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Final Report

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National Highway Traffic Safety Administration

Comprehensive Documentation of Passenger (PAC) Computer Model

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16. Abstract
This manual is written to give the user of the PAC 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 passenger of a vehicle and an air cushion restraint system in a crash situation. The air cushion is mounted to the dash and the gas generation system in a user specified geometrical arrangement. The entire airbag deployment sequence is modeled. Because of this, the effect of deployment forces on forward positioned passenger are able to be analyzed. The passenger is described by four lumped masses linked together in a prescribed relationship. The airbag is described by two masses.

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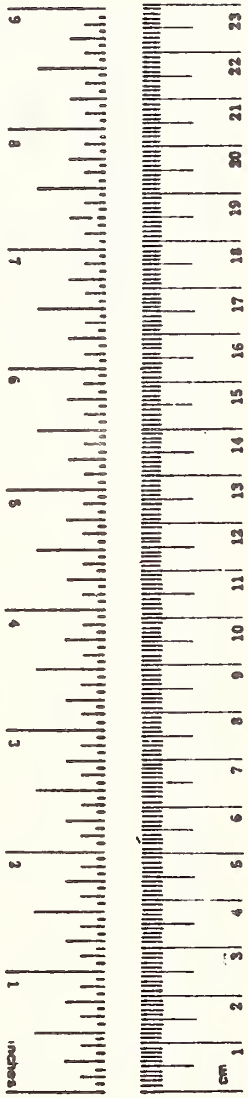
METRIC CONVERSION FACTORS

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

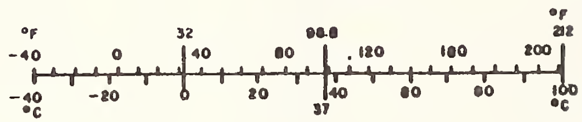


Table of Contents

PREFACE TO REVISION A OF THE "PAC" USER'S MANUAL

The original publication of the PAC User's Manual issued in August of 1980 is now somewhat dated. In the time that has elapsed since the original manual was written, several modifications have been made. The reason for the modifications have been primarily two-fold. First some program "bugs" were isolated in the program and required fixing. Second, certain enhancements have been made to the program that should be documented.

In the list that follows these modifications will be described.

a) The parameters "DELTTB" and "LT" have been removed from the program input file. These parameters are now solved for in the program in terms of other input parameters.

b) The parameters "XSTOP", "STEP", "PINT1" and "PINT2" which were previosly assigned values internally in the program have now been placed in the input file for convenience. These values are the time after T-0 at which the user wishes computation to cease, the integration interval step size, and the print interval for the "PRINT1" and PRINT2" subroutine block output respectively.

c) The computation of HIC (Head Injury Crition) has been added.

d) The output has been modified to be more pertinent to the average user by, first, limiting output to values of more general interest and by, second, providing an option to obtain only an abbreviated output of the critical parameters if one so desires.

e) The neck torque algorithm has been modified to include a resisting torque during the unloading phase.

f) The "SPRING" subroutine has been modified to prevent certain subscripts from becoming too large.

g) Errors found in the expressions for head and chest g's have been fixed.

h) The meaning of the input values "X1" and "Y1" have been changed from the coordinates of the airbag center to the inflator center. This was done to prevent the user from from having to change these values in the input file each time a new airbag shape was simulated. The program then makes the calculation to move these coordinates to the airbag center without user involvement.

i) The number of points that may be specified for the crash pulse has been increased from 30 to 50.

j) The neck tensile force and moment computation was removed from the program due to lack of data to which these computations be be checked for accuracy.

k) The knee trajectory equations were modified to allow the tibia angle to increase beyond ninety degrees (the vertical position) without the algorithm "blowing up".

In addition to these modifications, a new validation of the program has been included in the manual as an example case. The manual also has been extensively rewritten so the latest information is included.

Michael Fitzpatrick
September, 1982

1.0 Introduction

This manual is written to give the potential user of the "PAC" computer program the specific information he will need to:

a) Set up the data input file
b) Run the program
c) Interpret the results

Prior to discussing these main items however, let us present some background information on the program.

PAC is an acronym for "Passenger Air Cushion". As this title indicates, the program was written to describe the interaction between the passenger of the vehicle and his airbag in a crash situation. Other programs have been written in the past to describe such an interaction, but none incorporate the combination of useful features of this program which are described below.

a) Simulates the entire deployment sequence of the unfurling airbag from its stowed condition through the rebound of the passenger away from the fully deployed bag at the conclusion of the crash event.
b) Has the flexibility of simulating virtually any normal, passenger airbag shape from a circular cylinder airbag with hemispherical ends to an ellipsoidal cylinder airbag with ellipsoidal ends.
c) Has the versatility of specifying a variable airbag deployment angle and a variable airbag fabric weight.
d) Has the flexibility of the user being able to specify the up-down and fore-aft location of the gas generator relative to the seated passenger.

e) Is simple and, therefore, inexpensive enough to run on a small in-house computer with no "library routines" from an external source required for execution. Therefore the program is "self contained" as well as inexpensive and simple to operate so it can be efficiently used as a design tool.

f) As a design tool, the program is oriented to the user requirements of a typical restraint systems engineer with both the formulation and the input and output in units commonly used and/or measured in a typical test situation.

g) As a design tool, the program is also oriented toward the test hardware actually encountered in most situations. For example, past computer programs might model the passenger anthropometric properties very well but might neglect the bag shape actually used and/or the bag deployment forces that can be all important in the out-of-position child situation.

h) Finally, the program is balanced so that the various components that comprise a normal restraint system are modeled to be of approximately equal detail, complexity and accuracy.

With these features in mind, we will now discuss the PAC program in some detail.

2.0 Program Description

PAC is a two-dimensional, lumped mass computer model of a vehicle passenger interacting with an initially deploying or already deployed airbag of arbitrary shape in a crash situation. The model includes six primary masses - four to desribe the passenger and two to describe the airbag. The masses that are used to describe the passenger are the head mass, the main torso mass, the mass of the sternum (especially useful in those cases where "bag-slap" is of interest), and the lower body mass (legs and hips). The airbag masses are composed of the mass that impacts the passenger and the mass that surrounds the passenger and is relatively free to expand. These two airbag masses are known as the restrained airbag mass and the unrestrained airbag bag mass respectively.

The passenger airbag is simulated by an ellipsoidal cylinder with ends of arbitrary curvature into which a programmed amount of gas flows. By adjusting the airbag vent size, a selected amount of gas can be vented during the simulated crash in order to attenuate peak chest g's and rebound effects thereby aiding in the selection of an optimum airbag design for a given impact situation.

In addition to the basic model characteristics, the model has specific features that enable the user to ascertain how well a basic airbag design will protect the out-of-position child which may be sitting very close to the airbag at the instant of airbag actuation. In order to make this determination, the complete airbag deployment process had to be modeled. In order to lend as much flexibility to this feature as possible, we have made it possible for the user to specify in detail the airbag deployment geometry. Thus, the airbag deployment angle and the up-down and fore-aft location of the gas generator relative to the passenger are input variables specified by the user.

Specific output tailored to the out-of-position child are the bag-slap forces and the chest and sternal deflections, velocities and accelerations induced by the deploying airbag.

In addition to these basic model characteristics, neck rotational resistance, seat friction, force-deflection and damping properties of the chest and sternum, and knee restraint force-deflection properties are additional variables that need to be specified prior to running the program.

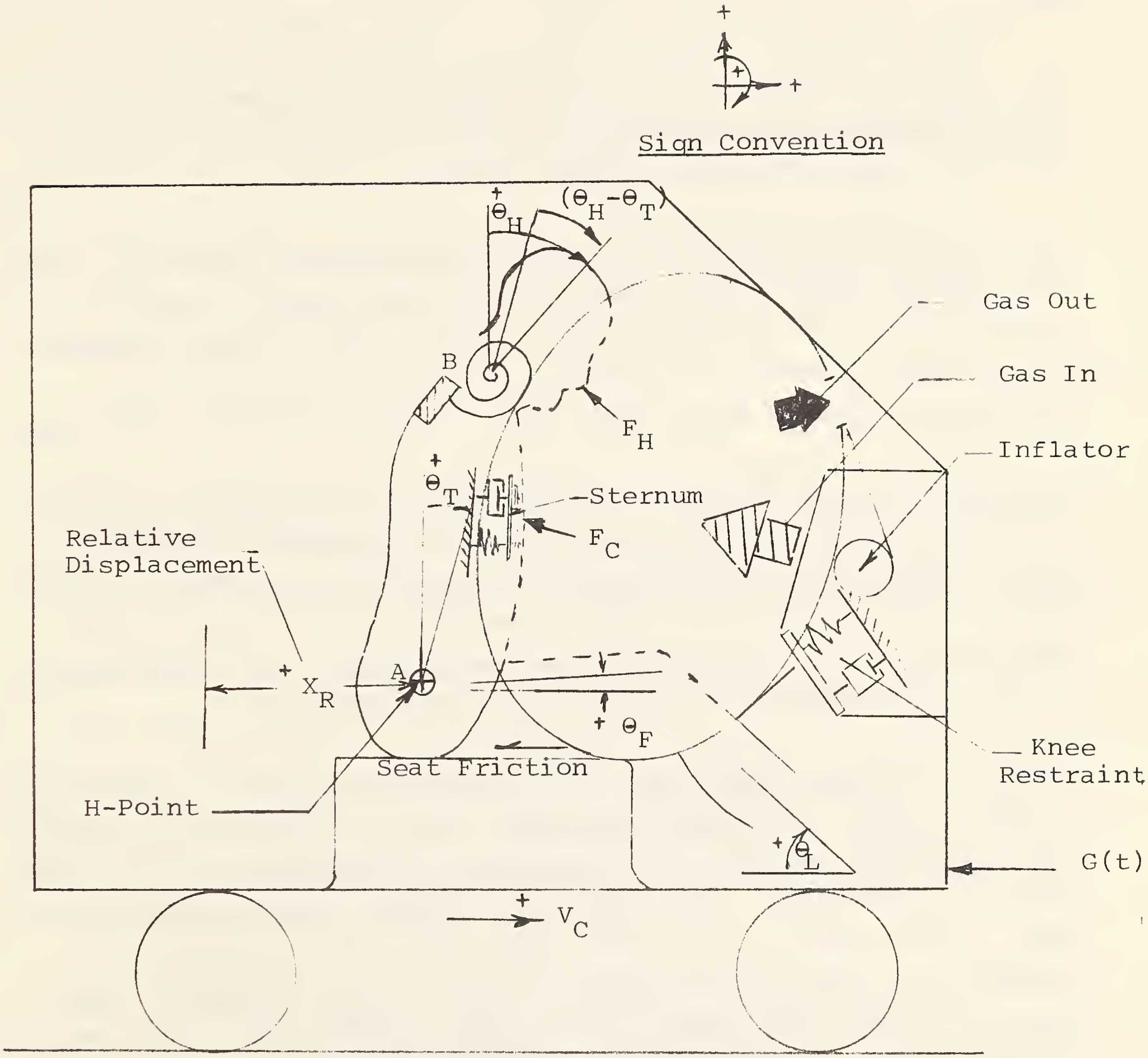
2.1 Mathematical Formulation

The mathematical formulation of the equations of motion follows the classical Lagrangian derivation (Appendix A) with body pivot points at A and B of Figure 1.

The lower body mass, consisting of hips and legs, is constrained to move horizontally. The torso mass and the head mass are free to both translate and rotate about the H-point and neck pivots. The sternal mass is constrained to move in a direction perpendicular to the chest.

PAC 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.

PAC has been written in Fortran IV and set up to operate in an interactive time share mode for maximum utility to the design engineer. The program is self contained in that no external routines



Schematic of "PAC" Computer Model

Figure 1.

are required for execution. The program is also set up in modular format to facilitate the addition of other subroutines at a future time.

Data input is read by PAC from a previously created file which is then displayed and described as a portion of the total output immediately before the main program output.

As previously mentioned, PAC has been programmed in modular format with several subroutines. This enables the program to exhibit flexibility in two important ways. First, additional algorithms may be added if desired. Second, it makes for an easy way to provide for tabular data input. PAC provides for this in two ways.

For data in which the particular value of the dependent variable is a function only of the value for the independent variable, a simple table look up and interpolation subroutine,"LOOKUP" is provided. Inflator gas flow versus time, vehicle g's versus time, neck torque versus angle, and chest and sternal force versus deflection are examples of this method of data operation.

However, in those cases where the dependent variable is a function not only of the independent variable, but also depends on whether the independent variable is increasing or decreasing , a different subroutine, "SPRING", that allows for complex plastic behavior is used. In this case one must not only specify the values of the dependent variable for different values of the independent variable, but must also specify the "unload slopes" for those conditions in which the member is undergoing unloading during a lessening of the degree of deformation. Knee restraint force as a function of crush and seat friction force as a function of stroke are handled by this subroutine.

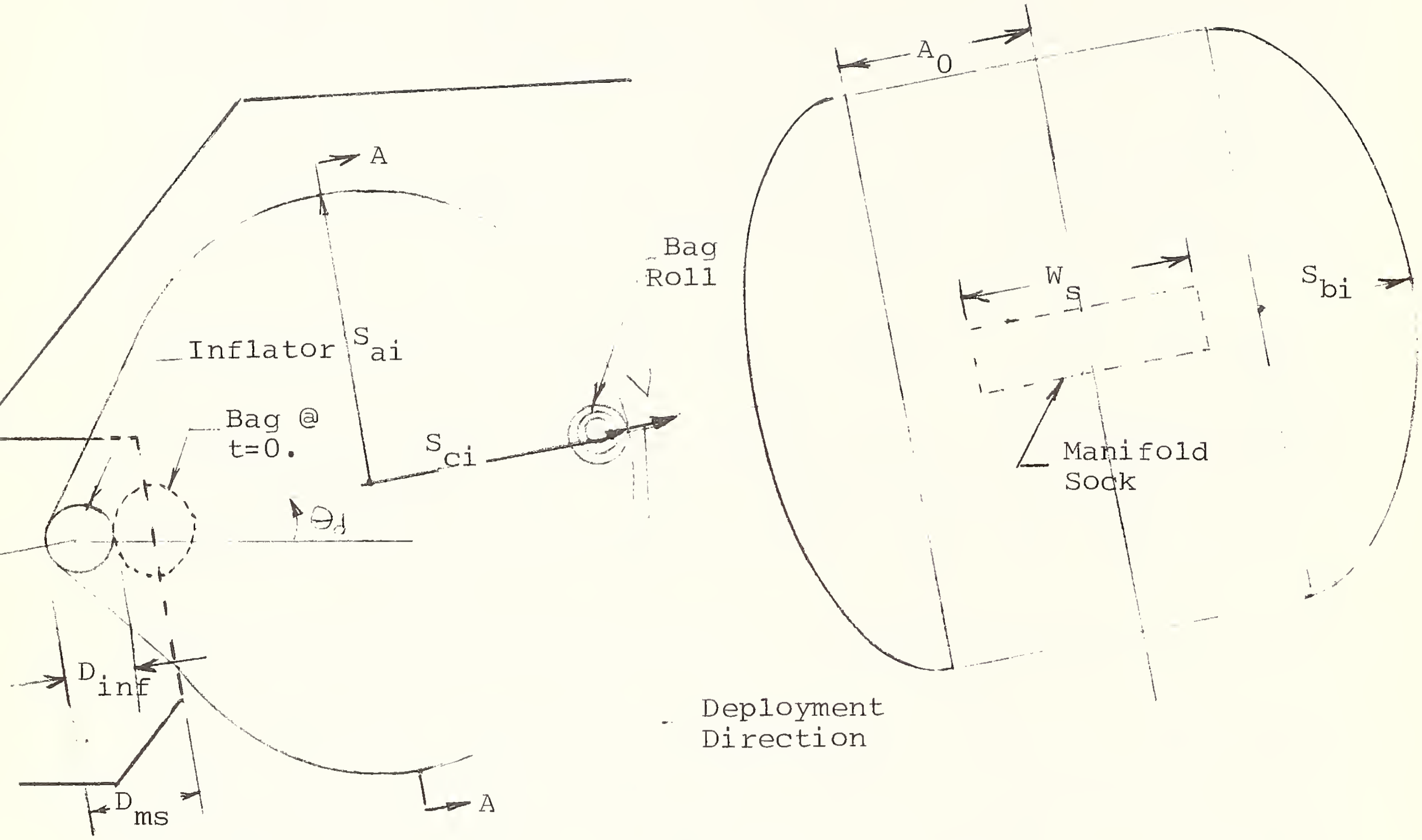
2.2 Airbag

The airbag shape chosen for use in the PAC model has been chosen to be of as general a shape as possible without introducing an airbag algorithm that would require unrealistically high amounts of run time on the computer or be incompatible with the degree of complexity of the remainder of the program. Figure 2 shows the airbag shape chosen for the PAC model. As can be seen from the figure, three ellipsoidal axes dimensions (a_i, b_i, and c_i) plus the half lengh of the cylindrical portion (A_o) are necessary to describe the general airbag shape.

In addition to these variables, three more are required to describe the shape of the bag in area where the bag encloses the inflator. These variables are the inflator diameter (D_{inf}), the distance the "manifold sock" extends forward of the dash (D_{ms}), and the width of the manifold sock (W_{sock}) which is equivalent to the inflator length.

Initially the airbag is assumed to be rolled up and have the shape of a very small ellipsoidal cylinder with an axis length c_i equal to $D_{ms} - D_{inf}$. After bag inflation begins, the bag is assumed to inflate along all three airbag axes a proportionate amount so that a constant ratio of axis lengths exist until full airbag inflation is obtained. The direction the bag deploys is specified by assigning the value desired to Θ_d in the input file.

In order to properly describe the deployment sequence, it is necessary to keep track of two separate airbag masses; the airbag mass that impinges upon the torso of the passenger which is called the "restrained" airbag mass, and the airbag mass that is free to expand until full deployment which is called the "unrestrained" airbag mass.



"PAC" Airbag Schematic

Figure 2.

Appendix B contains the derivations of key equations that were necessary to describe the airbag deployment sequence as well as other airbag related items such as derivation of wraparound forces, pressure forces, contact areas, airbag volume, etc.

2.3 Knee Restraint and Seat Friction

As previously mentioned, the program is set up to accept tabular input for the force versus crush properties of the knee restraint and the force versus displacement properties of seat friction. It is these values that primarily determine the kinematics of the lower body. Appendix C contains the derivation of knee restraint equations.

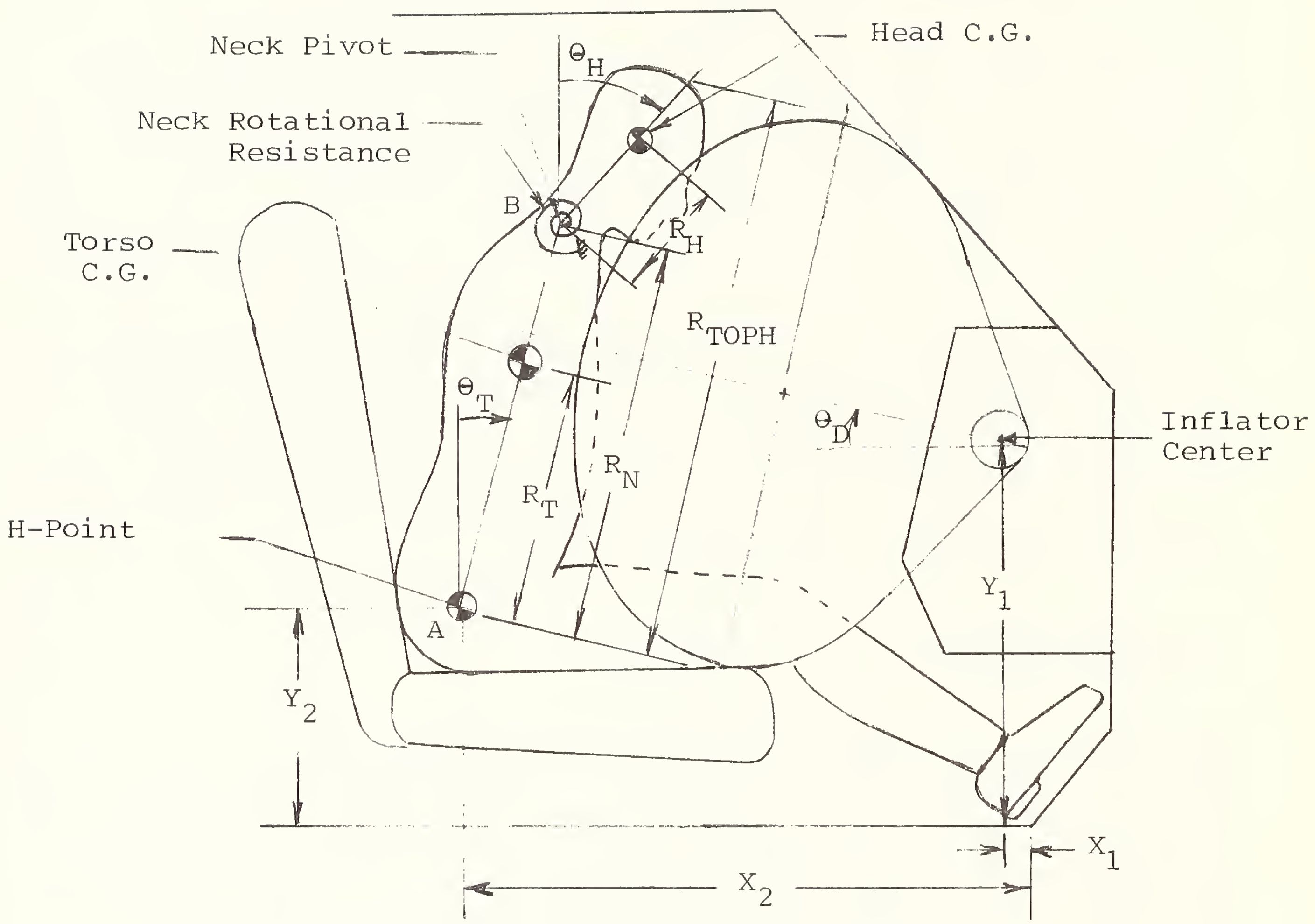
The user specifies in tabular format in a data file what these properties are to be. In addition, the user specifies the "unload slope" so the program can compute the path the unloading sequence is to take during rebound away from the knee bolster or movement rearward over the passenger seat. Specifics on how this and all other data input is handled is discussed in Section 3.1.

2.4 The Passenger

The passenger is modeled by four masses, the head, the main torso mass, the sternal mass, and the lower body mass. Pivot points exist at points A and B as shown in Figure 3. This figure also describes the overall passenger geometry and location of the passenger with respect to the vehicle interior.

Specific details of providing the passenger related input into the data file is discussed in Section 3.1.

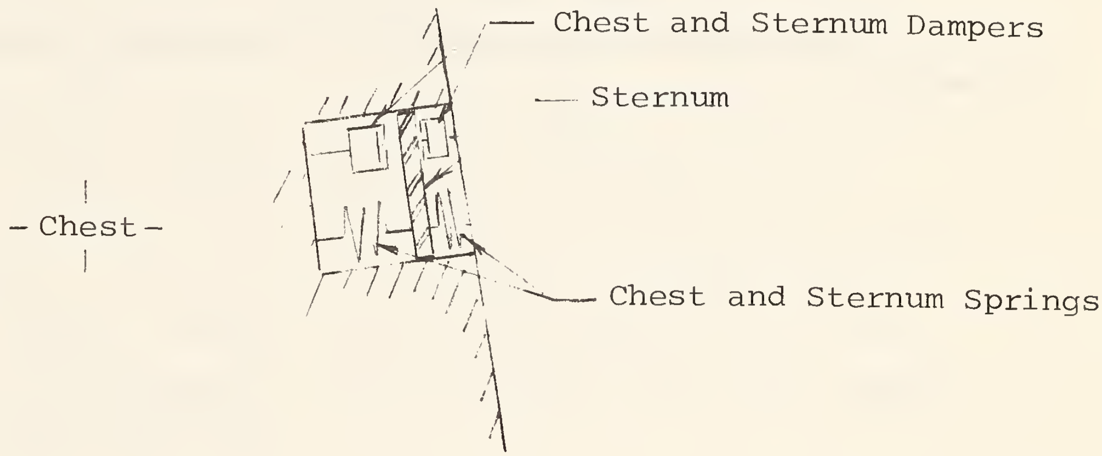
The torso and sternal masses are assumed to be connected in series



Geometric Nomenclature for "PAC" Computer Model

Figure 3.

as shown below. The spring forces as a function of the deflection of the spring are input in tabular format. The damping forces are assumed to be a function of velocity and are computed by multiplying the relative velocity between the bag mass and the sternal mass and the sternal mass and the main torso mass by an appropriate factor included as part of the data input. These factors, one for each mass, are known as the damping coefficients.



A further comment is necessary in regard to the resisting torque generated by neck muscular resistance and anatomical interferences due to relative displacement between the head and the torso since these forces are only applied if certain conditions are met.

In those cases where the head is returning to be more nearly in line with the passenger's torso (unloading), the neck torque resisting head/neck relative movement is reduced to 0.5 times the "loading" value for hyperextension and 0.4 times this value for hyperflexion. This has been done to make the neck unloading conform to recommended performance parameters for mechanical necks.

In addition to the neck resisting torque based upon angular displacement of the head relative to the torso, we have also included a damping coefficient for the head based based upon the angular velocity of the head relative to the torso. This value, known as DCN in the input data file, is multiplied by this angular velocity and added to the neck torque calculated as a function of the angular displacement of the head relative to the torso for the total neck torque resisting head/torso relative motion.

For an overall listing of the PAC program, please refer to Appendix D.

3.0 Example

The best way to illustrate the use of the PAC model is by an example. For our example we chose to simulate a recent sled test supervised by Fitzpatrick Engineering and conducted at Transportation Research Center of East Liberty, Ohio. This test was conducted as part of Contract No. DTNH22-81-C-07132, "A Systems Analysis Approach into Integrating Airbags into A Production Ready Small Car". In this program, Fitzpatrick Engineering designed air cushion restraint systems for the driver and passenger of the DeLorean sports car. By simulating an actual sled test we will not only be able to illustrate the use of PAC by example, but we will also be able to compare test results with computer results giving some indiction as to the degree to which the program is able to predict what will happen in an actual crash situation.

The test case chosen was TRC sled run no. 7 of the above referenced contract. This test was a frontal test at 34 mph with an airbag sensing time of 15 msec. The Part 572, 50th percentile male ATD was seated normally in the DeLorean passenger seat. The gas flow rate into the airbag, appropriate airbag dimensions, airbag deployment geometry and other information needed to specify the information required for computer input were obtained from the appropriate source and prepared for computer input.

3.1 Creation of the Data Input File

The first thing one must do in preparation for making a computer run is to set up the data input file. This file is a listing in a pre-ordained format of the information the program requires in order to run the given case. Pages 15 through 18 list the parameters for the data file for this particular case as well as showing how to set up the data file for any other case. We will now discuss how the information presented on pages 15 through 18 relates to the data file.

On page 15 the first column shows the location of a particular piece of data in the input file. For example under "LOCATION", the "LINE NO." corresponds to the line number in the data file. Line number "1" would correspond to the first line of the data file, line number "2" the second line, etc.

The second number under the "LOCATION" heading is the "LINE LOC." which is the location in the line of a particular piece of data. For example, a "2" in this column indicates the second piece of data in that particular line.

In the second main column we encounter a column heading,"NAME/UNITS". The "NAME" is the name of the particular piece of data referred to in the first column. Further, this name is as programmed in the PAC program and is, therefore, alpha-numeric in character. The "UNITS" part of the second column gives the units in which the particular data piece must be entered in the file.

In the third main column a short description of the data in the particular file location is given.

In column four, the actual value used in the file for this particular example is given.

LOCATION LINE NO.	LOCATION LINE LOC.	NAME / UNITS	DESCRIPTION	VALUE
1	1	Y(4) / MPH	Vehicle Impact Velocity	34.0
1	2	Y(6) / DEG	Head Angle (Fig.1)	-9.5
1	3	Y(7) / DEG	Torso Angle (Fig. 1)	-27.5
2	1	Z_L / LB	Lower Body Weight	71.0
2	2	Z_T / LB	Torso Weight	58.4
2	3	Z_S / LB	Sternal Weight	2.5
2	4	Z_H / LB	Head Weight	11.4
2	5	R_T / IN	H-Point to Torso C.G. (Fig. 3)	14.0
2	6	R_N / IN	H-Point to Neck Pivot (Fig. 3)	20.5
2	7	R_H / IN	Neck Pivot to Head C.G. (Fig. 3)	4.75
2	8	RTOPH / IN	H-Point to Top of Head (Fig. 3)	28.75
3	1	NPN	No. of Points on Lines 14 & 15	3
3	2	NKR	No. of Points on Lines 18 & 19	8
3	3	NV	No. of Points on Lines 16 & 17	18
3	4	NSF	No. of Points on Lines 12 & 13	6
3	5	NPG	No. of Points on Lines 5 & 6	14
3	6	SUN / LB/IN	Seat Friction Unload Slope	5000.
3	7	SKR / LB/IN	Knee Restraint Unload Slope	2400.
4	1	NST	No. of Points on Lines 20 & 21	5

LOCATION LINE NO.	LOCATION LINE LOC.	NAME / UNITS	DESCRIPTION	VALUE
4	2	NC	No. of Points on Lines 22 & 23	5
*5	*ALL	GEN(1,K) / MS	Gas Flow Data; Time	(see Fig. 4)
6	All	GEN(2,K) / LB/SEC	Gas Flow Data; Rate	(see Fig. 4)
7	1	ATMOP / PSIA	Local Atmospheric Pressure	14.7
7	2	PGZ / PSIG	Initial Airbag Pressure	0.0
7	3	GTZ / ^{o}R	Temperature of Gas Entering Airbag	1660.0
7	4	U / $\frac{IN\cdot LBF}{LBM\ ^{o}R}$	Gas Constant	662.0
7	5	PN1	Polytropic Gas Exponent; Flow	1.4
7	6	PN2	Polytropic Gas Exponent; Compression	1.4
7	7	PN3	Polytropic Gas Exponent; Expansion	1.4
8	1	VC1	Vent Discharge Coeff.; Subsonic Flow	0.7
8	2	VC2	Vent Discharge Coeff.; Sonic Flow	0.7
8	3	AV / IN^2	Vent Area	4.0
8	4	SA / IN	Major Axis Length of Airbag (Fig. 2)	13.0
8	5	SB / IN	Minor Axis Length of Airbag (Fig. 2)	2.0
8	6	SC / IN	Minor Axis Length of Airbag (Fig. 2)	11.0
8	7	X1 / IN	Horiz. Inflator Ref. Dim. (Fig. 3)	13.35
8	8	Y1 / IN	Vertical Inflator Ref. Dim. (Fig. 3)	24.5
9	1	A0 / IN	One-Half Cyl. Length of A/B (Fig.2)	9.5

*Note: The <u>second</u> value entered on this line <u>must</u> be the sensing time.

LOCATION LINE NO.	LOCATION LINE LOC.	NAME / UNITS	DESCRIPTION	VALUE
9	2	THETAD / DEG	Airbag Deployment Angle (Fig. 3)	0.0
9	3	FABWGT / OZ/YD^2	Airbag Fabric Weight	8.4
9	4	STDAMP / LB/IN/SEC	Sternum Damping Coeff.	0.0
9	5	CDAMP / LB/IN/SEC	Chest Damping Coeff.	3.0
9	6	DMS / IN	See Figure 2.	6.0
9	7	DINF / IN	Inflator Diameter	4.0
9	8	WSOCK / IN	Width of Manifold Sock (Inflator Len.)	13.0
10	1	WH / IN	Head Width	6.1
10	2	DROLLZ / IN	Initial Bag Roll Diameter	5.0
10	3	X2Z / IN	Horiz. H-Point Ref. Dim. (Fig. 3)	31.7
10	4	Y2Z / IN	Vertical H-Point Ref. Dim. (Fig.3)	8.38
10	5	WB / IN	Width of Passenger's Body	18.38
10	6	LF / IN	Length of Passenger's Femur	16.7
10	7	DCN / FT LB RAD/SEC	Neck Pivot Damping Coefficient	0.0
11	1	THFO / DEG	Initial Femur Angle (Fig. 1)	19.0
11	2	THLO / DEG	Initial Leg (Tibia) Angle (Fig. 1)	44.0
11	3	XSTOP / SEC	Desired Time to Stop Simulation	0.15
11	4	STEP / SEC	Integration Interval Step Size	0.001
11	5	PRINT1 / SEC	Print Interval - Subroutine PRINT1	0.005

LOCATION LINE NO.	LINE LOC.	NAME / UNITS	DESCRIPTION	VALUE
11	6	PINT2 / SEC	Print Interval - Subroutine PRINT2	0.005
12	All	SFN(1,K) / IN	Seat Friction Data; Displacement	(see Fig. 4)
13	ALL	SFN(2,K) / LB	Seat Friction Data; Force	(see Fig. 4)
14	ALL	FNECK(1,K) / DEG	Neck Torque Data; Head/Torso Rel. Ang.	(see Fig. 4)
15	ALL	FNECK(2,K) / FT-LB	Neck Torque Data; Torque	(see Fig. 4)
16	All	VEHGS(1,K) / MS	Crash Pulse Data; Time	(see Fig. 4)
17	ALL	VEHGS(2,K) / G'S	Crash Pulse Data; Acceleration	(see Fig. 4)
18	ALL	KRN(1,K) / IN	Knee Restraint Crush Data; Crush	(see Fig. 4)
19	All	KRN(2,K) / LB	Knee Restraint Crush Data; Force	(see Fig. 4)
20	All	STF(1,K) / IN	Sternum Data; Displacement	(see Fig. 4)
21	ALL	STF(2,K) / LB	Sternum Data; Force	(see Fig. 4)
22	ALL	CF(1,K) / IN	Chest Data; Displacement	(see Fig. 4)
23	ALL	CF(2,K) / LB	Chest Data; Force	(see Fig. 4)

In summary, consider the first line on page 15. In this line the first column tells us that the information being described is entered on the first line of the data file in the first position in the line. The second main column tells us that the piece of data that appears in this first line in the first position is known as "Y(4)" in the program and has units of "MPH" in the file. The third column tells us that this variable is the "Vehicle Impact Velocity" while the fourth and final column tells us that its value in this particular example is "34.0" mph.

The data file that results from the information given on pages 15 through 18 is shown by Figure 4. We have chosen to call this file "TRCST7P".

3.2 Running the Program

Once the input file has been created and saved, the program is ready to be run. At this point the user accesses PAC and tells the computer to run the program. The computer will respond by asking the user to name the data input file. In this case we would respond by entering "TRCST7P" from the keyboard, as shown by the sample run shown as Appendix E. Next the user is prompted for a choice on whether he wishes the full or abbreviated list of output. Assuming, a full list is desired, the user types "1". (If the abbreviated list were selected by typing "2", the output would be as shown in the second list of output in Appendix E). Once these answers are given, the computer will print out the input data followed by the selected output. We will now discuss this output.

Altogether there are ten separate blocks of output, most with seven pieces of information presented. In each block of output, the first piece of information is always the same and is the elapsed time from the begining of impact in msec.

```
TRCST7P      10:11EDT    09/07/82

1 34.,-9.5,-27.5
2 71.,58.4,2.5,11.4,14.,20.5,4.75,28.75
3 3,8,18,6,14,5000.,2400.
4 5,5
5 0.,15.,18.,22.,25.,30.,35.,40.,45.,50.,55.,60.,75.5,100.
6 0.,0.,3.4,3.9,7.54,8.09,7.5,5.87,4.,2.54,1.49,.82,0.,0.
7 14.7,0.,1660.,662.,1.4,1.4,1.4
8 .7,.7,4.0,13.,2.,11.,13.35,24.5
9 9.5,0.,8.4,0.,3.,6.,4.,13.
10 6.1,5.,31.7,8.38,18.38,16.7,0.
11 19.,44.,.15,.001,.005,.005
12 -50.,0.,1.,14.,15.,50.
13 0.,0.,350.,350.,0.,0.
14 -81.,18.,90.
15 117.,0.,-87.
16 0.,7.,17.,21.,26.,33.,45.,52.,54.,58.,65.,70.,76.,80.,90.,93.,107.,150.
17 0.,0.,13.3,12.7,15.6,10.7,18.3,29.8,30.7,29.8,21.3,23.2,17.8,19.5,11.7,12.6,0
.,0.
18 0.,2.,2.5,2.75,3.,3.5,4.5,15.
19 0.,0.,200.,700.,1800.,2300.,2500.,2700.
20 -50.,0.,.25,1.,10.
21 0.,0.,400.,1600.,25000.
22 -11.25,-1.25,0.,1.25,11.25
23 -4650.,-150.,0.,150.,4650.
```

Note: Prior to running the PAC program, the line numbers must be stripped from the file. These are line numbers 1 through 23 as shown above.

Figure 4.

The first block of output shown in Appendix E consists of the following items as we read from left to right across the page: elapsed time (TIME), vehicle g's (VEH G'S), vehicle velocity (VEH VEL), vehicle crush (VEH DISP), amount of bag penetration by the chest (CHEST BP), chest wraparound force (CWA FORCE), and chest pressure force (CPR FORCE). The units for these variables are indicated immediately below the headings.

The second data block contains: elapsed time (TIME), overground displacement of the H-point (H-P DISP), the overground velocity of the H-point (H-P VEL), the force imparted to the passenger through seat friction in sliding over the seat (SEAT FR.), the force imparted to each femur by the knee restraint (FEM FORCE), the angle of the femur from horizontal (see Figure 1) (KNEE ANG), and the angle of the tibia from horizontal (see Figure 1). This parameter is shown as "TIB ANG" in the output.

The third data block contains: elapsed time (TIME), the overground horizontal displacement of the torso center-of-gravity (TORSO DISP), the angle of torso inclination with respect to a vertical line as shown in Figure 3 (TORSO ANG), the angular velocity of the torso (TORSO VEL), the angular acceleration of the torso (TORSO ACC), the displacement of the torso in a horizontal direction with respect to the vehicle compartment (TORSO R.D.), and the velocity of the torso in a horizontal direction with respect to the vehicle compartment (TORSO R.V.).

The fourth data block contains the exact equivalent to the third data block with the exception that the data is for the head instead of the torso and the last item in the data block is the head angle relative to the torso (HEAD R. ANG) as shown in Figure 1.

The fifth data block contains: elapsed time (TIME), the restrained bag (part of bag impinging on chest) acceleration (R BAG ACC), the restrained bag velocity with respect to the ground in the horizontal direction (RBV WR GND), the restrained bag velocity with respect to the chest in a direction normal to the chest (RBV WR CST), the restrained bag velocity with respect to the dashboard in the direction of airbag deployment (RBV WR DSH), the restrained bag displacement relative to the ground in a horizontal direction (RBD WR GND), and the restrained bag displacement with respect to the dashboard in the direction of airbag deployment (RBD WR DSH).

The information contained in the sixth data block is exactly equivalent to that presented in the fifth data block with the exception that the information pertains to the unrestrained portion of the airbag (that part not in contact with the passenger).

The seventh data block contains: elapsed time (TIME), the force applied to the chest due to "bagslap" (CST F BSP), the force applied to the sternum due to bagslap (STN F BSP), the velocity of the sternum with respect to the chest in a direction normal to the chest surface (STV WR CST), the deflection of the sternum by the impacting bag roll (RLD WR STN), the deflection of the sternum with respect to the chest (STD WR CST), and the distance from the aft edge of the inflator to the torso in the bag deployment direction (DTORSO).

The eighth data block contains: elapsed time (TIME), the amount of bag penetration by the head (HEAD BP.), the airbag volume (BAG VOL.), the airbag pressure (BAG PRESS.), the head wraparound force (HW/A Force), the head pressure force (HP FORCE), and the volume of the airbag intercepted by the chest and head (INT. VOL).

The ninth data block contains: elapsed time (TIME), the chest A-P (anterior-posterior) g's (CHEST AP), the chest S-I (superior-inferior) g's (CHEST SI), the head A-P g's (HEAD AP), and the head S-I g's (HEAD SI).

The tenth and final data block presents the following data: elapsed time (TIME), the diameter of the bag roll (ROLL DIA), the distance from the H-point to the point where the bag roll impacts the chest (ROLL RAD), the X coordinate of the airbag center from the chosen reference point (XC B CTR), the Y coordinate of the airbag center from the chosen reference point (YC B CTR), the weight of the restrained portion of the airbag (WRB), and the weight of the unrestrained portion of the airbag (WURB).

At the end of the output, the user is asked whether he wishes a HIC computation. If so, the user types "1" and the HIC is computed along with the beginining and ending times of the computation.

<u>Sign Convention</u>

Now that the input file and the output values have been described in some detail, it is necessary to discuss the sign convention which has been used in setting up these groupings of data. The input file will be discussed first followed by the output file.

<u>Input</u>

The sign convention for the data in the input file in Figure 4 is to be generally positive <u>except</u> for the following cases where specific signs must be given to avoid confusion.

Y(6); Head Angle; Line 1, Location 2; Positive as shown in Fig.1.

Y(7); Torso Angle; Line 1, Location 3; Positive as shown in Fig. 1.

FNECK(1,K); Neck Torque Relative Angle (Y(6)-Y(7)); Line 14, All; Positive when head pitched forward relative to chest as shown in Fig. 1.

FNECK(2,K);Neck Torque; Line 15, ALL; Positive when in direction of positive Y(6).

CF(1,K); Chest Deflection due to bagslap; Line 22, All; Positive when chest compressed.

CF(2,K); Chest Force due to bagslap; Line 23, All; Positive when producing chest compression.

This completes the discussion on sign convention for the input file. We will now discuss the sign convention used in presenting the output values presented in Appendix E.

Output

Displacements, velocities and accelerations are considered positive when they are in either the upward direction in the vertical mode or in the direction of original vehicle travel in the horizontal mode.

When the direction of displacement, velocity or acceleration is neither horizontal nor vertical (such as the restrained bag diameter with respect to the dash, RBD WR DSH, which is in the bag deployment direction) the sign given in the output is the sign that corresponds to the direction of its horizontal component. Thus a negative value for "RBD WR DSH" mean that the restrained bag displacement with respect to the dash is in a direction opposite to the direction of original vehicle travel; i.e. toward the passenger.

In the case of forces and moments applied to the passenger in which the direction of application is obvious, the values listed in the output are listed as positive values. For example, the following forces; the CWA FORCE, the CPR FORCE, the HW/A FORCE, the H P FORCE, FSTBS, FCBS, the FEM FORCE and the SEAT FR. force are listed in the output as positive values and are understood to be in a direction opposing further airbag penetration, knee restraint penetration and sliding across the seat when applied to the passenger.

3.3 Comparing Computer Results with Test Results

Test conditions for TRC Sled Test No. 7 were duplicated on the computer as accurately as possible and then a simulation of this test was made to verify the ability of PAC to reproduce actual test results. Figure 5 shows the sled test "crash" pulse and the data points used for input. Other data needed for input were obtained from pre-test measurements, "known" dummy properties and gas flow information provided by Thiokol, the gas generator manufacturer.

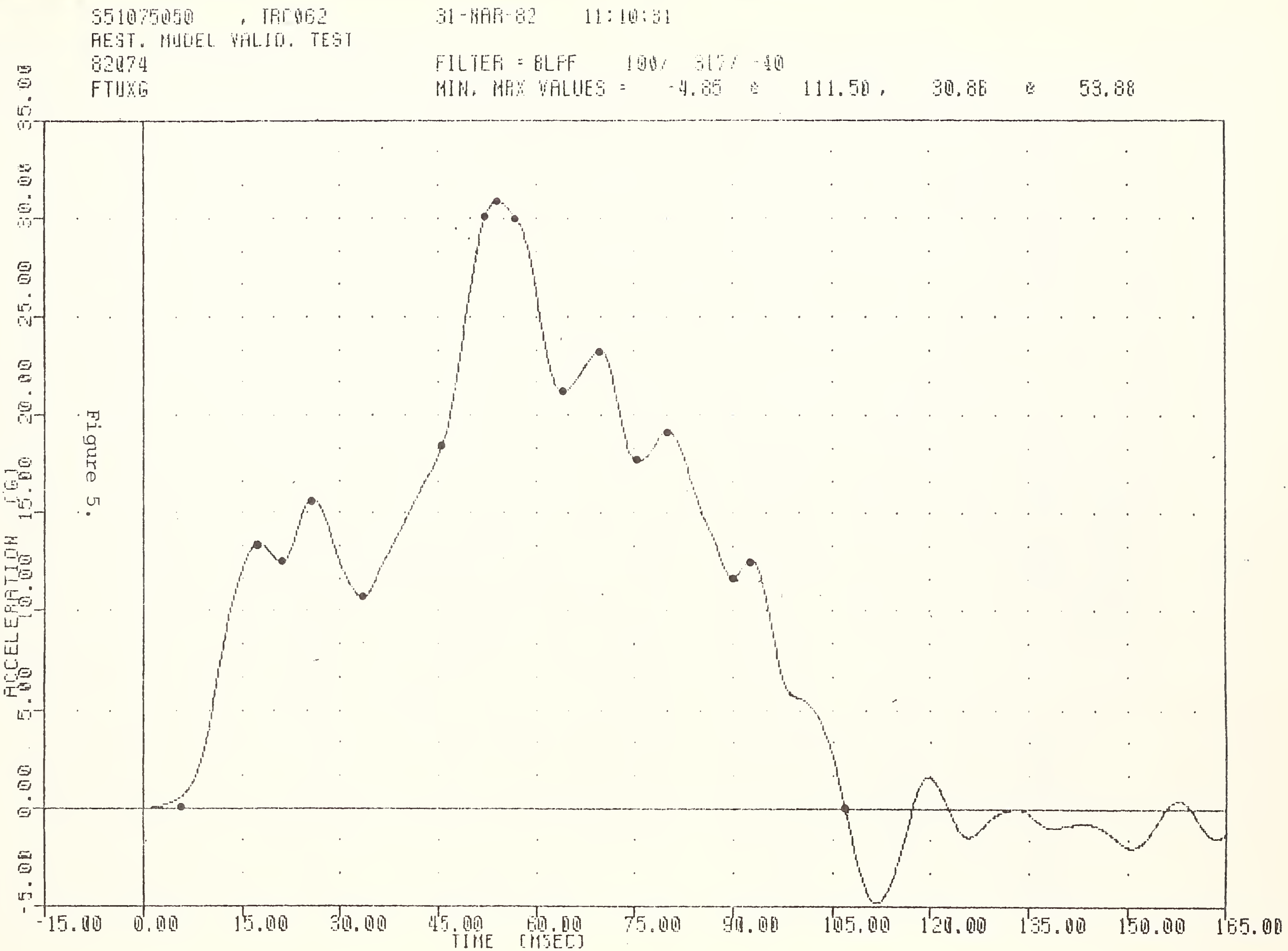
Figures 6 through 10 show the comparison of computer results and test results (Appendix E shows the actual computer run). As is evident from the figures, very good correlation was obtained.

Figure 11 shows the passenger trajectory as computed and then plotted by computer. Comparison of this trajectory with the results actually observed in the test show very similar dummy movement. The only difference noticed was that in the test the dummy H-point appeared to be approximately two inches lower than was measured before the test. This was perhaps due to seat compression which is not computed in the PAC simulation. Thus the head is shown very close to the windshield in Figure 11 whereas in actuality is was not quite so close.

The table on the following page compares the injury measures actually measured in the test with those predicted by the computer.

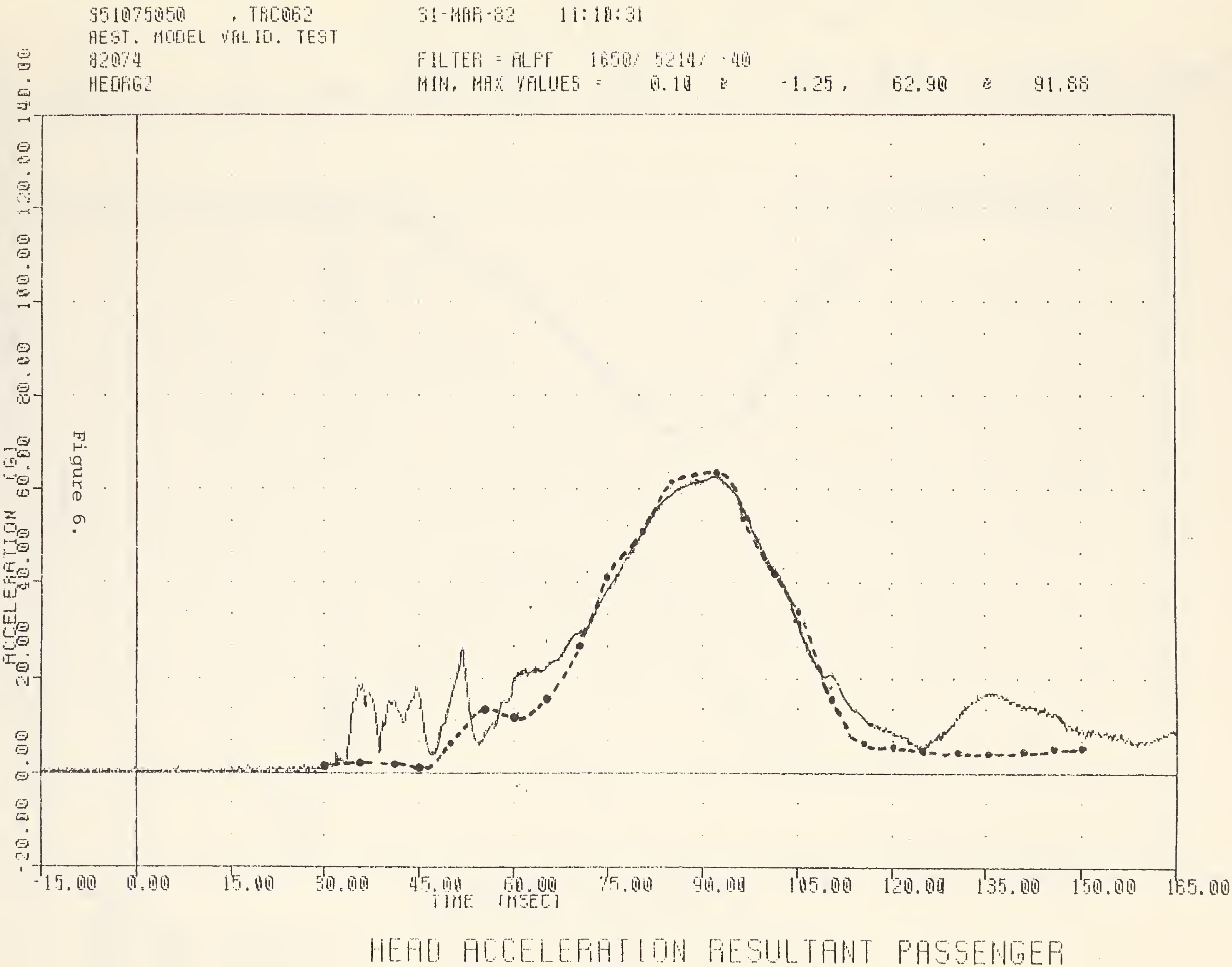
SLED TEST NO. 7

Injury Measure	Test Results	Computer Results
HIC	606	619
Pk. Res. Chest G's (-3 msec)	50	50
Pk. Femur Loads (Lb: Righr, Left)	1070, 1140	1097, 1097



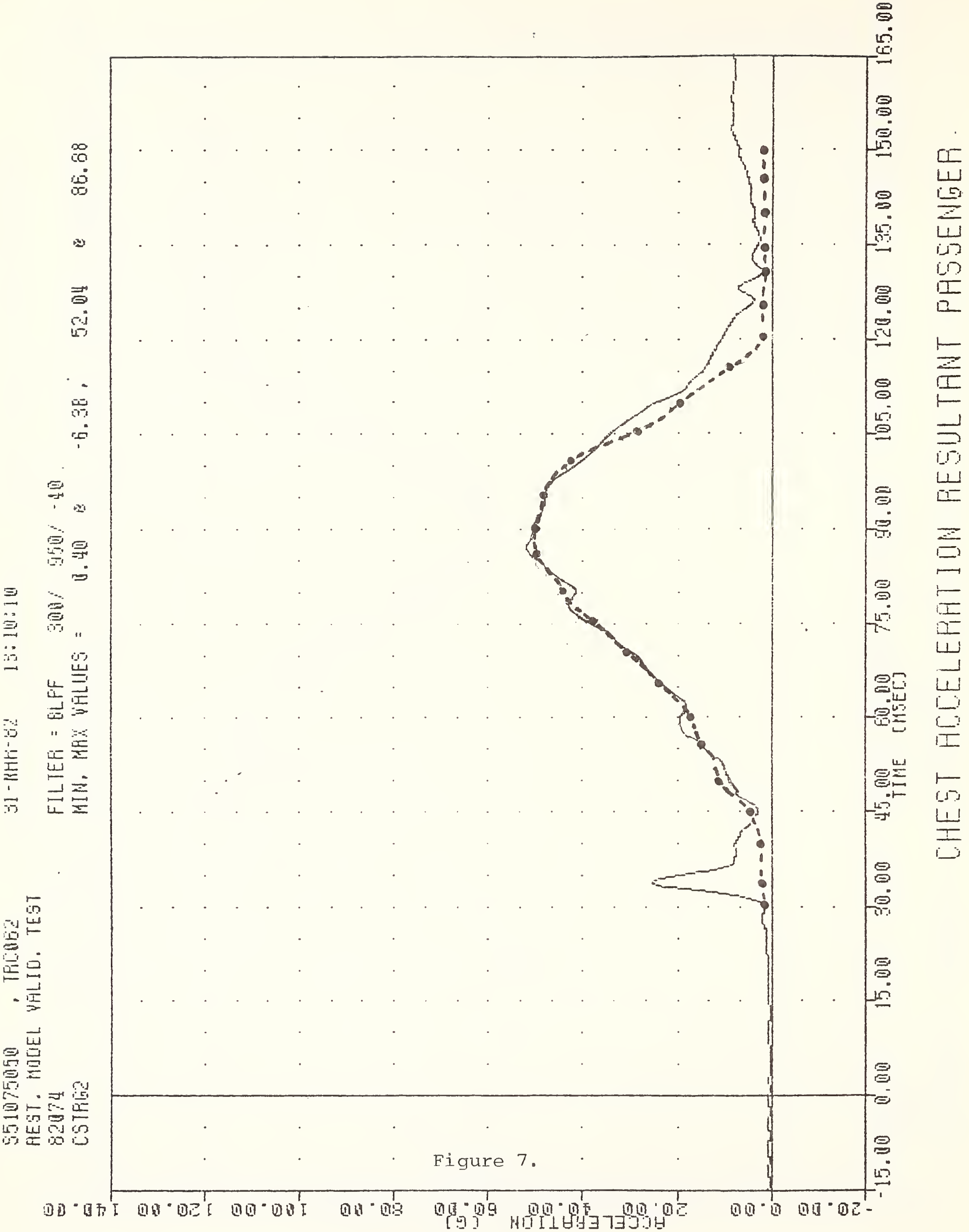
FLOOR PAN TUNNEL ACCELERATION

Figure 5.



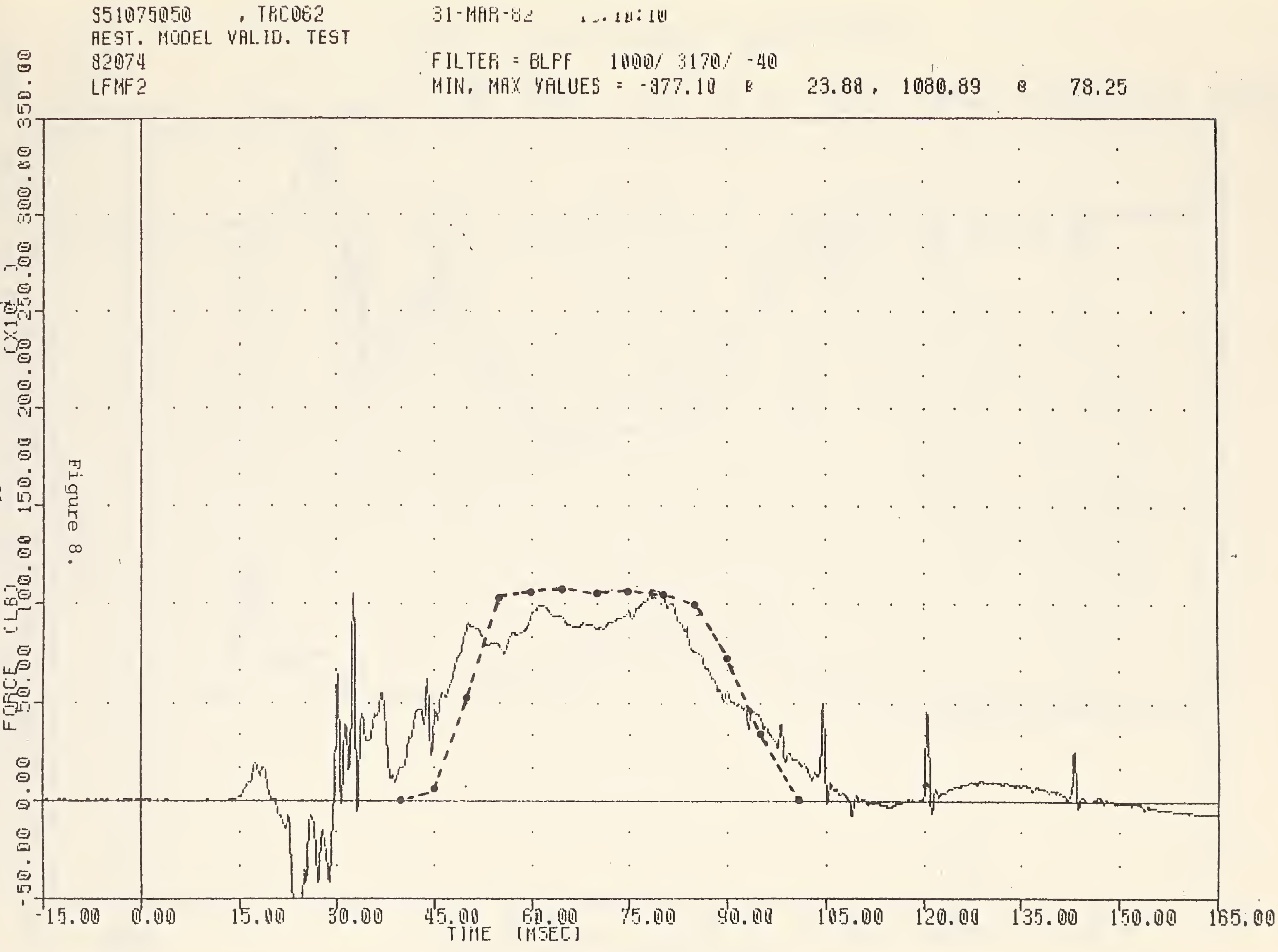
551075050 , TRC062
31-MAR-82 11:10:31
REST. MODEL VALID. TEST
82074
HEDRG2
FILTER = ALPF 1650/ 5214/ -40
MIN, MAX VALUES = 0.10 @ -1.25 , 62.90 @ 91.88
ACCELERATION (G)
-20.00 0.00 20.00 40.00 60.00 80.00 100.00 120.00 140.00
-15.00 0.00 15.00 30.00 45.00 60.00 75.00 90.00 105.00 120.00 135.00 150.00 165.00
TIME (MSEC)
HEAD ACCELERATION RESULTANT PASSENGER

Figure 6.



951075050 , TRC062
REST. MODEL VALID. TEST
82074
CSTRG2
31-MAR-82 13:10:10
FILTER = BLFF 300/ 950/ -40
MIN, MAX VALUES = 0.40 @ -6.38 , 52.04 @ 86.88
CHEST ACCELERATION RESULTANT PASSENGER
TIME (MSEC)
ACCELERATION (G)

Figure 7.



LEFT FEMUR FORCE PASSENGER

Figure 8.

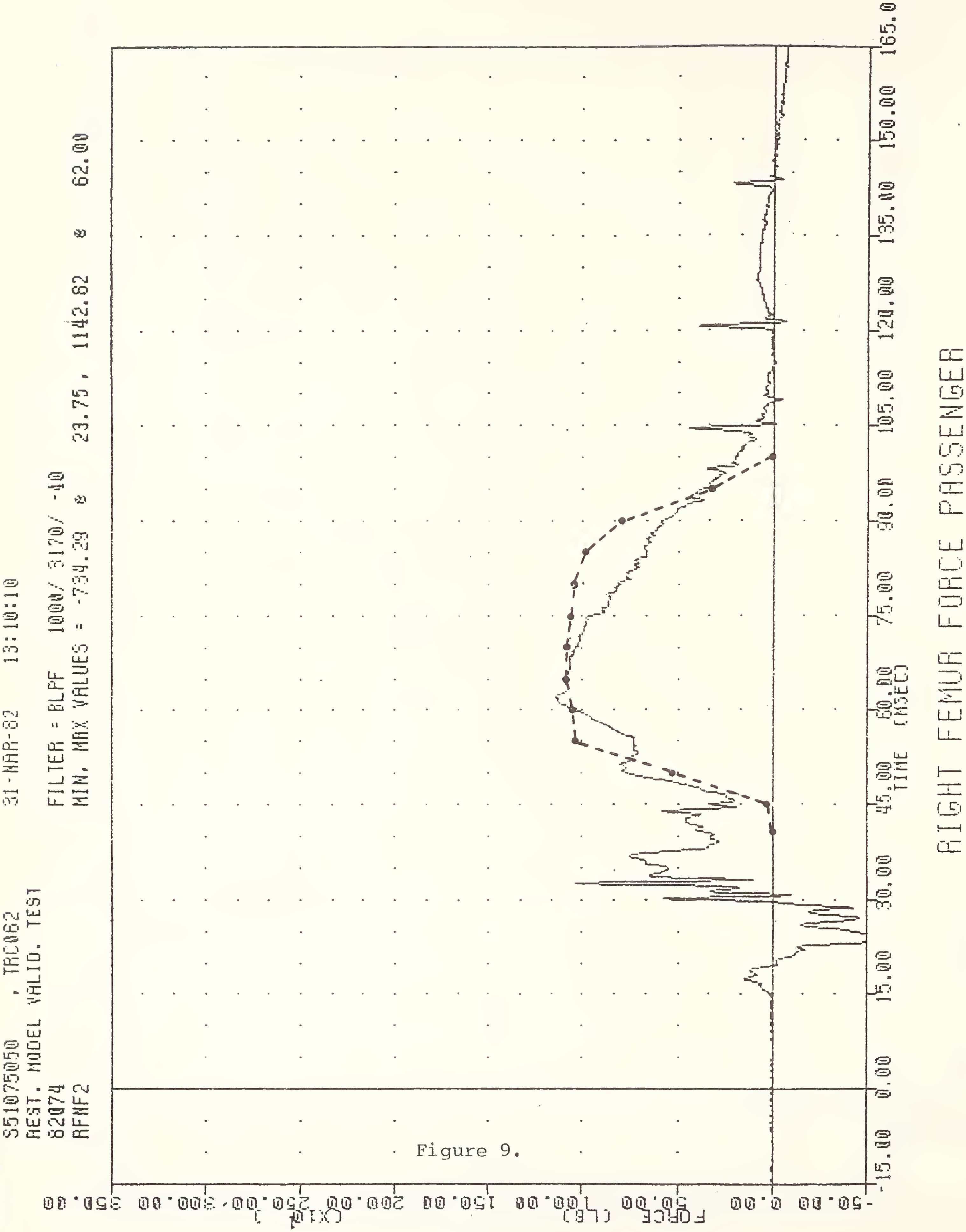
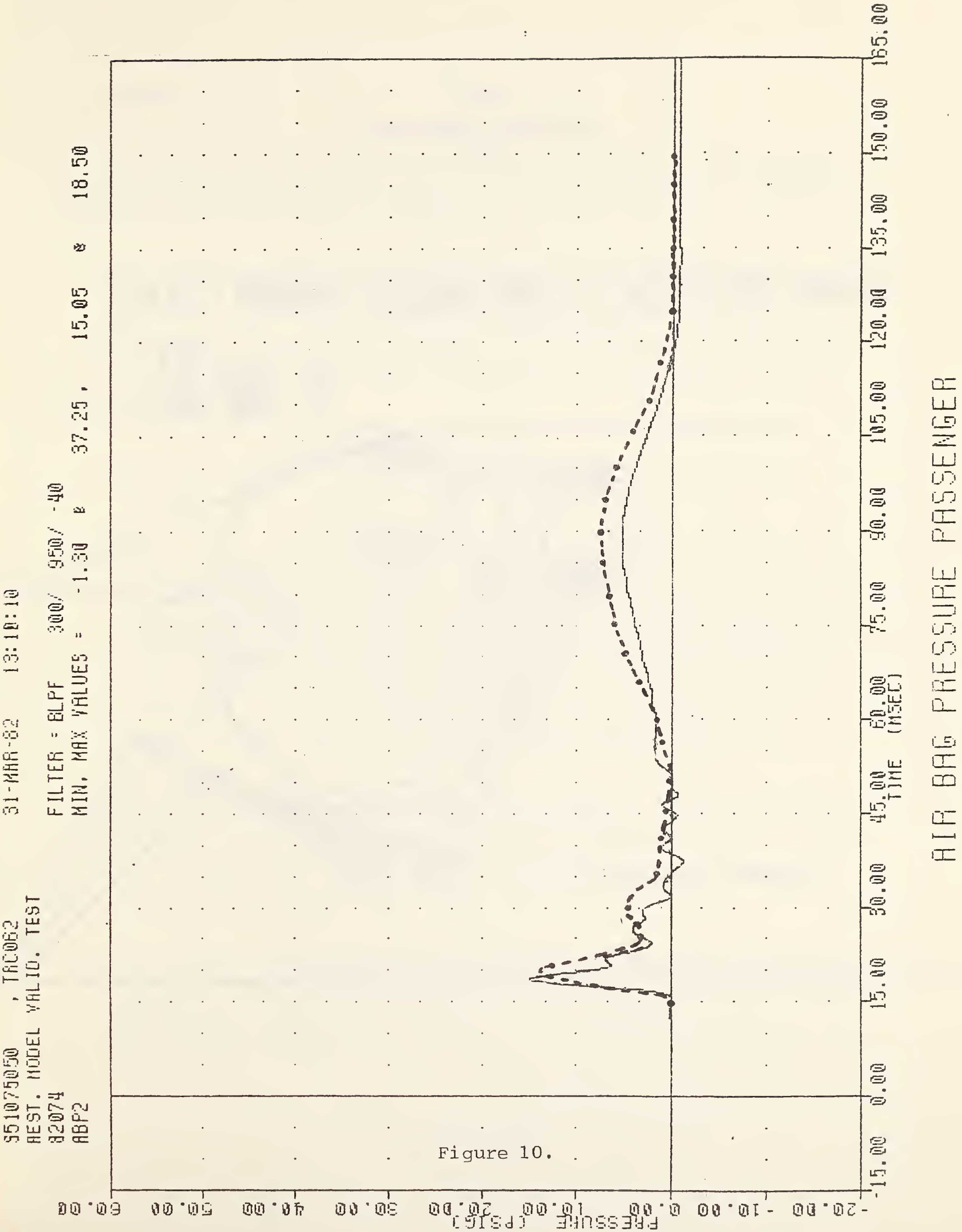

S5107505Ø , TRCØ62 31-MAR-82 13:10:10
REST. MODEL VALID. TEST
82074 FILTER = 8LPF 1000/ 3170/ -40
RFNF2 MIN. MAX VALUES = -734.29 @ 23.75 , 1142.82 @ 62.00
-15.00 0.00 15.00 30.00 45.00 60.00 75.00 90.00 105.00 120.00 135.00 150.00 165.00
TIME (MSEC)
-50.00 0.00 50.00 100.00 150.00 200.00 250.00 300.00 350.00
FORCE (LB) (X10¹)
RIGHT FEMUR FORCE PASSENGER

Figure 9.



551075050 , TRC062
AEST. MODEL VALID. TEST
82074
ABP2
31-MAR-82 13:10:10
FILTER = BLPF 300/ 950/ -40
MIN. MAX VALUES = -1.30 @ 37.25 , 15.05 @ 18.50
-15.00
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
135.00
150.00
165.00
TIME (MSEC)
-20.00
-10.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
PRESSURE (PSIG)
AIR BAG PRESSURE PASSENGER

Figure 10.

"PAC"

COMPUTER SIMULATION

OF:

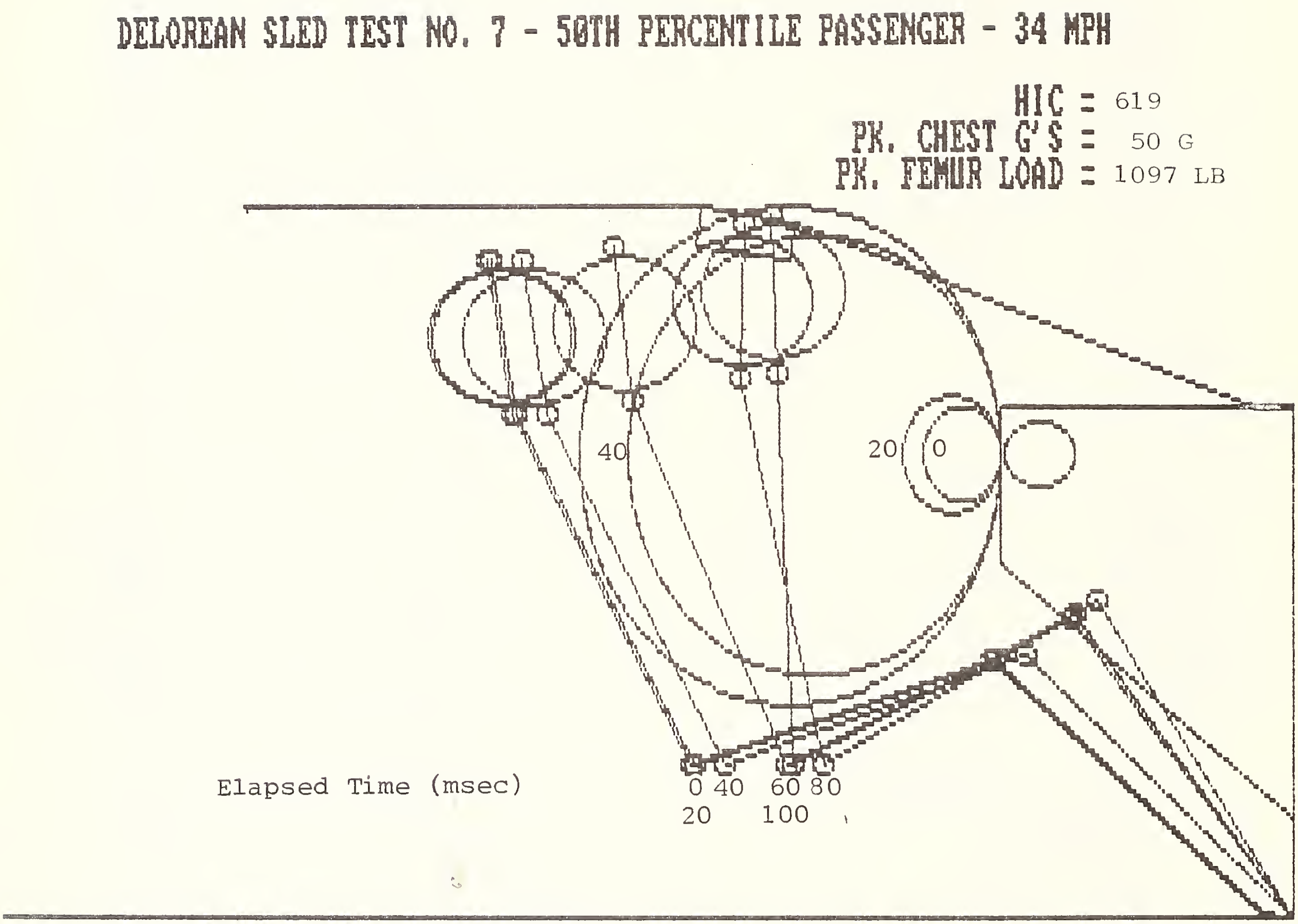


Figure 11.

3.4 Helpful Hints

In the following list we will leave the user with a few "helpful hints" which should assist the user of the PAC model in obtaining the most accurate results possible.

1. The integration interval (STEP) should not be greater than .001 sec for adult passengers nor greater than .0005 sec for child passengers. Further, for sternal masses less than 1.5 lbs, the integration interval should not exceed .0002 sec.

2. The chest should not be placed closer than one inch to the dash.

3. As presently set up, the H-point is assumed to be the lower body pivot point. It is assumed that the airbag contact line passes through this point and the neck pivot. For greatest simulation accuracy, the effective pivot points should be moved foreward slightly (approximately one-half the torso thickness) so that the line corresponds with the front surface of the torso and not the torso centerline.

4. For airbags which are unsymmetrical about a horizontal line, the user should account for this in the simulation by raising or lowering the effective mounting point of the airbag an appropriate amount.

5. For airbags which deviate significantly from the ellipsoidal cylinder shape assumed in the PAC derivation, the user should approximate the actual airbag by an ellipsoidal cylinder of most similar shape.

6. As presently derived, the PAC model assumes a <u>seated</u> passenger. If, for example, one wishes to simulate a <u>standing</u> child, the "R_T" dimension must be modified to be the distance from the H-point to the "effective" C.G. of the upper <u>and</u> lower body. This roughly accounts for the mass of the legs distributed below the H-point which is significant for the standing child. Past experience has shown this value for R_T to be much smaller than the normal value for the seated child.

APPENDIX A

Derivation of the Equations of Motion for the Passenger

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) $X_T = X_L + r_T \, \mathrm{SIN}\theta_T$

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

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

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

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

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

MATHEMATICAL MODEL

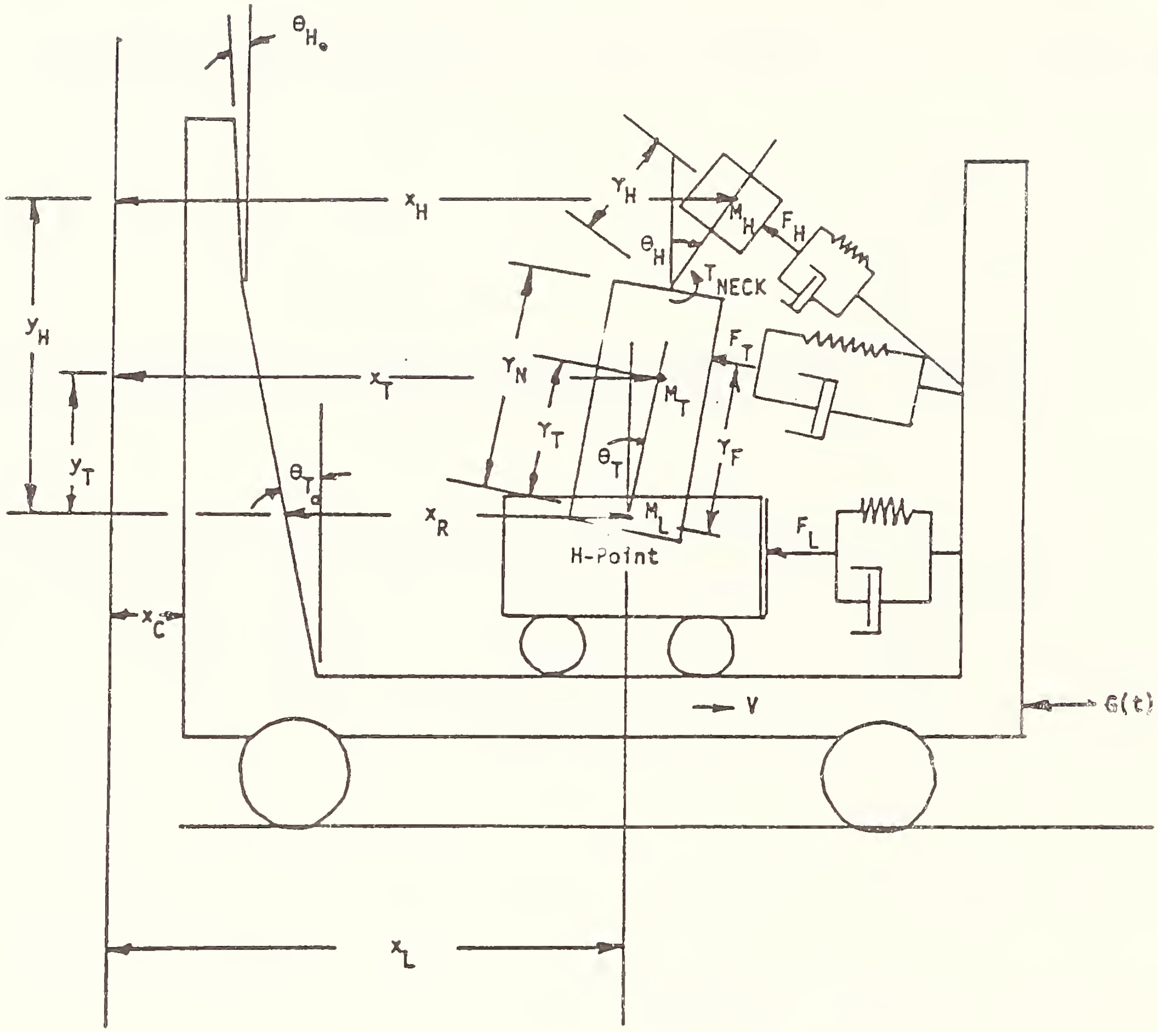


Figure A-1. Passenger/Airbag Interaction Schematic

(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:

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

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:

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

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

$$r_H\, \mathrm{SIN}\theta_H\, \dot{\theta}_H^2) + M_T\, r_T\, \mathrm{COS}\theta_T\, \ddot{\theta}_T + M_H\,(r_N\, \mathrm{COS}\theta_T\, \ddot{\theta}_T +$$

$$r_H\, \mathrm{COS}\theta_H\, \ddot{\theta}_H)$$

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

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

$$\left. + \mathrm{SIN}\theta_T\, \mathrm{SIN}\theta_H\, \dot{\theta}_H) + r_N^2\, \dot{\theta}_T\right]$$

(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:

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

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

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

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

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

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

Rewriting the above yields:

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

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

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

which is the equation of motion of the torso mass.

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

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

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

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

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

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

Rewriting the preceding yields:

$$(26) \quad M_H \left[\ddot{X}_L r_H \cos\theta_H - r_N r_H (\sin\theta_T \cos\theta_H \dot{\theta}_T^2 - \cos\theta_T \cos\theta_H \ddot{\theta}_T - \cos\theta_T \sin\theta_H \dot{\theta}_T^2 - \sin\theta_T \sin\theta_H \ddot{\theta}_T) + r_H^2 \ddot{\theta}_H \right] - M_H g r_H \sin\theta_H = F_{\theta H} ,$$

which is the equation of motion for the head mass.

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

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

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

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

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

$$(29) \qquad \ddot{\theta}_H = \frac{F_{\theta H}}{M_H \, r_H^2} - \frac{\ddot{X}_L \, COS\theta_H}{r_H} - \frac{r_N}{r_H} \Big[(COS\theta_H \; COS\theta_T + SIN\theta_H \; SIN\theta_T) \, \ddot{\theta}_T$$

$$+ (SIN\theta_H \; COS\theta_T - COS\theta_H \; SIN\theta_T) \, \dot{\theta}_T^2 \Big] + \frac{g}{r_H} \, SIN\theta_H \quad ,$$

where:

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

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

$$F_{XL} = F_H \, COS\theta_H + F_T \, COS\theta_T + F_L \quad .$$

APPENDIX B

Derivation of the Airbag Algorithm

CALCULATION SHEET

PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

THE OBJECTIVE OF THE FOLLOWING ANALYSIS IS TO DERIVE THE EQN'S NECESSARY TO DESCRIBE A PASSENGER AIRBAG SYSTEM INTERACTING WITH THE PASSENGER. IN THIS ANALYSIS WE WILL MODEL THE COMPLETE DEPLOYMENT SEQUENCE SO THAT THE IMPULSIVE EFFECTS OF BAG IMPACT WITH THE PASSENGER MAY BE DETERMINED. THE PASSENGER WILL BE MODELED BY FOUR MASSES AS SHOWN BELOW.

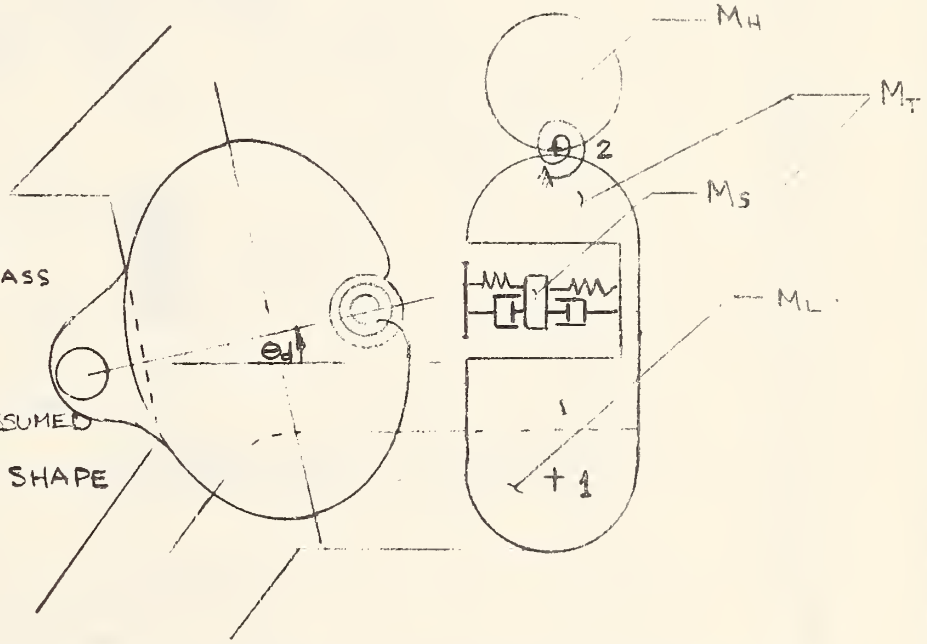
WHERE:

M_H = HEAD MASS

M_T = TORSO MASS

M_S = STERNUM MASS

M_L = LOWER BODY MASS



THE AIRBAG WILL BE ASSUMED TO BE OF ELLIPTICAL SHAPE IN CROSS SECTION.

THE MODEL OF THE PASSENGER WILL HAVE 2 PIVOT POINTS SHOWN BY PTS 1 & 2 ABOVE.

THE DEPLOYMENT ANGLE IS θd.

THE TORSO & HEAD WILL BE RESTRAINED BY THE AIRBAG WHILE THE LOWER BODY WILL BE RESTRAINED BY A KNEE BOLSTER (OR KNEE BAG REPRESENTED BY KNOWN FORCE DISPLACEMENT PROPERTIES).

THE NEXT 2 PG'S SHOW THE OVERALL COORDINATE SYSTEMS EMPLOYED FOR THIS DERIVATION.

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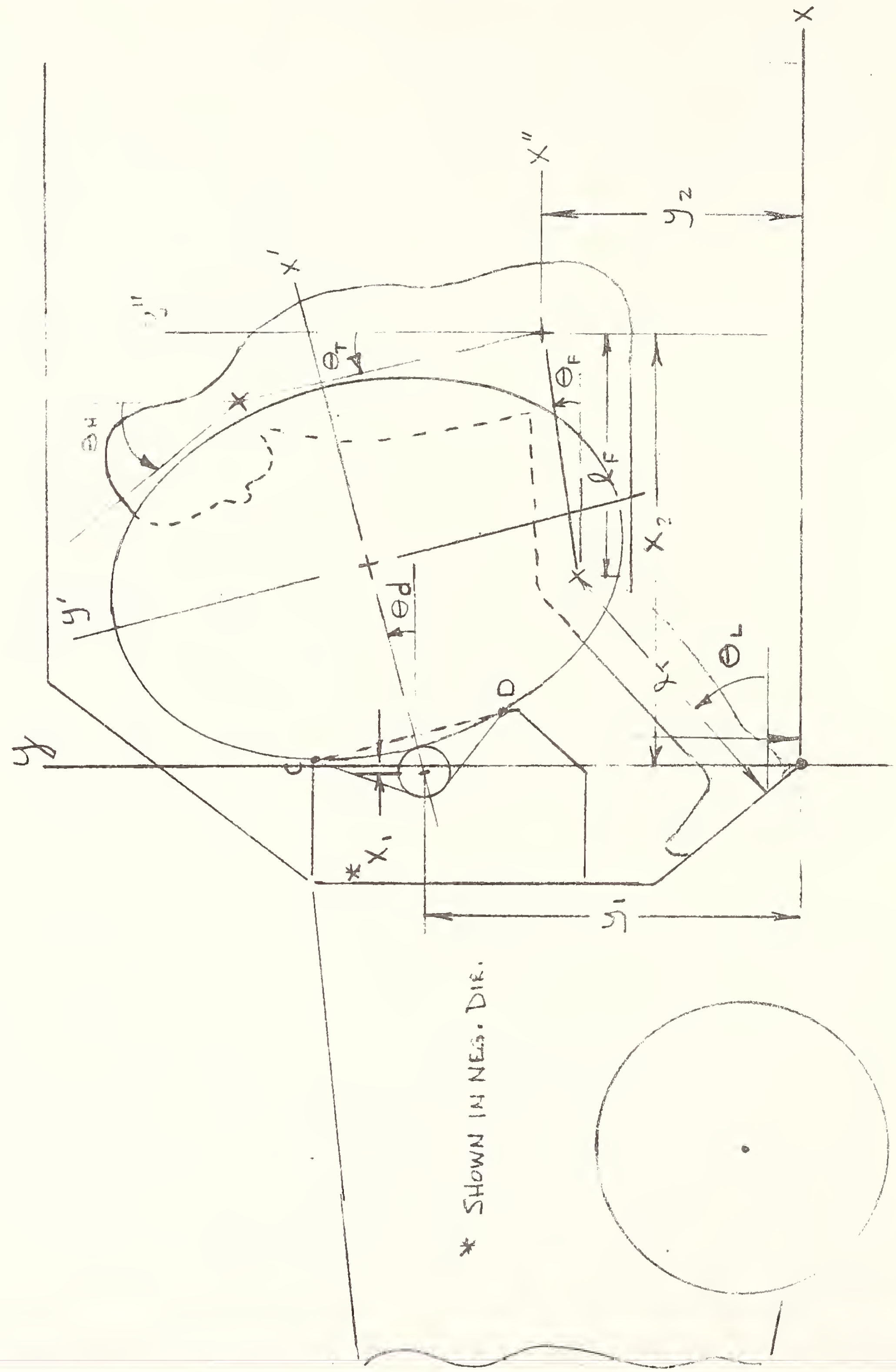
CALCULATION SHEET

PROJECT	JOB ORDER NO	CALCULATION SERIAL NO

PROGRAM COORDINATE SYSTEMS



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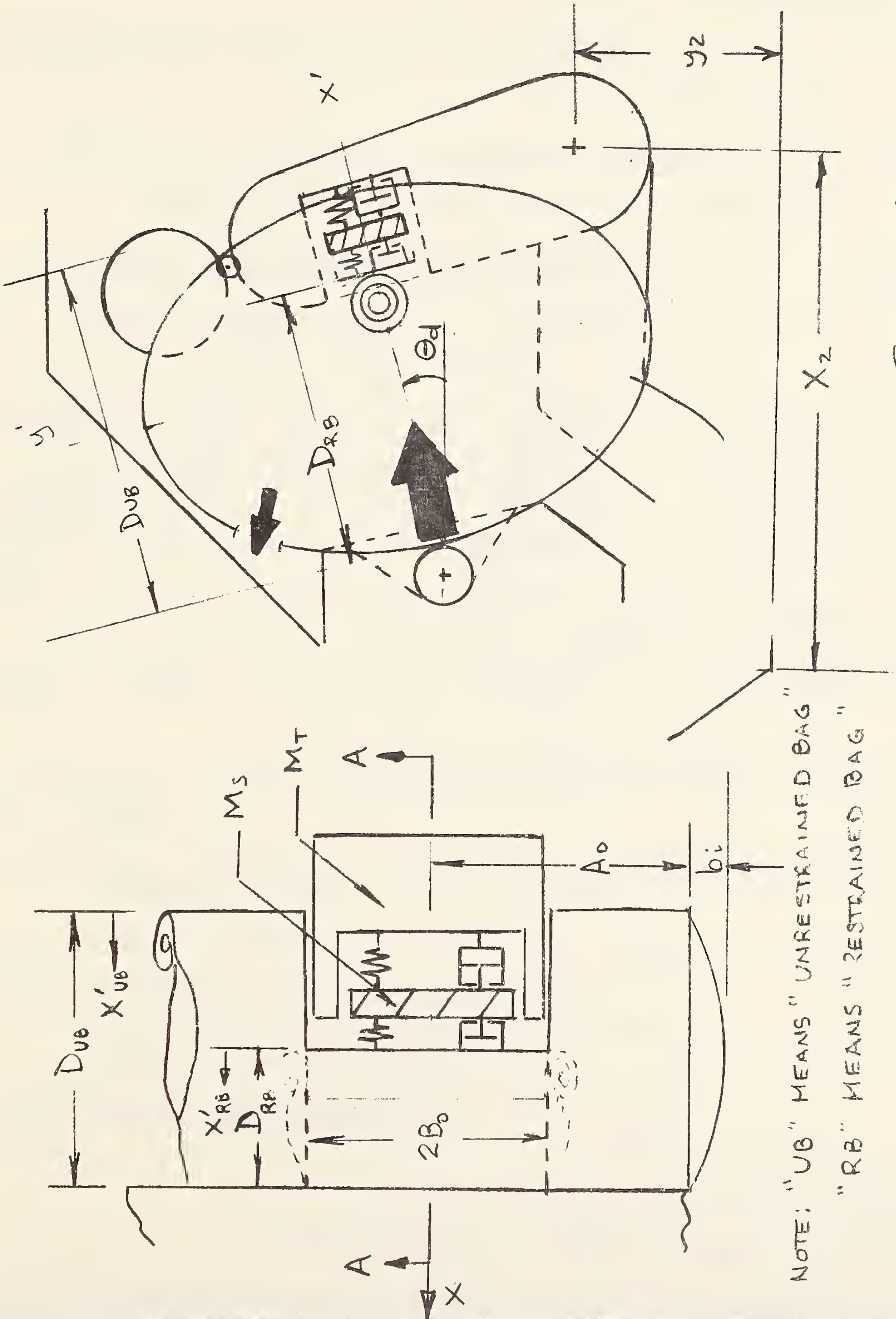
CALCULATION SHEET	PAGE 3 OF

PROJECT	JOB ORDER NO.	CALCULATION SERIAL



Schematic of "PAC" Computer Model

NOTE: "UB" MEANS " UNRESTRAINED BAG "
"RB" MEANS " RESTRAINED BAG "

PREPARED BY	DATE
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CALCULATION SHEET

PAGE 4 OF ____

PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

AIRBAG DYNAMICS

(1) LET $X_{V/G}$ = HORIZONTAL COMPONENT OF OVERGROUND DISTANCE VEHICLE HAS TRAVELED.

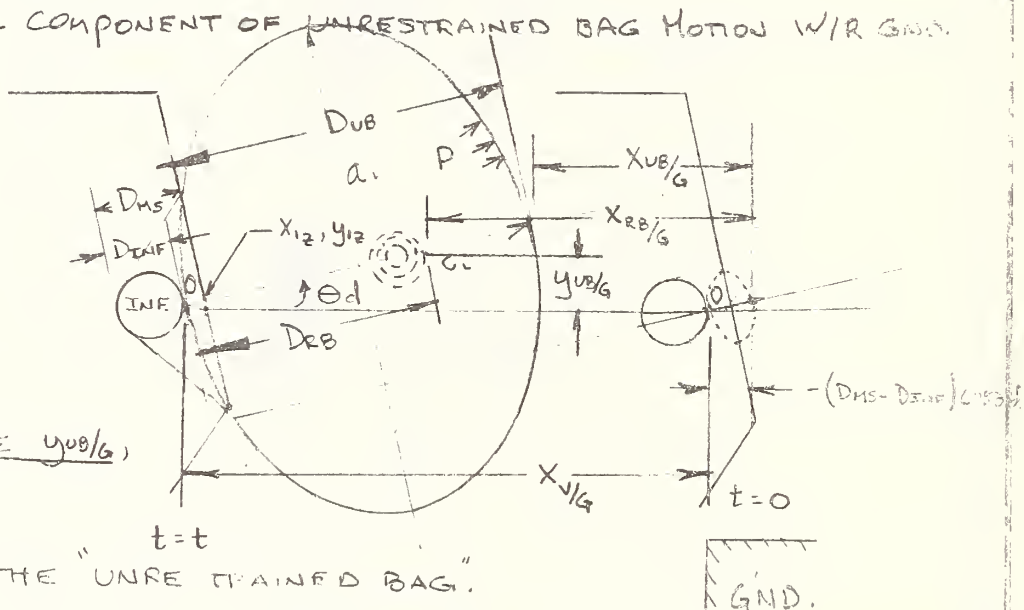
LET $X_{UB/G}$ = HORIZONTAL COMPONENT UNRESTRAINED PORTION OF BAG HAS TRAVELED RELATIVE TO THE GROUND.

LET $y_{UB/G}$ = VERTICAL COMPONENT OF UNRESTRAINED BAG MOTION W/R GND.

NOTE:

$X_{V/G}$ IS OBTAINED BY A SIMPLE DOUBLE INTEGRATION OF THE VEHICLE CRASH PULSE;

LET US NOW CALCULATE $y_{UB/G}$, $X_{UB/G}$ AND D_{UB}.



LET G_{UB} = G'S ON THE "UNRESTRAINED BAG".

$G_{UB} = -P\left[4a_i(A_o - B_o) + \pi a_i b_i\right]/W_{UB}$ W_{UB} = WEIGHT OF UNRESTRAINED PORTION OF BAG.

(2) $\dot{y}_{UB/G_i} = \dot{y}_{UB/G_{i-1}} - 386.4\, G_{UB_{i-1}} \sin\theta_d\, \Delta t$; (@ $t=0$, $\dot{y}_{UB/G} = 0$)

(3) $y_{UB/G_i} = y_{UB/G_{i-1}} + \dot{y}_{UB/G_{i-1}}\Delta t - 193.2\, G_{UB_{i-1}} \sin\theta_d\, \Delta t^2$; (@ $t=0$, $y_{UB/G} = (D_{MS} - D_{INF})\sin\theta_d$)

(4) $\dot{X}_{UB/G_i} = \dot{X}_{UB/G_{i-1}} + 386.4\, G_{UB_{i-1}} \cos\theta_d\, \Delta t$; (@ $t=0$, $\dot{X}_{UB/G} = \dot{X}_{V/G}$)

(5) $X_{UB/G_i} = X_{UB/G_{i-1}} + \dot{X}_{UB/G_{i-1}}\Delta t + 193.2\, G_{UB_{i-1}} \cos\theta_d\, \Delta t^2$; (@ $t=0$, $X_{UB/G} = -(D_{MS} - D_{INF})\cos\theta_d$)

SOLVING FOR D_{UB},

(6) $D_{UB_i} = \sqrt{(X_{V/G_i} - X_{UB/G_i})^2 + y_{UB/G}^2}$; BY DEF'N

(7) $C_i = D_{UBi}/2$

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WE NOW ASSUME THAT BAG GROWS UNIFORMLY, i.e.

(8) $a_i = \frac{a}{c} c_i$

(9) $b_i = \frac{b}{c} c_i$

WHERE C_i IS GIVEN BY EQN 7.

WE WILL NOW CALCULATE $y_{RB/G}$, $X_{RB/G}$, AND D_{RB}

(10) LET $y_{RB/G}$ & $X_{RB/G}$ = VERTICAL AND HORIZONTAL DISTANCES THE RESTRAINED BAG MOVES W/R TO GROUND.

LET G_{RB} = G'S ON RESTRAINED PORTION OF BAG

(11) $G_{RB} = \left[F\cos(\theta_d - \theta_T) - 4 P a_i B_o\right] / W_{RB}$ (WHERE F = fcn OF [illegible] ON PG'S 15 AND 16.)

WHERE, WRB = WEIGHT OF THE "RESTRAINED PORTION OF THE BAG."

(12) $\dot{y}_{RB/G_i} = \dot{y}_{RB/G_{i-1}} - 386.4\, G_{RB_{i-1}} \sin\theta_d\, \Delta t$; $(@t=0,\ \dot{y}_{RB/G} = 0)$

(13) $y_{RB/G_i} = y_{RB/G_{i-1}} + \dot{y}_{RB/G_{i-1}}\Delta t - 193.2\, G_{RB_{i-1}} \sin\theta_d\, \Delta t^2$; $(@t=0,\ y_{RB/G} = (D_{MS} - D_{JNF})\sin\theta)$

(14) $\dot{X}_{RB/G_i} = \dot{X}_{RB/G_{i-1}} + 386.4\, G_{RB_{i-1}} \cos\theta_d\, \Delta t$ $(@t=0,\ \dot{X}_{RB/G} = \dot{X}_{V/G})$

(15) $X_{RB/G_i} = X_{RB/G_{i-1}} + \dot{X}_{RB/G_{i-1}}\Delta t + 193.2\, G_{RB_{i-1}} \cos\theta_d\, \Delta t^2$ $(@t=0,\ X_{RB/G} = -(D_{MS} - D_{JNF})\cos\theta_d)$

WRITING THE EQN. FOR D_{RB} WE HAVE:

(16) $D_{RB_i} = \sqrt{(X_{V/G_i} - X_{RB/G_i})^2 + y_{RB_i}^2}$

CALCULATION SHEET

PROJECT	JOB ORDER NO.	CALCULATION SERIAL NO

WE MAY NOW CALCULATE THE COORDINATES OF THE BAG CENTER, X_1 & Y_1 FOR THE UNRESTRAINED PART OF THE BAG (SEE FIG. ON PG 4).

(17) $$X_1 = X_{1_Z} + \frac{D_{UB} \cos \theta d}{2} - C_Z \cos \theta d$$

WHERE "Z" SUBSCRIPT DENOTES VALUE @ $t = 0^+$

(18) $$y_1 = y_{1_Z} + \frac{D_{UB} \sin \theta d}{2} - C_Z \sin \theta d$$

ON THE NEXT PG. WE WILL OBTAIN RELATIONSHIPS BETWEEN THE COORDINATE SYSTEMS WHICH WILL ENABLE US TO SOLVE FOR THE POINTS WHERE THE TORSO INTERSECTS THE AIRBAG.

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PROJECT: DETERMINATION OF TORSO INTERCEPTS

JOB ORDER NO

CALCULATION SERIAL NO

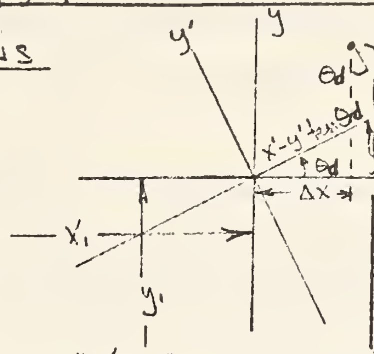
COORDINATE TRANSFORMATION EQUATIONS

19) $y = y_2 + y''$

20) $X = X_2 + X''$

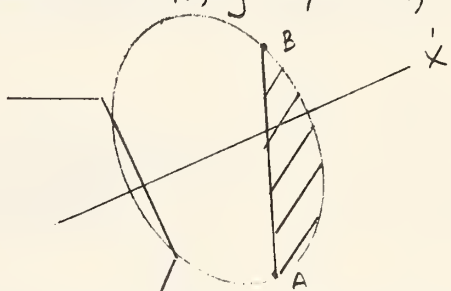
21) $y = y_1 + y'\cos\Theta d + X'\sin\Theta d$

22) $X = X_1 + X'\cos\Theta d - y'\sin\Theta d$



$\Delta X = X'\cos\Theta d - y'\sin\Theta d$
$X = X_1 + \Delta X$
$\Delta y = y'\cos\Theta d + X'\sin\Theta d$
$y = y_1 + \Delta y$

TO OBTAIN TRANSFORMATION EQNS FOR X'' & y'' INTO THE X', y' SYSTEM, SUBSTITUTE 19 & 20 INTO 21 & 22:



23) $X' = \dfrac{X_2 - X_1 + X'' + y'\sin\Theta d}{\cos\Theta d}$

24) $y' = \dfrac{y_2 - y_1 + y'' - X'\sin\Theta d}{\cos\Theta d}$

ASSUME 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 ON THE FIGURE ABOVE. ASSUME FURTHER THAT THE AIRBAG IS AN ELLIPSE IN CROSS SECTION WITH SYMMETRY IN THE X-Y PLANE IS AS SHOWN ON THE FIGURE. OUR JOB NOW WILL BE TO DERIVE AN EQUATION FOR THE BAG INTERCEPT PTS. IN THE X'-y' COORDINATE SYSTEM.

IN THE X"-y" SYSTEM THE EQN. FOR LINE A-B IS:

25) $y'' = mX'' + b$

SUBSTITUTING 25 INTO 24

26) $y' = \dfrac{y_2 - y_1 + mX'' + b - X'\sin\Theta d}{\cos\Theta d}$

SUBSTITUTING IN 26 FOR X" FROM 20 & 22:

27) $y' = \dfrac{y_2 - y_1 + m\left(X'\cos\Theta d - X_2 + X_1 - y'\sin\Theta d\right) - X'\sin\Theta d + b}{\cos\Theta d}$

WHICH IS THE DESIRED EQN IN THE X', y' SYSTEM

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DATE

PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

LET $y_2 - y_1 + b - m(X_2 - X_1) = B$ (A CONSTANT) AND SOLVE (27) FOR y':

$$y'(\cos\theta d + m\sin\theta d) = B + X'(m\cos\theta d - \sin\theta d)$$

28) $$y' = \frac{B + X'(m\cos\theta d - \sin\theta d)}{\cos\theta d + m\sin\theta d}$$ (EQN. FOR A-B IN X', y' SYSTEM)

THE EQN. FOR THE AIRBAG IN THE X'-y' SYSTEM IS:

29) $$\frac{X'^2}{c_i^2} + \frac{y'^2}{a_i^2} = 1$$

SUBSTITUTING (10) INTO (11) AND COLLECTING TERMS:

$$X'^2\left[a_i^2(\cos\theta_d + m\sin\theta_d)^2 + c_i^2(\sin\theta_d + m\cos\theta_d)^2\right] + 2Bc_i^2X'(m\cos\theta_d - \sin\theta_d) + B^2c_i^2 - a_i^2c_i^2(\cos\theta_d + m\sin\theta_d)^2 = 0$$

WHICH IS A QUADRATIC EQN. IN TERMS OF X'.

LET $A = a_i^2(\cos\theta d + m\sin\theta d)^2 + c_i^2(\sin\theta d + m\cos\theta d)^2$

$D = 2Bc_i^2(m\cos\theta d - \sin\theta d)$

$E = B^2c_i^2 - a_i^2c_i^2(\cos\theta d + m\sin\theta d)^2$

$$AX'^2 + DX' + E = 0$$

30) $$X' = \frac{-D \pm \sqrt{D^2 - 4AE}}{2A}$$

VALUES FOR X' OBTAINED WITH **30** WHEN SUBSTITUTED INTO **28** WILL GIVE THE CORRESPONDING VALUES FOR y'. WE NOW HAVE DEFINED THE LINE OF INTERCEPT (A-B) OF THE OCCUPANTS 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 PASSENGER.

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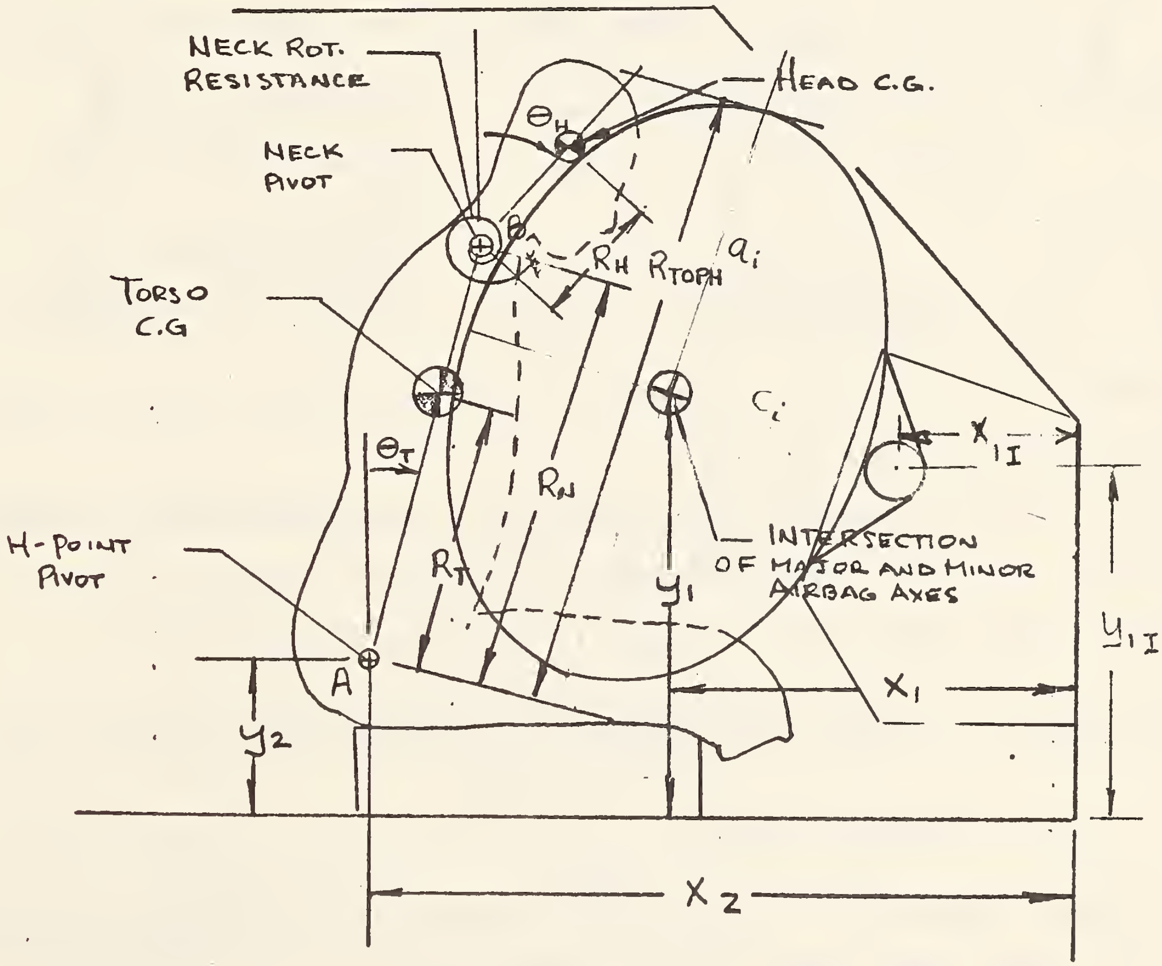
PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

Note: X_{1I} and Y_{1I} are the X_1 and Y_1 values as <u>input</u> and describe the X and Y coordinates of the inflator center. The program is written to change these coordinates to the airbag center when the program is run. This has been done to prevent the user having to respecify the airbag coordinates each time a new airbag shape is analyzed.



PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

FORCES WILL NOW BE CALCULATED DUE TO PRESSURE EFFECTS. THE FORCE ON THE HEAD AND CHEST ARE COMPOSED OF TWO COMPONENTS - A PRESSURE COMPONENT AND A "WRAPAROUND" COMPONENT DUE TO FABRIC TENSION; i.e.

31) $F_{CHEST} = F_{P_C} + F_{FT_C}$

NOTE: FOR NOW, BAGSLAP AND NECK RESISTANCE ARE NEGLECTED.

32) $F_{HEAD} = F_{PH} + F_{FT_H}$

THE PRESSURE FORCES ACT NORMAL TO THE HEAD AND CHEST.

33) $F_{PC} = P\,\omega_b\,(R_N - R_{BAG}) \qquad (R_N - R_{BAG}) < \overline{AB}$

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

34) $F_{PH} = P\,\omega_H\,(R_{TOPH} - R_N) \qquad (R_{TOPH} - R_{BAG}) < \overline{AB}$

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

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-PT. AND NECK PIVOTS AS OUR REFERENCE PTS;

35) $F_{\Theta_T} = F_{CHEST} \cdot R_{FT} + F_{HEAD}\, R_N \cos(\Theta_H - \Theta_T) + F_{\Theta H}$

36) $F_{\Theta H} = F_{HEAD} \cdot R_{HEAD}$

WHERE F_{CHEST} AND F_{HEAD} ARE GIVEN BY THE EQN'S 31 AND 32. WE WILL NOW EVALUATE R_{FT} AND R_{HEAD}.

IN ORDER TO SOLVE FOR R_{FT}, WE MUST DERIVE EQN'S FOR THE H. PT. LOCATION IN TERMS OF THE X'. Y' COORDINATE SYSTEM (SEE FIG. ON NEXT PG.).

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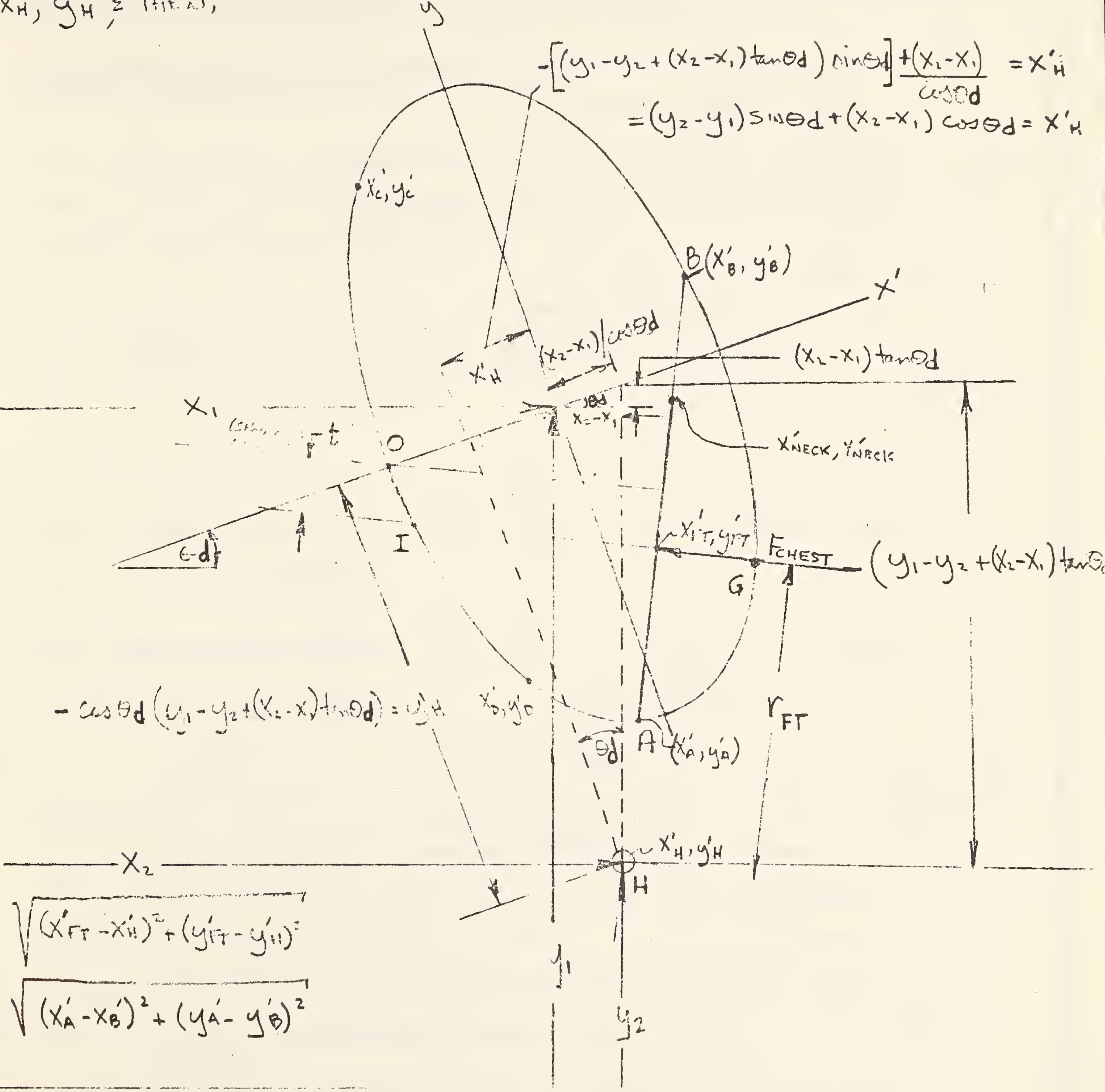
FIND x'_H, y'_H & THEN, r_{FT}.



$$r_{FT} = \sqrt{(x'_{FT} - x'_H)^2 + (y'_{FT} - y'_H)^2}$$

$$\overline{AB} = \sqrt{(x'_A - x'_B)^2 + (y'_A - y'_B)^2}$$

PROJECT	JOB ORDER NO	CALCULATION SERIAL NO

FROM THE GEOMETRY OF THE MID PLANE OF BAG IMPACT:

THE H-PT COORDINATES ARE:

37) $X'_H = (y_2 - y_1)\sin\Theta d + (X_2 - X_1)\cos\Theta d$

38) $y'_H = \cos\Theta d\left[y_2 - y_1 - (X_2 - X_1)\tan\Theta d\right]$

THE EQN. FOR RFT IS:

39) $R_{FT} = \sqrt{(X'_{FT} - X'_H)^2 + (y'_{FT} - y'_H)^2}$

WHERE:

40) $X'_{FT} = \dfrac{(X'_A + X'_{NECK})}{2}$

41) $Y'_{FT} = \dfrac{Y'_A + Y'_{NECK}}{2}$

THE EQ'N FOR RHEAD IS:

42) $R_{HEAD} = \dfrac{R_{TOPH} - R_H}{2}$ $\qquad \overline{AB} + R_{BAG} > R_{TOPH}$

43) $R_{HEAD} = \dfrac{\overline{AB} + R_{BAG} - R_H}{2}$ $\qquad \overline{AB} + R_{BAG} \leq R_{TOPH}$

THIS DERIVATION COMPLETES THE SOLUTION FOR TERMS NEEDED FOR PRESSURE FORCE AND BODY MOMENT COMPUTATION. WE MUST NOW DERIVE EQN'S FOR THE FABRIC TENSION COMPONENT OF BAG FORCE DUE TO BAG WRAP-AROUND 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 THAT NO WRAP-AROUND WILL OCCUR.

PREPARED BY	DATE
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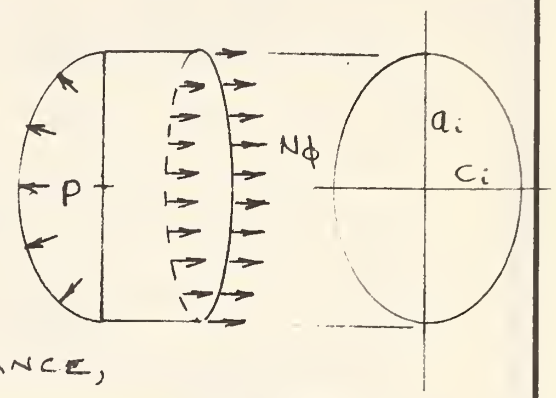
CALCULATION SHEET

PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

FABRIC TENSION COMPUTATION



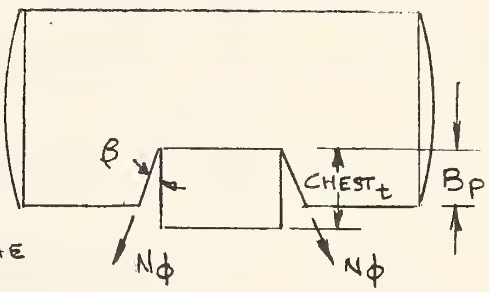
THE FORCE $N\phi$ IS IN LB/IN AND IS THE LONGITUDINAL FABRIC TENSION LOAD CAUSED BY THE BAG PRESSURE P.

$N\phi$ IS OBTAINED BY SETTING UP A FORCE BALANCE,

44) $$N\phi = \frac{\text{BAG PRESSURE} \times \text{BAG X-SECT. AREA}}{\text{BAG PERIMETER}} \cong \frac{P(\pi a_i c_i)}{2\pi\sqrt{\frac{a_i^2 + c_i^2}{2}}} = \frac{P a_i c_i}{2\sqrt{\frac{a_i^2 + c_i^2}{2}}}$$

THE DENOMINATOR IN THE EQN. ABOVE IS AN APPROXIMATE EXPRESSION FOR BAG PERIMETER SUFFICIENTLY CLOSE TO THE EXACT EXPRESSION FOR USE IN OUR APPLICATION.

THE FABRIC TENSION FORCE, F_{FT}, MAY BE WRITTEN AS FOLLOWS;



BP = BAG PENETRATION OF MID-PT. OF $\overline{AB}$.

45) $$F_{FT} = 2 N\phi \, \overline{AB} \cos\beta \qquad {}^{*}(R_N > AB + R_{BAG})$$

WHERE:

* OTHER CONDITIONS ARE HANDLED AS REQ'D IN THE PROGRAM.

$N\phi$ IS GIVEN BY EQN 44

$\overline{AB}$ IS GIVEN ON PG. 11.

β IS ASSUMED TO HAVE THE FOLLOWING RELATIONSHIP.

46) $$\cos\beta = \frac{B_P}{CHEST_t} \qquad 0 < B_P < CHEST_t$$

47) $$\cos\beta = 1 \qquad CHEST_t < B_P \quad \text{WHERE,}$$

B_P IS THE BAG PENETRATION AT THE MID-PT OF A-B AND IS DERIVED ON THE FOLLOWING PAGE

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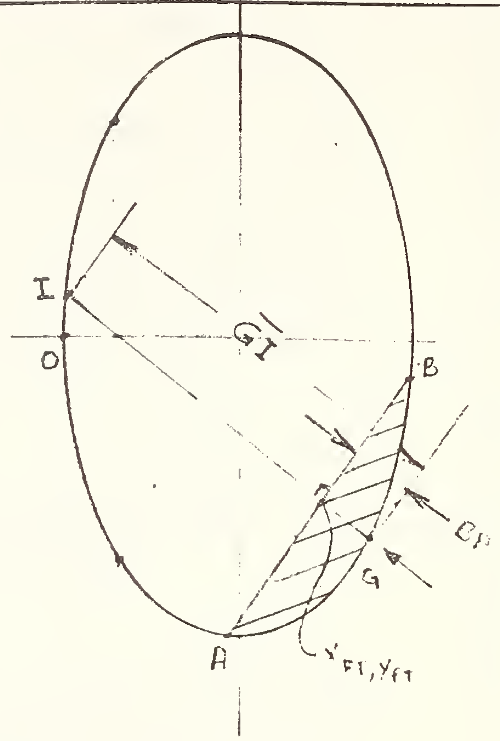
PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

CALCULATE BP



DERIVE EQN. FOR $\overline{GI}$.

48) SLOPE OF $\overline{GI}$ = m'_{PAB}

PT. IT GOES THROUGH IS X_{FT}, y_{FT}

WRITING THE EQN. FOR $\overline{GI}$,

49) $(y' - y_{FT}) = m'_{PAB}(X' - X_{FT})$

REWRITING THE EQN.

50) $y' = m'_{PAB}(X' - X_{FT}) + y_{FT}$

EQN. FOR MID-PLANE OF ELLIPSE;

51) $\frac{X'^2}{c^2} + \frac{y'^2}{a^2} = 1$

SUBSTITUTING y' INTO THE ABOVE AND COLLECTING TERMS,

52) $X'^2\left(\frac{1}{c^2} + \frac{m'^2_{PAB}}{a^2}\right) + \frac{2m'_{PAB}X'}{a^2}(y_{FT} - m'_{PAB}X_{FT}) + \frac{(y_{FT} - m'_{PAB}X_{FT})^2}{a^2} - 1 = 0$

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

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

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

56) $X_G = \frac{-B1 + \sqrt{B1^2 - 4A1C1}}{2A1}$; $y_G = m'_{PAB}(X_G - X_{FT}) + y_{FT}$

57) $X_I = \frac{-B1 - \sqrt{B1^2 - 4A1C1}}{2A_1}$; $y_I = m'_{PAB}(X_I - X_{FT}) + y_{FT}$

58) $GI = \sqrt{(y_I - y_G)^2 + (X_I - X_G)^2}$

59) $BP = \sqrt{(y_{FT} - y_G)^2 + (X_{FT} - X_G)^2}$ WHICH IS THE DESIRED EQN.

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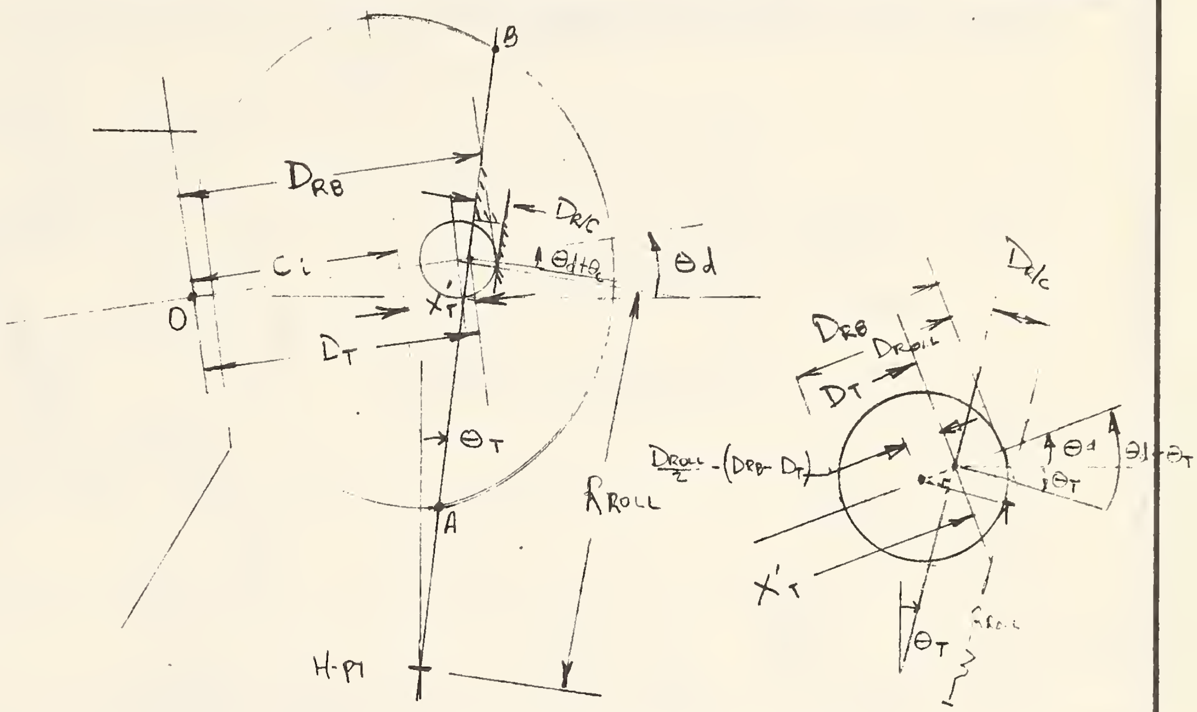
PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

WE WILL NOW CALCULATE THE DYNAMICS OF THE "BAGSLAP" EFFECT.

CALCULATE $D_{R/C}$, THE DISPLACEMENT OF THE BAG ROLL RELATIVE TO THE CHEST



WE WANT TO FIND D_T, THE DISTANCE OF THE TORSO FROM PT. O.

60) $D_T = C_i + X'_T$ WHERE X'_T CAN BE OBTAINED BY SETTING $y' = 0$ IN EQN. 28, i.e.

61) $$X'_T = \frac{-B}{m\cos\Theta_d - \sin\Theta_d}$$

KNOWING D_{RB} AND D_T ENABLES US TO SOLVE FOR $D_{R/C}$, THE DISPLACEMENT OF THE BAG ROLL RELATIVE TO THE CHEST (FOR $D_{RB} > D_T$).

62) $$D_{R/C} = \frac{D_{ROLL}}{2} - \left(\frac{D_{ROLL}}{2} - (D_{RB} - D_T)\cos(\Theta_d - \Theta_T)\right)$$

NOW LET US CALCULATE R_{ROLL},

63) $$R_{ROLL} = \sqrt{(X'_H - X'_T)^2 + {Y'_H}^2} - \left[\frac{D_{ROLL}}{2} - (D_{RB} - D_T)\right]\sin(\Theta_d - \Theta_T)$$

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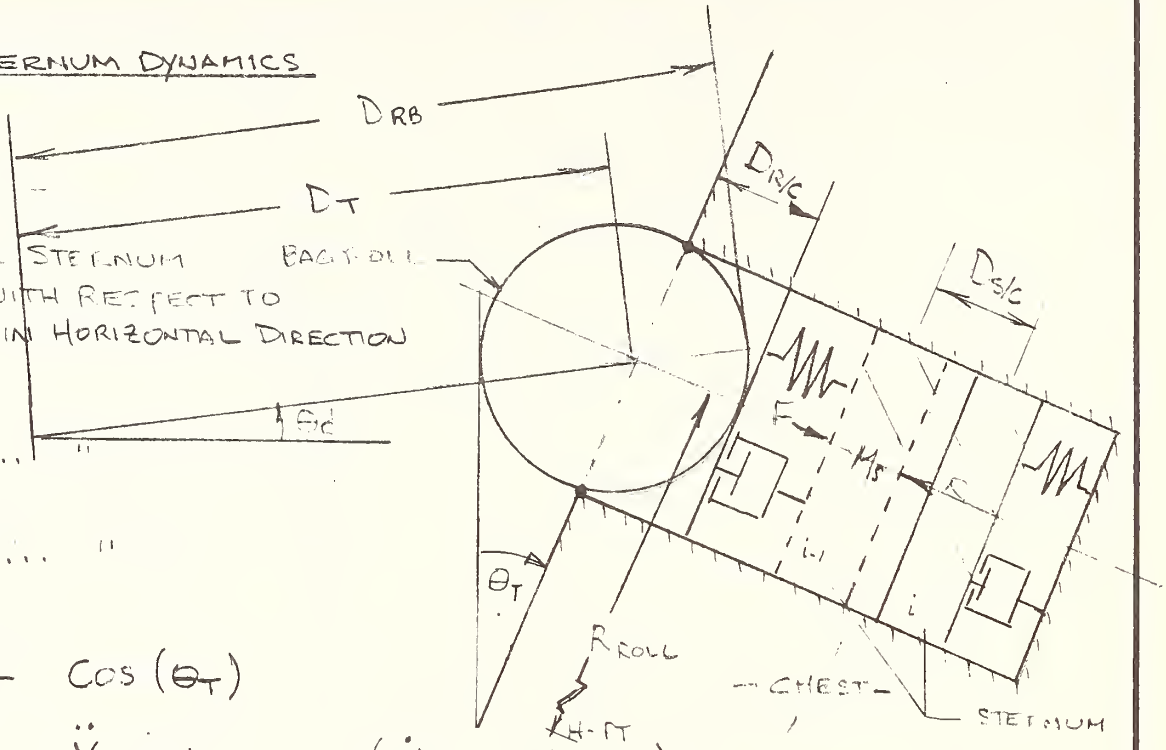
PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

<u>CALCULATE STERNUM DYNAMICS</u>



$X_{s/G}$ = <u>DISTANCE</u> STERNUM MOVES WITH RESPECT TO GROUND IN HORIZONTAL DIRECTION

$\dot{X}_{s/G}$ = <u>VEL.</u> .... "

$\ddot{X}_{s/G}$ = <u>ACC.</u> .... "

64) $\ddot{X}_{s/G} = \dfrac{R-F}{M_s} \cos(\theta_T)$

65) $\dot{X}_{s/G_i} = \dot{X}_{s/G\,i-1} + \ddot{X}_{s/G}\Delta t$; $(\dot{X}_{s/G_0} = \dot{X}_{\frac{VEH}{G}\,0})$

66) $X_{s/G_i} = X_{s/G\,i-1} + \dot{X}_{s/G\,i-1}\Delta t + \ddot{X}_{s/G}\dfrac{\Delta t^2}{2}$; $(X_{s/G_0} = 0)$

THE EQUATIONS WRITTEN ABOVE DESCRIBE THE MOTION OF THE STERNUM PORTION OF THE OVERALL CHEST WITH RESPECT TO THE GROUND. WHAT WE REALLY WANT IS $D_{s/c}$ IN THE FIGURE ABOVE; i.e. THE DISPLACEMENT OF THE STERNUM WITH RESPECT TO THE CHEST. IN ORDER TO GET THIS WE MUST FIRST SOLVE FOR THE DISPLACEMENT OF THE CHEST RELATIVE TO THE GROUND.

67) $X_{c/G} = X_L + R_{ROLL}\left(\sin(\theta_T) - \sin(\theta_{T0})\right)$ WHERE X_L = OVERGROUND DISPLACEMENT OF LWR BODY MASS.

THE HORIZONTAL COMPONENT OF THE STERNUM DISPLACEMENT WITH RESPECT TO THE CHEST IS:

68) $X_{s/c} = X_{c/G} - X_{s/G}$ ($X_{s/G}$ FROM EQN 66 AND $X_{c/G}$ FROM EQN 67).

NOW WE MUST SOLVE FOR THE <u>VERTICAL</u> DISPLACEMENTS OF THE STERNUM AND THE CHEST RELATIVE TO THE GROUND SO WE CAN OBTAIN THE VERTICAL DISPLACEMENT OF THE STERNUM RELATIVE TO THE CHEST AND THEN USING (68), THE RESULTANT DISPLACEMENT OF THE STERNUM RELATIVE TO THE CHEST.

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PROJECT	JOB ORDER NO	CALCULATION SERIAL NO

$y_{s/G}$ = DISTANCE STERNUM MOVES RELATIVE TO THE GROUND IN A VERTICAL DIRECTION.

$\dot{y}_{s/G}$ = VELOCITY ....

$\ddot{y}_{s/G}$ = ACCELERATION ....

(69) $$\ddot{y}_{s/G} = \frac{(F-R)}{M_S} \sin\theta_T$$

(70) $$\dot{y}_{s/G_i} = \dot{y}_{s/G\,i-1} + \ddot{y}_{s/G}\,\Delta t \; ; \; (\dot{y}_{s/G} @ t=0, = 0.)$$

(71) $$y_{s/G_i} = y_{s/G\,i-1} + \dot{y}_{s/G\,i-1}\,\Delta t + \ddot{y}_{s/G}\,\Delta t^2/2 \; ; \; (y_{s/G} @ t=0 = 0.)$$

NOW WE WRITE THE EQUATION FOR THE VERTICAL MOTION OF THE <u>CHEST</u> RELATIVE THE GROUND.

(72) $$y_{c/G} = R_{ROLL}(\cos\theta_T - \cos\theta_{T0})$$

NOW THE VERTICAL MOTION OF THE STERNUM RELATIVE TO THE CHEST.

(73) $$y_{s/c} = y_{c/G} - y_{s/G}$$

THE RESULTANT MOTION OF THE STERNUM RELATIVE TO THE CHEST IS GIVEN BY:

$D_{s/c} = X_{s/c}\cos\theta_T - y_{s/c}\sin\theta_T$ WHERE $X_{s/c}$ IS GIVEN BY EQN. 68 AND $y_{s/c}$ IS GIVEN BY EQN. 73. WE CAN NOW FIND "R" SINCE R= fcn OF $D_{s/c}$.

TO FIND "F" WE MUST SOLVE FOR THE DISPLACEMENT OF THE BAG ROLL RELATIVE TO THE STERNUM. THEREFORE USING EQN 62 AND THE EXPRESSION FOR $D_{s/c}$ ABOVE WE HAVE:

$D_{R/S} = D_{R/c} - D_{s/c}$.

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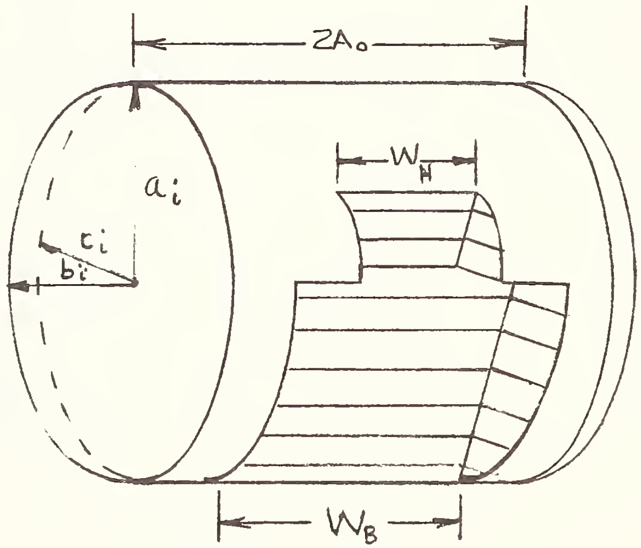
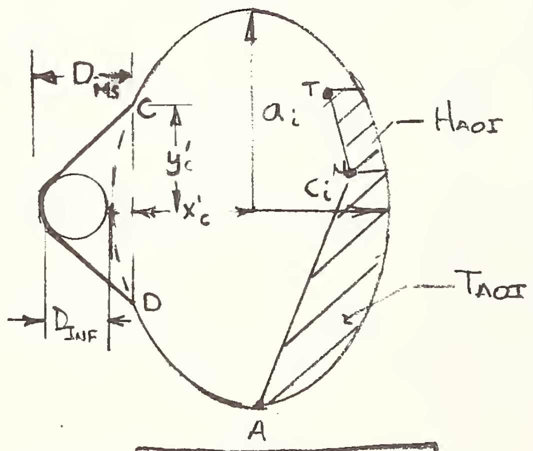
VOLUME COMPUTATION



$$X'_c = -c_i + D_{MS} - D_{INF}$$



$$y'_c = a_i \sqrt{1 - \frac{(-c_i + D_{MS} - D_{INF})^2}{c_i^2}}$$

74) A_{OI} = AREA OF BODY INTERCEPT = $H_{AOI} + T_{AOI}$

75) V_{OI} = VOLUME OF BODY INTERCEPT = $W_H H_{AOI} + W_B T_{AOI}$

76) $V = \frac{4}{3}\pi a_i b_i c_i + 2\pi a_i c_i A_0 - V_{OI} + y'_c W_{SOCK}\left[D_{MS} - (c_i + X'_c)\right]$

WHERE:

a_i, b_i, c_i = INSTANTANEOUS VALUES FOR ELLIPSOIDAL AXES LENGTHS

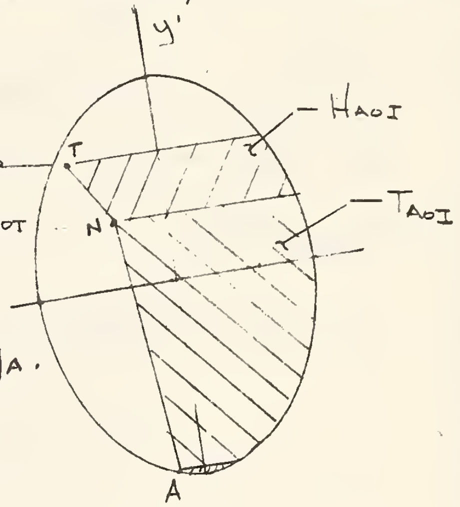
T_{AOI} IS GIVEN BY EQN. 82, AND H_{AOI} BY EQN. 100 (OR 101)

W_{SOCK} = WIDTH OF INFLATOR "SOCK."

AND THE REST OF THE VALUES ARE DEFINED IN THE FIGURE.

VOLUME ANALYSIS, DETERMINATION OF V_{OI}

ON THE PRECEDING PG. A SKETCH OF THE ASSUMED BAG INTERCEPT PROFILE IS GIVEN FOR COMPUTATION PURPOSES. ALL THAT REMAINS TO BE DERIVED IS V_{OI}, THE VOLUME OF BODY INTERCEPT.



CALCULATE TORSO AREA OF INTERCEPT, T_{AOI}

T. AREA OF INTERCEPT, $T_{AOI} = \int_{y_A}^{y_N} \bar{X}\, dy'$

WHERE,

$\bar{X} = X_{BAG} - X_{\substack{LINE\\A-N}}$ FOR A GIVEN y' BETWEEN y_N & y_A.

FOR X_{BAG}, THE X' DISTANCE BETWEEN THE BAG SURFACE AND THE y' AXIS,

77) $X_{BAG} = C_i \sqrt{1 - \dfrac{y'^2}{a_i^2}}$ (EQN. FOR INSTANTANEOUS BAG SHAPE)

78) $$BAG = \int_{y_A}^{y_N} C_i \sqrt{1 - \frac{y'^2}{a_i^2}}\, dy' = \frac{C_i}{2a_i}\left[y'\sqrt{a_i^2 - y'^2} + a_i^2 \sin^{-1}\left(\frac{y'}{a_i}\right)\right]_{y_A}^{y_N}$$

FOR $X_{\substack{LINE\\A-N}}$, USING EQN 1, PG 43 OF "ANALYTIC GEOMETRY" BY UNDERWOOD,

79) $$X_{\substack{LINE\\A-N}} = X_A - \left(\frac{X_A - X_N}{y_A - y_N}\, y_A\right) + \left(\frac{X_A - X_N}{y_A - y_N}\right) y'$$

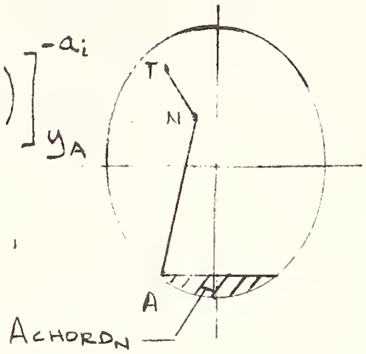
THEREFORE,

80) $$LINE = \int_{y_A}^{y_N} X_{\substack{LINE\\A-N}}\, dy' = \left[\left(X_A - \frac{X_A - X_N}{y_A - y_N}\, y_A\right) y' + \frac{X_A - X_N}{2(y_A - y_N)}\, y'^2\right]_{y_A}^{y_N}$$

PROJECT	JOB ORDER NO	CALCULATION SERIAL NO

UNDER CERTAIN CONDITIONS; i.e. $X_A < 0$ WE HAVE TO ADD "A_{CHORD_N}" TO THE AREA OF INTERCEPT EQN.

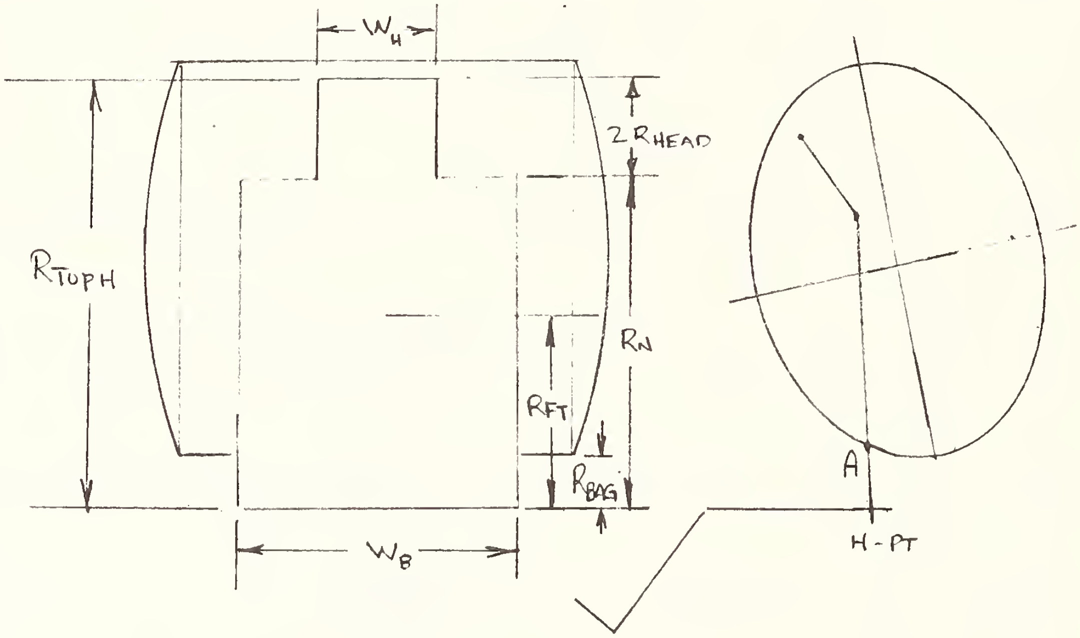
81) $$A_{CHORD_N} = 2\int_{y_A}^{-a_i} X_{BAG}\,dy' = \frac{c_i}{a_i}\left[y'\sqrt{a_i^2-y'^2} + a_i^2 \sin^{-1}\left(\frac{y'}{a_i}\right)\right]_{y_A}^{-a_i}$$



FINALLY, ADDING (74), (76), AND (77), WE HAVE THE DESIRED EQN FOR T_{AOI}.

82) T_{AOI} = BAG - LINE + ACHORDN

TO OBTAIN T_{VOI} WE SIMPLY MULTIPLY T_{AOI} BY THE BODY WIDTH, W_B; i.e.



83) $T_{VOI} = T_{AOI}\, W_B$

WE NOW NEED TO CALCULATE, H_{AOI}.

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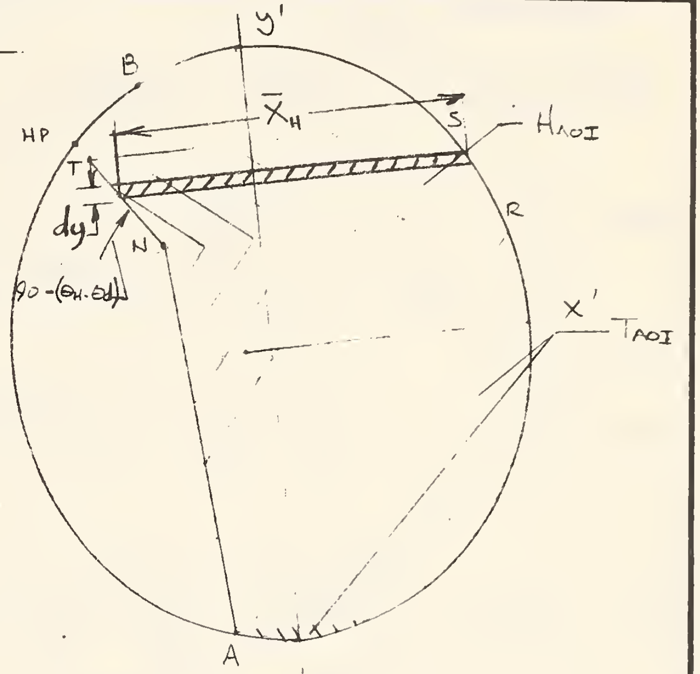
CHECKED BY	DATE

PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

CALCULATE HEAD AREA OF INTERCEPT, HAOI

FIND X' & y' COORDINATES OF PT HP WHICH IS POINT WHERE HEAD WOULD INTERSECT BAG IF $\overline{NT}$ WERE EXTENDED.



LET H_{SLOPE} = SLOPE OF $\overline{NT}$ IN X', y' SYSTEM.

84) $H_{SLOPE} = \tan\left(90 + (\Theta_H - \Theta_d)\right)$

WRITING THE EQN FOR LINE $\overline{NT}$,

85) $y' = H_{SLOPE}(X' - X_N) + Y_N$

THE EQN FOR THE ELLIPSE IS:

86) $\dfrac{X'^2}{C_i^2} + \dfrac{y'^2}{a_i^2} = 1$

SOLVING 81 AND 82 SIMULTANEOUSLY WE HAVE:

87) $X_{HP} = \dfrac{-B_H \pm \sqrt{B_H^2 - 4A_H C_H}}{2A_H}$ WHERE:

88) $A_H = \dfrac{H_{SLOPE}^2}{a_i^2} + \dfrac{1}{C_i^2}$

89) $B_H = \dfrac{2 H_{SLOPE}(Y_N - H_{SLOPE} X_N)}{a_i^2}$

90) $C_H = \dfrac{H_{SLOPE} X_N (H_{SLOPE} X_N - 2Y_N) + Y_N^2}{a_i^2} - 1$

SUBSTITUTING X_{HP} INTO 81,

91) $y_{HP} = H_{SLOPE}(X_{HP} - X_N) + Y_N$

WE CAN NOW SOLVE FOR H_{AOI}.

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CALCULATION SHEET

PROJECT	JOB ORDER NO	CALCULATION SERIAL NO

92) $H_{AOI} = \int_{y_N}^{y_T} \bar{x}_H \, dy$ WHERE,

93) $\bar{x}_H = X_{BAGH} - X_{\substack{LINE\\N-T}}$

FOR X_{BAGH}, THE X' DISTANCE BETWEEN THE BAG SURFACE AND THE y' AXIS,

94) $X_{BAGH} = c_i \sqrt{1 - \frac{y'^2}{a_i^2}}$ (EQN. FOR INSTANTANEOUS BAG SHAPE.)

SO THAT,

95) $BAGH = \int_{y_N}^{y_T} c_i \sqrt{1 - \frac{y'^2}{a_i^2}} \, dy' = c_i/_{2a_i} \left[y' \sqrt{a_i^2 - y'^2} + a_i^2 \sin^{-1}\left(\frac{y'}{a_i}\right) \right]_{y_N}^{y_T}$

FOR $X_{\substack{LINE\\N-T}}$, USING EQN 1, PG. NO. 43 OF "ANALYTIC GEOMETRY" BY UNDERWOOD,

96) $X_{\substack{LINE\\N-T}} = X_N - \left(\frac{X_N - X_T}{y_N - y_T}\right) y_N + \frac{X_N - X_T}{y_N - y_T} y'$

SO THAT,

97) $\underset{N-T}{LINE} = \int_{y_N}^{y_T} X_{\substack{LINE\\NT}} \, dy' = \left[\left(X_N - \left(\frac{X_N - X_T}{y_N - y_T}\right) y_N \right) y' + \frac{Y_N - X_T}{2(y_N - y_T)} y'^2 \right]_{y_N}^{y_T}$

THE ABOVE EQNS ARE VALID FOR $y_T \leq y_{HP}$. IF IT TURNS OUT $y_T > y_{HP}$, THEN y_{HP} SHOULD BE USED INSTEAD OF y_T IN THE EQNS., PLUS, IF $X_{HP} < 0$, THE AREA A_{CHORDP} SHOULD BE ADDED AS SHOWN ON THE NEXT PG.; i.e.

IF $y_T \leq y_{HP}$ AND/OR $X_{HP} \geq 0$, $A_{CHORD} = 0$.

IF $y_T > y_{HP}$ AND $X_{HP} < 0$, A_{CHORD} IS AS CALCULATED ON NEXT PG.

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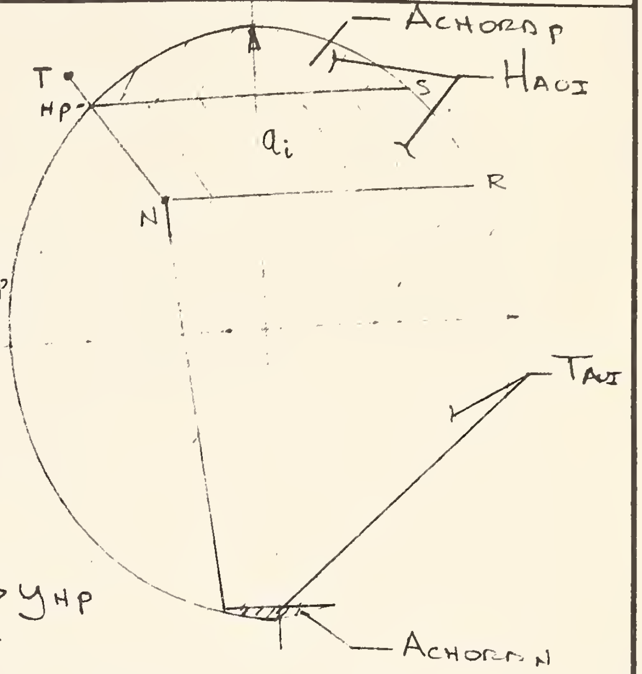


98) $$A_{CHORD\,P} = 2\int_{y_{HP}}^{+a_i} X_{BAG}\, dy'$$

99) $$= \frac{C_i}{a_i}\left[y'\sqrt{a_i^2 - y'^2} + a_i^2 \sin^{-1}\left(\frac{y'}{a_i}\right)\right]_{y_{HP}}^{+a_i}$$

FINALLY, ADDING 95, 97 & 99 WE HAVE THE DESIRED EQN FOR H_{AOI}.

100) $$H_{AOI} = \text{BAG-LINE}_{N-T} \qquad y_T \le y_{HP} \quad \text{OR,}$$

101) $$H_{AOI} = \text{BAG-LINE}_{N-HP} + A_{CHORD\,P} \qquad y_T > y_{HP}$$

KNOWING T_{AOI} & H_{AOI} WE MAY CALCULATE H_{VOI}, THE VOLUME OF HEAD INTERCEPT;

102) $$H_{VOI} = W_H H_{AOI}$$ WHERE W_H = HEAD WIDTH
W_B = BODY WIDTH.

103) $$V_{OI} = H_{VOI} + T_{VOI} = H_{AOI} W_H + T_{AOI} W_B$$

WHICH IS THE EQN. DESIRED SO THAT EQN. 76 CAN BE EVALUATED.

APPENDIX C

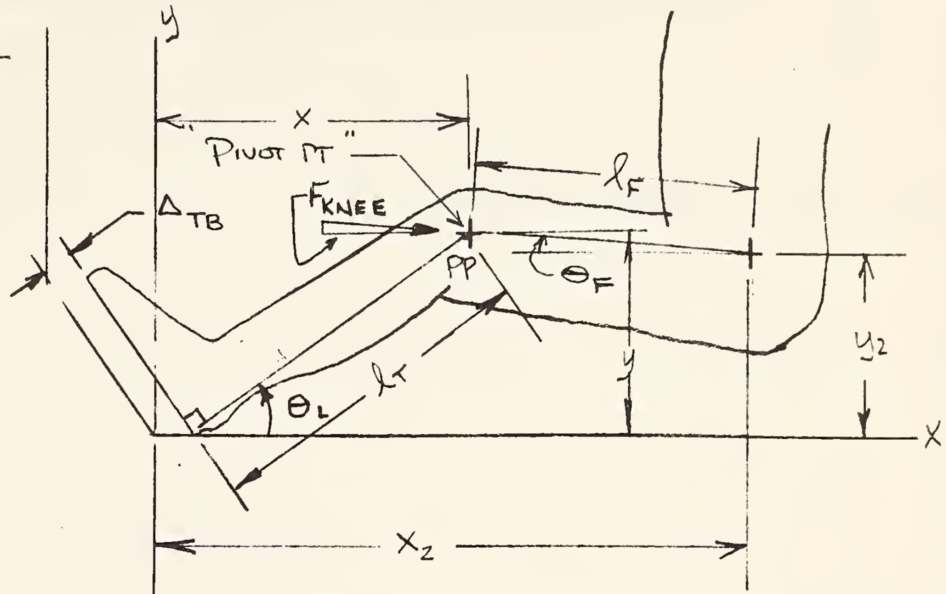
Derivation of the Knee Restraint Equations

CALCULATION SHEET

PROJECT	JOB ORDER NO	CALCULATION SERIAL NO

KNEE TRAJECTORY

WHEN THE H-PT HAS MOVED MORE THAN $\Delta_{TB}/\cos\Theta_L$ RELATIVE TO THE COMPARTMENT, THE FOLLOWING EQN'S APPLY.



1) $X^2 + y^2 = l_T^{\,2}$ EQN OF CIRCLE, CENTER AT TOEBOARD, FLOOR JUNCTION.

2) $(X - X_2)^2 + (y - y_2)^2 = l_F^{\,2}$ EQN. OF CIRCLE, CENTER AT H-PT.

WHEN WE SOLVE THESE TWO EQN'S SIMULTANEOUSLY WE SOLVE FOR THE KNEE "PIVOT POINT", PP IN THE X-Y COORDINATE SYSTEM.

SOLVING THEM SIMULTANEOUSLY YIELDS :

3) $$X X_2 + y_2\sqrt{l_T^2 - X^2} = \frac{l_T^2 - l_F^2 + X_2^2 + y_2^2}{2}$$

THIS EQN. WILL BE SOLVED NUMERICALLY BY THE NEWTON-RAPHSON METHOD FOR "X".

4) $y = \sqrt{l_T^2 - X^2}$ (SUBSTITUTING y INTO 4, WE OBTAIN y)

KNOWING X & y WE CAN SOLVE FOR Θ_F & Θ_L

5) $$\Theta_F = \tan^{-1}\left(\frac{y - y_2}{X_2 - X}\right)$$

$$\Theta_L = \tan^{-1}\left(\frac{y}{X}\right)$$

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PROJECT | JOB ORDER NO | CALCULATION SERIAL NO

AND KNOWING Θ_F, WE CAN SOLVE FOR THE FEMUR FORCE F_F.

6) $F_F = F_{KNEE} \cos \Theta_F$

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Appendix D

PAC Program Listing

```
C                              *** PAC ***
C
C
C        THIS PROGRAM PREDICTS THE PASSENGER KINEMATICS IN A CRASH SITUATION
C        IN WHICH THE PASSENGER IS RESTRAINED BY AN AIRBAG AND KNEE RESTRAINT.
C        THE AIRBAG IS MOUNTED TO THE DASH IN A SPECIFIED POSITION AND
C        DEPLOYS TOWARD THE PASSENGER  AT A DEPLOYMENT ANGLE SPECIFIED
C        BY THE USER. THE COMPLETE DELOYMENT PROCESS OF THE BAG IS MODELED.
C
C        THE KNEE RESTRAINT ABSORBS THE KINETIC ENERGY OF THE LOWER BODY.
C
C        THE PASSENGER IS MODELED BY FOUR MASSES-A HEAD MASS, TWO CHEST
C        MASSES AND A LOWER BODY MASS. THE PASSENGER IS CONSTRAINED TO HAVE
C        PLANAR MOTION SO THAT THE PROGRAM IS STRICTLY APPLICABLE ONLY
C        TO FRONTAL CRASH SITUATIONS.
C
C        RESTRAINT  PERFORMANCE CAN BE OPTIMIZED BY APPROPRIATE CHANGES
C        IN THE DESIGN PARAMETERS.
C
C        TYPICAL DESIGN PARAMETERS THAT CAN BE EVALUATED ARE BAG SIZE, BAG
C       SHAPE, INFLATION CHARACTERISTICS, VENT AREA, INFLATOR LOCATION IN
C       BOTH THE UP-DOWN AND FORE-AFT DIRECTIONS,BAG DEPLOYMENT ANGLE,
C       AIRBAG FABRIC WEIGHT, LEG ANGLE, CHEST MASS AND DAMPING PROPERTIES,
C       AS WELL AS OTHER SYSTEM PARAMETERS.
C
C        THIS PROGRAM IS SELF CONTAINED IN THAT NO EXTERNAL FUNCTIONS OR
C        SUBROUTINES ARE REQUIRED.
C
C            AUTHOR:   MICHAEL FITZPATRICK
C                      FITZPATRICK ENGINEERING
C                      WARSAW, INDIANA  46580
C                      TEL.  (219)-267-4437
C      ORIGINALLY WRITTEN NOV. 23, 1981. THIS IS REVISION A; AUG. 28, 1982
C
C
C
         FILENAME INFILE
         COMMON/FLAG/NOUTPUT
         REAL NECKCHK,KRN,LT,LF
         COMMON/OUT/NRD,T(175),X0(6,175),X1(6,175),X2(6,175),X3(6,175),X7(6,17
5),
         &X8(6,175),X9(6,175),X10(6,175),X11(6,175)
         COMMON/OUT1/NOUT,TOUT(175),X4(6,175),X5(6,175),X6(6,175)
         COMMON/TIME/STEP,XSTOP,DELTAT,PINT1,PINT2
         COMMON/HIC/THIC(175),HRGS(175),CRGS(175)
         COMMON/NAME/INFILE
    1050 PRINT ,"INPUT FILE NAME"
         INPUT ,INFILE
         PRINT,"ENTER 1 IF YOU WANT FULL LIST OF OUTPUT; ENTER 2 IF YOU
         & WANT ABBREVIATED LIST."
         INPUT,NOUTPUT
```

PAC 08/30/82

```
      NPD=0
      NOUT=0
      CALL SOLVE(8)
      IF(NPD.GT.175)NPD=175
      IF(NOUT.GT.175)NOUT=175
 1120 FORMAT(1H-)
 1125 FORMAT(F7.4,2F6.1,2F7.2,2F8.3,F8.1,2F7.2)
 1130 FORMAT(1X,7F11.3)
 1140 FORMAT(V)
 1150 FORMAT(1X,7(4X,"=======")//)
      IF(NOUTPUT.EQ.2)GO TO 1629
      PRINT 1120
 1170 FORMAT(1X,"          TIME       VEH G'S      VEH VEL      VEH DISP    CHES
      &T BP   CWA FORCE    CPR FORCE"/1X,"           (MS)         (G'S)         (FPS)
      &       (INCHES)     (INCHES)     (LBS)         (LBS)")
      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       H-P R.D.     H-P VEL      SEAT FR.   FEM FO
      &RCE    FEM ANG     TIB ANG"/1X,"          (MS)        (INCHES)       (FPS)
      &        (LBS)         (LBS)         (DEG)         (DEG)")
      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)      (FPS)")
      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
  1400 FORMAT(1X,"          TIME     A BAG ACC   ABV WP GND   ABV WP CST ABV
       & WP DSH ABD WP GND ABD WP DSH"/1X,"            (MS)        (G'S)
       &       (FPS)        (FPS)         (FPS)      (INCHES)     (INCHES)")
       PRINT 1400
       PRINT 1150
       DO 1460 K=1,NOUT
```

PAC 08/30/82

```
1460 PRINT 1130,TOUT(K),(X4(J,K),J=1,6)
     PRINT 1120
1465 FORMAT(1X,"       TIME    U BAG ACC  UBV WR GND  UBV WR CST UBV
     & WR DSH UBD WR GND UBD WR DSH"/1X,"       (MS)       (G'S)
     &      (FPS)       (FPS)       (FPS)      (INCHES)    (INCHES)")
     PRINT 1465
     PRINT 1150
     DO 1468 K=1,NOUT
1468 PRINT 1130,TOUT(K),(X5(J,K),J=1,6)
     PRINT 1120
1471 FORMAT(1X,"       TIME    CST F BSP  STN F BSP  STV WR CST RLD
     & WR STN  STD WR CST   DTORSO "/1X,"       (MS)       (LBS)
     &      (LBS)       (FPS)      (INCHES)    (INCHES)     (INCHES)")
     PRINT 1471
     PRINT 1150
     DO 1474 K=1,NOUT
1474 PRINT 1130,TOUT(K),(X6(J,K),J=1,6)
     PRINT 1120
1480 FORMAT(1X,"       TIME      HEAD BP.    BAG VOL.  BAG PRESS. HW/A
     & FORCE  HP FORCE   INT. VOL"/1X,"       (MS)       (INCHES)    (CU.IN.)
     &    (PSIG)      (LBS)       (LBS)       (CU.IN.)")
     PRINT 1480
     PRINT 1150
     DO 1540 K=1,NPD
1540 PRINT 1130,T(K),(X7(J,K),J=1,6)
     PRINT 1120
1560 FORMAT(1X,"       TIME      CHEST AP   CHEST SI    HEAD AP
     &    HEAD SI"/1X,"       (MS)       (G'S)
     & (G'S)       (G'S)
     &      (G'S)")
     PRINT 1560
     PRINT 1150
     DO 1620 K=1,NPD
1620 PRINT 1130,T(K),(X8(J,K),J=1,4)
     PRINT 1120
1625 FORMAT(1X,"       TIME      STN ACC     ROLL RAD   XC B CTR
     &   YC B CTR     WRB          WURB"/1X,"       (MS)       (G'S)       (IN
     &CHES)     (INCHES)    (INCHES)    (LBS)       (LBS)")
     PRINT 1625
     PRINT 1150
     DO 1628 K=1,NPD
1628 PRINT 1130,T(K),(X9(J,K),J=1,6)
     GO TO 1637
1629 PRINT 1120
1630 FORMAT(1X,"       TIME      CST R GS    HD R GS     STN ACC
     &   FEM FORCE  RBV WR CST BAG PRESS"/1X,"       (MS)       (G'S)
     &      (G'S)       (G'S)       (LBS)       (FPS)       (PSIG)")
     PRINT 1630
     PRINT 1150
     DO 1632 K=1,NPD
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RAC 08/30/82

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1632 PRINT 1130,T(K),(X10(J,K),J=1,6)
     PRINT 1120
1634 FORMAT(1X,"      TIME     TORSO ANG    HEAD ANG    FEMUR ANG   STV W
     &R CST   H-P R.D.   CHEST DEFL"/1X,"        (MS)         (DEG)         (DEG)
     &       (DEG)        (FPS)       (INCHES)     (INCHES)")
     PRINT 1634
     PRINT 1150
     DO 1636 K=1,NPD
1636 PRINT 1130,T(K),(X11(J,K),J=1,6)
1637 PRINT 1120
     PRINT,"ENTER 1 TO CALCULATE HIC"
     INPUT ,NRES
     IF(NRES.NE.1) GO TO 2000
1640 PEAK=0.
     NSTOP=NPD
     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+ARGS(L)*PINT2
1717 CONTINUE
     DELT=THIC(K)
     CHECK=SUM/DELT
     IF(PEAK-CHECK) 1718,1716,1716
1718 PEAK=CHECK
     TLOW=(L-1)*PINT2
     THIGH=I*PINT2
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 PASSENGER KINEMATICS.
     SUBROUTINE DIFEQ(T,Y,DY)
     COMMON/MANDAT/ZL,ZT,ZS,ZH,RT,RN,RH,RTORH,X2Z,Y2Z,WB,R0,WH,LT,LF
     DOUBLE PRECISION Y(8)
     DIMENSION DY(8)
     CALL FORCETH(Y,TNECK)
     CALL DECEL(T,GS)
     CALL BAGSUB(T,Y,DY,TNECK,FTH,FX,FTT,GS)
     SH=SIN(Y(6))
     ST=SIN(Y(7))
     CH=COS(Y(6))
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      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*RH*RH)
      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*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)
      FILENAME INFILE,OUTFILE
      REAL NECKCHK,KRN,LT,LF
      COMMON/SEATFRIC/NSF,SUN,SFUT,RELSF,SFN(2,24)
      COMMON/STFORCE/NST,STF(2,24)
      COMMON/CFORCE/NC,CF(2,24)
      COMMON/KNEEREST/NKR,SKR,RUT,RELKR,KRN(2,24)
      COMMON/NAME/INFILE,OUTFILE
      COMMON/TIME/STEP,XSTOP,DELTAT,PINT1,PINT2
      COMMON/MANDAT/ZL,ZT,ZS,ZH,RT,RN,RH,RTORH,X2Z,Y2Z,WB,B0,WH,LT,LF
      COMMON/MMANDAT/STDAMP,CDAMP,CHESTT,HEADT,THEO,THLO,DELTTB
      COMMON/NECK/NPN,FNECK(2,24),DCN
      COMMON/VEH/NV,VEHGS(2,50)
      COMMON/GASFLO/NPG,GEN(2,24)
      COMMON/GASDAT/ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
      COMMON/BAGDAT/VC1,VC2,AV,FSA,FSC,FSB,A0,WBAG,DROLLZ,THETAD,X1,Y1
      COMMON/MBAGDAT/DMS,DINF,WSOCK,DURBZ,VCGH,VCGV
     &,SA,SB,SC,SAR
      COMMON/MDAT/DURBGH,DURBGV,DRBGH,DRBGV,VURBGH,VRBGH,VURBGV,VRBGV,
     &GURBH,GURBV,GRBH,GRBV,VSGH
      COMMON/PARAM/RFT,THETATZ,THETAHZ,PG1,FKNEE,GRB,DRB,ACI
      COMMON/MPARAM/SF,FSTBS,FCBS,GURB,DURB,DRC,DRS,DSC
      COMMON/MMISC/FM2,PR8,PA5,GT,FPN,VOLO,GW
      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     MSTERN      MHEAD         RT          RN
```

```
           &          RH          RTOPH"/1X,8G10.3)
     2120 FORMAT(1X,"       ATMOP        PGZ        GTZ         U         PN1
           &          PN2          PN3"/1X,7G10.3)
     2130 FORMAT(1X,"       VC1          VC2         AV         FSA        FSB
           &          FSC          X1          Y1"/1X,8G10.3)
     2132 FORMAT(1X,"       A0        THETAD     FABWGT      STDAMP     CDAMP
           &     DMS       DINF      WSOCK"/1X,8G10.3)
     2134 FORMAT(1X,"       WH        DROLLZ     X2Z        Y2Z
           &        WB          LF         DCN"/1X,8G10.3)
     2135 FORMAT(1X,"GAS FLOW TIME"/1X,10G10.3)
     2136 FORMAT(1X,"GAS FLOW - LB/SEC"/1X,10G10.3)
     2140 FORMAT(1X,"NECK ANGLE"/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
           & SL.ST     SL.KR"/1X,7G10.3)
     2170 FORMAT(1X,"       NPTS STER NPTS CHST"/1X,
           &2G10.3)
     2250 FORMAT(1X,"VEH. PULSE - TIME"/1X,10G10.3)
     2260 FORMAT(1X,"VEH. PULSE - DECELERATION"/1X,10G10.3)
     2265 FORMAT(1X,"SEAT FRICTION DISPLACEMENT"/1X,10G10.3)
     2267 FORMAT(1X,"SEAT FRICTION FORCE - LBS"/1X,10G10.3)
     2268 FORMAT(1X,"KNEE DISPLACEMENT"/1X,10G10.3)
     2269 FORMAT(1X,"KNEE FORCE - LBS"/1X,10G10.3)
     2270 FORMAT(1X,"STERNUM DISPLACEMENT"/1X,10G10.3)
     2271 FORMAT(1X,"STERNUM FORCE - LBS"/1X,10G10.3)
     2272 FORMAT(1X,"CHEST DISPLACEMENT"/1X,10G10.3)
     2273 FORMAT(1X,"CHEST FORCE - LBS"/1X,10G10.3)
     2274 FORMAT(1X,"        THFD        THLD      XSTOP     STEP        PINT1       PIN
T2"/1X,6G10.3)
          READ(INFILE,2070)Y(4),Y(6),Y(7)
          READ(INFILE,2070)ZL,ZT,ZS,ZH,RT,RN,RH,RTOPH
          READ(INFILE,2070)NPN,NKR,NV,NSF,NPG,SUN,SKR
          READ(INFILE,2070)NST,NC
          READ(INFILE,2070) (GEN(1,K),K=1,NPG)
          READ(INFILE,2070) (GEN(2,K),K=1,NPG)
          READ(INFILE,2070)ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
          READ(INFILE,2070)VC1,VC2,AV,FSA,FSB,FSC,X1,Y1
          READ(INFILE,2070)A0,THETAD,FABWGT,STDAMP,CDAMP,DMS,DINF,WSOCK
          READ(INFILE,2070)WH,DROLLZ,X2Z,Y2Z,WB,LF,DCN
          READ(INFILE,2070)THFD,THLD,XSTOP,STEP,PINT1,PINT2
          READ(INFILE,2070) (SFN(1,K),K=1,NSF)
          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) (STF(1,K),K=1,NST)
          READ(INFILE,2070) (STF(2,K),K=1,NST)
          READ(INFILE,2070) (CF(1,K),K=1,NC)
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RAC 08/30/82

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      READ(INFILE,2070)(CF(2,K),K=1,NC)
      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,ZS,ZH,RT,RN,RH,RTORH
      PRINT 2160,NRN,NKR,NV,NSF,NRG,SUN,SKR
      PRINT 2170,NST,NC
      PRINT 2135,(GEN(1,K),K=1,NRG)
      PRINT 2136,(GEN(2,K),K=1,NRG)
      PRINT 2265,(SFN(1,K),K=1,NSF)
      PRINT 2267,(SFN(2,K),K=1,NSF)
      PRINT 2140,(RNECK(1,K),K=1,NRN)
      PRINT 2150,(RNECK(2,K),K=1,NRN)
      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 2270,(STF(1,K),K=1,NST)
      PRINT 2271,(STF(2,K),K=1,NST)
      PRINT 2272,(CF(1,K),K=1,NC)
      PRINT 2273,(CF(2,K),K=1,NC)
      PRINT 2120,ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
      PRINT 2130,VC1,VC2,AV,FSA,FSB,FSC,X1,Y1
      PRINT 2132,A0,THETAD,FARWGT,STDAMP,CDAMP,DMS,DINF,WSOCK
      PRINT 2134,WH,DROLLZ,X2Z,Y2Z,WB,LF,DCN
      PRINT 2274,THRO,THLO,XSTOP,STEP,PINT1,PINT2
      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)
      THRO=THRO*.01745329
      THLO=THLO*.01745329
      LT=(Y2Z+LF*SIN(THRO))/SIN(THLO)
      DELTTB=(X2Z-LT*COS(THLO)-LF*COS(THRO))*COS(THLO)
      ZL=ZL/32.2
      ZT=ZT/32.2
      ZS=ZS/32.2
      ZH=ZH/32.2
      RT=RT/12.
      RN=RN/12.
      RH=RH/12.
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```
      RTOPH=RTOPH/12.
      SUN=SUN*12.
      SKR=SKR*12.
      THETAD=THETAD*.01745329
      X1=X1+(DMS-DINF/2.)*COS(THETAD)
      Y1=Y1+(DMS-DINF/2.)*SIN(THETAD)
      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
      B0=WB/2.
      CHESTT=B0
      HEADT=1.3*WH
      SAR=6.28318*(2.*A0*SQRT((FSA**2+FSC**2)/2.)+FSB*FSC+FSA*FSB+FSA*FSC)
      WBAG=SAR*FABWGT/20736.
      DURBZ=2.*(DMS-DINF)
      DURB=DURBZ
      DRB=DURBZ
      DURBGH=-DURBZ*COS(THETAD)
      DURBGV=DURBZ*SIN(THETAD)
      DRBGH=DURBGH
      DRBGV=DURBGV
      VURBGH=Y(4)*12.
      VURBGV=0.
      VRBGH=Y(4)*12.
      VRBGV=0.
      GURB=0.
      GURBH=0.
      GURBV=0.
      GRB=0.
      GRBH=0.
      GRBV=0.
      VCGH=Y(4)*12.
      VSGH=Y(4)*12.
      SC=DURBZ/2.
      SA=SC/FSC*FSA
      SB=SC/FSC*FSB
      VOLZ=4.1887*SA*SB*SC+6.2831*SA*SC*A0+WSOCK*SA*(DMS-SC)
      VOLO=VOLZ
      GW=(PA*VOLZ)/(U*GTZ)
      DO 3010 J=1,24
      GEN(1,J)=GEN(1,J)/1000.
      FNECK(1,J)=FNECK(1,J)*.01745329
      SFN(1,J)=SFN(1,J)/12.
 3010 KRN(1,J)=KRN(1,J)/12.
      DO 3050 J=1,NV
      VEHGS(1,J)=VEHGS(1,J)/1000.
 3050 VEHGS(2,J)=VEHGS(2,J)*32.2
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PAC 08/30/82

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            SFUT=0.
            RUT=0.
        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(2,50)
            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 AND RELATIVE VELOCITY.
            SUBROUTINE FORCETH(Y,TNECK)
            COMMON/NECK/NPN,FNECK(2,24),DCN
            DOUBLE PRECISION Y(8)
            TNECK=0.
            TDAMP=-DCN*(Y(2)-Y(3))
            VREL=Y(2)-Y(3)
            TREL=Y(6)-Y(7)
            CALL LOOKUP(TREL,FNECK,NPN,TNECK)
            IF(TREL.GT.0.0.AND.VREL.LE.0.)TNECK=-TNECK*0.4
            IF(TREL.LT.0.0.AND.VREL.GE.0.)TNECK=-TNECK*0.5
           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(2,50)
            CALL LOOKUP(T,VEHGS,NV,GS)
            RETURN
            END
C
C           THIS SUBROUTINE COMPRISES THE MAJOR PART OF THE "PAC" PROGRAM.  IT
C           EVALUATES THE KINEMATICS OF THE DEPLOYING AIRBAG, CALCULATES
C           THE FORCES THE BAG APPLIES TO THE PASSENGER, CALCULATES THE
C           BAG VOLUME AND PRESSURE, DETERMINES THE GAS GENERATOR FLOW
C           CHARACTERISTICS AND CALCULATES THE IMPULSIVE LOADS ON THE
C           BODY DUE TO BAGSLAP.
            SUBROUTINE BAGSUB(X,Y,DY,TNECK,FTH,FX,FTT,GS)
            REAL NECKCHK,KRN,LT,LF
            COMMON/SEATFRIC/NSF,SUN,SFUT,RELSF,SFN(2,24)
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      COMMON/STFORCE/NST,STF(2,24)
      COMMON/CFORCE/NC,CF(2,24)
      COMMON/KNEEREST/NKR,SKR,RUT,RELKR,KRN(2,24)
      COMMON/MANDAT/ZL,ZT,ZS,ZH,RT,RN,RH,RTOPH,X2Z,Y2Z,WB,B0,WH,LT,LF
      COMMON/MMANDAT/STDAMP,CDAMP,CHESTT,HEADT,THFO,THLO,DELTTB
      COMMON/GASFLO/NPG,GEN(2,24)
      COMMON/GASDAT/ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
      COMMON/BAGDAT/VC1,VC2,AV,FSA,FSC,FSB,A0,WBAG,DROLLZ,THETAD,X1,Y1
      COMMON/MBAGDAT/DMS,DINF,WSOCK,DURBZ,VCGH,VCGV
      &,SA,SB,SC,SAR
      COMMON/MDAT/DURBGH,DURBGV,DRBGH,DRBGV,VURBGH,VRBGH,VURBGV,VRBGV,
      &GURBH,GURBV,GRBH,GRBV,VSGH
      COMMON/MMISC/RM2,RR8,RA5,GT,RRN,VOLD,GW
      COMMON/PARAM/RFT,THETATZ,THETAHZ,PG1,FKNEE,GRB,DRB,AOI
      COMMON/MPARAM/SF,FSTBS,FCBS,GURB,DURB,DRC,DRS,DSC,GST
      COMMON/TIME/STEP,XSTOP,DELTAT,PINT1,PINT2
      COMMON/MMPARAM/BP,VOL,FFTC,FPC,VSC,WRB,DROLL,RROLL,XPT,DTORSO
      COMMON/MPRINT/FFTH,FPH,THEF,THEL,BPH,VOI,WURB,ROOT
      DOUBLE PRECISION Y(8),B,A,D,E,A1,B1,C1,X2,Y2
    2 FORMAT(1H-)
      DIMENSION DY(8)
      THETAT=Y(7)
      THETAH=Y(6)
C     CHECK TO SEE IF PASSENGER SUBMARINING.
      IF(ABS(THETAD-THETAT).GT.1.57) GO TO 500
C     CALCULATE THE SLOPE OF THE PASSENGER TORSO.
      OSLOPE=TAN(3.14159/2.+THETAT)
      IF(ABS(OSLOPE).GT.1000.)OSLOPE =1000.*ABS(OSLOPE)/OSLOPE
C     CALCULATE THE NEW H-POINT COORDINATES.
      X2=X2Z-(Y(5)-Y(8))*12.
      Y2=Y2Z
C     CALCULATE THE WEIGHT OF THE UNRESTRAINED PORTION OF THE BAG.
      WURB=WBAG*(A0+FSB-B0)*(1-(DURB-DURBZ)/(2.*FSC))/(A0+FSB)
      WURB=WURB+(WBAG-WURB)*4.*SA*(A0+FSB-B0)/SAR
C     CALCULATE THE WEIGHT OF THE RESTRAINED PORTION OF THE BAG.
      WRB=WBAG*B0*(1-(DRB-DURBZ)/(2.*FSC))/(A0+FSB)
      WRB=WRB+(WBAG-WRB)*4.*SA*B0/SAR
C     CALCULATE THE DISTANCE THE UNRESTRAINED BAG FRONT HAS MOVED
C     RELATIVE TO THE GROUND IN THE HORIZONTAL DIRECTION.
      DURBGH=DURBGH+VURBGH*DELTAT+193.2*GURBH*DELTAT**2
C     CALCULATE THE VELOCITY OF THE UNRESTRAINED BAG FRONT RELATIVE
C     TO THE GROUND.
      VURBGH=VURBGH+386.4*GURBH*DELTAT
C     DISTANCE THE UNRESTRAINED BAG HAS MOVED IN THE VERTICAL DIRECTION.
      DURBGV=DURBGV+VURBGV*DELTAT-193.2*GURBV*DELTAT**2
C     VELOCITY OF THE UNRESTRAINED BAG IN THE VERTICAL DIRECTION.
      VURBGV=VURBGV-386.4*GURBV*DELTAT
C     COMPUTE THE GROWTH OF THE UNRESTRAINED PORTION OF THE BAG
C     WITH RESPECT TO THE VEHICLE IN THE HORIZONTAL DIRECTION.
      DURBH=Y(8)*12.-DURBGH
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C       NOW IN THE VERTICAL DIRECTION,
        DURBV=DURBGV
C       TOTAL U.R. BAG GROWTH W/R TO THE VEHICLE IN THE DIRECTION THETAD.
        DURB=SQRT(DURBH**2+DURBV**2)
C       CALCULATE THE INSTANTANEOUS LENGTH OF THE "C" BAG AXIS.
        SCO=SC
        SC=DURB/2.
C       DO THE SAME FOR THE "A" AXIS.
        SA=FSA/FSC*SC
C       AND NOW THE "B" AXIS.
        SB=FSB/FSC*SC
        XC=-(SC-(DMS-DINF))
C       CALCULATE THE DISTANCE THE RESTRAINED BAG FRONT HAS MOVED
C       RELATIVE TO THE GROUND IN THE HORIZONTAL DIRECTION.
        DRBGH=DRBGH+VRBGH*DELTAT+193.2*GRBH*DELTAT**2
C       CALCULATE THE VELOCITY OF THE RESTRAINED BAG FRONT RELATIVE TO
C       THE GROUND.
        VRBGH=VRBGH+386.4*GRBH*DELTAT
C       DISTANCE THE RESTRAINED BAG HAS MOVED IN THE VERTICAL DIRECTION.
        DRBGV=DRBGV+VRBGV*DELTAT-193.2*GRBV*DELTAT**2
C       VELOCITY OF THE RESTRAINED BAG IN THE VERTICAL DIRECTION.
        VRBGV=VRBGV-386.4*GRBV*DELTAT
C       COMPUTE THE GROWTH OF THE RESTRAINED PORTION OF THE BAG
C       WITH RESPECT TO THE VEHICLE IN THE HORIZONTAL DIRECTION.
        DRBH=Y(8)*12.-DRBGH
C       NOW IN THE VERTICAL DIRECTION,
        DRBV=DRBGV
C       TOTAL R. BAG GROWTH W/R TO THE VEHICLE IN THE DIRECTION THETAD.
        DRB=SQRT(DRBH**2+DRBV**2)
C       X AND Y COORD. OF H-POINT IN XPRIME, YPRIME COORD. SYSTEM
        XH=((Y2-Y1)*SIN(THETAD)+(X2-X1)*COS(THETAD))
        YH=((Y2-Y1)-(X2-X1)*TAN(THETAD))*(+COS(THETAD))
C       CALCULATE THE X AND Y COORDINATES OF THE NECK PIVOT IN THE
C       X'-Y' SYSTEM.
        XNECK=XH-RN*12.*SIN(THETAT-THETAD)
        YNECK=YH+RN*12.*COS(THETAT-THETAD)
C       IN THE NEXT SEVERAL STATEMENTS THE INTERCEPTS OF THE AIRBAG
C       AND THE TORSO AND HEAD ARE CALCULATED. THESE INTERCEPTS ARE
C       DESIGNATED BY XA,YA AND XB,YB IN THE AIRBAG COORDINATE SYSTEM.
        B=Y2-Y1-DSLOPE*(X2-X1)
        A=SA**2*(COS(THETAD)+DSLOPE*SIN(THETAD))**2
        &+SC**2*(SIN(THETAD)-DSLOPE*COS(THETAD))**2
        D=2.*B*SC**2*(DSLOPE*COS(THETAD)-SIN(THETAD))
        E=B**2*(SC**2)-SA**2*(SC**2)*(COS(THETAD)+DSLOPE*SIN(THETAD))**2
C       TEST FOR SIGN OF DISCRIMINATE
        IF(D**2-4.*A*E) 3,4,4
      3 TVOI=0.
        GO TO 14
C       REAL DISTINCT ROOTS (TORSO LINE PASSES THROUGH BAG).
      4 DISC=(D**2-4.*A*E)**.5
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PAC 08/30/82

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C     BAG INTERCEPT POINTS, XA,XB AND YA,YB
      XA=(-D-DISC)/(2.*A)
      XB=(-D+DISC)/(2.*A)
      YA=(B+XA*(DSLOPE*COS(THETAD)-SIN(THETAD)))/(COS(THETAD)+DSLOPE*
     &SIN(THETAD))
      IF(SA.LE.ABS(YA))YA=ABS(YA)/YA*(SA-.001)
      YB=(B+XB*(DSLOPE*COS(THETAD)-SIN(THETAD)))/(COS(THETAD)+DSLOPE*
     &SIN(THETAD))
      IF(SA.LE.ABS(YB))YB=ABS(YB)/YB*(SA-.001)
      IF(THETAT-THETAD.GT.0..AND.YA.LT.0.)GO TO 512
      IF(THETAT-THETAD.LT.0..AND.YA.GT.0.)GO TO 510
C     ABST=DISTANCE FROM POINT A TO POINT B.
      ABST=SQRT((XA-XB)**2+(YA-YB)**2)
      IF(THETAT-THETAD)6,6,7
    6 YP=YB
      YN=YA
      XP=XB
      XN=XA
      GO TO 8
    7 YP=YA
      YN=YB
      XP=XA
      XN=XB
C     CALCULATE THE DISTANCE FROM THE H-POINT TO THE BAG SURFACE
C     ALONG THE TORSO LINE.
    8 RBAG=SQRT((XN-XH)**2+(YN-YH)**2)
      IF(YN.LT.YH) RBAG=-RBAG
      IF(RBAG.GT.RN*12.)GO TO 3
C     COMPUTE THE X AND Y COORDINATES OF THE POINT OF FORCE APPLICATION
C     ON THE TORSO IN THE X'-Y' SYSTEM.
      IF(ABST+RBAG-12.*RN)9,9,10
    9 YUT=YP
      XUT=XP
      YLT=YN
      XLT=XN
      GO TO 11
   10 YUT=YNECK
      XUT=XNECK
      YLT=YN
      XLT=XN
   11 YFT=(YUT+YLT)/2.
      XFT=(XUT+XLT)/2.
C     RFT=DISTANCE FROM H-POINT TO POINT OF FORCE APPLICATION ON TORSO
      RFT=SQRT((XH-XFT)**2+(YH-YFT)**2)
C     PSLOPE=THE SLOPE OF A LINE PERPENDICULAR TO THE TORSO. THIS IS
C     USED TO FIND THE X' AND Y' COORDINATES OF THE POINT WHERE THIS
C     LINE INTERSECTS THE AIRBAG SO THAT THE DEPTH OF BAG PENETRATION
C     CAN BE COMPUTED.
      PSLOPE=-(COS(THETAD)+DSLOPE*SIN(THETAD))/(DSLOPE*COS(THETAD)
     &-SIN(THETAD))
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      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     THE X' AND Y' COORDINATES OF THIS POINT ARE XG AND YG.
      XG=(-B1+SQRT(B1**2-4.*A1*C1))/(2.*A1)
      YG=PSLOPE*(XG-XFT)+YFT
C     THE BAG PENETRATION IS "BP".
      BP=SQRT((XFT-XG)**2+(YFT-YG)**2)
C     COMPUTE THE TORSO AREA OF INTERCEPT IN THE FOLLOWING STATEMENTS.
      ACHORDP=0.
      ACHORDN=0.
      ACHORDHP=0.
C     SOLVE FOR THE ARC SIN OF YUT/SA AND YLT/SA.
   13 ASYUTSA=ATAN((YUT/SA)/(SQRT(1.-(YUT/SA)**2)))
      ASYLTSA=ATAN((YLT/SA)/(SQRT(1.-(YLT/SA)**2)))
C     BAG, TLINE AND ACHORD ARE INTERMEDIATE VALUES REQUIRED FOR THE
C     AREA OF INTERCEPT CALCULATION.
      IF(XP.LT.0..AND.YNECK.GT.SA)ACHORDP=SC/SA*(3.14159*SA**2
     &/2.-(YUT*SQRT(SA**2-YUT**2)+SA**2*ASYUTSA))
      BAG=SC/(2.*SA)*((YUT*SQRT(SA**2-YUT**2)+SA**2*ASYUTSA)-
     &(YLT*SQRT(SA**2-YLT**2)+SA**2*ASYLTSA))
      TLINE=(XLT-(XN-XNECK)/(YN-YNECK)*YLT)*YUT+(XN-XNECK)/(2.*(YN-YNECK
     &))*YUT**2-(XLT
     &-(XN-XNECK)/(YN-YNECK)*YLT)*YLT-(XN-XNECK)/(2.*(YN-YNECK))*YLT**2
      IF(XN.LT.0.)ACHORDN=SC/SA*(YLT*SQRT(SA**2-YLT**2)+SA**2*
     &ASYLTSA+3.14159*SA**2/2.)
C     SOLVE FOR THE TORSO AREA AND VOLUME OF INTERCEPT.
      TAOI=BAG-TLINE+ACHORDP+ACHORDN
      TVOI=TAOI*WB
C     CALCULATE THE HEAD INTERCEPT WITH THE BAG.
C     FIRST CALCULATE SLOPE OF HEAD.
   14 IF(ABS(THETAH-THETAD).GE.3.141593/2.) GO TO 518
      HSLOPE=+TAN(3.14159/2.+(THETAH-THETAD))
      AH=HSLOPE**2/SA**2+1./SC**2
      BH=2.*HSLOPE*(YNECK-HSLOPE*XNECK)/SA**2
      CH=(HSLOPE*XNECK*(HSLOPE*XNECK-2.*YNECK)+YNECK**2)/SA**2-1.
      IF(BH**2-4.*AH*CH) 15,17,17
   15 HAOI=0.
      GO TO 50
   17 DISCH=SQRT(BH**2-4.*AH*CH)
C     THE COORDINATES OF THE HEAD INTERCEPTS WITH THE BAG ARE:
      XHA=(-BH-DISCH)/(2.*AH)
      XHB=(-BH+DISCH)/(2.*AH)
      YHA=HSLOPE*(XHA-XNECK)+YNECK
      IF(SA.LE.YHA)YHA=ABS(YHA)/YHA*(SA-.001)
      YHB=HSLOPE*(XHB-XNECK)+YNECK
      IF(SA.LE.YHB)YHB=ABS(YHB)/YHB*(SA-.001)
      IF(THETAH-THETAD) 19,19,20
C     DISTINGUISH BETWEEN UPPER AND LOWER VALUES OF HEAD INTERCEPT PTS.
   19 YHP=YHB
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PAC 08/30/82

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      YHN=YHA
      XHP=XHB
      XHN=XHA
      GO TO 21
   20 YHP=YHA
      YHN=YHB
      XHP=XHA
      XHN=XHB
C     DEFINE X AND Y COORDINATES OF TOP OF HEAD IN X'-Y' SYSTEM.
   21 XTOPH=XNECK-12.*(RTOPH-RN)*SIN(THETAH-THETAD)
      YTOPH=YNECK+12.*(RTOPH-RN)*COS(THETAH-THETAD)
C     SEE IF BOTH NECK PIVOT AND TOP OF HEAD RESIDE WITHIN BAG.
      TOPCHK=XTOPH**2/SC**2+YTOPH**2/SA**2
      NECKCHK=XNECK**2/SC**2+YNECK**2/SA**2
      IF(TOPCHK.LT.1..AND.NECKCHK.LT.1.) GO TO 35
C     SEE IF THE NECK PIVOT PT. RESIDES WITHIN BAG.
      IF(NECKCHK.LT.1.) GO TO 30
C     SEE IF ANY PART OF HEAD RESIDES WITHIN BAG.
      IF(TOPCHK.GE.1.) GO TO 15
C     NECK PIVOT NOT WITHIN BAG BUT HEAD TOP IS.
      YUH=YTOPH
      XUH=XTOPH
      YLH=YHN
      XLH=XHN
      GO TO 38
C     NECK PIVOT WITHIN BAG, BUT HEAD TOP IS NOT.
   30 YUH=YHP
      XUH=XHP
      YLH=YNECK
      XLH=XNECK
      GO TO 38
C     BOTH NECK PIVOT AND HEAD TOP WITHIN BAG.
   35 YUH=YTOPH
      XUH=XTOPH
      YLH=YNECK
      XLH=XNECK
C     NOW CALCULATE THE X' AND Y' COORDINATES OF THE POINT WHERE THE
C     FORCE IS APPLIED TO THE HEAD.
   38 YFH=(YUH+YLH)/2.
      XFH=(XUH+XLH)/2.
C     CALCULATE THE PENETRATION OF THE AIRBAG BY THE HEAD.
      HPSLOPE=-1/HSLOPE
      HA1=1./SC**2+HPSLOPE**2/SA**2
      HB1=2.*HPSLOPE/SA**2*(YFH-HPSLOPE*XFH)
      HC1=(YFH-HPSLOPE*XFH)**2/SA**2-1.
      XGH=(-HB1+SQRT(HB1**2-4.*HA1*HC1))/(2.*HA1)
      YGH=HPSLOPE*(XGH-XFH)+YFH
      BPH=SQRT((XFH-XGH)**2+(YFH-YGH)**2)
C     COMPUTE ARCSINS YLH/SA AND YUH/SA.
   40 ASYLHSA=ATAN((YLH/SA)/(SQRT(1.-(YLH/SA)**2)))
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      ASYUHSA=ATAN((YUH/SA)/(SQRT(1.-(YUH/SA)**2)))
      BAGH=SC/(2.*SA)*((YUH*SQRT(SA**2-YUH**2)+SA**2*ASYUHSA)-
     &(YLH*SQRT(SA**2-YLH**2)+SA**2*ASYLHSA))
      HLINE=(XLH-(XNECK-XHP)/(YNECK-YHP)*YLH)*YUH+(XNECK-XHP)/(2.*(YN
     &ECK-YHP))*YUH**2-
     &(XLH-(XNECK-XHP)/(YNECK-YHP)*YLH)*YLH-(XNECK-XHP)/(2.*(YNE
     &CK-YHP))*YLH**2
      IF(XHP.LT.0..AND.YTOPH.GT.SA)ACHORDHP=SC/SA*(3.141593*SA**2/2.
     &-(YUH*SQRT(SA**2-YUH**2)+SA**2*ASYUHSA))
      IF(ACHORDP.NE.0.) ACHORDHP=0.
C     SOLVE FOR THE HEAD AREA AND VOLUME OF INTERCEPT.
      HADI=BAGH-HLINE+ACHORDHP
   50 HVOI=HADI*WH
C     "VOI"=VOLUME OF BAG INTERCEPT.
C     CALCULATE THE TOTAL VOLUME OF BODY INTERCEPT WITH THE BAG.
      VOI=TVOI+HVOI
      YC=SA*SQRT(1.-XC**2/(C**2)
      VOL=4.1887*SA*SB*SC+6.2831*SA*SC*A0+WSOCK*YC*(DMS-(SC+XC))-VOI
      IF(X-GEN(1,2)) 90,90,101
   90 PA=ATMOP
      GO TO 113
C     COMPUTE GAS FLOW INTO BAG
  101 CALL GASIN(X,QIN)
      GW1=GW+QIN*DELTAT
C     COMPUTE NEW TEMP. AND PRESS. DUE TO NET GAS GAIN IN BAG
      GT7=(GW*GT+QIN*GTZ*DELTAT)/GW1
      PNUM=U*GT7*GW1
      PA7=PNUM/VOLD
C     COMPUTE NEW GAS PRESS. AND TEMP. DUE TO POLYTROPIC COMP. OF 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
      IF(GW.LT.0.) GW=0.
      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)
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C       COMPUTE PRESSURE RATIO TO DETERMINE WHETHER GAS COMPRESSED OR
C       EXPANDED THIS TIME THRU LOOP; THEN SET PROPER POLYTROPIC EXPONENT.
        PR6=PA8/PA5
        IF (PR6.LT.1.0001) GO TO 112
        PPN=PN2
        GO TO 113
  112   PPN=PN3
C       COMPUTE BAG PRESSURE.
  113   PG1=PA-ATMOP
        DROLL=DROLLZ*(1.-DURB/(2.*FSC))
        XPT=-B/(QSLOPE*COS(THETAD)-SIN(THETAD))
        DTORSD=SC+XPT
        IF(DURB.GE.2.*FSC.AND.DRB.GT.DTORSD)DRB=DTORSD
        PROLL=SQRT((XH-XPT)**2+YH**2)-(DROLL/2.-(DRB-DTORSD))*SIN(THETAD
        &-THETAT)
        IF(PROLL.GT.RTOPH*12..AND.FCBS.NE.0.)GO TO 520
        DSGH=DSGH+VSGH*DELTAT+193.2*GSTH*DELTAT**2
        VSGH=VSGH+386.4*GSTH*DELTAT
        DSGV=DSGV+VSGV*DELTAT+193.2*GSTV*DELTAT**2
        VSGV=VSGV+386.4*GSTV*DELTAT
        DCGH=Y(5)*12.+PROLL*(SIN(THETAT)-SIN(THETATZ))
        VCGH=Y(1)*12.+PROLL*Y(3)*COS(THETAT)
        DCGV=PROLL*(COS(THETAT)-COS(THETATZ))
        VCGV=-PROLL*Y(3)*SIN(THETAT)
        IF(DURB.LT.2.*FSC)GO TO 114
        VSGH=VCGH
        VSGV=VCGV
        DSGH=DCGH
        DSGV=DCGV
  114   DSCH=DCGH-DSGH
        DSCV=DCGV-DSGV
        DSC=DSCH*COS(THETAT)-DSCV*SIN(THETAT)
        VSCH=VCGH-VSGH
        VSCV=VCGV-VSGV
        VSC=VSCH*COS(THETAT)-VSCV*SIN(THETAT)
        CALL CFOR(DSC,FCBS)
        FCBS=FCBS+CDAMP*VSC
        IF(DRB-DTORSD)115,115,117
  115   DRS=0.
        DRC=0.
        FSTBS=0.
        PROLL=SQRT((XH-XPT)**2+YH**2)
        GO TO 118
  117   DRC=(DROLL/2.-(DROLL/2.-(DRB-DTORSD)))*COS(THETAD-THETAT))
        IF(DROLL/2..LT.DRB-DTORSD)DRC=(DRB-DTORSD)*COS(THETAD-THETAT)
        DRS=DRC-DSC
        CALL STFOR(DRS,FSTBS)
        IF(DURB.GE.2.*FSC) STDAMP=0.
        FSTBS=FSTBS+STDAMP*((VSGH-VRBGH)*COS(THETAT)+(VSGV-VRBGV)*SIN(TH
        &ETAT))
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      118 GST=(FCBS-FSTBS)/(ZS*32.2)
          GSTH=GST*COS(THETAT)
          GSTV=-GST*SIN(THETAT)
C         IF THE BAG PRESSURE IS NEGATIVE, CALL IT 0. FOR BAG FORCE CALCS.
          PG=PG1
          IF(PG.LT.0.) PG=0.
C         IF THE TORSO IS NOT IN CONTACT WITH THE BAG, SKIP THE BAG FORCE
C         CALCULATION.
          IF(D**2-4.*A*E) 120,125,125
      120 FFTC=0.
          FPC=0.
          BP=0.
          GO TO 128
C         THE BAG FORCES ARE CALCULATED IN THE NEXT SEVERAL STATEMENTS.
      125 IF(RBAG.GT.RN*12..OR.X.LT.GEN(1,2)) GO TO 120
          ENPHI=PG*SA*SC/(2.*SQRT((SA**2+SC**2)/2.))
          CHESTL=SQRT((XN-XUT)**2+(YN-YUT)**2)
          FFTC=2.*ENPHI*CHESTL
          IF(BP.LT.2.*CHESTT)FFTC=FFTC*(BP/(2.*CHESTT))
          FPC=PG*WB*CHESTL
      128 FCHEST=FPC+FFTC
          IF(BH**2-4.*AH*CH) 140,135,135
      135 IF(TORCHK.GT.1..AND.NECKCHK.GT.1.) GO TO 140
          IF(X.LT.GEN(1,2)) GO TO 140
          HEADL=SQRT((XUH-XLH)**2+(YUH-YLH)**2)
          FPH=PG*WH*HEADL
          FFTH=2.*ENPHI*HEADL
          IF(BPH.LT.2.*HEADT)FFTH=FFTH*(BPH/(2.*HEADT))
          GO TO 141
      140 FFTH=0.
          FPH=0.
          BPH=0.
      141 FHEAD=FFTH+FPH
          PHEAD=SQRT((XFH-XNECK)**2+(YFH-YNECK)**2)
          FTH=TNECK-FHEAD*PHEAD/12.
          TRANSTOR=-TNECK
          FTT=-FHEAD*RN*COS(Y(6)-Y(7))+TRANSTOR-(RROLL*FCBS+RFT*FCHEST)/12.
          IF(PG1.GT.0.) GO TO 142
          GRBH=-GS/32.2
          GRBV=0.
          GRB=GRBH*COS(THETAD)
          VRBGH=Y(4)*12.
          VRBGV=0.
          GURBH=-GS/32.2
          GURBV=0.
          GURB=GURBH*COS(THETAD)
          VURBGH=Y(4)*12.
          VURBGV=0.
          GO TO 146
      142 IF(DURB.GT.DURBZ+1.) GO TO 143
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PAC 08/30/82

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      GRB=(FSTBS-PG1*WSOCK*DROLL)/WBAG
      GURB=-PG1*WSOCK*DROLL/WBAG
      GO TO 144
  143 GRB=(FSTBS*COS(THETAD-THETAT)-4.*PG1*SA*B0)/WRB
      GURB=-PG1*(4.*SA*(A0-B0)+3.14159*SA*SB)/WURB
  144 GRBH=GRB*COS(THETAD)
      GRBV=GRB*SIN(THETAD)
      GURBH=GURB*COS(THETAD)
      GURBV=GURB*SIN(THETAD)
  146 IF(DURB.GE.2.*FSC)  GO TO 152
  149 IF(DRB.GE.2.*FSC)  GO TO 155
      IF(DURB.GT.DURBZ+1.)  GO TO 158
      IF(DRBGH-DURBZ*COS(THETAD).GE.Y(8)*12.)  DRBGH=Y(8)*12.-DURBZ*
     &COS(THETAD)
      GO TO 165
  152 GURBH=-GS/32.2
      GURBV=0.
      GURB=GURBH*COS(THETAD)
      VURBGH=Y(4)*12.
      VURBGV=0.
      IF(PG1.LT.0.)PG1=0.
      GO TO 149
  155 GST=(FCBS-FSTBS)/(ZS*32.2)
      GSTH=GST*COS(THETAT)
      GSTV=-GST*SIN(THETAT)
      GRB=FSTBS*COS(THETAD-THETAT)/WRB
      IF(GRB.LT.-GS/32.2)GO TO 156
      GRBH=GRB*COS(THETAD)
      GRBV=GRB*SIN(THETAD)
      VRBGH=Y(4)*12.
      VRBGV=0.
      IF(DRB.GE.DTOPSO)GO TO 165
  156 GRBH=-GS/32.2
      GRBV=0.
      GRB=GRBH*COS(THETAD)
      VRBGH=Y(4)*12.
      VRBGV=0.
      GO TO 165
  158 IF(DURB.GE.2.*FSC)  GO TO 159
      GO TO 161
  159 GST=DY(1)/32.2*COS(THETAT)+RROLL*DY(3)/386.4
      GSTH=DY(1)/32.2+RROLL*(DY(3)*COS(THETAT)-Y(3)**2*SIN(THETAT))/386.4
      GSTV=-RROLL*(DY(3)*SIN(THETAT)+Y(3)**2*COS(THETAT))/386.4
      GRBH=GSTH
      GRBV=GSTV
      GRB=GST*COS(THETAD-THETAT)
      VRBGH=VSGH
      VRBGV=VSGV
      GO TO 165
  161 IF(PG1.GT.0.)  GO TO 165
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      IF(FSTBS.EQ.0.)  GO TO 165
      GRB=FSTBS*COS(THETAD-THETAT)/WRB
      GRBH=GRB*COS(THETAD)
      GRBV=GRB*SIN(THETAD)
  165 X1=X1+(SC-SCO)*COS(THETAD)
      Y1=Y1+(SC-SCO)*SIN(THETAD)
C     UPDATE OLD VALUES.
      VOLO=VOL
      PA5=PA
      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))170,170,173
  170 THEF=THFO
      THEL=THLO
      RELKR=Y(5)-Y(8)
      GO TO 270
  173 IF(DELTTB.LT.0.)GO TO 514
      NLOOP=1
      EPSLON=.0001
      ROOTG=LT*COS(THEL)
      ROOT=ROOTG
  175 FROOT=ROOT*X2+Y2*SQRT(LT**2-ROOT**2)-(LT**2-LF**2+X2**2+Y2**2)/2.
      DFROOT=X2-Y2*ROOT/SQRT(LT**2-ROOT**2)
      DELRT=-FROOT/DFROOT
      ROOT=ROOT+DELRT
      IF(ABS(DELRT).LE.EPSLON)  GO TO 180
      NLOOP=NLOOP+1
      IF(NLOOP.GT.20.)  GO TO 516
      GO TO 175
  180 YROOT=SQRT(LT**2-ROOT**2)
      THEF=ATAN((YROOT-Y2)/(X2-ROOT))
      THEL=ATAN(YROOT/ROOT)
      IF(ROOT.LT.0.)THEL=1.5707963-ATAN(ROOT/YROOT)
      RELKR=LT/12.*(COS(THLO)-COS(THEL))+DELTTB/(12.*COS(THLO))
  270 CALL SPRING(KRN,RUT,RELKR,SKR,0.0,FKNEE,NKR)
      FX=-(SF+FKNEE+(FCHEST+FCBS)*COS(Y(7))+FHEAD*COS(Y(6)))
      N=1
      GO TO 540
  500 XSTOP=X
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT ,"PASSENGER SUBMARINING, NOT RECOVERABLE, RUN STOPPE
D."
      GO TO 540
  510 XSTOP=X
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT ,"LOWER CHEST IMPACT WITH DASH, RUN STOPPED."
      GO TO 540
  512 XSTOP=X
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PAC 08/30/82

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      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT ,"UPPER CHEST IMPACT WITH DASH, RUN STOPPED."
      GO TO 540
  514 XSTOP=X
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT,"X2 INPUT NOT CONSISTENT WITH OTHER LEG INPUT."
      GO TO 540
  516 XSTOP=X
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT,"KNEE ANGLE SOLUTION NOT CONVERGING."
      GO TO 540
  518 XSTOP=X
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT,"HEAD ROTATION > 90 DEG., RUN STOPPED."
      GO TO 540
  520 XSTOP=X
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT,"BAG ROLL DEPLOYING HIGHER THAN HEAD, STOP RUN."
  540 RETURN
      END
C
C     THIS SUBROUTINE CALCULATES THE STERNUM BAGSLAP FORCE AS A FUNCTION
C     OF THE AIRBAG ROLL INTO THE STERNUM.
      SUBROUTINE STFOR(DRS,FSTBS)
      COMMON/STFORCE/NST,STF(2,24)
      CALL LOOKUP(DRS,STF,NST,FSTBS)
      RETURN
      END
C
C     THIS SUBROUTINE CALCULATES THE CHEST BAGSLAP FORCE AS A FUNCTION
C     OF THE DEFLECTION OF THE STERNUM RELATIVE TO THE CHEST.
      SUBROUTINE CFOR(DSC,FCBS)
      COMMON/CFORCE/NC,CF(2,24)
      CALL LOOKUP(DSC,CF,NC,FCBS)
      RETURN
       END
C
C      THIS SUBROUTINE COMPUTES THE RATE THAT GAS ENTERS THE BAG.
       SUBROUTINE GASIN(X,QIN)
       COMMON/GASFLO/NPG,GEN(2,24)
       CALL LOOKUP(X,GEN,NPG,QIN)
       RETURN
       END
C
C      THIS SUBROUTINE PLACES CERTAIN VALUES IN MATRIX FORMAT FOR PRINTING
```

PAC 08/30/82

```
      SUBROUTINE PRINT1(X,Y,DY)
      COMMON/OUT1/N,T(175),X4(6,175),X5(6,175),X6(6,175)
      COMMON/STFORCE/NST,STF(2,24)
      COMMON/CFORCE/NC,CF(2,24)
      COMMON/MMANDAT/STDAMP,CDAMP,CHESTT,HEADT,THFO,THLO,DELTTB
      COMMON/BAGDAT/VC1,VC2,AV,FSA,FSC,FSB,A0,WBAG,DROLLZ,THETAD,X1,Y1
      COMMON/MBAGDAT/DMS,DINF,WSOCK,DURBZ,VCGH,VCGV
     &,SA,SB,SC,SAR
      COMMON/MDAT/DURBGH,DURBGV,DRBGH,DRBGV,VURBGH,VRBGH,VURBGV,VRBGV,
     &GURBH,GURBV,GRBH,GRBV,VSGH
      COMMON/PARAM/RET,THETATZ,THETAHZ,PG1,FKNEE,GRB,DRB,ADI
      COMMON/MPARAM/SF,FSTBS,FCBS,GURB,DURB,DRC,DRS,DSC
      COMMON/MMPARAM/BP,VOL,FETC,FPC,VSC,WRB,DROLL,RROLL,XPT,DTORSO
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      N=N+1
      DATA F/12./
      IF(N.GT.175)RETURN
      X4(1,N)=GRB
      X4(2,N)=VRBGH/F
      X4(3,N)=((VRBGH-VCGH)*COS(THETAT)+(VRBGV-VCGV)*SIN(THETAT))/F
      X4(4,N)=((VRBGH-Y(4)*12.)*COS(THETAD)+VRBGV*SIN(THETAD))/F
      X4(5,N)=DRBGH
      X4(6,N)=-DRB
      X5(1,N)=GURB
      X5(2,N)=VURBGH/F
      X5(3,N)=((VURBGH-VCGH)*COS(THETAT)+(VURBGV-VCGV)*SIN(THETAT))/F
      X5(4,N)=((VURBGH-Y(4)*12.)*COS(THETAD)+VURBGV*SIN(THETAD))/F
      X5(5,N)=DURBGH
      X5(6,N)=-DURB
      X6(1,N)=FCBS
      X6(2,N)=FSTBS
      X6(3,N)=-VSC/F
      X6(4,N)=-DRS
      X6(5,N)=-DSC
      X6(6,N)=DTORSO
      T(N)=X*1000.
      RETURN
      END
C
C     THIS SUBROUTINE SOLVES THE DIFFERENTIAL EQUATIONS THAT DETERMINE
C     THE PASSENGER 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,DELTAT,PINT1,PINT2
      COMMON/GASFLO/NPG,GEN(2,24)
      DOUBLE PRECISION Y(8),YT(8)
      DOUBLE PRECISION B270,B19,B251
```

```
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT ,"UPPER CHEST IMPACT WITH DASH, RUN STOPPED."
      GO TO 540
  514 XSTOP=X
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT,"X2 INPUT NOT CONSISTENT WITH OTHER LEG INPUT."
      GO TO 540
  516 XSTOP=X
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT,"KNEE ANGLE SOLUTION NOT CONVERGING."
      GO TO 540
  518 XSTOP=X
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT,"HEAD ROTATION > 90 DEG., RUN STOPPED."
      GO TO 540
  520 XSTOP=X
      N=N+1
      PRINT 2
      IF(N.EQ.2)PRINT,"BAG ROLL DEPLOYING HIGHER THAN HEAD, STOP RUN."
  540 RETURN
      END
C
C     THIS SUBROUTINE CALCULATES THE STERNUM BAGSLAP FORCE AS A FUNCTION
C     OF THE AIRBAG ROLL INTO THE STERNUM.
      SUBROUTINE STFOR(DRS,FSTBS)
      COMMON/STFORCE/NST,STF(2,24)
      CALL LOOKUP(DRS,STF,NST,FSTBS)
      RETURN
      END
C
C     THIS SUBROUTINE CALCULATES THE CHEST BAGSLAP FORCE AS A FUNCTION
C     OF THE DEFLECTION OF THE STERNUM RELATIVE TO THE CHEST.
      SUBROUTINE CFOR(DSC,FCBS)
      COMMON/CFORCE/NC,CF(2,24)
      CALL LOOKUP(DSC,CF,NC,FCBS)
      RETURN
      END
C
C     THIS SUBROUTINE COMPUTES THE RATE THAT GAS ENTERS THE BAG.
      SUBROUTINE GASIN(X,QIN)
      COMMON/GASFLO/NPG,GEN(2,24)
      CALL LOOKUP(X,GEN,NPG,QIN)
      RETURN
      END
C
C     THIS SUBROUTINE PLACES CERTAIN VALUES IN MATRIX FORMAT FOR PRINTING
```

```
      SUBROUTINE PRINT1(X,Y,DY)
      COMMON/OUT1/N,T(175),X4(6,175),X5(6,175),X6(6,175)
      COMMON/STFORCE/NST,STF(2,24)
      COMMON/CFORCE/NC,CF(2,24)
      COMMON/MMANDAT/STDAMP,CDAMP,CHESTT,HEADT,THFO,THLO,DELTTB
      COMMON/BAGDAT/VC1,VC2,AV,FSA,FSC,FSB,A0,WBAG,DROLLZ,THETAD,X1,Y1
      COMMON/MBAGDAT/DMS,DINF,WSOCK,DURBZ,VCGH,VCGV
     &,SA,SB,SC,SAR
      COMMON/MDAT/DURBGH,DURBGV,DRBGH,DRBGV,VURBGH,VRBGH,VURBGV,VRBGV,
     &GURBH,GURBV,GRBH,GRBV,VSGH
      COMMON/PARAM/RET,THETATZ,THETAHZ,PG1,FKNEE,GRB,DRB,ADI
      COMMON/MPARAM/SF,FSTBS,FCBS,GURB,DURB,DRC,DRS,DSC
      COMMON/MMPARAM/BP,VOL,FFTC,FPC,VSC,WRB,DROLL,RROLL,XPT,DTORSO
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      N=N+1
      DATA F/12./
      IF(N.GT.175)RETURN
      X4(1,N)=GRB
      X4(2,N)=VRBGH/F
      X4(3,N)=((VRBGH-VCGH)*COS(THETAT)+(VRBGV-VCGV)*SIN(THETAT))/F
      X4(4,N)=((VRBGH-Y(4)*12.)*COS(THETAD)+VRBGV*SIN(THETAD))/F
      X4(5,N)=DRBGH
      X4(6,N)=-DRB
      X5(1,N)=GURB
      X5(2,N)=VURBGH/F
      X5(3,N)=((VURBGH-VCGH)*COS(THETAT)+(VURBGV-VCGV)*SIN(THETAT))/F
      X5(4,N)=((VURBGH-Y(4)*12.)*COS(THETAD)+VURBGV*SIN(THETAD))/F
      X5(5,N)=DURBGH
      X5(6,N)=-DURB
      X6(1,N)=FCBS
      X6(2,N)=FSTBS
      X6(3,N)=-VSC/F
      X6(4,N)=-DRS
      X6(5,N)=-DSC
      X6(6,N)=DTORSO
      T(N)=X*1000.
      RETURN
      END
C
C     THIS SUBROUTINE SOLVES THE DIFFERENTIAL EQUATIONS THAT DETERMINE
C     THE PASSENGER 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,DELTAT,PINT1,PINT2
      COMMON/GASFLO/NPG,GEN(2,24)
      DOUBLE PRECISION Y(8),YT(8)
      DOUBLE PRECISION B270,B19,B251
```

PAC 08/30/82

```
      DIMENSION DY(8),F(3,8),J(3),S(8)
      B251=251.
      B270=270.
      B19=19.
      PRI1=0.
      PRI2=0.
      DELTAT=0.
      CALL SETUP(X,Y)
      CALL DIFEQ(X,Y,DY)
      DELTAT=STEP/4.
      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.
      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
          DELTAT=STEP/2.
     7700 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
          CALL DIFEQ(X,Y,DY)
          CALL UPDATE(X,Y,DY)
C         PRINTING SECTION
          PRI1=PRI1+STEP
          PRI2=PRI2+STEP
          IF(PRI1.LT.PINT1)  GO TO 7890
          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
C         THE SEAT FRICTION FORCE. HYSTERESIS EFFECTS MAY BE INCLUDED.
          SUBROUTINE SPRING(F,DELTA,DIST,SLOPE1,SLOPE2,FORCE,NPTS)
          DIMENSION F(2,24)
          P=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 PRINTING
.
          SUBROUTINE PRINT2(X,Y,DY)
          COMMON/OUT/N,T(175),X0(6,175),X1(6,175),X2(6,175),X3(6,175),X7(6,17
5),
          &X8(6,175),X9(6,175),X10(6,175),X11(6,175)
          DOUBLE PRECISION Y(8)
          DIMENSION DY(8)
          COMMON/MANDAT/ZL,ZT,ZS,ZH,RT,RN,RH,RTOPH,X2Z,Y2Z,WB,BO,WH,LT,LF
          COMMON/MMANDAT/STDAMP,CDAMP,CHESTT,HEADT,THFO,THLO,DELTTB
          COMMON/BAGDAT/VC1,VC2,AV,FSA,FSC,FSB,A0,WBAG,DROLLZ,THETAD,XONE,YON
E
          COMMON/MBAGDAT/DMS,DINF,WSOCK,DURBZ,VCGH,VCGV
          &,SA,SB,SC,SAR
```

```
COMMON/PARAM/RFT,THETATZ,THETAHZ,PG1,FKNEE,GPB,DPB,AOI
COMMON/MPARAM/SF,FSTBS,FCBS,GUPB,DUPB,DPC,DPS,DSC,GST
COMMON/MMPARAM/BP,VOL,FFTC,FPC,VSC,WPB,DROLL,RROLL,XPT,DTORSQ
COMMON/MPRINT/FFTH,FPH,THEF,THEL,BPH,VOI,WUPB,ROOT
COMMON/MDAT/DUPBGH,DUPBGV,DPBGH,DPBGV,VUPBGH,VPBGH,VUPBGV,VPBGV,
&GUPBH,GUPBV,GPBH,GPBV,VSGH
COMMON/HIC/THIC(175),HPGS(175),CPGS(175)
COMMON/TIME/STEP,XSTOP,DELTAT,PINT1,PINT2
DATA F/12./,G/32.2/,D/57.295780/
N=N+1
IF(N.GT.175)RETURN
CH=COS(Y(6))
CT=COS(Y(7))
SH=SIN(Y(6))
ST=SIN(Y(7))
T(N)=X*1000.
X0(1,N)=DY(4)/G
X0(2,N)=Y(4)
X0(3,N)=Y(8)*F
X0(4,N)=BP
X0(5,N)=FFTC
X0(6,N)=FPC
X1(1,N)=(Y(5)-Y(8))*F
X1(2,N)=Y(1)
X1(3,N)=SF
X1(4,N)=FKNEE*COS(THEF)/2.
X1(5,N)=THEF*D
X1(6,N)=THEL*D
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))
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
X7(1,N)=BPH
X7(2,N)=VOL
X7(3,N)=PG1
X7(4,N)=FFTH
X7(5,N)=FPH
X7(6,N)=VOI
X8(1,N)=(DY(1)*CT+RT*DY(3))/32.2
X8(2,N)=(-DY(1)*ST+RT*Y(3)*Y(3))/32.2
X8(3,N)=(RH*DY(2)+DY(1)*CH+RN*(DY(3)*(CH*CT+SH*ST)+Y(3)
```

```
     &*Y(3)*(SH*CT-CH*ST)))/32.2
      X8(4,N)=(RH*Y(2)*Y(2)+RN*(Y(3)*Y(3)*(SH*ST+CH*CT)-DY(3)
     &*(SH*CT-CH*ST))-DY(1)*SH)/32.2
      X9(1,N)=GST
      X9(2,N)=RROLL
      X9(3,N)=XONE
      X9(4,N)=YONE
      X9(5,N)=WRB
      X9(6,N)=WURB
      CRGS(N)=SQRT(X8(1,N)**2+X8(2,N)**2)
      THIC(N)=(N*PINT2)**0.6
      HRGS(N)=SQRT(X8(3,N)**2+X8(4,N)**2)
      X10(1,N)=CRGS(N)
      X10(2,N)=HRGS(N)
      X10(3,N)=GST
      X10(4,N)=FKNEE*COS(THEF)/2.
      X10(5,N)=((VRBGH-VCGH)*COS(THETAT)+(VRBGV-VCGV)*SIN(THETAT))/F
      X10(6,N)=RG1
      X11(1,N)=Y(7)*D
      X11(2,N)=Y(6)*D
      X11(3,N)=THEF*D
      X11(4,N)=-VSC/F
      X11(5,N)=(Y(5)-Y(8))*F
      X11(6,N)=-DRC
      RETURN
      END
C
      SUBROUTINE UPDATE(X,Y,DY)
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      COMMON/KNEEREST/NKR,SKR,RUT,RELKR,KRN(2,24)
      COMMON/SEATFRIC/NSF,SUN,SFUT,RELSF,SFN(2,24)
      SFUT=RELSF
      RUT=RELKR
      RETURN
      END
```

Appendix E

PAC Sample Run

PAC SAMPLE RUN - FULL LIST OF OUTPUT

```
READY
RUN


PAC           16:04EDT     09/08/82


INPUT FILE NAME?TRCST7P

ENTER 1 IF YOU WANT FULL LIST OF OUTPUT; ENTER 2 IF YOU WANT ABBREVIATED LIST.?1



INPUT VALUES -- INPUT UNITS( MSEC, MPH, DEGREES, INCHES, LBS, FT-LBS, G'S)
INITIAL VELOCITY:          34.0
INITIAL HEAD ANGLE:         -9.50
INITIAL TORSO ANGLE:         -27.5
      MLEG      MTORSO     MSTERN     MHEAD      RT         RN         RH         RTOPH
      71.0      58.4       2.50       11.4       14.0       20.5       4.75       28.7
     NPTS NECK  NPTS KR   NPTS VEH   NPTS SEAT NPTS GAS SL.ST     SL.KR
        3          8         18          6          14 0.500E+04 0.240E+04
     NPTS STER NPTS CHST
        5          5
GAS FLOW TIME
        0.       15.0       18.0       22.0       25.0       30.0       35.0       40.0
      45.0       50.0
GAS FLOW TIME
      55.0       60.0       75.5       100.
GAS FLOW - LB/SEC
        0.         0.       3.40       3.90       7.54       8.09       7.50       5.87
      4.00       2.54
GAS FLOW - LB/SEC
      1.49      0.820         0.         0.
```

```
SEAT FRICTION DISPLACEMENT
      -50.0        0.       1.00       14.0       15.0       50.0
SEAT FRICTION FORCE - LBS
        0.         0.       350.       350.        0.         0.
NECK ANGLE
      -81.0       18.0      90.0
NECK TORQUE - FT-LBS
       117.        0.      -87.0
VEH. PULSE - TIME
        0.        7.00      17.0       21.0       26.0       33.0       45.0       52.0
       54.0       58.0
VEH. PULSE - TIME
       65.0       70.0      76.0       80.0       90.0       93.0       107.       150.
VEH. PULSE - DECELERATION
        0.         0.       13.3       12.7       15.6       10.7       18.3       29.8
       30.7       29.8
VEH. PULSE - DECELERATION
       21.3       23.2      17.8       19.5       11.7       12.6        0.         0.
KNEE DISPLACEMENT
        0.        2.00      2.50       2.75       3.00       3.50       4.50       15.0
KNEE FORCE - LBS
        0.         0.       200.       700.  0.180E+04  0.230E+04  0.250E+04  0.270E+04
STERNUM DISPLACEMENT
      -50.0        0.      0.250       1.00       10.0
STERNUM FORCE - LBS
        0.         0.       400.  0.160E+04  0.250E+05
CHEST DISPLACEMENT
      -11.2      -1.25        0.       1.25       11.2
CHEST FORCE - LBS
 -0.465E+04      -150.        0.       150.  0.465E+04
      ATMOP        PGZ       GTZ          U        PN1        PN2        PN3
       14.7         0. 0.166E+04       662.       1.40       1.40       1.40
        VC1        VC2        AV        FSA        FSB        FSC         X1         Y1
      0.700      0.700      4.00       13.0       2.00       11.0       13.4       24.5
         A0     THETAD    FABWGT     STDAMP      CDAMP        DMS       DINF      WSDCK
       9.50         0.      8.40         0.       3.00       6.00       4.00       13.0
         WH     DROLLZ       X2Z        Y2Z         WB         LF        DCN
       6.10       5.00      31.7       8.38       18.4       16.7         0.
       THFD       THLD     XSTOP       STEP      PINT1      PINT2
       19.0       44.0     0.150  0.100E-02  0.500E-02  0.500E-02
```

TIME (MS)	VEH G'S (G'S)	VEH VEL (FPS)	VEH DISP (INCHES)	CHEST BP (INCHES)	CWA FORCE (LBS)	CPR FORCE (LBS)
0.	0.	49.87	0.	0.	0.	0.
5.00	0.	49.87	2.99	0.	0.	0.
10.00	-3.99	49.68	5.98	0.	0.	0.
15.00	-10.64	48.50	8.93	0.	0.	0.
20.00	-12.85	46.46	11.78	0.	0.	0.
25.00	-15.02	44.27	14.51	0.	0.	0.
30.00	-12.80	41.94	17.09	0.	0.	0.
35.00	-11.97	40.08	19.55	0.	0.	0.
40.00	-15.13	37.90	21.89	0.	0.	0.
45.00	-18.30	35.21	24.09	0.	0.	0.
50.00	-26.51	31.60	26.10	1.73	6.88	117.53
55.00	-30.47	26.85	27.86	3.63	35.89	280.99
60.00	-27.37	22.10	29.32	4.74	118.67	709.89
65.00	-21.30	18.18	30.53	5.96	239.22	1138.60
70.00	-23.20	14.60	31.51	7.20	398.04	1569.15
75.00	-18.70	11.22	32.28	8.40	580.49	1959.47
80.00	-19.50	8.24	32.87	9.47	758.43	2267.71
85.00	-15.60	5.41	33.27	10.33	897.65	2459.84
90.00	-11.70	3.21	33.53	10.88	949.36	2469.65
95.00	-10.80	1.29	33.66	11.06	886.55	2269.25
100.00	-6.30	-0.09	33.69	10.84	727.42	1899.16
105.00	-1.80	-0.74	33.67	10.28	517.78	1425.70
110.00	0.	-0.80	33.62	9.44	307.12	920.54
115.00	0.	-0.80	33.57	8.43	131.59	441.82
120.00	0.	-0.80	33.52	7.34	10.86	41.86
125.00	0.	-0.80	33.47	6.25	0.	0.
130.00	0.	-0.80	33.43	5.19	0.	0.
135.00	0.	-0.80	33.38	4.15	0.	0.
140.00	0.	-0.80	33.33	3.13	0.	0.
145.00	0.	-0.80	33.28	2.09	0.	0.
150.00	0.	-0.80	33.23	1.05	0.	0.

TIME (MS)	H-P R.D. (INCHES)	H-P VEL (FPS)	SEAT FR. (LBS)	FEM FORCE (LBS)	FEM ANG (DEG)	TIB ANG (DEG)
=======	=======	=======	=======	=======	=======	=======
0.	0.	49.87	0.	0.	19.00	44.00
5.00	0.00	49.87	0.03	0.	19.00	44.00
10.00	0.00	49.88	1.02	0.	19.00	44.00
15.00	0.05	49.88	15.82	0.	19.00	44.00
20.00	0.19	49.82	65.24	0.	19.00	44.00
25.00	0.45	49.64	156.55	0.	19.00	44.00
30.00	0.83	49.26	291.04	0.	19.00	44.00
35.00	1.31	48.64	350.00	0.	19.00	44.00
40.00	1.87	48.00	350.00	0.	19.72	44.80
45.00	2.53	47.27	350.00	52.66	21.46	46.76
50.00	3.33	45.98	350.00	546.25	23.40	49.00
55.00	4.21	41.86	350.00	1039.22	25.42	51.42
60.00	5.10	36.36	350.00	1079.40	27.30	53.74
65.00	5.90	30.26	350.00	1096.31	28.89	55.79
70.00	6.53	23.65	350.00	1087.19	30.09	57.38
75.00	6.97	16.58	350.00	1080.92	30.89	58.47
80.00	7.16	9.15	350.00	1078.24	31.23	58.93
85.00	7.07	1.77	0.	1013.60	31.08	58.73
90.00	6.73	-4.33	0.	763.74	30.47	57.89
95.00	6.20	-8.60	0.	364.84	29.48	56.56
100.00	5.59	-10.29	0.	0.	28.29	55.01
105.00	4.98	-10.91	0.	0.	27.06	53.44
110.00	4.36	-11.32	0.	0.	25.74	51.81
115.00	3.73	-11.40	0.	0.	24.33	50.10
120.00	3.09	-11.33	0.	0.	22.84	48.35
125.00	2.46	-11.32	0.	0.	21.28	46.55
130.00	1.83	-11.39	0.	0.	19.62	44.68
135.00	1.19	-11.49	0.	0.	19.00	44.00
140.00	0.54	-11.61	0.	0.	19.00	44.00
145.00	-0.11	-11.73	0.	0.	19.00	44.00
150.00	-0.77	-11.85	0.	0.	19.00	44.00

TIME (MS) =======	TORSO DISP (INCHES) =======	TORSO ANG (DEG) =======	TORSO VEL (D/SEC) =======	TORSO ACC (D/SEC**2) =======	TORSO R.D. (INCHES) =======	TORSO R.V. (FPS) =======
0.	0.00	-27.50	0.	-0.00	0.00	0.
5.00	2.99	-27.50	-0.79	51.90	-0.00	-0.01
10.00	5.98	-27.51	-0.65	254.78	0.00	0.19
15.00	8.98	-27.51	0.25	474.63	0.04	1.38
20.00	11.97	-27.50	3.32	1185.41	0.19	3.42
25.00	14.96	-27.46	11.42	2521.94	0.45	5.58
30.00	17.95	-27.37	27.65	4505.57	0.86	7.81
35.00	20.93	-27.17	53.14	5555.91	1.38	9.52
40.00	23.90	-26.84	80.43	5658.37	2.01	11.56
45.00	26.87	-26.37	103.36	118.58	2.78	13.95
50.00	29.78	-25.86	102.57	9245.36	3.66	16.26
55.00	32.60	-25.09	228.30	36541.22	4.74	19.22
60.00	35.30	-23.50	400.81	31200.80	5.98	21.75
65.00	37.84	-21.13	543.78	24811.53	7.31	22.41
70.00	40.15	-18.12	651.42	17462.42	8.64	21.65
75.00	42.17	-14.68	721.33	9534.02	9.88	19.56
80.00	43.82	-10.98	750.57	1658.07	10.95	15.92
85.00	45.05	-7.24	738.24	-13531.32	11.77	11.15
90.00	45.80	-3.81	628.00	-28820.01	12.27	5.22
95.00	46.06	-1.10	441.23	-49069.26	12.40	-0.90
100.00	45.86	0.44	161.80	-59609.24	12.16	-6.91
105.00	45.26	0.60	-82.60	-40383.29	11.59	-11.65
110.00	44.38	-0.26	-250.69	-29541.17	10.76	-15.63
115.00	43.31	-1.84	-368.93	-15981.09	9.74	-19.10
120.00	42.14	-3.83	-416.93	-2957.77	8.62	-19.00
125.00	40.95	-5.93	-418.77	963.08	7.48	-19.00
130.00	39.77	-8.00	-410.48	2326.03	6.34	-18.87
135.00	38.60	-10.02	-396.59	3178.04	5.22	-19.64
140.00	37.44	-11.97	-379.56	3582.03	4.11	-18.37
145.00	36.30	-13.82	-361.28	3697.72	3.01	-18.07
150.00	35.17	-15.58	-342.78	3685.19	1.94	-17.77

TIME (MS)	HEAD DISP (INCHES)	HEAD ANG (DEG)	HEAD VEL (I/SEC)	HEAD ACC (I/SEC**2)	HEAD R.D. (INCHES)	HEAD R.ANG (DEG)
0.	0.00	-9.50	0.	0.00	0.00	18.00
5.00	2.99	-9.49	3.24	789.89	0.00	18.01
10.00	5.99	-9.47	4.23	-55.56	0.00	18.03
15.00	8.98	-9.45	3.60	-159.11	0.05	18.05
20.00	11.97	-9.44	2.56	-268.43	0.19	18.06
25.00	14.97	-9.43	0.47	-937.45	0.46	18.04
30.00	17.97	-9.44	-4.70	-1790.78	0.88	17.93
35.00	20.97	-9.49	-17.52	-3459.50	1.42	17.68
40.00	23.96	-9.62	-36.63	-4095.67	2.07	17.21
45.00	26.95	-9.85	-39.13	20350.08	2.86	16.52
50.00	29.94	-9.65	157.21	53846.73	3.84	16.21
55.00	32.93	-8.41	292.69	-4189.67	5.08	16.68
60.00	35.92	-6.95	303.78	12034.81	6.60	16.55
65.00	38.85	-5.25	375.30	12670.96	8.32	15.88
70.00	41.64	-3.28	394.01	-9000.61	10.13	14.84
75.00	44.18	-1.54	290.05	-27069.34	11.90	13.14
80.00	46.33	-0.46	135.85	-34504.37	13.46	10.52
85.00	47.99	-0.24	-57.08	-36072.19	14.72	7.00
90.00	49.07	-0.91	-201.72	-20665.48	15.55	2.90
95.00	49.55	-2.08	-206.55	46757.31	15.89	-0.99
100.00	49.49	-2.43	101.18	81679.80	15.79	-2.87
105.00	48.99	-1.41	271.18	22073.70	15.33	-2.00
110.00	48.15	0.22	385.36	58489.83	14.53	0.48
115.00	47.13	2.92	676.51	45691.58	13.56	4.76
120.00	46.05	6.77	841.72	17220.70	12.53	10.60
125.00	44.98	11.09	865.81	-4922.37	11.51	17.02
130.00	43.90	15.30	808.17	-18139.43	10.48	23.30
135.00	42.80	19.07	691.26	-28395.43	9.42	29.09
140.00	41.66	22.14	530.27	-35715.52	8.33	34.10
145.00	40.48	24.32	338.71	-40633.47	7.20	38.14
150.00	39.26	25.49	127.31	-43682.26	6.02	41.07

TIME (MS)	R BAG ACC (G'S)	RBV WR GND (FPS)	RBV WR CST (FPS)	RBV WR DSH (FPS)	RBD WR GND (INCHES)	RBD WR DSH (INCHES)
0.	0.	49.87	0.	0.00	-4.00	-4.00
5.00	0.	49.87	0.00	0.00	-1.01	-4.00
10.00	-3.99	49.68	-0.20	-0.00	1.98	-4.00
15.00	-10.64	48.50	-1.38	0.00	4.93	-4.00
20.00	-571.90	4.15	-45.71	-4[illegible].31	7.03	-4.75
25.00	-879.41	-135.13	-184.94	-179.40	2.85	-11.65
30.00	-3793.64	-69.18	-118.98	-111.12	-1.62	-18.71
35.00	-11.97	40.09	-9.76	0.00	-2.76	-22.32
40.00	-15.13	37.90	-11.95	0.00	-0.43	-22.32
45.00	1378.22	35.21	-14.49	-0.00	1.98	-22.11
50.00	-511.36	43.77	-4.64	12.17	4.73	-21.37
55.00	1.54	47.22	0.	20.37	7.19	-19.60
60.00	-6.20	45.76	0.	23.67	9.98	-18.20
65.00	-15.13	43.01	0.	24.83	12.64	-16.63
70.00	-24.63	38.92	0.	24.32	15.10	-15.05
75.00	-34.41	33.49	0.	22.27	17.26	-13.57
80.00	-43.38	26.75	0.	18.52	19.06	-12.30
85.00	-50.19	18.94	0.	12.53	20.41	-11.31
90.00	-53.54	10.40	0.	7.18	21.26	-10.68
95.00	-53.99	1.75	0.	0.46	21.60	-10.45
100.00	-48.07	-6.50	0.	-6.41	21.43	-10.64
105.00	-33.45	-12.85	0.	-12.11	20.82	-11.20
110.00	-23.17	-17.20	0.	-16.40	19.90	-12.07
115.00	-12.15	-20.05	0.	-19.25	18.76	-13.14
120.00	-2.02	-21.11	0.	-20.31	17.51	-14.34
125.00	0.39	-21.14	0.	-20.34	16.25	-15.57
130.00	1.13	-21.01	0.	-20.21	14.99	-16.79
135.00	1.62	-20.79	0.	-19.99	13.73	-18.01
140.00	1.88	-20.51	0.	-19.71	12.49	-19.22
145.00	1.99	-20.20	0.	-19.40	11.27	-20.43
150.00	2.03	-19.88	0.	-19.08	10.07	-21.61

TIME (MS) =======	U BAG ACC (G'S) =======	UBV WR GND (FPS) =======	UBV WR CST (FPS) =======	UBV WR DSH (FPS) =======	UBD WR GND (INCHES) =======	UBD WR DSH (INCHES) =======
0.	0.	49.87	0.	0.00	-4.00	-4.00
5.00	0.	49.87	0.00	0.00	-1.01	-4.00
10.00	-3.99	49.68	-0.20	-0.00	1.98	-4.00
15.00	-10.64	48.50	-1.38	0.00	4.93	-4.00
20.00	-571.90	4.15	-45.71	-42.31	7.03	-4.75
25.00	-304.68	-46.07	-95.88	-90.33	5.56	-8.94
30.00	-1150.44	7.84	-41.96	-34.11	4.91	-12.18
35.00	-740.53	35.44	-14.40	-4.64	3.57	-15.98
40.00	-865.61	25.74	-24.11	-12.16	3.70	-18.19
45.00	-714.19	5.00	-44.70	-30.21	4.29	-19.79
50.00	-486.14	-5.62	-54.03	-37.22	4.94	-21.16
55.00	-30.47	26.85	-20.37	-0.00	5.82	-22.04
60.00	-27.37	22.10	-23.67	-0.00	7.27	-22.05
65.00	-21.30	18.18	-24.83	-0.00	8.46	-22.06
70.00	-23.20	14.60	-24.32	0.00	9.44	-22.07
75.00	-18.70	11.22	-22.27	0.00	10.20	-22.08
80.00	-19.50	8.24	-18.52	0.00	10.77	-22.09
85.00	-15.60	5.41	-13.53	0.00	11.17	-22.10
90.00	-11.70	3.21	-7.18	0.00	11.42	-22.11
95.00	-10.80	1.29	-0.46	-0.00	11.55	-22.11
100.00	-6.30	-0.09	6.41	-0.00	11.58	-22.12
105.00	-1.80	-0.74	12.11	0.00	11.55	-22.12
110.00	0.	-0.80	16.40	0.00	11.50	-22.12
115.00	0.	-0.80	19.25	0.00	11.45	-22.12
120.00	0.	-0.80	20.31	0.00	11.40	-22.12
125.00	0.	-0.80	20.34	0.00	11.35	-22.12
130.00	0.	-0.80	20.21	0.00	11.31	-22.12
135.00	0.	-0.80	19.99	0.00	11.26	-22.12
140.00	0.	-0.80	19.71	0.00	11.21	-22.12
145.00	0.	-0.80	19.40	0.00	11.16	-22.12
150.00	0.	-0.80	19.08	0.00	11.11	-22.12

TIME (MS)	CST F BSP (LBS)	STN F BSP (LBS)	STV WR CST (FPS)	RLD WR STN (INCHES)	STD WR CST (INCHES)	DTORSO (INCHES)
0.	0.00	0.	0.	0.	-0.00	24.74
5.00	-14.74	0.	0.38	0.	0.01	24.59
10.00	-18.79	0.	0.42	0.	0.03	24.59
15.00	-19.00	0.	0.36	0.	0.05	24.55
20.00	-19.17	0.	0.31	0.	0.07	24.53
25.00	-18.52	0.	0.25	0.	0.08	24.42
30.00	-17.41	0.	0.20	0.	0.08	23.82
35.00	-16.34	0.	0.17	0.	0.08	23.20
40.00	-16.29	0.	0.16	0.	0.09	22.55
45.00	200.20	451.22	-5.53	-0.28	-0.01	21.78
50.00	223.78	66.10	-4.80	-0.04	-0.43	20.85
55.00	0.	0.	0.	0.	0.	19.60
60.00	0.	0.	0.	0.	0.	18.20
65.00	0.	0.	0.	0.	0.	16.63
70.00	0.	0.	0.	0.	0.	15.05
75.00	0.	0.	0.	0.	0.	13.57
80.00	0.	0.	0.	0.	0.	12.30
85.00	0.	0.	0.	0.	0.	11.31
90.00	0.	0.	0.	0.	0.	10.68
95.00	0.	0.	0.	0.	0.	10.45
100.00	0.	0.	0.	0.	0.	10.64
105.00	0.	0.	0.	0.	0.	11.20
110.00	0.	0.	0.	0.	0.	12.07
115.00	0.	0.	0.	0.	0.	13.14
120.00	0.	0.	0.	0.	0.	14.34
125.00	0.	0.	0.	0.	0.	15.57
130.00	0.	0.	0.	0.	0.	16.79
135.00	0.	0.	0.	0.	0.	18.01
140.00	0.	0.	0.	0.	0.	19.22
145.00	0.	0.	0.	0.	0.	20.43
150.00	0.	0.	0.	0.	0.	21.61

TIME (MS)	HEAD BP. (INCHES)	BAG VOL. (CU. IN.)	BAG PRESS. (PSIG)	HW/A FORCE (LBS)	HP FORCE (LBS)	INT. VOL (CU. IN.)
0.	0.	412.28	0.	0.	0.	0.
5.00	0.	412.28	0.	0.	0.	0.
10.00	0.	412.40	0.	0.	0.	0.
15.00	0.	413.07	-0.03	0.	0.	0.
20.00	0.	554.32	11.99	0.	0.	0.
25.00	0.	1719.61	2.81	0.	0.	0.
30.00	0.	3097.23	5.34	0.	0.	0.
35.00	0.	5290.75	1.73	0.	0.	0.
40.00	0.	6864.94	1.40	0.	0.	0.
45.00	0.	8149.05	0.90	0.	0.	0.
50.00	0.	9063.26	0.49	0.	0.	281.12
55.00	0.65	9315.43	0.92	1.21	15.23	843.00
60.00	1.57	8935.70	2.27	13.35	69.15	1236.13
65.00	2.69	8484.60	3.61	49.07	147.93	1698.27
70.00	3.93	8006.10	4.94	115.45	238.56	2187.07
75.00	5.31	7539.76	6.17	203.02	310.26	2662.91
80.00	6.62	7137.58	7.14	292.98	359.10	3073.68
85.00	7.71	6835.65	7.73	370.11	389.06	3383.56
90.00	8.54	6664.39	7.74	410.49	389.63	3561.00
95.00	9.00	6636.95	7.09	396.50	356.92	3593.88
100.00	8.95	6739.05	5.92	329.17	297.93	3495.63
105.00	8.35	6949.04	4.45	230.58	223.75	3287.37
110.00	7.37	7245.43	2.88	131.70	144.83	2991.09
115.00	6.17	7603.62	1.39	53.23	69.93	2632.90
120.00	4.96	7991.90	0.13	4.10	6.69	2244.62
125.00	3.88	8383.11	0.	0.	0.	1853.42
130.00	2.95	8767.41	0.	0.	0.	1469.12
135.00	2.12	9140.45	0.	0.	0.	1096.08
140.00	1.33	9497.50	0.	0.	0.	739.02
145.00	0.47	9831.51	0.	0.	0.	405.02
150.00	0.	10094.87	0.	0.	0.	141.65

TIME (MS)	CHEST AP (G'S)	CHEST SI (G'S)	HEAD AP (G'S)	HEAD SI (G'S)		
=======	=======	=======	=======	=======	=======	=======
0.	-0.00	-0.00	-0.00	0.00		
5.00	0.22	0.10	0.42	0.02		
10.00	0.31	0.08	0.38	-0.05		
15.00	0.31	0.00	0.39	-0.14		
20.00	0.27	-0.25	0.45	-0.43		
25.00	0.19	-0.73	0.48	-0.98		
30.00	0.09	-1.42	0.52	-1.78		
35.00	0.02	-1.73	0.36	-2.15		
40.00	0.10	-1.69	0.32	-2.10		
45.00	-4.36	-2.02	-0.36	-0.71		
50.00	-8.38	-6.81	4.26	-4.82		
55.00	-6.17	-13.13	-0.22	-13.31		
60.00	-13.56	-12.70	-5.02	-9.79		
65.00	-21.46	-11.09	-13.54	-4.81		
70.00	-29.55	-8.60	-27.18	0.62		
75.00	-37.71	-5.71	-40.49	5.28		
80.00	-45.07	-2.73	-51.21	8.37		
85.00	-49.97	0.67	-60.76	9.96		
90.00	-51.08	2.16	-63.69	7.34		
95.00	-49.38	1.80	-53.80	1.86		
100.00	-41.91	0.32	-41.84	-2.48		
105.00	-28.91	0.11	-36.00	-1.00		
110.00	-20.27	0.69	-16.38	1.81		
115.00	-10.13	1.50	-4.79	5.13		
120.00	-1.41	1.95	1.98	5.86		
125.00	0.38	1.91	0.35	5.31		
130.00	0.93	1.78	-1.36	4.24		
135.00	1.32	1.61	-2.94	2.81		
140.00	1.53	1.43	-4.31	1.40		
145.00	1.62	1.26	-5.40	0.28		
150.00	1.66	1.11	-6.18	-0.45		

TIME (MS)	STN ACC (G'S)	ROLL RAD (INCHES)	XC B CTR (INCHES)	YC B CTR (INCHES)	WRB (LBS)	WURB (LBS)
0.	0.00	18.17	17.35	24.50	0.86	0.22
5.00	-5.90	18.17	17.35	24.50	0.85	0.22
10.00	-7.51	18.17	17.35	24.50	0.85	0.22
15.00	-7.60	18.17	17.35	24.50	0.85	0.22
20.00	-7.67	18.17	17.73	24.50	0.83	0.22
25.00	-7.41	18.17	19.82	24.50	0.62	0.19
30.00	-6.96	18.15	21.44	24.50	0.37	0.16
35.00	-6.54	18.12	23.34	24.50	0.26	0.13
40.00	-6.51	18.07	24.45	24.50	0.28	0.11
45.00	-100.41	18.03	25.25	24.50	0.29	0.10
50.00	63.07	18.10	25.93	24.50	0.33	0.09
55.00	1.70	17.80	26.37	24.50	0.39	0.08
60.00	-6.76	17.58	26.38	24.50	0.44	0.08
65.00	-16.22	17.28	26.38	24.50	0.49	0.08
70.00	-25.92	16.96	26.39	24.50	0.54	0.08
75.00	-35.57	16.66	26.39	24.50	0.59	0.09
80.00	-44.19	16.42	26.40	24.50	0.63	0.08
85.00	-50.59	16.25	26.40	24.50	0.66	0.09
90.00	-53.66	16.16	26.40	24.50	0.68	0.08
95.00	-54.00	16.12	26.41	24.50	0.69	0.09
100.00	-48.07	16.12	26.41	24.50	0.68	0.09
105.00	-33.45	16.12	26.41	24.50	0.66	0.09
110.00	-23.17	16.12	26.41	24.50	0.64	0.09
115.00	-12.16	16.13	26.41	24.50	0.60	0.09
120.00	-2.02	16.16	26.41	24.50	0.56	0.09
125.00	0.39	16.21	26.41	24.50	0.53	0.09
130.00	1.14	16.28	26.41	24.50	0.49	0.09
135.00	1.65	16.37	26.41	24.50	0.45	0.09
140.00	1.92	16.48	26.41	24.50	0.41	0.09
145.00	2.05	16.60	26.41	24.50	0.37	0.09
150.00	2.11	16.73	26.41	24.50	0.33	0.09

ENTER 1 TO CALCULATE HIC?1

THE HIC IS 6.1942641E+02
T1= 7.5000000E-02
T2= 1.1000000E-01

PROGRAM STOP AT 1950

PAC SAMPLE RUN - ABBREVIATED OUTPUT

```
RUN


PAC          16:23EDT    09/08/82


INPUT FILE NAME?TRCST7P

ENTER 1 IF YOU WANT FULL LIST OF OUTPUT; ENTER 2 IF YOU WANT ABBREVIATED LIST.?2




INPUT VALUES -- INPUT UNITS( MSEC, MPH, DEGREES, INCHES, LBS, FT-LBS, G'S)
INITIAL VELOCITY:          34.0
INITIAL HEAD ANGLE:          -9.50
INITIAL TORSO ANGLE:          -27.5
      MLEG      MTORSO     MSTERN      MHEAD       RT          RN          RH          RTOPH
      71.0       58.4       2.50       11.4       14.0        20.5        4.75         28.7
     NPTS NECK  NPTS KR  NPTS VEH  NPTS SEAT NPTS GAS SL.ST      SL.KR
        3          8         18          6          14 0.500E+04 0.240E+04
     NPTS STER NPTS CHST
        5          5
GAS FLOW TIME
        0.       15.0       18.0       22.0       25.0        30.0        35.0        40.0
      45.0       50.0
GAS FLOW TIME
      55.0       60.0       75.5       100.
GAS FLOW - LB/SEC
        0.         0.       3.40       3.90       7.54        8.09        7.50        5.87
      4.00       2.54
GAS FLOW - LB/SEC
      1.49      0.820         0.         0.
```

```
SEAT FRICTION DISPLACEMENT
     -50.0         0.       1.00       14.0       15.0       50.0
SEAT FRICTION FORCE - LBS
        0.         0.       350.       350.         0.         0.
NECK ANGLE
     -81.0       18.0       90.0
NECK TORQUE - FT-LBS
      117.         0.      -87.0
VEH. PULSE - TIME
        0.       7.00       17.0       21.0       26.0       33.0       45.0       52.0
      54.0       58.0
VEH. PULSE - TIME
      65.0       70.0       76.0       80.0       90.0       93.0       107.       150.
VEH. PULSE - DECELERATION
        0.         0.       13.3       12.7       15.6       10.7       18.3       29.8
      30.7       29.8
VEH. PULSE - DECELERATION
      21.3       23.2       17.8       19.5       11.7       12.6         0.         0.
KNEE DISPLACEMENT
        0.       2.00       2.50       2.75       3.00       3.50       4.50       15.0
KNEE FORCE - LBS
        0.         0.       200.       700. 0.180E+04 0.230E+04 0.250E+04 0.270E+04
STERNUM DISPLACEMENT
     -50.0         0.      0.250       1.00       10.0
STERNUM FORCE - LBS
        0.         0.       400. 0.160E+04 0.250E+05
CHEST DISPLACEMENT
     -11.2      -1.25         0.       1.25       11.2
CHEST FORCE - LBS
-0.465E+04      -150.         0.       150. 0.465E+04
     ATMOP        PGZ        GTZ          U        PN1        PN2        PN3
      14.7         0. 0.166E+04       662.       1.40       1.40       1.40
       VC1        VC2         AV        FSA        FSB        FSC         X1         Y1
     0.700      0.700       4.00       13.0       2.00       11.0       13.4       24.5
        A0     THETAD     FABWGT     STDAMP      CDAMP        DMS       DINF      WSOCK
      9.50         0.       8.40         0.       3.00       6.00       4.00       13.0
        WH     DROLLZ        X2Z        Y2Z         WB         LF        DCN
      6.10       5.00       31.7       8.38       18.4       16.7         0.
      THFO       THLO      XSTOP       STEP      PINT1      PINT2
      19.0       44.0      0.150  0.100E-02  0.500E-02  0.500E-02
```

TIME (MS)	CST R GS (G'S)	HD R GS (G'S)	STN ACC (G'S)	FEM FORCE (LBS)	RBV WR CST (FPS)	BAG PRESS (PSIG)
0.	0.00	0.00	0.00	0.	0.	0.
5.00	0.24	0.42	-5.90	0.	0.00	0.
10.00	0.32	0.38	-7.51	0.	-0.20	0.
15.00	0.31	0.41	-7.60	0.	-1.38	-0.03
20.00	0.37	0.62	-7.67	0.	-45.71	11.99
25.00	0.75	1.09	-7.41	0.	-184.94	2.81
30.00	1.42	1.86	-6.96	0.	-118.98	5.34
35.00	1.73	2.19	-6.54	0.	-9.76	1.73
40.00	1.69	2.12	-6.51	0.	-11.95	1.40
45.00	4.83	0.79	-100.41	52.66	-14.49	0.90
50.00	10.80	6.43	63.07	546.25	-4.64	0.49
55.00	14.50	13.31	1.70	1039.22	0.	0.92
60.00	18.58	11.00	-6.76	1079.40	0.	2.27
65.00	24.16	14.37	-16.22	1096.31	0.	3.61
70.00	30.77	27.19	-25.92	1087.19	0.	4.94
75.00	38.14	40.84	-35.57	1080.92	0.	6.17
80.00	45.15	51.89	-44.19	1078.24	0.	7.14
85.00	49.87	61.58	-50.59	1013.60	0.	7.73
90.00	51.13	64.11	-53.66	763.74	0.	7.74
95.00	49.42	53.83	-54.00	364.84	0.	7.09
100.00	41.91	41.91	-48.07	0.	0.	5.92
105.00	28.91	36.01	-33.45	0.	0.	4.45
110.00	20.28	16.48	-23.17	0.	0.	2.88
115.00	10.24	7.02	-12.16	0.	0.	1.39
120.00	2.41	6.19	-2.02	0.	0.	0.13
125.00	1.94	5.32	0.39	0.	0.	0.
130.00	2.01	4.45	1.14	0.	0.	0.
135.00	2.09	4.07	1.65	0.	0.	0.
140.00	2.10	4.53	1.92	0.	0.	0.
145.00	2.05	5.40	2.05	0.	0.	0.
150.00	1.99	6.20	2.11	0.	0.	0.

TIME (MS)	TORSO ANG (DEG)	HEAD ANG (DEG)	FEMUR ANG (DEG)	STV WR CST (FPS)	H-P R.D. (INCHES)	CHEST DEFL (INCHES)
0.	-27.50	-9.50	19.00	0.	0.	0.
5.00	-27.50	-9.49	19.00	0.38	0.00	0.
10.00	-27.51	-9.47	19.00	0.42	0.00	0.
15.00	-27.51	-9.45	19.00	0.36	0.05	0.
20.00	-27.50	-9.44	19.00	0.31	0.19	0.
25.00	-27.46	-9.43	19.00	0.25	0.45	0.
30.00	-27.37	-9.44	19.00	0.20	0.83	0.
35.00	-27.17	-9.49	19.00	0.17	1.31	0.
40.00	-26.84	-9.62	19.72	0.16	1.87	0.
45.00	-26.37	-9.85	21.46	-5.53	2.53	-0.29
50.00	-25.86	-9.65	23.40	-4.80	3.33	-0.47
55.00	-25.08	-8.41	25.42	0.	4.21	0.
60.00	-23.50	-6.95	27.30	0.	5.10	0.
65.00	-21.13	-5.25	28.69	0.	5.90	0.
70.00	-18.12	-3.29	30.09	0.	6.53	0.
75.00	-14.68	-1.54	30.89	0.	6.97	0.
80.00	-10.98	-0.46	31.23	0.	7.16	0.
85.00	-7.24	-0.24	31.08	0.	7.07	0.
90.00	-3.81	-0.91	30.47	0.	6.73	0.
95.00	-1.10	-2.08	29.48	0.	6.20	0.
100.00	0.44	-2.43	28.29	0.	5.59	0.
105.00	0.60	-1.41	27.06	0.	4.98	0.
110.00	-0.26	0.22	25.74	0.	4.36	0.
115.00	-1.84	2.92	24.37	0.	3.73	0.
120.00	-3.83	6.77	22.84	0.	3.09	0.
125.00	-5.93	11.09	21.28	0.	2.46	0.
130.00	-8.00	15.30	19.62	0.	1.83	0.
135.00	-10.02	19.07	19.00	0.	1.19	0.
140.00	-11.97	22.14	19.00	0.	0.54	0.
145.00	-13.82	24.32	19.00	0.	-0.11	0.
150.00	-15.58	25.49	19.00	0.	-0.77	0.

```
ENTER 1 TO CALCULATE HIC?1

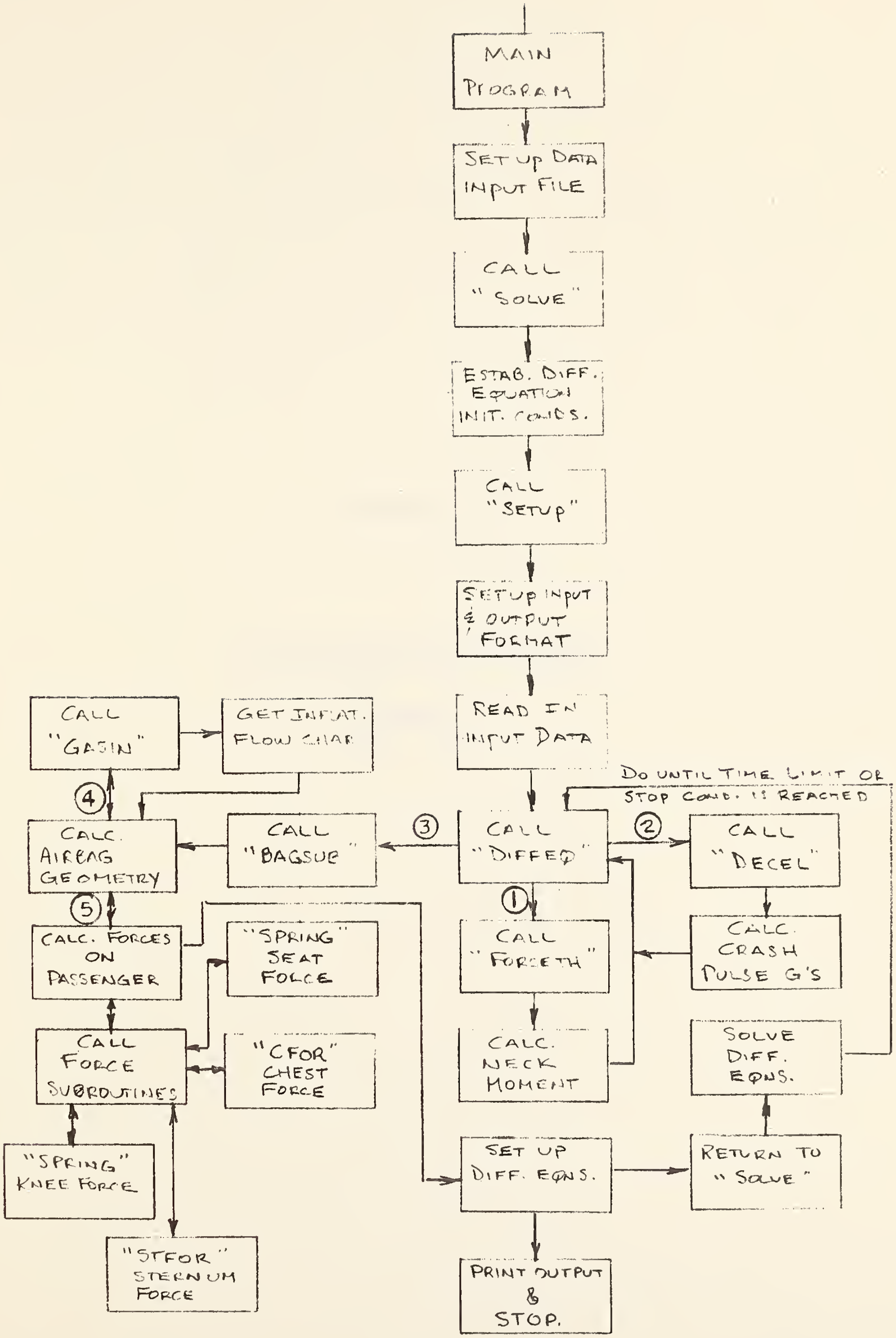
THE HIC IS    6.1942641E+02
T1=    7.5000000E-02
T2=    1.1000000E-01

PROGRAM STOP AT 1950
```

APPENDIX F

PAC Computer Program

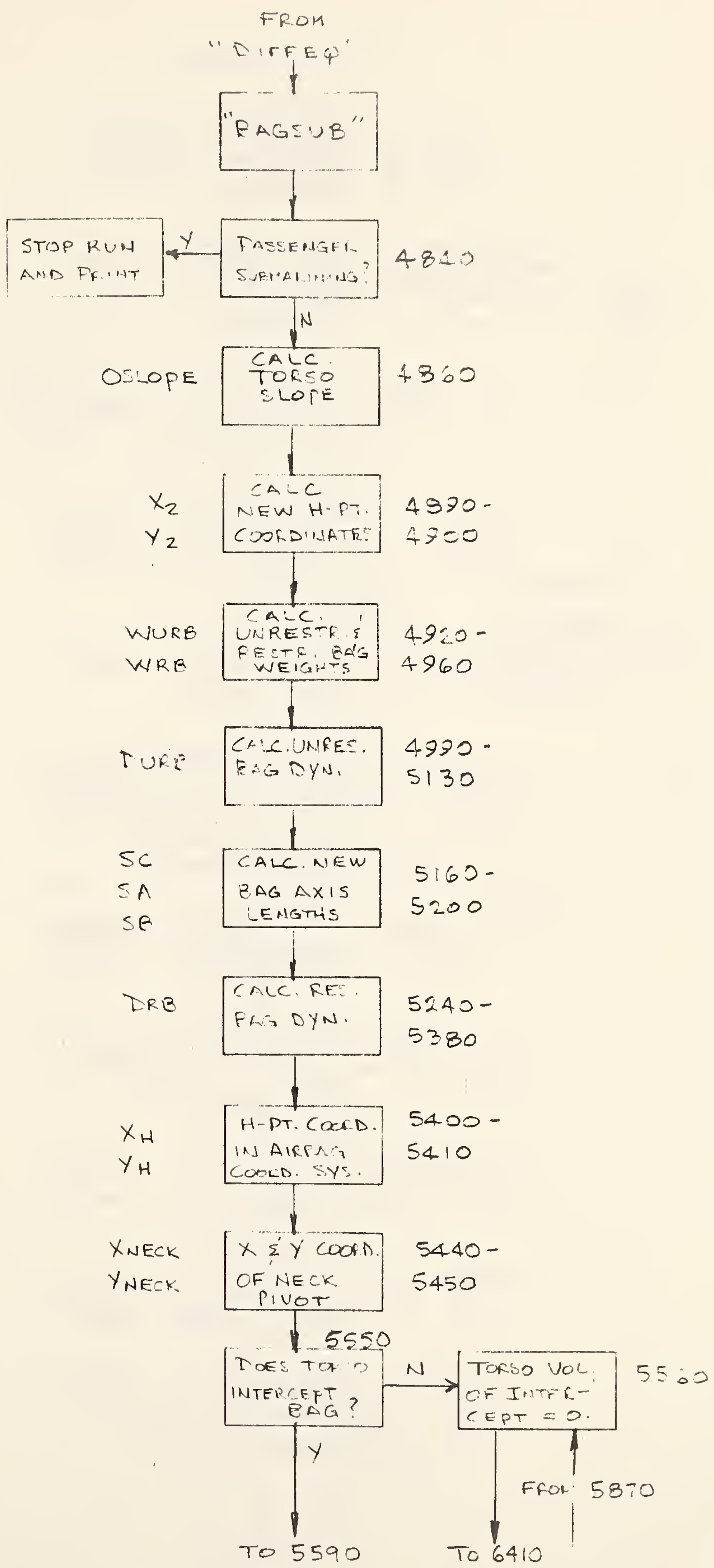
Overall Flow Chart

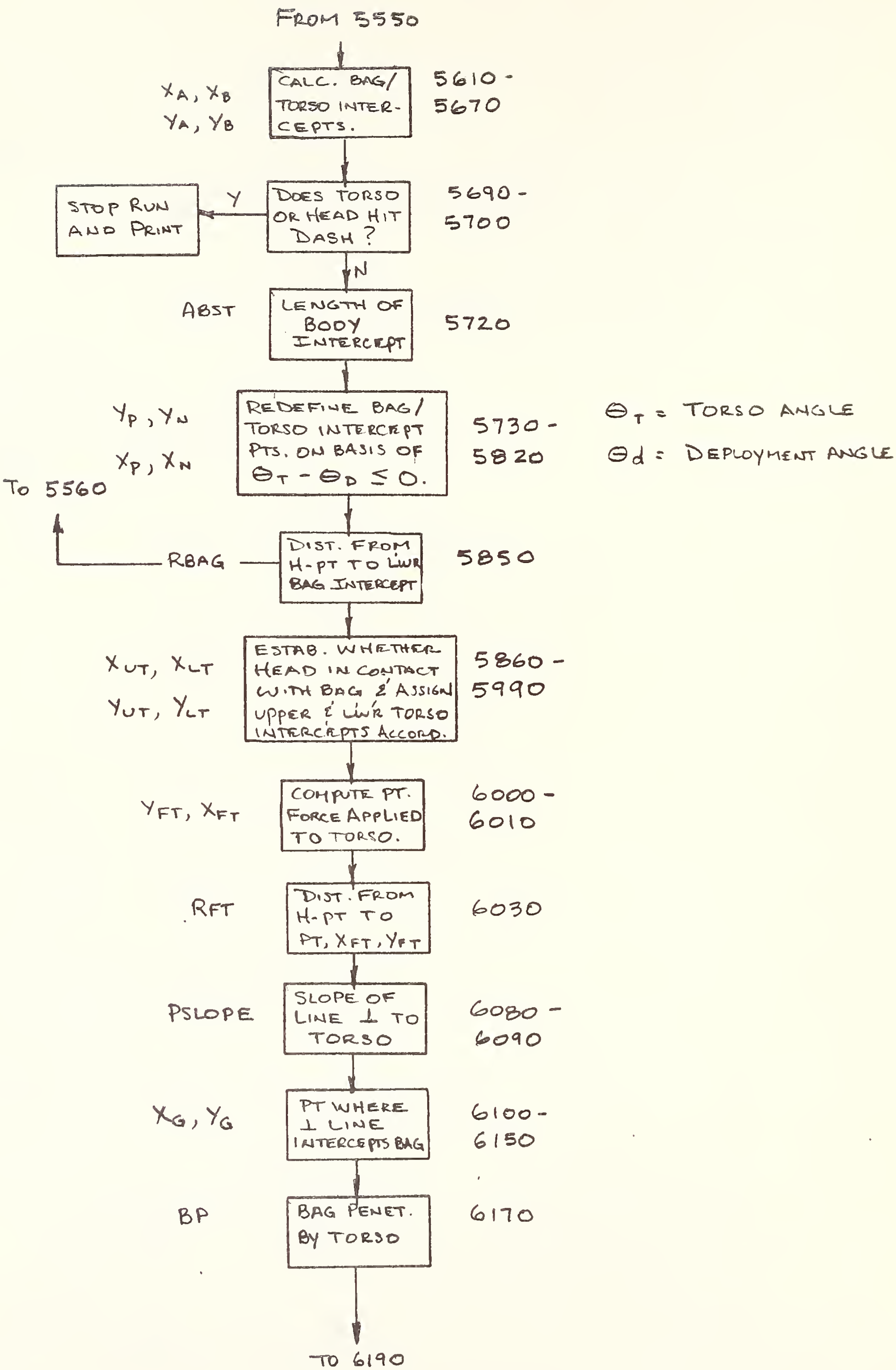

MAIN PROGRAM
SET UP DATA INPUT FILE
CALL "SOLVE"
ESTAB. DIFF. EQUATION INIT. CONDS.
CALL "SETUP"
SETUP INPUT & OUTPUT FORMAT
READ IN INPUT DATA
DO UNTIL TIME LIMIT OR STOP COND. IS REACHED
CALL "DIFFEQ"
CALL "DECEL"
CALC. CRASH PULSE G'S
SOLVE DIFF. EQNS.
CALL "FORCETH"
CALC. NECK MOMENT
SET UP DIFF. EQNS.
RETURN TO "SOLVE"
PRINT OUTPUT & STOP.
CALL "BAGSUB"
CALC. AIRBAG GEOMETRY
CALL "GASIN"
GET INFLAT. FLOW CHAR
CALC. FORCES ON PASSENGER
"SPRING" SEAT FORCE
CALL FORCE SUBROUTINES
"CFOR" CHEST FORCE
"SPRING" KNEE FORCE
"STFOR" STERNUM FORCE
1
2
3
4
5

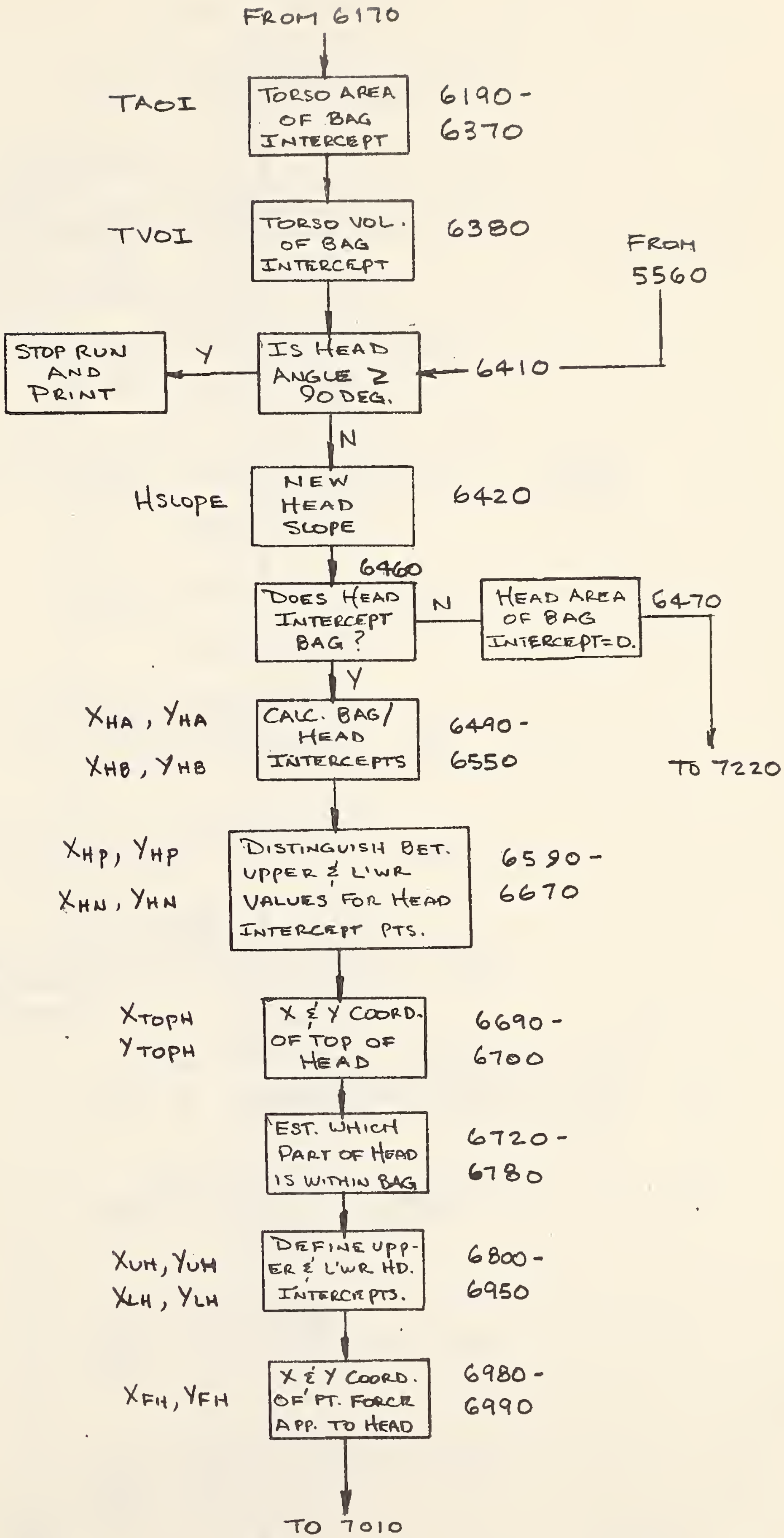
APPENDIX G

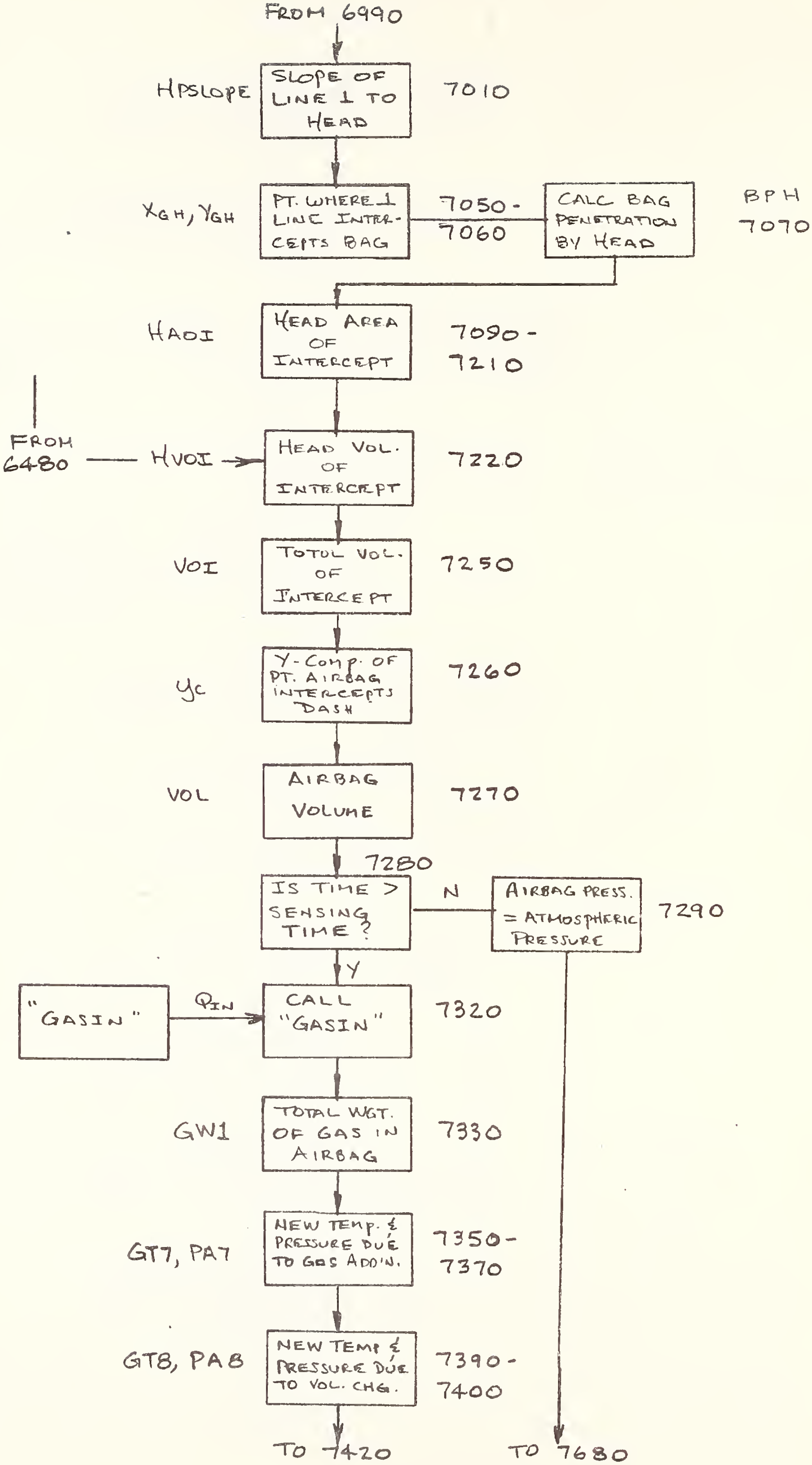
PAC Subroutine "BAGSUB"

Flowchart

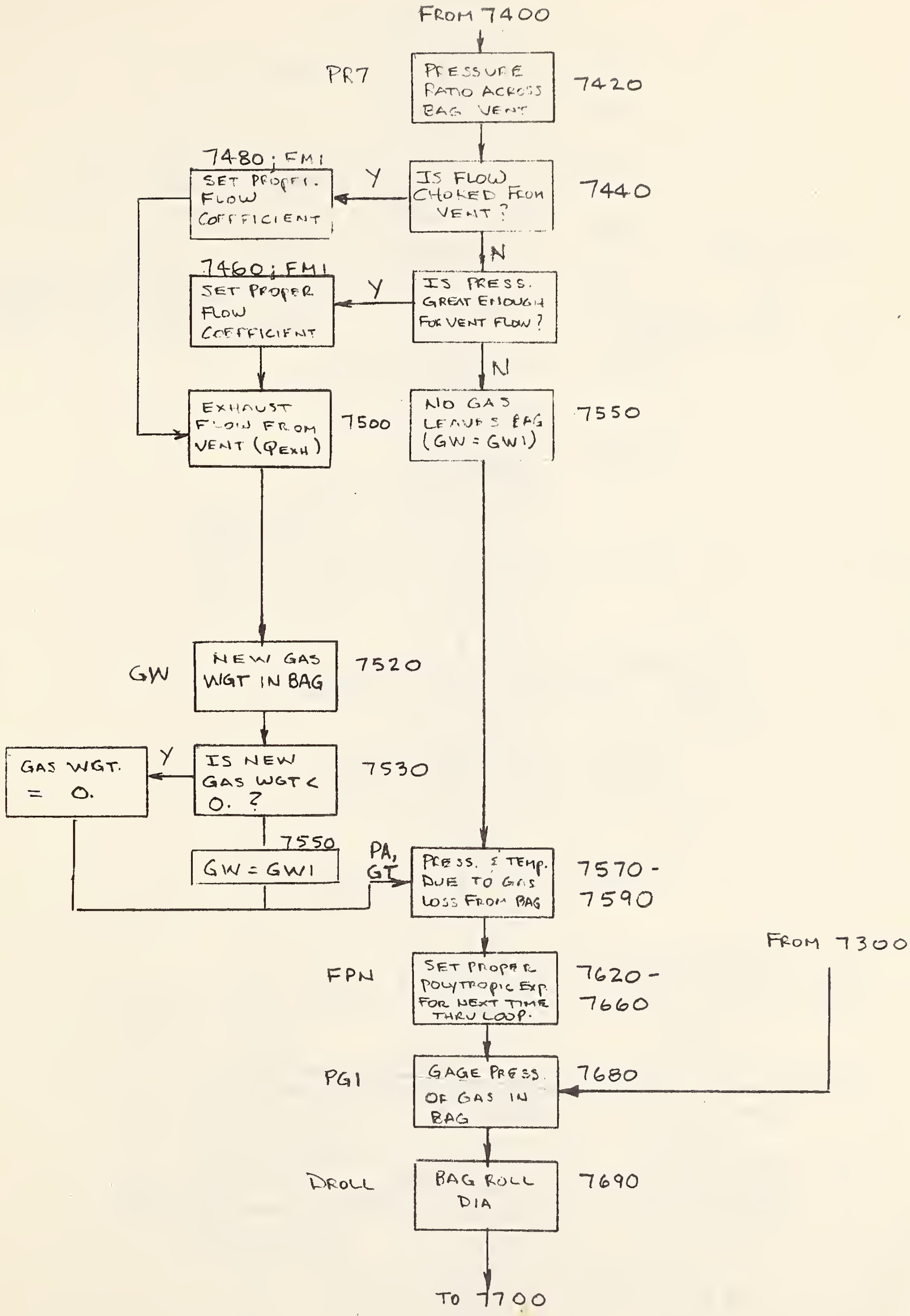

FROM "DIFFEQ"
"BAGSUB"
STOP RUN AND PRINT
Y
PASSENGER SUBMARINING?
4810
N
OSLOPE
CALC. TORSO SLOPE
4860
X2
Y2
CALC NEW H-PT. COORDINATES
4890-4900
WURB
WRB
CALC. UNRESTR. & RESTR. BAG WEIGHTS
4920-4960
DURB
CALC. UNRES. BAG DYN.
4990-5130
SC
SA
SB
CALC. NEW BAG AXIS LENGTHS
5160-5200
DRB
CALC. RES. BAG DYN.
5240-5380
XH
YH
H-PT. COORD. IN AIRBAG COORD. SYS.
5400-5410
XNECK
YNECK
X & Y COORD. OF NECK PIVOT
5440-5450
5550
DOES TORSO INTERCEPT BAG?
N
TORSO VOL. OF INTERCEPT = 0.
5560
Y
FROM 5870
TO 5590
TO 6410

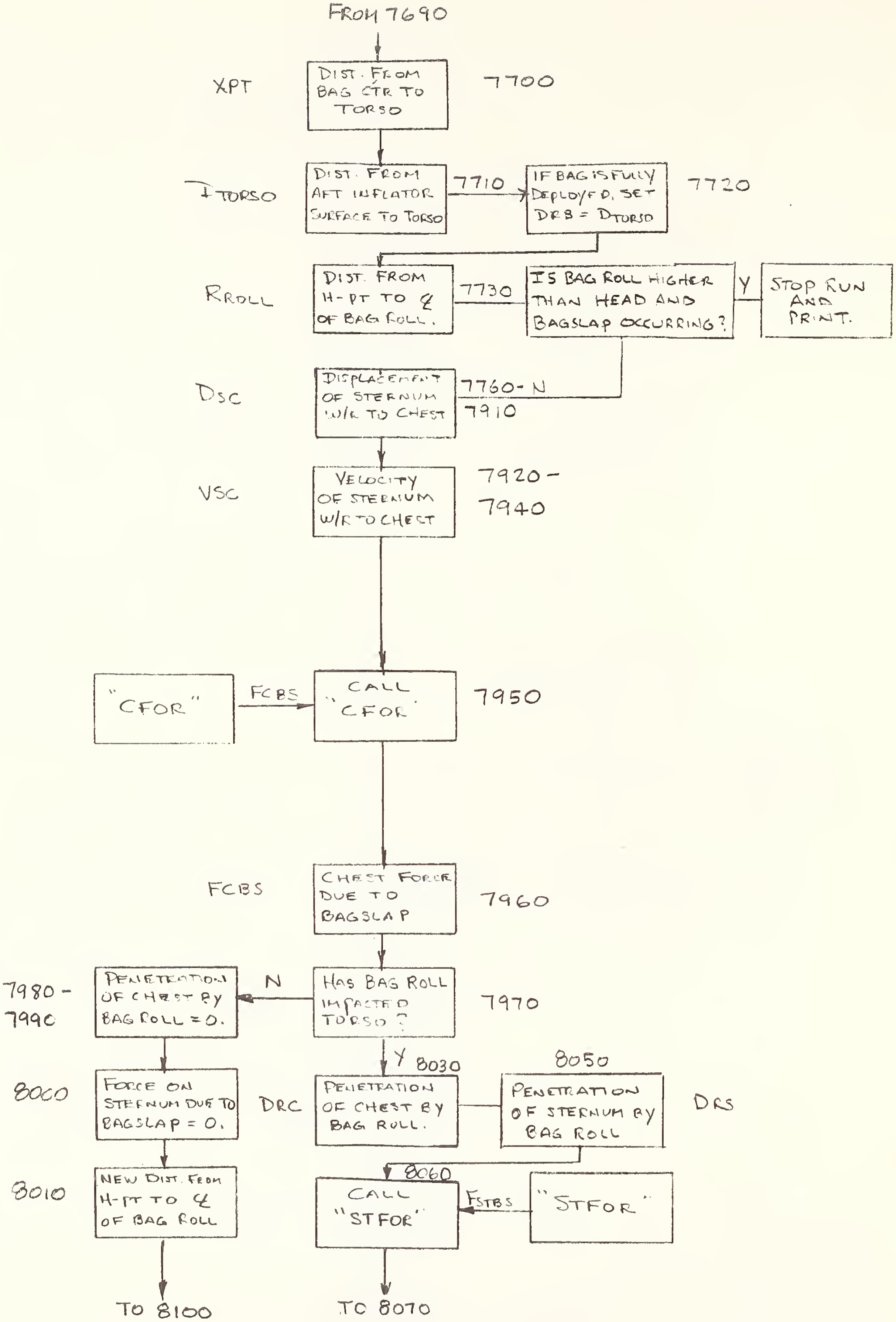

FROM 5550
CALC. BAG/ TORSO INTER-CEPTS.
X_A, X_B
Y_A, Y_B
5610 - 5670
DOES TORSO OR HEAD HIT DASH?
Y
STOP RUN AND PRINT
N
5690 - 5700
LENGTH OF BODY INTERCEPT
ABST
5720
REDEFINE BAG/ TORSO INTERCEPT PTS. ON BASIS OF $\Theta_T - \Theta_D \leq 0$.
Y_P, Y_N
X_P, X_N
5730 - 5820
Θ_T = TORSO ANGLE
Θd = DEPLOYMENT ANGLE
TO 5560
DIST. FROM H-PT TO LWR BAG INTERCEPT
RBAG
5850
ESTAB. WHETHER HEAD IN CONTACT WITH BAG & ASSIGN UPPER & LWR TORSO INTERCEPTS ACCORD.
X_{UT}, X_{LT}
Y_{UT}, Y_{LT}
5860 - 5990
COMPUTE PT. FORCE APPLIED TO TORSO.
Y_{FT}, X_{FT}
6000 - 6010
DIST. FROM H-PT TO PT, X_{FT}, Y_{FT}
RFT
6030
SLOPE OF LINE ⊥ TO TORSO
PSLOPE
6080 - 6090
PT WHERE ⊥ LINE INTERCEPTS BAG
X_G, Y_G
6100 - 6150
BAG PENET. BY TORSO
BP
6170
TO 6190

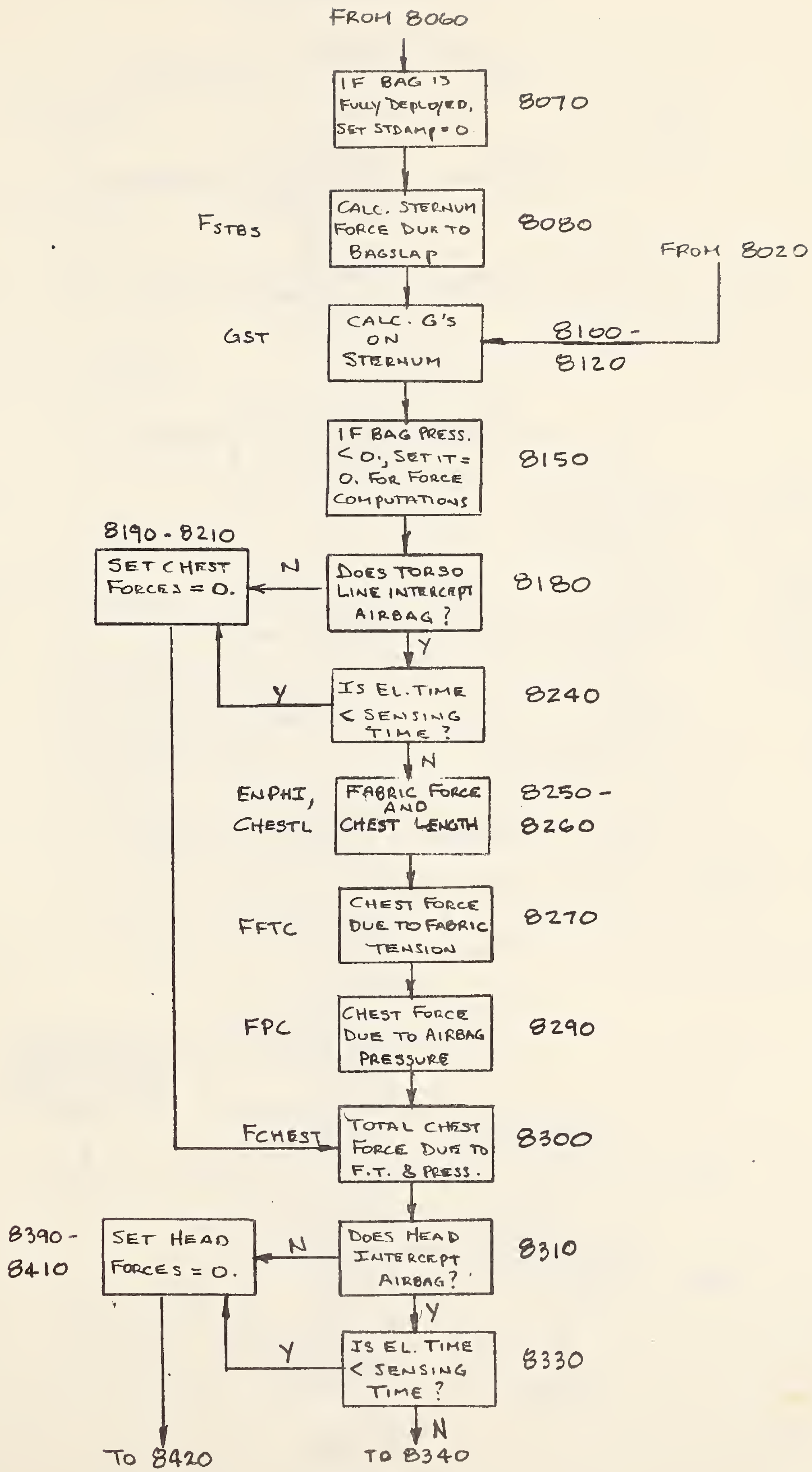

FROM 6170
TAOI
TORSO AREA OF BAG INTERCEPT
6190-6370
TVOI
TORSO VOL. OF BAG INTERCEPT
6380
FROM 5560
STOP RUN AND PRINT
Y
IS HEAD ANGLE ≥ 90 DEG.
6410
N
HSLOPE
NEW HEAD SLOPE
6420
6460
DOES HEAD INTERCEPT BAG?
N
HEAD AREA OF BAG INTERCEPT=0.
6470
Y
XHA, YHA
XHB, YHB
CALC. BAG/HEAD INTERCEPTS
6490-6550
TO 7220
XHP, YHP
XHN, YHN
DISTINGUISH BET. UPPER & L'WR VALUES FOR HEAD INTERCEPT PTS.
6590-6670
XTOPH
YTOPH
X & Y COORD. OF TOP OF HEAD
6690-6700
EST. WHICH PART OF HEAD IS WITHIN BAG
6720-6780
XUH, YUH
XLH, YLH
DEFINE UPPER & L'WR HD. INTERCEPTS.
6800-6950
XFH, YFH
X & Y COORD. OF PT. FORCE APP. TO HEAD
6980-6990
TO 7010

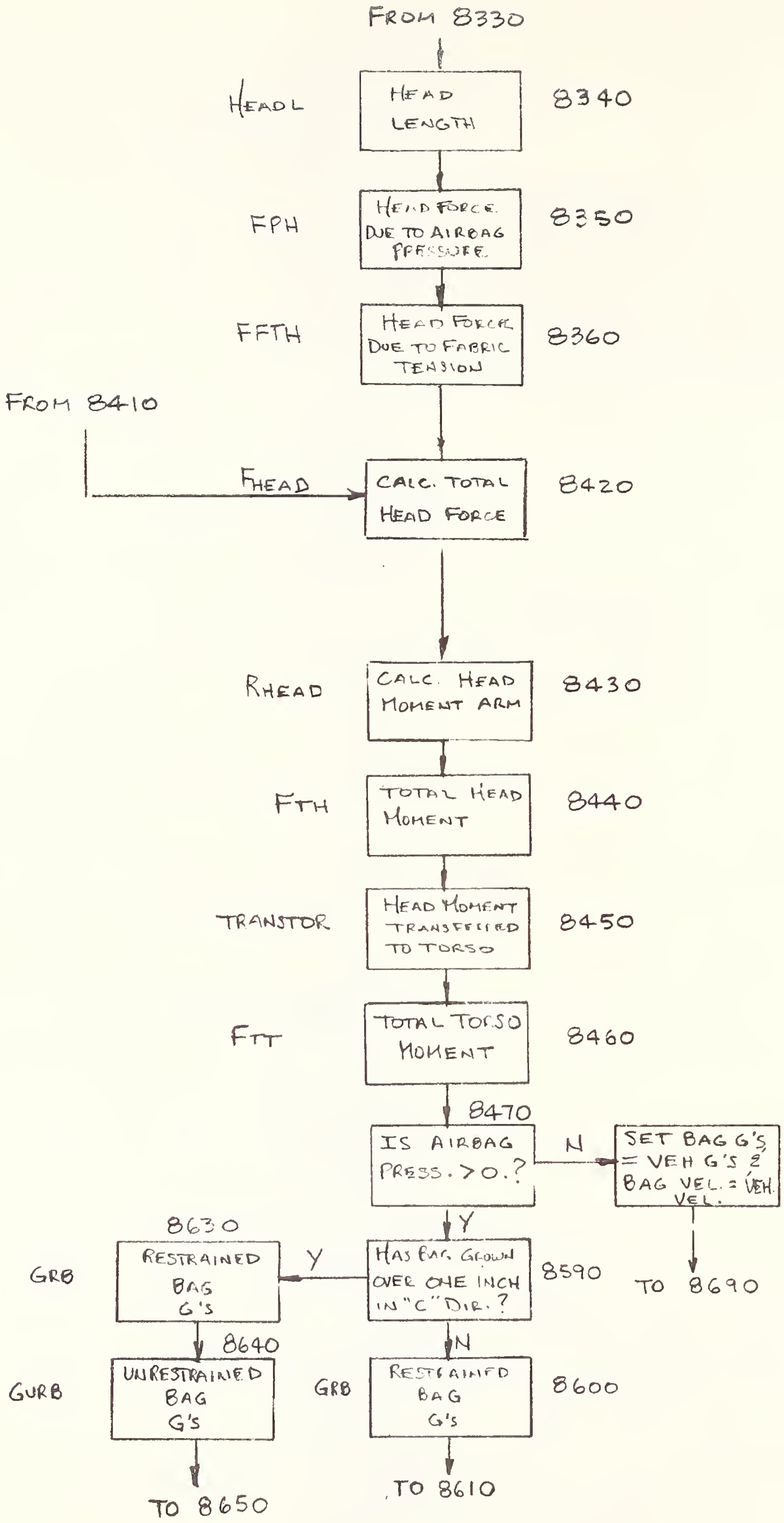


FROM 6990
HPSLOPE
SLOPE OF LINE ⊥ TO HEAD
7010
XGH, YGH
PT. WHERE ⊥ LINE INTERCEPTS BAG
7050-7060
CALC BAG PENETRATION BY HEAD
BPH 7070
HAOI
HEAD AREA OF INTERCEPT
7090-7210
FROM 6480
HVOI
HEAD VOL. OF INTERCEPT
7220
VOI
TOTAL VOL. OF INTERCEPT
7250
Yc
Y-COMP. OF PT. AIRBAG INTERCEPTS DASH
7260
VOL
AIRBAG VOLUME
7270
7280
IS TIME > SENSING TIME?
N
AIRBAG PRESS. = ATMOSPHERIC PRESSURE
7290
Y
"GASIN"
QIN
CALL "GASIN"
7320
GW1
TOTAL WGT. OF GAS IN AIRBAG
7330
GT7, PA7
NEW TEMP. & PRESSURE DUE TO GAS ADD'N.
7350-7370
GT8, PA8
NEW TEMP & PRESSURE DUE TO VOL. CHG.
7390-7400
TO 7420
TO 7680

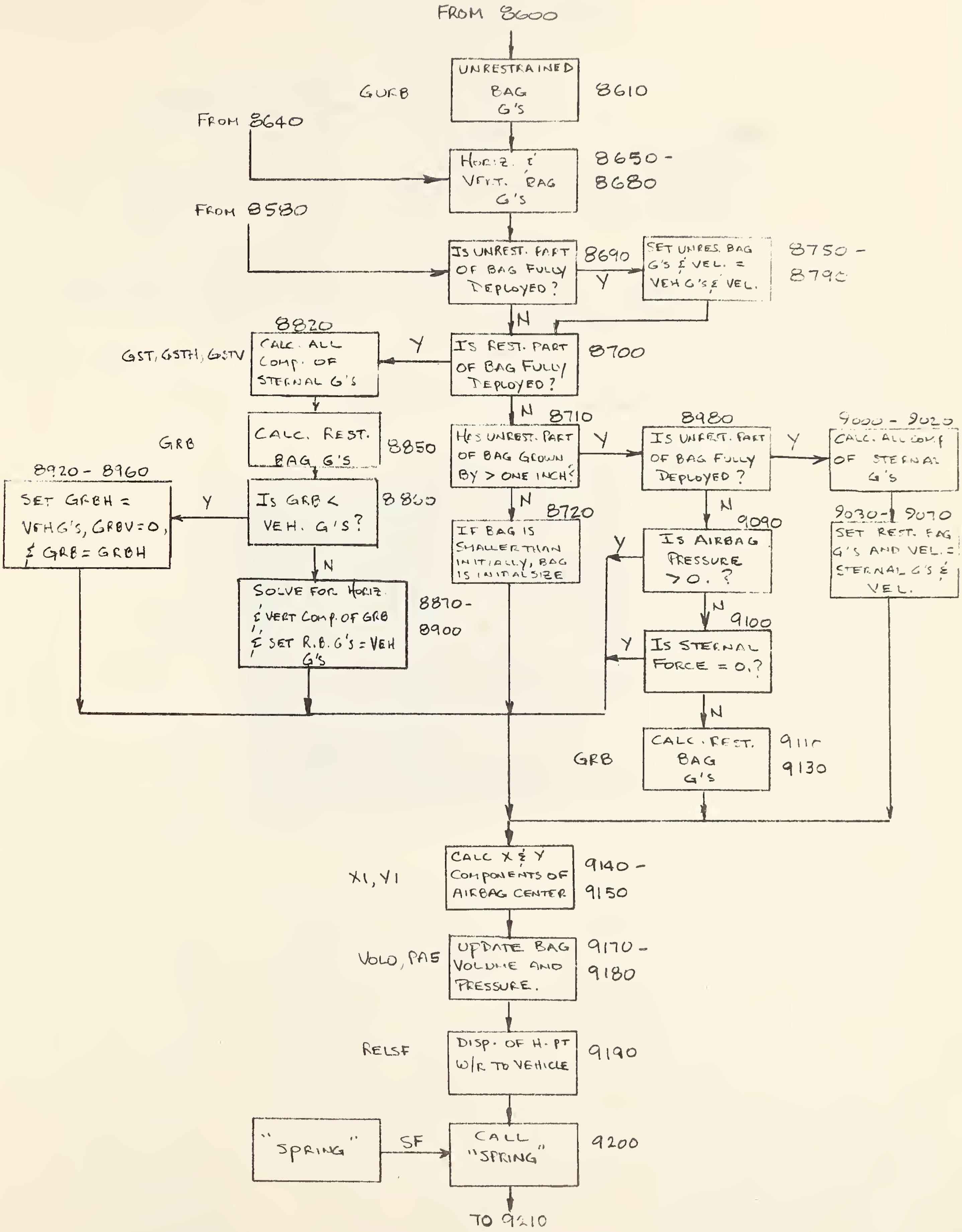

FROM 7400
PR7
PRESSURE RATIO ACROSS BAG VENT
7420
7480; FM1
SET PROPER FLOW COEFFICIENT
Y
IS FLOW CHOKED FROM VENT?
7440
N
7460; FM1
SET PROPER FLOW COEFFICIENT
Y
IS PRESS. GREAT ENOUGH FOR VENT FLOW?
N
EXHAUST FLOW FROM VENT (QEXH)
7500
NO GAS LEAVES BAG (GW = GW1)
7550
GW
NEW GAS WGT IN BAG
7520
GAS WGT. = 0.
Y
IS NEW GAS WGT < 0. ?
7530
7550
GW = GW1
PA, GT
PRESS. & TEMP. DUE TO GAS LOSS FROM BAG
7570 - 7590
FROM 7300
FPN
SET PROPER POLYTROPIC EXP. FOR NEXT TIME THRU LOOP.
7620 - 7660
PG1
GAGE PRESS. OF GAS IN BAG
7680
DROLL
BAG ROLL DIA
7690
TO 7700

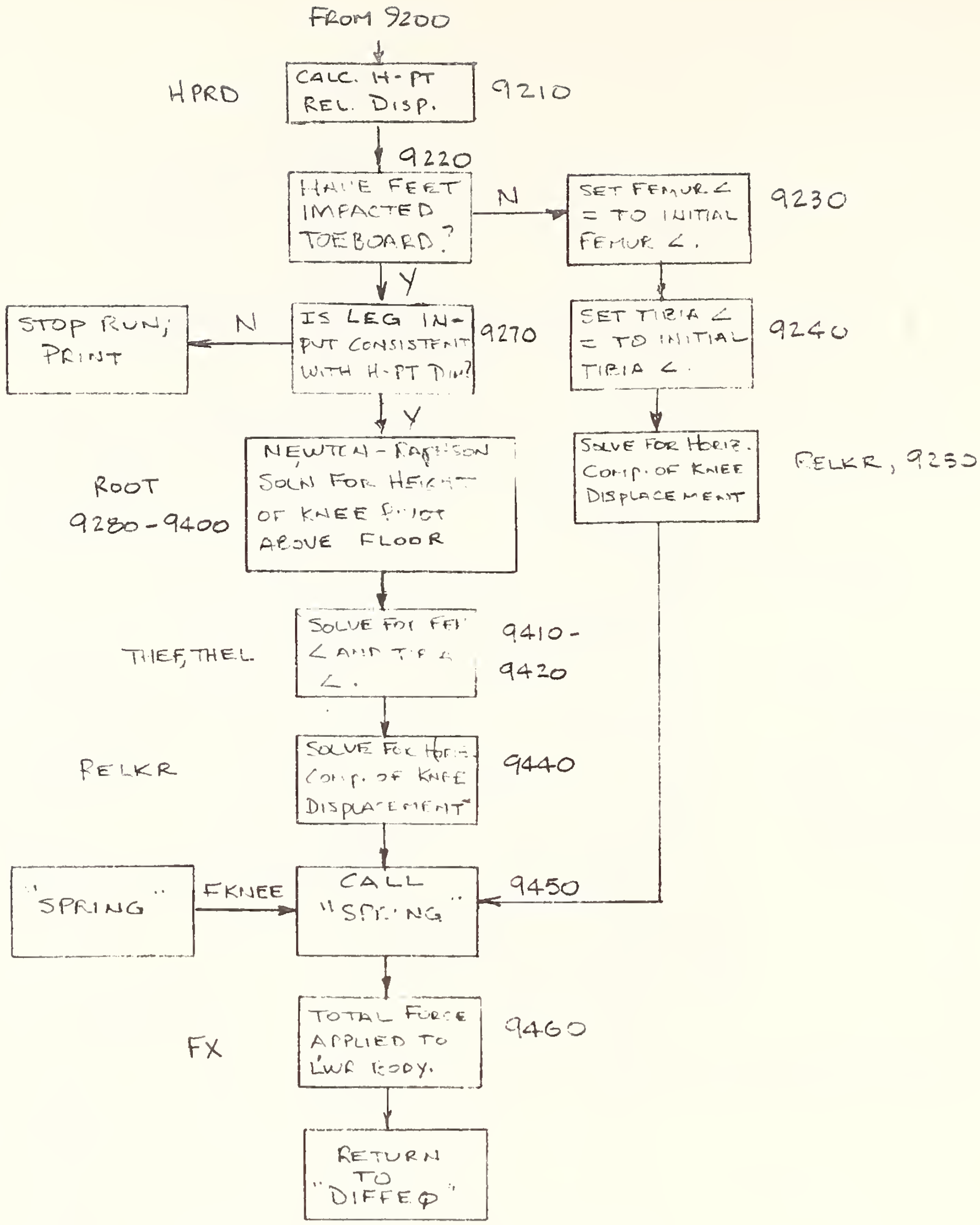

FROM 7690
XPT
DIST. FROM BAG CTR TO TORSO
7700
TTORSO
DIST. FROM AFT INFLATOR SURFACE TO TORSO
7710
IF BAG IS FULLY DEPLOYED, SET DRB = DTORSO
7720
RROLL
DIST. FROM H-PT TO ℄ OF BAG ROLL.
7730
IS BAG ROLL HIGHER THAN HEAD AND BAGSLAP OCCURRING?
Y
STOP RUN AND PRINT.
DSC
DISPLACEMENT OF STERNUM W/R TO CHEST
7760-N
7910
VSC
VELOCITY OF STERNUM W/R TO CHEST
7920-
7940
"CFOR"
FCBS
CALL "CFOR"
7950
FCBS
CHEST FORCE DUE TO BAGSLAP
7960
7980-
7990
PENETRATION OF CHEST BY BAG ROLL = O.
N
HAS BAG ROLL IMPACTED TORSO?
7970
Y
8030
8050
8000
FORCE ON STERNUM DUE TO BAGSLAP = O.
DRC
PENETRATION OF CHEST BY BAG ROLL.
PENETRATION OF STERNUM BY BAG ROLL
DRS
8060
8010
NEW DIST. FROM H-PT TO ℄ OF BAG ROLL
CALL "STFOR"
FSTBS
"STFOR"
TO 8100
TO 8070


FROM 8060
IF BAG IS FULLY DEPLOYED, SET STDAMP = 0.
8070
FSTBS
CALC. STERNUM FORCE DUE TO BAGSLAP
8080
FROM 8020
GST
CALC. G'S ON STERNUM
8100 - 8120
IF BAG PRESS. < 0., SET IT = 0. FOR FORCE COMPUTATIONS
8150
8190 - 8210
SET CHEST FORCES = 0.
N
DOES TORSO LINE INTERCEPT AIRBAG ?
8180
Y
Y
IS EL. TIME < SENSING TIME ?
8240
N
ENPHI, CHESTL
FABRIC FORCE AND CHEST LENGTH
8250 - 8260
FFTC
CHEST FORCE DUE TO FABRIC TENSION
8270
FPC
CHEST FORCE DUE TO AIRBAG PRESSURE
8290
FCHEST
TOTAL CHEST FORCE DUE TO F.T. & PRESS.
8300
8390 - 8410
SET HEAD FORCES = 0.
N
DOES HEAD INTERCEPT AIRBAG?
8310
Y
Y
IS EL. TIME < SENSING TIME ?
8330
N
TO 8420
TO 8340



FROM 8330
HEADL
HEAD LENGTH
8340
FPH
HEAD FORCE DUE TO AIRBAG PRESSURE
8350
FFTH
HEAD FORCE DUE TO FABRIC TENSION
8360
FROM 8410
FHEAD
CALC. TOTAL HEAD FORCE
8420
RHEAD
CALC. HEAD MOMENT ARM
8430
FTH
TOTAL HEAD MOMENT
8440
TRANSTOR
HEAD MOMENT TRANSFERRED TO TORSO
8450
FTT
TOTAL TORSO MOMENT
8460
8470
IS AIRBAG PRESS. > O.?
N
SET BAG G'S = VEH G'S & BAG VEL. = VEH. VEL.
TO 8690
Y
8630
GRB
RESTRAINED BAG G'S
Y
HAS BAG GROWN OVER ONE INCH IN "C" DIR.?
8590
N
8640
GURB
UNRESTRAINED BAG G'S
GRB
RESTRAINED BAG G's
8600
TO 8650
TO 8610


FROM 8600
UNRESTRAINED BAG G'S
GURB
8610
FROM 8640
HORIZ. & VERT. BAG G'S
8650 - 8680
FROM 8580
IS UNREST. PART OF BAG FULLY DEPLOYED?
8690
Y
SET UNRES. BAG G'S & VEL. = VEH G'S & VEL.
8750 - 8790
N
8820
CALC. ALL COMP. OF STERNAL G'S
GST, GSTH, GSTV
Y
IS REST. PART OF BAG FULLY DEPLOYED?
8700
N
8710
8980
9000 - 9020
CALC. REST. BAG G'S
GRB
8850
HAS UNREST. PART OF BAG GROWN BY > ONE INCH?
Y
IS UNREST. PART OF BAG FULLY DEPLOYED?
Y
CALC. ALL COMP OF STERNAL G'S
8920 - 8960
SET GRBH = VEHG'S, GRBV=0, & GRB = GRBH
Y
IS GRB < VEH. G'S?
8860
N
8720
IF BAG IS SMALLER THAN INITIALLY, BAG IS INITIAL SIZE
N
9090
IS AIRBAG PRESSURE > 0.?
Y
9030 - 9070
SET REST. BAG G'S AND VEL. = STERNAL G'S & VEL.
N
SOLVE FOR HORIZ. & VERT COMP. OF GRB & SET R.B.G'S = VEH G'S
8870 - 8900
N
9100
IS STERNAL FORCE = 0.?
Y
N
GRB
CALC. REST. BAG G'S
9110 9130
CALC X & Y COMPONENTS OF AIRBAG CENTER
X1, Y1
9140 - 9150
UPDATE BAG VOLUME AND PRESSURE.
VOLO, PA5
9170 - 9180
DISP. OF H. PT W/R TO VEHICLE
RELSF
9190
"SPRING"
SF
CALL "SPRING"
9200
TO 9210



FROM 9200
HPRD
CALC. H-PT REL. DISP.
9210
9220
HAVE FEET IMPACTED TOEBOARD?
N
SET FEMUR ∠ = TO INITIAL FEMUR ∠.
9230
Y
STOP RUN; PRINT
N
IS LEG INPUT CONSISTENT WITH H-PT DIM?
9270
SET TIBIA ∠ = TO INITIAL TIBIA ∠.
9240
Y
ROOT
9280-9400
NEWTON-RAPHSON SOLN FOR HEIGHT OF KNEE PIVOT ABOVE FLOOR
SOLVE FOR HORIZ. COMP. OF KNEE DISPLACEMENT
RELKR, 9250
THEF, THEL
SOLVE FOR FEM ∠ AND TIBIA ∠.
9410-9420
RELKR
SOLVE FOR HORIZ. COMP. OF KNEE DISPLACEMENT
9440
"SPRING"
FKNEE
CALL "SPRING"
9450
FX
TOTAL FORCE APPLIED TO LWR BODY.
9460
RETURN TO "DIFFEQ"