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**National Highway
Traffic Safety
Administration**

Comprehensive Documentation of Driver (DRACR) and Passenger (PAC) Computer Models

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16. Abstract

This manual is written to give the user of the DRACR computer model the specific information he will need to:

a) set up the input file
b) run the program
c) interpret the results

This model describes the interaction between the driver of a vehicle and an air cushion restraint system. The air cushion is mounted to a steering wheel/steering column assembly which is modeled to stroke and rotate during the crash. A previous model called DRAC could not model this rotation; hence the descriptor "R" for "rotation" is added to this model to distinguish it from the functionally similar but less powerful DRAC model.

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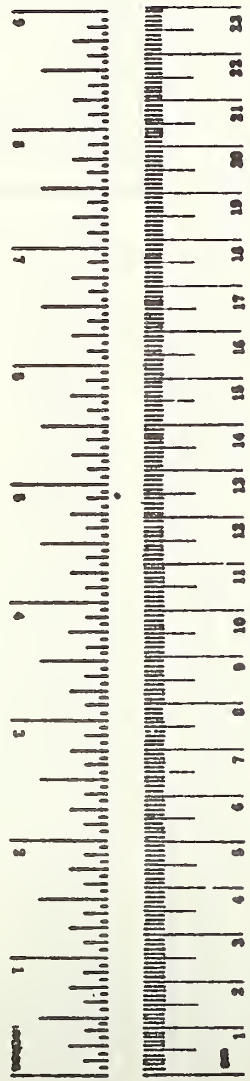
METRIC CONVERSION FACTORS

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

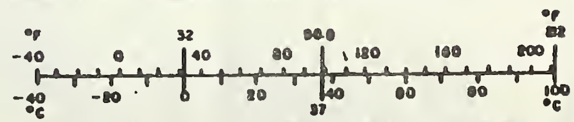


TABLE OF CONTENTS

1.0 INTRODUCTION

The purpose of this manual is to give to the potential DRACR user specific information to:

a. Set up the input file

b. Run the program

c. interpret the results

Prior to discussing these things, however, some background information on the DRACR program will be presented.

DRACR is an acronym for "DRiver Air Cushion - Rotation". As the title indicates, the program was written to describe the interaction, during a crash, between the driver of a vehicle and his airbag. The airbag is mounted to a steering wheel and steering column which is modeled to not only stroke but also rotate during the crash. A previous computer program (DRAC), also written by Fitzpatrick Engineering, does not model the rotation of the steering wheel and column; Hence, the term "rotation" is added to the descriptor of the DRACR program so it can be distinguished from the functionally similar but less powerful DRAC program.

Other programs have been written to describe the interaction between a driver and an airbag but none were specifically suitable to the characteristics exhibited by certain types of restraint systems. Some of the unique characteristics of the DRACR program which exist in combination to provide the greatest versatility and accuracy possible for a hardware design type of computer program are:

1. It has the capability of simulating an airbag shape typical of the ellipsoidal shape which almost all driver bags have.
2. The program is able to independently describe the simultaneous effects of steering column crush, steering wheel crush, steering column rotation with respect to the compartment, and steering wheel rotation with respect to the column and then assess their effect on the degree of injury imparted to the driver.
3. The program is set up to be a design tool oriented to the user requirements of a typical restraint system engineer with both the formulation and the input-output in units commonly used and measured in normal hardware design and test environments.
4. As a design tool, the program is oriented toward the test hardware actually encountered in most test situations. For example, past computer programs might model the driver very accurately but neglect the bag shape actually used and/or the column binding and frictional forces which are almost always present and influence the results greatly.
5. DRACR is derived to have the same level of detail, complexity and accuracy for all of the restraint system components. For example, there are several different types of steering columns, all of which behave somewhat differently. It does little good to have an elaborate airbag or driver algorithm and then to include it with a steering column algorithm that is so simple it

is described by only a force-stroke characteristic. To be accurate and capable of describing the important differences between column types in the areas of frictional and binding effects and the wheel and column resistance to rotation, a program such a DRACR is required.

2.0 PROGRAM DESCRIPTION

DRACR is a two-dimensional, lumped mass computer model of the driver interacting with an ellipsoidal airbag mounted to a steering column and wheel one or both of which may stroke and/or rotate depending on the relative stiffness and strength of the individual components. The model includes five masses. Three represent the driver (i.e., the head, torso and lower body) while two describe the restraint system (i.e., the steering wheel and the steering column). The airbag is simulated by an oblate spheroid into which a programmed amount of gas flows. By adjusting the airbag vent size, a selected amount of gas can be exhausted during the crash in order to attenuate peak head and chest g's and the rebound velocity.

2.1 PROGRAM FORMULATION

The mathematical formulation of the equations of motion follows the classical Lagrangian derivation (see Appendix A of this manual) with body pivot points at A and B of Figure 1. The lower body mass (hips and legs) is constrained to move horizontally.

DRACR uses a fixed time step integration routine to solve the differential equations of motion numerically. The integration routine chosen was the Adams-Moulton predictor corrector method, with the fourth order Runge-Kutta method employed to determine the first four solution points. DRACR has been written in FORTRAN IV and was developed to operate in an interactive time share mode for greatest versatility for the

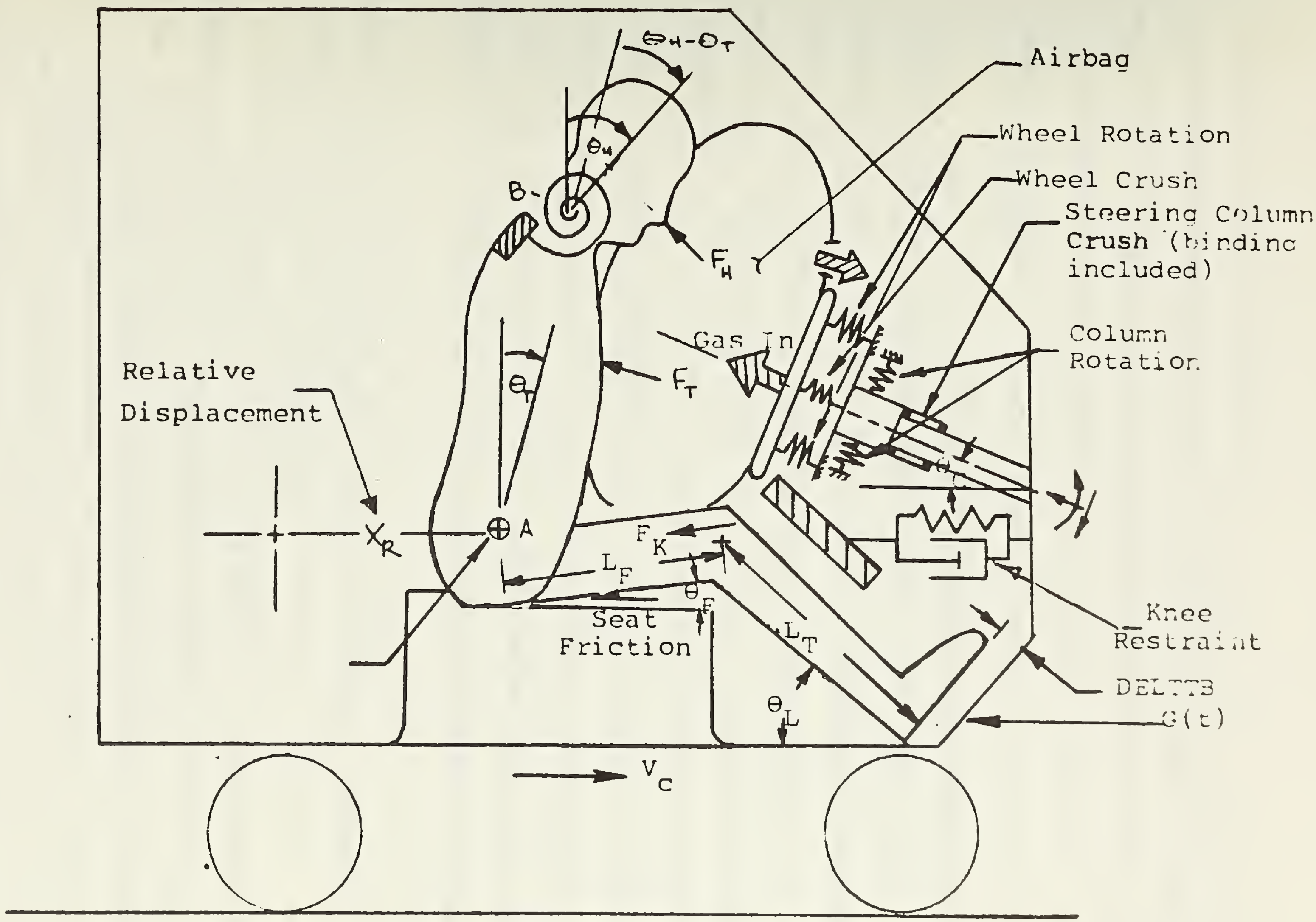


Figure 1. Schematic of "DRACR" Computer Model.

design engineer. The program is self contained, in that no external routines are required for execution. It is also modular in construction, so as to facilitate the addition of other subroutines at a future time, if desired. The data input is from a previously created disk file and the input parameters appear directly on the terminal, immediately preceding the complete program output.

As mentioned above, DRACR has been programmed in modular format with several subroutines. The reason for this is to enable other features to be easily added at a future time. For example, consider the tabular data input. For simple data where the particular value of the dependent variable is a function only of the value of the independent variable, a simple table look-up and interpolation subroutine, "LOOK-UP" is provided. Gas flow versus time, vehicle acceleration versus time, neck torque versus angle, column force versus crush, and steering wheel force versus crush are examples of this method of data retrieval.

However, in those cases in which the dependent variable is a function not only of the value of the independant variable but also depends on whether the independent variable is increasing or decreasing, a different subroutine, "SPRING", that allows for plastic behavior, is used. This subroutine is used principally for those cases in which hysterises (or plastic action of a deformable member) is modeled. In these cases, one must not only specify the values for the dependent variable for different values of the independent variable, but must also specify the "unload slope(s)" for those conditions in which the member is undergoing unloading during a lessening of the degree of deformation. Knee restraint force versus crush, and seat friction force versus stroke are handled by this subroutine.

2.2 AIRBAG

Most of the driver/airbag interaction models being used today rely on relatively simple spherical or cylindrical airbag shapes (in which the bags exhibit a constant radius of curvature regardless of impact angle). Unfortunately, these simple bag shapes do not adequately describe the shape of most of the airbags presently being used. Of all the geometric shapes that could be postulated as candidates for the driver airbag, the ellipsoid (oblate spheroid to be specific) is most nearly the shape of the driver airbag. For this reason we chose the oblate spheroid as the shape upon which to base the bag shape algorithm (see Appendix B of this manual). Unfortunately, the oblate spheroid is not as mathematically easy to describe as the sphere or cylinder, since the bag radius of curvature and the intercepted volume of the airbag are not independent of the angle of torso inclination.

Figure 2 shows a simple schematic of the airbag, along with the variables necessary to describe the airbag shape. The airbag is assumed to be symmetric about a line coincident with the steering column's longitudinal axis.

2.3 STEERING COLUMN

As previously mentioned, the proper modeling of the steering column is very important to the overall accuracy of the program in repro-

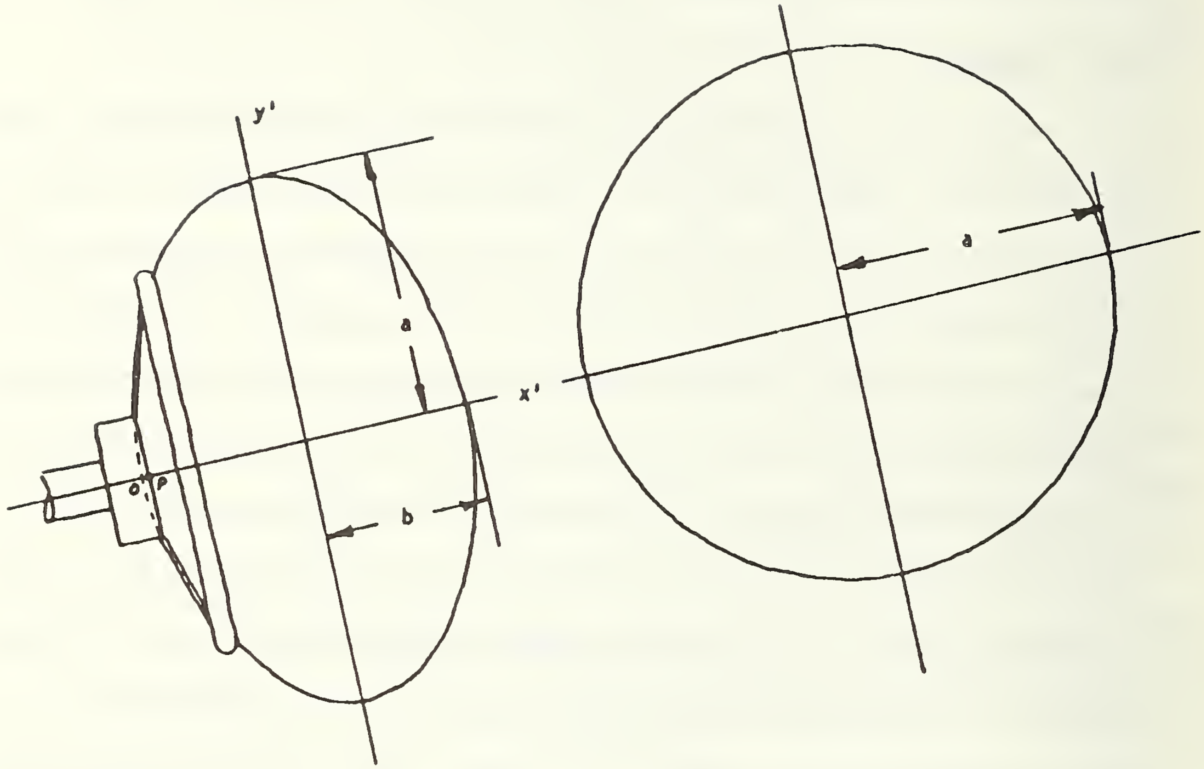
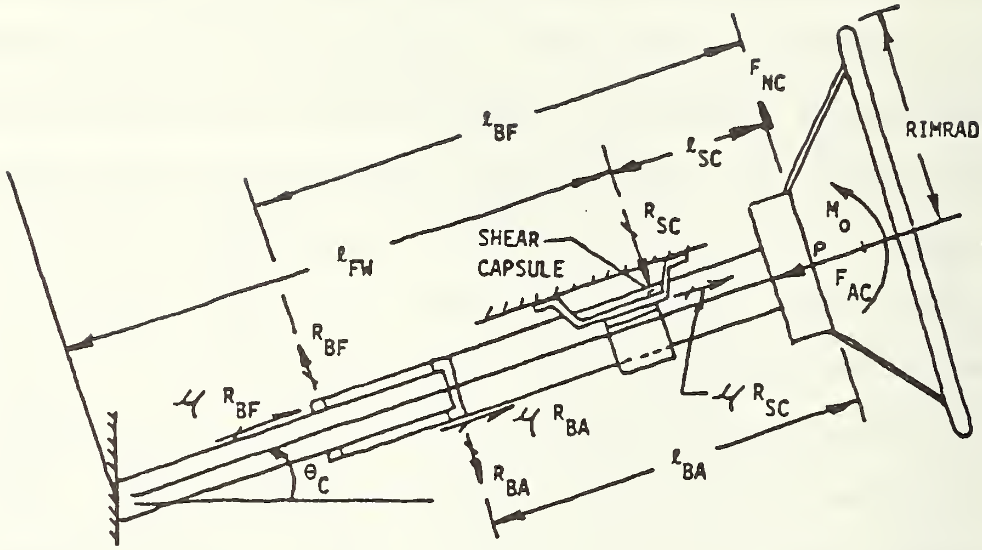


Figure 2. DRACR Airbag Geometry.

ducing "real world" behavior for the driver restraint system. Most driver restraint system models specify only a force versus stroke characteristic for the column. In many cases these models neglect column angle, column mass, column frictional and binding effects and the location and strength of the specific bracketry that supports the column. In setting up the column for this program, we have chosen a generic type of column that is widely used. This column is the General Motors "ball-and-groove" type column shown in Figure 3. Other types could have been specified, but, because of the modular program construction, other types may be easily added as required. As it turns out, the GM type column is fairly typical of a wide variety of columns, so the program can be used "as is" for a wide variety of situations by properly adjusting the input parameters that describe this steering column.

The program is set up to calculate the airbag forces and pressure before moving on to the column force calculations. Therefore, the airbag forces are resolved into a column axial force, a column normal force and a column bending moment as applied loads to the column. This is done before entering the column stroke and rotational dynamics portion of the routine. All the user need specify is the column mass, the column angle, the basic force-stroke properties of the column, the coefficient of friction at the column's internal and external "rub" surfaces, the pertinent column dimensions, and the location and strength of the column support bracketry for the computer to calculate the complete column dynamics.

One might wonder why it is so important to accurately describe the steering column rotation. The main reason is that it commonly occurs, and



R_{SC} = Reaction at Shear Capsule

R_{BA} = Reaction at Aft Bushing

R_{BF} = Reaction at Forward Bushing

μ = Coefficient of Friction

M_o = Applied Moment

F_{AC} = Applied Axial Force

F_{NC} = Applied Normal Force

Figure 3. Geometry of DRACR Steering Column.

when it does it almost universally causes higher injury measures than would occur otherwise. The reason for the higher injury measures is that when the brackety collapse or yielding causes column rotation, the rotation is almost always in an upward direction so that bag placement moves higher and higher on the driver resulting in less and less effective torso mass being brought to bear on the column. When this happens, the column ceases to stroke, chest g's increase and the driver begins to submarine. Using DRACR we may, therefore, determine whether bracket strengths are adequate to prevent, or at least, control such an occurance. In a slightly different vein, we could determine just what loads the column brackets must be designed to withstand without catastrophic collapse.

Appendix C contains additional details on the steering column algorithm derivation.

2.4 STEERING WHEEL

The steering wheel as modeled by DRACR has two degrees of freedom. It may crush axially and/or rotate up or down relative to the column. Like the steering column, the accurate simulation of the steering wheel is important to achieving overall simulation realism.

In terms of wheel crush, recent testing has shown that typical airbag systems can be made safer and less complex by using advantages inherent in a crushable steering wheel. The overall system can be made safer since wheel crush adds to the total controlled stroke in the passenger compartment plus the steering wheel, as opposed to the steering column, is of relatively low mass with no friction resulting in generally lower injury measures and greater reliability. Additionally, wheel crush can add redundancy to the total system by adding a second mechanical method by which energy may be absorbed in case the column fails to stroke. Given a choice between designing a mechanical energy absorber into a steering column or into a crushable steering wheel (assuming the wheel may crush as much as the column under consideration), it is much less complex, less costly and more reliable to implement this crush into the steering wheel as opposed to the steering column.

Now, in terms of steering wheel rotation, recent testing has also shown that a "self aligning" steering wheel has several desirable attributes, some of which are listed below. Thus, the self aligning (rotating) wheel results in:

a) Lower contact forces if the bag "bottoms" on the wheel rim.

b) Better bag placement on the chest since the wheel has this tendency to align itself with the chest.

c) More total energy absorbing stroke.

Advantages of being able to simulate the steering wheel rotation with DRACR are:

a) A more realistic simulation of what actually happens to the steering wheel in an actual crash.

b) Makes it possible to investigate the relative importance of factors that cause steering wheel rotation and which factors cause rotation in either the upward or downward directions so as to obtain the desired effect in the final design.

c) Makes it possible to tailor the steering wheel rotational stiffness to obtain lowest injury levels.

In order to obtain an accurate simulation of steering wheel behavior in the crash, the user of DRACR must specify the steering wheel mass, the mass of the airbag and inflator package, the wheel angle from a vertical reference (normally this angle is the same as the column angle initially, but can be different if a vehicle with a tilt wheel is being simulated), the basic force-crush properties of the wheel, the pertinent wheel dimensions, and the torsional resistance at the wheel/column interface in both the upward and downward directions.

Figure 4 shows a schematic of the original and final positions of the column and wheel for a typical crash situation. In the figure all four mechanisms (wheel crush, wheel rotation, column crush and column rotation) are evident.

One might wonder how the DRACR program is set up to determine <u>which</u> of the four modes of energy absorption will actually occur in a given situation. The method is explained in the following.

All four modes are assumed possible each time the program computes new values each time through the computation loop. For a one millisecond integration interval this would be every one millisecond. The computer is instructed to compare the applied torque or force with the resisting torque or force for each of the four possible yield modes. For each case in which the applied torque or force is <u>less</u> than the resisting

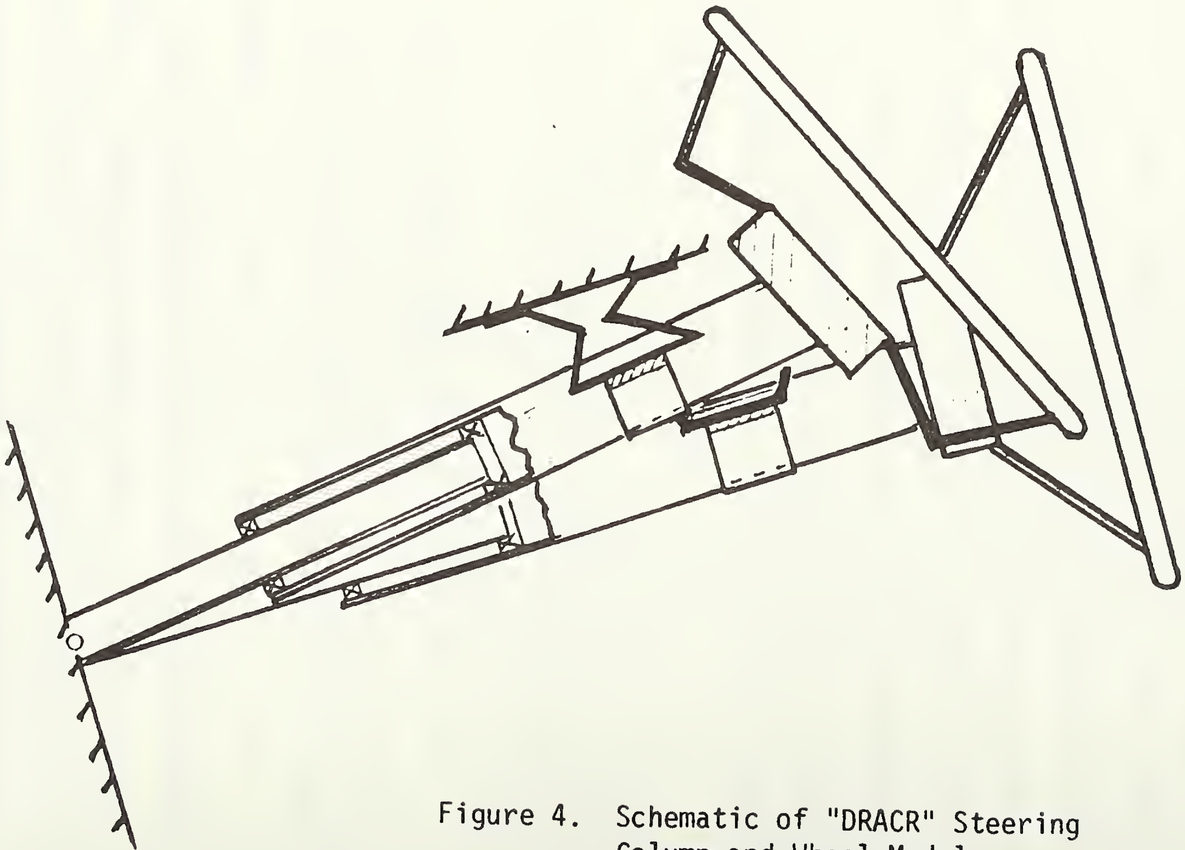


Figure 4. Schematic of "DRACR" Steering Column and Wheel Model.

torque or force, the computer allows no further crush or rotation due to this applied torque or force during this time interval.

In those cases where more than one yield mode is possible during the time interval, the one that is actually allowed to occur is determined by the "minimum energy" principle. That is, the energy absorption mode that requires the least expenditure of energy per horizontal distance traveled by the deforming item during the time interval is the mode that is allowed to occur. Other modes are suppressed until the next time through the loop at which time the whole process begins again.

2.5 KNEE RESTRAINT AND SEAT FRICTION

The DRACR computer program is set up to accept tabular input for the force-crush properties of the knee restraint and the force-displacement properties of seat friction. It is the sum of these two forces which primarily determine what the lower body restraint for the lower torso, hips and legs will be.

The user specifies, in tabular format, the values these forces and displacements are to take. In addition, the user specifies the "unload slope", so the program can compute the unloading force path to be taken during rebound away from the knee bolster or movement rearward across the seat.

The user also specifies the initial angles of the tibia and femur and the femur length. As the driver translates forward during the crash these angles are recalculated so as to obtain the proper angle at which the knee loads are applied to the femurs and lower body.

The specifics of how all the input is handled is given in Section 3.1.

2.6 THE DRIVER ALGORITHM

The driver is modeled by three lumped masses (i.e., the head, the torso and the lower body) which pivot at points A and B in Figure 5. This figure also describes the driver geometry and the location of the airbag and the driver with respect to the compartment. Specific details needed to provide driver related computer input are described in Section 3.1.

A comment is necessary on the resisting torque generated by neck muscular resistance and the anatomical interferences caused by the relative displacement between the head and torso. These values are only applied if certain conditions are met. For example, in cases where the head is returning to become more nearly in line with the torso ($\Theta_H - \Theta_T$ becoming smaller) the torque is not applied. Only when the head is becoming more out of line with the chest ($\Theta_H - \Theta_T$ becoming larger) is the neck torque applied. I.e.,

For $\Theta_H - \Theta_T > 0$ and $\dot{\Theta}_H - \dot{\Theta}_T > 0$, $T < 0$

For $\Theta_H - \Theta_T > 0$ and $\dot{\Theta}_H - \dot{\Theta}_T < 0$, $T = 0$

For $\Theta_H - \Theta_T < 0$ and $\dot{\Theta}_H - \dot{\Theta}_T > 0$, $T = 0$

for $\Theta_H - \Theta_T < 0$ and $\dot{\Theta}_H - \dot{\Theta}_T < 0$, $T > 0$

Where,

T = Neck Resisting Torque

Θ_H is defined in Figure 5

Θ_T is defined in Figure 5

$\Theta_H - \Theta_T$ is defined in Figure 1

$\dot{\Theta}_H - \dot{\Theta}_T$ is the time rate of change of $\Theta_H - \Theta_T$

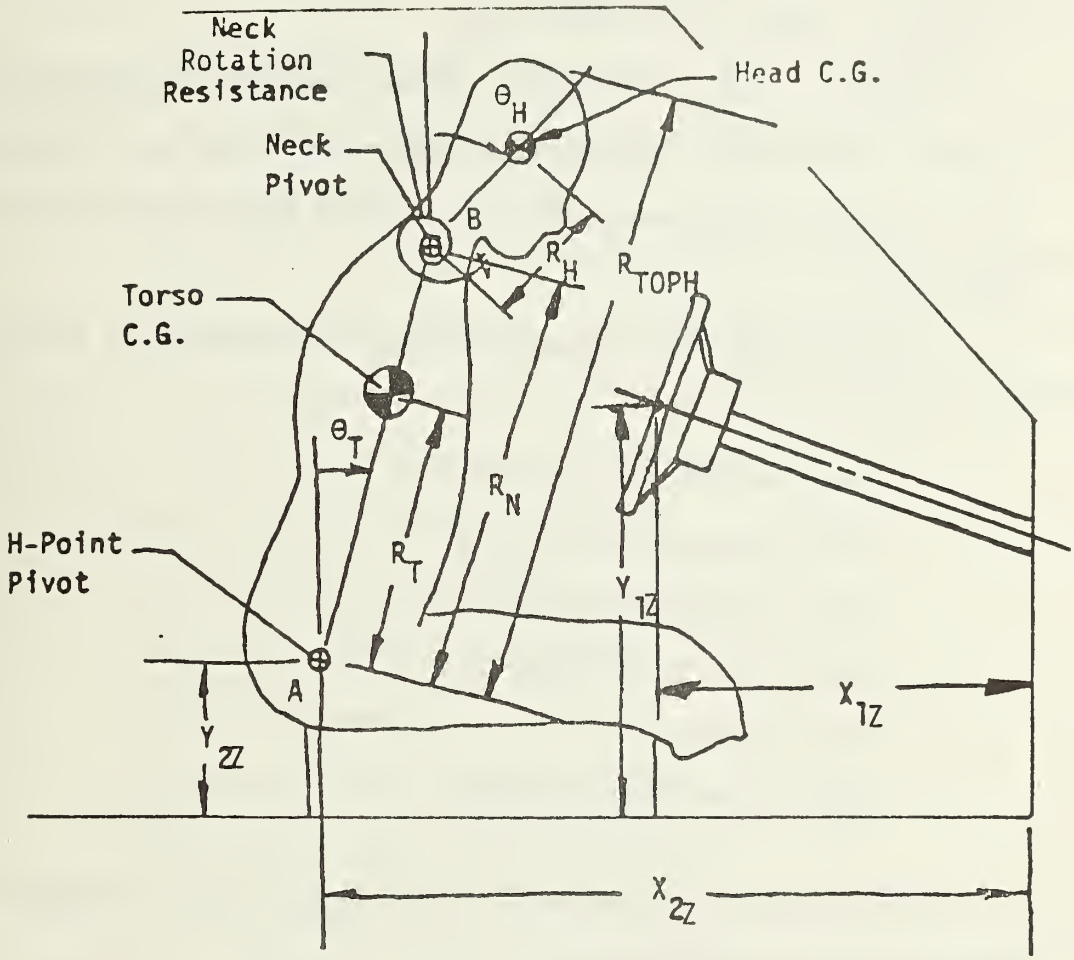


Figure 5. Driver Nomenclature

In addition to the neck resisting torque based upon the angular displacement of the head relative to the torso, we also have included a damping coefficient for the head/neck based upon the angular velocity of the head relative to the torso. The value of this coefficient is known as "DCN" in the input data.

Thus, the overall resistance of the head/neck to rotation with respect to the torso is composed of two terms - one term based upon relative angular displacement and a second term based upon relative angular velocity.

The injury measures computed by DRACR for the driver are the following:

a. Head Anterior-Posterior g's

b. Head Superior-Inferior g's

c. Chest Anterior-Posterior g's

d. Chest Superior-Inferior g's

e. Femur Loads

f. Head Injury Criterion (HIC)

Appendix D, of this manual contains a listing of the DRACR program and the logic flow diagrams.

3.0 EXAMPLE OF DRACR PROGRAM USE

This section describes the use of the DRACR program by citing an actual sled impact test case. This test case was conducted as part of the test effort in Contract No. DTNH22-82-C-07132, "Systems Analysis Approach to Restraint Systems Integration", and is documented in a test report[1]. The test was conducted in East Liberty Ohio using the HYGE sled test facility of NHTSA-SRL/TRC.

In addition to the above sled test, vehicle component and dummy tests were conducted to determine the performance characteristics of the various key components comprising the vehicle restraint and dummy systems. These tests included the following:

- o Steering Wheel Static Crush Tests
- o Steering Column Static Crush Tests
- o Knee Bolster Static Crush Tests
- o Dummy Measurements
- o Dummy Neck Static Resistance Tests
- o Dummy Neck Dynamic Resistance Tests

These tests were conducted at the NHTSA-SRL/TRC test facility in East Liberty Ohio, under Contract No. DTNH22-82-P-07224, "Sled Testing and Data Collection at NHTSA-SRL, Ohio - DRACR Validation".

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[1] Fitzpatrick Engineering, "Systems Analysis Approach to Restraint Systems Integration - Sled Test Support", Contract No. DTNH22-82-C-07132, Interim Report, Vols. I and III.

3.1 CREATING THE DATA INPUT FILE

The first thing to be done in preparation for making a DRACR computer run is to set up a data input file containing information which the program requires to run. Table 1 is a list of parameters that make up this file.

In Table 1, the first column shows the data file line number. The second column shows the location of a particular piece of data in the line ("2", for example, would indicate the 2^{nd} position in the line). The third column gives the alpha-numeric name of the variable at that particular point in the line, followed by the units the variable must have in the data file. The fourth column contains a short description of what the variable is. The fifth column gives the actual value of the variable used in the sample case. The file that results from this input is shown in Figure 6. We have chosen to call the file "LSRL5005".

A word about the subroutine "SPRING" is in order here. As previously mentioned, "SPRING" is used in those cases where one wishes to include the effects of hysterises in the deforming element. Figure 7 illustrates the logic involved in modeling this type of behavior. In general, the force will increase in a non-linear way as shown by Path 1 (Figure 7). If the spring begins to unload at point A, we expect a linear unloading curve as shown by path 2. If the spring continues to expand past the zero force (point B) we might expect some kind of tension force (negative) to build up as in path 3. Reloading of the spring again would cause a force build-up as in Path 4. If the previous maximum compression point A were then exceeded, a new unloading curve would result as in Path 5, parallel to the old one.

TABLE 1. Input File

Line No.	Location In Line	Variable Name and Units	Description	Value
1	1	Y(4), mph	Vehicle Impact Velocity	28.
1	2	Y(6), deg	Head Angle (Θ_H - Fig. 1)	-6.
1	3	Y(7), deg	Torso Angle (Θ_T - Fig. 1)	-24.
2	1	Z_L, lb	Weight of Lower Body (Fig. 8)	71.04
2	2	Z_T, lb	Weight of Torso (Fig. 8)	58.4
2	3	Z_H, lb	Weight of Head (Fig. 8)	11.44
2	4	R_T, in	Distance From H-Point to Torso c.g. (Figure 8)	14.
2	5	R_N, in	Distance From H-Point to Neck Pivot (Figure 8)	20.5
2	6	R_H, in	Distance From Neck Pivot to Head c.g. When $\Theta_H = \Theta_T$ (Figure 8)	4.75
2	7	R_{TOPH}, in	Distance from H-Point to Top of Head When $\Theta_H = \Theta_T$	27.75
3	1	NPN	No. of Points in Neck Torque vs Angle Curve	4
3	2	NKR	No. of Points in Knee Force vs Crush Curve	7
3	3	NV	No. of Points in Vehicle g's vs Time Curve	12
3	4	NSF	No. of Points in Seat Friction vs Displacement Curve	6
3	5	NPG	No. of Points in Gas Flow vs Time Curve	12
3	6	NPC	No. of Points in Column Force vs Crush Curve	12

TABLE 1. Input File ..... Cont'd

Line No.	Location In Line	Variable Name and Units	Description	Value
3	7	NPW	No. of Points in Wheel Force vs Crush Curve	11
3	8	NPWRP	No. of Points in Wheel Torque vs angle (positive) Curve	6
3	9	NPWRN	No. of Points in Wheel Torque vs Angle (negative) Curve	6
3	10	NPCRP	No. of Points in Column Torque (or force, depending on column type) vs Angle (positive) Curve	4
3	11	NPCRN	No. of Points in Column Torque (or force, depending on column type) vs Angle (negative) Curve	4
4	1	SUN, lb/in	Seat Friction Unload Slope	5000.
4	2	SKR, lb/in	Knee Restraint Unload Slope	5000.
5	all	GEN(1,K), msec	Gas Flow Time Points	(Fig. 9)
6	all	GEN(2,K), lb/s	Gas Flow Rate Points	(Fig. 9)
7	all	COL(1,K), in	Column Stroke Points	(Fig. 10)
8	all	COL(2,K), lb	Column Force Points	(Fig. 10)
9	1	ATMOP, psia	Local Atmospheric Pressure	14.7
9	2	PGZ, psig	Initial Airbag Pressure	-14.7
9	3	GTZ, deg R	Gas Temp. Entering Airbag	1660
9	4	U, $\frac{\text{in lb}_f}{\text{lb}_m \text{ deg R}}$	Universal Gas Constant	662

TABLE 1. Input File ..... Cont'd

Line No.	Location In Line	Variable Name and Units	Description	Value
9	5	PN1	Polytropic Gas Exponent, Flow	1.4
9	6	PN2	Polytropic Gas Exponent, Compression	1.4
9	7	PN3	Polytropic Gas Exponent, Expansion	1.4
10	1	THETAW, deg	Wheel Angle Measured From the Vertical	15.25
10	2	RIP, in	Radius of assumed circular Inflator and Airbag Package	2.5
10	3	WWH, lb	Weight of Steering Wheel	3.0
10	4	WIP, lb	Weight of Airbag and Inflator Package	2.0
10	5	RCOL, in	Distance from Column Pivot Point to Center of Mass	15.0
10	6	DCN, $\frac{\text{ft-lb-sec}}{\text{rad}}$	Head/Neck Damping Coeff.	0.69
11	1	VC1	Vent Discharge Coefficient, Subsonic Flow	0.7
11	2	VC2	Vent Discharge Coefficient, Sonic Flow	0.7
11	3	AV, sq. in.	Vent Area	2.07
11	4	SA, in	Airbag Major Axis Length	12.5
11	5	SC, in	Airbag Minor Axis Length	8.0
11	6	X1Z, in	Horizontal Airbag Reference Distance (Figure 5)	30.6
11	7	Y1Z, in	Vertical Airbag Reference Distance (Figure 5)	18.9
12	1	THETAC, deg	Column Angle Measured From Horizontal	15.25
12	2	MU	Coefficient of Friction (Figure 3)	0.0
12	3	LSCZ, in	Column Ref. Dimension to Shear Capsule (Figure 3)	11.0
12	4	LFWZ, in	Column Ref. Dimension to Firewall (Figure 3)	16.5

TABLE 1. Input File ..... Cont'd

Line No.	Location In Line	Variable Name and Units	Description	Value
12	5	LBAZ, in	Column Ref. Dimension to Aft Column Bearing (Fig. 3)	15.0
12	6	LBFZ, in	Column Ref. Dimension to Fwd Column Bearing (Fig. 3)	19.0
12	7	WC, lb	Column Weight	7.0
13	1	LF, in	Femur Length (Figure 1)	18.0
13	2	THFO, deg	Initial Femur Angle (Figure 1)	12.0
13	3	THLO, deg	Initial Tibia Angle (Figure 1)	35.0
14	1	XWH, in	X-Coordinate of Wheel Hub (Pt. "p" in Figure 2)	-6.0
14	2	RIMRAD, in	Radius of Wheel Rim	7.38
14	3	X2Z, in	Horizontal H-Point Ref. Dimension (Figure 5)	34.5
14	4	Y2Z, in	Vertical H-Point Ref. Dimension (Figure 5)	7.4
14	5	WB, in	Width of Torso	11.25
14	6	WH, in	Width of Head	5.0
15	all	SFN(1,k), in	Seat Friction Displacement Points	(Fig. 6)
16	all	SFN(2,k), lb	Seat Friction Force Points	(Fig. 6)
17	all	FNECK(1,k), deg	Head/Torso Relative Angle (Θ_H - Θ_T in Figure 1)	(Fig. 11)
18	all	FNECK(2,k), ft-lb	Neck Rotational Resistance Torque	(Fig. 11)
19	all	VEHGS(1,k), ms	Crash Pulse Time Points	(Fig. 12)
20	all	VEHGS(2,k), g's	Crash Pulse g Points	(Fig. 12)
21	all	KRN(1,k), in	Knee Displacement Points	(Fig. 13)
22	all	KRN(2,k), lb	Knee (femur) Force Points (sum of two knees)	(Fig. 13)
23	all	WHE(1,k), in	Wheel Stroke (crush) Points	(Fig. 14)
24	all	WHE(2,k), lb	Wheel Force Points	(Fig. 14)

TABLE 1. Input File ..... Cont'd

Line No.	Location In Line	Variable Name and Units	Description	Value
25	all	WHRP(1,k), deg	Wheel Rotation Angle Points, Upward With Respect to Column	(Fig. 15)
26	all	WHRP(2,k), in-lb	Wheel Rotation Resistance Points, Upward Rotation	(Fig. 15)
27	all	WHRN(1,k), deg	Wheel Rotation Angle Points, Downward With Respect to Column	(Fig. 15)
28	all	WHRN(2,k), in-lb	Wheel Rotation Resistance Points, Downward Rotation	(Fig 15)
29	all	COLRP(1,k), deg	Column Rotation Angle Points, Upward With Respect to Vehicle	(Fig. 6)
30	all	COLRP(2,k), lb if Type 1 Col., in-lb Otherwise	Column Rotation Resistance Points, Upward Rotation	(Fig. 6)
31	all	COLRN(1,k), deg	Column Rotation Angle Points, Downward With Respect to Vehicle	(Fig. 6)
32	all	COLRN(2,k), lb if Type 1 Col., in-lb Otherwise	Column Rotation Resistance Points, Downward Rotation	(Fig. 6)

LSRL5005   19:13EDT   07/29/82

```
28.,-6.,-24.
71.04,58.4,11.44,14.,20.5,4.75,27.75
4,7,12,6,12,12,11,6,6,4,4
5000.,5000.
0.,17.5,20.5,26.,31.,36.,41.,46.,51.,56.,71.,100.
0.,0.,3.4,4.09,4.26,3.6,2.45,1.63,.98,.49,0.,0.
-10.,0.,.55,.95,1.55,1.6,2.34,2.57,3.05,3.85,4.13,5.7
0.,0.,710.,900.,730.,500.,500.,930.,680.,860.,1100.,1510.
14.7,-14.7,1660.,662.,1.4,1.4,1.4
15.25,2.5,3.,2.,15.,.69
.7,.7,2.07,12.5,8.,30.6,18.9
15.25,0.,11.,16.5,15.,19.,7.
18.,12.,35.
-6.,7.38,34.5,7.4,11.25,5.
-50.,0.,1.,14.,15.,50.
0.,0.,250.,250.,0.,0.
-80.,18.,20.5,90.
115.,0.,-6.7,-86.7
0.,4.,14.,25.,33.,45.,57.,67.,73.,102.,118.,200.
0.,1.,10.,11.2,8.9,13.,22.,15.,17.2,8.6,-.5,-.5
-10.,3.15,3.25,3.58,3.68,4.13,10.
0.,0.,400.,900.,2100.,2500.,2500.
-10.,0.,.23,.5,.91,1.72,1.95,2.56,3.,3.66,6.
0.,0.,1075.,1305.,1165.,945.,990.,990.,1120.,680.,1355.
0.,1.6,4.9,8.9,16.,23.3
0.,3990.,3800.,3400.,3030.,2850.
0.,1.6,4.9,8.9,16.,23.3
0.,3990.,3800.,3400.,3030.,2850.
0.,5.,6.,7.
0.,50.,2000.,2000.
0.,5.,6.,7.
0.,50.,2000.,2000.
```

Figure 6. Listing, Data File LSRL5005

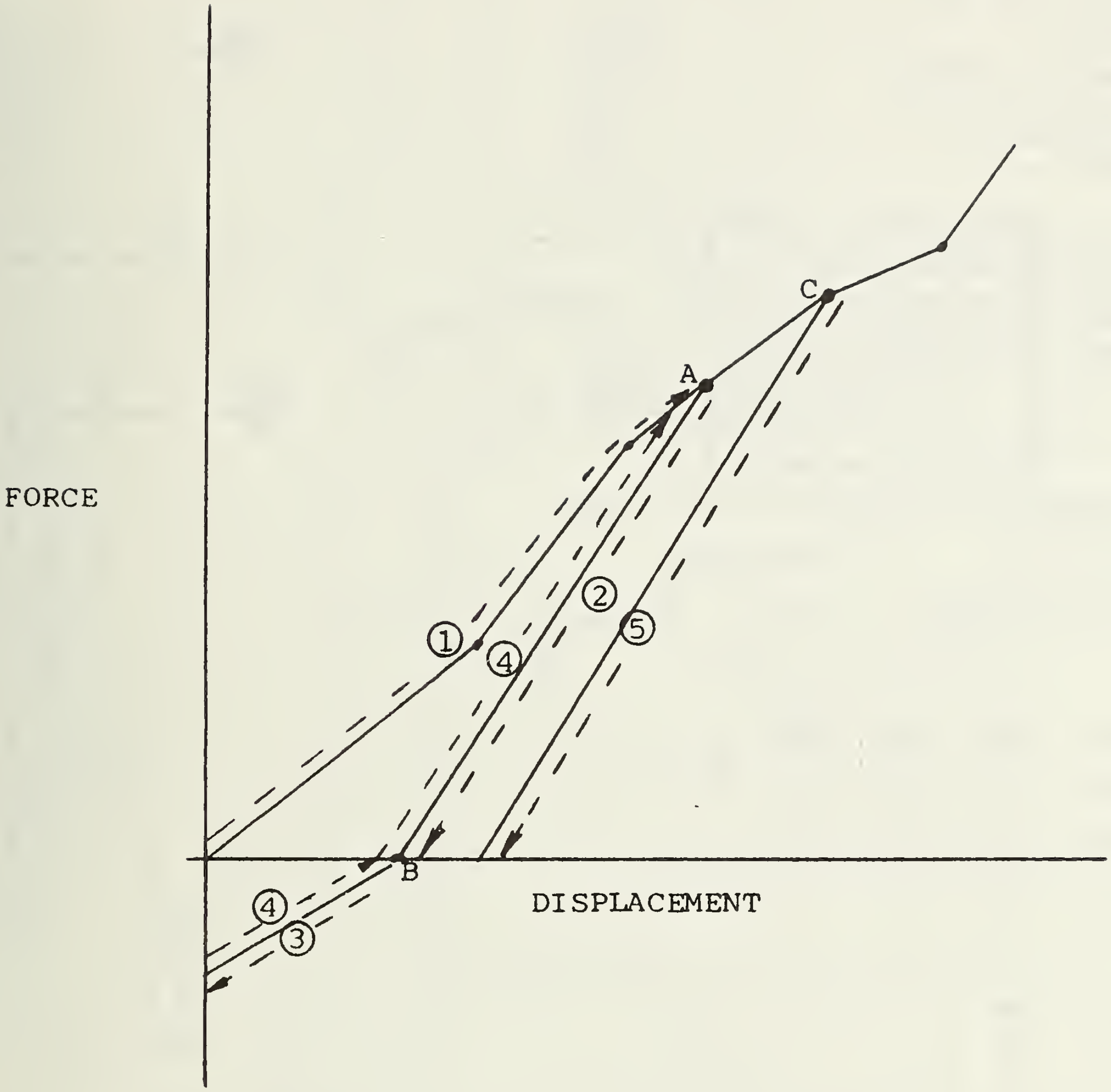


Figure 7. "SPRING" Nomenclature

SEGMENT WEIGHTS (50th % Male)[1]		
1.	Head (incl. Neck)	12.54 lbs
2.	Foot (ea.)	2.66
3.	Lower Leg (ea.)	8.07
4.	Upper Leg (ea.)	12.31
5.	Pelvis	38.35
6.	Thor+Shoul+Abdom	50.58
7.	Upper Arm (ea.)	3.91
8.	Forearm (ea.)	3.00
9.	Hand (ea.)	1.45
	TOT.	164.27 lbs

DRACR/PAC WEIGHTS		
1.	Head (incl. Neck - meas.) ..	11.44 lbs
2.	Torso (6 + 2*7)	58.40
3.	Hip (5 + 2*4 + 3)	71.04
	TOT	140.88 lbs

[1] Recommendations from Crash Test Dummy Task Force.

GEOMETRY DATA

1. $R_T = L_{19} - L_{26} = 14.0"$
2. $R_N = L_9 - L_{26} = 20.5"$
3. $R_{TOPH} = L_{10} - L_{26} - 2 = 27.75"$
4. $L_{FLESH} = L_{30} - L_{29} = 6.0"$
5. $L_F = L_{32} - (L29 + L28) = 18.0"$

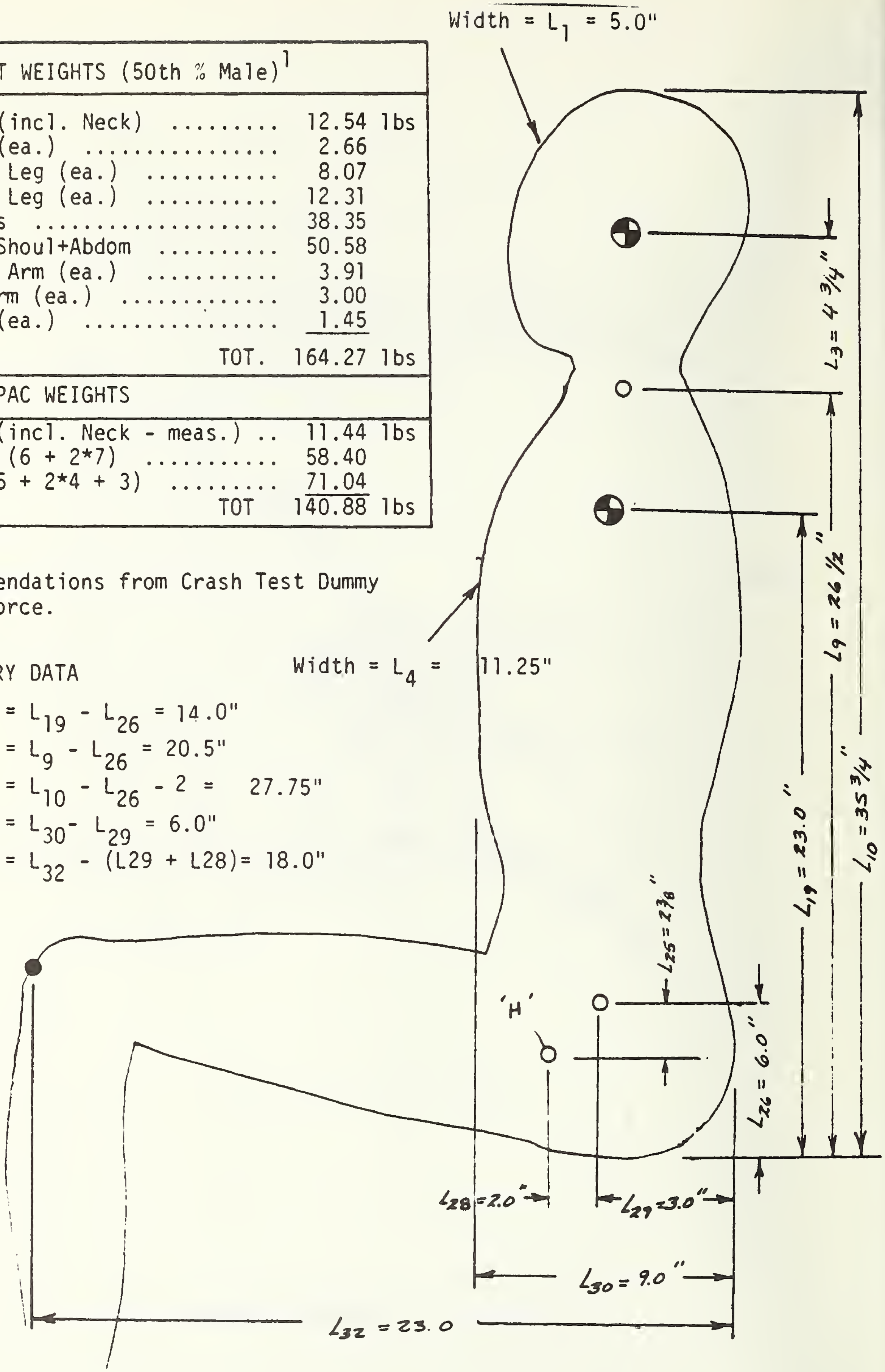


Figure 8. Dummy Measurements

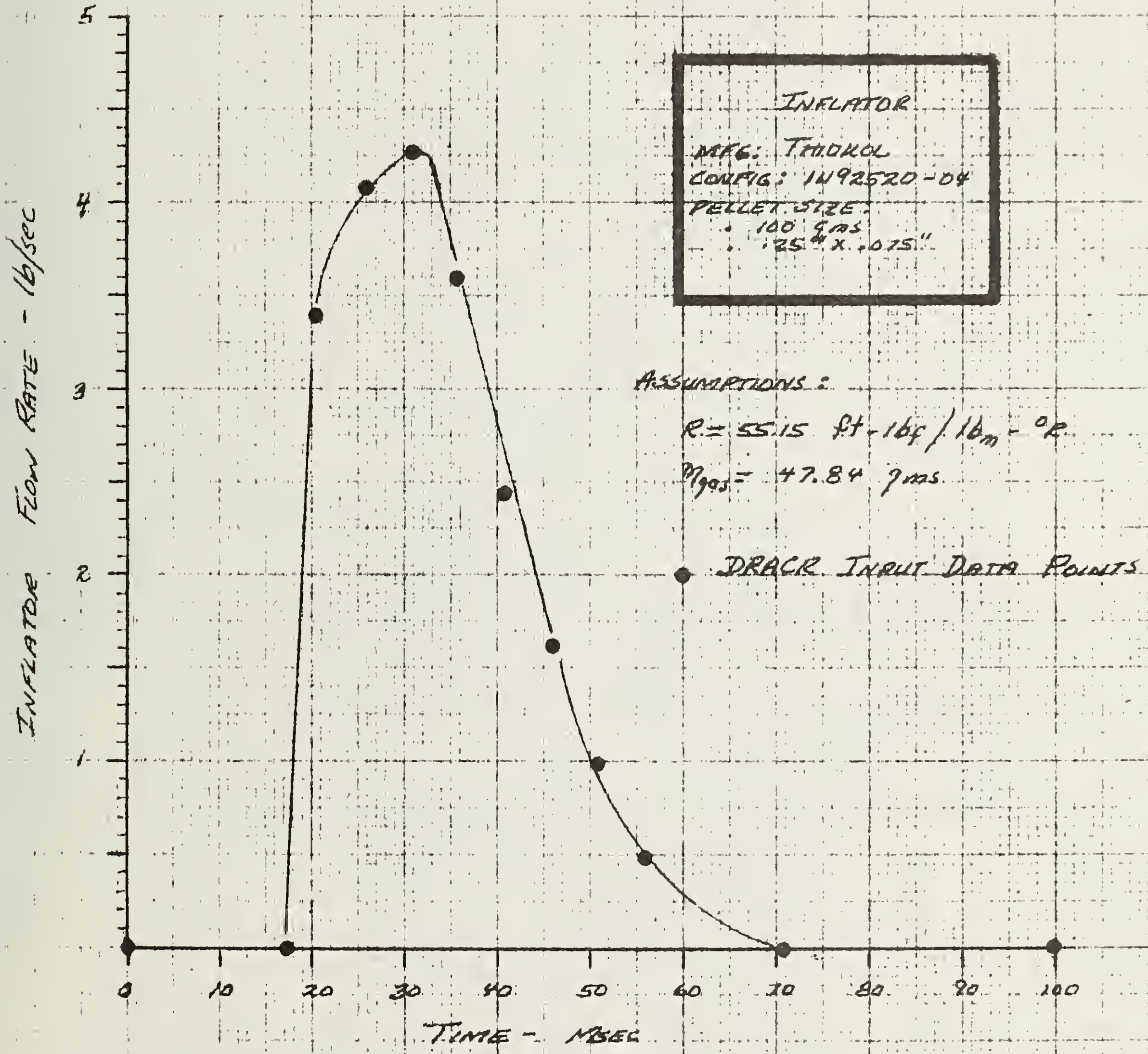


Figure 9. Air Bag Inflator
Mass Flow Rate Characteristics.

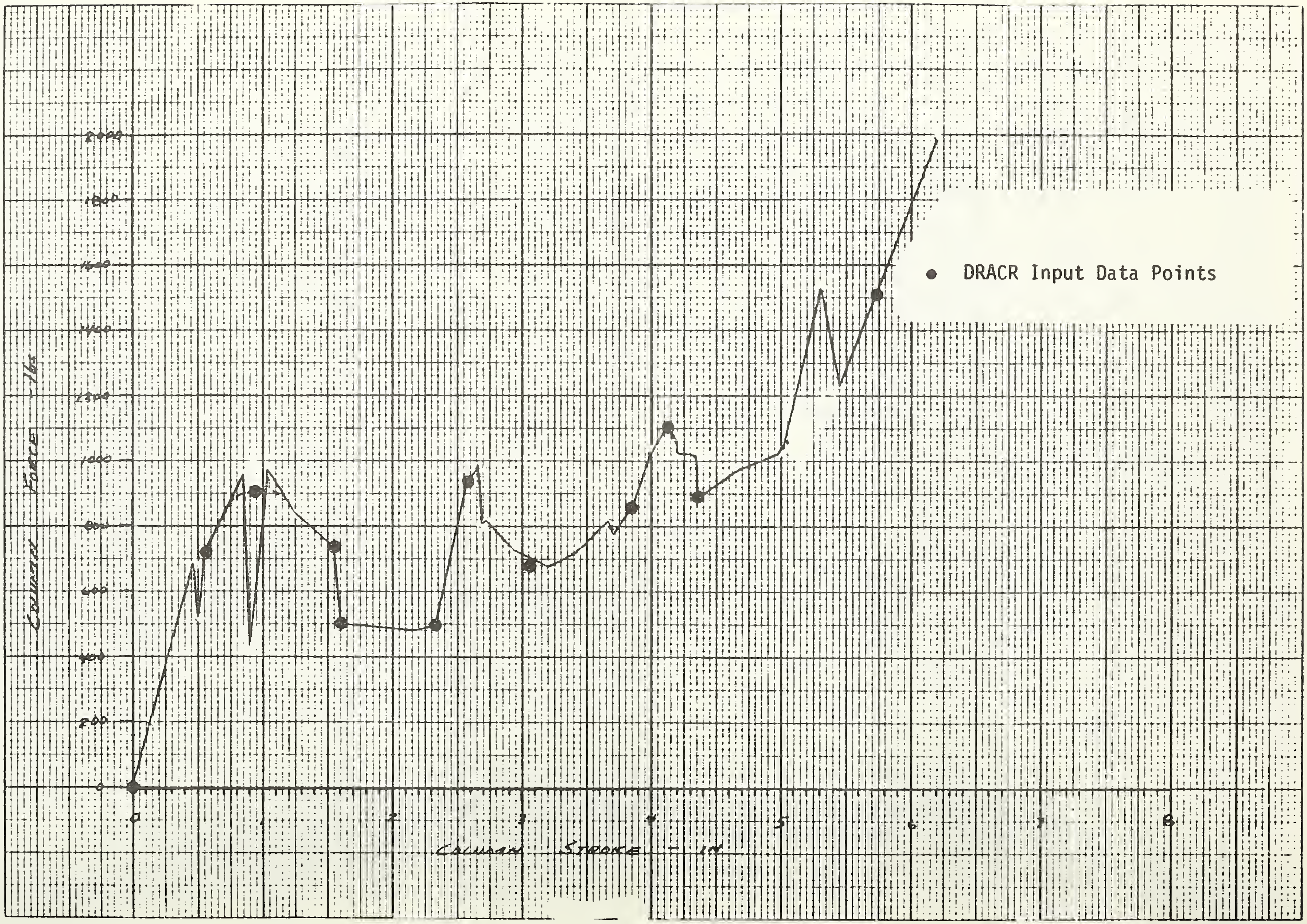


Figure 10. Steering Column Stroking Characteristics, Static - DeLorean Design.

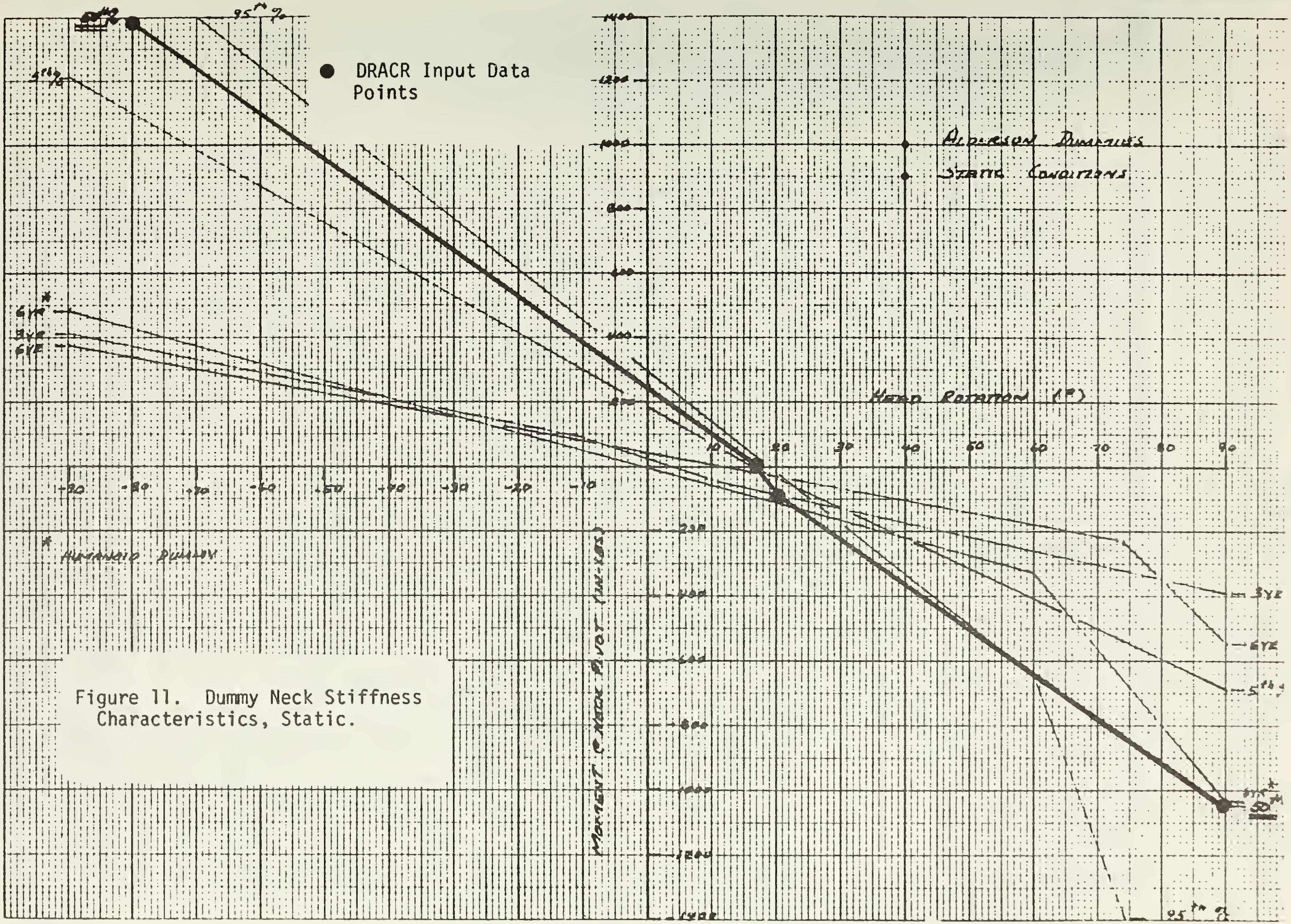


Figure 11. Dummy Neck Stiffness Characteristics, Static.

TRC060IF TRC060 S51055003 82069 14-APR-82 15:49:36
FTUXG FILTER = BLPF 100/ 317/ -40 30.0 MPH
MIN. MAX VALUES = -2.49 @ 157.000. 22.33 @ 57.325

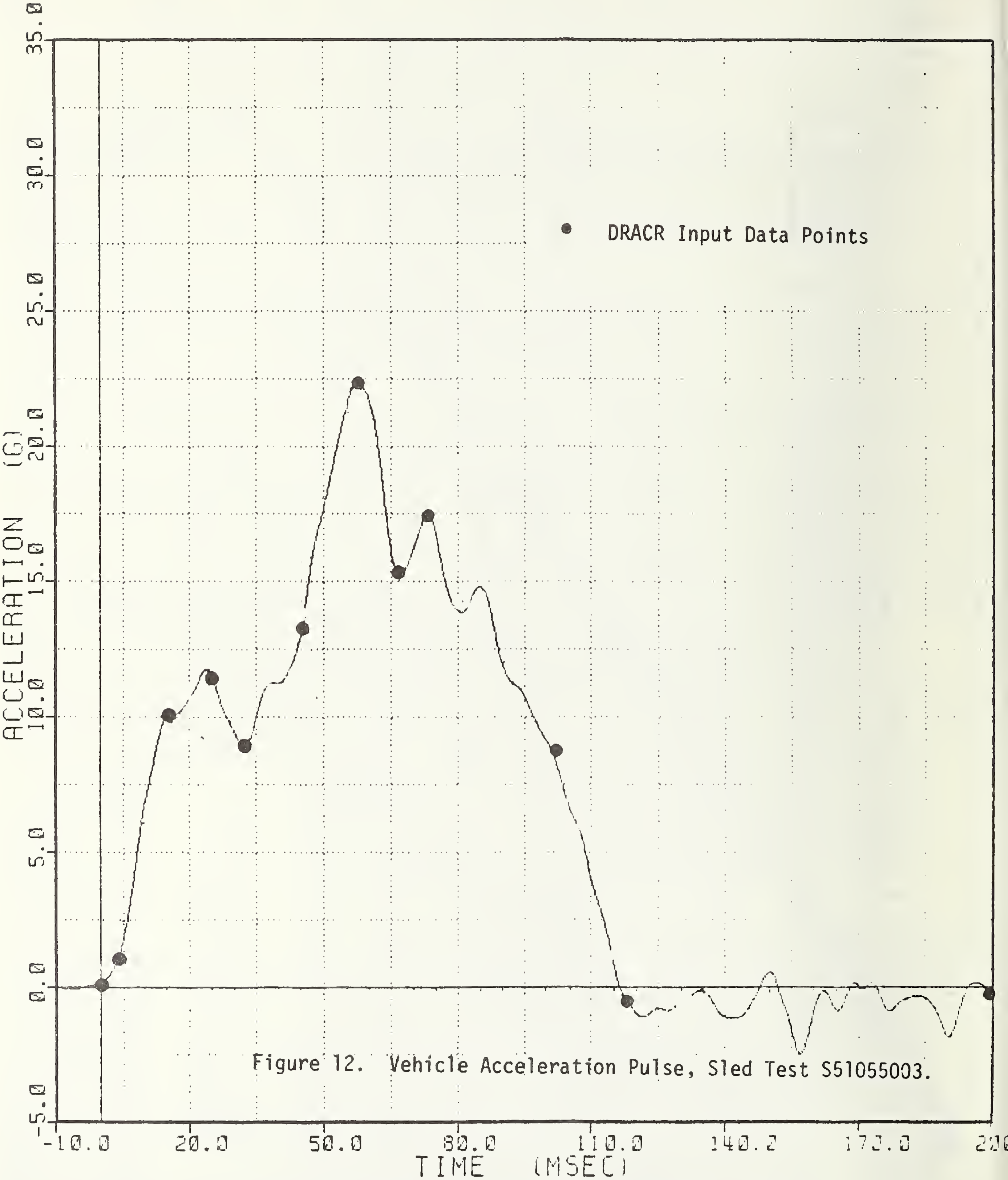


Figure 12. Vehicle Acceleration Pulse, Sled Test S51055003.

S51055003 - FLOORPAN ACC

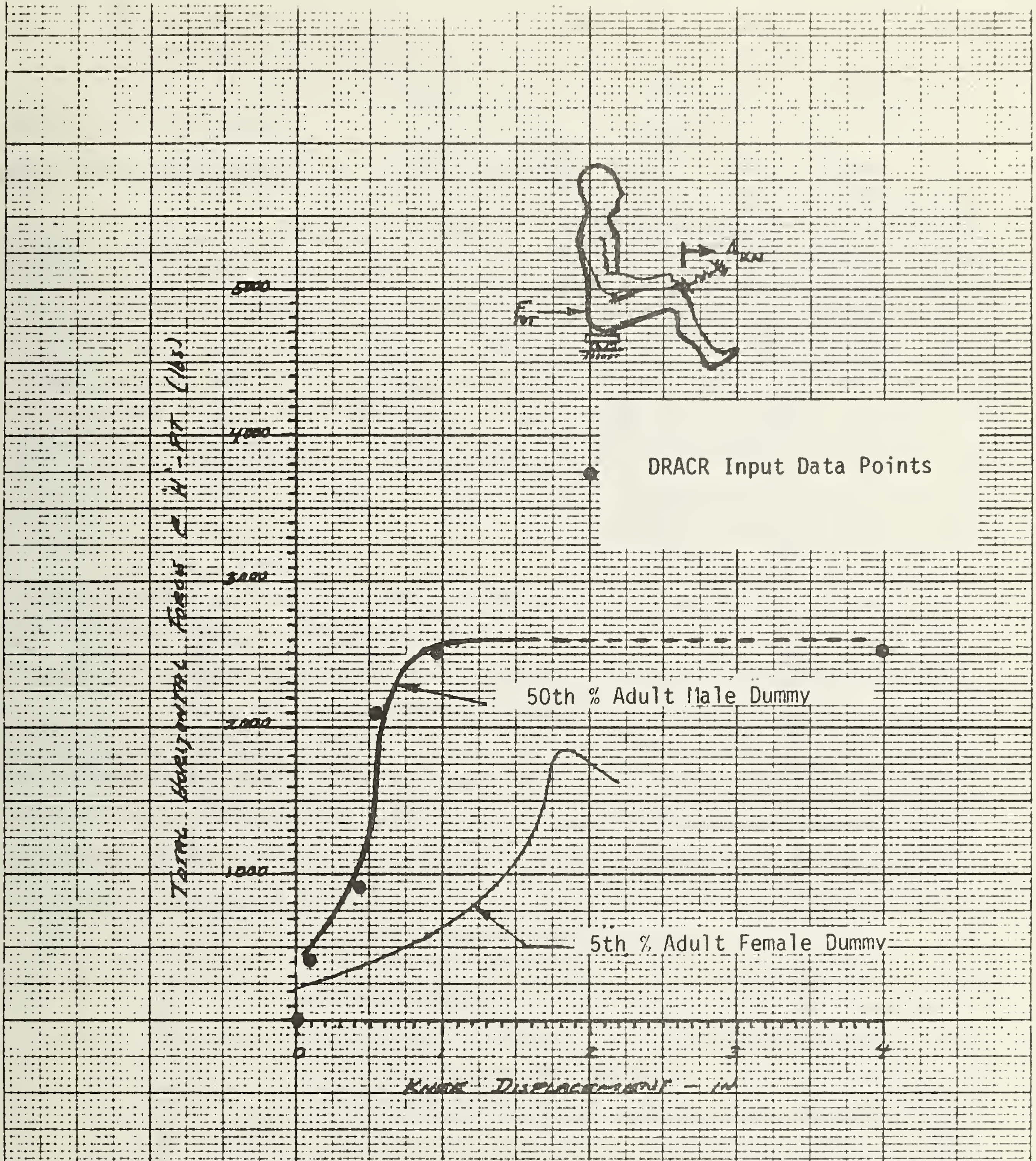


Figure 13. Knee Bolster Force vs Displacement Characteristics.

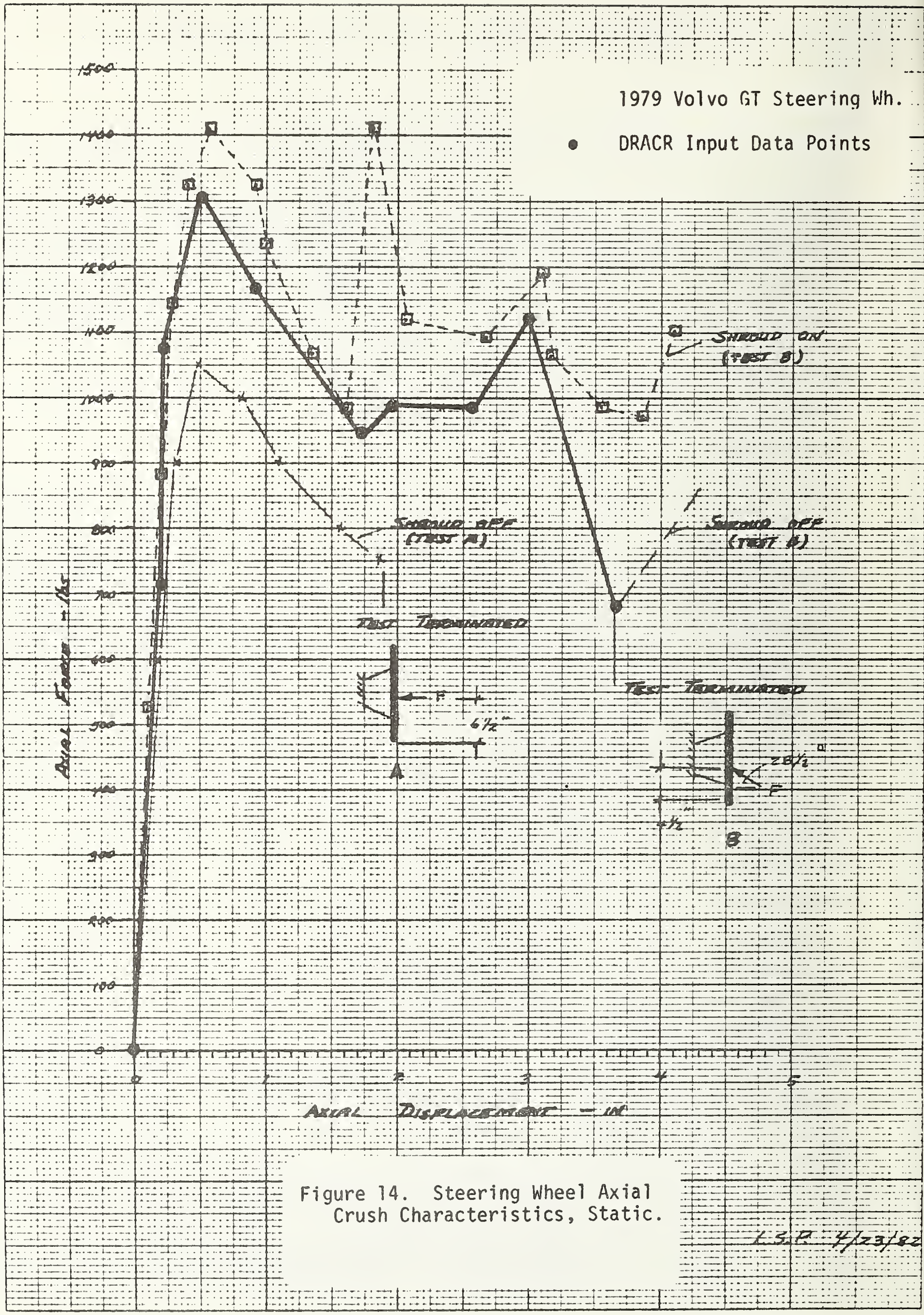


Figure 14. Steering Wheel Axial Crush Characteristics, Static.

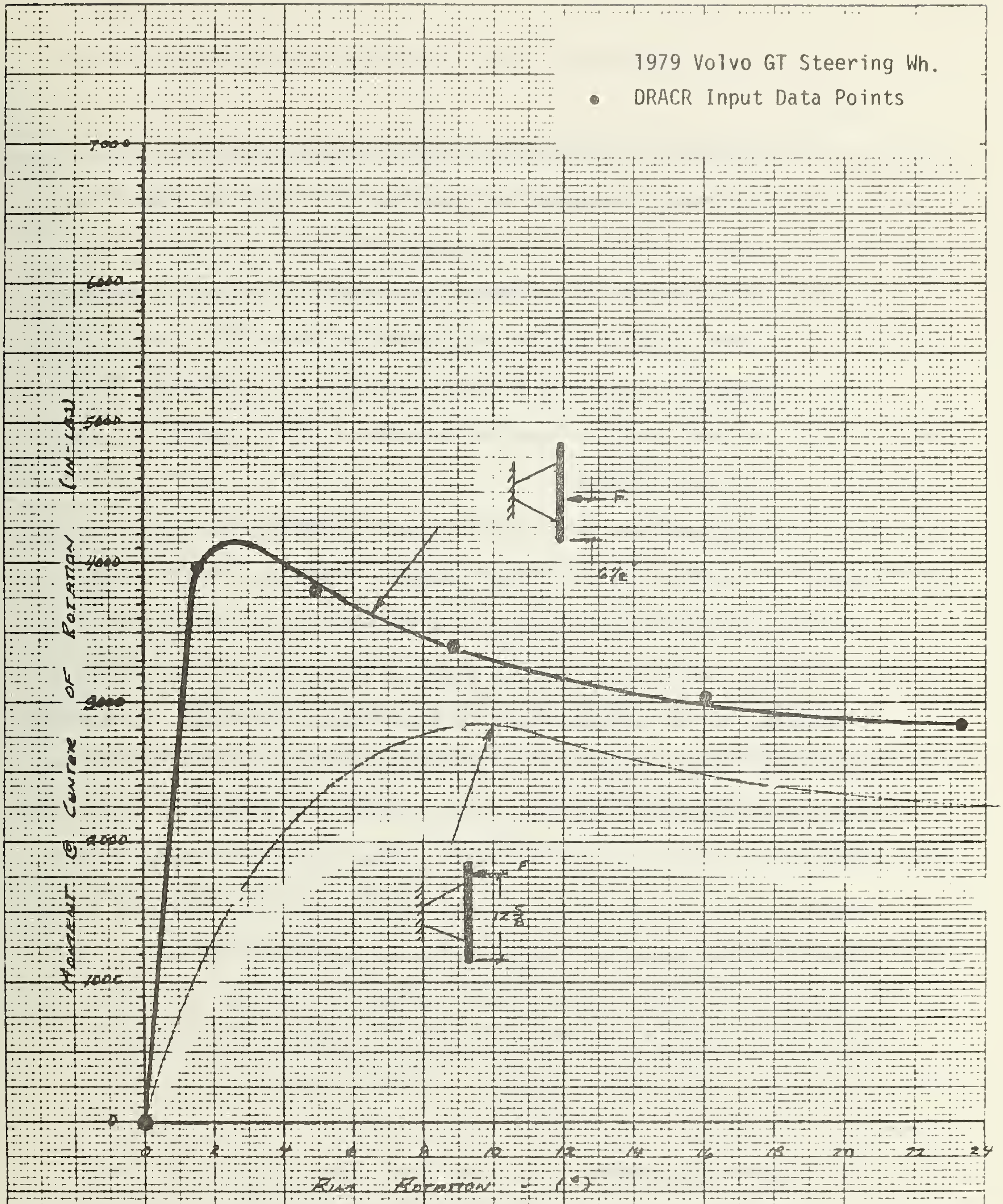


Figure 15. Steering Wheel Rotational Crush Characteristics, Static.

In order to handle this type of situation, certain data is required:

a) We need to know the non-linear spring characteristic for Path 1.

b) We need to know what the slope of the unloading curve is in paths 2 and 5.

c) If we want to allow the deforming member to develop negative forces when it unloads past the zero force point, we need to know what the slope of that portion of the unloading curve is in Path 3 (Note: based on experience, this slope is set equal to zero in DRACR).

Three subroutines have been included in DRACR to model this plastic behavior. The subroutine "SPRING" models a piecewise-linear force vs deflection characteristic stored in a two-dimensional array called "F". SPRING also requires the maximum previous displacement, the current displacement, the two unload slopes, and the number of points in the array F. With these data, SPRING calls a second subroutine "LOOKUP" which uses the array information and the current spring displacement to calculate a force as if the spring were loading up along the initial force vs deflection curve. SPRING then uses its built in logic to determine the path upon which the member is loading by comparing the current and the previous maximum member displacements and then calculating the correct force value. The previous maximum member displacement is kept current in a third subroutine called "UPDATE".

3.2 RUNNING THE PROGRAM

Once the input file has been created and saved, as shown in Figure 6, we are ready to run DRACR. At this point the user accesses DRACR and tells the computer to execute the program. The computer will respond by asking the user to name the input file; in the subject case we respond with "LSRL-

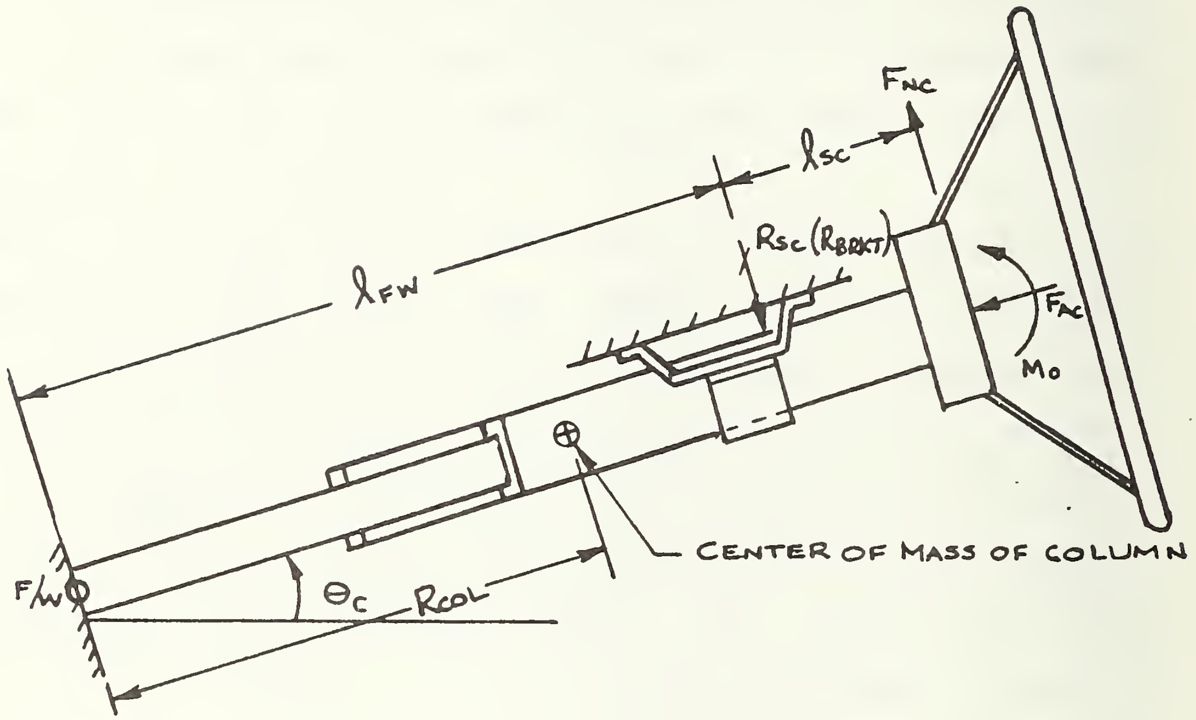
5005", as shown in Appendix E of this manual. The computer will then ask the user to type "1" if the steering column is supported at the firewall (as are most conventional columns), or "2" if the column is not (as is the case with some of the newer vehicles such as the GM X-Body cars and the Chrysler front wheel drive cars such as the OMNI and Horizon where the column is supported further aft by the A-post and plenum respectively).

Figure 16 shows a Type 1 column while Figure 17 shows a Type 2 column. If the user is simulating a Type 1 column, the support bracket strength at the shear capsule location is specified in Line Nos. 30 and 32 of the input file (Table 1) in units of pounds. Thus, for this case the applied moments are reacted by a couple between the firewall and the shear capsule. If, however, the user is simulating a Type 2 column where no firewall reaction exists, the support bracket strength is specified in inch-pounds. This is because all of the applied moment to the column is assumed to be reacted by this single bracket. Again, Line Nos. 30 and 32 are where this bracket strength is specified in the input file for the angular displacement values specified in Line Nos. 29 and 31.

Once these answers are given by the user, the computer will begin to print the input data followed immediately by the desired output. Let us now discuss this output. Altogether, there are eleven blocks of output data, each block consisting of the amount of output that can be conveniently grouped together (in terms of subject matter) on a single line. The contents of each block will now be described. Appendix E contains the actual output for the sample run.

Block 1 is basically a summary of some of the main parameters of interest and consists of the following items as we proceed left-to-right across the

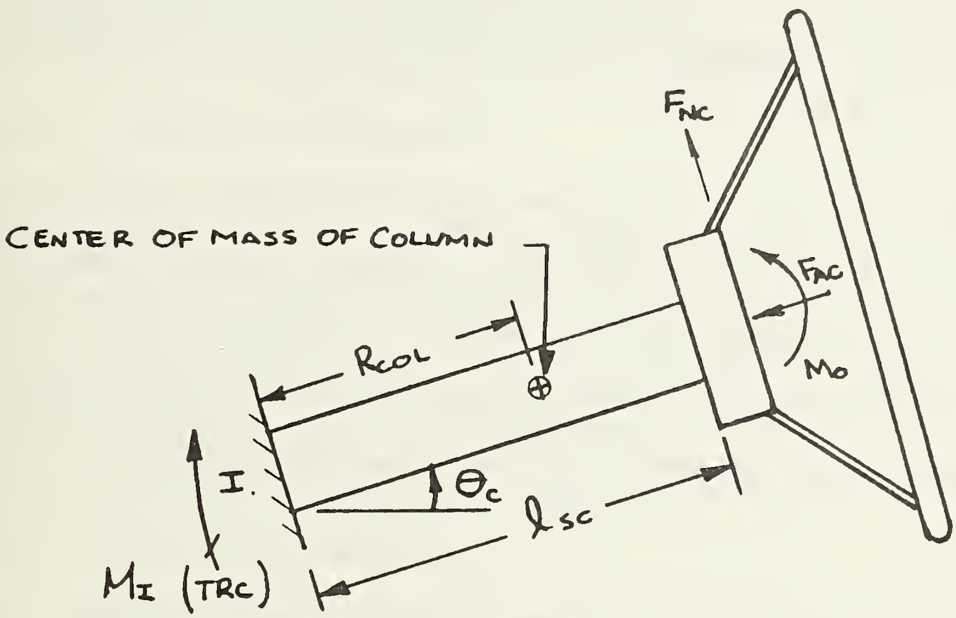
TYPE "1" STEERING COLUMN



Column Supported at the Firewall and some Intermediate Point.

Figure 16. Type "1" Steering Column Configuration.

TYPE "2" STEERING COLUMN



Column Supported Entirely at some One Point.

Figure 17. Type "2" Steering Column Configuration

page: Elapsed Time, Vehicle G's, Vehicle Velocity, Vehicle Displacement (crush), Body G's (chest A-P g's), Column Displacement (stroke), and Air-bag Pressure.

Block 2 Contains: Elapsed Time, Femur Angle (from horizontal, positive up), H-Point Velocity (with respect to ground), H-Point Acceleration, Femur Force (per femur), Seat Friction Force, H-Point Displacement Relative to the compartment.

Block 3 contains: Elapsed Time, Torso Displacement (horizontal with respect to ground), Torso Angle (Θ_T in Figure 1, positive when toward the dash), Torso Angular Velocity (positive toward the dash), Torso Angular Acceleration (positive toward the dash), Torso Horizontal Displacement Relative to Compartment, Torso Horizontal Velocity Relative to Compartment.

Block 4 contains: Elapsed Time, Head Displacement (horizontal with respect to ground), Head Angle (Θ_H in Figure 1, positive toward dash), Head Angular Velocity (positive toward dash), Head Angular Acceleration (positive toward dash), Head Horizontal Displacement Relative to Compartment, Head Angle Relative to Torso.

Block 5 contains: Elapsed Time, Axial Force Applied to Steering Wheel, Normal Force Applied to Steering Wheel, Bending Moment Applied to Steering Wheel (positive when in a direction that would rotate top of wheel toward windshield), Steering Wheel Resistance to Crush (in axial direction), Steering Wheel Crush, Steering Wheel Crushing Velocity (in axial direction, Relative to compartment).

Block 6 contains: Elapsed Time, Axial Force Applied to Steering Column, Normal Force Applied to Steering Column, Bending Moment Applied to Steering Column (positive when in a direction that would rotate column upward toward windshield), Steering Column Resistance to Stroke (in axial direction), Steering Column Stoke, Steering Column Stroking Velocity (in axial direction, relative to compartment).

Block 7 contains: Elapsed Time, Bending Moment Applied to Steering Wheel (positive when in a direction that would rotate top of wheel toward windshield), Torsional Resistance to Steering Wheel Rotation (same sign convention), Steering Wheel Angle (measured from vertical, positive when toward the windshield), Steering Wheel Angular Velocity (positive when top of wheel moving toward windshield).

Block 8 contains: Elapsed Time, Rotational Torque Applied to Steering Column about Column Pivot Point (positive when it would cause an upward rotation of the column), Rotational Resistance to Steering Column Rotation (same sign convention), Steering Column Angle (measured from horizontal, positive when column tilted upward), Steering Column Angular Velocity (positive when column rotating upward).

Block 9 contains: Elapsed Time, Airbag Penetration (measured normal to the torso, halfway between the two bag intercept points), Airbag Volume, Airbag Pressure, Airbag Wraparound (fabric tension) Force (applied to the chest), and Airbag Pressure Force (applied to the chest).

Block 10 contains: Elapsed Time, Chest A-P Acceleration, Chest S-I Acceleration, Head A-P Acceleration, Head S-I Acceleration.

Block 11 contains: Energy Absorbed if Steering Wheel Crush Occurs, Energy Absorbed if Steering Column Crush (stroke) Occurs, Energy Absorbed if Steering Wheel Rotation Occurs, Energy Absorbed if Steering Column Rotation Occurs, Energy Actually Absorbed for the mode that did occur.

After all of the above listed output data has been printed, the computer will ask the user to type "1" if he wishes the value for HIC to be computed. Typing "1" will cause the computer to proceed and calculate the value for HIC. Typing any other value or typing a carriage return will cause the computation to cease without computation of the value for HIC.

This completes the presentation of the information needed to use the DRACR program.

3.3 CORRELATION OF DRACR RESULTS WITH TEST DATA

This section compares the DRACR results, for input File LSRL5005 (Figure 6) with actual sled impact test data. Data File LSRL5005 represents the vehicle, restraint and dummy data for sled test No. S51055003, which was conducted as part of Contract No. DTNH22-82-C-07132.[1] This test was conducted at 30 mph with a 50th percentile adult male ATD driver.

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[1] Ibid., page 19.

Some of the data in File LSRL5005 are based on static test data obtained under Contract No. DTNH22-82-P-07224, "Sled Testing and Data Collection at NHTSA-SRL, Ohio". The data from these tests include:

- o Steering Wheel Static Crush Characteristics - Axial (Figure 14).
- o Steering Wheel Static Crush Characteristics - Rotational (Figure 15).
- o Steering Column Crush Characteristics - Axial (Figure 10).
- o Knee Bolster Crush Characteristics (Figure 13).
- o Dummy Measurements (Figure 8)
- o Dummy Neck Stiffness - Static (Figure 11).

Other data in File LSRL5005 were obtained from the actual sled impact test. These data include:

- o Vehicle Acceleration History (Figure 12).
- o Dummy Pre-test Measurement (Figure 18).
- o Impact Speed.

One point that is worth noting here is that in making the DRACR simulation no attempt was made to "fine-tune" the input data to achieve a better correlation with the test data. We simply used the available data without any modifications. The differences that resulted between the DRACR predictions and test results are discussed below. Figures 19 thru 27 compare the DRACR predictions with the test results. Table 2 summarizes the DRACR vs test results.

The differences between the DRACR predictions and the test results, as summarized in Figures 19 thru 27, have been attributed to the following

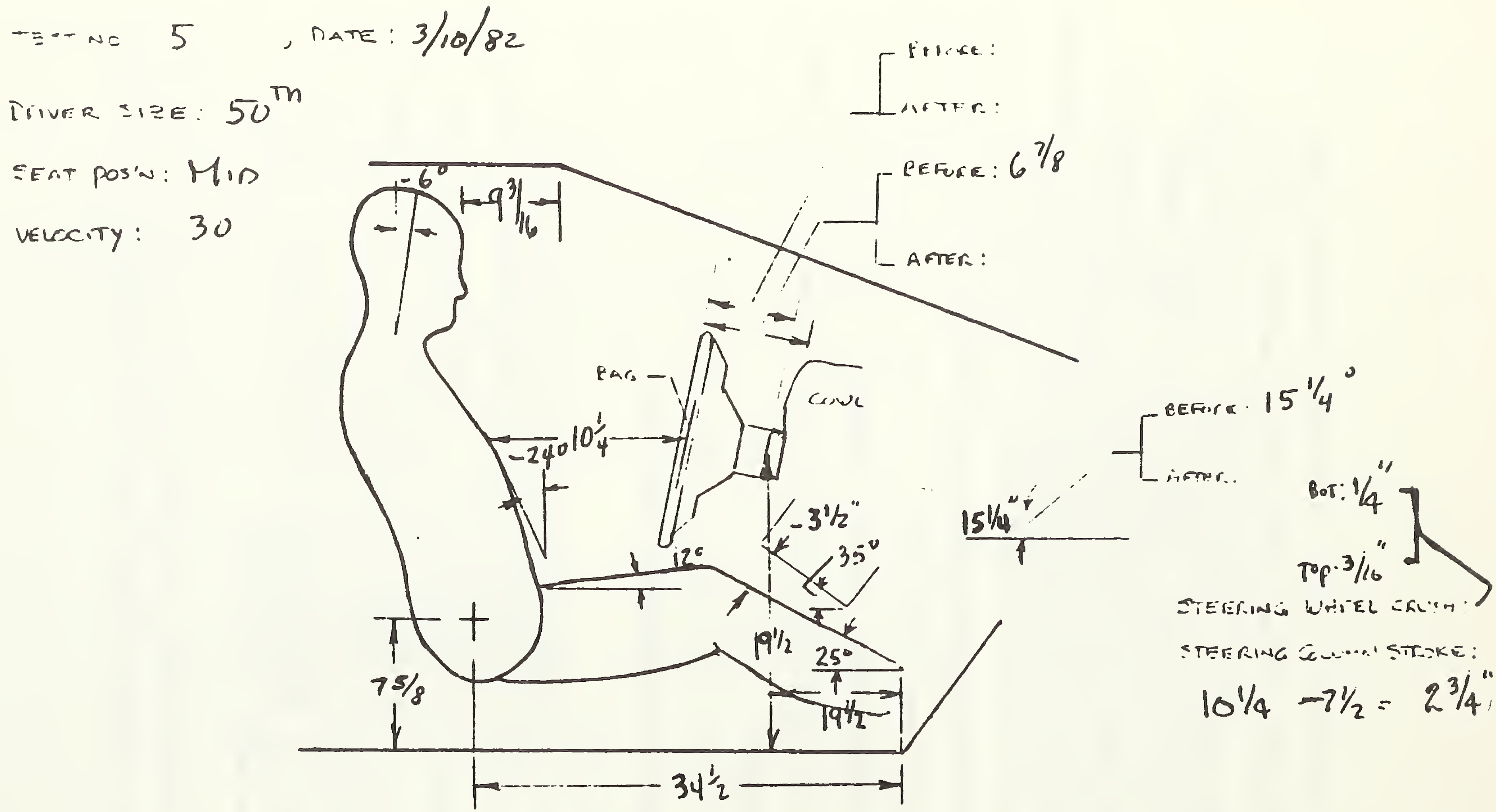

Figure 18. Pre-test Measurements, Test #5.

TRC060IF   TRC060   S51055003   82069   14-APR-82 15:49:36
ABP1   FILTER = BLPP   300/ 950/ -40   30.0 MPH
MIN, MAX VALUES =   -1.51 @ 23.750,   37.66 @ 20.250

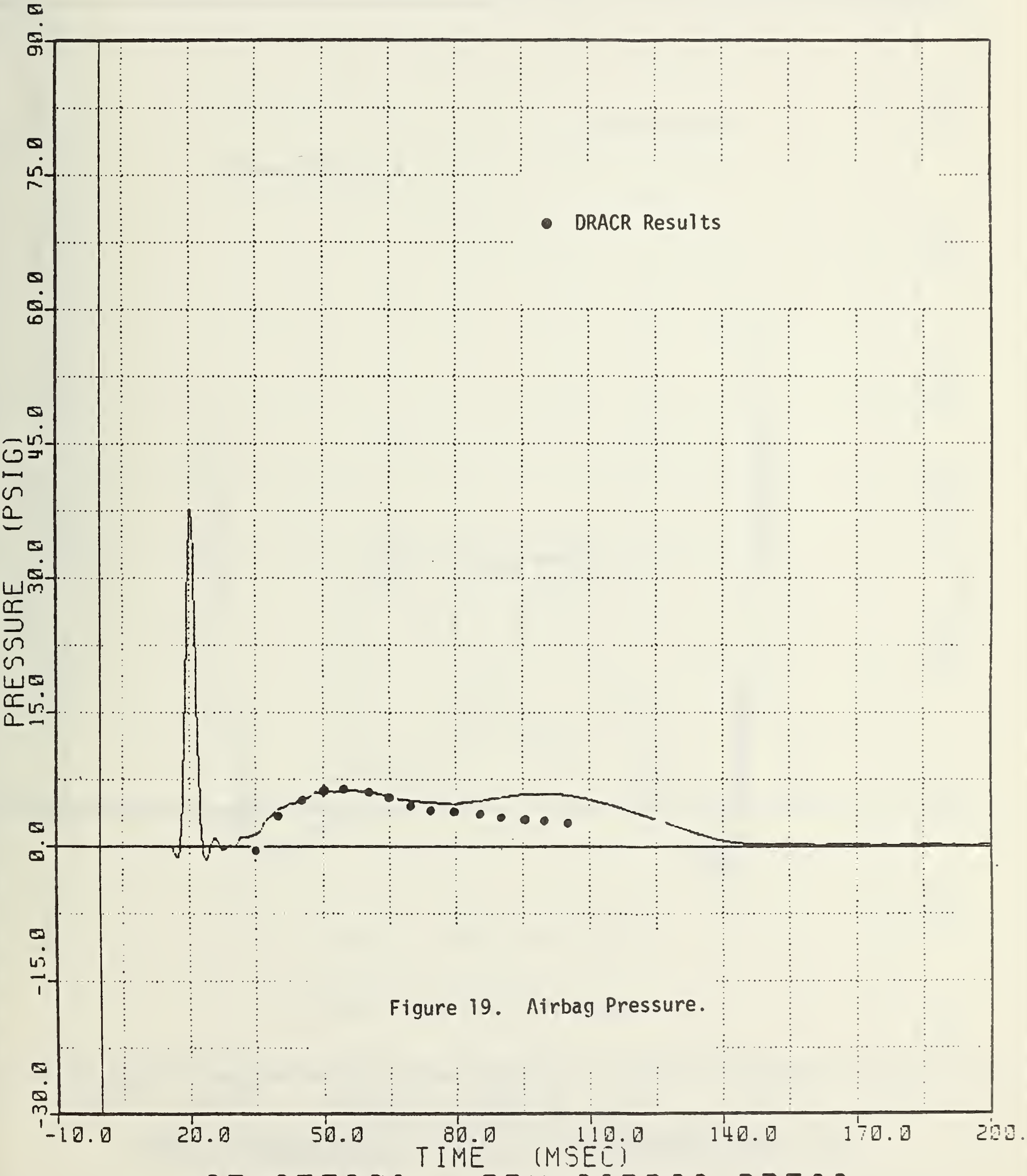

Figure 19. Airbag Pressure.

S51055003 - DRV AIRBAG PRESS

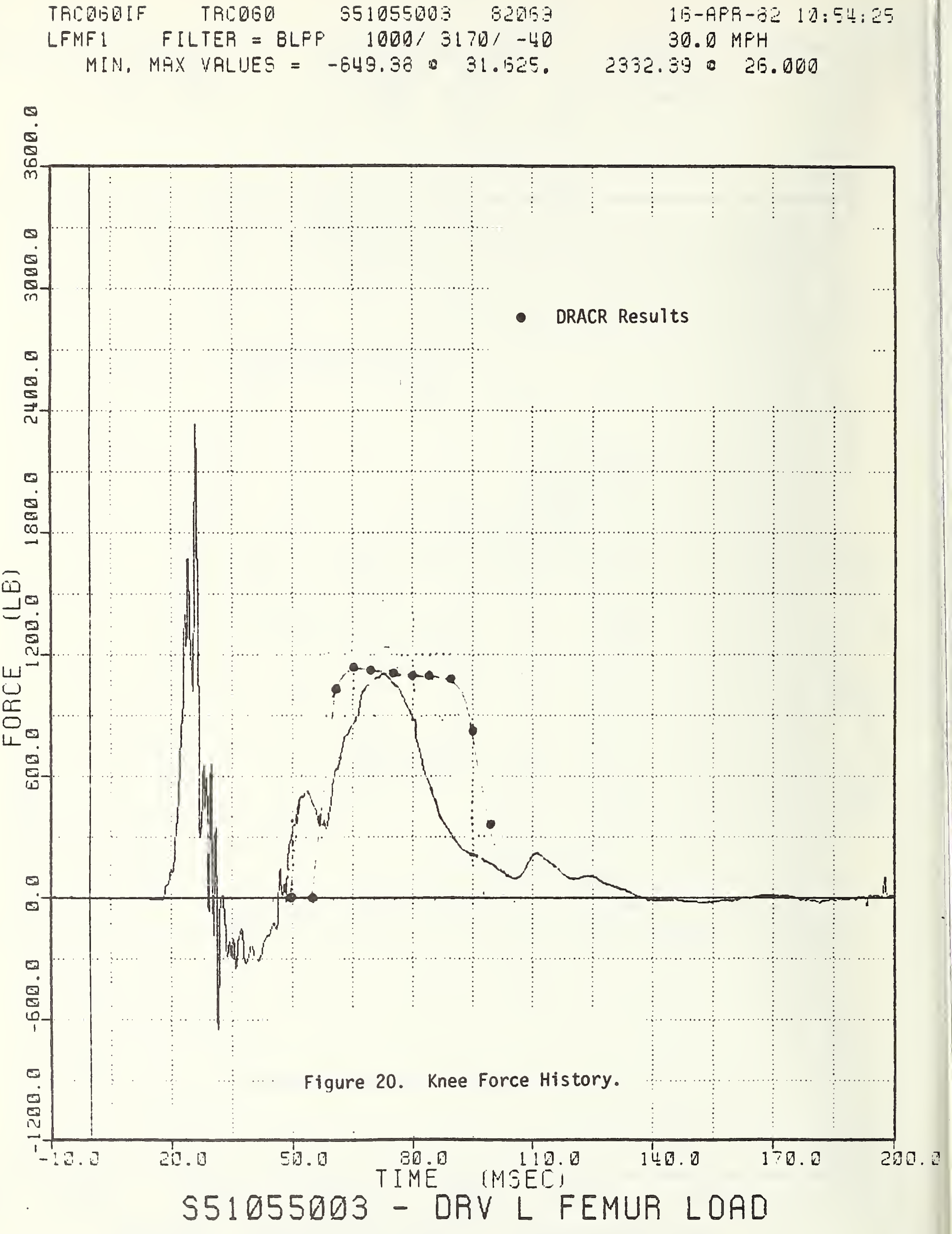

Figure 20. Knee Force History.

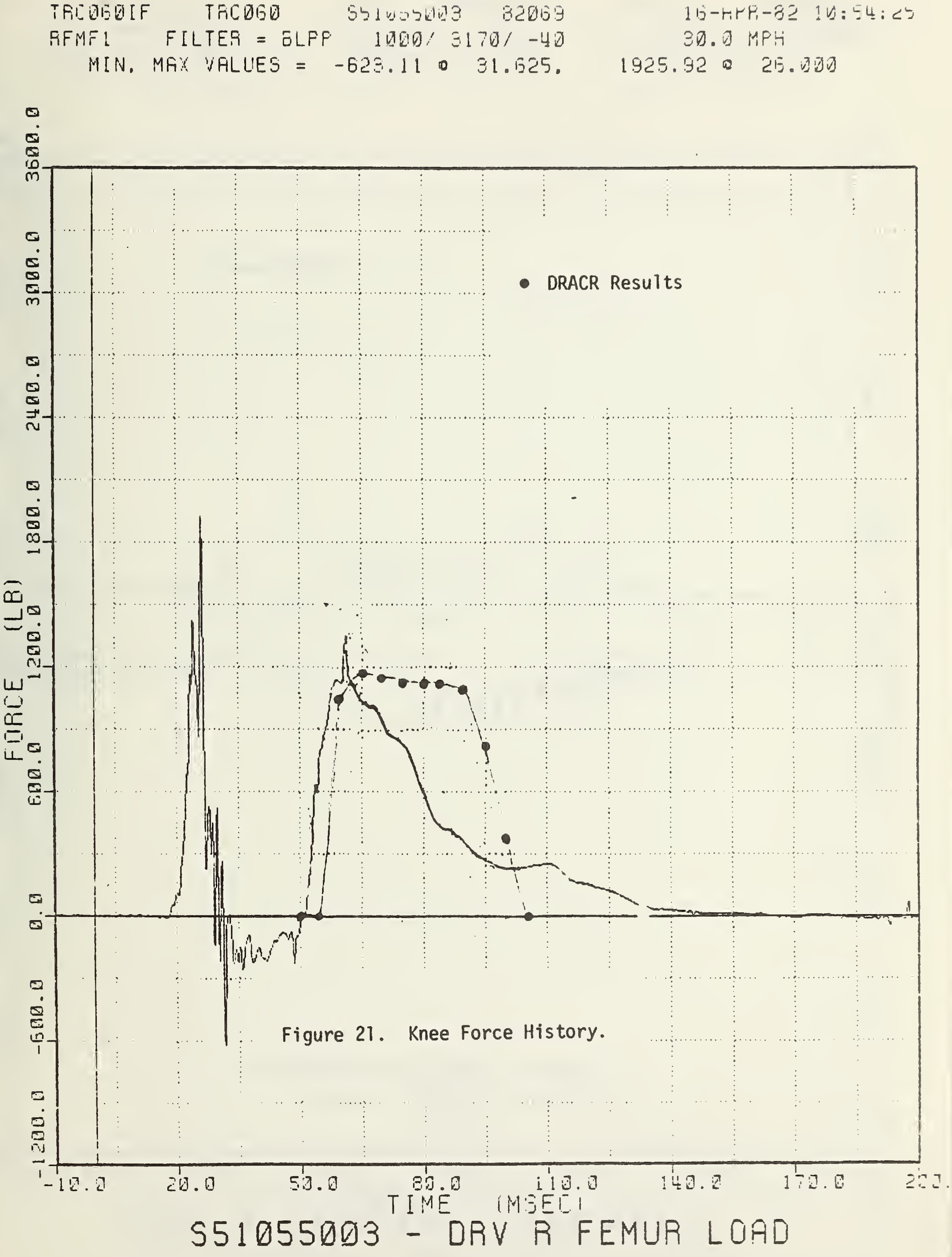

Figure 21. Knee Force History.

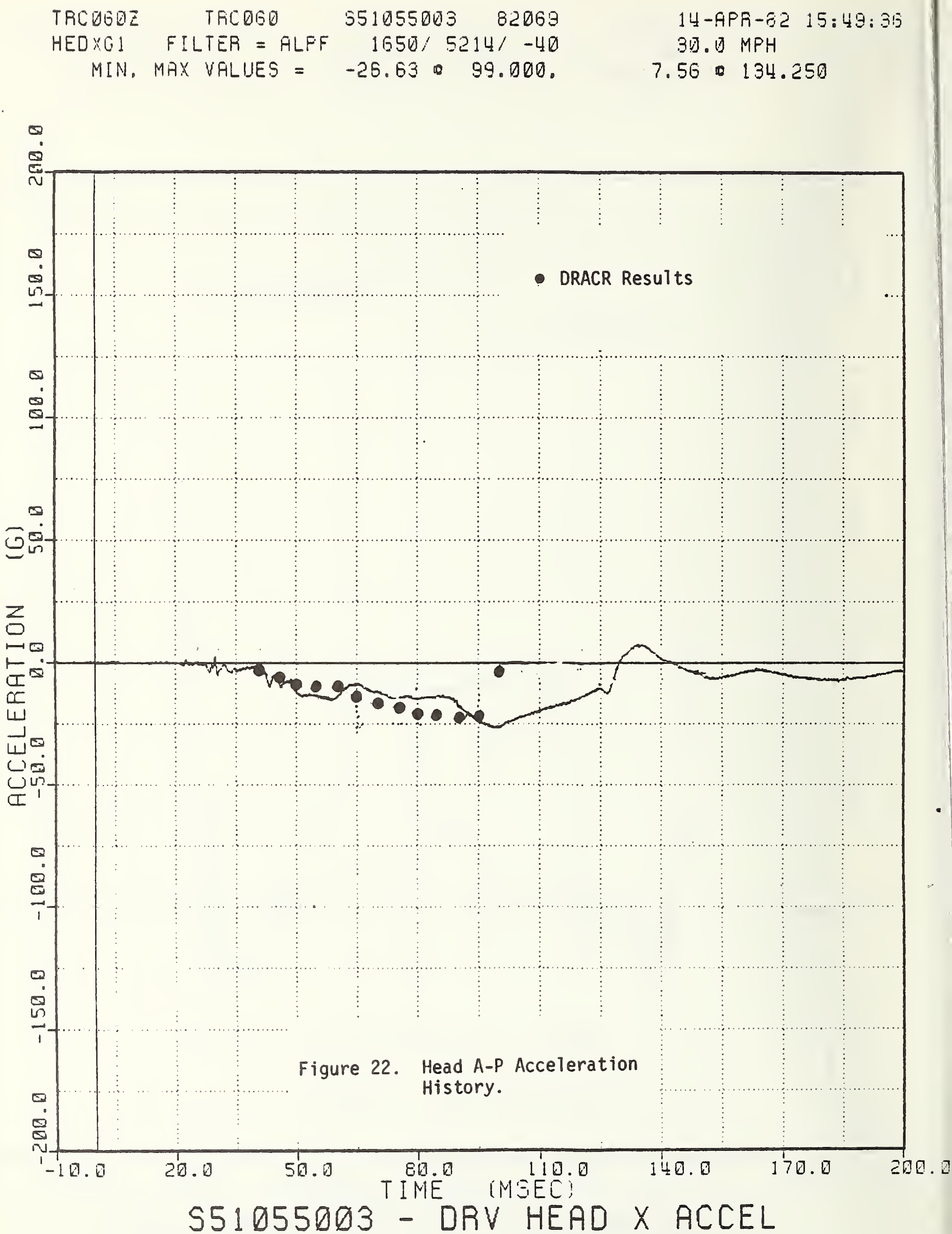

Figure 22. Head A-P Acceleration History.

TRC060Z TRC060 S51055003 82069 14-APR-82 15:49:36
HEDZG1 FILTER = ALPF 1650/ 5214/ -40 30.0 MPH
MIN, MAX VALUES = -29.01 @ 127.375, 13.21 @ 113.375

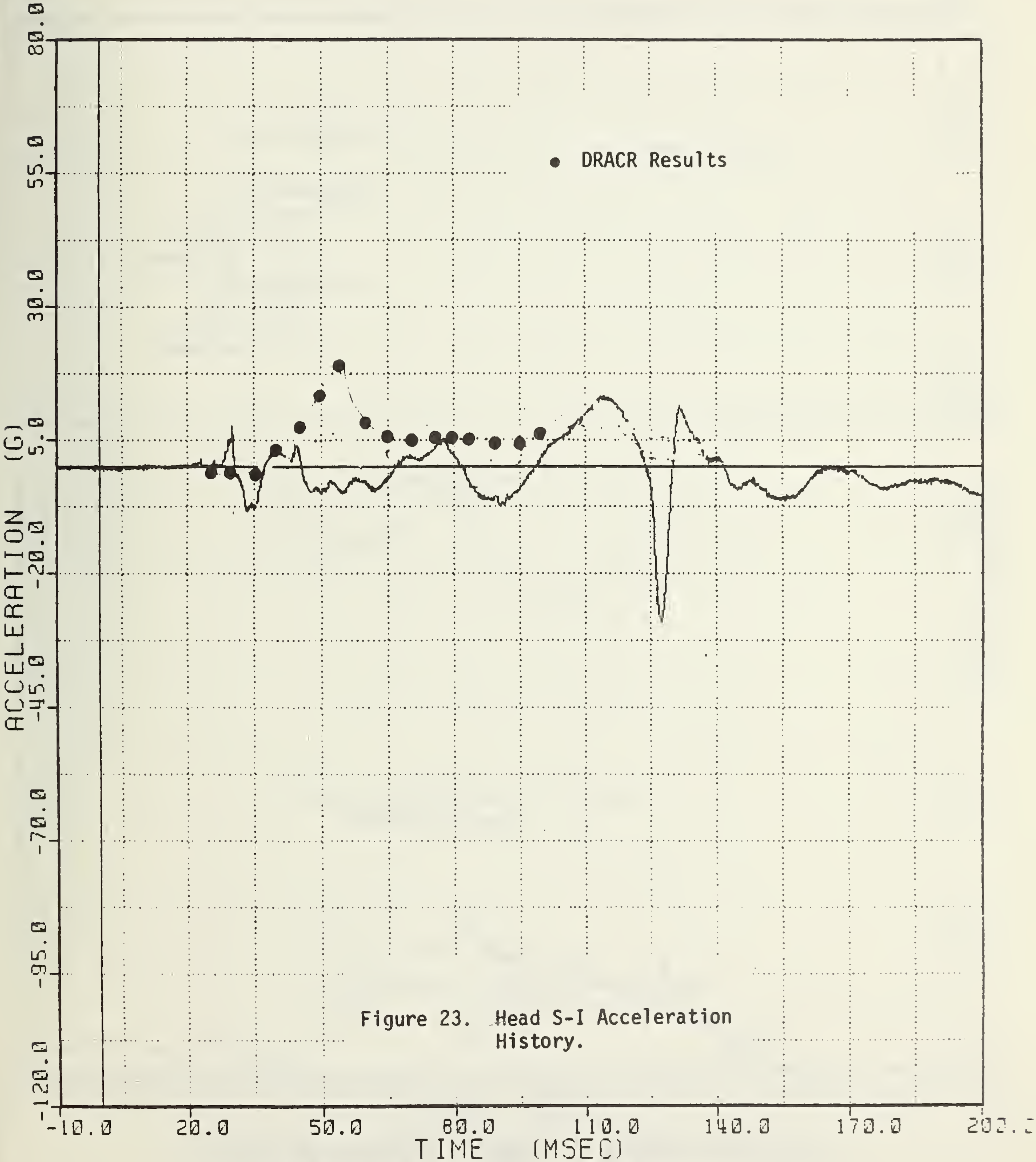

Figure 23. Head S-I Acceleration History.

S51055003 - DRV HEAD Z ACCEL

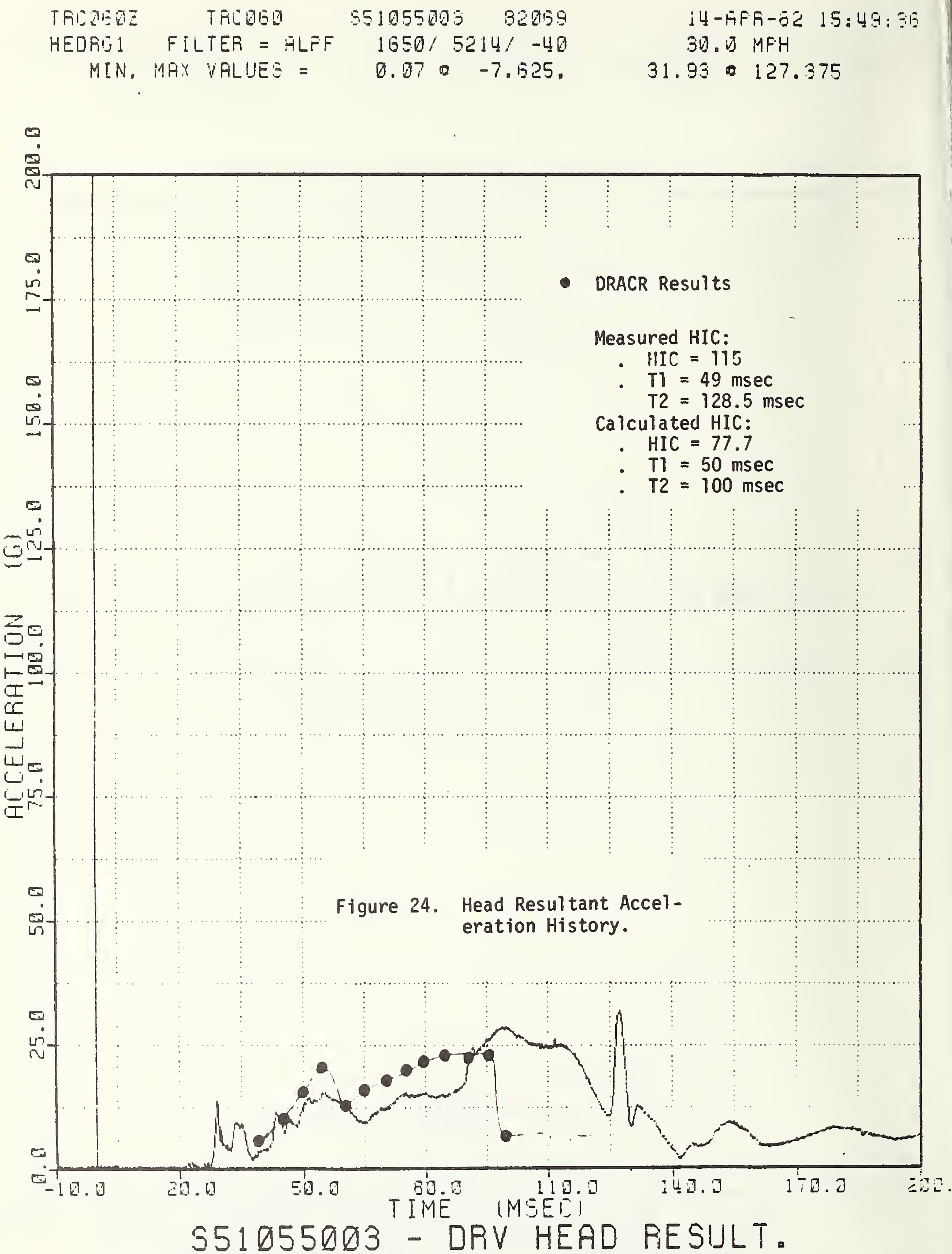

Figure 24. Head Resultant Acceleration History.

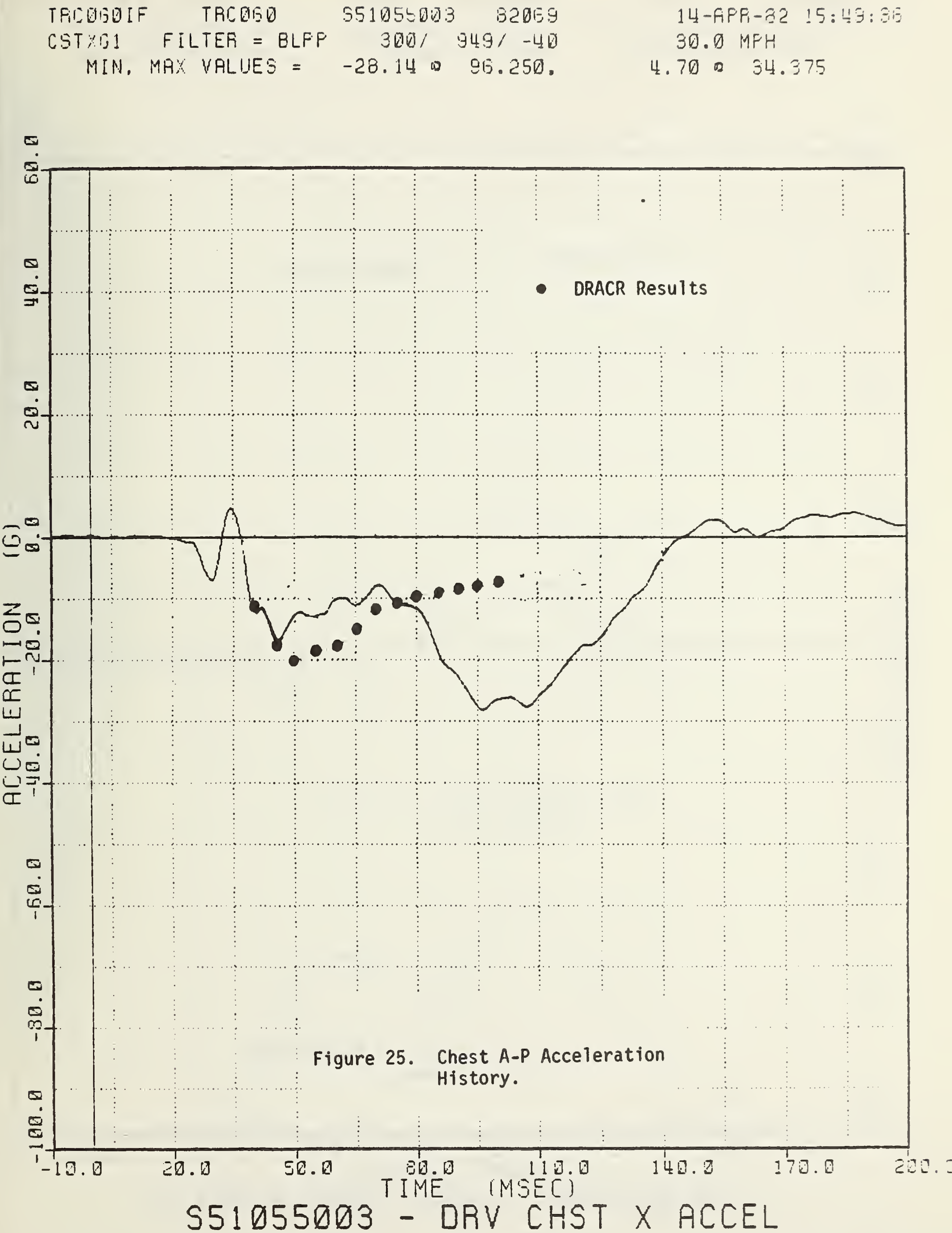

Figure 25. Chest A-P Acceleration History.

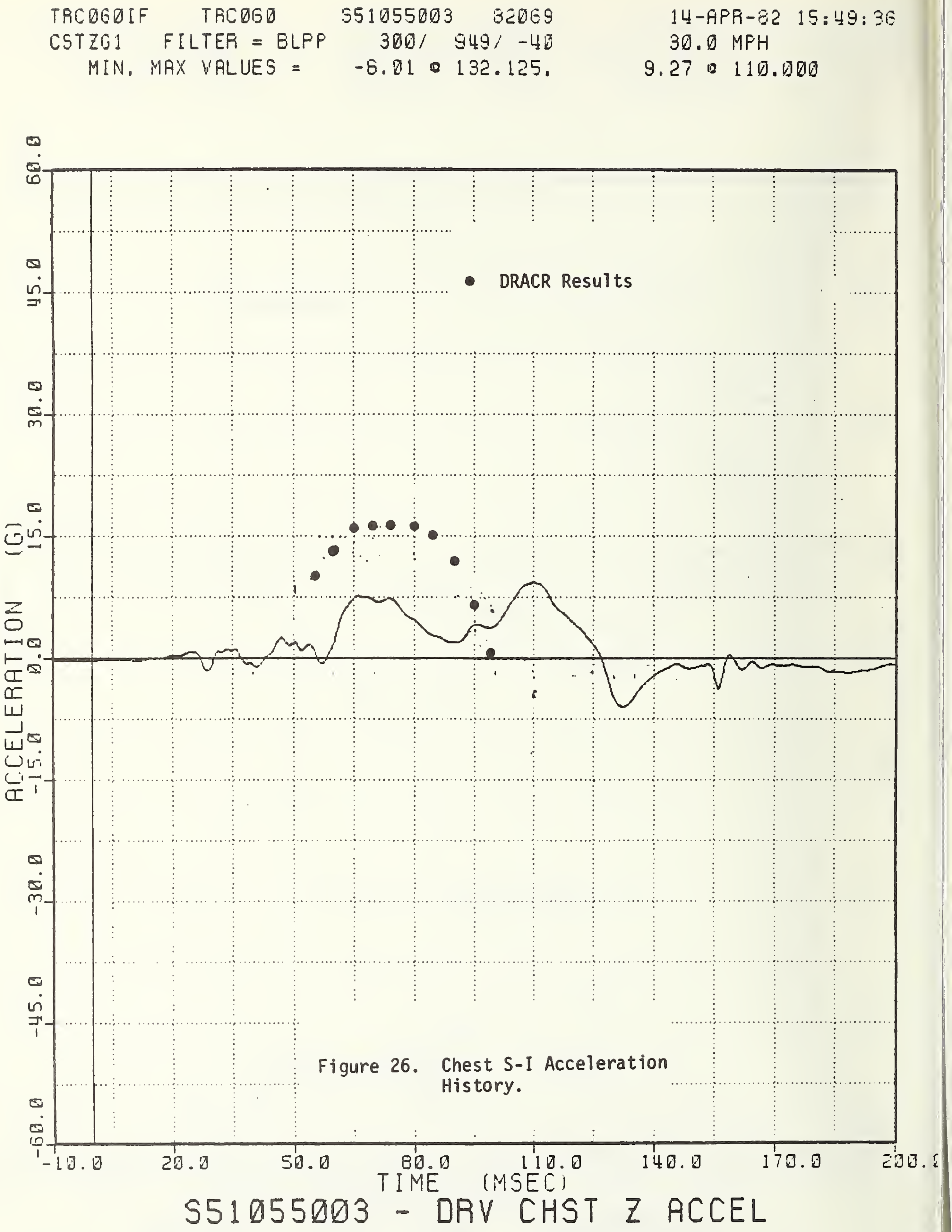

Figure 26. Chest S-I Acceleration History.

TRCØ6ØIF TRCØ6Ø 551… 82Ø69 14-APR-82 15:49:56
CSTRG1 FILTER = 6LPP 300/ 949/ -4Ø 30.Ø MPH
MIN, MAX VALUES = Ø.26 @ 13.625, 28.96 @ 107.125

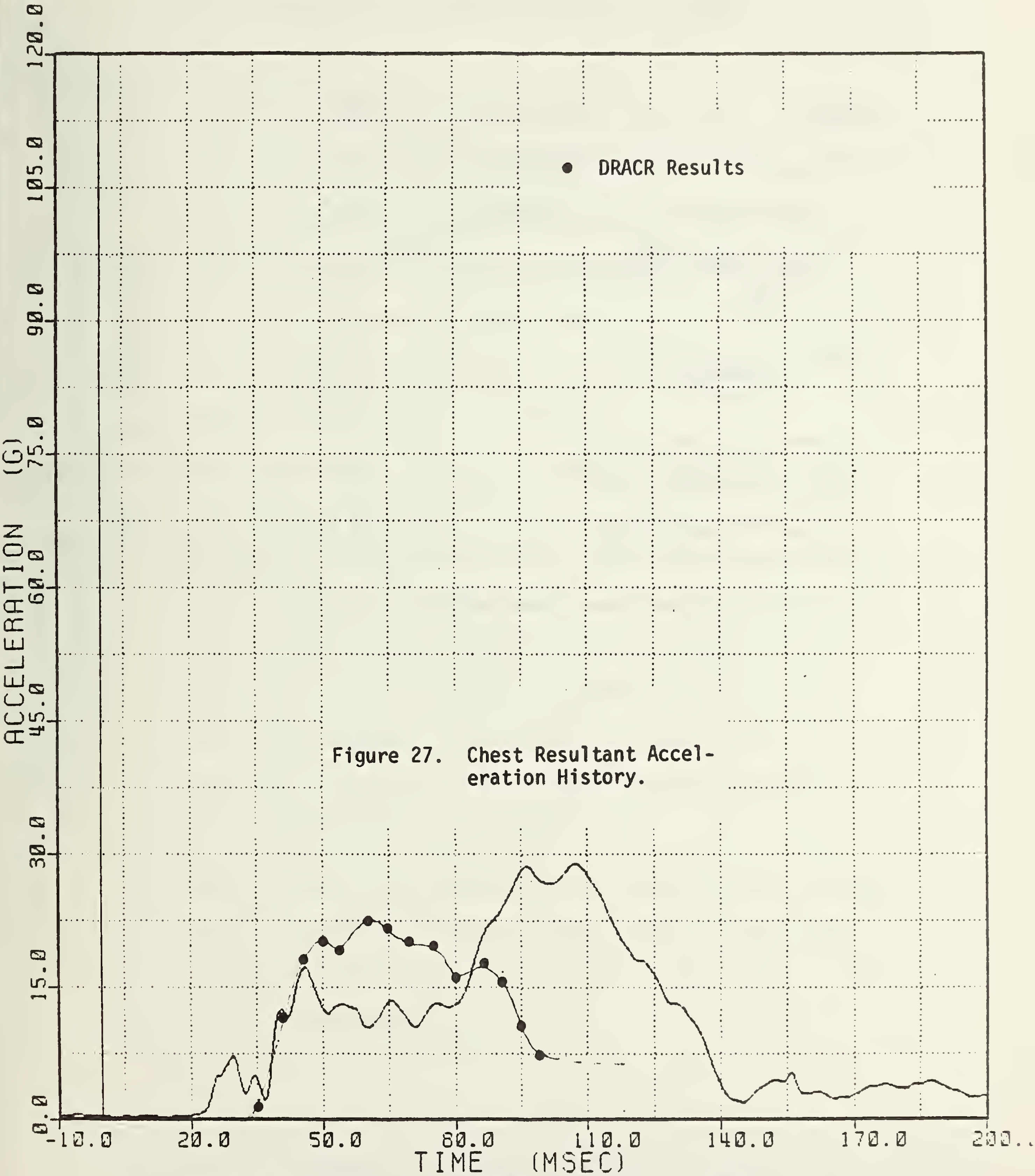

Figure 27. Chest Resultant Acceleration History.

S51Ø55ØØ3 - DRV CHST RESULT.

TABLE 2. Summary of DRACR v.s. Test Results

Item	DRACR	Test
Pk. Head Resultant g's (-3 msec)	23.0	27.5
Pk. Torso Resultant g's (-3 msec)	22.0	28.96
Pk. Femur Loads (lbs)		
. Left	1120	1080
. Right	1120	1200
HIC	68.3	115
. T1 (msec)........................	50.0 [1]	49.0
. T2 (msec)........................	100.0 [1]	128.5
Column Displacement (inch)	2.92	2.75
Wheel Displacement (inch)	.26	.22 (average)
Pk. Bag Pressure (psig)	6.45	6.0

[1] Run terminated, torso contacted rim.

The differences between the DRACR predictions and the test results, as summarized in Figures 19 thru 27, have been attributed to the following factors:[1]

1. The actual shape of the ACRS bag was a "tear-drop" rather than the idealized ellipsoidal bag shape assumed in DRACR. The actual tear-drop shape gives more head support and less initial bag penetration (by the torso) than the idealized DRACR shape.

2. The torso of the dummy appears to have contacted the steering wheel rim approximately 80 msec into the impact event. DRACR does not account for this interaction.

3. The "femur loads" calculated in DRACR are actually knee contact loads. These loads are different than the measured femur loads in the sled test in that they include the inertial loads corresponding to the total lower body mass of the occupant. The measured femur loads, on the other hand, do not include the inertial loads corresponding to the lower body mass of the occupant located forward of the load cell. Thus, there will always be some discrepancy between the DRACR "femur" loads and the measured femur loads.

4. DRACR restricts the movement of the 'H' point to the horizontal plane. In the actual sled tests the dummy's 'H' moved downward approximately 1-2 inches. This can have an effect on the torso S-I accelerations.

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[1] Based on the conclusions from the research work under Contract No. DTNH-22-82-P-07224, "Sled Testing and Data Collection at NHTSA-SRL, Ohio".

The differences between the DRACR predictions and the HYGE sled impact test results, as summarized above, suggest that additional testing need to be conducted to validate the DRACR model. We recommend a test program specifically designed for this validation effort (rather than sharing tests with an ongoing development effort, as was the case for the tests referenced herein). In this validation test program we would recommend additional instrumentation to monitor the steering wheel and steering column dynamic response as well as the hip response of the dummy.

APPENDIX A

DERIVATION OF THE EQUATIONS OF MOTION

The derivation of the equations of motion will be formulated utilizing Lagrangian techniques based upon the geometrical representation in Figure A-1.

Writing an expression for the total kinetic energy of the occupant, we have:

(1) $T = \frac{1}{2} [M_H (\dot{X}_H^2 + \dot{Y}_H^2) + M_T (\dot{X}_T^2 + \dot{Y}_T^2) + M_L \dot{X}_L^2]$

Note that $\dot{Y}_L \equiv 0$, as no movement normal to the X-direction is allowed for the hip-leg mass.

M_H = Head mass

M_T = Torso mass

M_L = Hip-leg mass

X_L = Horizontal translation of the hip-leg mass with respect to inertial reference point – which is positive when it is in direction shown.

X_T and X_H are similarly defined

Y_H = Vertical distance from H-point to the center of gravity of the head

Y_T = Vertical distance from H-point to the center of gravity of the torso

Successive dots indicate velocity and acceleration, respectively.

Writing the transformation equations, we have:

(2) $X_T = X_L + r_T \text{SIN}\theta_T$

(3) $Y_T = r_T \text{COS}\theta_T$

(4) $X_H = X_L + r_N \text{SIN}\theta_T + r_H \text{SIN}\theta_H$

(5) $Y_H = r_N \text{COS}\theta_T + r_H \text{COS}\theta_H$

(6) $\dot{X}_T = \dot{X}_L + r_T \text{COS}\theta_T \dot{\theta}_T$

(7) $\dot{Y}_T = -r_T \text{SIN}\theta_T \dot{\theta}_T$

MATHEMATICAL MODEL

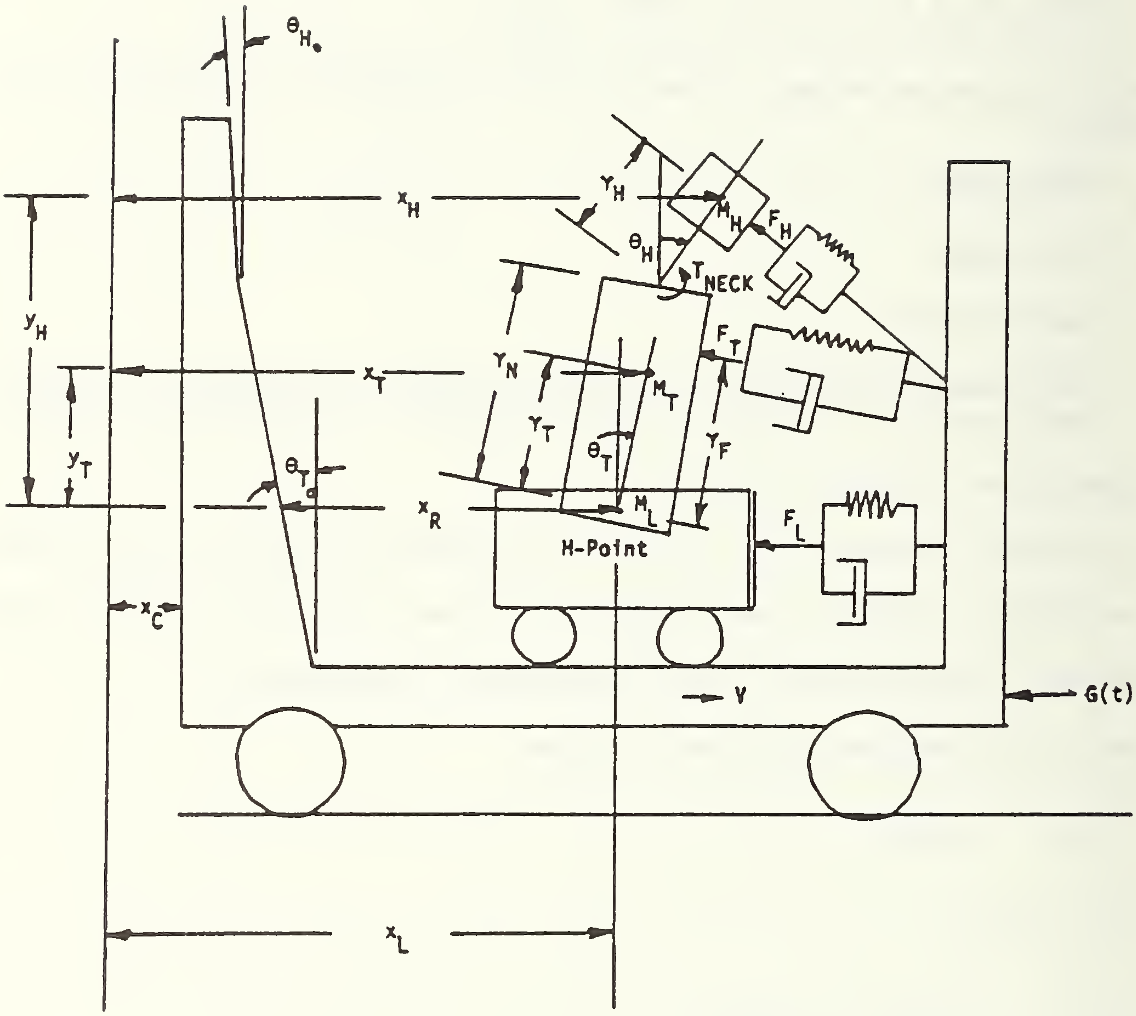


Figure A-1. Geometrical Representation of the Driver-Airbag Interaction

(8) $\dot{X}_H = \dot{X}_L\ r_N \cos\theta_T\ \dot{\theta}_T + r_H \cos\theta_H\ \dot{\theta}_H$

(9) $\dot{Y}_H = -r_N \sin\theta_T \dot{\theta}_T - r_H \sin\theta_H\ \dot{\theta}_H$

where:

r_T = Distance from hip H-point to torso center of gravity (The H-point is assumed to be coincident with the hip-leg center of gravity.)

r_N = Distance from H-point to neck pivot point

r_H = Distance from the neck pivot point to the center of gravity of the head

θ_H and θ_T are as defined in Figure A-1.

Substituting Equations 6 through 9 into Equation 1, we have:

(10) $$T = \tfrac{1}{2}\Big\{M_L\dot{X}_L^2 + M_T\left[\dot{X}_L^2 + 2\ \dot{X}_L r_T \cos\theta_T\ \dot{\theta}_T + r_T^2\ \dot{\theta}_T^2\right] + M_H\Big[\dot{X}_L^2 + 2\ \dot{X}_L\ (r_N \cos\theta_T\ \dot{\theta}_T + r_H \cos\theta_H\ \dot{\theta}_H) + 2\ r_N\ r_H\ (\cos\theta_T \cos\theta_H\ \dot{\theta}_T\ \dot{\theta}_H + \sin\theta_T \sin\theta_H\ \dot{\theta}_T\ \dot{\theta}_H) + r_N^2\ \dot{\theta}_T^2 + r_H^2\ \dot{\theta}_H^2\Big]\Big\}$$

The potential energy portion of the Lagrangian is:

(11) $V_T = M_T\ g\ r_T \cos\theta_T$

(12) $V_H = M_H\ g\ (r_H \cos\theta_H + r_N \cos\theta_T)$

Note: The applied forces and moments will be treated separately later on.

Writing the Lagrangian, we have:

(13) $L = T\text{-}V = T - (V_T + V_H)$,

where the values to be substituted into this equation are given by Equations 10, 11 and 12.

The basic equation in Lagrangian mechanics is:

$$(14) \quad \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = F_{qi}$$

where:

q_i = generalized displacement of the i^{th} mass

$\dot{q}_i$ = generalized velocity of the i^{th} mass

F_{qi} = generalized force acting on the i^{th} mass

Taking the required derivatives from Equation 13 for substitution into Equation 14, we obtain:

$$(15) \quad \frac{\partial L}{\partial \dot{X}_L} = (M_L + M_T + M_H)\,\dot{X}_L + M_T\, r_T \,COS\theta_T\,\dot{\theta}_T + M_H\,(r_N\,COS\theta_T\,\dot{\theta}_T + r_H\,COS\theta_H\,\dot{\theta}_H)$$

$$(16) \quad \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{X}_L}\right) = (M_L + M_T + M_H)\,\ddot{X}_L - M_T r_T\,SIN\theta_T\,\dot{\theta}_T^2 - M_H\,(r_N\,SIN\theta_T\,\dot{\theta}_T^2 + r_H\,SIN\theta_H\,\dot{\theta}_H^2) + M_T\,r_T\,COS\theta_T\,\ddot{\theta}_T + M_H\,(r_N\,COS\theta_T\,\ddot{\theta}_T + r_H\,COS\theta_H\,\ddot{\theta}_H)$$

$$(17) \quad \frac{\partial L}{\partial X_L} = 0$$

$$(18) \quad \frac{\partial L}{\partial \theta_T} = M_T\,(\dot{X}_L\,r_T\,COS\theta_T + r_T^2\,\dot{\theta}_T) + M_H\left[\dot{X}_L\,r_N\,COS\theta_T + r_N\,r_H\,(COS\theta_T\,COS\theta_H\,\dot{\theta}_H + SIN\theta_T\,SIN\theta_H\,\dot{\theta}_H) + r_N^2\,\dot{\theta}_T\right]$$

(19) $$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot\theta_T}\right) = M_T (\ddot X_L\, r_T\, COS\theta_T - \dot X_L\, r_T\, SIN\theta_T\, \dot\theta_T + r_T^2\, \ddot\theta_T)$$

$$+ M_H \Big[\ddot X_L\, r_N\, COS\theta_T - \dot X_L\, r_N\, SIN\theta_T\, \dot\theta_T - r_N\, r_H\, (SIN\theta_T\, \dot\theta_T\, COS\theta_H\, \dot\theta_H$$

$$+ COS\theta_T\, SIN\theta_H\, \dot\theta_H^2 - COS\theta_T\, COS\theta_H\, \ddot\theta_H - COS\theta_T\, \dot\theta_T \cdot SIN\theta_H\, \dot\theta_H$$

$$- SIN\theta_T\, COS\theta_H\, \dot\theta_H^2 - SIN\theta_T\, SIN\theta_H\, \ddot\theta_H) + r_N^2\, \ddot\theta_T \Big]$$

(20) $$\frac{\partial L}{\partial \theta_T} = -M_T\, \dot X_L\, r_T\, SIN\theta_T\, \dot\theta_T - M_H\, r_N\, (SIN\theta_T\, \dot\theta_T\, \dot X_L + r_H\, SIN\theta_T\, COS\theta_H \cdot$$

$$\dot\theta_T\, \dot\theta_H - r_H\, COS\theta_T\, SIN\theta_H\, \dot\theta_T\, \dot\theta_H) + M_T\, g\, r_T\, SIN\theta_T + M_H\, g\, r_N\, SIN\theta_T$$

(21) $$\frac{\partial L}{\partial \dot\theta_H} = M_H \Big[\dot X_L\, r_H\, COS\theta_H + r_N\, r_H\, (COS\theta_T\, COS\theta_H\, \dot\theta_T + SIN\theta_T\, SIN\theta_H\, \dot\theta_T)$$

$$+ r_H^2\, \dot\theta_H \Big]$$

(22) $$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot\theta_H}\right) = M_H \Big[\ddot X_L\, r_H\, COS\theta_H - \dot X_L\, r_H\, SIN\theta_H\, \dot\theta_H - r_N\, r_H\, (SIN\theta_T\, COS\theta_H\, \dot\theta_T^2$$

$$+ COS\theta_T\, SIN\theta_H\, \dot\theta_T\, \dot\theta_H - COS\theta_T\, COS\theta_H\, \ddot\theta_T - COS\theta_T\, SIN\theta_H\, \dot\theta_T^2$$

$$- SIN\theta_T\, COS\theta_H\, \dot\theta_T \dot\theta_H - SIN\theta_T\, SIN\theta_H\, \ddot\theta_T) + r_H^2\, \ddot\theta_H \Big]$$

(23) $$\frac{\partial L}{\partial \theta_H} = - M_H\, r_H \Big[SIN\theta_H\, \dot\theta_H\, \dot X_L + r_N\, (COS\theta_T\, SIN\theta_H\, \dot\theta_T\, \dot\theta_H - SIN\theta_T\, COS\theta_H \cdot$$

$$\dot\theta_T\, \dot\theta_H) \Big] + M_H\, g\, r_H\, SIN\theta_H$$

Substituting Equations 16 and 17 into Equation 14, we have:

(24) $$(M_L + M_T + M_H)\, \ddot X_L - M_T\, r_T\, SIN\theta_T\, \dot\theta_T^2 - M_H\, (r_N\, SIN\theta_T \dot\theta_T^2 + r_H\, SIN\theta_H\, \dot\theta_H^2)$$

$$+ M_T\, r_T\, COS\theta_T\, \ddot\theta_T + M_H\, (r_N\, COS\theta_T\, \ddot\theta_T + r_H\, COS\theta_H\, \ddot\theta_H) = F_{XL}$$

which is the equation of motion for mass M_L.

Substituting Equations 19 and 20 into Equation 14, we have:

$$M_T (\ddot{X}_L r_T \cos\theta_T - \dot{X}_L r_T \sin\theta_T \dot{\theta}_T + r_T^2 \ddot{\theta}_T) + M_H \Big[\ddot{X}_L r_N \cos\theta_T$$

$$- \dot{X}_L r_N \sin\theta_T \dot{\theta}_T - r_N r_H (\sin\theta_T \dot{\theta}_T \cos\theta_H \dot{\theta}_H + \cos\theta_T \sin\theta_H \dot{\theta}_H^2$$

$$- \cos\theta_T \cos\theta_H \ddot{\theta}_H - \cos\theta_T \dot{\theta}_T \sin\theta_H \dot{\theta}_H - \sin\theta_T \cos\theta_H \dot{\theta}_H^2$$

$$- \sin\theta_T \sin\theta_H \ddot{\theta}_H) + r_N^2 \ddot{\theta}_T \Big] + M_T \dot{X}_L r_T \sin\theta_T \dot{\theta}_T + M_H r_N ($$

$$\sin\theta_T \dot{\theta}_T \dot{X}_L + r_H \sin\theta_T \cos\theta_H \dot{\theta}_T \dot{\theta}_H - r_H \cos\theta_T \sin\theta_H \dot{\theta}_T \dot{\theta}_H)$$

$$- M_T g r_T \sin\theta_T - M_H g r_N \sin\theta_T = F_{\theta T} .$$

Rewriting the above yields:

$$(25) \quad M_T (\ddot{X}_L r_T \cos\theta_T + r_T^2 \ddot{\theta}_T) + M_H \Big[\ddot{X}_L r_N \cos\theta_T - r_N r_H (\cos\theta_T \sin\theta_H \dot{\theta}_H^2$$

$$- \cos\theta_T \cos\theta_H \ddot{\theta}_H - \sin\theta_T \cos\theta_H \dot{\theta}_H^2 - \sin\theta_T \sin\theta_H \ddot{\theta}_H)$$

$$+ r_N^2 \ddot{\theta}_T\Big] - M_T g r_T \sin\theta_T - M_H g r_N \sin\theta_T = F\theta_T .$$

which is the equation of motion of the torso mass.

Substituting Equations 22 and 23 into Equation 14, we have:

$$M_H \Big[\ddot{X}_L r_H \cos\theta_H - \dot{X}_L r_H \sin\theta_H \dot{\theta}_H - r_N r_H (\sin\theta_T \cos\theta_H \dot{\theta}_T^2$$

$$+ \cos\theta_T \sin\theta_H \dot{\theta}_T \dot{\theta}_H - \cos\theta_T \cos\theta_H \ddot{\theta}_T - \cos\theta_T \sin\theta_H \dot{\theta}_T^2$$

$$- \sin\theta_T \cos\theta_H \dot{\theta}_T \dot{\theta}_H - \sin\theta_T \sin\theta_H \ddot{\theta}_T) + r_H^2 \ddot{\theta}_H \Big] + M_H r_H \Big[$$

$$\sin\theta_H \dot{\theta}_H \dot{X}_L + r_N (\cos\theta_T \sin\theta_H \dot{\theta}_T \dot{\theta}_H - \sin\theta_T \cos\theta_H \dot{\theta}_T \dot{\theta}_H)\Big]$$

$$- M_H g r_H \sin\theta_H = F_{\theta H} .$$

Rewriting the preceding yields:

$$(26)\quad M_H \Big[\ddot{X}_L\, r_H\, COS\theta_H - r_N\, r_H\, (SIN\theta_T\, COS\theta_H\, \dot{\theta}_T^2 - COS\theta_T\, COS\theta_H\, \ddot{\theta}_T - COS\theta_T\, SIN\theta_H\, \dot{\theta}_T^2 - SIN\theta_T\, SIN\theta_H\, \ddot{\theta}_T) + r_H^2\, \theta_H \Big] - M_H\, g\, r_H\, SIN\theta_H = F_{\theta H} \quad ,$$

which is the equation of motion for the head mass.

Writing Equation 24 in terms of $\ddot{XL}$, we have:

$$(27)\quad \ddot{X}_L = \frac{1}{M_L + M_T + M_H} \Big\{ F_{XL} + (M_T\, r_T + M_H\, r_N)\, SIN\theta_T\, \dot{\theta}_T^2 + M_H\, r_H\, \dot{\theta}_H^2\, SIN\theta_H - (M_T\, r_T + M_H r_N)\, \ddot{\theta}_T\, COS\theta_T - M_H\, r_H\, \ddot{\theta}_H\, COS\theta_H \Big\} \quad .$$

Writing Equation 25 in terms of $\ddot{\theta}_T$, we have:

$$(28)\quad \ddot{\theta}_T = \frac{1}{M_T\, r_T^2 + M_H\, r_N^2} \Big\{ F_{\theta T} - (M_T\, r_T + M_H\, r_N)\, \ddot{X}_L\, COS\theta_T - M_H\, r_N\, r_H \Big[\ddot{\theta}_H\, (COS\theta_H\, COS\theta_T + SIN\theta_H\, SIN\theta_T) + \dot{\theta}_H^2\, (-SIN\theta_H\, COS\theta_T + COS\theta_H\, SIN\theta_T) \Big] + M_T\, g\, r_T\, SIN\theta_T + M_H\, g\, r_N\, SIN\theta_T \Big\} \quad .$$

Writing Equation 26 in terms of $\ddot{\theta}_H$, we have:

$$(29) \quad \ddot{\theta}_H = \frac{F_{\theta H}}{M_H r_H^2} - \frac{\ddot{X}_L \cos\theta_H}{r_H} - \frac{r_N}{r_H}\Big[(\cos\theta_H \cos\theta_T + \sin\theta_H \sin\theta_T)\ddot{\theta}_T + (\sin\theta_H \cos\theta_T - \cos\theta_H \sin\theta_T)\dot{\theta}_T^2\Big] + \frac{g}{r_H}\sin\theta_H ,$$

where:

$$F_{\theta H} = F_H r_H + T\ NECK$$

$$F_{\theta T} = F_H \cos(\theta_H - \theta_T) r_N + F_T r_F - T\ NECK$$

$$F_{XL} = F_H \cos\theta_H + F_T \cos\theta_T + F_L .$$

APPENDIX B

DERIVATION OF THE AIRBAG ALGORITHM

The angles and distances described in this appendix will be those depicted in Figure B-1.

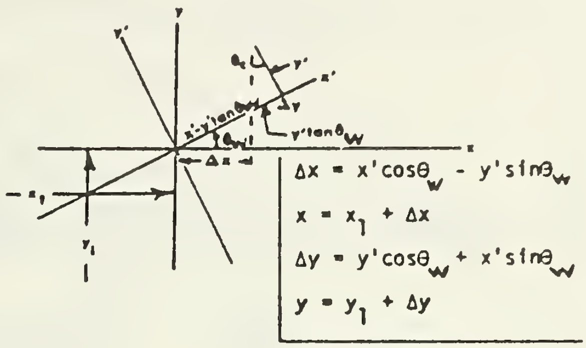
COORDINATE TRANSFORMATION EQUATIONS

(1) $y = y_2 + y''$

(2) $x = x_2 + x''$

(3) $y = y_1 + y' \, COS\theta_w + X' \, SIN\theta_w$

(4) $x = x_1 + x' \, COS\theta_w - y' \, SIN\theta_w$



To obtain transformation equations for x'' and y'' into the x',y' system, substitute Equations 1 and 2 into Equations 3 and 4 to get:

(5) $$x' = \frac{x_2 - x_1 + x'' + y' \, SIN\theta_w}{COS\theta_w}$$

(6) $$y' = \frac{y_2 - y_1 + y'' - x' \, SIN\theta_w}{COS\theta_w}$$

Assume that the torso may be represented by a plane that intersects the airbag at line A-B on the plane of symmetry of the airbag (as shown in Figure B-1). Assume further that the airbag is an ellipsoid whose plane of symmetry in the X-Y plane is as shown in the figure. Our job now will be to derive an equation for the bag intercept points in the x'-y' coordinate system.

In the x''-y'' system the equation for line A-B is:

(7) $y'' = mx'' + b$.

Substituting Equation 7 into Equation 6 yields:

(8) $$y' = \frac{y_2 - y_1 + mx'' + b - x' \, SIN\theta_w}{COS\theta_w} \, .$$

COMPARTMENT, BAG, DRIVER COORDINATE SYSTEM

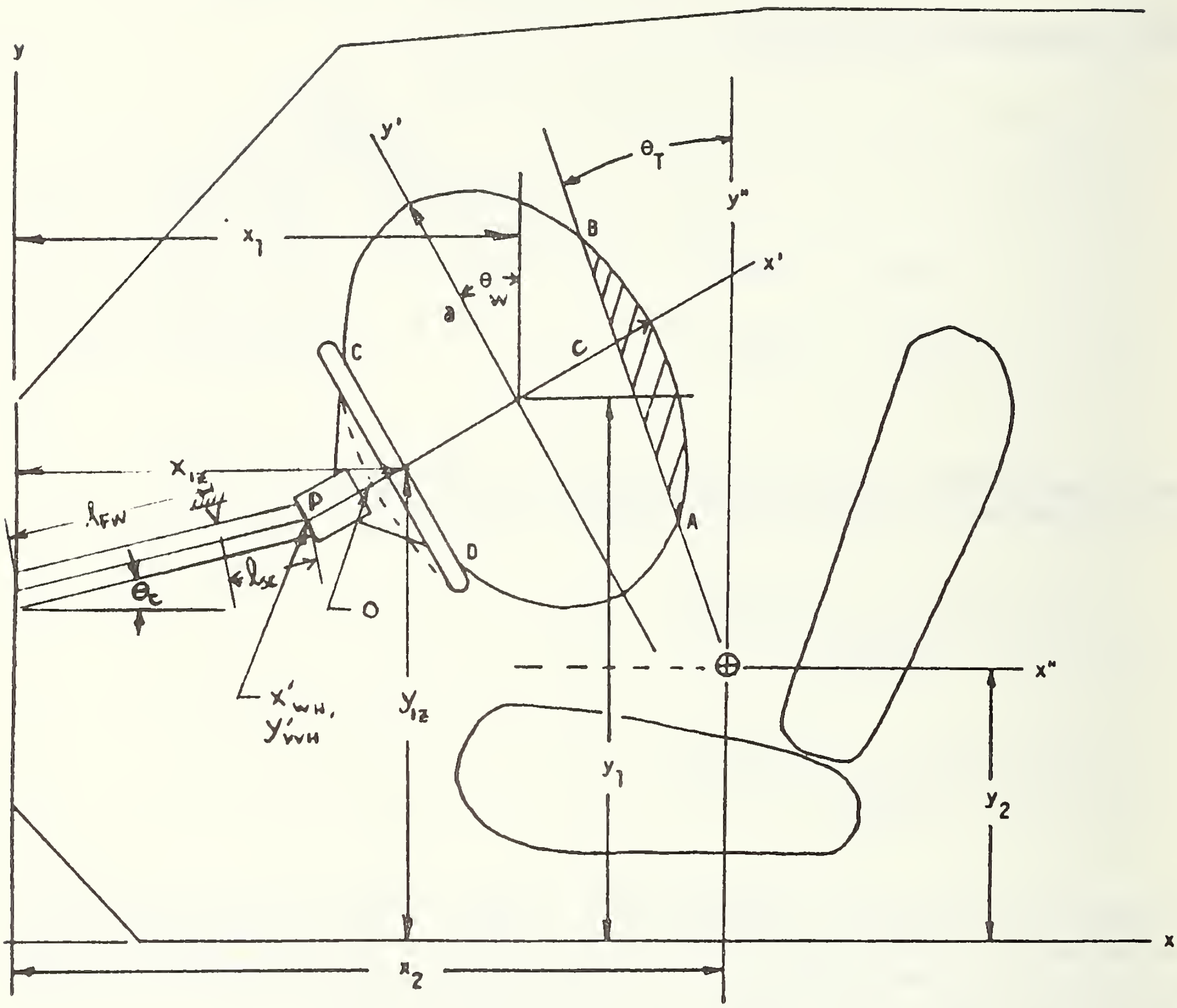


Figure B-1. Geometrical Representation of the Airbag Parameters

Substituting in Equation 8 for x" from Equations 2 and 4:

(9) $$y' = \frac{y_2 - y_1 + m\,(x'\ COS\theta_w - x_2 + x_1 - y'\ SIN\theta_w) - x'\ SIN\theta_w + b}{COS\theta_w},$$

which is the desired equation in the x',y' system.

Let $y_2 - y_1 + b - m\,(x_2 - x_1) = B$ (a constant) and solve Equation 9 for y':

$$y'\ (COS\theta_w + m\ SIN\theta_w) = B + x'\ (m\ COS\theta_w - SIN\theta_w)$$

(10) $$y' = \frac{B + x'\ (m\ COS\theta_w - SIN\theta_w)}{COS\theta_w + m\ SIN\theta_w}$$ (equation for A-B in x',y' system)

The equation for the airbag in the x'-y' system is:

(11) $$\frac{x'^2}{c^2} + \frac{y'^2}{a^2} = 1$$

Substituting Equations 10 into 11 and collecting terms:

$$x'^2\,[a^2\ (COS\theta_w + m\ SIN\theta_w)^2 + c^2(-SIN\theta_w + m\ COS\theta_w)^2]$$

$$+ 2\ Bc^2x'\ (m\ COS\theta_w - SIN\theta_w) + B^2\ c^2 - a^2\ c^2\ (COS\theta_w + m\ SIN\theta_w)^2 = 0,$$

which is a quadratic equation in terms of x'.

Let $A = a^2\ (COS\theta_w + m\ SIN\theta_w)^2 + c^2(-SIN\theta_w + m\ COS\theta_w)^2$

$D = 2\ B\ c^2\ (m\ COS\theta_w - SIN\theta_w)$

$E = B^2\ c^2 - a^2\ c^2\ (COS\theta_w + m\ SIN\theta_w)^2$

$Ax'^2 + Dx' + E = 0$

(12) $$x' = \frac{-D \pm \sqrt{D^2 - 4AE}}{2A}$$

Values for x' obtained with (12) when substituted into (10) will give the corresponding values for y'. We now have defined the line of intercept (A-B) of the occupant's body with the mid-plane of the airbag.

With this line now established, we can begin to calculate the restraint forces that will be applied to the driver.

Forces will now be calculated due to pressure effects (Figure B-2). The force on the head and chest are composed of two components – a pressure component and a "wrap-around" component due to fabric tension; i.e.,

(13) $$F_{CHEST} = F_{P_C} + F_{FT_C}$$

(14) $$F_{HEAD} = F_{P_H} + F_{FT_H} \ .$$

The pressure forces act normal to the head and chest:

(15) $$F_{P_C} = P\, w_b\, (R_N - R_{BAG}) \qquad (R_N - R_{BAG}) < \overline{AB}$$

$$= P\, w_b\, \overline{AB} \qquad (R_N - R_{BAG}) \geq \overline{AB}$$

(16) $$F_{P_H} = P\, w_H\, (R_{TOPH} - R_N) \qquad (R_{TOPH} - R_{BAG}) < \overline{AB}$$

$$= P\, w_H\, [\overline{AB} - (R_N - R_{BAG})] \qquad (R_{TOPH} - R_{BAG}) \geq \overline{AB} \ ,$$

where the pressure P must be calculated due to bag volume and thermodynamic effects.

The fabric tension component will be calculated later. Let us now calculate the body moments caused by these forces. Using the H-point and neck pivots as our reference points:

(17) $$F_{\theta_T} = F_{CHEST} \circ R_{FT}$$

(18) $$F_{\theta_H} = F_{HEAD} \circ R_{HEAD} \ ,$$

where F_{CHEST} and F_{HEAD} are given by Equations 13 and 14. We will now evaluate R_{FT} and R_{HEAD}.

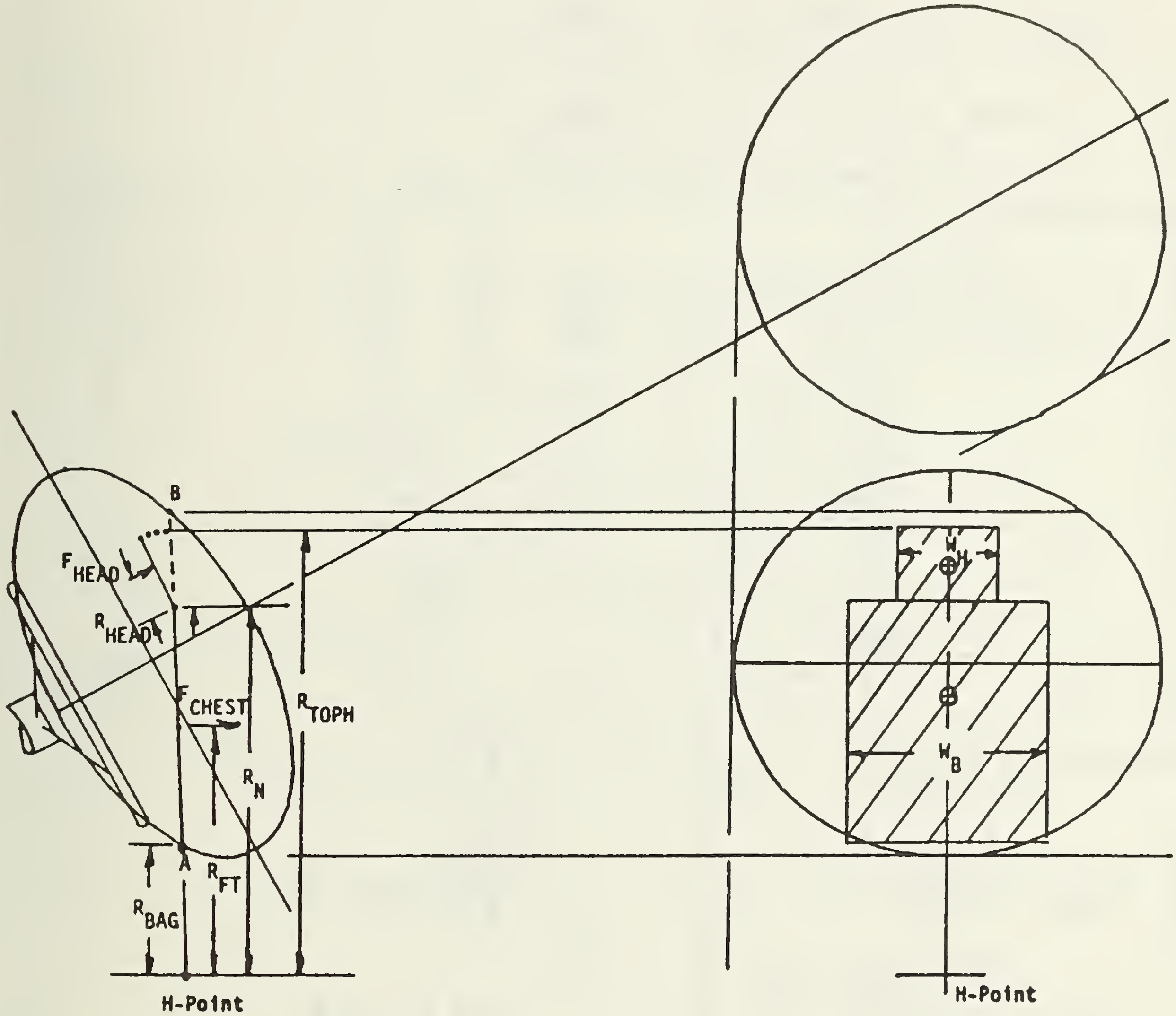


Figure B-2. Head-Bag Interaction Forces Diagram

In order to solve for R_{FT}, we must derive equations for the H-point location in terms of the x'-y' coordinate system (see Figure B-3).

From the geometry of the mid-plane of bag impact, the H-point coordinates are:

(19) $$x'_H = (y_2 - y_1)\ SIN\theta_w + (x_2 - x_1)\ COS\theta_w$$

(20) $$y'_H = COS\theta_w\ [y_2 - y_1 - (x_2 - x_1)\ TAN\theta_w] \quad .$$

The equation for R_{FT} is:

(21) $$R_{FT} = \sqrt{(x'_{FT} - x'_H)^2 + (y'_{FT} - y'_H)^2} \quad ,$$

where:

(22) $$x'_{FT} = \frac{(x'_A + x'_{NECK})}{2}$$

(23) $$y'_{FT} = \frac{y'_A + y'_{NECK}}{2} \quad .$$

The equation for R_{HEAD} is:

(24) $$R_{HEAD} = \frac{R_{TOPH} - R_N}{2} \qquad \overline{AB} + R_{BAG} > R_N$$

(25) $$R_{HEAD} = \frac{\overline{AB} + R_{BAG} - R_N}{2} \qquad AB + R_{BAG} \leq R_N \quad .$$

This derivation completes the solution for terms needed for pressure force and body moment computation. We must now derive equations for the fabric tension component of bag force due to bag wraparound in the lateral plane. (No wrap-around in the vertical plane is considered, since the body is generally as long as the bag is high, so no wrap-around will occur.)

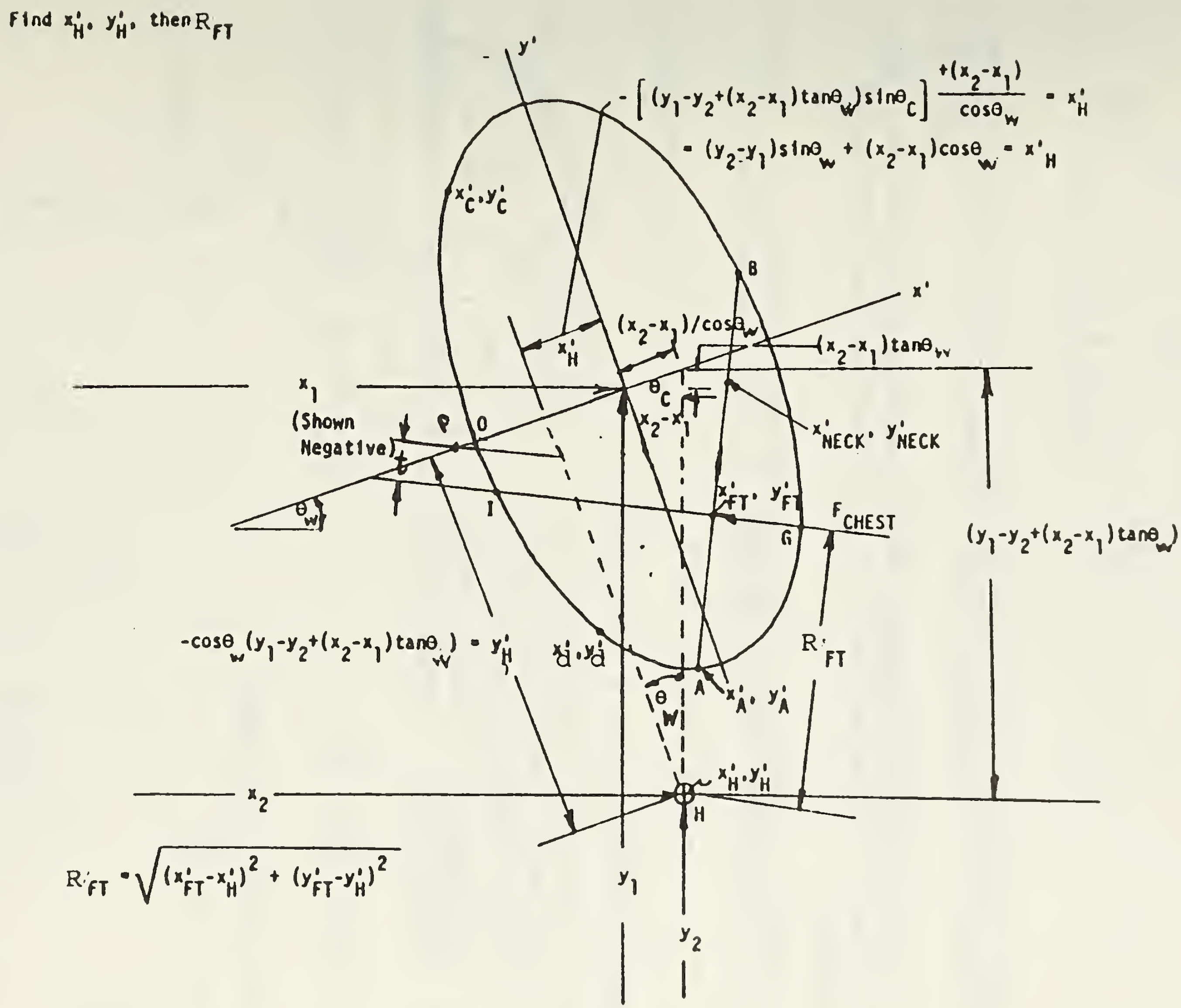
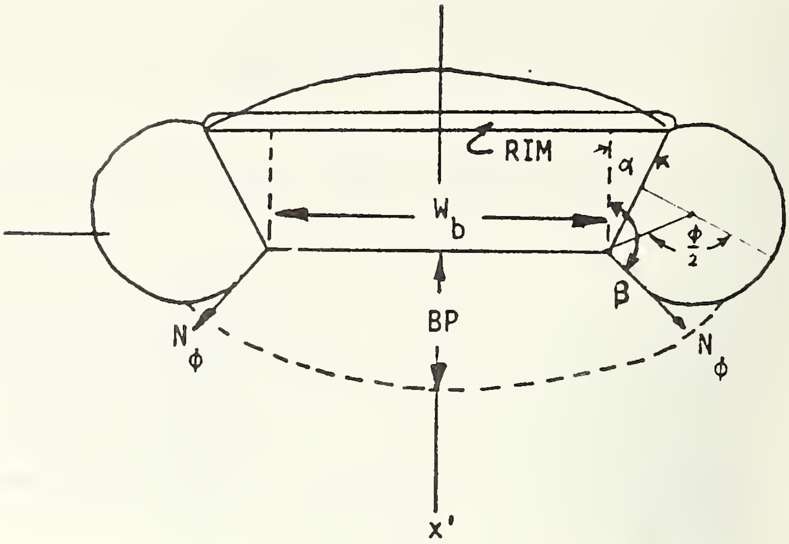


Figure B-3. H-Point Location in x'-y' Coordinate System

The figure on the right is a view looking down at the deformed bag.



Let us now consider the body wraparound forces caused by fabric tension. This component of force is influenced most by bag pressure, bag penetration and body to bag width.

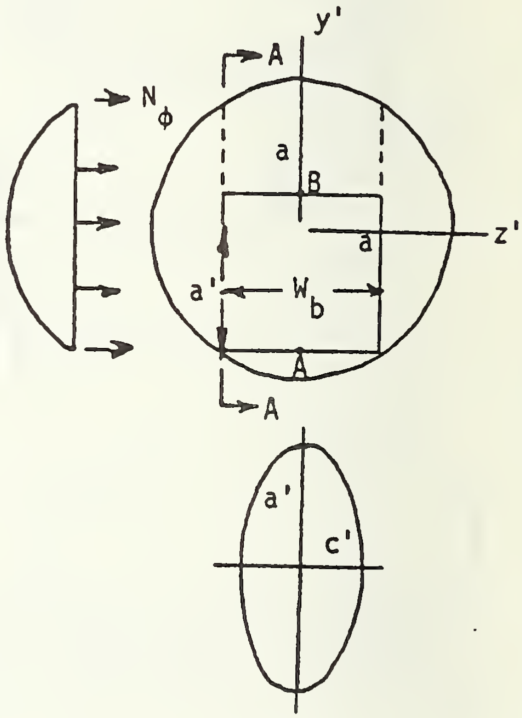
The force N_ϕ is the tensile force in the bag.

At $z = \frac{w_b}{2}$, N_ϕ is obtained by a force balance.

N_ϕ x perimeter of Section A-A = P x Area A-A,

or

(26) $$N_\phi = \frac{\text{P x Area A-A}}{\text{Perimeter A-A}}$$ (force per unit length of AB)



Sect A-A

Solve for a' and c' @ $z = \frac{w_b}{2}$.

We may write for the y',z' plane,

(27) $$y'^2 + z'^2 = a^2$$

For $z = \frac{w_b}{2}$

(28) $$y' = a' = \sqrt{a^2 - \frac{w_b^2}{4}}$$

For the x,z plane:

$$\frac{x'^2}{c^2} + \frac{z'^2}{a^2} = 1$$

(29) $$x' = c' = \sqrt{c^2\left(1 - \frac{w_b^2}{4a^2}\right)} .$$

Assume the area of Section A-A varies linearly with bag penetration from its initial value, $\pi a'c'$, to zero when fully compressed at a bag penetration of $\overline{GI}$. Then:

(30) $$A_{A-A} = \pi a'c' \left(1 - \frac{BP}{GI}\right) ,$$

where BP = bag penetration perpendicular to and at mid point of torso
GI = length across bag in BP direction.

The perimeter is given by:

(31) $$PER_{A-A} \simeq 2\pi\sqrt{\frac{a'^2 + c'^2}{2}}$$ (an approximate formula with accuracy sufficiently close to the exact formula which involves elliptic integrals)

Substituting (30) and (31) into (26):

(32) $$N = \frac{a'c'P}{2\sqrt{\frac{a'^2 + c'^2}{2}}} \left(1 - \frac{BP}{GI}\right) .$$

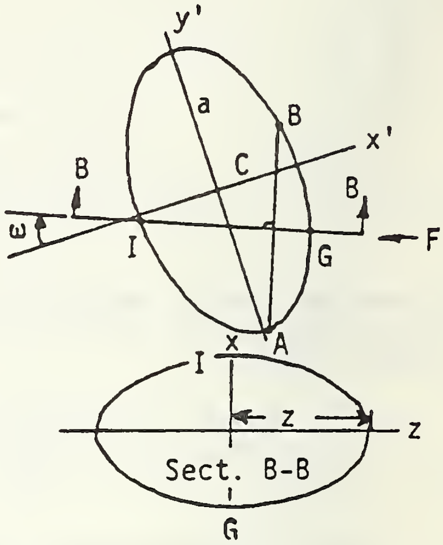
Substituting (28) and (29) into (32):

(33) $$N = \frac{P\sqrt{a^2 - \frac{w_b^2}{4}} \cdot \sqrt{c^2\left(1 - \frac{w_b^2}{4a^2}\right)}}{2\sqrt{a^2 - \frac{w_b^2}{4} + c^2\left(1 - \frac{w_b^2}{4a^2}\right)}} \left(1 - \frac{BP}{GI}\right) ,$$

which is the equation for the tension force in the ellipsoidal airbag in terms of the bag pressure, the lengths of the major and minor axes, the bag penetration, and the driver body widths; in units of force per unit length $\overline{AB}$.

The bag perimeter in the plane at the mid-point of AB at an angle ω to the x-axis can be found; see figure at right. This perimeter will remain constant and the wrap-around configuration must maintain this perimeter. To find the perimeter of ellipse cut by B-B, one must follow the steps:

1) Find the distance $\overline{GI}$ (which will be the length of one axis)
2) Find the mid-point of $\overline{GI}$
3) Find the other axis length.



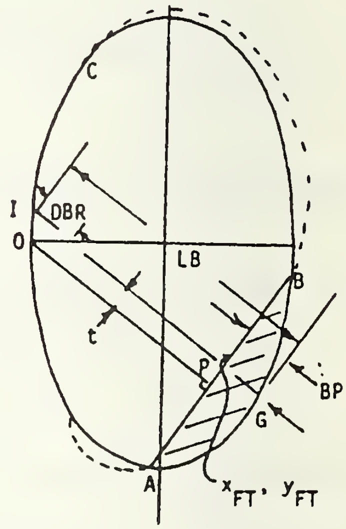
Calculate BP and GI

To derive the equation for $\overline{GI}$:

(34) Slope of $\overline{GI} = m'_{PAB}$.

The point it goes through is x_{FT}, y_{FT}.

Then, writing the equation for $\overline{GI}$,



(35) $(y' - y_{FT}) = m'_{PAB}(x' - x_{FT})$,

or, rewriting the equation,

(36) $y' = m'_{PAB}(x' - x_{FT}) + y_{FT}$.

The equation for the mid-plane of the ellipse is

(37) $\frac{x'^2}{c^2} + \frac{y'^2}{a^2} = 1$.

Substituting y' into the above and collecting terms, one obtains

(38) $x'^2\left(\frac{1}{c^2} + \frac{m'^2_{PAB}}{a^2}\right) + \frac{2\,m'_{PAB}\,x'}{a^2}\left(y_{FT} - m'_{PAB}\,x_{FT}\right) + \frac{\left(y_{FT} - m'_{PAB}\,x_{FT}\right)^2}{a^2} - 1 = 0$

Let

(39) $$A1 = \frac{1}{c^2} + \frac{m'_{PAB}{}^2}{a^2}$$

$$B1 = \frac{2\ m'_{PAB}}{a^2}\ (y_{FT} - m'_{PAB}\ x_{FT})$$

$$C1 = \frac{(y_{FT} - m'_{PAB}\ x_{FT})^2}{a^2} - 1$$

(40) $$x_G = \frac{-B1 + \sqrt{B1^2 - 4A1C1}}{2A_1} \quad , \qquad y_G = m'_{PAB}\ (x_G - x_{FT}) + y_{FT}$$

(41) $$x_I = \frac{-B1 - \sqrt{B1^2 - 4A1C1}}{2A_1} \quad , \qquad y_I = m'_{PAB}\ (x_I - x_{FT}) + y_{FT}$$

(42) $$GI = \sqrt{(y_I - y_G)^2 + (x_I - x_G)^2}$$

(43) $$BP = \sqrt{(y_{FT} - y_G)^2 + (x_{FT} - x_G)^2} \quad .$$

At the midpoint of $\overline{GI}$,

$$x_{MGI} = \frac{x_G + x_I}{2}$$

$$y_{MGI} = \frac{y_G + y_I}{2} \quad .$$

In the plane x' y',

$$\frac{x'^2}{c^2} + \frac{y'^2}{a^2} = 1 \quad ;$$

for $x' = x_{MGI}$ we have:

$$y'^2 = a^2 \left(1 - \frac{x_{MGI}^2}{c^2}\right) \quad .$$

Now, in the plane y-z, x_{MGI} away from the y', z' axis,

$$z^2 + y^2 = a^2 \left(1 - \frac{x_{MGI}^2}{c^2}\right)$$

or, for $y = y_{MGI}$,

$$z = \sqrt{a^2 \left(1 - \frac{x_{MGI}^2}{c^2}\right) - y_{MGI}^2} , \tag{44}$$

which is the length of the other axis.

Finally,

$$Per_{B-B} = 2\pi \sqrt{\frac{(\overline{GI}/2)^2 + z^2}{2}} , \tag{45}$$

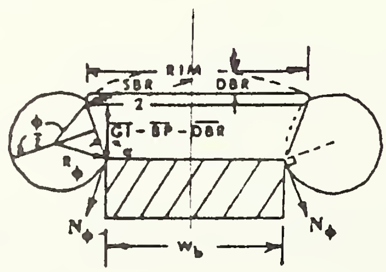
where GI and z are given by Equations 42 and 44, respectively.

For constant perimeter for section B-B,

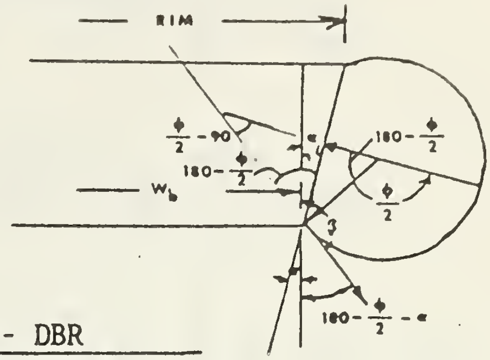
$$SBR \cong 2 \sqrt{\left(\frac{RIM}{2}\right)^2 + \overline{DBR}^2} .$$

$$\frac{Per_{BB} - W_b - SBR}{2} = R_\phi \phi \tag{46}$$

(RIM = RIM chord length at y_I; i.e., $RIM = 2\sqrt{R^2 - y_I^2}$, where $R = \frac{RIM\ DIA}{2}$.)



$$(47)\quad 2R_\phi \mathrm{SIN}(180 - \phi/2) = 2R_\phi \mathrm{SIN}\phi/2 = \frac{GI - BP - DBR}{\mathrm{COS}\alpha}$$



$$(48)\quad \alpha = \mathrm{TAN}^{-1}\frac{W_b - RIM}{2(\overline{GI} - BP - DBR)}$$

Solving (46) & (47) simultaneously gives:

$$(49)\quad \frac{Per_{B-B} - W_b - SBR}{\phi}\,\mathrm{SIN}\frac{\phi}{2} = \frac{\overline{GI} - BP - DBR}{\mathrm{COS}\left[\mathrm{TAN}^{-1}\left(\frac{W_b - RIM}{2(GI - BP - DBR)}\right)\right]}$$

Equation (49) must be solved numerically for ϕ.

The fabric tension force can now be calculated.

$$(50)\quad F_{FT} = 2N_\phi \overline{AB}\,\mathrm{COS}(180 - (\phi/2 + \alpha))$$
$$= -2N_\phi \overline{AB}\,\mathrm{COS}(\phi/2 + \alpha) \quad ; \quad \text{Let } \beta = \phi/2+\alpha$$
$$= -2N_\phi \overline{AB}\,\mathrm{COS}\beta,$$

where N_ϕ is given by Equation 33. $\overline{AB}$ is given by $\overline{AB} = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2}$,

ϕ is given by Equation 49, and α is given by Equation 48.

This completes the restraint force computation. It remains to compute the volume change as a function of bag penetration.

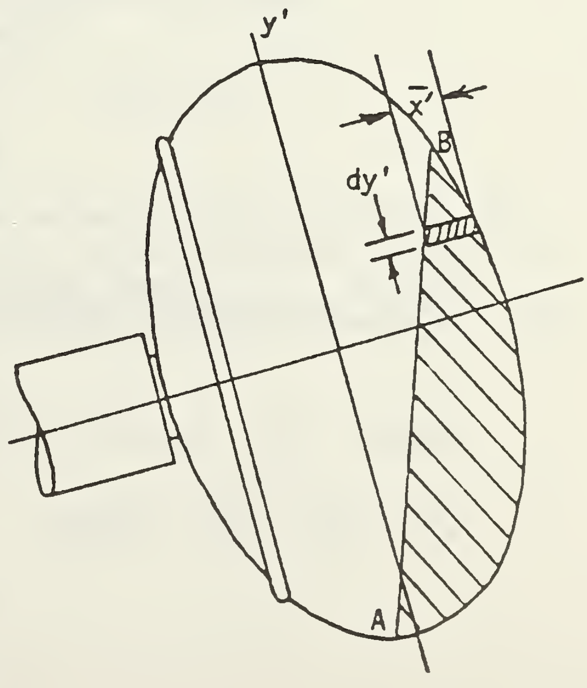
<u>Volume Analysis</u>

$$(51)\quad \text{Area of Intercept} = AOI = \int_{x_A}^{x_B} \bar{x}\,dy'$$

where,

$$\bar{x}' = x'_{BAG} - x'_{\underset{AB}{LINE}}$$

for a given y' between y_B and y_A.



For x'_{BAG},

$$x'_{BAG} = c\sqrt{1 - \frac{y'^2}{a^2}} \qquad \text{(Equation for bag original shape)}$$

$$BAG = \int_{y_A}^{y_B} c\sqrt{1 - \frac{y'^2}{a^2}}\, dy'$$

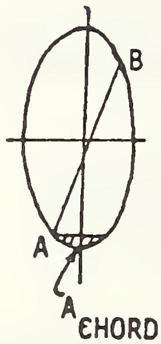
(52) $$BAG = \frac{c}{2a}\left[y'\sqrt{a^2 - y'^2} + a^2 SIN^{-1}\left(\frac{y'}{a}\right)\right]_{y'_A}^{y'_B} .$$

For $X'LINE_{AB}$, using analytic geometry,

$$X'LINE\overline{AB} = x_A - \left(\frac{x_A - x_B}{y_A - y_B}\, y_A\right) + \left(\frac{x_A - x_B}{(y_A - y_B)}\right) y' .$$

Therefore,

(53) $$LINE = \int_{y'_A}^{y'_B} x'_{LINE\,AB}\, dy' = \left[\left(x_A - \frac{(x_A - x_B)}{y_A - y_B}\, y_A\right) y' + \frac{(x_A - x_B)}{2(y_A - y_B)}\, y'^2\right]_{y_A}^{y_B} .$$



Under certain conditions (x_B and/or $x_A < 0$), we have to add "ACHORD":

$$ACHORD = 2\int_{y_A}^{-a} x_{BAG}\, dy' = c/a\left[y'\sqrt{a^2 - y'^2} + a^2 SIN^{-1}\,(y'/a)\right]_{y'_A}^{y'_B}$$

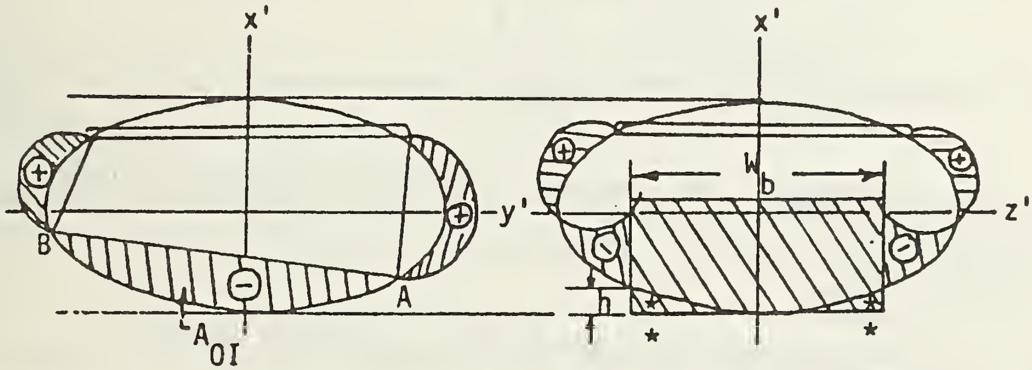
$$AOI = BAG - LINE + ACHORD$$

We now have the terms necessary for the volume of intercept calculation:

$$\text{(54)} \quad VOI \cong (AOI)W_{AVG} \quad .$$

where

$$W_{AVG} = \frac{(R_{FT} - R_{BAG})W_b + R_{HEAD} W_H}{R_{FT} - R_{BAG} + R_{HEAD}} \quad .$$



The error introduced by adding in the volume marked * above only occurs for $AB > W_b$ and will, for this condition, be a very small percentage of the total volume which will be compensated somewhat by bag stretch; i.e., we may approximate the missing volume * by (we assume LINE AB perpendicular to x-axis):

$$V_{MISSING} \cong \frac{2h_{AVG} \times \frac{W_b}{2} \times \overline{AB}}{2} \quad ,$$

where

$$h_{AVG} \approx \frac{h_{MAX} + h_{MIN}\nearrow^{0}}{2} = \frac{h_{MAX}}{2} = c - x' \text{ @ } y' = \frac{W_b}{2}$$

in

$$\frac{x'^2}{c^2} + \frac{y'^2}{a^2} = 1 ,$$

so that

$$h_{AVG} = \frac{c}{2}\left(1 - \sqrt{1 - \frac{W_b^2}{4a^2}}\right) ,$$

and,

$$V_{MISSING} \cong \frac{\frac{2c}{2}\left[1 - \sqrt{1 - \frac{W_b^2}{4a^2}}\right]}{2}\left(\frac{W_b}{2}\right)\left(\overline{AB}\right)$$

$$= \frac{W_b}{2}\ \overline{AB}\left(1 - \sqrt{1 - \frac{W_b^2}{4a^2}}\right) .$$

Since we are interested in this volume at the worst condition, high penetrations, let:

AB = 20 inches
a' = 13 inches
c' = 6 inches (a bag 26 inches high by 12 inches deep)
W_b = 15 inches
$V_{MISSING}$ = 13.7 cubic inches

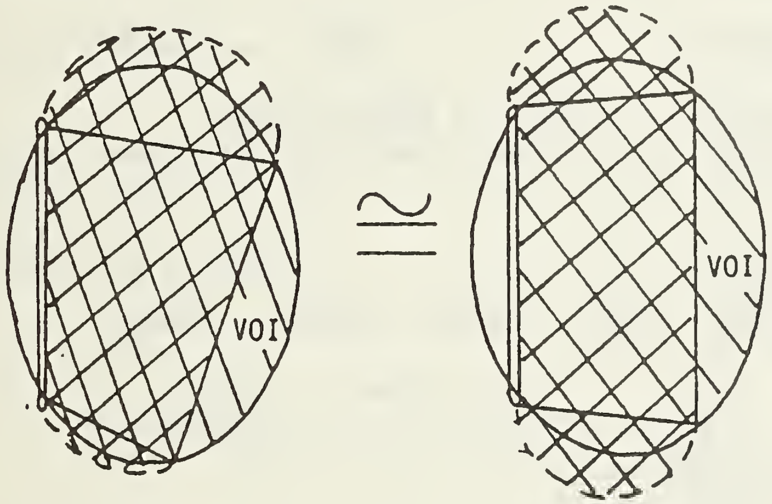
$$V_{BAG,\ ORIG.} = 4/3\pi\ a^2c = 4/3\pi\ (13)^2(6) = 4244 \text{ cubic inches}$$

$$\%\ ERROR = \frac{13.7}{4244} = 0.3\%, \text{ a negligible amount.}$$

We therefore conclude that we may safely sidestep the computation of the small volumes marked by the *.

The volume of the airbag for a given intercept $\overline{AB}$ is extremely difficult to compute exactly due to the assymmetry of the volumes marked by + and - on the previous page. In order to facilitate this computation we make the following assumption.

Assumption: The bag volume for a given volume of intercept, VOI, is independent of the torso inclination if the deformed periphery is the same; i.e., the crosshatched volumes are equal for constant periphery and constant volume of intercept (VOI).



The validity of this assumption must be checked by computer results versus test results.

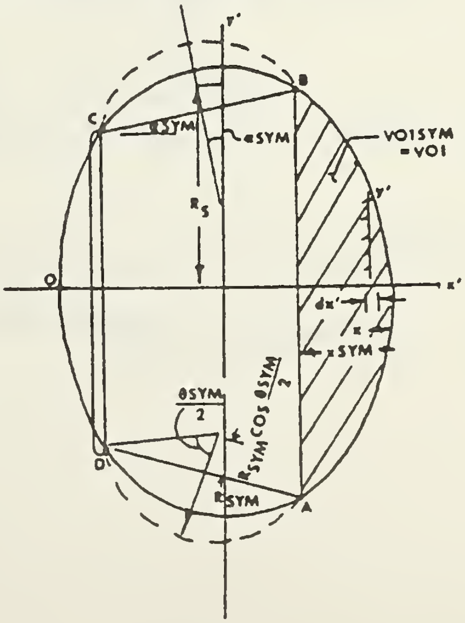
For subsequent volume computations we use the actual volume of intercept for a link in order to change the assymmetrical problem into a symmetrical one.

For the symmetrical case we assume a disc penetrates the bag.

(55) $$\text{VOISYM} = \int_0^{\text{xSYM}} \pi\, y'^2\, dx' \quad \text{where,}$$

(56) $$y'^2 = a^2\left(1 - \frac{(x' - c)^2}{c}\right)$$

(57) $$\text{VOISYM} = \int_0^{\text{xSYM}} \pi a^2 \left(1 - \frac{(x' - c)^2}{c^2}\right) dx'$$



(58) $$\text{VOISYM} = \pi a^2 \left[\text{xSYM} - \left(\frac{\text{xSYM}^3}{3c^2} - \frac{\text{xSYM}^2}{c} + \text{xSYM} \right) \right]$$

(59) $$\text{VOISYM} = \pi a^2 \left[-\frac{\text{xSYM}^3}{3c^2} + \frac{\text{xSYM}^2}{c} \right]$$

This cubic equation will be solved in the computer program by using the Newton-Raphson method.

For constant periphery;

(60) $$\text{Ellipse Perimeter} - 2\,(\overline{OC}) = 2\,\overset{\frown}{\text{BCSYM}} + \text{ABSYM}$$

Rewriting (60);

$$2\pi \sqrt{\frac{a^2 + c^2}{2}} - 2(\overline{OC}) = 2\,\overset{\frown}{\text{BCSYM}} + \overline{\text{ABSYM}} \qquad \text{where,}$$

$$\overline{\text{ABSYM}} = 2y' \text{ @ } x' = c - \text{xSYM} \quad \text{in} \quad \frac{x'^2}{c^2} + \frac{y'^2}{a^2} = 1$$

$$y' = a\sqrt{1 - \frac{(c - \text{xSYM})^2}{c^2}}$$

(61) $$\overline{\text{ABSYM}} = 2a\sqrt{1 - \frac{(c - \text{xSYM})^2}{c^2}}$$

Solving (60) for $\overset{\frown}{\text{BCSYM}}$

(62) $$\overset{\frown}{\text{BCSYM}} = \frac{2\pi\sqrt{\frac{a^2 + c^2}{2}} - 2\,\overline{OC} - 2a\sqrt{1 - \frac{(c-\text{xSYM})^2}{c^2}}}{2}$$

With $\overset{\frown}{\text{BCSYM}}$ known we can solve for RSYM and θSYM; i.e.,

(63) $$\text{RSYM}\,(\theta\text{SYM}) = \overset{\frown}{\text{BCSYM}}$$

$$(64) \quad RSYM\ SIN\left(\frac{\theta SYM}{2}\right) = \frac{\overline{BCSYM}}{2} \qquad \text{where,}$$

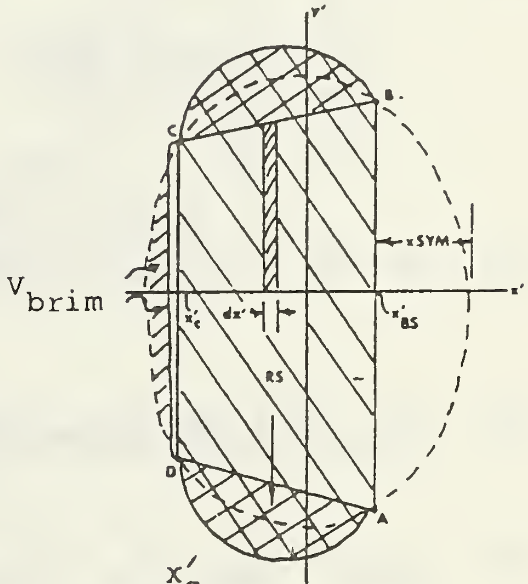
$$(65) \quad \overline{BCSYM} = \sqrt{(x'_B - x'_C)^2 + (y'_B - y'_C)^2} \qquad \text{(known)}$$

We now have 2 equations in 2 unknowns (63) & (64)

$$(66) \quad \frac{BCSYM}{\theta SYM}\ SIN\left(\frac{\theta SYM}{2}\right) = \frac{\overline{BCSYM}}{2}$$

This transcendental equation, like Equation 25 will be solved numerically on the computer for RSYM & θSYM.

Now to calculate the bag volume.



$$(67) \quad V_{ABCD} = \pi \int_{c-xSYM = x'_{BS}}^{x'_C} y'^2\, dx' \qquad \text{where,}$$

$$(68) \quad y' = \left(\frac{y'_{BS} - y'_C}{x'_{BS} - x'_C}\right)\left(x' - x'_C\right) + y'_C$$

Substituting (68) into (67):

$$(69) \quad V_{ABCD} = \pi\left[\left(\frac{y'_{BS} - y'_C}{x'_{BS} - x'_C}\right)^2 \int_{x'_{BS}}^{x'_C} (x' - x'_C)^2\, dx' + y'^2_C \int_{x'_{BS}}^{x'_C} dx' + 2y'_C\left(\frac{y'_{BS} - y'_C}{x'_{BS} - x'_C}\right)\int_{x'_{BS}}^{x'_C} (x' - x'_C)\, dx'\right]$$

where V_{ABCD} is the volume enclosed by the frustum ABCD.

(70) $$V_{BC} = 2\pi RS\left(\frac{1}{2}\,RSYM^2\left(\theta SYM - SIN(\theta SYM)\right)\right),$$

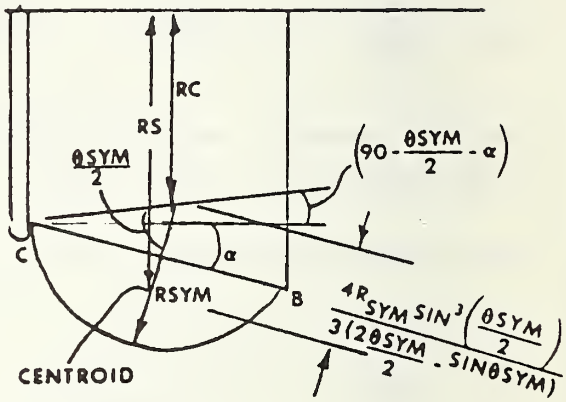
where V_{BC} is the volume of the ring around the volume V_{ABCD}.

RS = Distance to centroid of the segment BC · $\overline{BC}$

(71) $$\alpha = TAN^{-1}\left(\frac{y'_{BS} - y'_{C}}{x'_{BS} - x'_{C}}\right)$$

(72) $$RC = y'_{C} - RSYM\ SIN\left(90 - \frac{\theta SYM}{2} - \alpha\right)$$

$$= y'_{C} - RSYM\ COS\left(\frac{\theta SYM}{2} + \alpha\right)$$



(73) $$RS = RC + 4/3\left[\frac{RSYM\ SIN^3\left(\frac{\theta SYM}{2}\right)}{\theta SYM - SIN\ \theta SYM}\right]COS\alpha$$

(74) $V_{BRIM} = \frac{\pi}{6}\left(c+x'_c\right)\left(3y'^2_c+\left(c+x'_c\right)^2\right)$ substituting 69, 70, and 74 into 75 will yield the bag volume, V_{TOTAL}.

(75) $$V_{TOTAL} = V_{ABCD} + V_{BC} + V_{BRIM}$$

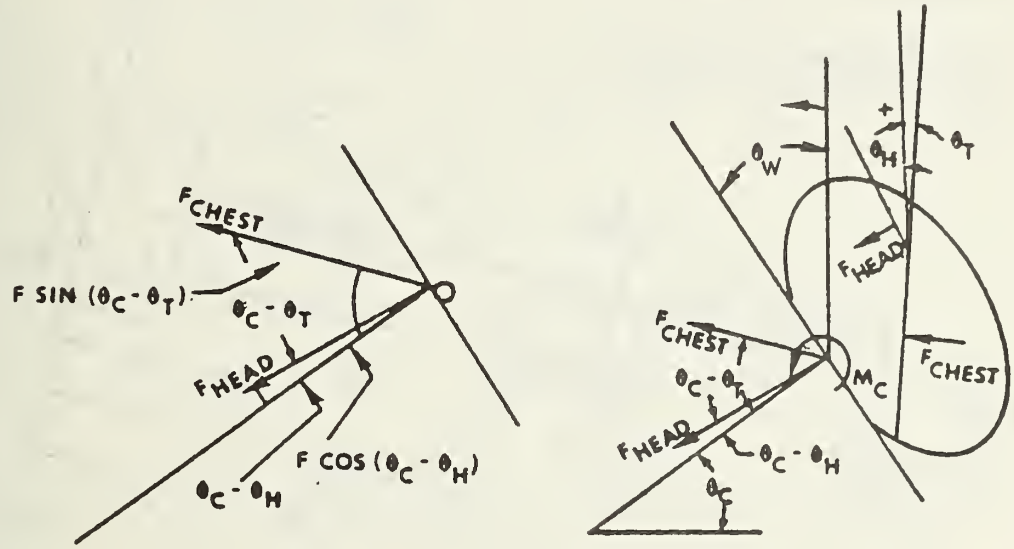
(For any $\overline{AB}$ resulting from a calculated volume of intercept, VOI.)

This completes the derivations necessary for programming the bag forces and geometry.

APPENDIX C

DERIVATION OF THE STEERING COLUMN ALGORITHM

COLUMN FORCE CALCULATIONS



The total force acting axially along the column is given by:

(76) $F_{AC} = F_{CHEST} \cos(\theta_C - \theta_T) + F_{HEAD} \cos(\theta_C - \theta_H)$

The total force acting normal to the column is given by:

(77) $F_{NC} = F_{CHEST} \sin(\theta_C - \theta_T) + F_{HEAD} \sin(\theta_C - \theta_H)$

The total moment acting at point O is given by:

(78) $M_O = F_{CHEST} \cdot t$ (t is shown on page 35 and calculated on page 53.

GM Type Column

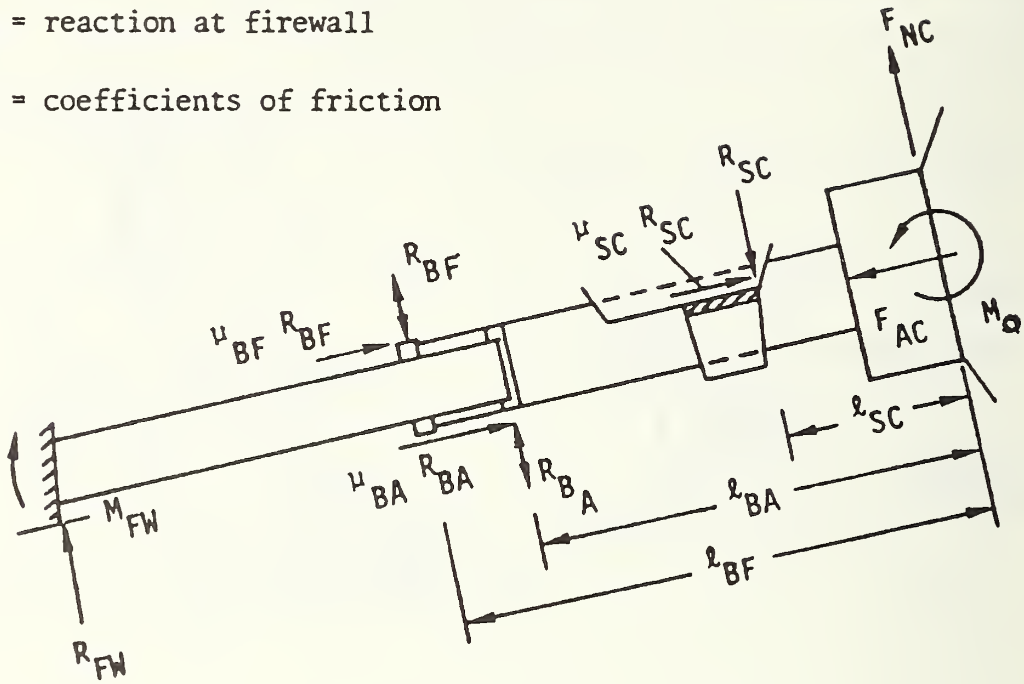
R_{SC} = reaction at shear capsule

R_{BA} = reaction at aft bushing

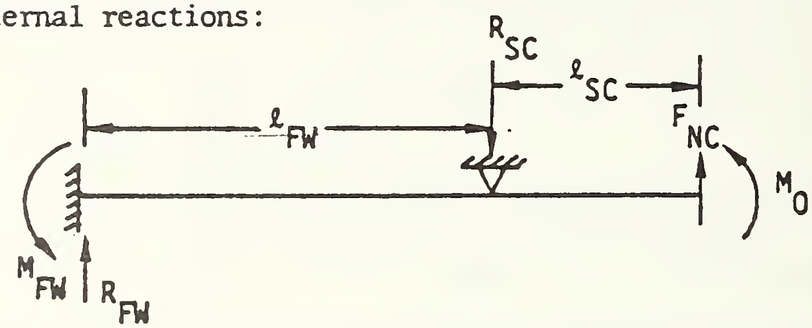
R_{BF} = reaction at forward bushing

R_{FW} = reaction at firewall

μ's = coefficients of friction



Solve for external reactions:



The problem is statically indeterminate; however, it can be reduced to:

$$R_{SC} = F_{NC} + \frac{\frac{3}{2}(M_O + F_{NC}\,\ell_{SC})}{\ell_{FW}} \tag{79}$$

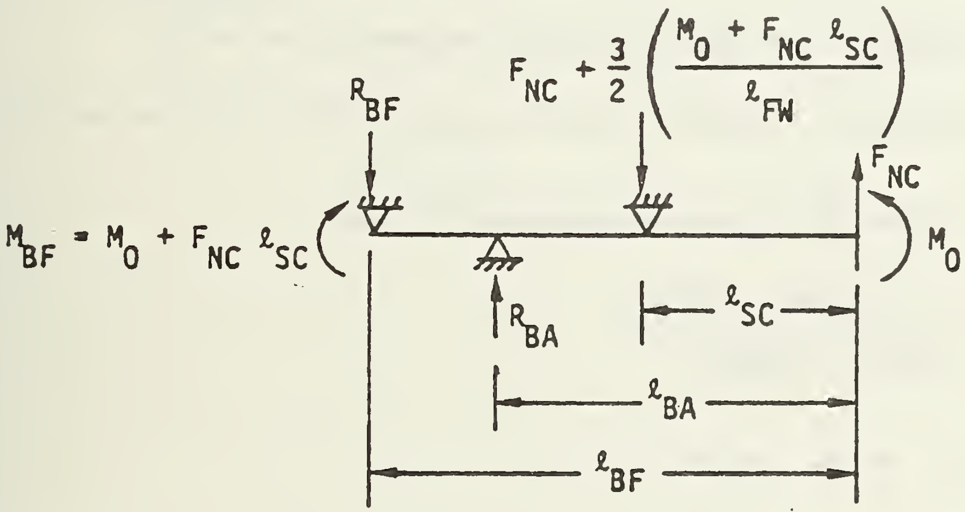
(80) $$R_{FW} = \frac{3}{2}\left(\frac{M_O + F_{NC}\,\ell_{SC}}{\ell_{FW}}\right)$$

(81) $$M_{FW} = \frac{M_O + F_{NC}\,\ell_{SC}}{2}$$

We may now solve for R_{BF} and R_{BA}.

$$\sum M_{BF} = M_{BF} = R_{BA}\,(\ell_{BF} - \ell_{BA}) - \left[F_{NC} + \frac{3}{2}\left(\frac{M_O + F_{NC}\,\ell_{SC}}{\ell_{FW}}\right)\right](\ell_{BF} - \ell_{SC})$$

$$+ F_{NC}\,\ell_{BF} + M_O = M_O + F_{NC}\,\ell_{SC}$$



Solving for R_{BA},

(82) $$R_{BA} = \frac{\left[F_{NC} + \frac{3}{2}\left(\frac{M_O + F_{NC}\,\ell_{SC}}{\ell_{FW}}\right)\right](\ell_{BF} - \ell_{SC}) + F_{NC}\,(\ell_{SC} - \ell_{BF})}{\ell_{BF} - \ell_{BA}}$$

$$\sum M_{BA} = 0 = -R_{BF}\,(\ell_{BF} - \ell_{BA}) + \left[F_{NC} + \frac{3}{2}\left(\frac{M_O + F_{NC}\,\ell_{SC}}{\ell_{FW}}\right)\right](\ell_{BA} - \ell_{SC})$$

$$- F_{NC}\,\ell_{BA} - M_O + M_O + F_{NC}\,\ell_{SC}$$

Solving for R_{BF},

(83) $$R_{BF} = \frac{\left[F_{NC} + \frac{3}{2}\left(\frac{M_O + F_{NC}\,\ell_{SC}}{\ell_{FW}}\right)\right](\ell_{BA} - \ell_{SC}) + F_{NC}\,(\ell_{SC} - \ell_{BA})}{\ell_{BF} - \ell_{BA}}$$

Note: For a pinned end at the firewall the 3/2 factor in Equations 79, 80, 82 and 83 is equal to 1.0 and $M_{FW} = 0$.

Solve for "t" the moment arm for F_P.

The methodology for this calculation is as follows:

1. Find equation for line from x'_o, y'_o perpendicular to $\overline{AB}$.

2. Find distance from this line to x'_{FT}, y'_{FT}. This distance is "t".

The equation for line $\overline{AB}$ is given by Equation 10, i.e.,

$$y' = \frac{B + x'\,(m\ \mathrm{COS}\theta_W - \mathrm{SIN}\theta_W)}{\mathrm{COS}\theta_W + m\ \mathrm{SIN}\theta_W}$$

where $B = y_2 - y_1 - m\,(x_2 - x_1)$.

The slope of $\overline{AB}$ is:

$$m' = \frac{m\ \mathrm{COS}\theta_W - \mathrm{SIN}\theta_W}{\mathrm{COS}\theta_W + m\ \mathrm{SIN}\theta_W}$$

For a line perpendicular to this line,

$$m'_{PAB} = -\frac{1}{m'}$$

The line from x'_o, y'_o perpendicular to $\overline{AB}$ is given by

$$(y' - y_o) = m'_{PAB}\,(x' - x_o)$$

Rewriting the equation,

$$-m'_{PAB}\ x' + y' - y_o + m'_{PAB}\ x_o = 0$$

The distance t is given by

$$(84)\qquad t = \frac{-m'_{PAB}\ x'_{FT} + y'_{FT} + (-y_o + m'_{PAB}\ x_o)}{\sqrt{m'^2_{PAB} + 1}}$$

$t > 0$ for x'_{FT}, y'_{FT} above a parallel line through point P (page B-7).

$t < 0$ for x'_{FT}, y'_{FT} below a parallel line through point P (page B-7).

APPENDIX D-1: PROGRAM LISTING

DRACR 07/28/82

```
100C                          **** DRACR ****
120C
140C
160C        THIS PROGRAM PREDICTS THE DRIVER KINEMATICS IN A CRASH SITUATION
180C        IN WHICH THE DRIVER IS RESTRAINED BY AN AIRBAG AND KNEE RESTRAINT.
200C        THE AIRBAG IS ATTACHED TO A STEERING COLUMN AND WHEEL THAT COLLAPSE
220C        ACCORDING TO A PREDETERMINED FORCE-CRUSH CHARACTERISTIC.
230C        IN ADDITION TO THE SIMPLE AXIAL CRUSH OF THE STEERING WHEEL AND
231C        STEERING COLUMN. THE PROGRAM HAS THE CAPABILITY OF INDIVIDUALLY
232C        SIMULATING BOTH STEERING WHEEL AND STEERING COLUMN ROTATION. THUS.
233C        FOUR SEPARATE ENERGY ABSORBING MODES ARE POSSIBLE FOR THE WHEEL
234C        AND COLUMN. WHICH ONE OF THESE MODES (IF ANY) WILL ACTUALLY OCCUR
235C        IN A GIVEN CRASH SITUATION DEPENDS UPON TWO CONDITIONS. FIRST. THE
236C        FORCE OR MOMENT MUST BE LARGE ENOUGH - THAT IS GREATER THAN THE FORC
E
237C        OR MOMENT CAPABLE OF BEING RESISTED BY THE WHEEL OR COLUMN. SECOND.
238C        IF THE FORCE  OR MOMENT IS LARGE ENOUGH FOR PERMANENT DEFORM-
239C        ATION IN MORE THAN ONE OF THESE FOUR MODES TO OCCUR. THE PROGRAM
240C        USES A MINIMUM ENERGY PRINCIPLE TO SELECT JUST WHICH  DEFORMATION
241C        MECHANISM ACTUALLY WILL OCCUR. THE ONE OF THE FOUR REQUIRING THE
242C        LEAST ENERGY IS THE ONE SELECTED.
300C        THE DRIVER IS MODELED BY THREE MASSES-A HEAD MASS. A TORSO MASS AND
320C        A LOWER BODY MASS. THE DRIVER IS CONSTRAINED TO HAVE PLANAR MOTION
340C        SO THAT THE PROGRAM IS STRICTLY APPLICABLE ONLY TO FRONTAL CRASH
360C        SITUATIONS.
380C        EVALUATIONS OF  AIRBAG. STEERING WHEEL. STEERING COLUMN. KNEE
400C        RESTRAINT AND VEHICLE PERFORMANCE CAN BE MADE BY APPROPRIATE CHANGES
420C        IN THE DESIGN PARAMETERS.
440C        TYPICAL DESIGN PARAMETERS THAT CAN BE EVALUATED ARE BAG SIZE. BAG
460C        SHAPE. INFLATION CHARACTERISTICS. VENT AREA. STEERING COLUMN AND/OR
480C        STEERING WHEEL CRUSH CHARACTERISTICS. KNEE RESTRAINT CRUSH CHAR-
500C        ACTERISTICS. STEERING COLUMN AND WHEEL SUPPORT STRUCTURE STIFFNESS.
520C        AS WELL AS OTHER SYSTEM PARAMETERS.
540C        THIS PROGRAM IS SELF CONTAINED IN THAT NO EXTERNAL FUNCTIONS OR
560C        SUBROUTINES ARE REQUIRED.
580C
600C            AUTHOR:   MICHAEL FITZPATRICK
620C                      FITZPATRICK ENGINEERING
640C                      WARSAW. INDIANA  46580
660C                      TEL.  (219)-267-4437
680C                      DEC.1. 1981
700C
720C
740C
760         FILENAME INFILE
780         COMMON/OUT/NPD.T(175).X0(6.175).X1(6.175).X2(6.175).X3(6.175).X4(6.1
75).
800         &X5(6.175).X6(6.175).X7(6.175).X8(6.175).X10(6.175)
820         COMMON/OUT1/N9.X9(4.175).T9(175)
840         COMMON/NAME/INFILE
860         COMMON/FLAG/NCOLTYPE
870         COMMON/TIME/STEP.XSTOP.PINT1.ILOOP
```

```
      COMMON/HIC/THIC(175),HRGS(175)
 1050 PRINT ,"INPUT FILE NAME"
      INPUT ,INFILE
      PRINT,"ENTER 1 IF COLUMN IS SUPPORTED AT THE FIREWALL: OTHERWISE
      & ENTER 2"
      INPUT,NCOLTYPE
      NPD=0
       N9=0
       CALL SOLVE(8)
       IF(NPD.GT.175)NPD=175
       IF(N9.GT.175)N9=175
  1120 FORMAT(1H-)
  1125 FORMAT(F7.4,2F6.1,2F7.2,2F8.3,F8.1,2F7.2)
  1130 FORMAT(1X,7F11.2)
  1140 FORMAT(V)
  1150 FORMAT(1X,7(4X,"=======")//)
       PRINT 1120
  1170 FORMAT(1X,"      TIME     VEH G'S    VEH VEL    VEH DISP   BODY
       & G'S  COL DISP   BAG PRESS"/1X,"       (MS)       (G'S)       (MPH)
       &     (INCHES)     (G'S)    (INCHES)   (PSIG)")
       PRINT 1170
       PRINT 1150
        DO 1221 K=1,NPD
  1221 PRINT 1130,T(K),(X0(J,K),J=1,6)
       PRINT 1120
  1223 FORMAT(1X,"      TIME    FEM ANGLE   H-P VEL    H-P ACC   FEM FO
       &RCE   SEAT FR.   H-P R.D."/1X,"      (MS)       (DEG)      (MPH)
       &      (G'S)      (LBS)      (LBS)      (INCHES)")
       PRINT 1223
       PRINT 1150
       DO 1230 K=1,NPD
  1230 PRINT 1130,T(K),(X1(J,K),J=1,6)
       PRINT 1120
  1250 FORMAT(1X,"      TIME   TORSO DISP  TORSO ANG  TORSO VEL  TORSO
       & ACC  TORSO R.D.  TORSO R.V."/1X,"       (MS)    (INCHES)
       &     (DEG)     (D/SEC)   (D/SEC**2)  (INCHES)    (MPH)")
       PRINT 1250
       PRINT 1150
       DO 1310 K=1,NPD
  1310 PRINT 1130,T(K),(X2(J,K),J=1,6)
       PRINT 1120
  1330 FORMAT(1X,"      TIME    HEAD DISP   HEAD ANG   HEAD VEL  HEAD
       & ACC   HEAD R.D.   HEAD R.ANG"/1X,"       (MS)    (INCHES)
       &     (DEG)     (D/SEC)   (D/SEC**2)  (INCHES)    (DEG)")
       PRINT 1330
       PRINT 1150
       DO 1380 K=1,NPD
  1380 PRINT 1130,T(K),(X3(J,K),J=1,6)
       PRINT 1120
  1390 FORMAT(1X,"      TIME    WH AX FOR   WH N FOR   WH MOMENT  WH
```

```
1860        & RESIST  WH STROKE  WH ST VEL"/1X."      (MS)       (LBS)
1880        &       (LBS)      (IN-LBS)     (LBS)      (INCHES)   (IN/SEC)")
1900        PRINT 1390
1920        PRINT 1150
1940        DO 1395 K=1.NPD
1960   1395 PRINT 1130.T(K).(X4(J.K).J=1.6)
1980        PRINT 1120
2000   1400 FORMAT(1X."       TIME   COL AX FOR  COL N FOR  COL MOMENT COL
2020        & RESIST COL STROKE COL ST VEL"/1X."      (MS)       (LBS)
2040        &       (LBS)      (IN-LBS)     (LBS)      (INCHES)   (IN/SEC)")
2060        PRINT 1400
2080        PRINT 1150
2100        DO 1460 K=1.NPD
2120   1460 PRINT 1130.T(K).(X5(J.K).J=1.6)
2140        PRINT 1120
2160   1465 FORMAT(1X."       TIME    WH AP MOM  WH RES MOM  WH ANGLE  WH
2180        & ANG VEL"/1X."      (MS)      (IN-LBS)   (IN-LBS)    (DEG)
2200        &     (DEG/SEC)")
2220        PRINT 1465
2240        PRINT 1150
2260        DO 1470 K=1.NPD
2280   1470 PRINT 1130.T(K).(X6(J.K).J=1.4)
2300        PRINT 1120
2320   1473 FORMAT(1X."       TIME   COL AP MOM COL RES MOM COL ANGLE COL
2340        & ANG VEL"/1X."      (MS)      (IN-LBS)   (IN-LBS)    (DEG)
2360        &     (DEG/SEC)")
2380        PRINT 1473
2400        PRINT 1150
2420        DO 1477 K=1.NPD
2440   1477 PRINT 1130.T(K).(X7(J.K).J=1.4)
2460        PRINT 1120
2480   1480 FORMAT(1X."       TIME      BAG PEN.   BAG VOL.  BAG PRESS.  W/A
2500        & FORCE  P. FORCE"/1X."      (MS)      (INCHES)   (CU.IN.)
2520        &   (PSIG)      (LBS)       (LBS)")
2540        PRINT 1480
2560        PRINT 1150
2580        DO 1540 K=1.NPD
2600   1540 PRINT 1130.T(K).(X8(J.K).J=1.5)
2620        PRINT 1120
2640   1560 FORMAT(1X."       TIME      CHEST AP   CHEST SI   HEAD AP
2660        &    HEAD SI"/1X."      (MS)       (G'S)       (G'S)       (G'S)
2680        &      (G'S)")
2700        PRINT 1560
2720        PRINT 1150
2740        DO 1620 K=1.N9
2760   1620 PRINT 1130.T9(K).(X9(J.K).J=1.4):PRINT 1120
2780   1622 FORMAT(1X."       TIME       EAWC        EACC        EAWR        EACR
2800        &          EA"/1X."      (MS)       (LBS)       (LBS)       (LBS)
2820        &    (LBS)       (LBS)  ")
2840        PRINT 1622
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DRACR 07/28/82

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      PRINT 1150
      DO 1625 K=1.NPD
 1625 PRINT 1130.T(K).(X10(J.K).J=1.5)
      PRINT 1120
 1630 PRINT."ENTER 1 TO CALCULATE HIC"
      INPUT .NRES
      IF(NRES.NE.1) GO TO 2000
 1640 PEAK=0.
      NSTOP=N9
      DO 1715 I=1.NSTOP
      DO 1716 J=1.I
      L=I+1
      SUM=0.
      DO 1717 K=1.J
      L=L-1
      SUM=SUM+HRGS(L)*PINT1
 1717 CONTINUE
      DELT=THIC(K)
      CHECK=SUM/DELT
      IF(PEAK-CHECK) 1718.1716.1716
 1718 PEAK=CHECK
      TLOW=(L-1)*PINT1
      THIGH=I*PINT1
 1716 CONTINUE
 1715 CONTINUE
      HIC=PEAK**2.5
      PRINT."THE HIC IS".HIC
      PRINT."T1=".TLOW
      PRINT."T2=".THIGH
 2000 STOP
      END
C
C     THIS SUBROUTINE SETS UP THE DIFFERENTIAL EQUATIONS THAT DESCRIBE
C     THE DRIVER KINEMATICS.
      SUBROUTINE DIFEQ(T.Y.DY)
      COMMON/MANDAT/ZL.ZT.ZH.RT.RN.RH.RTOPH.X2Z.Y2Z.WB.WH
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      CALL FORCETH(Y.TNECK)
      CALL DECEL(T.GS)
      CALL BAGSUB(T.Y.TNECK.FTH.FX.FTT.GS)
      SH=SIN(Y(6))
      ST=SIN(Y(7))
      CH=COS(Y(6))
      CT=COS(Y(7))
      DY(1)=(FX-(ZT*RT+ZH*RN)*(CT*DY(3)-ST*Y(3)*Y(3))
      &-ZH*RH*(CH*DY(2)-SH*Y(2)*Y(2)))/(ZL+ZT+ZH)
      DY(2)=(FTH-ZH*RH*DY(1)*CH-ZH*RN*RH*(CT*CH*DY(3)+CT*SH*Y(3)
      &*Y(3)-ST*CH*Y(3)*Y(3)+ST*SH*DY(3))+ZH*32.17*SH*RH)
      &/(ZH*RH*RH)
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DRACR 07/28/82

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      DY(3)=(FTT-(ZT*RT+ZH*RN)*DY(1)*CT-ZH*RN*RH*(CT*CH*DY(2)+Y(2)
      &*Y(2)*(ST*CH-CT*SH)+ST*SH*DY(2))+ZT*32.17*RT*ST+ZH*32.17*RN*ST)
      &/(ZT*RT*RT+ZH*RN*RN)
      DY(4)=-GS
      DY(5)=Y(1)
      DY(6)=Y(2)
      DY(7)=Y(3)
      DY(8)=Y(4)
      RETURN
      END
C
C     THIS SUBROUTINE READS IN THE INPUT DATA. SETS UP THE INPUT DATA
C     FOR DISPLAY AND INITIALIZES KEY VARIABLES.
      SUBROUTINE SETUP(X,Y)
      REAL MU,MC,LSC,LFW,LBA,LBF,LSCZ,LFWZ,LBAZ,LBFZ,KRN,MIP,MWH,MFW,LT,L
F
      COMMON/WROTP/NPWRP,WHRP(2,12),OMWO,THETAWO
      COMMON/WROTN/NPWRN,WHRN(2,12)
      COMMON/CROTP/NPCRP,COLRP(2,12),OMCO,THETACO
      COMMON/CROTN/NPCRN,COLRN(2,12)
      COMMON/SEATFRIC/NSF,SUN,SFUT,RELSF,SFN(2,12)
      COMMON/KNEEREST/NKR,SKR,RUT,RELKR,KRN(2,12)
      COMMON/NAME/INFILE,OUTFILE
      FILENAME INFILE,OUTFILE
      COMMON/MANDAT/ZL,ZT,ZH,RT,RN,RH,RTOPH,X2Z,Y2Z,WB,WH
      COMMON/MMANDAT/LT,LF,THFO,THLO,DELTTB,THEF
      COMMON/NECK/NPN,FNECK(2,12),DCN
      COMMON/VEH/NV,VEHGS(2,30)
      COMMON/GASFLO/NPG,GEN(2,12)
      COMMON/WHFOR/NPW,WHE(2,12),VWHCO,SWHCO
      COMMON/COLFOR/NPC,COL(2,12)
      COMMON/GASDAT/ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
      COMMON/BAGDAT/VC1,VC2,AV,SA,SC,X1,Y1
      COMMON/COLDAT/THETAC,THETACZ,MU,LSCZ,LFWZ,LBAZ,LBFZ,WC,RCOL
      COMMON/WHEEL/XWH,YWH,YO,RIMRAD,RIP,WWH,WIP,MIP,MWH
      COMMON/PARAM/RFT,THETATZ,THETAHZ,FAW,FNW,FRW,SWHC,VWHC,TAW,TRW
      COMMON/MMPARAM/BP,VOL,FFT,FP,THETAW,THETAWZ,OMW,TAC,TRC,RBRKT,OMC
      COMMON/MISC/VCOLCO,SCOLCO,PR8,BIG
      COMMON/MMISC/FM2,PA5,GT,FPN,MC,VOLO,GW,LSC,LFW,LBA,LBF
      DOUBLE PRECISION Y(8)
      X=0.
2070  FORMAT(V)
2080  FORMAT(1X,"INITIAL VELOCITY:  ",G10.3/1X,
      &"INITIAL HEAD ANGLE:  ",G10.3/1X,"INITIAL TORSO ANGLE:  ",
      &G10.3)
2100  FORMAT(1X,
      &"      MLEG    MTORSO     MHEAD         RT          RN          RH
      &      RTOPH"/1X,7G10.3)
2120  FORMAT(1X,"     ATMOP      PGZ       GTZ           U          PN1
      &      PN2       PN3"/1X,7G10.3)
2122  FORMAT(1X,"    THETAW       RIP        WWH        WIP         RCOL
```

```
     &       DCN"/1X,6G10.3)
2130 FORMAT(1X,"       VC1       VC2       AV        SA        SC
     &       X1Z       Y1Z"/1X,7G10.3)
2132 FORMAT(1X,"     THETAC      MU       LSCZ      LFWZ
     &       LBAZ      LBFZ      WC"/1X,8G10.3)
2133 FORMAT(1X,"       LF        THFO      THLO"
     &/1X,5G10.3)
2134 FORMAT(1X,"       XWH       RIMRAD    X2Z       Y2Z
     &       WB        WH"/1X,7G10.3)
2135 FORMAT(1X,"GAS FLOW TIME - MSEC"/1X,10G10.3)
2136 FORMAT(1X,"GAS FLOW - LB/SEC"/1X,10G10.3)
2137 FORMAT(1X,"COLUMN STROKE - INCHES"/1X,10G10.3)
2138 FORMAT(1X,"COLUMN FORCE - LBS"/1X,10G10.3)
2140 FORMAT(1X,"NECK ANGLE - DEG"/1X,10G10.3)
2150 FORMAT(1X,"NECK TORQUE - FT-LBS"/1X,10G10.3)
2160 FORMAT(1X,"     NPTS NECK  NPTS KR  NPTS VEH  NPTS SEAT NPTS GAS
     &  NPTS COL  NPTS WHC"/1X,10G10.3)
2170 FORMAT(1X,"     NP WRP    NP WRN    NP CRP    NP CRN"/1X,10G10.3)
2180 FORMAT(1X,"     SL SEAT  SL KR"/1X,10G10.3)
2250 FORMAT(1X,"VEH. PULSE TIME - MSEC"/1X,10G10.3)
2260 FORMAT(1X,"VEH. PULSE DECELERATION - G'S"/1X,10G10.3)
2265 FORMAT(1X,"SEAT FRICTION DISPLACEMENT - INCHES"/1X,10G10.3)
2267 FORMAT(1X,"SEAT FRICTION FORCE - LBS"/1X,10G10.3)
2268 FORMAT(1X,"KNEE DISPLACEMENT - INCHES"/1X,10G10.3)
2269 FORMAT(1X,"KNEE FORCE - LBS"/1X,10G10.3)
2280 FORMAT(1X,"WHEEL STROKE - INCHES"/1X,10G10.3)
2290 FORMAT(1X,"WHEEL FORCE - LBS"/1X,10G10.3)
2300 FORMAT(1X,"WHEEL ANGLE, POS. - DEG "/1X,10G10.3)
2310 FORMAT(1X,"WHEEL TORQUE, POS. - IN-LBS"/1X,10G10.3)
2314 FORMAT(1X,"WHEEL ANGLE, NEG. - DEG"/1X,10G10.3)
2318 FORMAT(1X,"WHEEL TORQUE, NEG. - IN-LBS"/1X,10G10.3)
2320 FORMAT(1X,"COLUMN ANGLE, POS. - DEG"/1X,10G10.3)
2330 FORMAT(1X,"COLUMN REACTION, POS. - IN-LBS IF 2: LBS IF 1"/1X,10G10.
3)
2334 FORMAT(1X,"COLUMN ANGLE, NEG. - DEG"/1X,10G10.3)
2338 FORMAT(1X,"COLUMN REACTION, NEG. - IN-LBS IF 2: LBS IF 1"/1X,10G10.
3)
     READ(INFILE,2070)Y(4),Y(6),Y(7)
     READ(INFILE,2070)ZL,ZT,ZH,RT,RN,RH,RTOPH
     READ(INFILE,2070)NPN,NKR,NV,NSF,NPG,NPC,NPW,NPWRP,NPWRN,NPCRP,NPCRN
     READ(INFILE,2070)SUN,SKR
     READ(INFILE,2070)(GEN(1,K),K=1,NPG)
     READ(INFILE,2070)(GEN(2,K),K=1,NPG)
     READ(INFILE,2070)(COL(1,K),K=1,NPC)
     READ(INFILE,2070)(COL(2,K),K=1,NPC)
     READ(INFILE,2070)ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
     READ(INFILE,2070)THETAW,RIP,WWH,WIP,RCOL,DCN
     READ(INFILE,2070)VC1,VC2,AV,SA,SC,X1Z,Y1Z
     READ(INFILE,2070)THETAC,MU,LSCZ,LFWZ,LBAZ,LBFZ,WC
     READ(INFILE,2070)LF,THFO,THLO
     READ(INFILE,2070)XWH,RIMRAD,X2Z,Y2Z,WB,WH
     READ(INFILE,2070)(SFN(1,K),K=1,NSF)
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      READ(INFILE,2070)(SFN(2,K),K=1,NSF)
      READ(INFILE,2070)(FNECK(1,K),K=1,NPN)
      READ(INFILE,2070)(FNECK(2,K),K=1,NPN)
      READ(INFILE,2070)(VEHGS(1,K),K=1,NV)
      READ(INFILE,2070)(VEHGS(2,K),K=1,NV)
      READ(INFILE,2070)(KRN(1,K),K=1,NKR)
      READ(INFILE,2070)(KRN(2,K),K=1,NKR)
      READ(INFILE,2070)(WHE(1,K),K=1,NPW)
      READ(INFILE,2070)(WHE(2,K),K=1,NPW)
      READ(INFILE,2070)(WHRP(1,K),K=1,NPWRP)
      READ(INFILE,2070)(WHRP(2,K),K=1,NPWRP)
      READ(INFILE,2070)(WHRN(1,K),K=1,NPWRN)
      READ(INFILE,2070)(WHRN(2,K),K=1,NPWRN)
      READ(INFILE,2070)(COLRP(1,K),K=1,NPCRP)
      READ(INFILE,2070)(COLRP(2,K),K=1,NPCRP)
      READ(INFILE,2070)(COLRN(1,K),K=1,NPCRN)
      READ(INFILE,2070)(COLRN(2,K),K=1,NPCRN)
      PRINT 2490
      PRINT ,"INPUT VALUES -- INPUT UNITS( MSEC, MPH, DEGREES,
     & INCHES, LBS, FT-LBS, G'S)"
 2480 FORMAT(1X,10G10.3)
 2490 FORMAT(1H-)
 2520 PRINT 2080,Y(4),Y(6),Y(7)
      PRINT 2100,ZL,ZT,ZH,RT,RN,RH,RTOPH
      PRINT 2160,NPN,NKR,NV,NSF,NPG,NPC,NPW
      PRINT 2170,NPWRP,NPWRN,NPCRP,NPCRN
      PRINT 2180,SUN,SKR
      PRINT 2135,(GEN(1,K),K=1,NPG)
      PRINT 2136,(GEN(2,K),K=1,NPG)
      PRINT 2137,(COL(1,K),K=1,NPC)
      PRINT 2138,(COL(2,K),K=1,NPC)
      PRINT 2265,(SFN(1,K),K=1,NSF)
      PRINT 2267,(SFN(2,K),K=1,NSF)
      PRINT 2140,(FNECK(1,K),K=1,NPN)
      PRINT 2150,(FNECK(2,K),K=1,NPN)
      PRINT 2250,(VEHGS(1,K),K=1,NV)
      PRINT 2260,(VEHGS(2,K),K=1,NV)
      PRINT 2268,(KRN(1,K),K=1,NKR)
      PRINT 2269,(KRN(2,K),K=1,NKR)
      PRINT 2280,(WHE(1,K),K=1,NPW)
      PRINT 2290,(WHE(2,K),K=1,NPW)
      PRINT 2300,(WHRP(1,K),K=1,NPWRP)
      PRINT 2310,(WHRP(2,K),K=1,NPWRP)
      PRINT 2314,(WHRN(1,K),K=1,NPWRN)
      PRINT 2318,(WHRN(2,K),K=1,NPWRN)
      PRINT 2320,(COLRP(1,K),K=1,NPCRP)
      PRINT 2330,(COLRP(2,K),K=1,NPCRP)
      PRINT 2334,(COLRN(1,K),K=1,NPCRN)
      PRINT 2338,(COLRN(2,K),K=1,NPCRN)
      PRINT 2120,ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
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```
      PRINT 2130,VC1,VC2,AV,SA,SC,X1Z,Y1Z
      PRINT 2132,THETAC,MU,LSCZ,LFWZ,LBAZ,LBFZ,WC
      PRINT 2133,LF,THFO,THLO
      PRINT 2134,XWH,RIMRAD,X2Z,Y2Z,WB,WH
      PRINT 2122,THETAW,RIP,WWH,WIP,RCOL,DCN
      Y(2)=0.
      Y(3)=0.
      Y(4)=Y(4)*1.4666667
      Y(5)=0.
      Y(6)=Y(6)*.01745329
      THETAHZ=Y(6)
      Y(7)=Y(7)*.01745329
      THETATZ=Y(7)
      Y(8)=0.
      Y(1)=Y(4)
      THFO=THFO*.01745329
      THLO=THLO*.01745329
      LT=(Y2Z+LF*SIN(THFO))/SIN(THLO)
      DELTTB=(X2Z-LT*COS(THLO)-LF*COS(THFO))*COS(THLO)
      ZL=ZL/32.17
      ZT=ZT/32.17
      ZH=ZH/32.17
      RT=RT/12.
      RN=RN/12.
      RH=RH/12.
      RTOPH=RTOPH/12.
      SUN=SUN*12.
      SKR=SKR*12.
      THETAW=THETAW*.01745329
      THETAC=THETAC*.01745329
      ADD=SC*SQRT(1.-RIMRAD**2/SA**2)
      X1=X1Z+ADD*COS(THETAW)
      Y1=Y1Z+ADD*SIN(THETAW)
      VWHCO=0.
      SWHCO=0.
      VCOLCO=0.
      SCOLCO=0.
      OMWO=0.
      THETAWZ=THETAW
      THETAWO=THETAW
      OMCO=0.
      THETACZ=THETAC
      THETACO=THETAC
      PR8=(2./(PN1+1.))**(PN1/(PN1-1.))
      FM2=VC2*SQRT(PR8**(2./PN1)-PR8**((PN1+1.)/PN1))
      PA=PGZ+ATMOP
      PA5=PA
      GT=GTZ
      FPN=PN2
      MWH=WWH/386.
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```
      MIP=WIP/386.
      MC=WC/386.
      VOLZ=4./3.*3.14159*SA**2*SC
      VOLO=VOLZ
      GW=(PA*VOLZ)/(U*CTZ)
      LSC=LSCZ
      LFW=LFWZ
      LBA=LBAZ
      LDF=LBFZ
      DO 3010 J=1,12
      GEN(1,J)=GEN(1,J)/1000.
      FNECK(1,J)=FNECK(1,J)*.01745329
      WHRP(1,J)=WHRP(1,J)*.01745329
      WHRN(1,J)=WHRN(1,J)*.01745329
      COLRP(1,J)=COLRP(1,J)*.01745329
      COLRN(1,J)=COLRN(1,J)*.01745329
      SFN(1,J)=SFN(1,J)/12.
 3010 KRN(1,J)=KRN(1,J)/12.
      DO 3050 J=1,30
      VEHGS(1,J)=VEHGS(1,J)/1000.
 3050 VEHGS(2,J)=VEHGS(2,J)*32.17
      SFUT=0.
      RUT=0.
      YO=0.
      YWH=0.
      BIG=1000000.
  CONTINUE
      RETURN
      END
C
C     THIS SUBROUTINE IS A GENERALIZED TABLE LOOKUP AND INTERPOLATION
C     ROUTINE WHICH IS CALLED BY OTHER ROUTINES.
      SUBROUTINE LOOKUP(A,FUN,NPTS,B)
      DIMENSION FUN(2,30)
      DO 3190 J=1,NPTS
 3190 IF(FUN(1,J).GT.A)GOTO3200
 3200 IF(J.EQ.1)J=2
      K=J-1
      B=(A-FUN(1,K))*(FUN(2,J)-FUN(2,K))/(FUN(1,J)-FUN(1,K))+FUN(2,K)
      RETURN
      END
C
C     THIS SUBROUTINE CALCULATES THE NECK TORQUE AS A FUNCTION OF THE
C     NECK ANGLE.
      SUBROUTINE FORCETH(Y,TNECK)
      COMMON/NECK/NPN,FNECK(2,12),DCN
      DOUBLE PRECISION Y(8)
      TNECK=0.
      TDAMP=-DCN*(Y(2)-Y(3))
      VREL=Y(2)-Y(3)
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DRACR 07/28/82

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      TREL=Y(6)-Y(7)
      IF(TREL.GT.0.0.AND.VREL.LT.0.)GO TO 10
      IF(TREL.LT.0.0.AND.VREL.GT.0.)GO TO 10
      CALL LOOKUP(TREL.FNECK.NPN.TNECK)
   10 TNECK=TNECK+TDAMP
      RETURN
      END
C
C     THIS SUBROUTINE OBTAINS THE CRASH PULSE G'S AS A FUNCTION OF TIME.
      SUBROUTINE DECEL(T.GS)
      COMMON/VEH/NV.VEHGS(2.30)
      CALL LOOKUP(T.VEHGS.NV.GS)
      RETURN
      END
C
C     THIS SUBROUTINE COMPRISES THE MAJOR PART OF THE DRACR PROGRAM. IT
C     EVALUATES THE BAG SHAPE AS A FUNCTION OF BAG PENETRATION AND TORSO
C     ANGLE, CALCULATES THE FORCES THE BAG APPLIES TO THE DRIVER, CALC-
C     ULATES THE BAG VOLUME AND PRESSURE, DETERMINES THE GAS GENERATOR
C     FLOW CHARACTERISTICS AND CALCULATES THE STEERING COLUMN AND WHEEL
C     FORCES, MOMENTS, CRUSH AND ROTATION.
      SUBROUTINE BAGSUB(X.Y.TNECK.FTH.FX.FTT.GS)
      REAL MFW,MU,LSC.LFW.LBA.LBF.LFWZ.LSCZ.LBAZ.LBFZ.MO.MC.MIP.MWH
      REAL KRN.LT.LF
      COMMON/FLAG/NCOLTYPE
      COMMON/WROTP/NPWRP.WHRP(2.12).OMWO.THETAWO
      COMMON/WROTN/NPWRN.WHRN(2.12)
      COMMON/CROTP/NPCRP.COLRP(2.12).OMCO.THETACO
      COMMON/CROTN/NPCRN,COLRN(2,12)
      COMMON/SEATFRIC/NSF.SUN.SFUT.RELSF.SFN(2.12)
      COMMON/MANDAT/ZL,ZT.ZH.RT.RN.RH.RTOPH.X2Z.Y2Z.WB.WH
      COMMON/MMANDAT/LT.LF.THFO.THLO.DELTTB.THEF
      COMMON/KNEEREST/NKR.SKR.RUT.RELKR.KRN(2.12)
      COMMON/GASFLO/NPG.GEN(2.12)
      COMMON/WHFOR/NPW.WHE(2,12).VWHCO.SWHCO
      COMMON/COLFOR/NPC.COL(2,12)
      COMMON/GASDAT/ATMOP.PGZ.GTZ.U.PN1.PN2.PN3
      COMMON/BAGDAT/VC1.VC2.AV.SA.SC.X1.Y1
      COMMON/COLDAT/THETAC.THETACZ.MU.LSCZ.LFWZ.LBAZ.LBFZ.WC.RCOL
      COMMON/WHEEL/XWH.YWH.YO.RIMRAD.RIP.WWH.WIP.MIP.MWH
      COMMON/MISC/VCOLCO,SCOLCO.PR8.BIG
      COMMON/MMISC/FM2.PA5.GT.FPN.MC.VOLO.GW.LSC.LFW.LBA.LBF
      COMMON/PARAM/RFT.THETATZ.THETAHZ.FAW.FNW.FRW.SWHC.VWHC.TAW.TRW
      COMMON/TIME/STEP.XSTOP.PINT1,ILOOP
      COMMON/MPARAM/FACOL.SCOLC.PG1,FKNEE.SF,FNCOL.MO.FRCOL.VCOLC.REACT
      COMMON/MMPARAM/BP.VOL.FFT.FP.THETAW.THETAWZ.OMW.TAC.TRC.RBRKT.OMC
      COMMON/EABS/EAWC.EACC.EAWR,EACR.EA
      DOUBLE PRECISION Y(8).B.A.D.E.A1.B1.C1.X2.Y2
    5 FORMAT(1H-)
      DIMENSION DY(8)
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      WBACT=WB
      WHACT=WH
      THETAT=Y(7)
      THETAH=Y(6)
C     CHECK TO SEE IF DRIVER SUBMARINING.
      IF(ABS(THETAW-THETAT).GT.1.4) GO TO 500
C     CALCULATE THE SLOPE OF THE DRIVER TORSO.
      OSLOPE=TAN(3.14159/2.+THETAT)
C     CALCULATE THE NEW H-POINT COORDINATES AND THE X-COORDINATE OF THE
C     POINT WHERE THE RIM INTERSECTS THE BAG.
      X2=X2Z-(Y(5)-Y(8))*12.
      Y2=Y2Z
      XC=-SC*SQRT(1.-RIMRAD**2/SA**2)
      B=Y2-Y1-OSLOPE*(X2-X1)
      A=SA**2*(COS(THETAW)+OSLOPE*SIN(THETAW))**2
      &+SC**2*(SIN(THETAW)-OSLOPE*COS(THETAW))**2
      D=2.*B*SC**2*(OSLOPE*COS(THETAW)-SIN(THETAW))
      E=B**2*(SC**2)-SA**2*(SC**2)*(COS(THETAW)+OSLOPE*SIN(THETAW))**2
C     TEST FOR SIGN OF DISCRIMINATE
    6 IF (D**2-4.*A*E) 80,7,7
C     REAL DISTINCT ROOTS (DEFINITE TORSO AND BAG CONTACT)
    7 DISC=(D**2-4.*A*E)**.5
C     BAG INTERCEPT POINTS. XA,XB AND YA,YB
      XA=(-D-DISC)/(2.*A)
      IF(SC.LE.ABS(XA))XA=ABS(XA)/XA*(SC-.001)
      XB=(-D+DISC)/(2.*A)
      IF(SC.LE.ABS(XB))XB=ABS(XB)/XB*(SC-.001)
      YA=(B+XA*(OSLOPE*COS(THETAW)-SIN(THETAW)))/(COS(THETAW)+OSLOPE*
      &SIN(THETAW))
      IF(SA.LE.ABS(YA))YA=ABS(YA)/YA*(SA-.001)
      YB=(B+XB*(OSLOPE*COS(THETAW)-SIN(THETAW)))/(COS(THETAW)+OSLOPE*
      &SIN(THETAW))
      IF(SA.LE.ABS(YB))YB=ABS(YB)/YB*(SA-.001)
C     ABST=DISTANCE FROM POINT A TO POINT B.
      ABST=SQRT((XA-XB)**2+(YA-YB)**2)
C     X AND Y COORD. OF H-POINT IN XPRIME, YPRIME COORD. SYSTEM
      XH=((Y2-Y1)*SIN(THETAW)+(X2-X1)*COS(THETAW))
      YH=((Y2-Y1)-(X2-X1)*TAN(THETAW))*(+COS(THETAW))
      IF(THETAT-THETAW)8,8,9
    8 YP=YB
      YN=YA
      XP=XB
      XN=XA
      GO TO 10
    9 YP=YA
      YN=YB
      XP=XA
      XN=XB
   10 RBAG=SQRT((XN-XH)**2+(YN-YH)**2)
      IF(ABST+RBAG-12.*RN)11,11,12
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DRACR 07/28/82

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   11 XFT=(XA+XB)/2.
      YFT=(YA+YB)/2.
      GO TO 13
   12 XNECK=XN-(RN*12.-RBAG)*SIN(THETAT-THETAW)
      YNECK=YN+(RN*12.-RBAG)*COS(THETAT-THETAW)
      XFT=(XN+XNECK)/2.
      YFT=(YN+YNECK)/2.
C     RFT=DISTANCE FROM H-POINT TO POINT OF FORCE APPLICATION ON TORSO
   13 RFT=SQRT((XH-XFT)**2+(YH-YFT)**2)
C     SLOPE OF LINE PERPENDICULAR TO AB
      PSLOPE=-(COS(THETAW)+OSLOPE*SIN(THETAW))/(OSLOPE*COS(THETAW)
      &-SIN(THETAW))
C     T=MOMENT ARM OF TORSO FORCES
      XO=-SC
      T=(-XFT*PSLOPE+YFT-YWH+PSLOPE*XWH)/SQRT(PSLOPE**2+1.)
      A1=1./SC**2+PSLOPE**2/SA**2
      B1=2.*PSLOPE/SA**2*(YFT-PSLOPE*XFT)
      C1=(YFT-PSLOPE*XFT)**2/SA**2-1.
C     POINTS G AND I ARE THE POINTS WHERE THE LINE OF ACTION OF THE FORC
E
C     WOULD INTERSECT THE BAG.
      XG=(-B1+SQRT(B1**2-4.*A1*C1))/(2.*A1)
      XI=(-B1-SQRT(B1**2-4.*A1*C1))/(2.*A1)
      YG=PSLOPE*(XG-XFT)+YFT
      YI=PSLOPE*(XI-XFT)+YFT
      YRIM=PSLOPE*(XC-XFT)+YFT
      GI=SQRT((XI-XG)**2+(YI-YG)**2)
C     CALCULATE THE BAG PENETRATION.
      BP=SQRT((XFT-XG)**2+(YFT-YG)**2)
C     DETERMINE THE MIDPOINT OF LINE GI.
      XMGI=(XG+XI)/2.
      YMGI=(YG+YI)/2.
C     CALCULATE MAJOR AXIS LENGTH OF ELLIPSE PERPENDICULAR TO TORSO
      ZP=SQRT(SA**2*(1-XMGI**2/SC**2)-YMGI**2)
C     CALCULATE PERIMETER OF ELLIPSE PERPENDICULAR TO TORSO
      PERBB=2.*3.14159*SQRT(((GI/2.)**2+ZP**2)/2.)
C     SOLVE FOR THE ANGLE(BETA) THAT THE FABRIC TENSION FORCE COMPONENT
C     MAKES WITH RESPECT TO A LINE NORMAL TO THE TORSO. FIRST SOLVE FOR
C     PHI, USING THE NEWTON RAPHSON METHOD OF SOLVING TRANCENDENTAL EQNS
.
C     LET PHIO=AN ESTIMATE OF THE ROOT PHI AND EPSLON=THE DESIRED ACC-
C     URACY OF THE ROOT.
      PHIO=3.14
      EPSLON=.00001
      PHI=PHIO
      IF(ABS(YRIM)-RIMRAD)17,16,16
   16 RIM=0.
      GOTO18
C     "RIM" IS THE CHORD LENGTH OF THE RIM AT POINT I.
   17 RIM=SQRT(RIMRAD**2-YRIM**2)*2.
C     FOR BAG PENETRATIONS LESS THAN ONE-HALF THE CHEST THICKNESS. THE
C     BODY WIDTH IN CONTACT WITH THE BAG WILL NOT EXCEED THE LENGTH OF
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C      THE BODY IN CONTACT WITH THE BAG.
    18 CHESTT=WBACT/2.5
       IF(BP.LT.CHESTT/2..AND.WBACT.GT.ABST)WB=ABST
       DBR=SQRT((XC-XI)**2+(YRIM-YI)**2)
       SBR=SQRT(.25*RIM**2+DBR**2)*2.
    21 FPHI=(PERBB-WB-SBR)*SIN(PHI/2.)/PHI-(GI-BP-DBR)/(COS(ATAN((WB-RIM)
       &/(2.*(GI-BP-DBR)))))
       DFPHI=(PERBB-WB-SBR)*COS(PHI/2.)/(2.*PHI)-((PERBB-WB-SBR)*SIN(PHI/
2.
       &)/PHI**2)
       DEL=-FPHI/DFPHI
       PHI=PHI+DEL
       IF(PHI.GT.2.*3.141593.OR.PHI.LT.0.)GO TO 520
       IF (ABS(DEL).LE.EPSLON) GO TO 22
       GO TO 21
    22 ALPHA=ATAN((WB-RIM)/(2.*(GI-BP-DBR)))
       BETA=PHI/2.+ALPHA
C      SOLVE FOR THE ARC SIN OF YP/SA AND YN/SA.
    25 ASYPSA=ATAN((YP/SA)/(SQRT(1.-(YP/SA)**2)))
       ASYNSA=ATAN((YN/SA)/(SQRT(1.-(YN/SA)**2)))
C      BAG, TLINE AND ACHORD ARE INTERMEDIATE VALUES REQUIRED FOR THE
C      AREA OF INTERCEPT CALCULATION.
       BAG=SC/(2.*SA)*((YP*SQRT(SA**2-YP**2)+SA**2*ASYPSA)-
       &(YN*SQRT(SA**2-YN**2)+SA**2*ASYNSA))
       TLINE=(XA-(XA-XB)/(YA-YB)*YA)*YP+(XA-XB)/(2.*(YA-YB))*YP**2-
       &(XA-(XA-XB)/(YA-YB)*YA)*YN-(XA-XB)/(2.*(YA-YB))*YN**2
       ACHORD=0.
       IF(XP.LT.0.)ACHORD=SC/SA*(3.141593*SA**2/2.-(YP*SQRT(SA**2-YP**2)
       &+SA**2*ASYPSA))
       IF(XN.LT.0.)ACHORD=ACHORD+SC/SA*(YN*SQRT(SA**2-YN**2)+SA**2*ASYNSA
       &+3.14159*SA**2/2.)
C      SOLVE FOR THE AREA OF INTERCEPT.
       AOI=BAG-TLINE+ACHORD
C      "VOI"=VOLUME OF BAG INTERCEPT.
       WAVG=((RFT-RBAG)*WB+RHEAD*WH)/(RFT-RBAG+RHEAD)
       VOI=WAVG*AOI
C      THE FOLLOWING ROUTINE USES THE NEWTON-RAPHSON METHOD TO SOLVE
C      A CUBIC EQUATION FOR THE BAG PENETRATION THATWOULD EXIST FOR
C      THE SYMMETRICAL CASE WITH A GIVEN VOI.
       ROOTG=0.8*BP
       IF(BP.GE.SC+ABS(XC))ROOTG=SC
       ROOT=ROOTG
    73 FROOT=3.14159*SA**2*(-ROOT**3/(3.*SC**2)+ROOT**2/SC)-VOI
       DFROOT=3.14159*SA**2*(-ROOT**2/SC**2+2.*ROOT/SC)
       DELRT=-FROOT/DFROOT
       ROOT=ROOT+DELRT
       IF(ROOT.GT.2.*SC.OR.ROOT.LT.0.)GO TO 518
       IF (ABS(DELRT).LE.EPSLON) GO TO 74
       GO TO 73
    74 PER=2.*3.14159*SQRT((SA**2+SC**2)/2.)
       BPSYM=ROOT
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DRACR 07/28/82

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11920       ABSYM=2.*SA*SQRT(1.-(SC-BPSYM)**2/SC**2)
11940       YC=RIMRAD
11960       OC=SQRT((XC-XO)**2+(YC-YO)**2)
11980       BCSYMC=(PER-2.*OC-ABSYM)/2.
12000       XBS=SC-BPSYM
12020       YBS=ABSYM/2.
12040C      BEFORE CALCULATING THE LENGTH OF THE LINE BC FOR THE SYMMETRICAL
12060C      CASE CHECK TO SEE THAT THE HEAD AND CHEST HAVE NOT BOTTOMED
12080C      OUT ON THE WHEEL RIM. IF THEY HAVE. STOP THE RUN.
12100       IF(XA.LT.XC.AND.YA.LT.0.) GO TO 510
12120       IF(XA.LT.XC.AND.YA.GT.0.) GO TO 512
12140       BCSYMS=SQRT((XBS-XC)**2+(YBS-YC)**2)
12160C      THE FOLLOWING ROUTINE USES THE NEWTON-RAPHSON METHOD TO SOLVE A
12180C      TRANCENDENTAL EQUATION SO THAT THE RADIUS AND ANGLE OF THE VERTICA
L
12200C      BAG ENDS CAN BE CALCULATED.
12220       THEO=3.14
12240       THE=THEO
12260    75 FTHE=BCSYMC*SIN(THE/2.)/THE-BCSYMS/2.
12280       DFTHE=BCSYMC*COS(THE/2.)/(2.*THE)-BCSYMC*SIN(THE/2.)/THE**2
12300       DELTH=-FTHE/DFTHE
12320       THE=THE+DELTH
12340       IF(THE.GT.2.*3.141593.OR.THE.LT.0.)GO TO 516
12360       IF (ABS(DELTH).LE.EPSLON) GO TO 76
12380       GO TO 75
12400    76 RSYM=BCSYMC/THE
12420C      THE FOLLOWING STATEMENTS ARE USED TO CALCULATE THE AIRBAG VOLUME.
12440       SLOPE=(YBS-YC)/(XBS-XC)
12460       V1=SLOPE**2*(XC**3/3.-XBS**3/3.+XBS**2*XC-XC**2*XBS)
12480       V2=YC**2*(XC-XBS)
12500       V3=2.*YC*SLOPE*(XBS*XC-XBS**2/2.-XC**2/2.)
12520       VABCD=ABS(V1+V2+V3)*3.14159
12540       ALPHAS=ATAN(SLOPE)
12560       RC=YC-RSYM*COS(THE/2.+ALPHAS)
12580       RS=RC+4./3.*(RSYM*SIN(THE/2.)**3)*COS(ALPHAS)/(THE-SIN(THE))
12600       VBC=2.*3.14159*RS*(RSYM**2/2.*(THE-SIN(THE)))
12620       VBRIM=3.14159/6.*(SC+XC)*(3.*YC**2+(SC+XC)**2)
12640       VOL=VABCD+VBC+VBRIM
12660C      CONFINE BAG VOLUME TO ORIGINAL VOLUME IF THE BAG PRESSURE IS LESS
12680C      THAN AMBIENT.
12700       IF(VOL.GE.VOLO.AND.PG1.LE.0.)VOL=VOLO
12720       GO TO 101
12820C      COMPLEX ROOTS (NO TORSO AND BAG CONTACT)
12840    80 VOL=VOLO
12860       FTI=0.
12880       FTH=0.
12900C      COMPUTE GAS FLOW INTO BAG
12920   101 CALL GASIN(X.QIN)
12940C      SINCE SUBROUTINE "SOLVE" CALLS "BAGSUB" TWICE PER SOLUTION
12960C      POINT WE MUST DIVIDE THE TIME STEP BY 2.
12980       DELTAT=STEP
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DRACR 07/28/82

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      IF(ILOOP.NE.1)DELTAT=0
      GW1=GW+QIN*DELTAT
C     TEST TO SEE IF BAG DEPLOYED YET:IS BAG PRESS.>ATMOS. PRESS.?
      IF(X.EQ.0.)DTIME=.25
      IF(PA.GE.ATMOP.OR.X.GT.DTIME)GO TO 107
      GW=GW1
      PA=GW*GTZ*U/VOL
      PG1=PA-ATMOP
      GT=GTZ
      FFT=0.
      FP=0.
      FTT=0.
      FHEAD=0.
      FTH=0.
      DTIME=X+STEP
      GO TO 490
C     COMPUTE NEW TEMP. AND PRESS. DUE TO NET GAS GAIN IN BAG
  107 GT7=(GW*GT+QIN*GTZ*DELTAT)/GW1
      PNUM=U*GT7*GW1
      PA7=PNUM/VOLO
C     COMPUTE NEW GAS PRESS. AND TEMP. DUE TO POLYTROPIC COMP. OR EXPANS
.
      PA8=(PNUM/VOL)**FPN/PA7**(FPN-1.)
      GT8=GT7*(PA8/PA7)**((FPN-1.)/FPN)
C     BAG VENTING COMPUTATIONS; FIRST CALC. PRESS. RATIO ACROSS VENT
      PR7=ATMOP/PA8
C     TEST FOR CHOKED FLOW; ALSO, IF PR7>1,BYPASS QEXH.& SET GW=GW1
      IF (PR7.LT.PR8) GO TO 108
      IF (PR7.GE.1.) GO TO 110
      FM1=VC1*SQRT(PR7**(2./PN1)-PR7**((PN1+1.)/PN1))
      GO TO 109
  108 FM1=FM2
C     COMPUTE EXHAUST FLOW AND RESIDUAL GAS WEIGHT
  109 QEXH=SQRT((772.*PN1)/(PN1-1.))*AV*PA8*FM1/SQRT(U*GT8)
      GW=GW1-QEXH*DELTAT
      GO TO 111
  110 GW=GW1
C     COMPUTE PRESS. AND TEMP. OF GAS AFTER VENTING
  111 RATIO=GW/GW1
      PA=PA8*RATIO**PN1
      GT=GT8*RATIO**(PN1-1)
C     COMPUTE PRESS. RATIO TO DETERMINE WHETHER GAS COMP. OR EXPANDED TH
IS
C     TIME THRU LOOP; THEN SET PROPER POLYTROPIC EXPONENT.
      PR6=PA8/PA5
      IF (PR6.LT.1.0001) GO TO 112
      FPN=PN2
      GO TO 113
  112 FPN=PN3
C     COMPUTE BAG PRESSURE.
  113 PG1=PA-ATMOP
C     IF THE BAG PRESSURE IS NEGATIVE, CALL IT 0. FOR BAG FORCE CALCS.
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      IF(PG1.LT.0.)PG1=0.
C     IF THE TORSO IS NOT IN CONTACT WITH THE BAG, SKIP THE BAG FORCE
C     CALCULATION.
      IF(D**2-4.*A*E)490,115,115
C     THE BAG FORCES ARE CALCULATED IN THE NEXT SEVERAL STATEMENTS.
  115 ENPHI=PG1*SQRT(SA**2-WB**2/4.)*(SQRT(SC**2*(1-WB**2/(4.*
     &SA**2))))*(1-BP/GI)/(2.*SQRT(SA**2-WB**2/4.+SC**2*(1-WB**2
     &/(4.*SA**2))))
      FFT=-2.*ENPHI*ABST*COS(BETA)
      IF (BETA.LE.1.5708) FFT=0.
      FP=PG1*WB*ABST
      IF(RBAG+ABST-RN*12.)140,140,135
  135 IF(ABST+RBAG.GT.RTOPH*12.) GO TO 136
      RHEAD=(ABST+RBAG-RN*12.)/2.
      GO TO 137
  136 RHEAD=((RTOPH-RN)*12.)/2.
  137 HEADT=WHACT
      IF(BP.LT.HEADT/2..AND.WHACT.GT.2.*RHEAD)WH=2.*RHEAD
      FHEAD=2.*RHEAD*WH*PG1+2.*RHEAD*FFT/ABST
      IF(Y(6)-Y(7).LT.0.)FHEAD=FHEAD*COS(Y(6)-Y(7))
      FTH=TNECK-FHEAD*RHEAD/12.
      FP=FP*(RN*12.-RBAG)/ABST
      FFT=FFT*(RN*12.-RBAG)/ABST
      GO TO 141
  140 FHEAD=0.
      FTH=TNECK
  141 FCHEST=FFT+FP
      IF(FHEAD*RHEAD-ABS(TNECK)*12.)142,143,143
  142 TRANSTOR=-FHEAD*RHEAD/12.
      GO TO 144
  143 IF(TNECK.LE.0.)TRANSTOR=TNECK
      IF(TNECK.GT.0.)TRANSTOR=-TNECK
  144 FTT=-FHEAD*RN*COS(Y(6)-Y(7))+TRANSTOR-RFT*FCHEST/12.
C
C     THIS PART OF THE PROGRAM COMPUTES THE DYNAMICS OF STEERING
C     WHEEL CRUSH.
      FAW=FCHEST*COS(THETAW-THETAT)+FHEAD*COS(THETAW-THETAH)+GS*WWH/
     &32.17*COS(THETAW)
      FNW=FCHEST*SIN(THETAW-THETAT)+FHEAD*SIN(THETAW-THETAH)+GS
     &*WWH/32.17*SIN(THETAW)
      CALL WHF(SWHC,FRW)
      IF(FRW.EQ.0.)FRW=1.
      DELFW=FAW-FRW
      IF(DELFW)190,192,192
  190 EAWC=BIG
      GO TO 195
  192 VWHC=VWHCO+DELFW*DELTAT/MWH
      SWHC=SWHCO+VWHCO*DELTAT+DELFW*DELTAT**2/(2.*MWH)
      EAWC=FRW/COS(THETAW)
      X1WC=X1-(SWHC-SWHCO)*COS(THETAW)
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DRACR 07/28/82

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      Y1WC=Y1-(SWHC-SWHCO)*SIN(THETAW)
C
C     THIS PART OF THE PROGRAM COMPUTES THE DYNAMICS OF STEERING
C     COLUMN CRUSH.
C     COMPUTE THE BENDING MOMENT APPLIED TO THE COLUMN AT THE WHEEL HUB.
  195 MO=FCHEST*T
C     COMPUTE THE NORMAL FORCE APPLIED TO THE COLUMN.
      FNC=FCHEST*SIN(THETAC-THETAT)+FHEAD*SIN(THETAC-THETAH)
      FNCOL=FNC+GS/32.17*(WC+WWH)*SIN(THETAC)
C     COMPUTE THE REACTIONS AT THE COLUMN SUPPORT POINTS.
      RSC=FNCOL+(MO+FNCOL*LSC)/LFW
      RBA=(RSC*(LBF-LSC)+FNCOL*(LSC-LBF))/(LBF-LBA)
      RBF=(RSC*(LBA-LSC)+FNCOL*(LSC-LBA))/(LBF-LBA)
      FACOL=FCHEST*COS(THETAC-THETAT)+FHEAD*COS(THETAC-THETAH)+GS*(WC+
     &WWH)/32.17*COS(THETAC)
      CALL COLF(SCOLC,FCOL)
      IF(FCOL.EQ.0.)FCOL=1.
      FRCOL=FCOL+MU*ABS(RBF+RBA+RSC)
      DELFC=FACOL-FRCOL
      IF(DELFC)205,207,207
  205 EACC=BIG
      GO TO 208
  207 VCOLC=VCOLCO+DELFC*DELTAT/MC
      SCOLC=SCOLCO+VCOLCO*DELTAT+DELFC*DELTAT**2/(2.*MC)
      EACC=FRCOL/COS(THETAC)
      X1CC=X1-(SCOLC-SCOLCO)*COS(THETAC)
      Y1CC=Y1-(SCOLC-SCOLCO)*SIN(THETAC)
  208 IF(EAWC-EACC)210,230,220
  210 EAC=EAWC
      X1C=X1WC
      Y1C=Y1WC
      GO TO 240
  220 EAC=EACC
      X1C=X1CC
      Y1C=Y1CC
      GO TO 240
  230 EAC=BIG
C
C     THIS PART OF THE PROGRAM COMPUTES THE DYNAMICS OF STEERING
C     WHEEL ROTATION.
  240 WIN=MWH*RIMRAD**2/2.+MIP*RIP**2/4.
      TAW=FCHEST*T
      RELWR=THETAW-THETAC
      IF(RELWR.GE.0.)GO TO 244
      RELWR=-RELWR
      CALL WHROTN(RELWR,TRW)
      GO TO 248
  244 CALL WHROTP(RELWR,TRW)
  248 IF(TRW.EQ.0.)TRW=1.
      TRW=-(TAW+1.)/ABS((TAW+1.))*TRW
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16005       IF(TAW.EQ.O.)TRW=+(OMWO+1.)/ABS(OMWO+1.)*TRW
16020       DELTW=TAW+TRW
16040       IF(ABS(TAW)-ABS(TRW))250,250,260
16060   250 EAWR=BIG
16080       GO TO 261
16100   260 ALW=DELTW/WIN
16120       OMW=OMWO+ALW*DELTAT
16140       THETAW=THETAWO+OMWO*DELTAT+ALW*DELTAT**2/2.
16160       DTHW=THETAW-THETAWO
16200       X1WR=X1-XWH*(COS(THETAW)-COS(THETAWO))
16220       Y1WR=Y1-XWH*(SIN(THETAW)-SIN(THETAWO))
16230       IF(X1.EQ.X1WR)X1WR=X1+.0001
16240       EAWR=ABS(TRW*DTHW/(X1-X1WR))
16250C
16260C      THIS PART OF THE PROGRAM COMPUTES THE DYNAMICS OF STEERING
16280C      COLUMN ROTATION.
16300   261 COI=MC*RCOL**2+(MWH+MIP)*(LFW+LSC)**2
16310       IF(SCOLC.LT.2.)GO TO 270
16320       RELCR=THETAC-THETACZ
16322       IF(RELCR.GE.0.)GO TO 263
16324       RELCR=-RELCR
16328       CALL COLROTN(RELCR,REACT)
16330       GO TO 265
16340   263 CALL COLROTP(RELCR,REACT)
16360   265 IF(REACT.EQ.0.)REACT=1.
16380       IF(NCOLTYPE-1)268,267,268
16420   267 RBRKT=REACT
16460       TAC=FNCOL*(LFW+LSC)+MO
16470       TRC=-(TAC+1.)/ABS((TAC+1.))*RBRKT*LFW
16475       IF(TAC.EQ.0.)TRC=-(OMCO+1.)/ABS(OMCO+1.)*RBRKT*LFW
16480       DELTC=TAC+TRC
16500       IF(ABS(TAC)-ABS(TRC))270,270,280
16520   268 TAC=MO+FNCOL*LSC
16540       TRC=-(TAC+1.)/ABS((TAC+1.))*REACT
16545       IF(TAC.EQ.0.)TRC=-(OMCO+1.)/ABS(OMCO+1.)*REACT
16580       DELTC=TAC+TRC
16600       IF(ABS(TAC)-ABS(TRC))270,270,280
16620   270 EACR=BIG
16640       GO TO 300
16660   280 ALC=DELTC/COI
16680       OMC=OMCO+ALC*DELTAT
16700       THETAC=THETACO+OMCO*DELTAT+ALC*DELTAT**2/2.
16720       DTHC=THETAC-THETACO
16760       RPIVOT=LFW+LSC+XWH*COS(THETAW-THETAC)
16780       X1CR=X1+RPIVOT*(COS(THETAC)-COS(THETACO))
16800       Y1CR=Y1+RPIVOT*(SIN(THETAC)-SIN(THETACO))
16810       IF(X1.EQ.X1CR)X1CR=X1+.0001
16820       EACR=ABS(TRC*DTHC/(X1-X1CR))
16840   300 IF(EAWR-EACR)310,330,320
16860   310 EAR=EAWR
```

(Note: Statement 16310 added for the specialized test case - not in the original DRACR program)

```
      X1R=X1WR
      Y1R=Y1WR
      GO TO 400
  320 EAR=EACR
      X1R=X1CR
      Y1R=Y1CR
      GO TO 400
  330 EAR=BIG
  400 IF(EAR-EAC)410,450,430
  410 EA=EAR
      X1=X1R
      Y1=Y1R
      VWHC=VWHCO-FRW*DELTAT/MWH
      IF(VWHC.LT.0.)VWHC=0.
      SWHC=SWHCO+VWHCO*DELTAT-FRW*DELTAT**2/(2.*MWH)
      IF(SWHC.LT.SWHCO)SWHC=SWHCO
      X1=X1-(SWHC-SWHCO)*COS(THETAW)
      Y1=Y1-(SWHC-SWHCO)*SIN(THETAW)
      VWHCO=VWHC
      SWHCO=SWHC
      VCOLC=VCOLCO-FRCOL*DELTAT/MC
      IF(VCOLC.LT.0.)VCOLC=0.
      SCOLC=SCOLCO+VCOLCO*DELTAT-FRCOL*DELTAT**2/(2.*MC)
      IF(SCOLC.LT.SCOLCO)SCOLC=SCOLCO
      X1=X1-(SCOLC-SCOLCO)*COS(THETAC)
      Y1=Y1-(SCOLC-SCOLCO)*SIN(THETAC)
      VCOLCO=VCOLC
      SCOLCO=SCOLC
      IF(EAWR-EACR)417,421,421
  417 IF(ABS(OMCO))418,418,419
  418 OMC=OMCO
      THETAC=THETACO
      GO TO 420
  419 OMC=OMCO+TRC/COI*DELTAT
      IF(OMC*OMCO.LT.0.)OMC=0.
      THETAC=THETACO+OMCO*DELTAT+TRC/(2.*COI)*DELTAT**2
      THETAW=THETAW+THETAC-THETACO
      X1=X1+RPIVOT*(COS(THETAC)-COS(THETACO))
      Y1=Y1+RPIVOT*(SIN(THETAC)-SIN(THETACO))
      OMCO=OMC
      THETACO=THETAC
  420 OMWO=OMW
      THETAWO=THETAW
      GO TO 490
  421 IF(ABS(OMWO))422,422,423
  422 OMW=OMWO
      THETAW=THETAWO+DTHC
      THETAWO=THETAW
      GO TO 424
  423 OMW=OMWO+TRW/WIN*DELTAT
```

```
      IF(OMW*OMWO.LT.O.)OMW=0.
      THETAW=THETAWO+OMWO*DELTAT+TRW/(2.*WIN)*DELTAT**2+DTHC
      X1=X1-XWH*(COS(THETAW)-COS(THETAWO))
      Y1=Y1-XWH*(SIN(THETAW)-SIN(THETAWO))
      OMWO=OMW
      THETAWO=THETAW
  424 OMCO=OMC
      THETACO=THETAC
      GO TO 490
  430 EA=EAC
      X1=X1C
      Y1=Y1C
      IF(ABS(OMWO))431,431,432
  431 OMW=OMWO
      THETAW=THETAWO
      GO TO 433
  432 OMW=OMWO+TRW/WIN*DELTAT
      IF(OMW*OMWO.LT.O.)OMW=0.
      THETAW=THETAWO+OMWO*DELTAT+TRW/(2.*WIN)*DELTAT**2
      X1=X1-XWH*(COS(THETAW)-COS(THETAWO))
      Y1=Y1-XWH*(SIN(THETAW)-SIN(THETAWO))
      OMWO=OMW
      THETAWO=THETAW
  433 IF(ABS(OMCO))434,434.435
  434 OMC=OMCO
      THETAC=THETACO
      GO TO 436
  435 OMC=OMCO+TRC/COI*DELTAT
      IF(OMC*OMCO.LT.O.)OMC=0.
      THETAC=THETACO+OMCO*DELTAT+TRC/(2.*COI)*DELTAT**2
      THETAW=THETAW+THETAC-THETACO
      X1=X1+RPIVOT*(COS(THETAC)-COS(THETACO))
      Y1=Y1+RPIVOT*(SIN(THETAC)-SIN(THETACO))
      OMCO=OMC
      THETACO=THETAC
      THETAWO=THETAW
  436 IF(EAWC-EACC)439,443,443
  439 VCOLC=VCOLCO-FRCOL*DELTAT/MC
      IF(VCOLC.LT.O.)VCOLC=0.
      SCOLC=SCOLCO+VCOLCO*DELTAT-FRCOL*DELTAT**2/(2.*MC)
      IF(SCOLC.LT.SCOLCO)SCOLC=SCOLCO
      X1=X1-(SCOLC-SCOLCO)*COS(THETAC)
      Y1=Y1-(SCOLC-SCOLCO)*SIN(THETAC)
      VCOLCO=VCOLC
      SCOLCO=SCOLC
      VWHCO=VWHC
      SWHCO=SWHC
      GO TO 490
  443 VWHC=VWHCO-FRW*DELTAT/MWH
      IF(VWHC.LT.O.)VWHC=0.
```

```
      SWHC=SWHCO+VWHCO*DELTAT-FRW*DELTAT**2/(2.*MWH)
      IF(SWHC.LT.SWHCO)SWHC=SWHCO
      X1=X1-(SWHC-SWHCO)*COS(THETAW)
      Y1=Y1-(SWHC-SWHCO)*SIN(THETAW)
      VWHCO=VWHC
      SWHCO=SWHC
      VCOLCO=VCOLC
      SCOLCO=SCOLC
      GO TO 490
  450 EA=BIG
      VWHC=VWHCO-FRW*DELTAT/MWH
      IF(VWHC.LT.0.)VWHC=0.
      SWHC=SWHCO+VWHCO*DELTAT-FRW*DELTAT**2/(2.*MWH)
      IF(SWHC.LT.SWHCO)SWHC=SWHCO
      X1=X1-(SWHC-SWHCO)*COS(THETAW)
      Y1=Y1-(SWHC-SWHCO)*SIN(THETAW)
      VWHCO=VWHC
      SWHCO=SWHC
      VCOLC=VCOLCO-FRCOL*DELTAT/MC
      IF(VCOLC.LT.0.)VCOLC=0.
      SCOLC=SCOLCO+VCOLCO*DELTAT-FRCOL*DELTAT**2/(2.*MC)
      IF(SCOLC.LT.SCOLCO)SCOLC=SCOLCO
      X1=X1-(SCOLC-SCOLCO)*COS(THETAC)
      Y1=Y1-(SCOLC-SCOLCO)*SIN(THETAC)
      VCOLCO=VCOLC
      SCOLCO=SCOLC
      IF(ABS(OMWO))457,457,458
  457 OMW=OMWO
      THETAW=THETAWO
      GO TO 459
  458 OMW=OMWO+TRW/WIN*DELTAT
      IF(OMW*OMWO.LT.0.)OMW=0.
      THETAW=THETAWO+OMWO*DELTAT+TRW/(2.*WIN)*DELTAT**2
      X1=X1-XWH*(COS(THETAW)-COS(THETAWO))
      Y1=Y1-XWH*(SIN(THETAW)-SIN(THETAWO))
      OMWO=OMW
      THETAWO=THETAW
  459 IF(ABS(OMCO))460,460,461
  460 OMC=OMCO
      THETAC=THETACO
      GO TO 490
  461 OMC=OMCO+TRC/COI*DELTAT
      IF(OMC*OMCO.LT.0.)OMC=0.
      THETAC=THETACO+OMCO*DELTAT+TRC/(2.*COI)*DELTAT**2
      THETAW=THETAW+THETAC-THETACO
      X1=X1+RPIVOT*(COS(THETAC)-COS(THETACO))
      Y1=Y1+RPIVOT*(SIN(THETAC)-SIN(THETACO))
      OMCO=OMC
      THETACO=THETAC
      THETAWO=THETAW
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DRACR 07/28/82

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C
C      UPDATE OLD VALUES.
   490 VOLD=VOL
       PA5=PA
       LBA=LBAZ-SCOLC
       IF(LBA.LE.0.) GO TO 514
       LFW=LFWZ-SCOLC
       WB=WBACT
       WH=WHACT
       RELSF=Y(5)-Y(8)
       CALL SPRING(SFN,SFUT,RELSF,SUN,0.0,SF,NSF)
       HPRD=(Y(5)-Y(8))*12.
       IF(HPRD-DELTTB/COS(THLO))492,492,493
   492 THEF=THFO
       THEL=THLO
       RELKR=Y(5)-Y(8)
       GO TO 499
   493 IF(DELTTB.LT.0.)GO TO 522
       NLOOP=1
       ROTG=(Y2+LT)/2.
       ROT=ROTG
   495 FROT=ROT*Y2+X2*SQRT(LT**2-ROT**2)-(LT**2-LF**2+X2**2+Y2**2)/2.
       DFROT=Y2-X2*ROT/SQRT(LT**2-ROT**2)
       DELROT=-FROT/DFROT
       ROT=ROT+DELROT
       IF(ROT.GT.LT)ROT=LT-.01
       IF(ABS(DELROT).LE.EPSLON)GO TO 496
       NLOOP=NLOOP+1
       IF(NLOOP.GT.20.)GO TO 524
       GO TO 495
   496 THEF=ATAN(((ROT-Y2)/LF)/(SQRT(1.-((ROT-Y2)/LF)**2)))
       THEL=ATAN((ROT/LT)/(SQRT(1.-(ROT/LT)**2)))
       RELKR=LT/12.*(COS(THLO)-COS(THEL))+DELTTB/(12.*COS(THLO))
   499 CALL SPRING(KRN,RUT,RELKR,SKR,0.0,FKNEE,NKR)
       FX=-(SF+FKNEE+FCHEST*COS(Y(7))+FHEAD*COS(Y(6)))
       N=1
       GO TO 540
   500 XSTOP=X
       N=N+1
       PRINT 5
       IF(N.EQ.2)PRINT ,"DRIVER SUBMARINING. NOT RECOVERABLE. RUN STOPPED
."
       GO TO 540
   510 XSTOP=X
       N=N+1
       PRINT 5
       IF(N.EQ.2)PRINT ,"CHEST IMPACT WITH LOWER WHEEL RIM. RUN STOPPED."
       GO TO 540
   512 XSTOP=X
       N=N+1
       PRINT 5
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      IF(N.EQ.2)PRINT ,"BODY IMPACT WITH UPPER WHEEL RIM, RUN STOPPED."
      GO TO 540
  514 XSTOP=X
      N=N+1
      PRINT 5
      IF(N.EQ.2)PRINT,"COL.STROKE > SHEAR CAP. DIM.(LBAZ), RUN STOPPED"
      GO TO 540
  516 XSTOP=X
      N=N+1
      PRINT 5
      IF(N.EQ.2)PRINT,"THETA NOT CONVERGING, RUN STOPPED."
      GO TO 540
  518 XSTOP=X
      N=N+1
      PRINT 5
      IF(N.EQ.2)PRINT,"BAG PENETRATION SOLUTION NOT CONVERGING, RUN
     &STOPPED."
      GO TO 540
  520 XSTOP=X
      N=N+1
      PRINT 5
      IF(N.EQ.2)PRINT,"PHI NOT CONVERGING, RUN STOPPED."
      GO TO 540
  522 XSTOP=X
      N=N+1
      PRINT 5
      IF(N.EQ.2)PRINT,"X2 INPUT NOT CONSISTENT WITH OTHER LEG INPUT."
      GO TO 540
  524 XSTOP=X
      N=N+1
      PRINT 5
      IF(N.EQ.2)PRINT,"KNEE ANGLE SOLUTION NOT CONVERGING."
  540 RETURN
      END
C
C     THIS SUBROUTINE COMPUTES THE RATE THAT GAS ENTERS THE BAG.
      SUBROUTINE GASIN(X,QIN)
      COMMON/GASFLO/NPG,GEN(2,12)
      CALL LOOKUP(X,GEN,NPG,QIN)
      RETURN
      END
C
C     THIS SUBROUTINE COMPUTES THE WHEEL FORCE AS A FCN OF STROKE.
      SUBROUTINE WHF(SWHC,FRW)
      COMMON/WHFOR/NPW,WHE(2,12),VWHCO,SWHCO
      CALL LOOKUP(SWHC,WHE,NPW,FRW)
      RETURN
      END
C
C     THIS SUBROUTINE COMPUTES THE COLUMN FORCE AS A FCN OF STROKE.
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DRACR 07/28/82

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      SUBROUTINE COLF(SCOLC,FCOL)
      COMMON/COLFOR/NPC,COL(2,12)
      CALL LOOKUP(SCOLC,COL,NPC,FCOL)
      RETURN
      END
C
C     THIS SUBROUTINE COMPUTES THE WHEEL MOMENT AS A FCN OF POSITIVE
C     (UPWARD) ROTATION.
      SUBROUTINE WHROTP(RELWR,TRW)
      COMMON/WROTP/NPWRP,WHRP(2,12).OMWO,THETAWO
      CALL LOOKUP(RELWR.WHRP,NPWRP.TRW)
      RETURN
      END
C
C     THIS SUBROUTINE COMPUTES THE WHEEL MOMENT AS A FCN OF NEGATIVE
      SUBROUTINE WHROTN(RELWR,TRW)
      COMMON/WROTN/NPWRN,WHRN(2.12)
      CALL LOOKUP(RELWR.WHRN,NPWRN.TRW)
      RETURN
      END
C
C     THIS SUBROUTINE COMPUTES THE COLUMN MOMENT (OR FORCE) AS A FCN
C     OF POSITIVE (UPWARD) ROTATION.
      SUBROUTINE COLROTP(RELCR,REACT)
      COMMON/CROTP/NPCRP,COLRP(2,12),OMCO,THETACO
      CALL LOOKUP(RELCR.COLRP,NPCRP,REACT)
      RETURN
      END
C
C     THIS SUBROUTINE COMPUTES THE COLUMN MOMENT (OR FORCE) AS A FCN
C     OF NEGATIVE (DOWNWARD) ROTATION.
      SUBROUTINE COLROTN(RELCR,REACT)
      COMMON/CROTN/NPCRN,COLRN(2.12)
      CALL LOOKUP(RELCR,COLRN,NPCRN,REACT)
      RETURN
      END
C
C     THIS SUBROUTINE PLACES CERTAIN VALUES IN MATRIX FORMAT FOR PRINTIN
G.
      SUBROUTINE PRINT1(X.Y.DY)
      COMMON /OUT1/N9.X9(4.175).T9(175)
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      COMMON/MANDAT/ZL.ZT.ZH,RT,RN,RH,RTOPH,X2Z,Y2Z,WB.WH
      COMMON/HIC/THIC(175),HRGS(175)
      COMMON/TIME/STEP.XSTOP,PINT1.ILOOP
      N9=N9+1
      IF(N9.GT.175)RETURN
      CH=COS(Y(6))
      CT=COS(Y(7))
```

```
      SH=SIN(Y(6))
      ST=SIN(Y(7))
      X9(1,N9)=(DY(1)*CT+RT*DY(3))/32.17
      X9(2,N9)=-(DY(1)*ST-RT*Y(3)*Y(3))/32.17
      X9(3,N9)=(RH*DY(2)+DY(1)*CH+RN*(DY(3)*(CH*CT+SH*ST)+Y(3)
      &*Y(3)*(SH*CT-CH*ST)))/32.17
      X9(4,N9)=(RH*Y(2)*Y(2)+RN*(Y(3)*Y(3)*(SH*ST+CH*CT)-DY(3)
      &*(SH*CT-CH*ST))-DY(1)*SH)/32.17
      T9(N9)=X*1000.
      THIC(N9)=(N9*PINT1)**0.6
      HRGS(N9)=SQRT(X9(3,N9)**2+X9(4,N9)**2)
      RETURN
      END
C
C     THIS SUBROUTINE SOLVES THE DIFFERENTIAL EQUATIONS THAT DETERMINE
C     THE DRIVER KINEMATICS AND VEHICLE MOTION. THE FOURTH ORDER RUNGE-
C     KUTTA METHOD IS USED TO START THE INTEGRATION, BUT ONCE THE FIRST
C     FOUR POINTS ARE OBTAINED WE SWITCH TO THE MORE ECONOMICAL FOURTH
C     ORDER ADAMS-MOULTON PREDICTOR-CORRECTOR METHOD.
      SUBROUTINE SOLVE(N)
      COMMON/TIME/STEP,XSTOP,PINT1,ILOOP
      DOUBLE PRECISION Y(8),YT(8)
      REAL DY
      DOUBLE PRECISION B270,B19,B251
      DIMENSION DY(8),F(3,8),J(3),S(8)
      B251=251.
      B270=270.
      B19=19.
      PRI1=0.
      PRI2=0.
      XSTOP=.120
      STEP=.001
      CALL SETUP(X,Y)
      CALL DIFEQ(X,Y,DY)
      PINT1=.005
      PINT2=.005
      CALL PRINT1(X,Y,DY)
      CALL PRINT2(X,Y,DY)
      IF(XSTOP.GT..25)XSTOP=.25
C     START OF INTEGRATION ROUTINE
C     RUNGE KUTTA START UP
      J(1)=1
      J(2)=2
      J(3)=3
      DO 7270 K=1,N
 7270 F(3,K)=DY(K)
      DO 7550 JK=1,3
      DO 7300 K=1,N
 7300 S(K)=DY(K)*STEP
      XN=X+STEP/2.
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```
      DO 7330 K=1,N
 7330 YT(K)=Y(K)+S(K)/2.
      CALL DIFEQ(XN,YT,DY)
      DO 7360 K=1,N
 7360 S(K)=S(K)+2.*DY(K)*STEP
      DO 7380 K=1,N
 7380 YT(K)=Y(K)+STEP*DY(K)/2.
      CALL DIFEQ(XN,YT,DY)
      DO 7410 K=1,N
 7410 S(K)=S(K)+2.*DY(K)*STEP
      DO 7430 K=1,N
 7430 YT(K)=Y(K)+DY(K)*STEP
      X=X+STEP
      CALL DIFEQ(X,YT,DY)
      DO 7470 K=1,N
 7470 Y(K)=Y(K)+(S(K)+DY(K)*STEP)/6.
      CALL DIFEQ(X,Y,DY)
      GOTO(7500,7530,7550),JK
 7500 DO 7510 K=1,N
 7510 F(2,K)=DY(K)
      GO TO 7550
 7530 DO 7540 K=1,N
 7540 F(1,K)=DY(K)
 7550 PRI1=X
      PRI2=X
C     PREDICTOR-CORRECTOR SECTION
C     PREDICTOR
 7590 DO 7600 K=1,N
 7600 YT(K)=Y(K)+STEP*(55.*DY(K)-59.*F(J(1),K)+37.*F(J(2),K)
     &-9.*F(J(3),K))/24.
C     SAVE DY'S
      DO 7640 K=1,N
 7640 F(J(3),K)=DY(K)
C     EVALUATE STEP
      X=X+STEP
      ILOOP=1
      CALL DIFEQ(X,YT,DY)
C     ROTATE VECTOR POINTER
      UT=J(3)
      J(3)=J(2)
      J(2)=J(1)
      J(1)=UT
C     CORRECTOR
      DO 7750 K=1,N
 7750 Y(K)=Y(K)+STEP*(9.*DY(K)+19.*F(J(1),K)-5.*F(J(2),K)+F(J(3),
     &K))/24.
C     ADDITION OF ERROR TERM
      DO 7800 K=1,N
 7800 Y(K)=(B251*Y(K)+B19*YT(K))/B270
C     SECOND EVALUATION STEP
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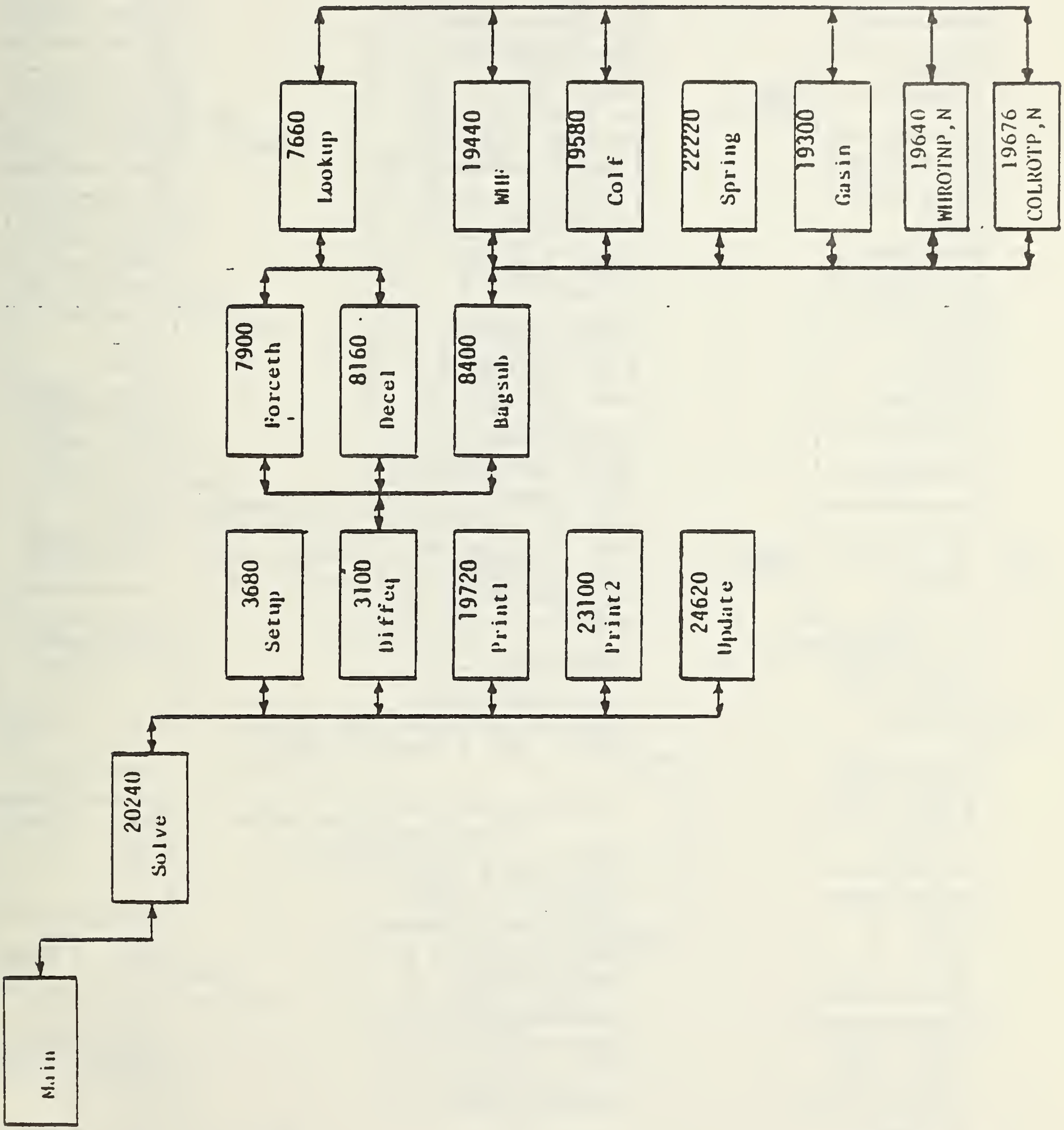
```
      ILOOP=2
      CALL DIFEQ(X,Y,DY)
      CALL UPDATE(X,Y,DY)
C     PRINTING SECTION
      PRI1=PRI1+STEP
      PRI2=PRI2+STEP
      IF(PRI1.LT.PINT1)GOTO7890
      PRI1=PRI1-PINT1
      CALL PRINT1(X,Y,DY)
 7890 IF(PRI2.LT.PINT2)GOTO7920
      PRI2=PRI2-PINT2
      CALL PRINT2(X,Y,DY)
 7920 IF(X.LT.XSTOP)GOTO7590
      RETURN
      END
C
C     THIS SUBROUTINE COMPUTES THE KNEE RESTRAINT CRUSH FORCE AND THE
C     SEAT FRICTION FORCE. HYSTERESIS EFFECTS CAN BE INCLUDED.
      SUBROUTINE SPRING(F,DELTA,DIST,SLOPE1,SLOPE2,FORCE,NPTS)
      DIMENSION F(2,12)
      R=0.
      IF(DIST.GE.DELTA)GO TO 8340
      M=2
      UT=DIST
      GO TO 8360
 8110 M=3
      UT=DELTA
      GO TO 8360
 8140 F(1,K)=DELTA
      F(2,K)=FORCE
      IF(K.GT.3)GOTO8180
      GO TO (8240,8240,8300),K
 8180 KK=K-3
      R=1.
      DO 8210 L=2,NPTS
      F(1,L)=F(1,L+KK)
 8210 F(2,L)=F(2,L+KK)
      NPTS=NPTS-KK
      GO TO 8300
 8240 KK=3-K
      R=2.
      DO 8280 LL=1,NPTS
      L=NPTS+1-LL
      F(1,L+KK)=F(1,L)
 8280 F(2,L+KK)=F(2,L)
      NPTS=NPTS+KK
 8300 F(1,2)=F(1,3)-F(2,3)/SLOPE1
      F(2,2)=0.
      F(2,1)=-SLOPE2*F(1,2)
      F(1,1)=0.
```

```
 8340 M=1
      UT=DIST
 8360 DO 8370 J=2,NPTS
 8370 IF(F(1,J).GT.UT)GOTO8380
 8380 K=J-1
 8390 FORCE=(UT-F(1,K))*(F(2,J)-F(2,K))/(F(1,J)-F(1,K))+F(2,K)
      IF(R.EQ.1.)NPTS=NPTS+KK
      IF(R.EQ.2.)NPTS=NPTS-KK
      GO TO (8450,8410,8140),M
 8410 IF(FORCE.LE.0.)GOTO8450
      IF(ABS((F(2,J)-F(2,K))/(F(1,J)-F(1,K))-SLOPE1).LT..01)
      &GOTO8450
      GO TO 8110
 8450 RETURN
      END
C
C     THIS SUBROUTINE PLACES CERTAIN VALUES IN MATRIX FORMAT FOR PRINTIN
G.
      SUBROUTINE PRINT2(X,Y,DY)
      REAL MO
      COMMON/OUT/N,T(175),X0(6,175),X1(6,175),X2(6,175),X3(6,175),X4(6,1
75)
      &,X5(6,175),X6(6,175),X7(6,175),X8(6,175),X10(6,175)
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      COMMON/MANDAT/ZL,ZT,ZH,RT,RN,RH,RTOPH,X2Z,Y2Z,WB,WH
      COMMON/MMANDAT/LT,LF,THFO,THLO,DELTTB,THEF
      COMMON/PARAM/RFT,THETATZ,THETAHZ,FAW,FNW,FRW,SWHC,VWHC,TAW,TRW
      COMMON/MPARAM/FACOL,SCOLC,PG1,FKNEE,SF,FNCOL,MO,FRCOL,VCOLC,REACT
      COMMON/MMPARAM/BP,VOL,FFT,FP,THETAW,THETAWZ,OMW,TAC,TRC,RBRKT,OMC
      COMMON/EABS/EAWC,EACC,EAWR,EACR,EA
      COMMON/COLDAT/THETAC,THETACZ,MU,LSCZ,LFWZ,LBAZ,LBFZ,WC,RCOL
      COMMON/MISC/VCOLCO,SCOLCO,PR8,BIG
      DATA F/12./,V/.68181818/,G/32.17/,D/57.295780/
      N=N+1
      IF(N.GT.175)RETURN
      CT=COS(Y(7))
      T(N)=X*1000.
      X0(1,N)=-DY(4)/G
      X0(2,N)=Y(4)*V
      X0(3,N)=Y(8)*F
      X0(4,N)=(DY(1)*CT+RT*DY(3))/G
      X0(5,N)=SCOLC
      X0(6,N)=PG1
      X1(1,N)=THEF*D
      X1(2,N)=Y(1)*V
      X1(3,N)=-DY(1)/G
      X1(4,N)=FKNEE*COS(THEF)/2.
      X1(5,N)=SF
      X1(6,N)=(Y(5)-Y(8))*F
      X2(1,N)=(Y(5)+RT*(SIN(Y(7))-SIN(THETATZ)))*F
      X2(2,N)=Y(7)*D
```

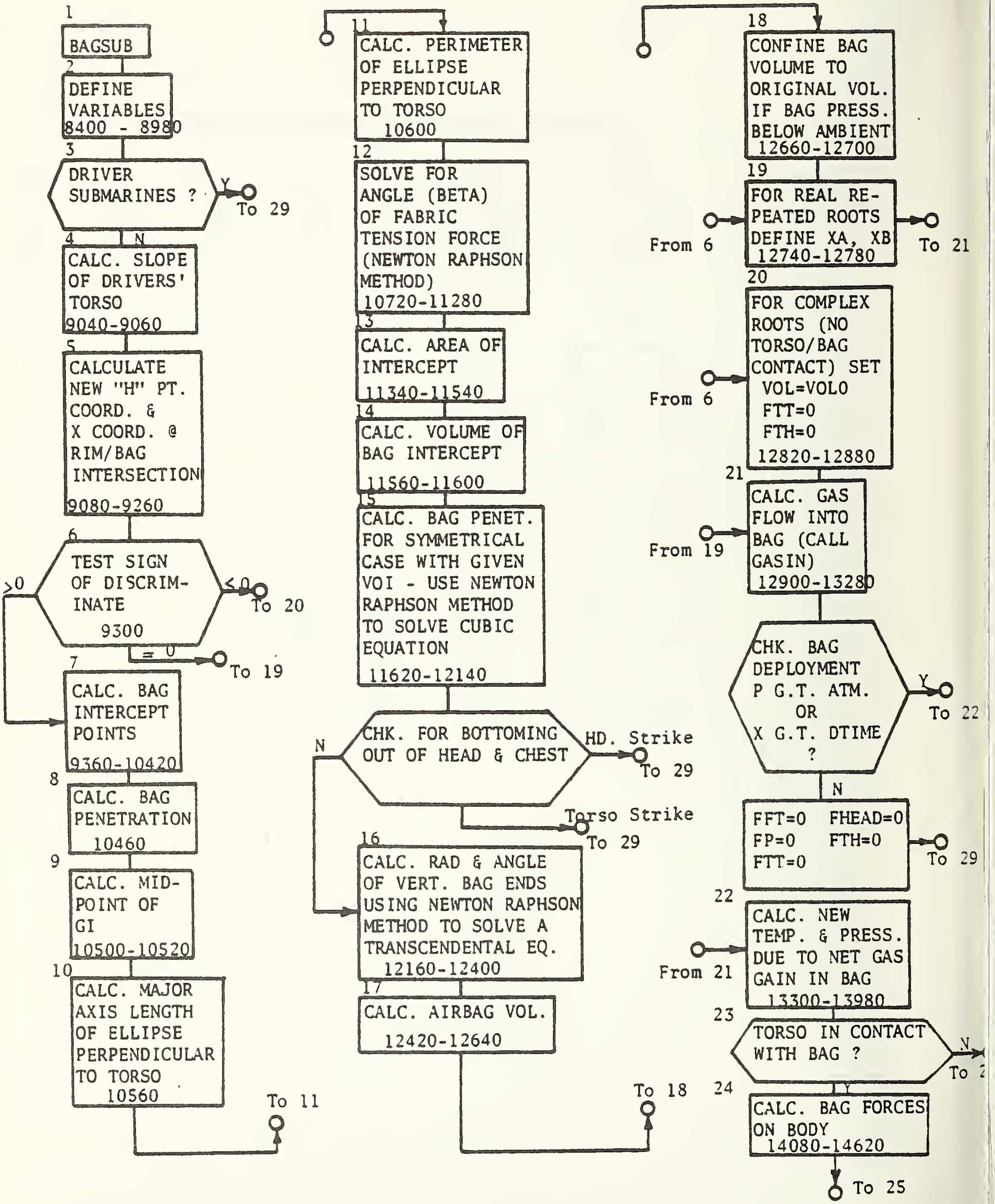
```
      X2(3,N)=Y(3)*D
      X2(4,N)=DY(3)*D
      X2(5,N)=X2(1,N)-Y(8)*F
      X2(6,N)=(RT*Y(3)*CT+Y(1)-Y(4))*V
      X3(1,N)=F*(Y(5)+RN*(SIN(Y(7))-SIN(THETATZ))+RH*(SIN(Y(6))-
     &SIN(THETAHZ)))
      X3(2,N)=Y(6)*D
      X3(3,N)=Y(2)*D
      X3(4,N)=DY(2)*D
      X3(5,N)=X3(1,N)-Y(8)*F
      X3(6,N)=(Y(6)-Y(7))*D
      X4(1,N)=FAW
      X4(2,N)=FNW
      X4(3,N)=MO
      X4(4,N)=FRW
      X4(5,N)=SWHC
      X4(6,N)=VWHC
      X5(1,N)=FACOL
      X5(2,N)=FNCOL
      X5(3,N)=MO
      X5(4,N)=FRCOL
      X5(5,N)=SCOLC
      X5(6,N)=VCOLC
      X6(1,N)=TAW
      X6(2,N)=TRW
      X6(3,N)=THETAW*D
      X6(4,N)=OMW*D
      X7(1,N)=TAC
      X7(2,N)=TRC
      X7(3,N)=THETAC*D
      X7(4,N)=OMC*D
      X8(1,N)=BP
      X8(2,N)=VOL
      X8(3,N)=PG1
      X8(4,N)=FFT
      X8(5,N)=FP
      X10(1,N)=EAWC
      X10(2,N)=EACC
      X10(3,N)=EAWR
      X10(4,N)=EACR
      X10(5,N)=EA
      RETURN
      END
C
      SUBROUTINE UPDATE(X,Y,DY)
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      COMMON/KNEEREST/NKR,SKR,RUT,RELKR
      COMMON/SEATFRIC/NSF,SUN,SFUT,RELSF
      SFUT=RELSF
```

```
      RUT=RELKR
      RETURN
      END
```

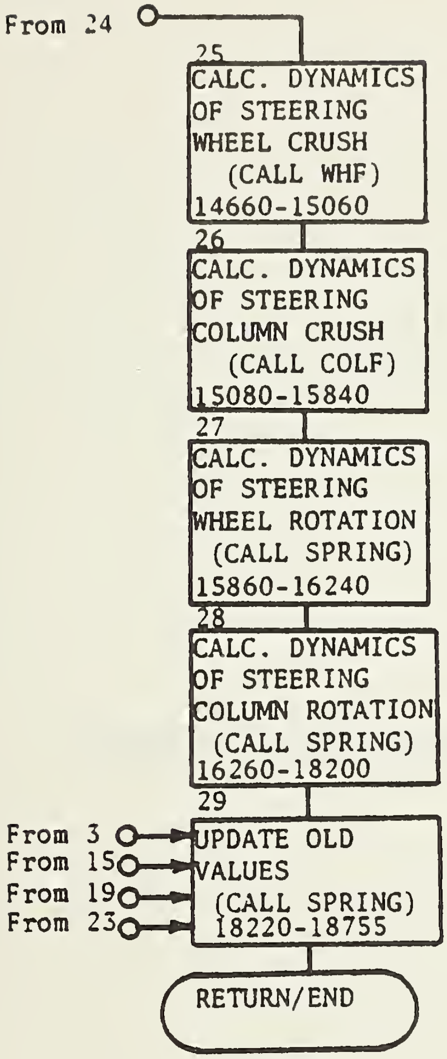
APPENDIX D-2: FLOW DIAGRAMS


Main
20240 Solve
3680 Setup
3100 Diffeq
19720 Print1
23100 Print2
24620 Update
7900 Forceth
8160 Decel
8400 Bagsub
7660 Lookup
19440 WHF
19580 Colf
22220 Spring
19300 Gasin
19640 WHROTNP,N
19676 COLROTP,N

FLOW DIAGRAM - BAGSUB



FLOW DIAGRAM - BAGSUB



APPENDIX E: "DRACR" SAMPLE RUN

```
DRACR       10:37EDT    08/03/82


INPUT FILE NAME?LSRL5005

ENTER 1 IF COLUMN IS SUPPORTED AT THE FIREWALL: OTHERWISE ENTER 2?1




INPUT VALUES -- INPUT UNITS( MSEC. MPH. DEGREES. INCHES. LBS. FT-LBS. G'S)
INITIAL VELOCITY:          28.0
INITIAL HEAD ANGLE:         -6.00
INITIAL TORSO ANGLE:         -24.0
      MLEG    MTORSO     MHEAD       RT         RN         RH       RTOPH
      71.0     58.4      11.4      14.0       20.5       4.75      27.7
     NPTS NECK  NPTS KR  NPTS VEH  NPTS SEAT NPTS GAS   NPTS COL  NPTS WHC
         4         7        12         6         12         12        11
     NP WRP    NP WRN    NP CRP    NP CRN
         6         6         4         4
     SL SEAT  SL KR
 0.500E+04 0.500E+04
GAS FLOW TIME - MSEC
        0.       17.5      20.5      26.0       31.0       36.0      41.0       46.
0      51.0       56.0
GAS FLOW TIME - MSEC
      71.0       100.
GAS FLOW - LB/SEC
        0.        0.       3.40      4.09       4.26       3.60      2.45       1.6
3     0.980     0.490
GAS FLOW - LB/SEC
        0.        0.
COLUMN STROKE - INCHES
     -10.0        0.     0.550     0.950      1.55       1.60      2.34       2.5
7      3.05      3.85
COLUMN STROKE - INCHES
      4.13       5.70
COLUMN FORCE - LBS
        0.        0.      710.      900.       730.       500.      500.       930
.      680.      860.
COLUMN FORCE - LBS
 0.110E+04 0.151E+04
SEAT FRICTION DISPLACEMENT - INCHES
     -50.0        0.      1.00      14.0       15.0       50.0
SEAT FRICTION FORCE - LBS
        0.        0.      250.      250.        0.         0.
NECK ANGLE - DEG
     -80.0      18.0      20.5      90.0
NECK TORQUE - FT-LBS
      115.        0.     -6.70     -86.7
VEH. PULSE TIME - MSEC
        0.      4.00      14.0      25.0       33.0       45.0      57.0       67.
0      73.0      102.
VEH. PULSE TIME - MSEC
      118.      200.
VEH. PULSE DECELERATION - G'S
        0.      1.00      10.0      11.2       8.90       13.0      22.0       15.
0      17.2      8.60
VEH. PULSE DECELERATION - G'S
    -0.500    -0.500
KNEE DISPLACEMENT - INCHES
     -10.0      3.15      3.25      3.58       3.68       4.13      10.0
```

```
KNEE FORCE - LBS
        0.        0.      400.       900. 0.210E+04 0.250E+04 0.250E+04
WHEEL STROKE - INCHES
     -10.0        0.     0.230     0.500     0.910      1.72      1.95      2.5
6     3.00      3.66
WHEEL STROKE - INCHES
      6.00
WHEEL FORCE - LBS
        0.        0. 0.108E+04 0.131E+04 0.117E+04      945.      990.      990
. 0.112E+04      680.
WHEEL FORCE - LBS
 0.136E+04
WHEEL ANGLE. POS. - DEG
        0.      1.60      4.90      8.90      16.0      23.3
WHEEL TORQUE. POS. - IN-LBS
        0. 0.399E+04 0.380E+04 0.340E+04 0.303E+04 0.285E+04
WHEEL ANGLE. NEG. - DEG
        0.      1.60      4.90      8.90      16.0      23.3
WHEEL TORQUE. NEG. - IN-LBS
        0. 0.399E+04 0.380E+04 0.340E+04 0.303E+04 0.285E+04
COLUMN ANGLE. POS. - DEG
        0.      5.00      6.00      7.00
COLUMN REACTION. POS. - IN-LBS IF 2: LBS IF 1
        0.      50.0 0.200E+04 0.200E+04
COLUMN ANGLE. NEG. - DEG
        0.      5.00      6.00      7.00
COLUMN REACTION. NEG. - IN-LBS IF 2: LBS IF 1
        0.      50.0 0.200E+04 0.200E+04
     ATMOP       PGZ       GTZ         U       PN1       PN2       PN3
      14.7     -14.7 0.166E+04      662.      1.40      1.40      1.40
       VC1       VC2        AV        SA        SC       X1Z       Y1Z
     0.700     0.700      2.07      12.5      8.00      30.6      18.9
    THETAC        MU      LSCZ      LFWZ      LBAZ      LBFZ        WC
      15.2        0.      11.0      16.5      15.0      19.0      7.00
        LF      THFO      THLO
      18.0      12.0      35.0
       XWH    RIMRAD       X2Z       Y2Z        WB        WH
     -6.00      7.38      34.5      7.40      11.2      5.00
    THETAW       RIP       WWH       WIP      RCOL       DCN
      15.2      2.50      3.00      2.00      15.0     0.690


CHEST IMPACT WITH LOWER WHEEL RIM. RUN STOPPED.
```

TIME (MS)	VEH G'S (G'S)	VEH VEL (MPH)	VEH DISP (INCHES)	BODY G'S (G'S)	COL DISP (INCHES)	BAG PRESS (PSIG)
0.	0.	28.00	0.	-0.35	0.	-14.70
5.00	1.90	27.93	2.46	-0.46	0.	-14.70
10.00	6.40	27.47	4.90	-0.47	0.	-14.70
15.00	10.11	26.53	7.28	-0.49	0.	-14.70
20.00	10.65	25.39	9.57	-0.52	0.	-13.56
25.00	11.20	24.19	11.75	-0.57	0.	-9.40
30.00	9.76	23.04	13.83	-0.63	0.	-4.66
35.00	9.58	22.02	15.81	-0.62	0.	-0.01
40.00	11.29	20.88	17.70	-10.55	0.08	3.22
45.00	13.00	19.55	19.48	-16.30	0.70	5.12
50.00	16.75	17.92	21.13	-18.69	1.05	6.18
55.00	20.50	15.87	22.62	-17.95	1.72	6.45
60.00	19.90	13.56	23.91	-17.59	2.75	6.07
65.00	16.40	11.57	25.02	-14.58	2.90	5.39
70.00	16.10	9.86	25.96	-11.53	2.92	4.57
75.00	16.61	8.02	26.75	-10.04	2.92	4.09
80.00	15.12	6.28	27.37	-9.43	2.92	3.82
85.00	13.64	4.70	27.86	-9.15	2.92	3.58
90.00	12.16	3.29	28.21	-8.95	2.92	3.38
95.00	10.68	2.04	28.44	-8.40	2.92	3.22
100.00	9.19	0.95	28.57	-7.39	2.92	3.08

TIME (MS)	FEM ANGLE (DEG)	H-P VEL (MPH)	H-P ACC (G'S)	FEM FORCE (LBS)	SEAT FR. (LBS)	H-P R.D. (I~0-0
0.	12.00	28.00	0.	0.	0.	0.
5.00	12.00	28.03	-0.31	0.	0.83	0.00
10.00	12.00	28.06	-0.23	0.	7.62	0.03
15.00	12.00	28.08	0.03	0.	30.37	0.12
20.00	12.00	28.05	0.57	0.	76.59	0.31
25.00	12.00	27.94	1.40	0.	147.11	0.59
30.00	12.00	27.73	2.50	0.	240.50	0.96
35.00	13.47	27.44	2.66	0.	250.00	1.41
40.00	15.10	27.01	4.40	0.	250.00	1.92
45.00	16.81	26.46	5.26	0.	250.00	2.49
50.00	18.62	25.83	6.11	0.	250.00	3.14
55.00	20.55	25.12	6.61	0.	250.00	3.89
60.00	22.59	23.39	30.37	1002.77	250.00	4.75
65.00	24.36	19.75	33.51	1138.74	250.00	5.55
70.00	25.68	16.15	32.17	1126.51	250.00	6.18
75.00	26.64	12.65	31.74	1117.30	250.00	6.66
80.00	27.28	9.17	31.80	1110.95	250.00	6.99
85.00	27.61	5.66	32.29	1107.69	250.00	7.17
90.00	27.59	2.12	30.67	1063.03	110.58	7.16
95.00	27.24	-0.82	22.52	773.13	0.	6.97
100.00	26.67	-2.73	11.11	299.76	0.	6.68

TIME (MS)	TORSO DISP (INCHES)	TORSO ANG (DEG)	TORSO VEL (D/SEC)	TORSO ACC (D/SEC**2)	TORSO R.D. (INCHES)	TORSO R.V. (MPH)
0.	0.00	-24.00	0.	-550.61	0.00	0.
5.00	2.46	-24.01	-5.64	-1172.29	0.00	0.03
10.00	4.92	-24.06	-11.33	-1071.77	0.02	0.45
15.00	7.38	-24.13	-16.00	-723.00	0.09	1.35
20.00	9.83	-24.21	-18.07	0.52	0.26	2.43
25.00	12.27	-24.30	-15.59	1113.88	0.52	3.55
30.00	14.71	-24.36	-6.65	2595.12	0.88	4.61
35.00	17.14	-24.36	7.42	2855.39	1.33	5.52
40.00	19.54	-24.33	-7.84	-10339.37	1.84	6.03
45.00	21.85	-24.53	-81.44	-18186.32	2.37	5.89
50.00	24.01	-25.18	-180.12	-20804.07	2.88	5.65
55.00	25.99	-26.34	-282.25	-19005.27	3.37	5.74
60.00	27.81	-27.89	-311.86	14628.15	3.89	6.00
65.00	29.42	-29.21	-210.99	23172.70	4.41	5.62
70.00	30.84	-29.97	-88.82	25819.48	4.88	5.22
75.00	32.09	-30.08	44.77	27518.07	5.34	5.17
80.00	33.17	-29.51	185.39	28831.09	5.79	5.13
85.00	34.10	-28.22	333.44	30507.13	6.24	5.04
90.00	34.89	-26.16	488.40	29359.21	6.68	4.92
95.00	35.55	-23.39	611.67	19383.94	7.11	4.94
100.00	36.12	-20.14	675.87	4808.77	7.55	5.14

TIME (MS)	HEAD DISP (INCHES)	HEAD ANG (DEG)	HEAD VEL (D/SEC)	HEAD ACC (D/SEC**2)	HEAD R.D. (INCHES)	HEAD R.ANG (DEG)
0.	0.00	-6.00	0.	-486.74	0.00	18.00
5.00	2.46	-5.97	12.94	2919.14	0.00	18.04
10.00	4.93	-5.87	27.58	2909.81	0.02	18.19
15.00	7.39	-5.70	42.11	2797.49	0.11	18.43
20.00	9.85	-5.45	55.78	2470.10	0.28	18.76
25.00	12.31	-5.14	67.43	1910.03	0.56	19.16
30.00	14.77	-4.78	75.94	1136.57	0.95	19.58
35.00	17.23	-4.39	78.87	410.72	1.42	19.96
40.00	19.68	-3.89	165.98	45885.45	1.98	20.44
45.00	22.10	-2.34	475.21	75055.84	2.62	22.19
50.00	24.46	0.99	859.39	75370.16	3.33	26.17
55.00	26.76	6.16	1192.31	54718.84	4.14	32.50
60.00	28.96	12.78	1448.55	43370.10	5.05	40.67
65.00	31.05	20.41	1584.59	14783.20	6.03	49.63
70.00	33.00	28.45	1614.89	-2245.84	7.04	58.42
75.00	34.79	36.45	1575.94	-12969.93	8.04	66.53
80.00	36.41	44.13	1487.05	-23031.97	9.04	73.63
85.00	37.87	51.23	1342.49	-35251.10	10.01	79.44
90.00	39.16	57.44	1126.18	-55018.74	10.96	83.60
95.00	40.31	62.25	775.59	-84585.90	11.87	85.64
100.00	41.34	65.40	548.65	-28691.19	12.77	85.55

TIME (MS)	WH AX FOR (LBS)	WH N FOR (LBS)	WH MOMENT (IN-LBS)	WH RESIST (LBS)	WH STROKE (INCHES)	WH ST VEL (IN/SEC)
0.	0.	0.	0.	0.	0.	~◊◊
5.00	0.	0.	0.	0.	0.	0.
10.00	0.	0.	0.	0.	0.	0.
15.00	0.	0.	0.	0.	0.	0.
20.00	0.	0.	0.	0.	0.	0.
25.00	0.	0.	0.	0.	0.	0.
30.00	0.	0.	0.	0.	0.	0.
35.00	0.	0.	0.	0.	0.	0.
40.00	614.84	474.29	1396.32	424.36	0.09	47.04
45.00	955.71	763.68	2411.73	654.96	0.14	59.19
50.00	1144.86	935.04	3088.70	1101.88	0.26	0.
55.00	1183.34	998.75	3532.51	1101.88	0.26	0.
60.00	1052.38	982.22	3718.27	1101.88	0.26	0.
65.00	789.50	871.21	2976.67	1101.88	0.26	0.
70.00	572.68	717.67	2211.17	1101.88	0.26	0.
75.00	495.47	624.31	1832.77	1101.88	0.26	0.
80.00	471.79	559.83	1592.05	1101.88	0.26	0.
85.00	456.71	499.70	1370.11	1101.88	0.26	0.
90.00	450.36	445.02	1170.11	1101.88	0.26	0.
95.00	452.08	395.47	989.05	1101.88	0.26	0.
100.00	458.94	349.86	823.90	1101.88	0.26	0.

TIME (MS)	COL AX FOR (LBS)	COL N FOR (LBS)	COL MOMENT (IN-LBS)	COL RESIST (LBS)	COL STROKE (INCHES)	COL ST VEL (IN/SEC)
0.	0.	0.	0.	0.	0.	0.
5.00	0.	0.	0.	0.	0.	0.
10.00	0.	0.	0.	0.	0.	0.
15.00	0.	0.	0.	0.	0.	0.
20.00	0.	0.	0.	0.	0.	0.
25.00	0.	0.	0.	0.	0.	0.
30.00	0.	0.	0.	0.	0.	0.
35.00	0.	0.	0.	0.	0.	0.
40.00	693.16	492.39	1396.32	107.26	0.08	61.60
45.00	1053.01	775.57	2411.73	783.39	0.70	97.57
50.00	1272.79	947.45	3088.70	870.91	1.05	66.33
55.00	1337.61	1017.44	3532.51	500.00	1.72	211.40
60.00	1201.62	1004.48	3718.27	838.23	2.75	117.29
65.00	910.68	899.17	2976.67	760.12	2.90	0.
70.00	682.81	759.29	2211.17	746.56	2.92	0.
75.00	607.83	669.81	1832.77	746.56	2.92	0.
80.00	574.00	600.98	1592.05	746.56	2.92	0.
85.00	548.82	536.39	1370.11	746.56	2.92	0.
90.00	532.45	477.12	1170.11	746.56	2.92	0.
95.00	524.21	422.87	989.05	746.56	2.92	0.
100.00	521.18	372.49	823.90	746.56	2.92	0.

TIME (MS)	WH AP MOM (IN-LBS)	WH RES MOM (IN-LBS)	WH ANGLE (DEG)	WH ANG VEL (DEG/SEC)		
=======	=======	=======	=======	=======	=======	=======
0.	0.	0.	15.25	0.		
5.00	0.	0.	15.25	0.		
10.00	0.	0.	15.25	0.		
15.00	0.	0.	15.25	0.		
20.00	0.	0.	15.25	0.		
25.00	0.	0.	15.25	0.		
30.00	0.	0.	15.25	0.		
35.00	0.	0.	15.25	0.		
40.00	1396.32	-623.99	15.50	0.		
45.00	2411.73	-1791.85	15.97	114.67		
50.00	3088.70	-2285.58	16.17	0.		
55.00	3532.51	-2285.58	16.17	0.		
60.00	3718.27	-2285.58	17.27	0.		
65.00	2976.67	-2285.58	21.68	0.		
70.00	2211.17	-1666.36	26.07	0.		
75.00	1832.77	-1979.04	27.60	0.		
80.00	1592.05	-1979.04	27.60	0.		
85.00	1370.11	-1979.04	27.60	0.		
90.00	1170.11	-1979.04	27.60	0.		
95.00	989.05	-1979.04	27.60	0.		
100.00	823.90	-1979.04	27.60	0.		

TIME (MS)	COL AP MOM (IN-LBS)	COL RES MOM (IN-LBS)	COL ANGLE (DEG)	COL ANG VEL (DEG/SEC)		
=======	=======	=======	=======	=======	=======	=======
0.	0.	0.	15.25	0.		
5.00	0.	0.	15.25	0.		
10.00	0.	0.	15.25	0.		
15.00	0.	0.	15.25	0.		
20.00	0.	0.	15.25	0.		
25.00	0.	0.	15.25	0.		
30.00	0.	0.	15.25	0.		
35.00	0.	0.	15.25	0.		
40.00	0.	0.	15.25	0.		
45.00	0.	0.	15.25	0.		
50.00	0.	0.	15.25	0.		
55.00	0.	0.	15.25	0.		
60.00	28583.04	-151.60	16.35	551.17		
65.00	25099.61	-14306.89	20.76	1198.79		
70.00	20872.90	-27155.57	25.40	607.16		
75.00	18295.23	-27155.57	26.80	0.		
80.00	16362.79	-27155.57	26.80	0.		
85.00	14553.34	-27155.57	26.80	0.		
90.00	12896.64	-27155.57	26.80	0.		
95.00	11382.22	-27155.57	26.80	0.		
100.00	9978.92	-27155.57	26.80	0.		

TIME (MS)	BAG PEN. (INCHES)	BAG VOL. (CU.IN.)	BAG PRESS. (PSIG)	W/A FORCE (LBS)	P. FORCE (LBS)
0.	6.44	4955.72	-14.70	0.	0.
5.00	6.45	4955.69	-14.70	0.	0.
10.00	6.46	4953.91	-14.70	0.	0.
15.00	6.54	4946.32	-14.70	0.	0.
20.00	6.70	4929.66	-13.56	0.	0.
25.00	6.95	4903.04	-9.40	0.	0.
30.00	7.29	4866.14	-4.66	0.	0.
35.00	7.71	4819.76	-0.01	0.	0.
40.00	8.05	4829.80	3.22	75.11	628.19
45.00	8.00	4833.03	5.12	122.66	1006.16
50.00	8.11	4821.96	6.18	152.74	1211.82
55.00	8.07	4828.26	6.45	165.42	1270.15
60.00	7.65	4874.70	6.07	158.37	1197.56
65.00	7.45	4949.09	5.39	126.26	971.58
70.00	7.12	5027.59	4.57	94.13	748.49
75.00	7.27	5033.32	4.09	82.02	641.33
80.00	7.69	5002.82	3.82	75.63	590.68
85.00	8.13	4967.16	3.58	69.71	549.73
90.00	8.57	4925.98	3.38	64.92	518.07
95.00	8.99	4879.53	3.22	61.23	494.40
100.00	9.40	4828.82	3.08	58.19	476.10

TIME (MS)	CHEST AP (G'S)	CHEST SI (G'S)	HEAD AP (G'S)	HEAD SI (G'S)
0.	-0.35	0.	-0.59	0.16
5.00	-0.46	0.12	-0.10	0.37
10.00	-0.47	0.09	-0.09	0.34
15.00	-0.49	-0.01	-0.07	0.22
20.00	-0.52	-0.23	-0.04	-0.04
25.00	-0.57	-0.57	-0.01	-0.44
30.00	-0.63	-1.03	0.02	-0.99
35.00	-0.62	-1.10	-0.08	-1.08
40.00	-10.55	-1.81	-3.51	3.15
45.00	-16.30	-2.11	-4.71	7.10
50.00	-18.69	-2.24	-6.99	11.85
55.00	-17.95	-2.05	-8.98	16.59
60.00	-17.59	-13.13	-9.00	6.94
65.00	-14.58	-15.86	-13.77	5.20
70.00	-11.53	-15.98	-16.12	4.78
75.00	-10.04	-15.88	-18.13	4.78
80.00	-9.43	-15.29	-19.71	4.95
85.00	-9.15	-14.04	-20.85	4.47
90.00	-8.95	-10.89	-21.46	3.99
95.00	-8.40	-4.81	-21.25	4.73
100.00	-7.39	1.22	-3.07	7.36

TIME (MS)	EAWC (LBS)	EACC (LBS)	EAWR (LBS)	EACR (LBS)	EA (LBS)	
=======	=======	=======	=======	=======	=======	=======
0.	0.	0.	0.	0.	0.	
5.00	0.	0.	0.	0.	0.	
10.00	0.	0.	0.	0.	0.	
15.00	0.	0.	0.	0.	0.	
20.00	0.	0.	0.	0.	0.	
25.00	0.	0.	0.	0.	0.	
30.00	0.	0.	0.	0.	0.	
35.00	0.	0.	0.	0.	0.	
40.00	440.38	111.17	0.	1000000.00	0.	
45.00	681.25	811.98	0.	1000000.00	0.	
50.00	1147.24	902.70	0.	1000000.00	0.	
55.00	1147.24	518.25	0.	1000000.00	0.	
60.00	1000000.00	873.57	0.	0.	873.57	
65.00	1000000.00	812.92	0.	0.	812.92	
70.00	1000000.00	1000000.00	0.	1000000.00	0.	
75.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00	
80.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00	
85.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00	
90.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00	
95.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00	
100.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00	

ENTER 1 TO CALCULATE HIC?1

THE HIC IS   6.8267609E+01
T1=   5.0000000E-02
T2=   1.0000000E-01

PROGRAM STOP AT 3030