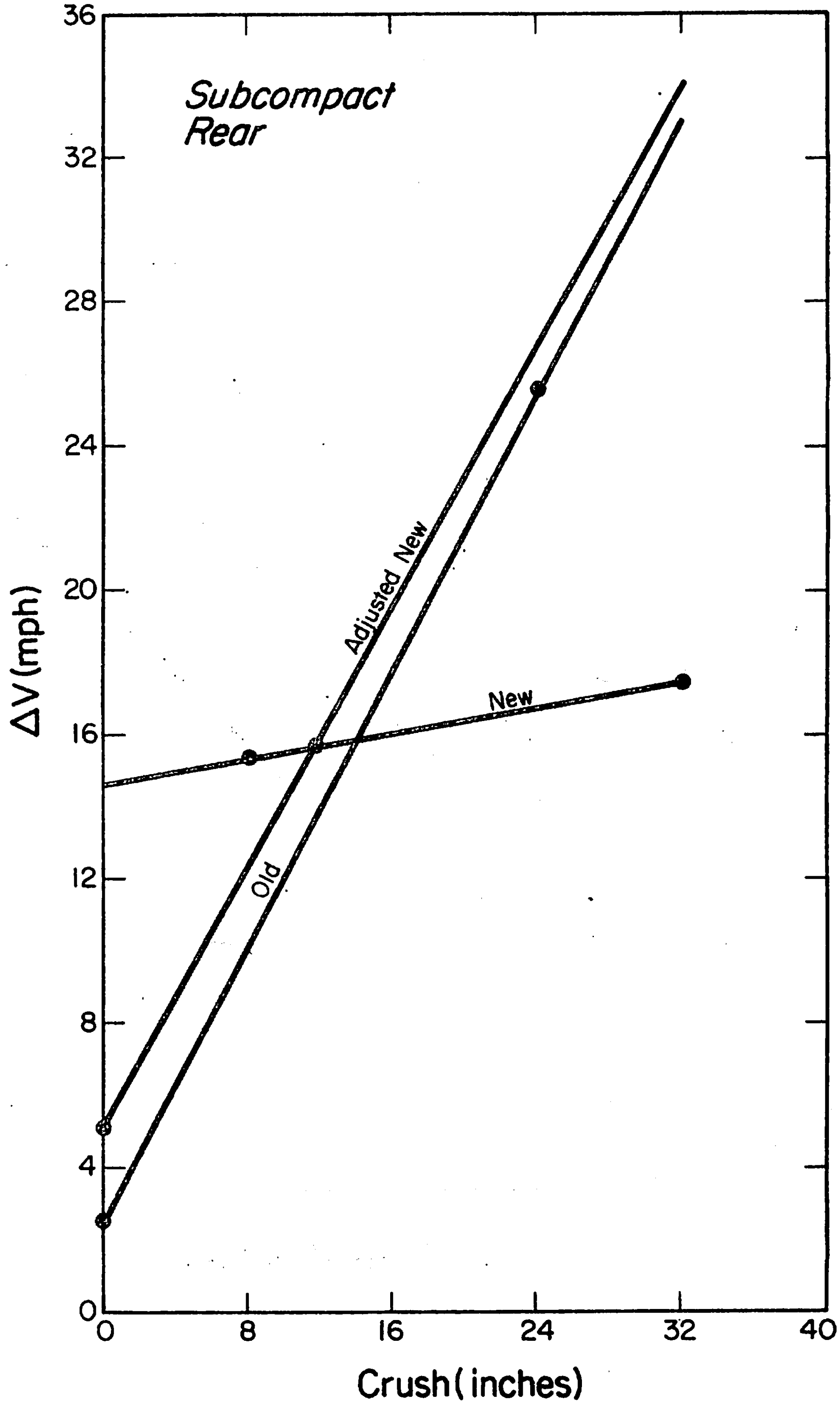


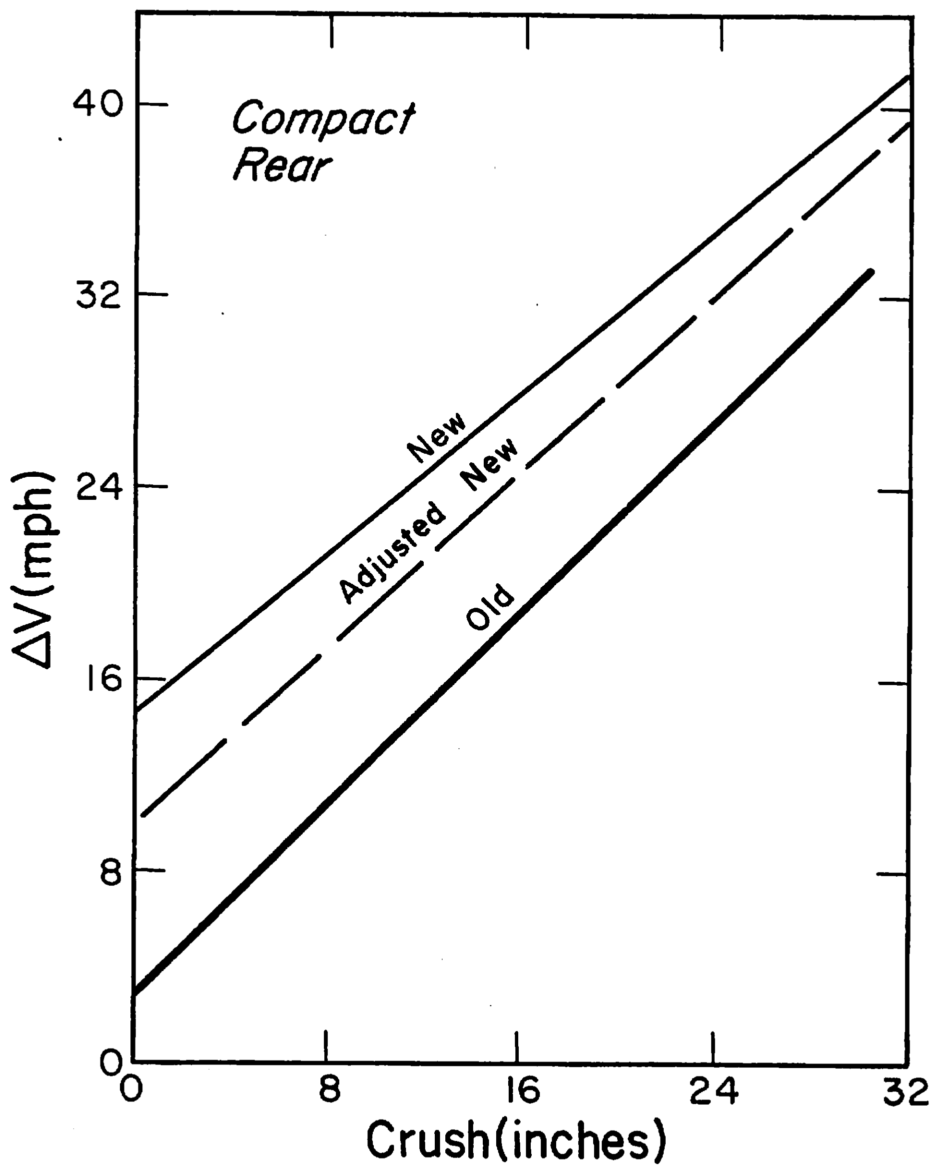
** Side values are considered tentative due to the sparsity of data:

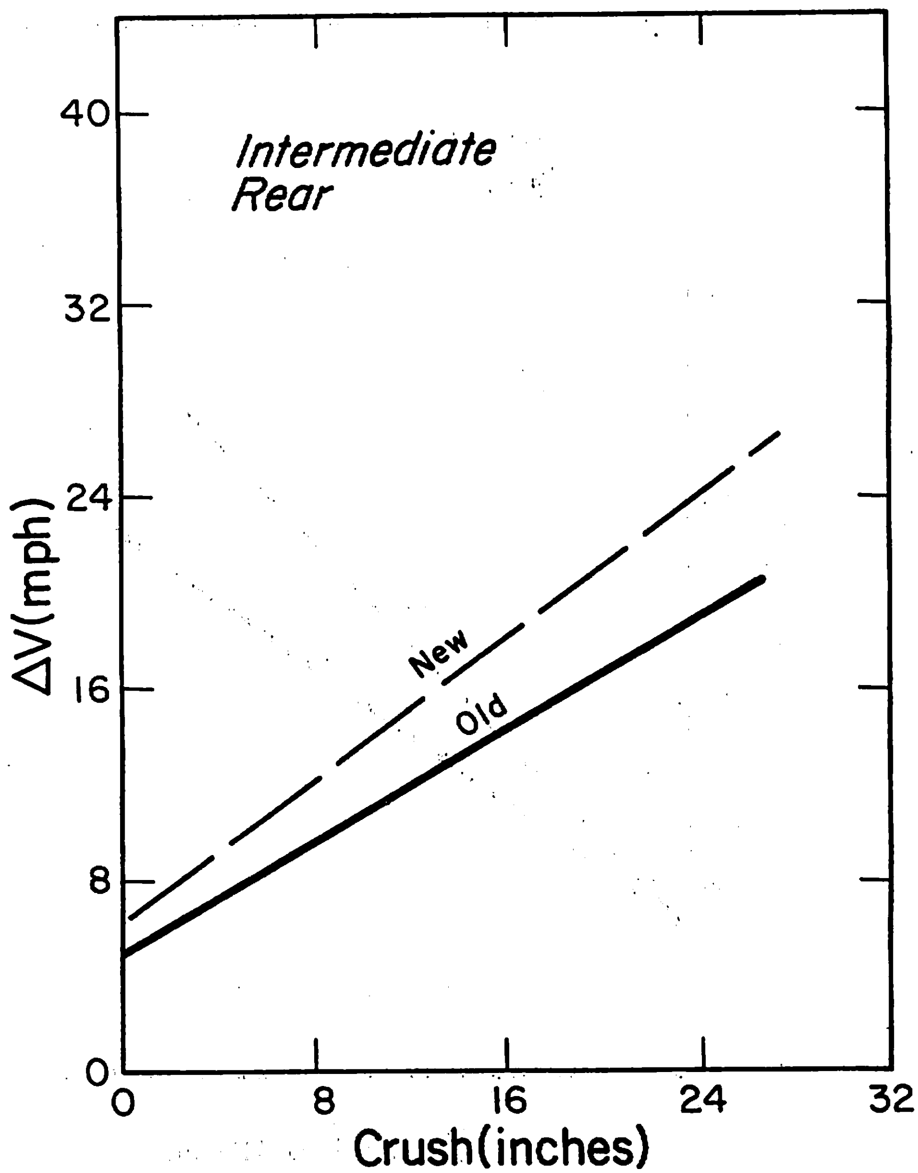


** Side values are considered tentative due to the sparsity of data.

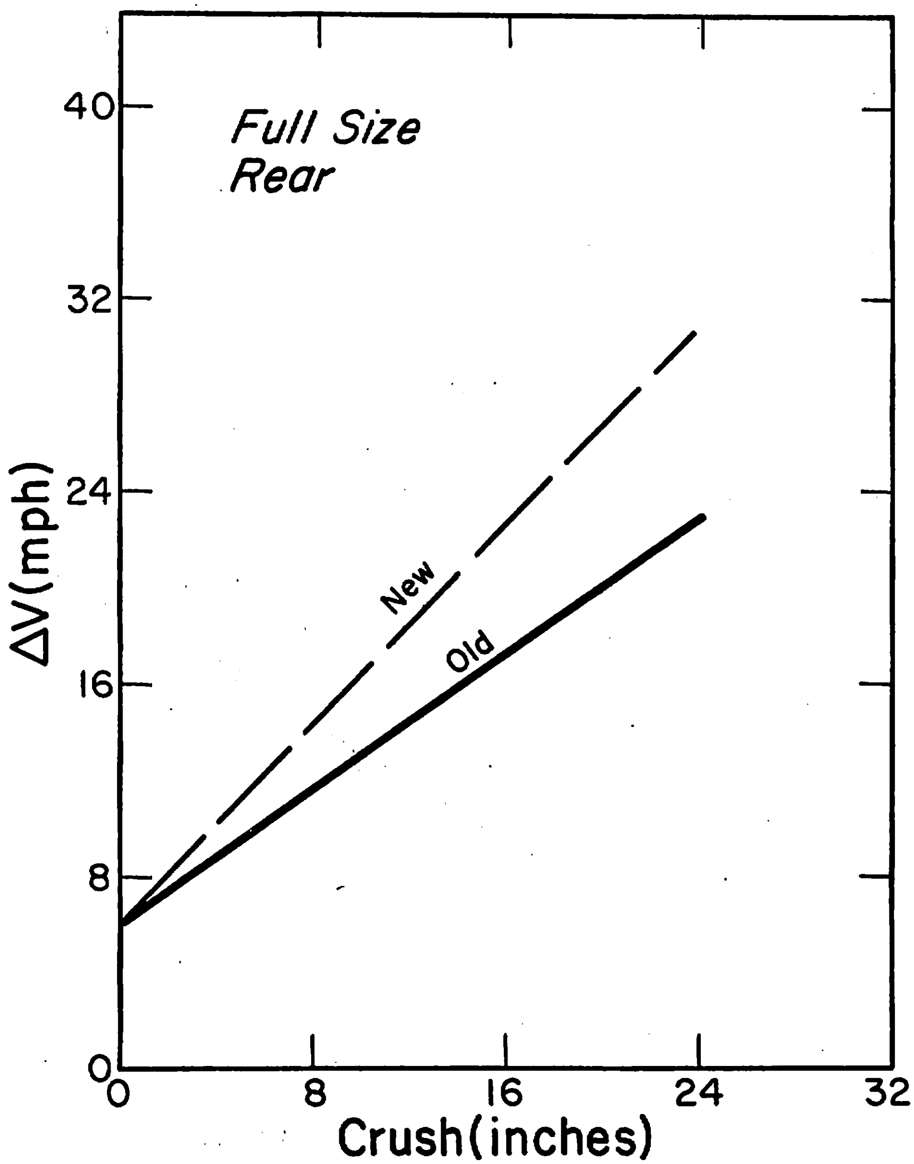

Minicar
Rear
New
Adjusted New
Old
ΔV (mph)
40
32
24
16
8
0
0
8
16
24
32
Crush (inches)

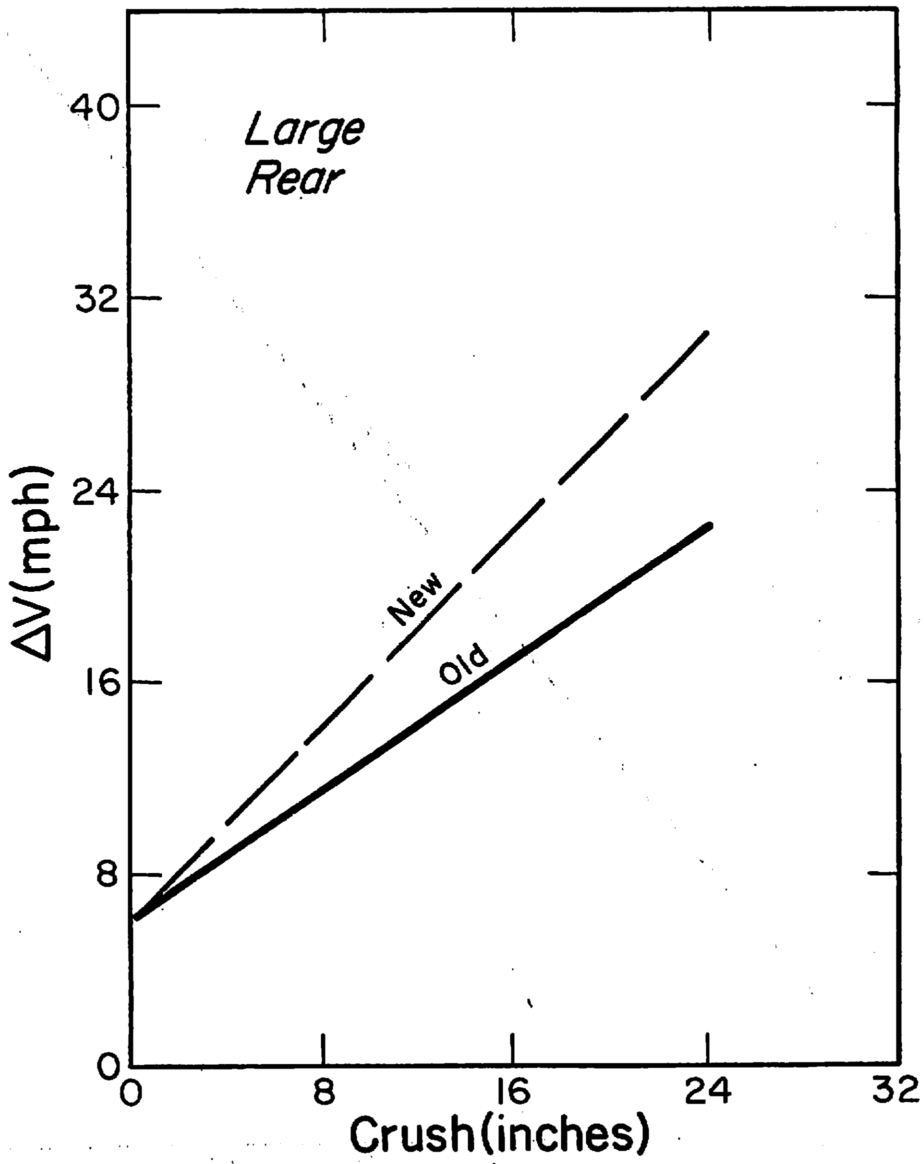

Subcompact
Rear
ΔV (mph)
36
32
28
24
20
16
12
8
4
0
Adjusted New
New
Old
0
8
16
24
32
40
Crush (inches)


Compact
Rear
New
Adjusted New
Old
ΔV(mph)
0
8
16
24
32
40
0
8
16
24
32
Crush(inches)

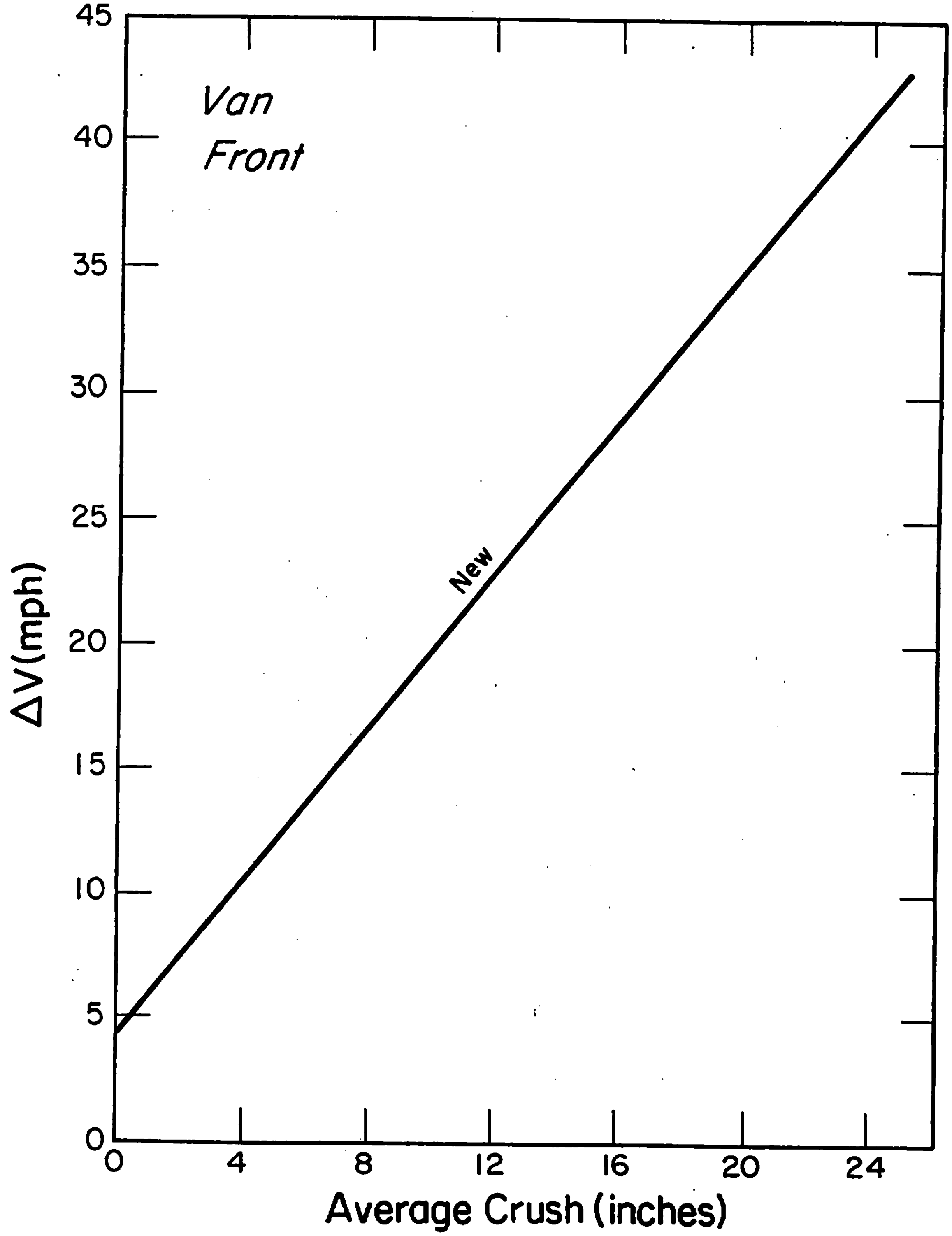


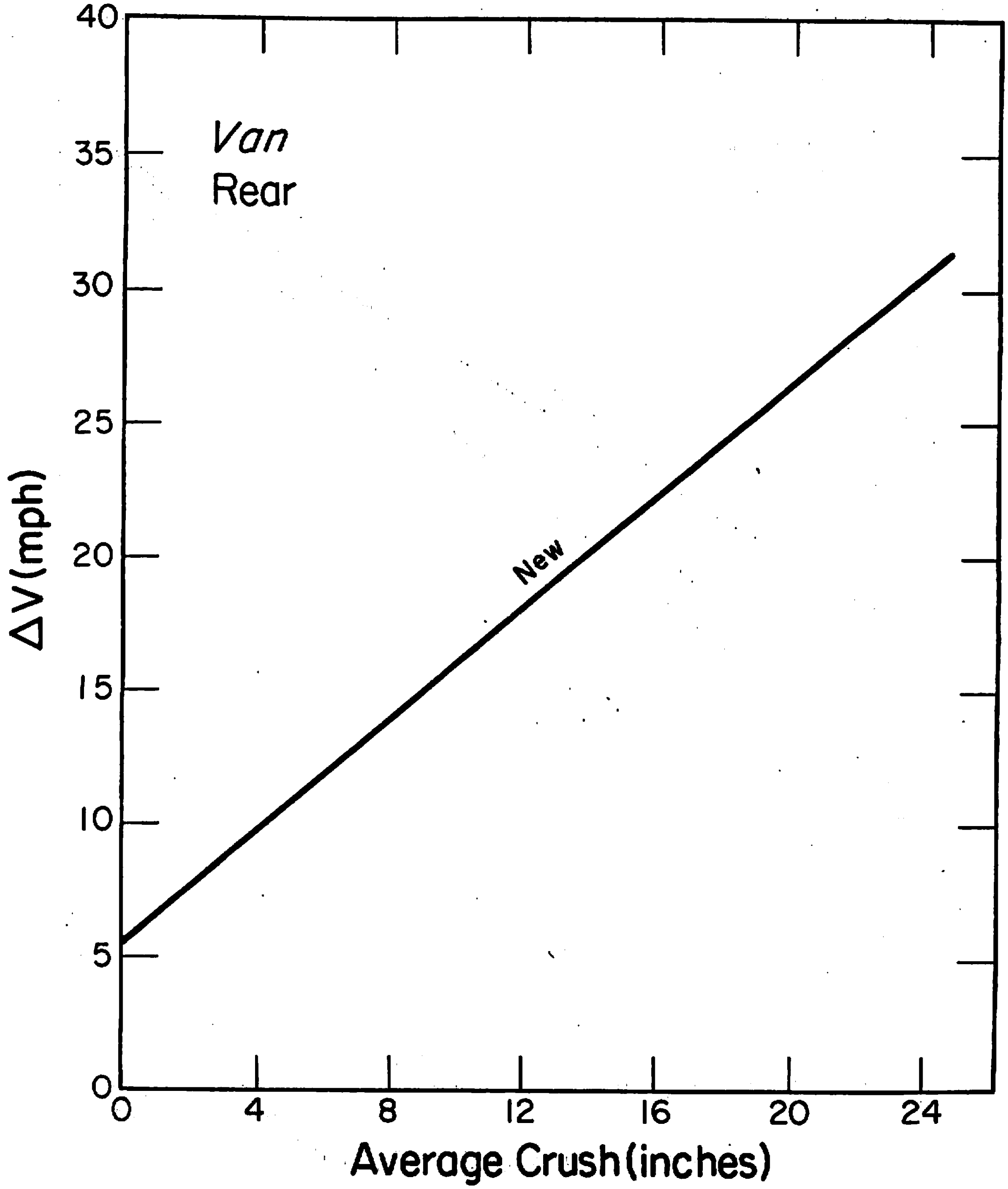
Intermediate
Rear
40
32
24
16
8
0
ΔV(mph)
New
Old
0
8
16
24
32
Crush(inches)


Full Size
Rear
ΔV(mph)
Crush(inches)
New
Old
0
8
16
24
32
40

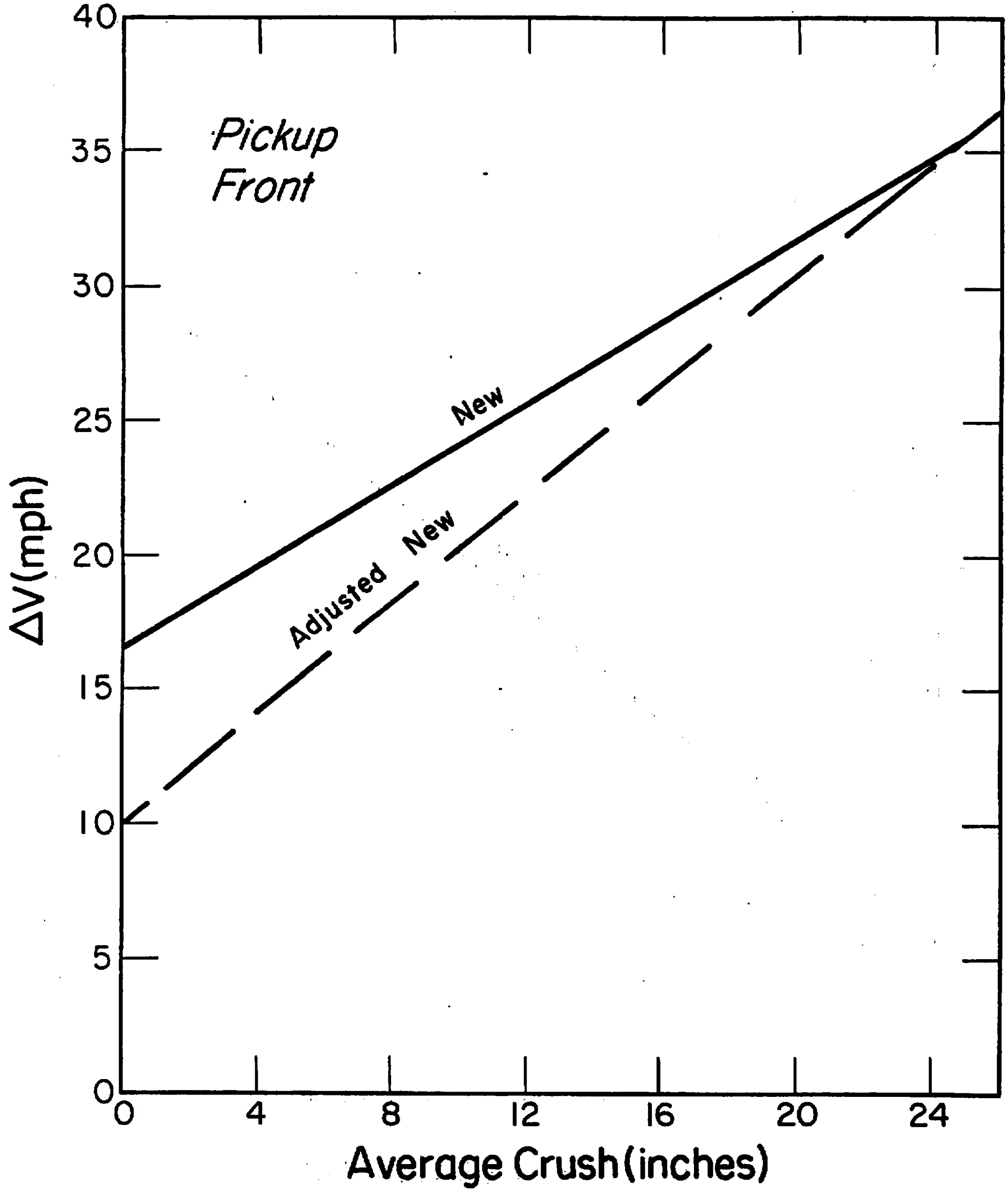


Large
Rear
New
Old
ΔV(mph)
Crush(inches)
0
8
16
24
32
40

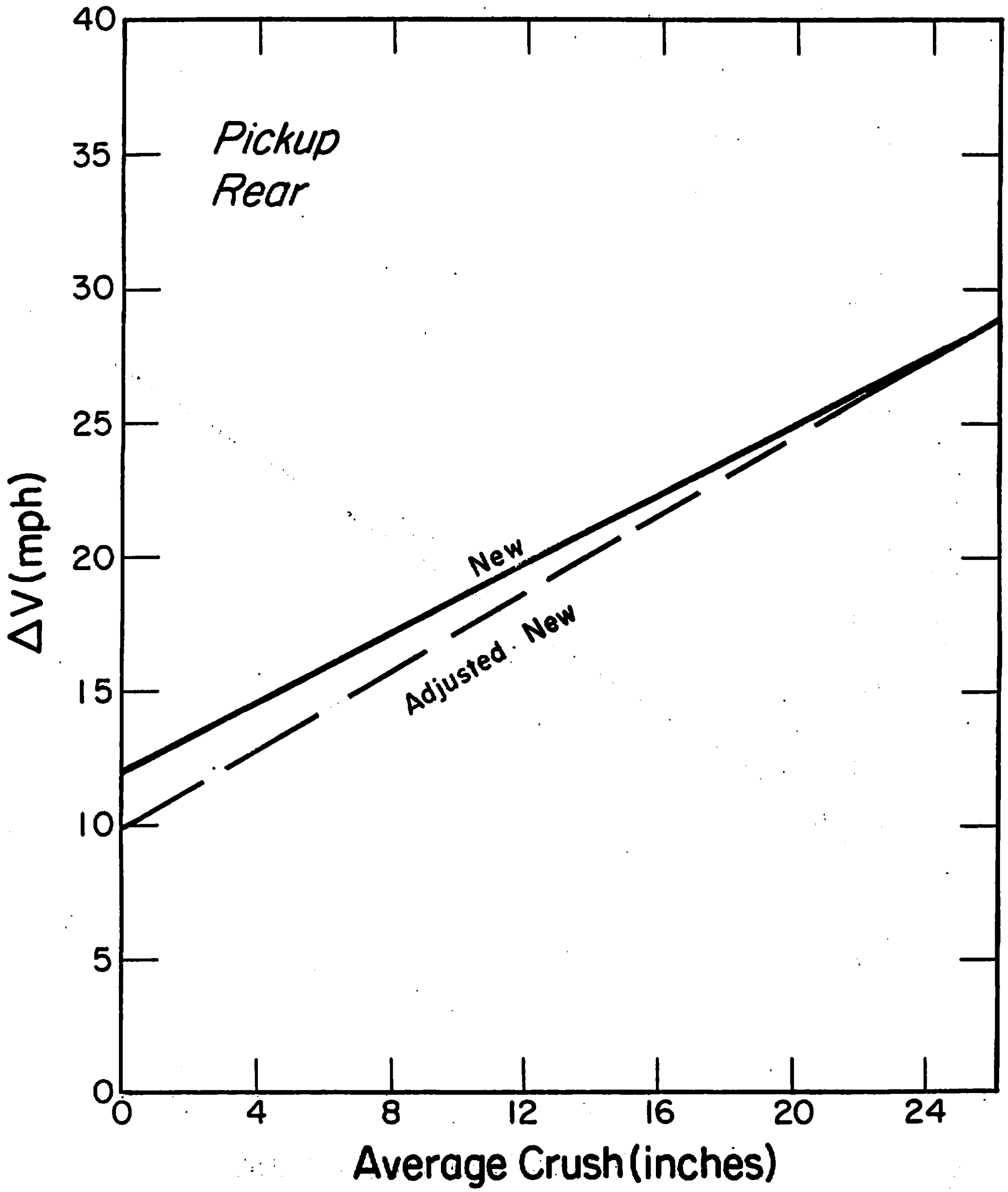

Van
Front
New
ΔV(mph)
0
5
10
15
20
25
30
35
40
45
0
4
8
12
16
20
24
Average Crush (inches)

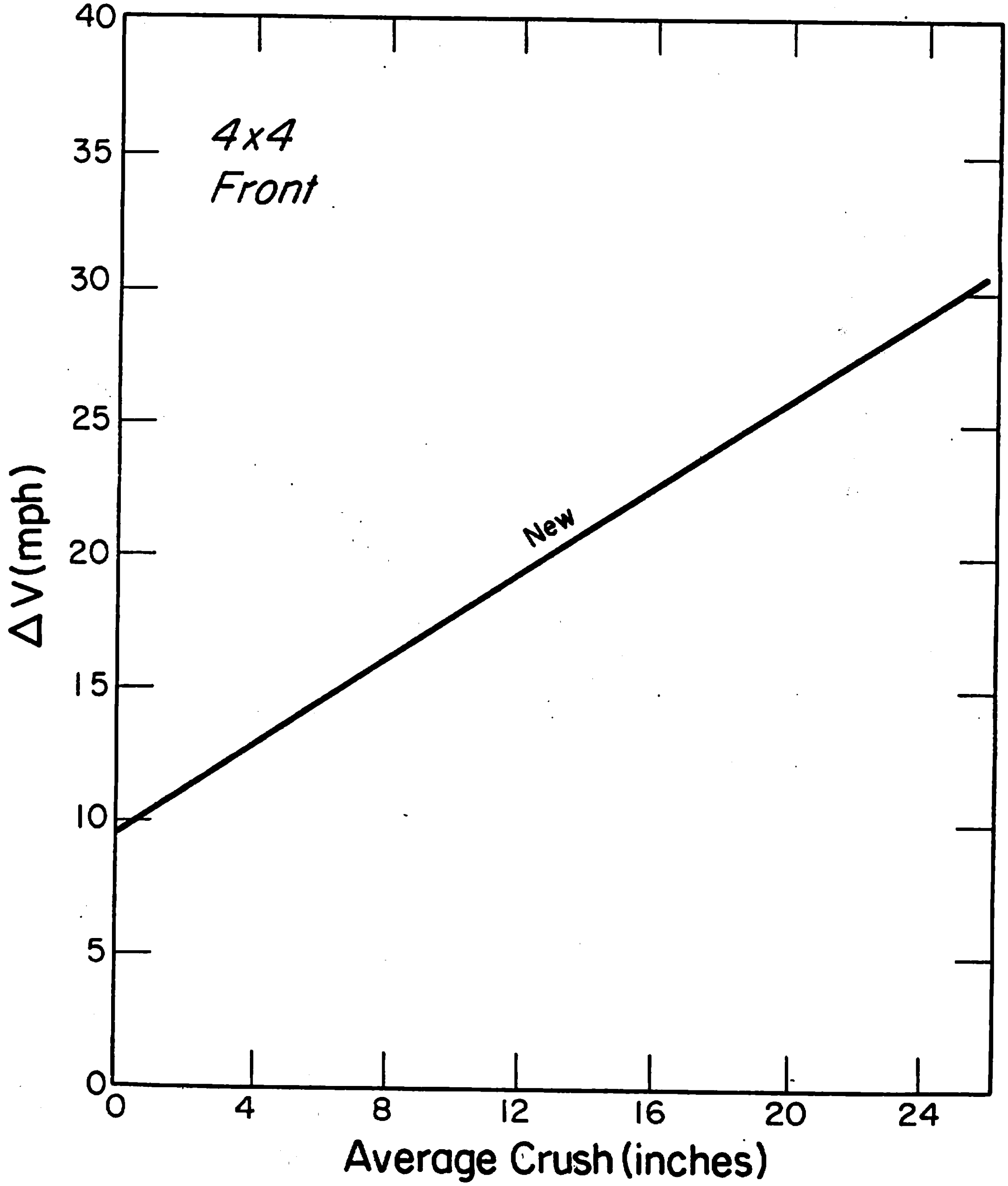


40
35
30
25
20
15
10
5
0
ΔV (mph)
Van
Rear
New
0
4
8
12
16
20
24
Average Crush (inches)



Pickup
Front
New
Adjusted New
ΔV (mph)
Average Crush (inches)
40
35
30
25
20
15
10
5
0
0
4
8
12
16
20
24


Pickup
Rear
New
Adjusted · New
ΔV (mph)
Average Crush (inches)
0
5
10
15
20
25
30
35
40
4
8
12
16
20
24


4x4
Front
New
ΔV (mph)
Average Crush (inches)
0
5
10
15
20
25
30
35
40
0
4
8
12
16
20
24

APPENDIX F

Validation (Level I and Level II)

Level I Validation of Frontal Stiffness Parameters
Minicar Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
8	DOT-HS-6-01477 78 Chevette	29.3800	0.0000	28.3000	0.0000	29.7000	0.0000
	DOT-HS-8-01938 77 Rabbit	34.8000	0.0000	32.6000	0.0000	33.1000	0.0000
6	DOT-HS-8-01938 79 Chevette	34.8000	0.0000	31.1000	0.0000	31.7000	0.0000
	DOT-HS-8-01938 75 Honda Civic	34.7500	0.0000	30.0000	0.0000	31.4000	0.0000
4	DOT-HS-6-01478 79 Datsun	35.2000	0.0000	37.5000	0.0000	37.2000	0.0000
	DOT-HS-01758 75 Honda	40.8300	0.0000	34.5000	0.0000	35.1000	0.0000
2	DOT-HS-5-01099 75 Torino	19.4800	9.7200	29.6000	14.8000	32.6000	16.2000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 35.5600

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 35.8000

7 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Frontal Stiffness Parameters
Subcompact Vehicles

Test #	NHTSA Contract No. & Test	Actual		Old		SRL	
		Delta-V1	Delta-V2	Delta-V1	Delta-V2	Delta-V1	Delta-V2
		30.2000	0.0000	38.0000	0.0000	33.0000	0.0000
		34.2000	0.0000	44.0000	0.0000	36.9000	0.0000
13	DOT-HS-6-01477 78 Gremlin	29.6000	0.0000	20.1000	0.0000	21.0000	0.0000
		29.3000	0.0000	21.1000	0.0000	21.2000	0.0000
		29.5600	0.0000	23.9000	0.0000	23.7000	0.0000
		29.4000	0.0000	29.0000	0.0000	28.0000	0.0000
		29.5800	0.0000	29.9000	0.0000	28.2000	0.0000
		29.6500	0.0000	28.3000	0.0000	26.0000	0.0000
		36.1000	0.0000	31.5000	0.0000	28.6000	0.0000
		29.6300	0.0000	39.9000	0.0000	35.3000	0.0000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 57.9000

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 47.6600

10 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Frontal Stiffness Parameters
Compact Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
22	DOT-HS-8-01938 80 Concord	34.7000	0.0000	29.2000	0.0000	30.5000	0.0000
23	DOT-HS-6-01477 78 Concord	29.6700	0.0000	24.6000	0.0000	27.5000	0.0000
24	DOT-HS-6-01477 78 604SL	29.4000	0.0000	23.9000	0.0000	26.7000	0.0000
25	DOT-HS-8-01938 79 Malibu	35.4000	0.0000	32.4000	0.0000	32.1000	0.0000
26	DOT-HS-6-01477 78 Monarch	29.0300	0.0000	27.6000	0.0000	29.4000	0.0000
27	DOT-HS-6-01477 78 Zephyr	29.6700	0.0000	26.9000	0.0000	29.7000	0.0000
28	DOT-HS-8-01938 79 Fairmont	35.4000	0.0000	33.7000	0.0000	34.1000	0.0000
29	DOT-HS-8-01938 79 Granada	34.6000	0.0000	36.4000	0.0000	35.0000	0.0000
30	DOT-HS-8-01938 79 Granada	34.5700	0.0000	33.2000	0.0000	32.5000	0.0000
31	DOT-HS-6-01478 79 Firebird	35.2400	0.0000	35.5000	0.0000	35.8000	0.0000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 30.4000

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 17.1000

10 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Frontal Stiffness Parameters
Intermediate Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
		29.8400	0.0000	28.2000	0.0000	30.6000	0.0000
		34.8400	0.0000	37.5000	0.0000	37.8000	0.0000
		35.8700	0.0000	34.2000	0.0000	34.9000	0.0000
43	DOT-HS-6-01478 79 Marquis	35.4200	0.0000	36.0000	0.0000	35.7000	0.0000
44	DOT-HS-6-01477 78 Magnum XE	29.8700	0.0000	24.9000	0.0000	27.5000	0.0000
45	DOT-HS-6-01478 78 Monaco	29.3400	0.0000	28.2000	0.0000	29.7000	0.0000
48	DOT-HS-8-01938 79 LeBaron	35.0400	0.0000	28.6000	0.0000	30.6000	0.0000
47	DOT-HS-8-01938 79 Volare	34.9900	0.0000	29.1000	0.0000	31.3000	0.0000
		29.8400	0.0000	29.9000	0.0000	31.4000	0.0000
		29.4500	0.0000	25.5000	0.0000	28.9000	0.0000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 29.0000

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 17.9400

10 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Frontal Stiffness Parameters
Fullsize Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
		31.0000	0.0000	27.5000	0.0000	29.2000	0.0000
		31.1000	0.0000	29.3000	0.0000	31.2000	0.0000
		30.5000	0.0000	30.5000	0.0000	32.4000	0.0000
		40.7000	0.0000	38.4000	0.0000	40.6000	0.0000
		29.6500	0.0000	27.9000	0.0000	29.6000	0.0000
56	DOT-HS-8-01938 79 Ford	35.3500	0.0000	31.4000	0.0000	33.4000	0.0000
55	DOT-HS-6-01478 79 Regency	34.9900	0.0000	32.1000	0.0000	34.1000	0.0000
54	DOT-HS-6-01477 78 LTDII Broughan	29.7200	0.0000	33.7000	0.0000	35.7000	0.0000
		40.3000	0.0000	33.7000	0.0000	35.6000	0.0000
		39.7300	0.0000	35.7000	0.0000	37.9000	0.0000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 30.8000

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 19.3000

10 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Rear Stiffness Parameters
Mini Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
		18.7900	10.8400	6.0000	3.5000	14.1000	8.1000
59	DOT-HS-6-01478 77 Chevette	29.3200	0.0000	10.3000	0.0000	22.4000	0.0000
		17.9100	11.8500	6.0000	4.0000	13.8000	9.1000
		19.0100	10.6400	7.7000	4.3000	16.9000	9.5000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 76.5600

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 24.4600

4 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Rear Stiffness Parameters
Subcompact Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
	NHTSA-8-0323 74 Pinto	18.3400	11.5400	13.9000	8.7000	20.2000	12.7000
	NHTSA-8-0323 74 Pinto	21.9500	13.3700	19.1000	11.6000	27.1000	16.5000
	NHTSA-8-0323 71 Vega	22.2500	12.5300	18.7000	10.5000	26.2000	14.8000
	NHTSA-8-0323 71 Pinto	19.3800	10.5300	14.6000	7.9000	23.5000	12.8000
	NHTSA-8-0323 71 Vega	26.1200	14.6100	21.1000	11.8000	29.4000	16.4000
	77 MVMA	15.9200	14.4800	8.2000	7.4000	16.8000	15.2000
	77 MVMA	15.6000	13.6100	6.4000	5.6000	13.5000	11.8000
	77 MVMA	15.7700	13.5500	6.7000	5.7000	14.2000	12.2000
	77 MVMA	16.8000	13.0000	8.5000	6.6000	17.6000	13.6000
	77 MVMA	16.2900	12.7100	7.8000	6.1000	16.4000	12.8000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 111.4500

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 39.0100

10 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Rear Stiffness Parameters
Compact Vehicles

Test #	NHTSA Contract No. & Test	Actual		Old		SRL	
		Delta-V1	Delta-V2	Delta-V1	Delta-V2	Delta-V1	Delta-V2
80	DOT-HS-8-01938 79 Monarch	35.0900	0.0000	14.8000	0.0000	32.8000	0.0000
82	DOT-HS-8-01938 79 Zephyr	35.3000	0.0000	17.1000	0.0000	36.5000	0.0000
85	DOT-HS-8-01938 79 Volvo	34.5500	0.0000	15.7000	0.0000	34.0000	0.0000
84	DOT-HS-8-01938 80 Concord	34.9700	0.0000	12.1000	0.0000	29.0000	0.0000
81	DOT-HS-8-01938 79 Zephyr	35.2000	0.0000	17.5000	0.0000	37.0000	0.0000
		16.5100	12.9800	8.7000	6.8000	22.0000	17.3000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 111.9000

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 21.6200

6 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Rear Stiffness Parameters
Intermediate Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
		29.3000	0.0000	11.3000	0.0000	22.4000	0.0000
90	DOT-HS-6-01477 79 Seville	13.4300	16.1400	6.5000	7.8000	12.7000	15.3000
91	DOT-HS-6-01477 79 Thunderbird	15.8500	19.3400	8.5000	10.4000	14.8000	18.1000
92	DOT-HS-6-01477 79 LTD Landau	16.9700	18.0400	11.1000	11.8000	18.2000	19.3000
93	DOT-HS-6-01477 79 Riviera S	16.5000	18.3100	9.4000	10.5000	15.7000	17.4000
		14.2600	16.3400	10.0000	11.5000	16.3000	18.7000
		14.9100	14.5300	8.1000	7.9000	15.2000	14.8000
94	DOT-HS-6-01478 78 Phoenix	14.0700	14.7400	8.7000	9.1000	15.3000	16.0000
88	DOT-HS-6-01478 78 Regal	15.2900	14.6100	11.0000	10.5000	18.0000	17.2000
		34.9000	0.0000	16.1000	0.0000	26.5000	0.0000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 137.3300

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 36.1100

10 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Rear Stiffness Parameters
Fullsize Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
95	DOT-HS-6-01477 79 Checker Taxi	13.6700	16.0000	6.4000	7.5000	11.9000	13.9000
		8.5900	12.4100	4.7000	6.8000	8.7000	12.5000
		12.0700	18.7300	6.0000	9.4000	11.2000	17.4000
		12.2500	18.6500	5.5000	8.4000	10.2000	15.5000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 57.6700

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 11.4700

4 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Side Stiffness Parameters
Subcompact Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
	RICSAC	11.3300	8.6700	13.0000	9.9000	12.1000	9.2000
	RICSAC	18.4000	12.2000	17.2000	11.4000	14.0000	9.3000
	MVMA	12.0500	8.3400	8.8000	8.1000	9.9000	6.9000
	MVMA	12.1600	8.4400	7.6000	5.2000	9.1000	6.3000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 16.1900

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 17.3900

4 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Side Stiffness Parameters
Compact Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
	RICSAC	11.2300	8.7600	11.6000	9.1000	10.7000	8.3000
	RICSAC	10.2800	9.7200	13.1000	12.4000	12.3000	11.6000
	RICSAC	17.0700	13.2000	17.2000	13.3000	20.0000	15.5000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 6.4200

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 10.1000

3 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Side Stiffness Parameters
Intermediate Vehicles

Test #	NHTSA Contract No. & Test	Actual		Old		SRL	
		Delta-V1	Delta-V2	Delta-V1	Delta-V2	Delta-V1	Delta-V2
	RICSAC	14.7100	15.8800	13.3000	14.1000	13.8000	14.8000
	RICSAC	7.1000	7.9000	7.0000	7.7000	12.3000	13.6000
	RICSAC	22.4800	24.1100	19.7000	21.1000	23.6000	25.3000
	RICSAC	14.7300	14.7700	8.9000	8.9000	14.1000	14.1000
	RICSAC	14.7900	15.7100	8.7000	9.3000	17.6000	18.7000
	RICSAC	22.0600	23.6400	18.3000	19.6000	21.9000	23.5000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 41.2800

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 22.6000

6 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Side Stiffness Parameters
Fullsize Vehicles

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	Old Delta-V1	Old Delta-V2	SRL Delta-V1	SRL Delta-V2
	MVMA-1975	8.8700	12.1300	7.3000	9.9000	7.7000	10.6000
	MVMA-1976	8.7800	12.4200	8.0000	11.0000	8.4000	11.8000
	RICSAC	9.2700	10.7300	9.7000	11.3000	10.1000	11.7000
	RICSAC	8.9600	11.0400	9.5000	11.7000	9.8000	12.0000

SUM OF DIFFERENCES USING OLD COEFFICIENTS = 8.2000

SUM OF DIFFERENCES USING NEW COEFFICIENTS = 7.3000

4 RUNS WERE MADE IN CALCULATING THESE VALUES

Level I Validation of Frontal Stiffness Parameters
Vans

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	SRL Delta-V1	SRL Delta-V2
98	DOT-HS-6-01477 78 Vandura	29.5250	0.0000	28.7000	0.0000
99	DOT-HS-8-01942 79 Econoline	15.2500	0.0000	15.0000	0.0000
100	DOT-HS-8-01942 79 Econoline	30.0200	0.0000	29.3000	0.0000
101	DOT-HS-8-01942 79 Dodge B200	15.2800	0.0000	14.9000	0.0000
102	DOT-HS-8-01942 79 Dodge B200	30.2200	0.0000	30.6000	0.0000
103	DOT-HS-8-01942 79 Dodge B200	25.1700	0.0000	27.4000	0.0000

Level II Validation of Frontal Stiffness Parameters
Vans

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	SRL Delta-V1	SRL Delta-V2
107	DOT-HS-6-01477 78 G20	29.4100	0.0000	26.4000	0.0000
97	DOT-HS-6-01477 78 P500	29.3800	0.0000	19.8000	0.0000
106	DOT-HS-6-01477	29.2200	0.0000	36.0000	0.0000

Level I Validation of Frontal Stiffness Parameters
Pickups

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	SRL Delta-V1	SRL Delta-V2
110	DOT-HS-6-01477 78 Courier	29.7300	0.0000	27.5000	0.0000
111	DOT-HS-6-01477 78 El Camino	29.7550	0.0000	32.4000	0.0000
112	DOT-HS-6-01477 78 Custom	29.1600	0.0000	26.1000	0.0000
113	DOT-HS-6-01477 78 Luv	29.7350	0.0000	27.1000	0.0000
114	DOT-HS-6-01477 78 Custom	29.8500	0.0000	28.5000	0.0000

Level I Validation of Rear Stiffness Parameters
Pickups

Test #	NHTSA Contract No. & Test	Actual Delta-V1	Actual Delta-V2	SRL Delta-V1	SRL Delta-V2
115	DOT-HS-6-01478 78 Datsun	16.6500	12.7500	15.0000	11.5000
116	DOT-HS-6-01478 78 Ford F-100	14.1100	15.5500	12.1000	13.3000
117	DOT-HS-6-01478 78 Dodge D-100	14.5100	14.9200	15.4000	15.8000
118	DOT-HS-6-01478 78 Ford Ranchero	13.5500	15.5600	12.6000	14.5000
120	DOT-HS-6-01478 78 GMC 1500	14.2600	14.9200	11.4000	12.0000

APPENDIX G

Procedure for Obtaining Instrumentation Force Direction

Note: Units for all force direction plots are degrees and seconds

The Contractor reported velocity-time histories for various vehicle locations were used to determine the average force direction. The procedure was as follows:

- the X and Y velocity time histories for the firewall and rear deck locations were digitized directly from the Contract report. (If a c.g. accelerometer was installed then it was used for the analysis instead.)
- at each point in time the average force angle was computed
  $A = \tan^{-1}(Y/X)$ where Y = velocity change in Y direction
  X = velocity change in X direction
- the separate averages of the firewall and rear deck were determined at a cut-off time of .150 seconds
- the firewall and rear deck .150 second values were then averaged to compensate for vehicle rotational effects on the accelerometers.

Test Number 1 of Contract DOT-HS-7-01511 will be used as an example. Figures G-1 and G-2 show the contractor velocity-time histories for the firewall location; G-3 and G-4 are the rear deck location. A computerized routine was utilized to accomplish the above procedural steps. The outcome of the computer is a plot of the force angle as a function of time. Figures G-5 and G-6 show the plot for the two accelerometer locations. Since the plots were derived from velocities rather than accelerations, the result is <u>not</u> a force direction time histroy. It is rather the average of the time history up to each point of consideration. It then shows how the average over time varies with time. Both locations indicate an average force direction of about 40 degrees at .150 seconds, which also indicates little rotational velocity.

Figures G-7 through G-18 show the plots of average force directions for the other tests which were analyzed by this method. The units are degrees and seconds.

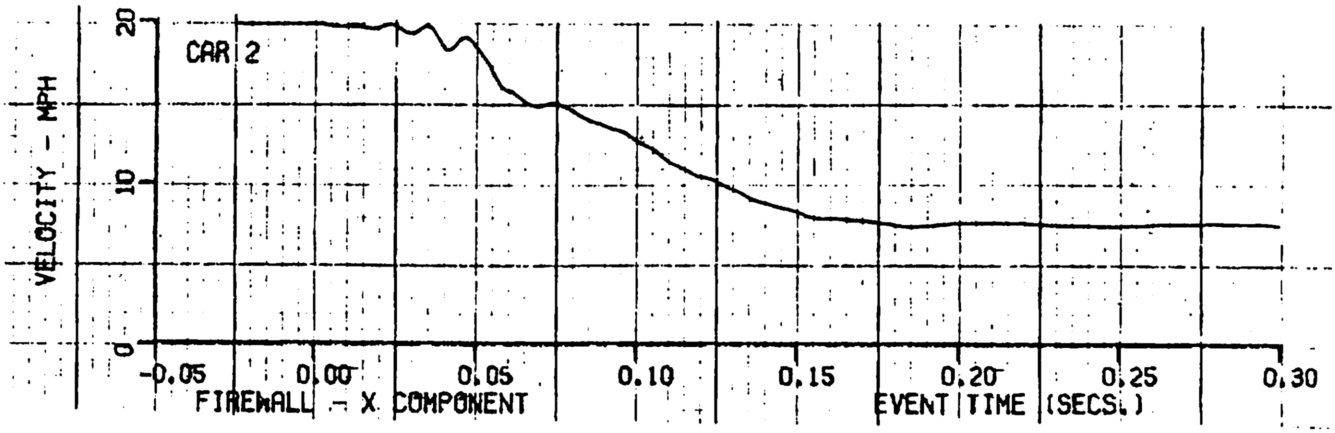


FIGURE G1

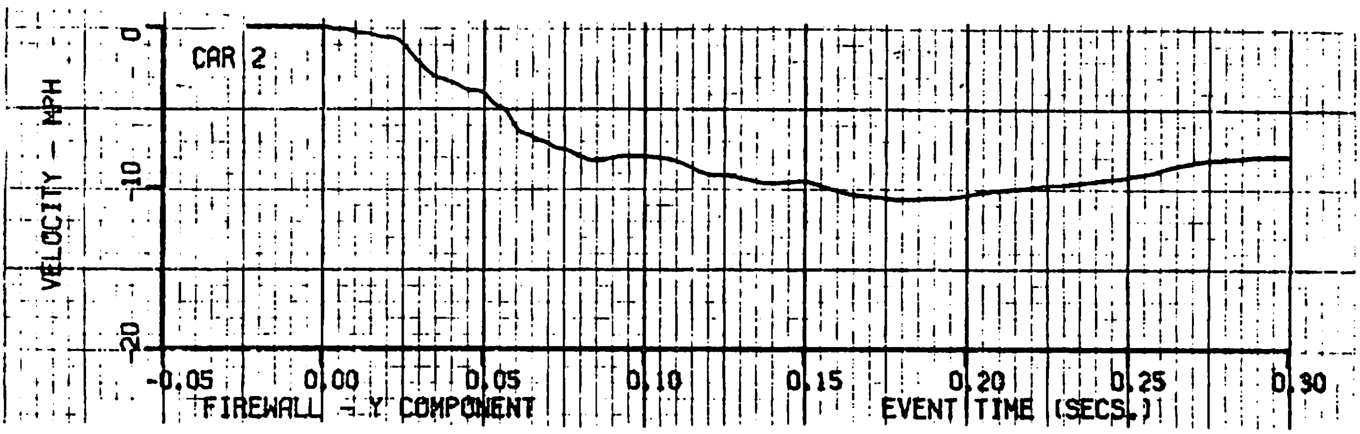


FIGURE G2

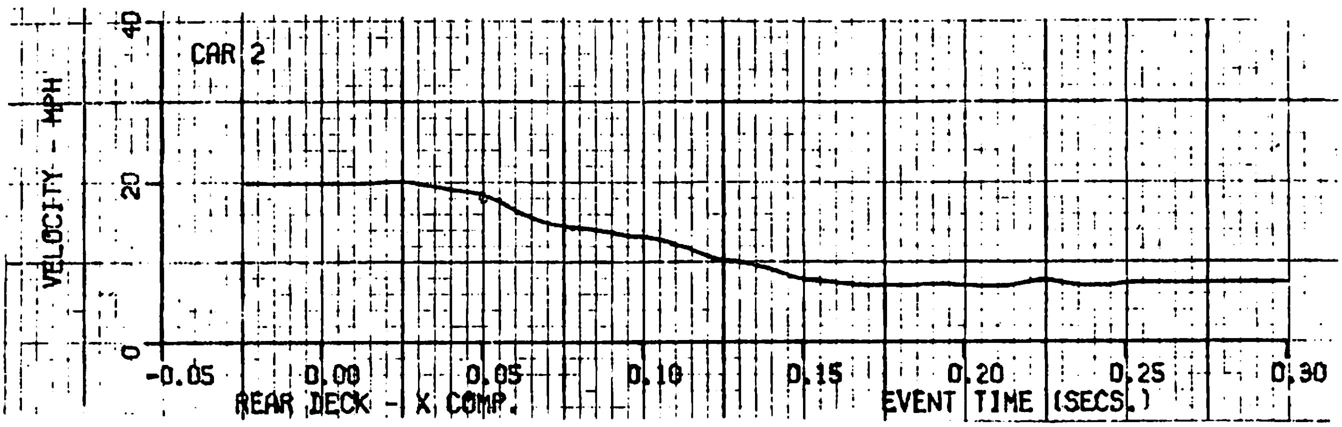


FIGURE G3

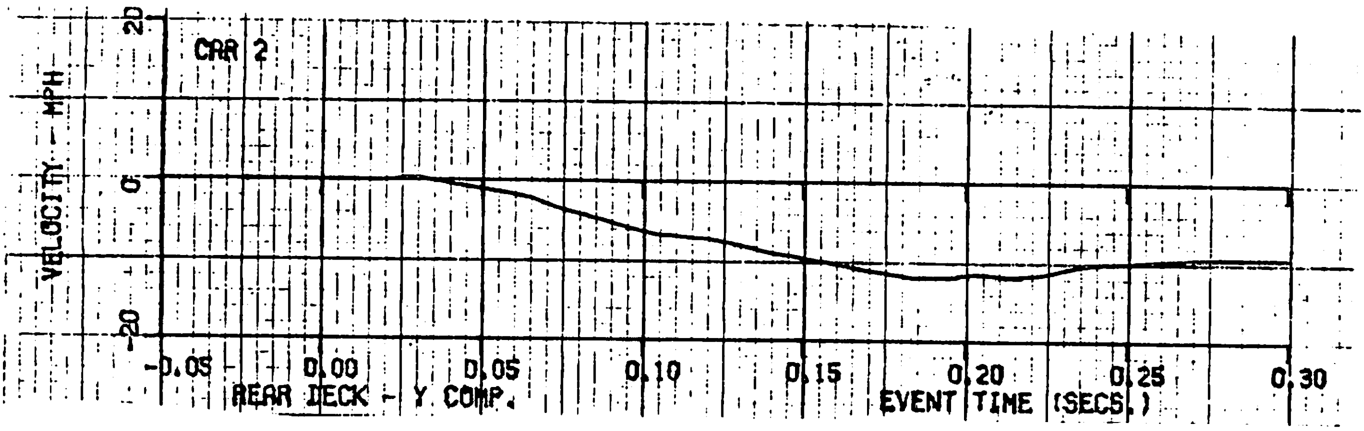


FIGURE G4

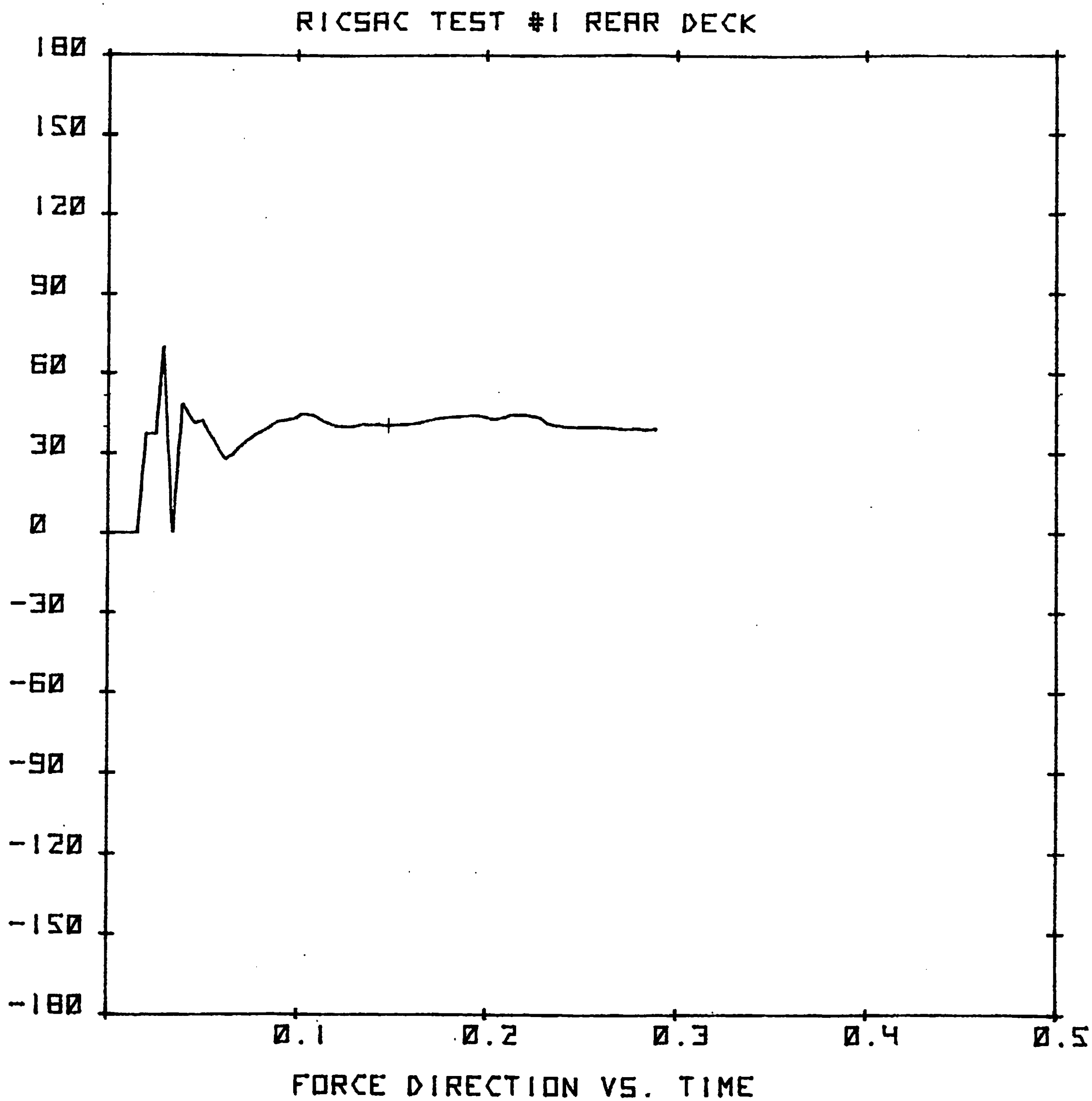

RICSAC TEST #1 REAR DECK
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 5

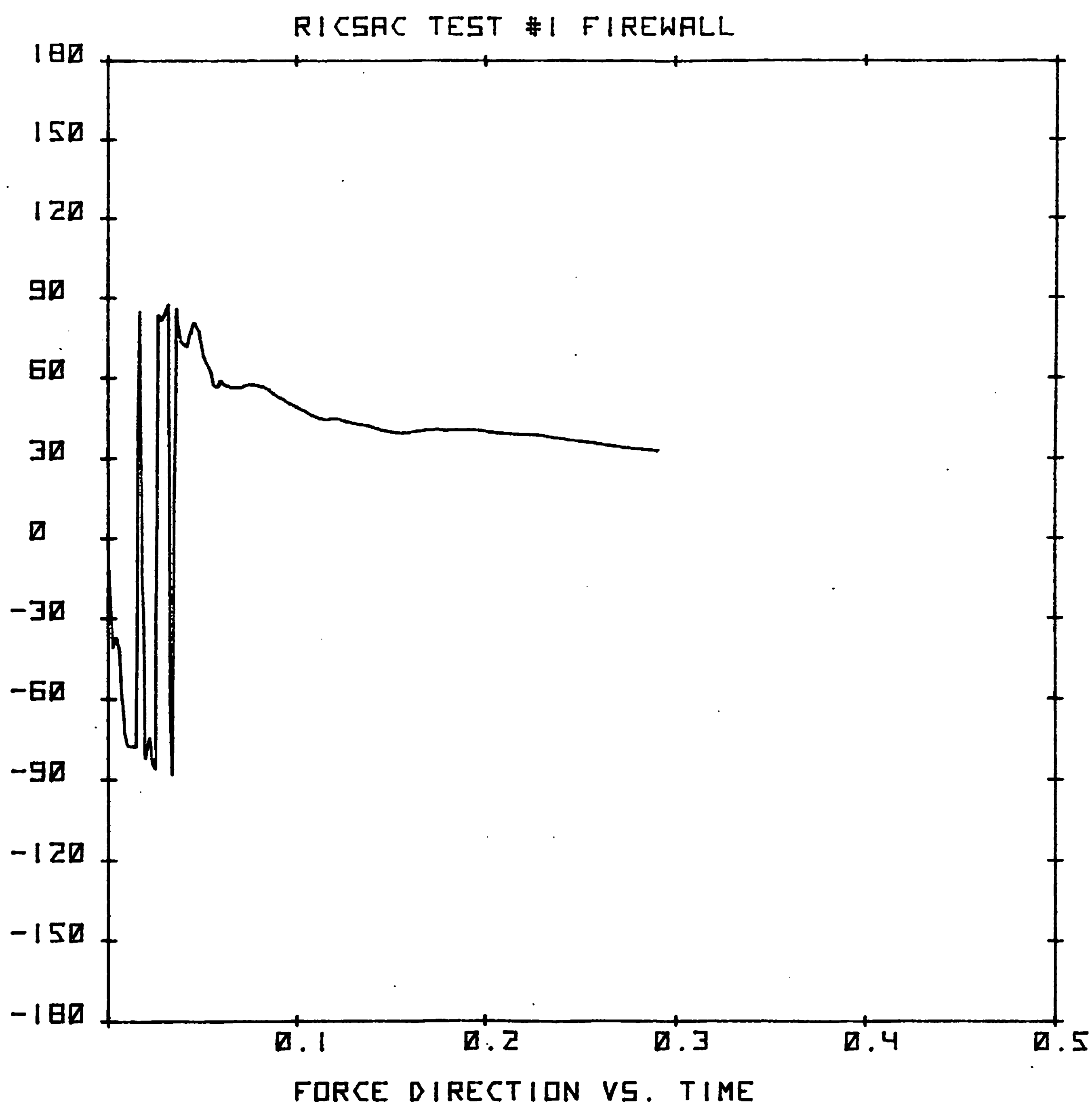

RICSAC TEST #1 FIREWALL
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 6

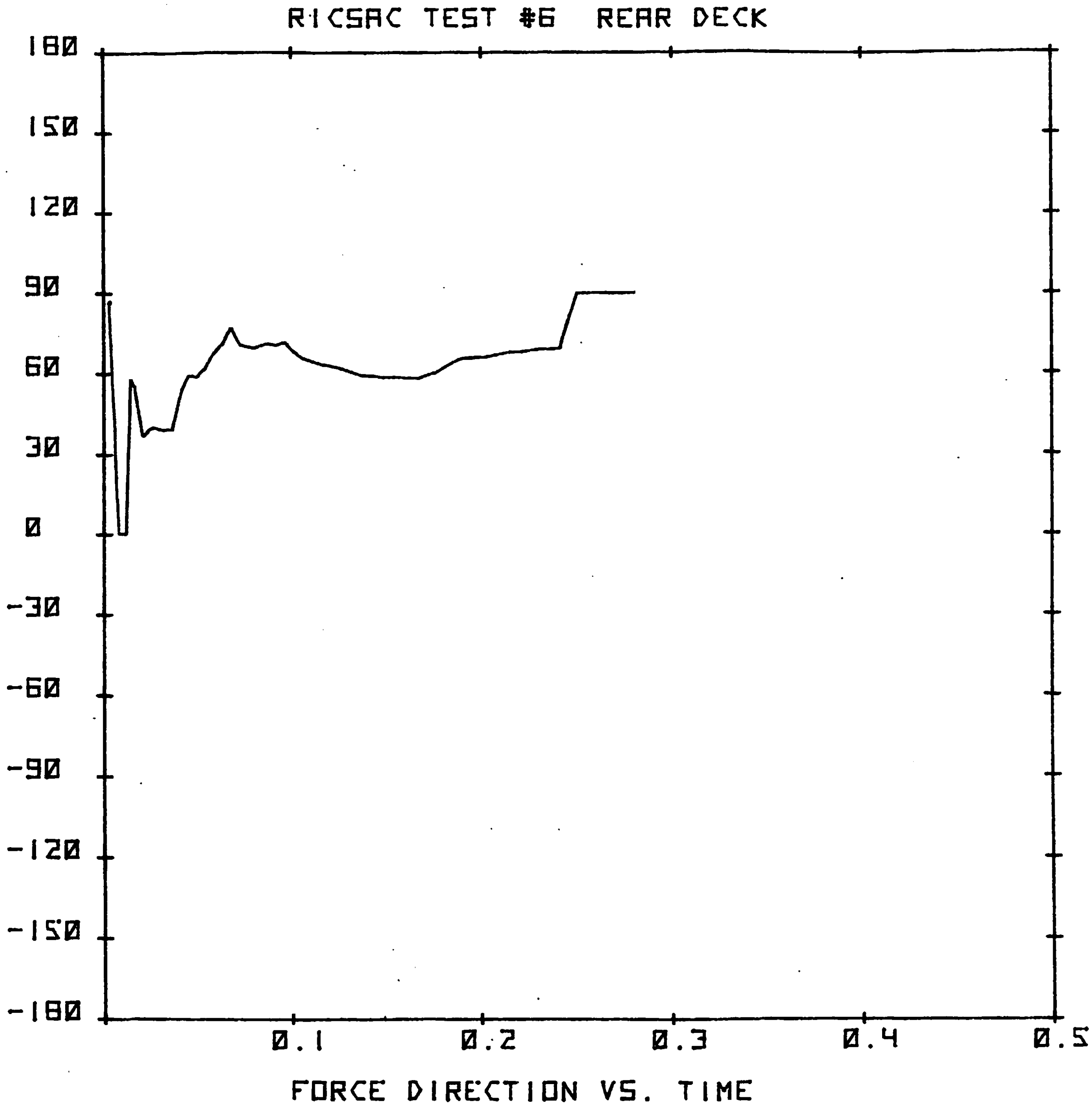

RICSAC TEST #6 REAR DECK
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 7

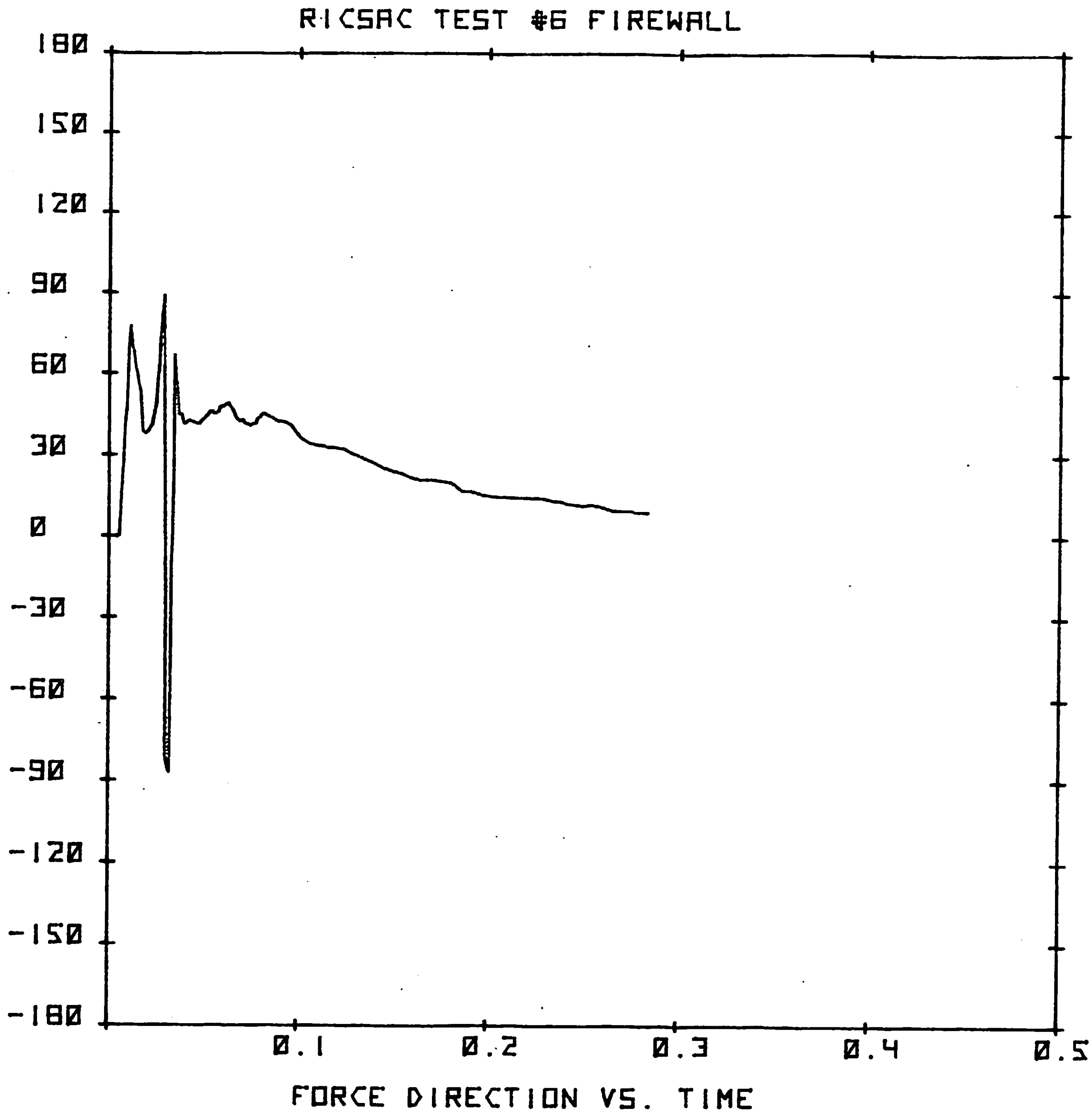

RICSAC TEST #6 FIREWALL
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 8

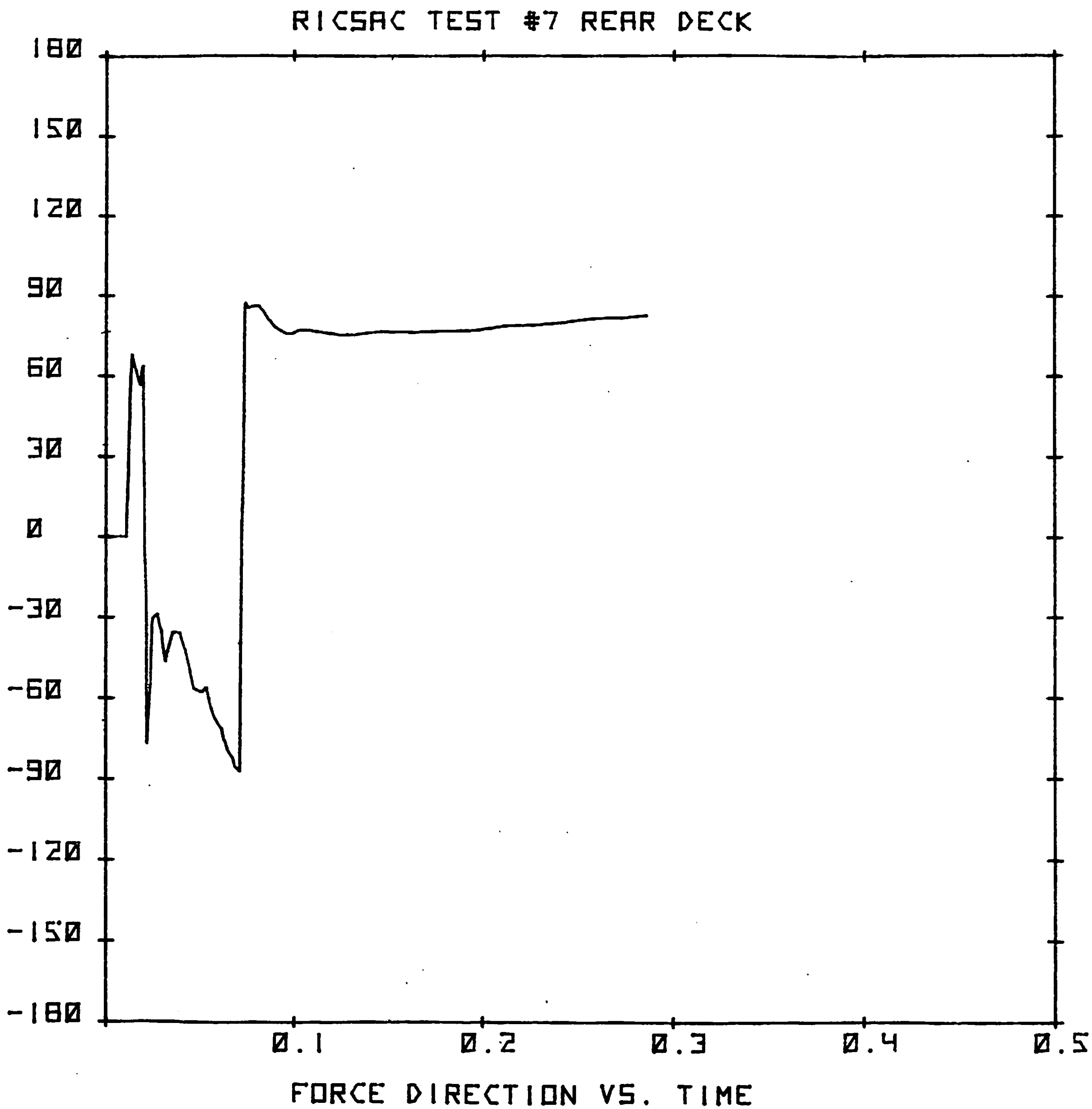

RICSAC TEST #7 REAR DECK
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 9

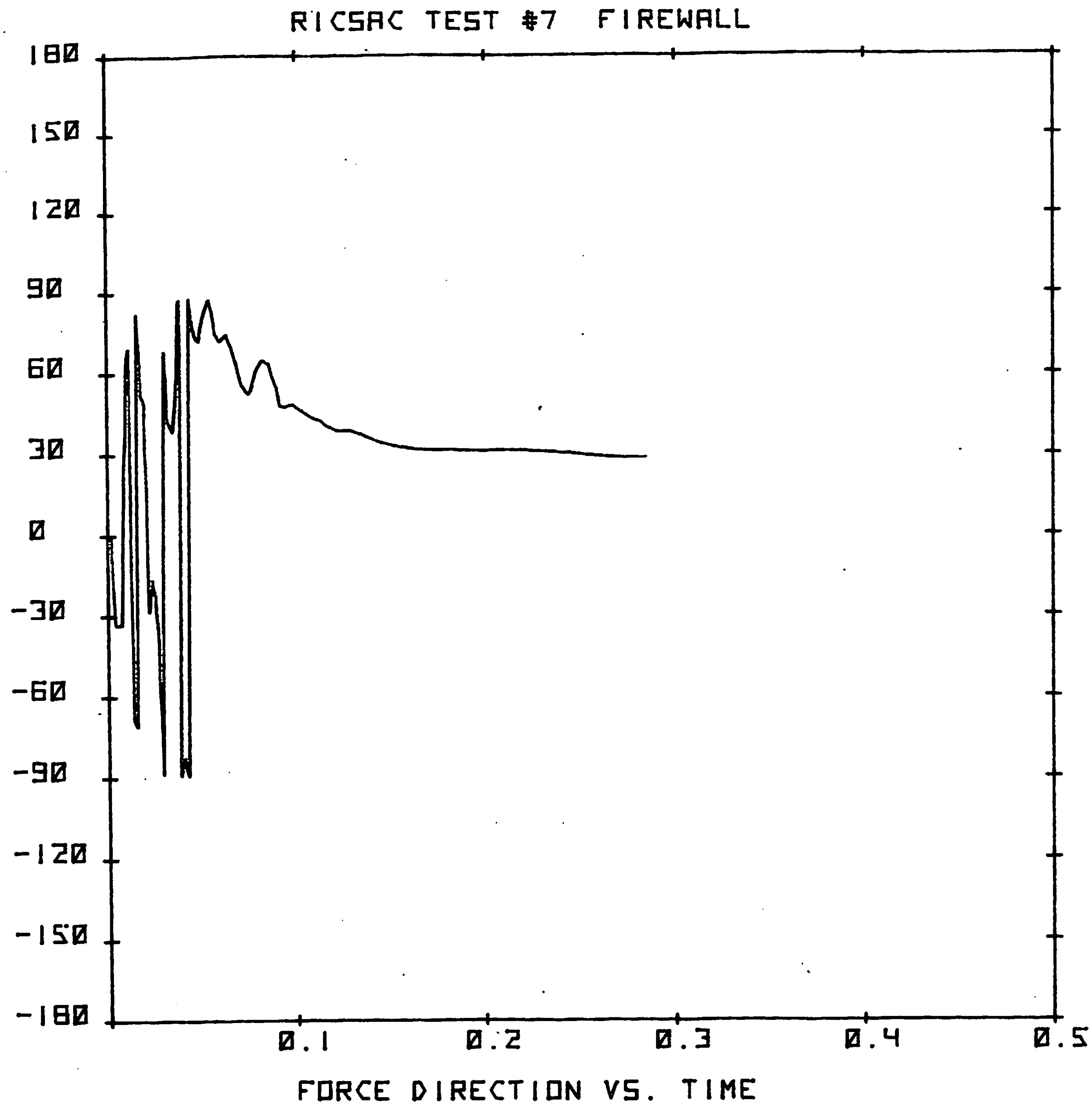

RICSAC TEST #7 FIREWALL
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 10

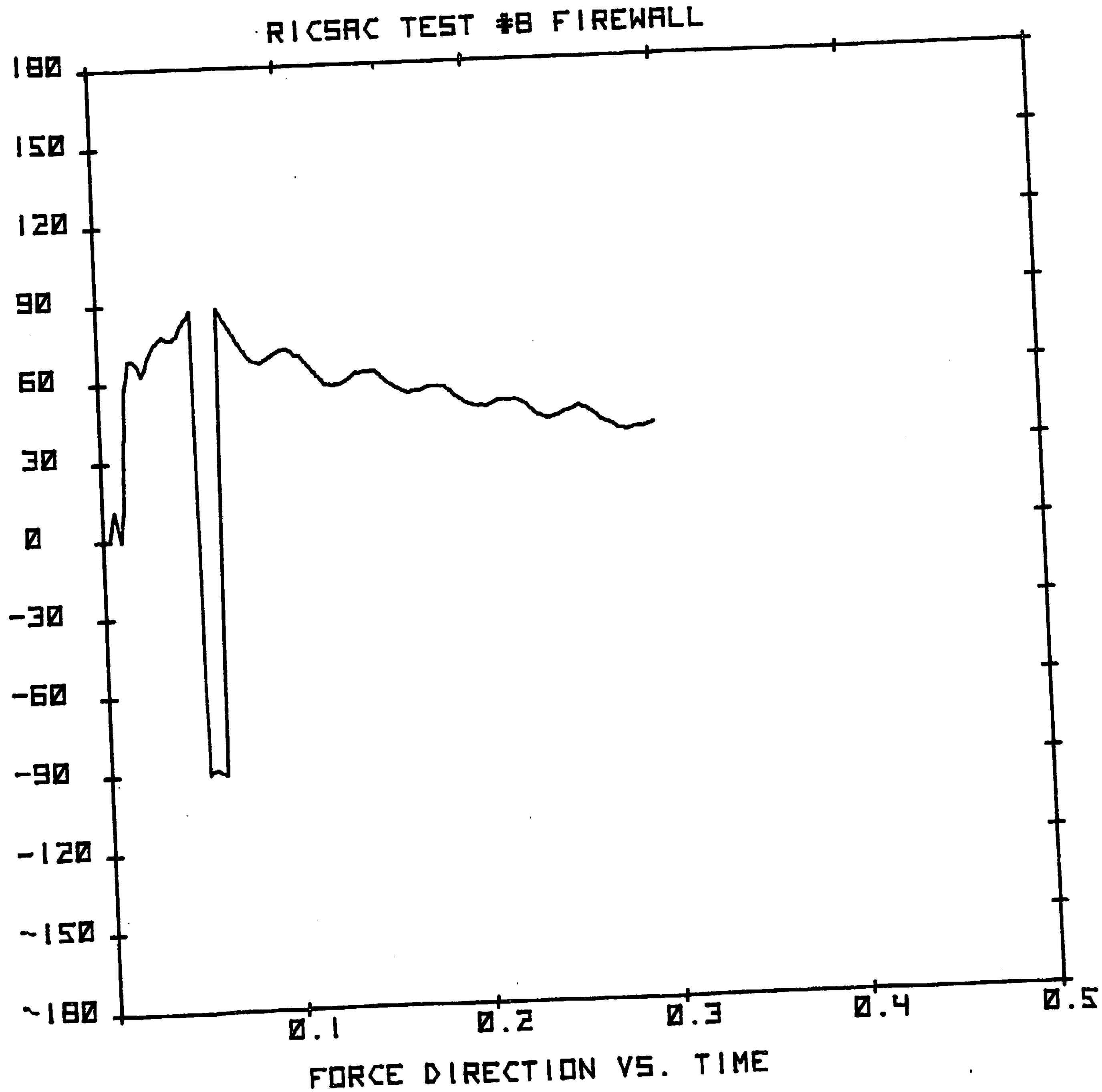

RICSAC TEST #8 FIREWALL
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 11

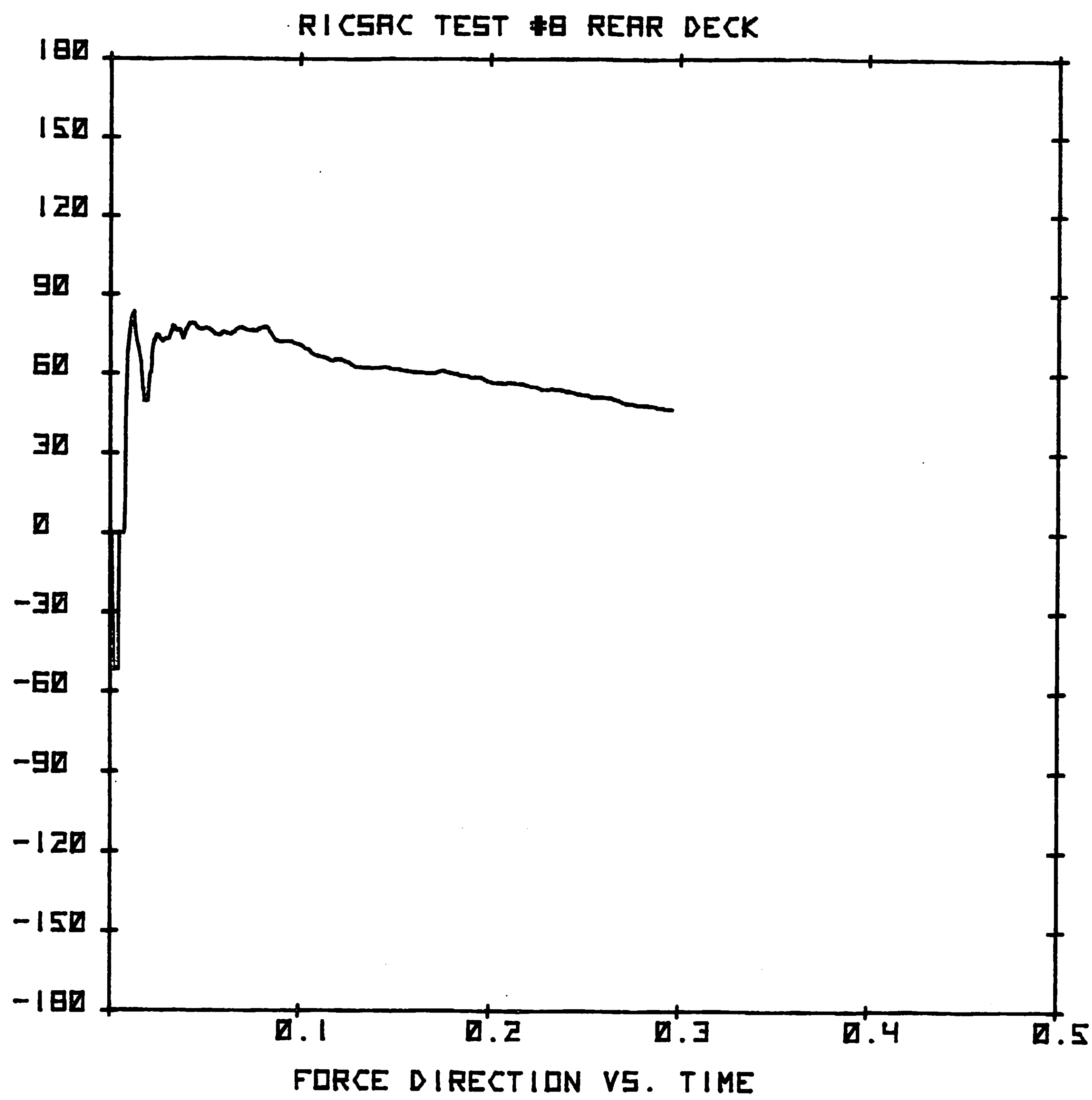

RICSAC TEST #8 REAR DECK
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 12

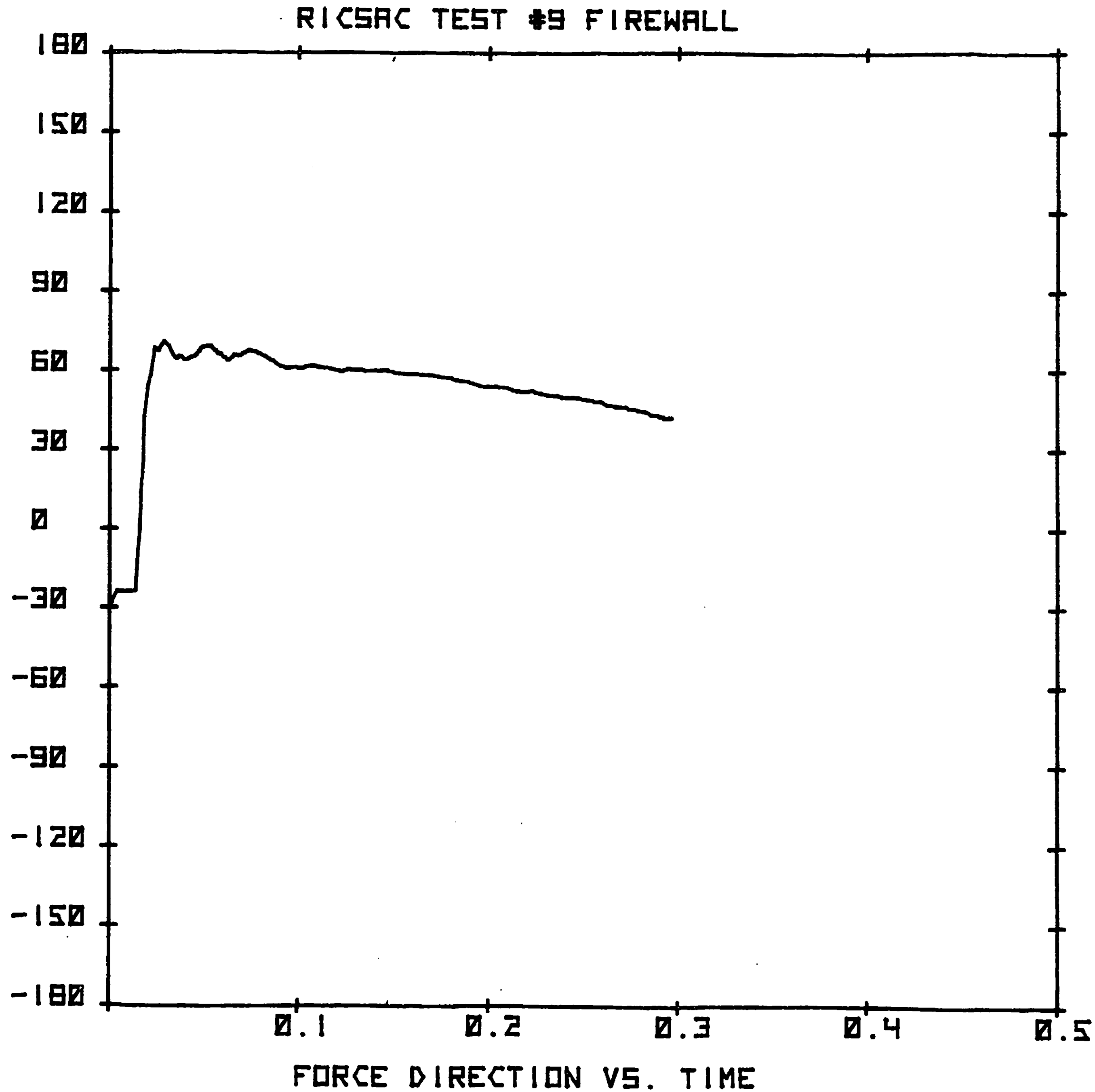

RICSAC TEST #9 FIREWALL
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 13

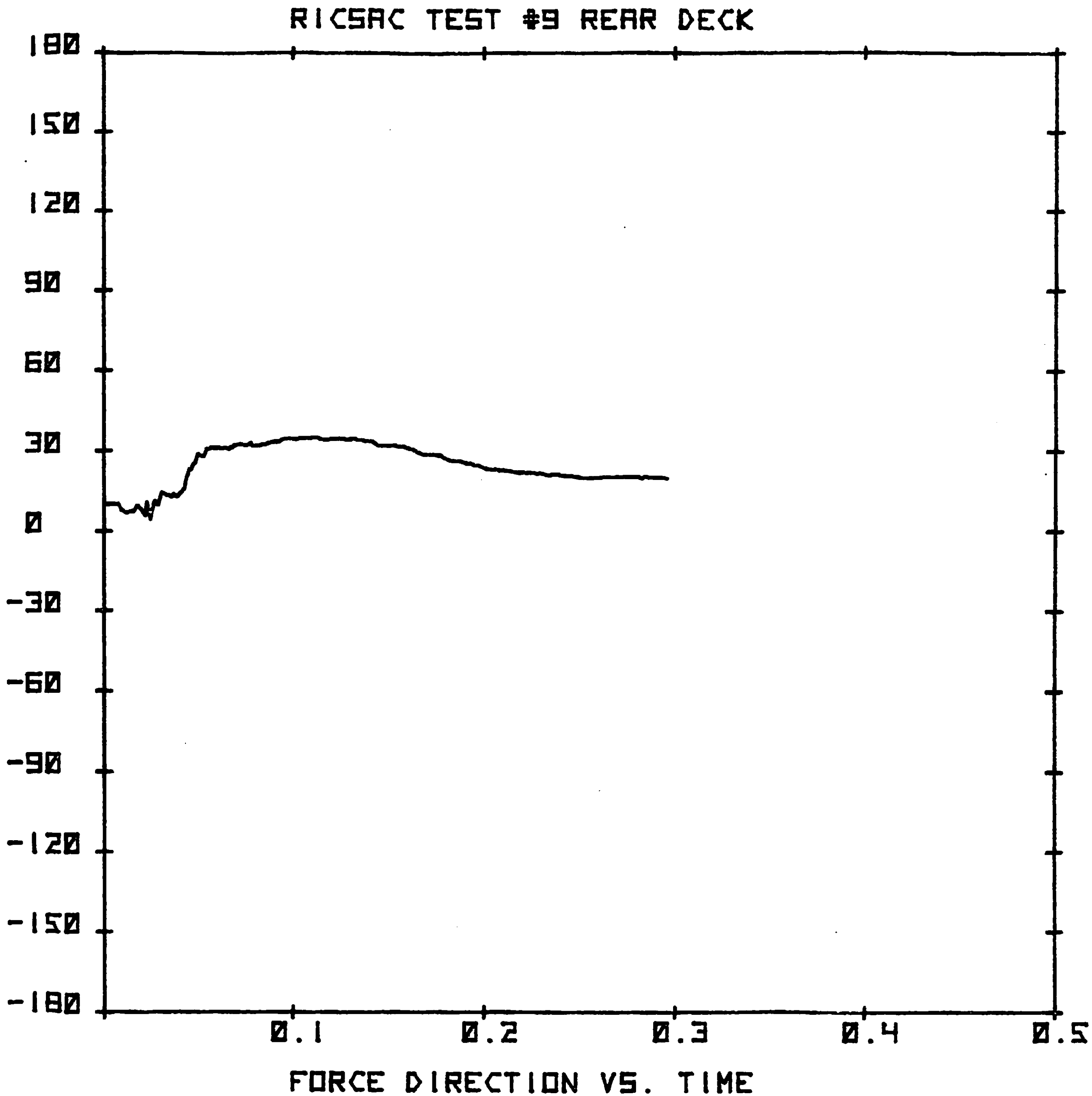

RICSAC TEST #9 REAR DECK
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 14

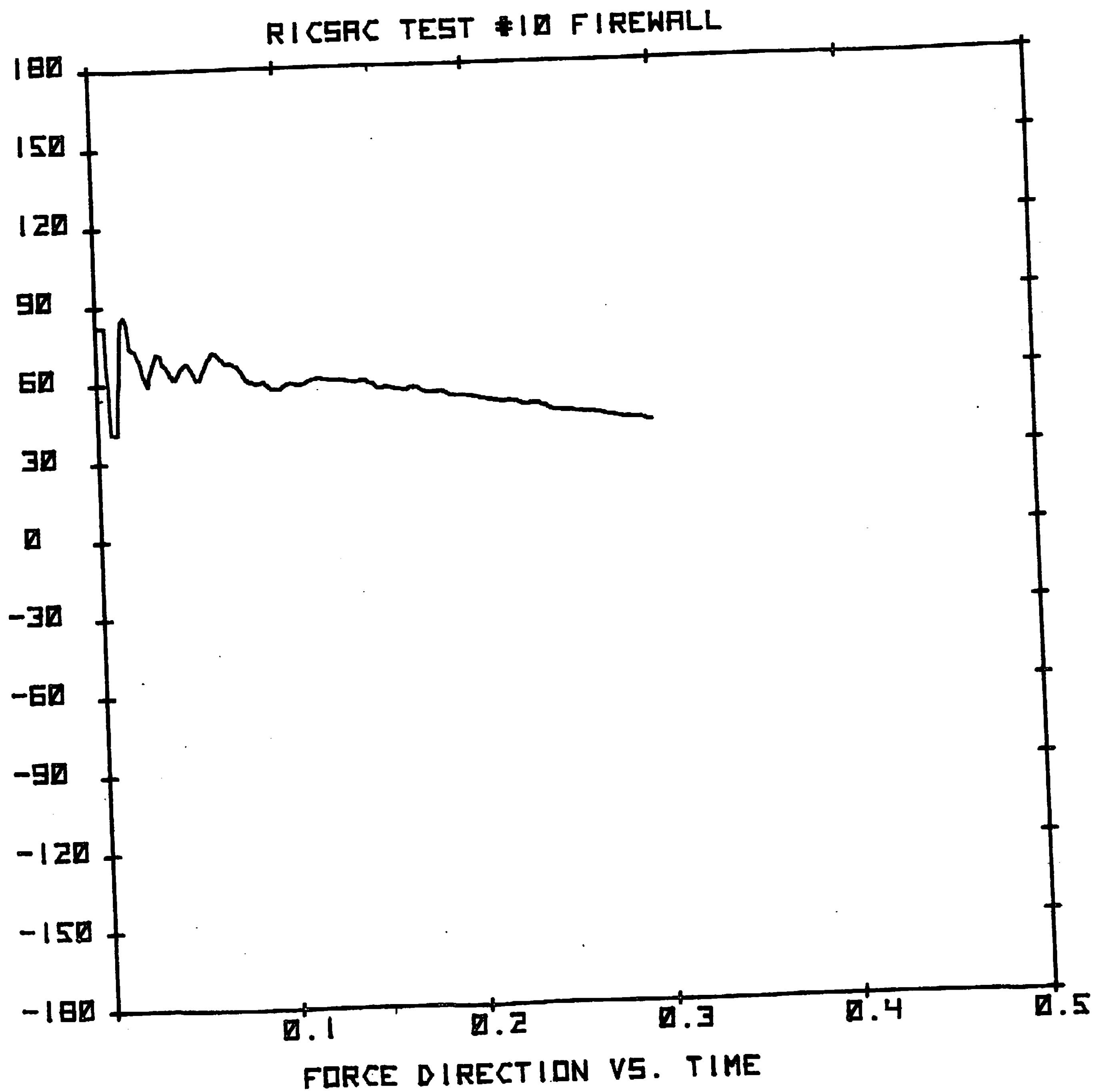

RICSAC TEST #10 FIREWALL
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 15

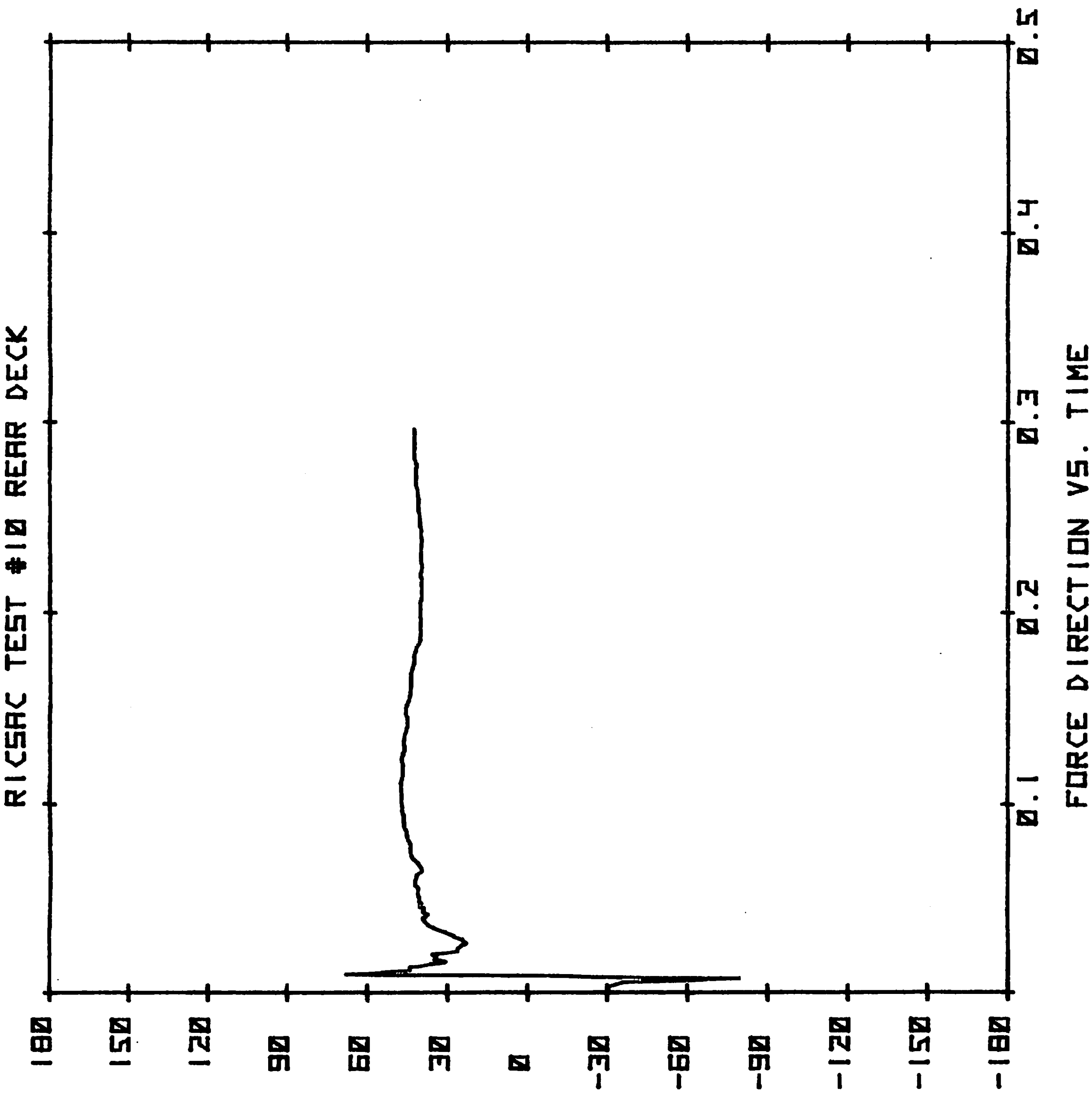

RICSAC TEST #10 REAR DECK
FORCE DIRECTION VS. TIME
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5

FIGURE G 16

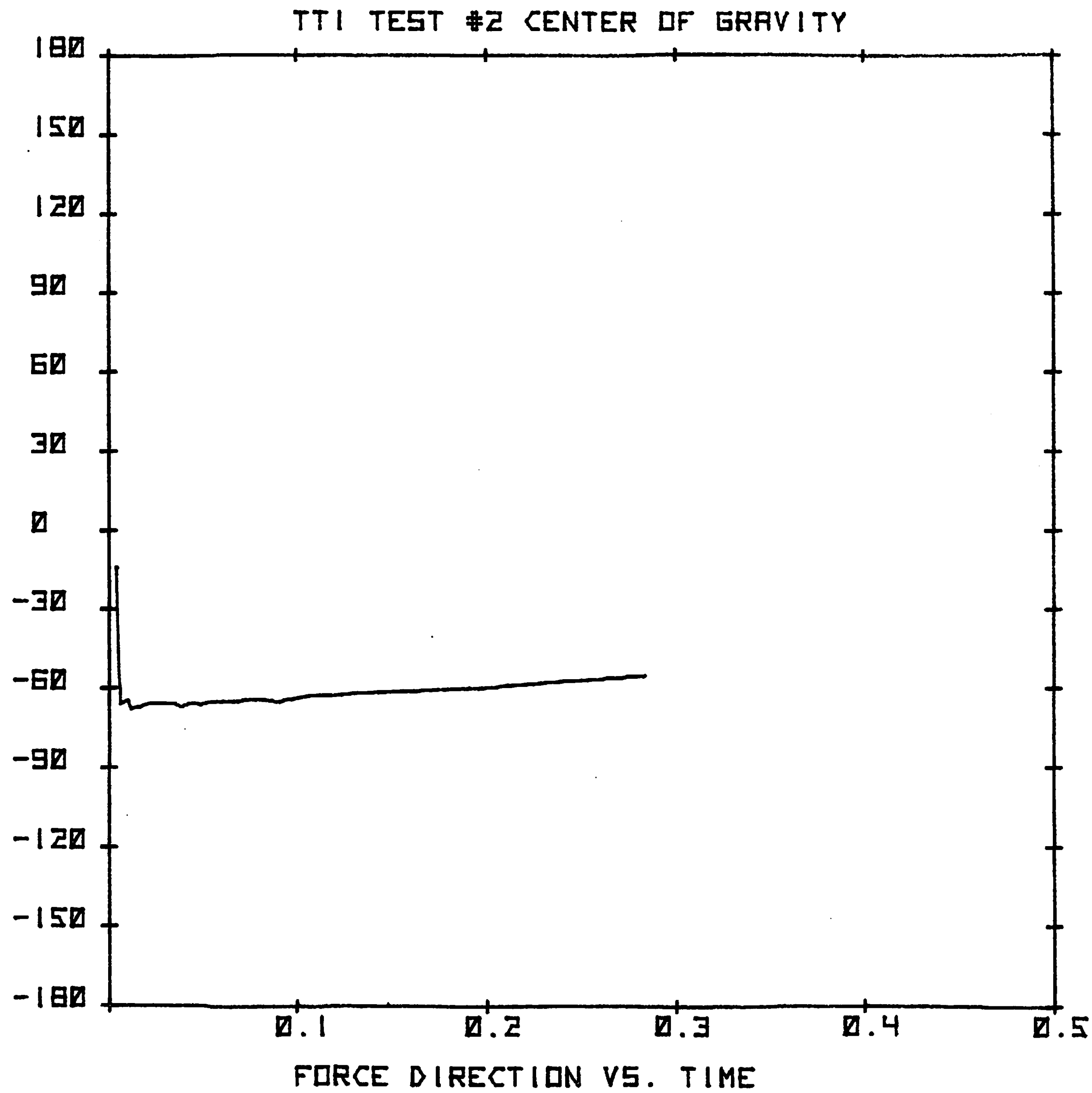

TTI TEST #2 CENTER OF GRAVITY
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 17

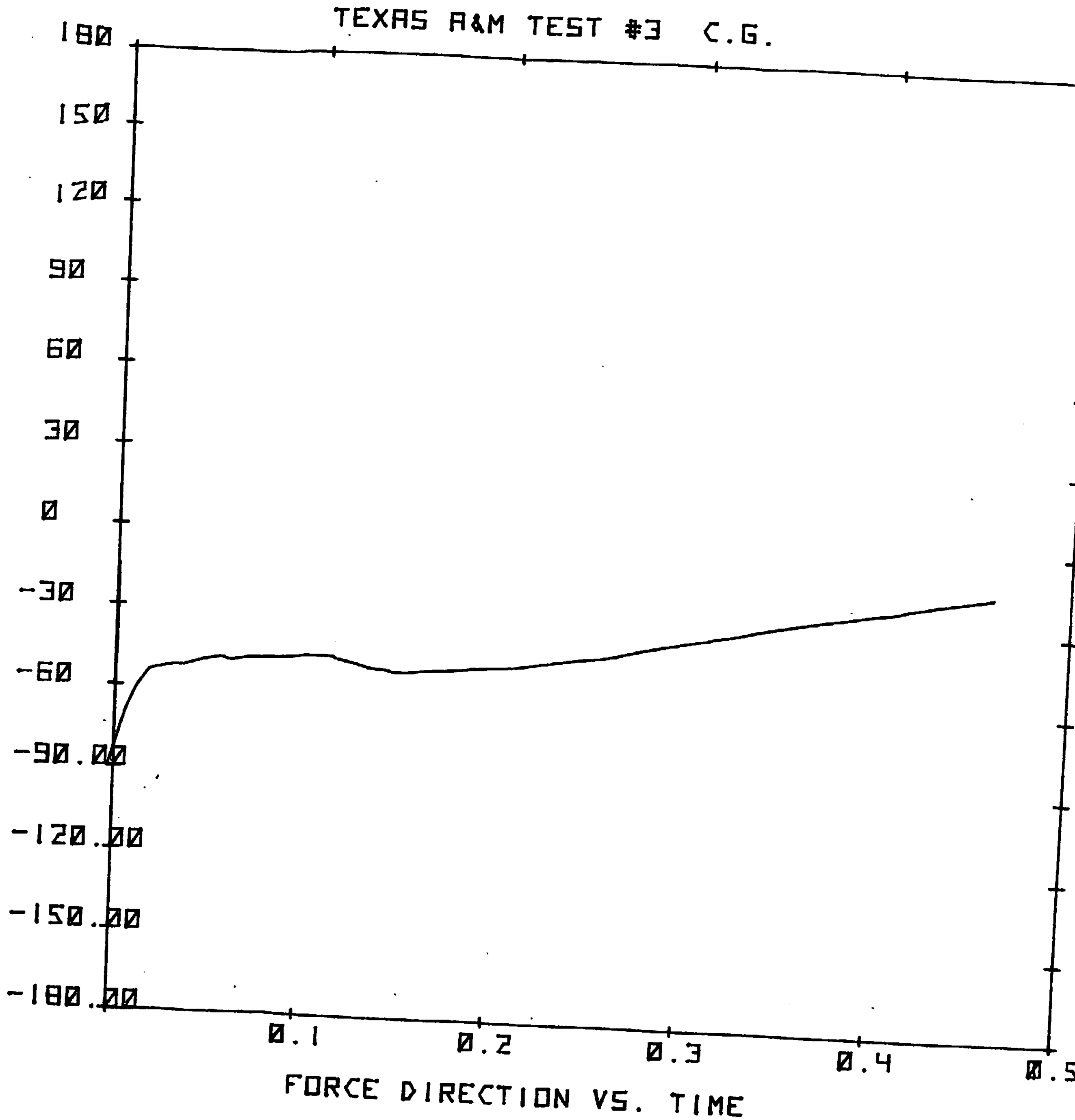

TEXAS A&M TEST #3 C.G.
180
150
120
90
60
30
0
-30
-60
-90.00
-120.00
-150.00
-180.00
0.1
0.2
0.3
0.4
0.5
FORCE DIRECTION VS. TIME

FIGURE G 18