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U.S. Department
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# "DRAC" User's Manual -- Revision B

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16. Abstract

This manual was written to give the Potential user of the DRAC computer program the specific information he will need to:

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

DRAC is an acronym for DRiver Air Cushion and was written to describe the interaction, during a crash, between the driver of the vehicle and his airbag.

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# SECTION 1
# INTRODUCTION

This manual is written to give the potential user of the DRAC program the specific information he or she will need to:

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

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

DRAC is an acronym for "DRiver Air Cushion" and, as the program name indicates, the program was written to describe the interaction, during a crash, between the driver of a vehicle and an airbag. Other programs have been written to describe such an interaction, but none were specifically suitable to the needs of this project which are:

1) To have the capability of simulating an airbag shape typical of the ellipsoidal shape which almost all driver bags have.
2) To be sufficiently simple and inexpensive that it can run on a small computer with no "library routines" necessary for execution. Therefore, the program must be self contained and inexpensive to operate so it can be used as a design tool.
3) To be, as a design tool, oriented to the user requirements of a typical restraint system engineer, with both the formulation and the input - output in units commonly used and measured.
4) To be, as a design tool, oriented toward the test hardware actually encountered in most situations. For example, past computer programs might model the driver very well but neglect the bag shape actually used and/or the column binding and frictional forces which are almost always present and influence the results greatly.

5) To have the same level of detail, complexity and accuracy for all the components of the restraint system. For example, there are several different kinds of steering colums, all of which behave differently. It does little good to have an elaborate airbag algorithm and then to back it up with a steering column that is so simple it is only described by a single force-stroke characteristic. Such a program must at least have the capability of describing the different column frictional and binding effects which are so important in determining the driver's injury levels.

In writing the DRAC computer program we have sought to fulfill these needs.

# SECTION 2
# PROGRAM DESCRIPTION

DRAC is a two-dimensional, lumped mass computer model of the driver interacting with an ellipsoidal airbag mounted to a stroking steering column. The model includes three masses, representing the head, torso and lower body. The airbag is simulated by a ellipsoid into which a programmed amount of gas flows. By adjusting the airbag vent size, a selected amount of gas can be vented during the crash in order to attenuate the peak chest Gs and the rebound effects.

The model also includes the steering column force-stroke characteristics (including all binding and frictional effects), the neck rotational resistance and the seat friction.

## 2.1 PROGRAM FORMULATION

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

DRAC 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. DRAC has been written in FORTRAN IV and was developed to operate in an interactive time share mode. The program is self-contained, in that no external routines are required for execution. It is also modular in construction, so as to facilitate the addition of other subroutines at a future time, if desired. The data input is from a previously created disk file and the input parameters appear directly on the terminal, immediately preceding the complete program output.

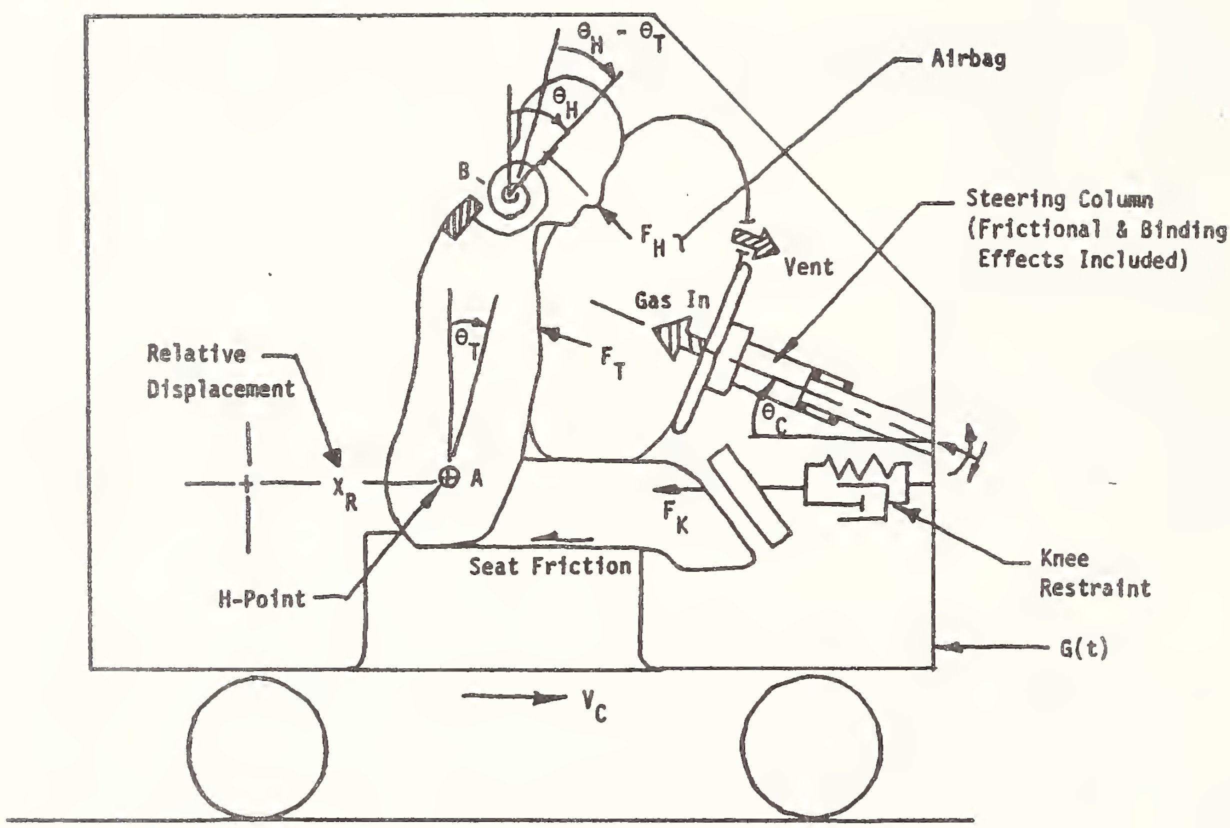



FIGURE 1. THE MATHEMATICAL MODEL

As mentioned above, DRAC has been programmed in modular format with several subroutines. The reason for this is to enable other features to be easily added at a future time. For example, consider the tabular data input. DRAC provides two basic ways to operate on this tabular input. For simple data (where the particular value of the dependent variable is a function only of the value of the independent variable), a simple table look up and interpolation subroutine, "LOOKUP," is provided. Gas flow versus time, vehicle acceleration versus time, neck torque versus angle, and column force versus crush are examples of this method of data retrieval. However, in those cases in which the dependent variable is a function not only of the value of the independent variable but also depends on whether the independent variable is increasing or decreasing, a different subroutine, "SPRING," that allows for plastic behavior, is used. This subroutine is used principally for those cases in which hysteresis (or plastic action of a deformable member) is modeled. 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 slope" 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 (as a function of stroke) are handled by this subroutine.

## 2.2 AIRBAG

Most of the driver airbag interaction models being used today rely on relatively simple spherical or cylindrical airbag shapes (in which the bags exhibit a constant radius of curvature regardless of impact angle). Unfortunately, these simple bag shapes do not adequately describe the shape of most of the driver airbags presently being used.

Of all the geometric shapes that could be postulated as candidates for the driver airbag, the ellipsoid is most nearly the shape of the driver airbag. For this reason, we chose the ellipsoid as the shape upon which to base the bag shape algorithm described in Appendix B of this manual. Unfortunately, the ellipsoid is not as mathematically easy to describe as the sphere or cylinder, since the bag radius of curvature and the intercepted volume of the airbag are

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

## 2.3 STEERING COLUMN

As previously mentioned, the proper modeling of the steering column is very important to the overall accuracy of the program in reproducing "real world" behavior for the driver restraint system. Most driver restraint models specify only a force versus stroke characteristic for the column. In many cases these models neglect column mass, column frictional and binding effects, and the specific points at which the column is supported. In setting up the column for this program, we have chosen a generic type of column that is widely used. This column is the General Motors type column shown in Figure 3. Other types could have been specified, but, because of the modular program construction, other types may be easily added as required. As it turns out, the GM type column is fairly typical of a wide variety of columns, so the program can be used "as is" for a wide variety of situations.

The program is set up to calculate the airbag forces and pressures before coming to the column force calculation. Therefore, the airbag forces are resolved into a column axial force, a column normal force and a column moment (as applied loads to the column) before entering the column dynamics routine. All the user need specify is the column mass, the column angle, the basic force- stroke properties of the column, the coefficient of friction at the column's support points, and the pertinent column dimensions (as shown in Figure 3) for the computer to calculate the complete column dynamics.

Appendix C of this manual contains the details of the steering column algorithm.

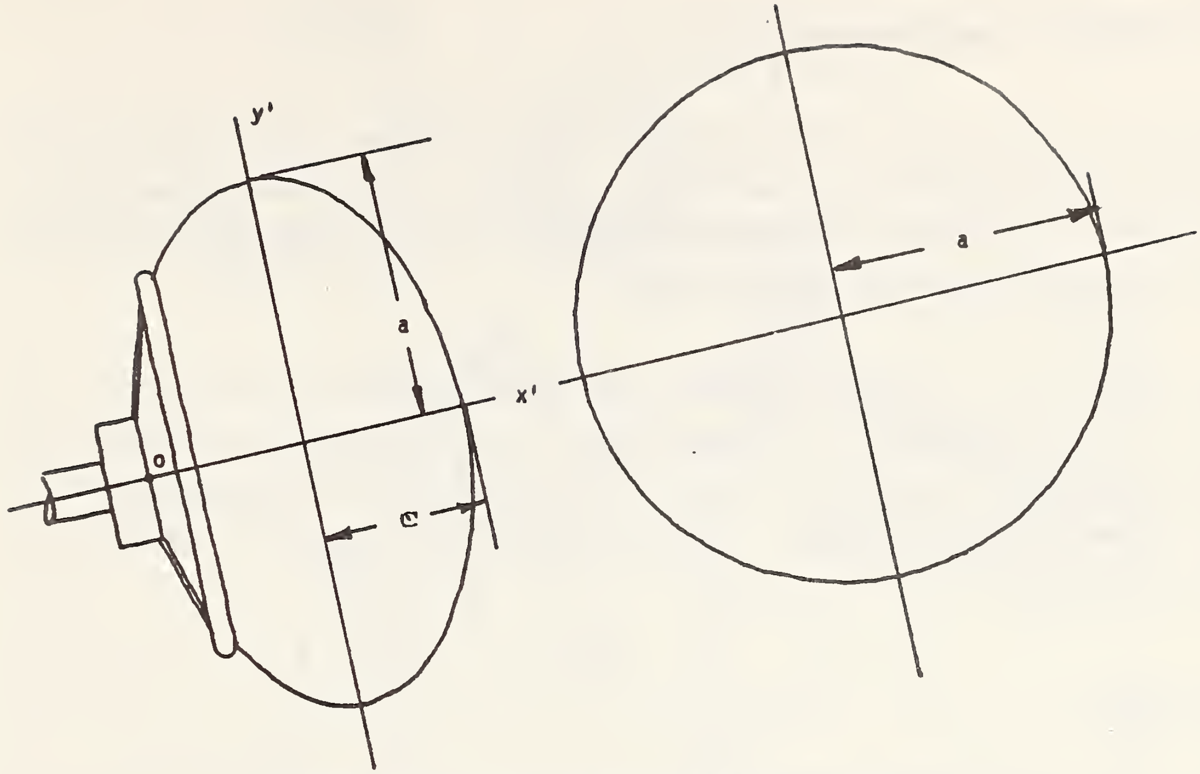
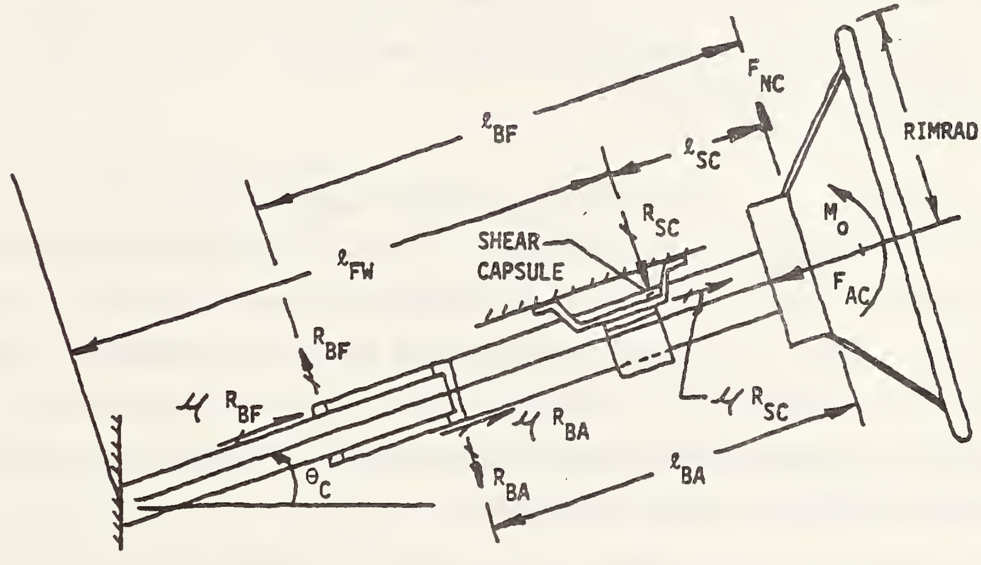



FIGURE 2. THE AIR BAG AND ITS VARIABLES




$R_{SC}$ = Reaction at Shear Capsule

$R_{BA}$ = Reaction at Aft Bushing

$R_{BF}$ = Reaction at Forward Bushing

$\mu$ = Coefficient of Friction

$M_o$ = Applied Moment

$F_{AC}$ = Applied Axial Force

$F_{NC}$ = Applied Normal Force

FIGURE 3. GM ACRS COLUMN

## 2.4 KNEE RESTRAINT AND SEAT FRICTION

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 which determine what the lower body restraint for the lower torso, hips and legs will be.

The user specifies, in tabular format, what these properties are to be. In addition, the user specifies the "unload slope," so the program can compute the unloading force path to be taken, during rebound, away from the knee bolster or movement rearward across the seat. Specifics of how the input is handled are discussed in Section 3.1.

## 2.5 THE DRIVER

The driver is modeled by three lumped masses (the head, the torso and the lower body) which pivot at points A and B in Figure 4. Figure 4 also describes the driver geometry and the location of the airbag and the driver with respect to the compartment. Specific details needed to provide driver related input to the program are described in Section 3.1.

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

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

where:

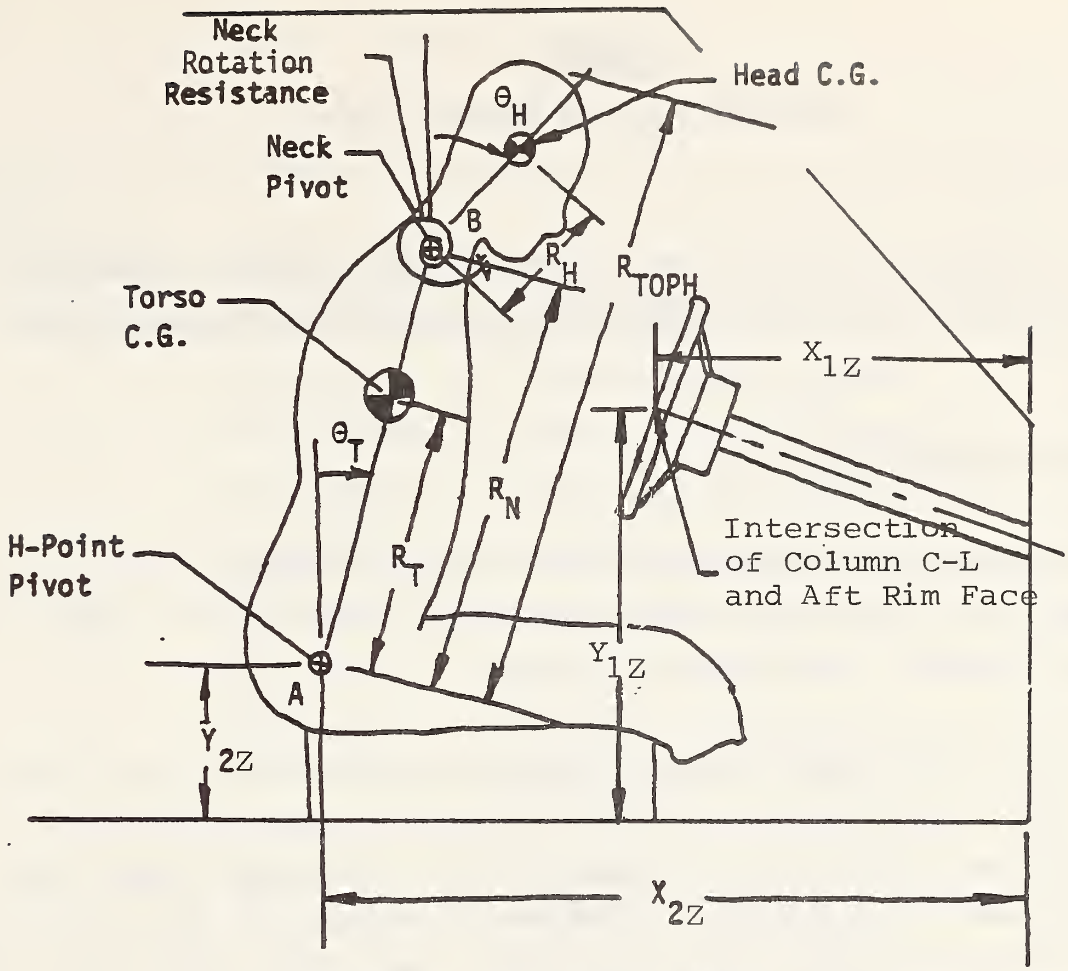



FIGURE 4. THE DRIVER MODEL

T = Neck resisting torque

$\Theta_H$ is as defined in Figure 4

$\Theta_T$ is as defined in Figure 4

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

$\Theta_H - \Theta_T$ is the time rate of change of $\Theta_H - \Theta_T$ .

In addition to the neck resisting torque (based on the angular displacement of the head relative to the torso), we also have included a damping coefficient for the head (based on the angular velocity of the head relative to the torso). This value is known as "DCN" in the input data. Thus the overall resistance of the head to rotation with respect to the torso is composed of two terms — one term based on relative angular displacement and a second term based on relative angular velocity.

Appendix D of this manual is an overall listing of the DRAC program.

# SECTION 3
# AN EXAMPLE OF THE PROGRAM'S USE

In order to illustrate the use of the program, we will describe a simulation of a sled test (Minicars Test 1411) of the Large Research Safety Vehicle (LRSV).

## 3.1 CREATING THE DATA INPUT FILE

The first thing one must do in preparation for making a computer run is to set up a data input file of information which the program needs to run. Table 1 is a list of the parameters that make up this file.

In Table 1, the first column shows the location of a particular piece of data in the input file. For example, 1-1 refers to the first data pointof Line 1, 1-2 refers to the second data point of Line 2, etc. The second column lists the alphanumeric name of the variable at that particular place in the data file and the units that the variable must have in the input file. The third column contains a short description of what the variable is, and the forth column gives the actual value of the variable for sled test 1411, as it was input into the data file. Thus, Table 1 gives all the required input to simulate test 1411. The file resulting from this input is shown in Figure 5. We have chosen to call the file LRSV.

TABLE 1. INPUT FILE

| Variable Location | | | | |
|---|---|---|---|---|
| Line No. | Location In Line | Variable Name and Units | Description | Value |
| 1 | 1 | y(4) mph | Vehicle impact velocity | 39.3 |
| 1 | 2 | y(6) degrees | Head angle ($\theta_H$ in Figure 1) | -5 |
| I | 3 | y(7) degrees | Torso angle ($\theta_T$ in Figure 1) | -18 |
| 2 | 1 | $Z_L$ pounds | Weight of lower body | 77 |
| 2 | 2 | $Z_T$ pounds | Weight of torso | 67 |
| 2 | 3 | $Z_H$ pounds | Weight of head | 11 |
| 2 | 4 | $R_T$ inches | Distance from H-point to torso center of gravity (Figure 4) | 13.8 |
| 2 | 5 | $R_N$ inches | Distance from H-point to neck pivot (Figure 4) | 19.5 |
| 2 | 6 | $R_H$ inches | Distance from neck pivot to head center of gravity when $\theta_H = \theta_T$ (Figure 4) | 4 |
| 2 | 7 | $R_{TOPH}$ inches | Distance from H-point to top of head | 28 |
| 3 | 1 | NPN | No. of points on Lines 14 and 15 | 9 |
| 3 | 2 | NKR | No. of points on Lines 18 and 19 | 8 |
| 3 | 3 | NV | No. of points on Lines 16 and 17 | 6 |
| 3 | 4 | NSF | No. of points on Lines 12 and 13 | 6 |
| 3 | 5 | NPG | No. of points on Lines 4 and 5 | 8 |
| 3 | 6 | NPC | No. of points on Lines 6 and 7 | 6 |
| 3 | 7 | SUN lb/in | Seat friction unload scope | 1000 |

TABLE 1. (CONT'D)

| Variable Location | | | | |
|---|---|---|---|---|
| Line No. | Location In Line | Variable Name and Units | Description | Value |
| 3 | 8 | SKR lb/in | Knee restraint unload scope | 2900 |
| 4 | 1 | GEN(1,1) msec | Gas flow time, first point | Figure 5, Line 4 |
| 4 | etc. | GEN(1,k) msec | Gas flow time, subsequent points | |
| 5 | 1 | GEN(2,1) lb/sec | Gas flow rate, first point | Figure 5, Line 5 |
| 5 | etc. | GEN(2,k) lb/sec | Gas flow rate, subsequent points | |
| 6 | 1 | COL(1,1) in | Column stroke, first point | Figure 5, Line 6 |
| 6 | etc. | COL(1,k) in | Column stroke, subsequent points | |
| 7 | 1 | COL(2,1) lb | Column force, first point | Figure 5, Line 7 |
| 7 | etc. | COL(2,k) lb | Column force, subsequent points | |
| 8 | 1 | ATMOP PSIA | Local atmospheric pressure | 14.7 |
| 8 | 2 | PGZ PSIG | Initial airbag pressure | -14.7 |
| 8 | 3 | GTZ Deg R | Temperature of gas entering airbag | 1160 |
| 8 | 4 | U $\frac{\text{in lb}_f}{\text{lb}_m\ {}^o\text{R}}$ | Gas constant | 660 |
| 8 | 5 | PN1 | Polytropic gas exponent, flow | 1.4 |
| 8 | 6 | PN2 | Polytropic gas exponent, compression | 1.4 |
| 8 | 7 | PN3 | Polytropic gas exponent, expansion | 1.4 |
| 9 | 1 | VC1 | Vent discharge coefficient - subsonic flow | 0.7 |
| 9 | 2 | VC2 | Vent discharge coefficient - sonic flow | 0.7 |
| 9 | 3 | AV sq in | Vent area | 3.5 |
| 9 | 4 | SA inches | Major axis length of airbag (Figure 2) | 11.5 |

TABLE 1. (CONT'D)

| Variable Location | | | | |
|---|---|---|---|---|
| Line No. | Location In Line | Variable Name and Units | Description | Value |
| 9 | 5 | SC inches | Minor axis length of airbag (Figure 2) | 7.5 |
| 9 | 6 | X1Z inches | Horizontal rim reference dim. (Figure 4) | 29.5 |
| 9 | 7 | Y1Z inches | Vertical rim reference dim. (Figure 4) | 23.0 |
| 9 | 8 | DCN $\frac{\text{ft-lb-sec}}{\text{rad}}$ | Neck damping coefficient | 2.5 |
| 10 | 1 | SLIM inches | Column stroke limit | 8.0 |
| 10 | 2 | THETAC degrees | Column angle (Figure 3) | 17 |
| 10 | 3 | MU | Column frictional co-efficient (Figure 3) | 0.16 |
| 10 | 4 | LSCZ inches | Column reference dim. to shear capsule (Figure 3) | 16 |
| 10 | 5 | LFWZ inches | Column reference dim. to firewall (Figure 3) | 14.75 |
| 10 | 6 | LBAZ inches | Column reference dim. to aft bushing (Figure 3) | 16 |
| 10 | 7 | LBFZ inches | Column reference dim. to forward bushing (Figure 3) | 23.25 |
| 10 | 8 | WC pounds | Column stroking weight | 18 |
| 11 | 1 | WH inches | Head width | 9 |
| 11 | 2 | YO inches | Y' coordinate point "0" (Figure 2) always = 0 | 0 |
| 11 | 3 | RIMRAD inches | Radius of steering wheel (Figure 3) | 7.75 |
| 11 | 4 | X2Z inches | Horizontal H-point reference dim. (Figure 4) | 36.5 |
| 11 | 5 | Y2Z inches | Vertical H-point reference dim. (Figure 4) | 9 |
| 11 | 6 | WB inches | Width of torso | 17 |

TABLE 1. (CONT'D)

| Variable Location: Line No. | Variable Location: Location In Line | Variable Name and Units | Description | Value |
|---|---|---|---|---|
| 12 | 1 | SFN(1,1) inches | Seat friction displacement, first point | Figure 5, Line 12 |
| 12 | etc. | SFN(1,k) inches | Seat friction displacement, subsequent points | |
| 13 | 1 | SFN(2,1) lb | Seat friction force, first point | Figure 5, Line 13 |
| 13 | etc. | SFN(2,k) lb | Seat friction force, subsequent points | |
| 14 | 1 | FNECK(1,1) deg. | Head relative angle ($\theta_H - \theta_T$, Figure 1), first point | Figure 5, Line 14 |
| 14 | etc. | FNECK(1,k) deg. | Head relative angle, subsequent points | |
| 15 | 1 | FNECK(2,1) ft-lb | Neck rotational resistance torque, first point | Figure 5, Line 15 |
| 15 | etc. | FNECK(2,k) ft-lb | Neck rotational resistance torque, subsequent points | |
| 16 | 1 | VEHGS(1,1) msec | Crash pulse time, first point | Figure 5, Line 16 |
| 16 | etc. | VEHGS(1,k) msec | Crash pulse time, subsequent points | |
| 17 | 1 | VEHGS(2,1) Gs | Crash pulse Gs, first point | Figure 5, Line 17 |
| 17 | etc. | VEHGS(2,k) Gs | Crash pulse Gs, subsequent points | |
| 18 | 1 | KRN(1,1) in | Knee displacement, first point | Figure 5, Line 18 |
| 18 | etc. | KRN(1,k) in | Knee displacement, subsequent points | |
| 19 | 1 | KRN(2,1) lb | Knee (femur) force total, 2 knees, first point | Figure 5, Line 19 |
| 19 | etc. | KRN(2,k) lb | Knee (femur) force total, 2 knees, subsequent points | |

```
LRSV          09:37EST     12/02/81

1 39:3,-5:,-18:
2 77.,67.,11:,13.8,19.5,4.,28.
3 9,8,6,6,8,6,1000:,2900:
4 -100:,14:,16:,19:,32:,65:,92:,100:
5 0:,0:,4:915,3:863,3:072,0:614,0:,0:
6 -100:,0:,0:25,0:5,1:5,8:
7 0:,0:,400:,400:,1600:,1600:
8 14:7,-14:7,1160:,660:,1:4,1:4,1:4
9 :7,:7,3:5,11:5,7:5,29:5,23:0,2:5
10 8:,17:,:16,16:,14:75,16:,23:25,18:
11 9:,0:,7:75,36:5,9:,17:
12 -100:,0:,0:5,15:,16:,100:
13 0:,0:,400:,300:,0:,0:
14 -90:,-75:,-60:,-30:,0:,30:,60:,75:,90:
15 200:,150:,100:,50:,0:,-50:,-100:,-150:,-200:
16 -100:,0:,40:,102:,115:,150:
17 0:,0:,21:,22:5,0:,0:
18 -50:,3:,3:75,6:5,7:5,9:,11:,50:
19 0:,0:,400:,2900:,2900:,1800:,1800:,1000:


READY
```

FIGURE 5. THE INPUT FILE LRSV

## 3.2 RUNNING THE PROGRAM

Once the input file has been created and saved, we are ready to run DRAC. At this point the user accesses DRAC and tells it to run. The computer will respond by asking the user to name the input file; in this case we respond "LRSV," as shown in Appendix E of this manual. Once this answer is given, the program will begin to print out the input data – first in the units input into the program and then in the units used by the program in the actual computation.

Let us now discuss the output.

Altogether there are seven blocks of output – each block consisting of the amount of data that can be conveniently grouped together in terms of subject. Block 1 of output in App. E has Elapsed Time, Chest A-P Acceleration, Chest S-I Acceleration, Head A-P Acceleration and Head S-I Acceleration.

Block 2-of output in Appendix E is basically in summary of the main parameters of interest in the program and consists of the following items (page 78 ): Elapsed Time, Vehicle Gs (Acceleration), Vehicle Velocity, Vehicle Displacement (Crush), Body Gs (chest A-P Gs), Column Displacement (Stroke), and Airbag Pressure.

Block 3-(page 79 ) has Elapsed Time, H-Point Displacement (with respect to ground), H-Point Velocity, H-Point Acceleration, Femur Force (each femur has this force), Seat Friction Force, and H-Point Relative Displacement (with respect to original position in compartment).

Block 4-(page 80 ) has Elapsed Time, Torso Displacement (with respect to ground), Torso Angle (with respect to a vertical line, positive when toward dash), Torso Angular Velocity (with respect to H-point pivot), Torso Angular Acceleration, Torso Relative Displacement and Torso Relative Velocity.

Block 5-(page 81 ) is the exact equivalent of Block 3, but for the head with respect to the neck pivot (instead of the torso with respect to the H-point pivot).

Block 6-(page 82 ) has Elapsed Time, Column Axial Applied Force, Column Normal Applied Force (positive when upward), Column Applied Moment (positive when bending the column upward), Force Resisting Column Stroke, Column Stroke, and Column Stroking Velocity (with respect to the compartment).

Block 7-(page 83 ) has the Elapsed Time, Bag Penetration (measured normal to the torso, halfway between the two bag intercept points), Bag Volume, Bag Pressure, Bag Wraparound (fabric tension) Force (on the chest) and Bag Pressure Force (on the chest).

## 3.3 DRAC OUTPUT CORRELATION WITH TEST RESULTS

In Section 3.1 we described the use of data for an LRSV sled test as input to DRAC. The correlation between the data resulting from the sled test and the output data from DRAC is, in general, a measure of the predictive capability of the simulation model.

Figures 6 through 10 illustrate the comparison between the experimentally determined test results and the DRAC predictions with identical input parameters.

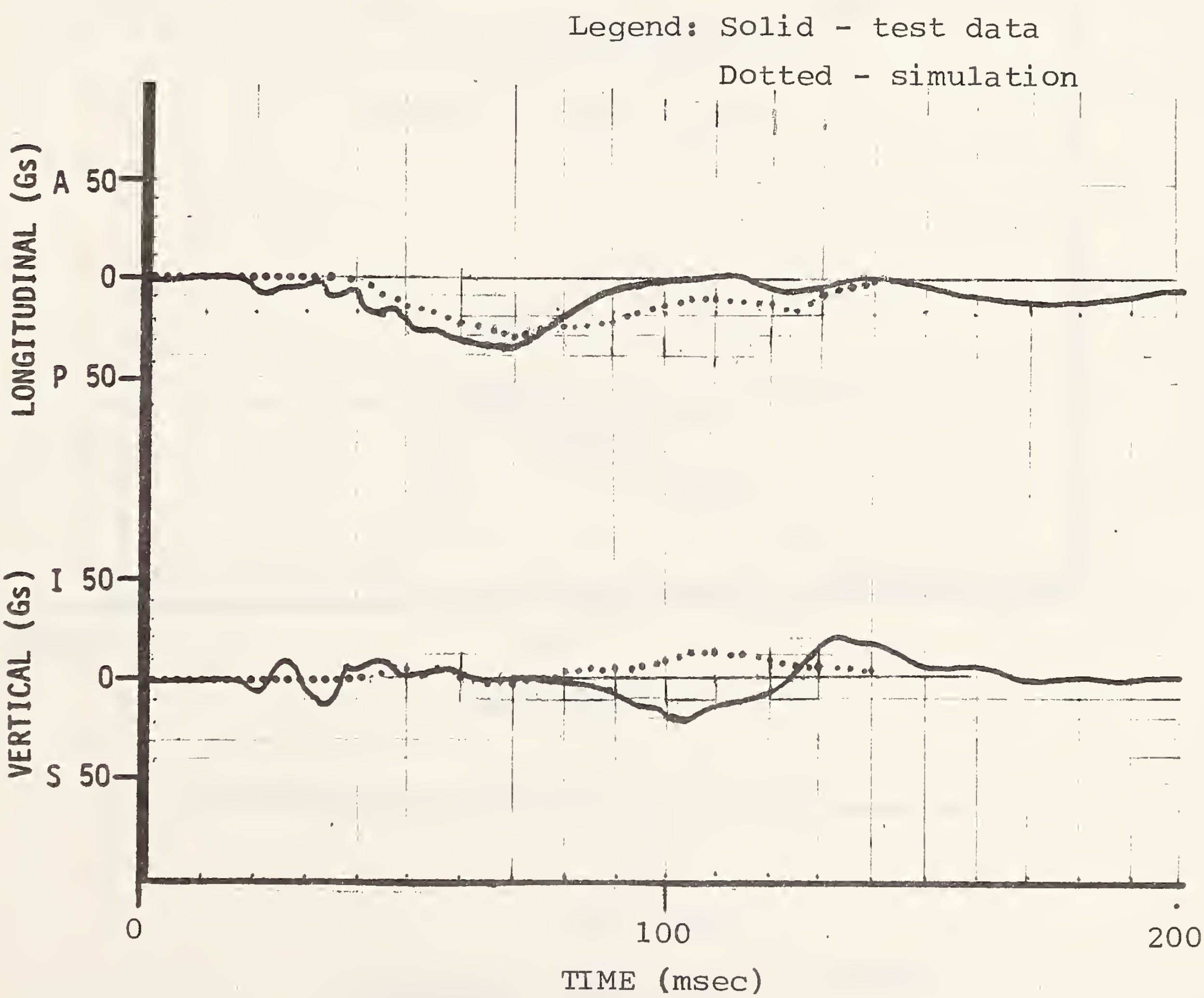



FIGURE 6. DRIVER HEAD ACCELERATION

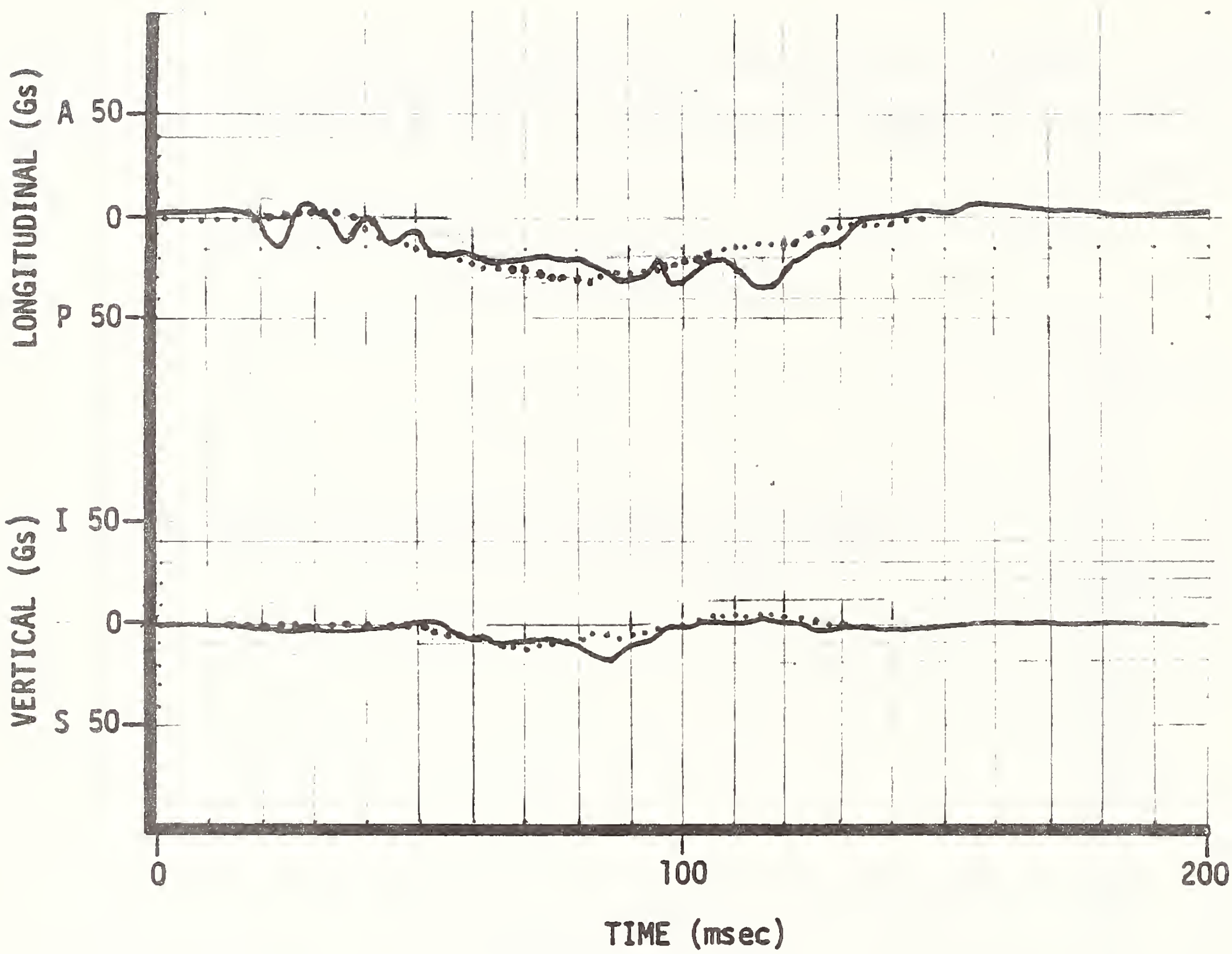



FIGURE 7. DRIVER CHEST ACCELERATION

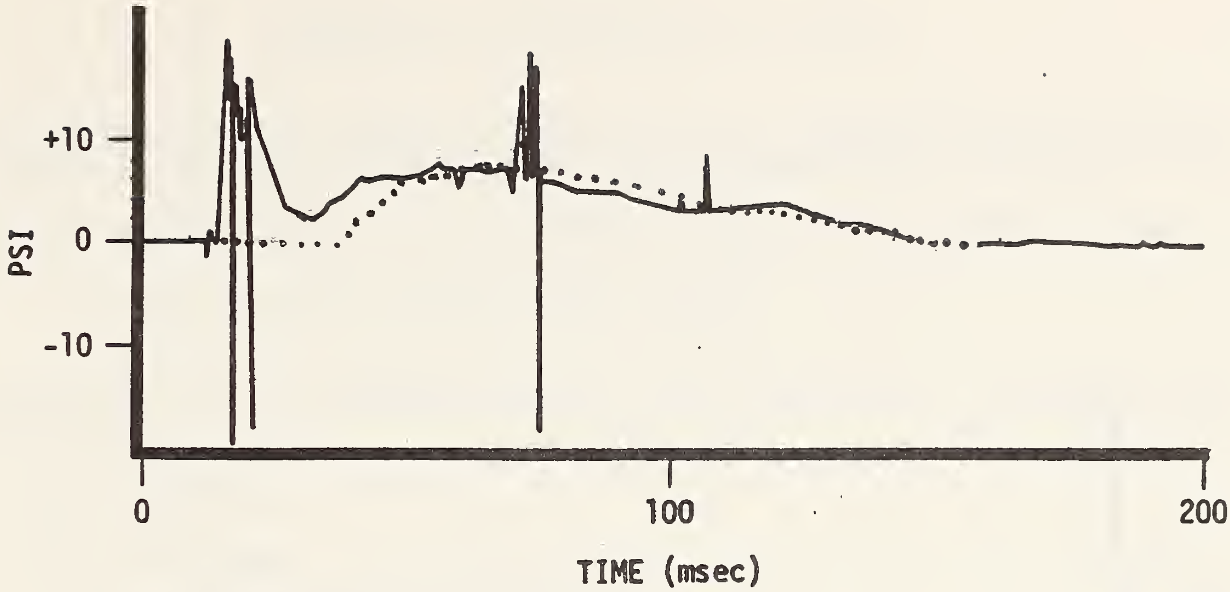



FIGURE 8. AIRBAG PRESSURE

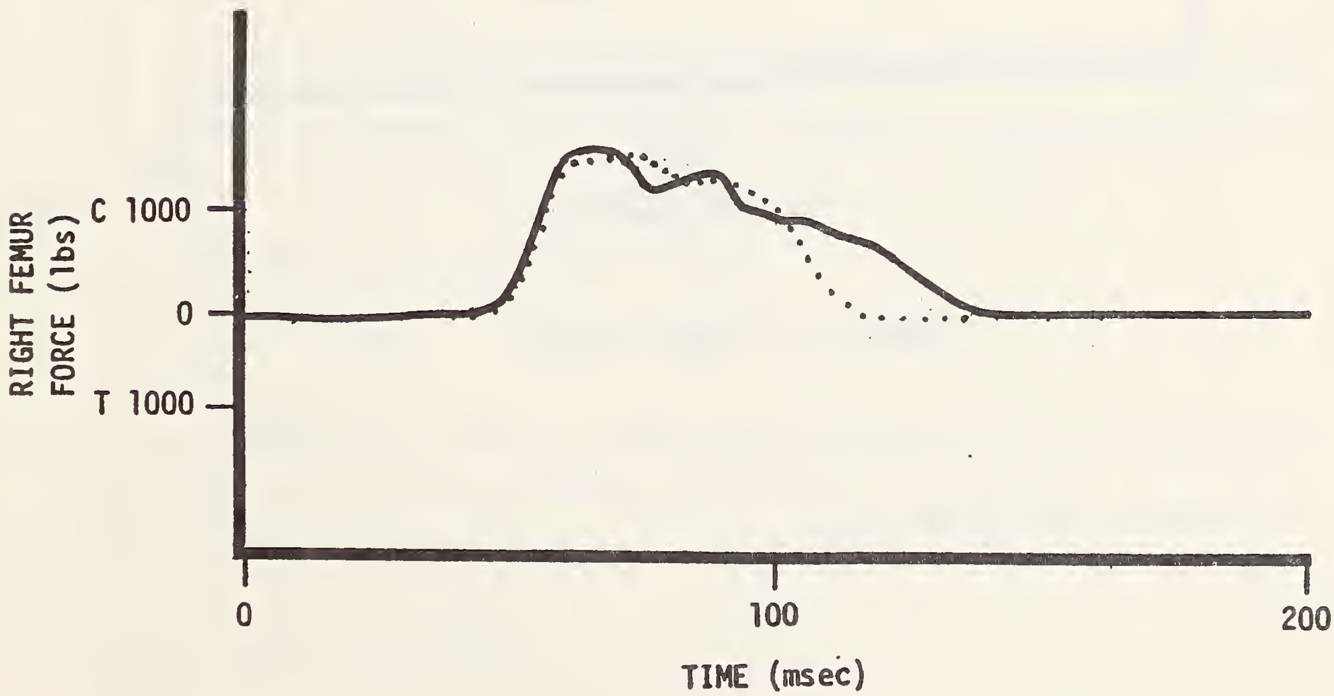



FIGURE 9. FEMUR LOADS

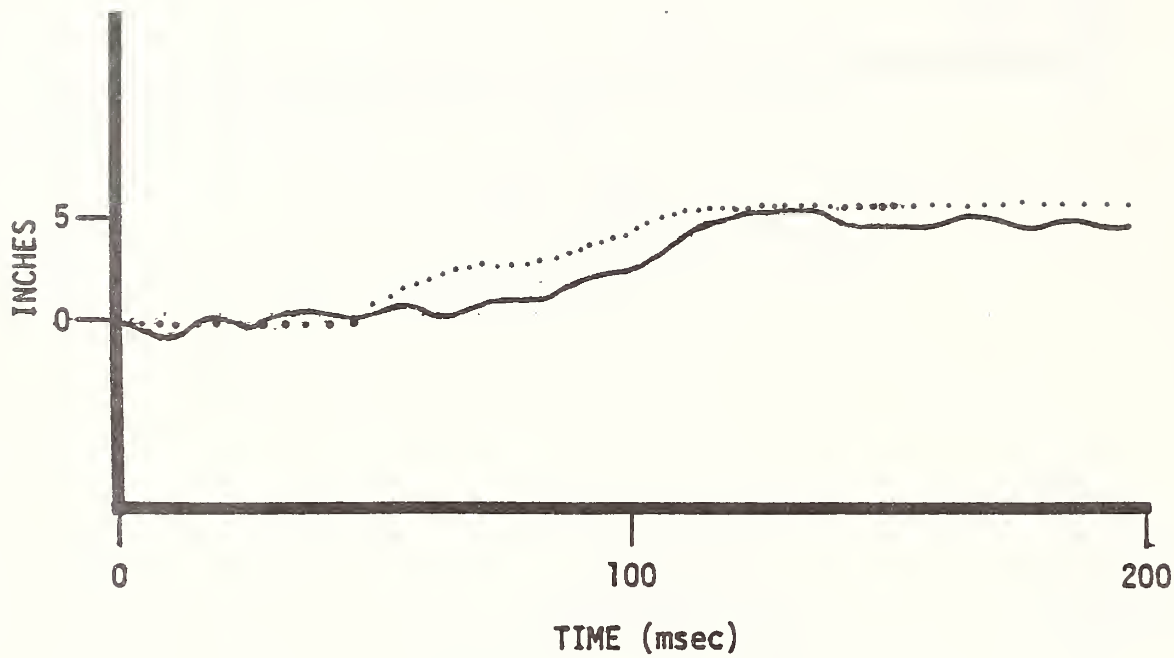



FIGURE 10. COLUMN COLLAPSE

The actual HIC for the sled test was 130 with $t_1$=42 msec and $t_2$ =163 msec. The computer simulation calculated an HIC of 158 with $t_1$=50 msec and $t_2$=130 msec.

# 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) $X_T = X_L + r_T \, SIN\theta_T$

(3) $Y_T = r_T \, COS\theta_T$

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

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

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

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

MATHEMATICAL MODEL

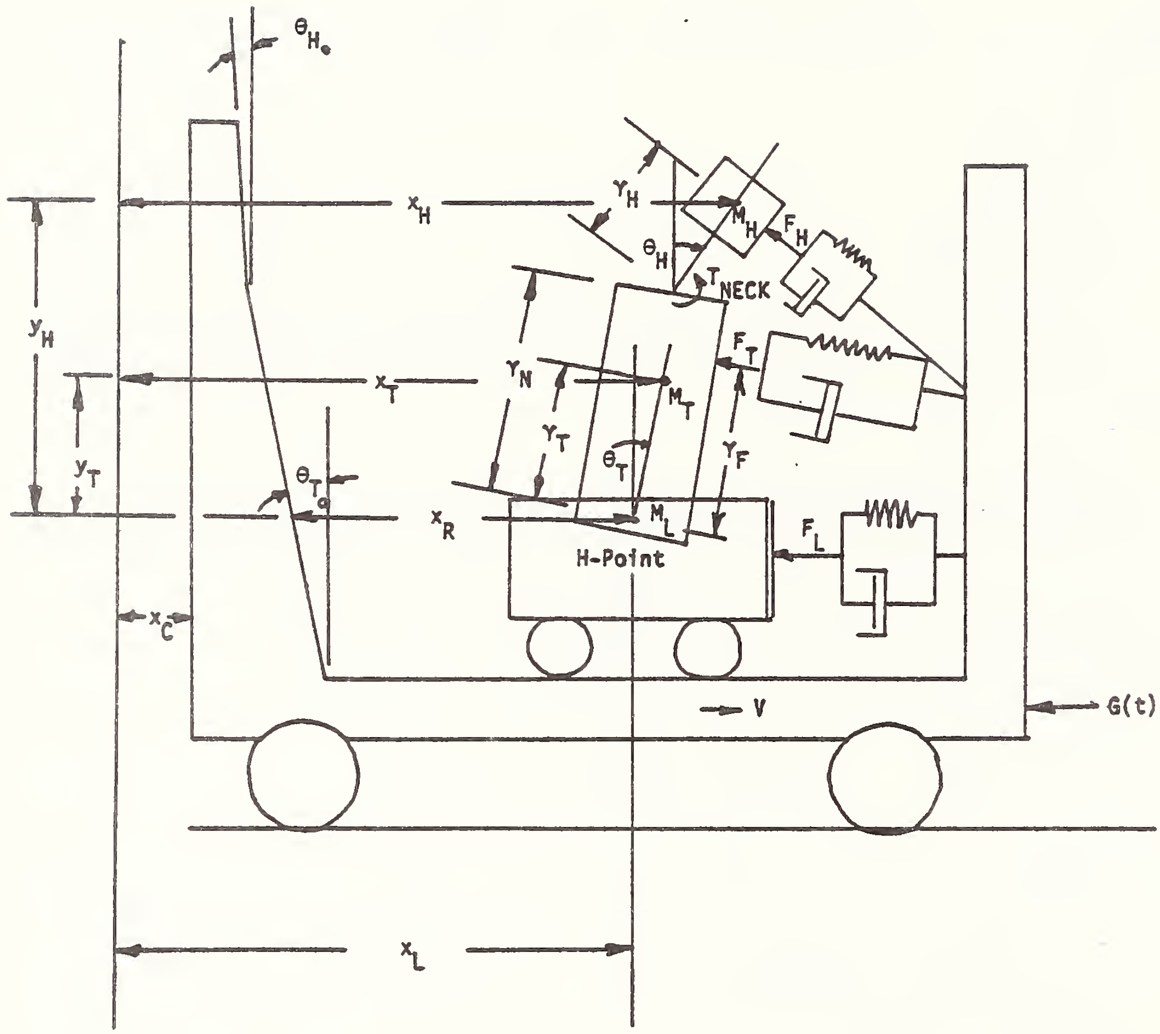



Figure A-1. Geometrical Representation of the Driver-Airbag Interaction

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

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

where:

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

$r_N$ = Distance from H-point to neck pivot point

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

$\theta_H$ and $\theta_T$ are as defined in Figure A-1.

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

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

The potential energy portion of the Lagrangian is:

(11) $V_T = M_T \, g \, r_T \, COS\theta_T$

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

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

Writing the Lagrangian, we have:

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

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

The basic equation in Lagrangian mechanics is:

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

where:

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

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

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

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

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

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

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

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

$$(19)\quad \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}_T}\right) = M_T (\ddot{X}_L r_T \text{COS}\theta_T - \dot{X}_L r_T \text{SIN}\theta_T \dot{\theta}_T + r_T^2 \ddot{\theta}_T$$

$$+ M_H \Big[ \ddot{X}_L r_N \text{COS}\theta_T - \dot{X}_L r_N \text{SIN}\theta_T \dot{\theta}_T - r_N r_H (\text{SIN}\theta_T \dot{\theta}_T \text{COS}\theta_H \dot{\theta}_H$$

$$+ \text{COS}\theta_T \text{SIN}\theta_H \dot{\theta}_H^2 - \text{COS}\theta_T \text{COS}\theta_H \ddot{\theta}_H - \text{COS}\theta_T \dot{\theta}_T \cdot \text{SIN}\theta_H \dot{\theta}_H$$

$$- \text{SIN}\theta_T \text{COS}\theta_H \dot{\theta}_H^2 - \text{SIN}\theta_T \text{SIN}\theta_H \ddot{\theta}_H) + r_N^2 \ddot{\theta}_T^2 \Big]$$

$$(20)\quad \frac{\partial L}{\partial \theta_T} = -M_T \dot{X}_L r_T \text{SIN}\theta_T \dot{\theta}_T - M_H r_N (\text{SIN}\theta_T \dot{\theta}_T \dot{X}_L + r_H \text{SIN}\theta_T \text{COS}\theta_H \cdot$$

$$\dot{\theta}_T \dot{\theta}_H - r_H \text{COS}\theta_T \text{SIN}\theta_H \dot{\theta}_T \dot{\theta}_H) + M_T g r_T \text{SIN}\theta_T + M_H g r_N \text{SIN}\theta_T$$

$$(21)\quad \frac{\partial L}{\partial \dot{\theta}_H} = M_H \Big[ \dot{X}_L r_H \text{COS}\theta_H + r_N r_H (\text{COS}\theta_T \text{COS}\theta_H \dot{\theta}_T + \text{SIN}\theta_T \text{SIN}\theta_H \dot{\theta}_T)$$

$$+ r_H^2 \dot{\theta}_H \Big]$$

$$(22)\quad \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}_H}\right) = M_H \Big[ \ddot{X}_L r_H \text{COS}\theta_H - \dot{X}_L r_H \text{SIN}\theta_H \dot{\theta}_H - r_N r_H (\text{SIN}\theta_T \text{COS}\theta_H \dot{\theta}_T^2$$

$$+ \text{COS}\theta_T \text{SIN}\theta_H \dot{\theta}_T \dot{\theta}_H - \text{COS}\theta_T \text{COS}\theta_H \ddot{\theta}_T - \text{COS}\theta_T \text{SIN}\theta_H \dot{\theta}_T^2$$

$$- \text{SIN}\theta_T \text{COS}\theta_H \dot{\theta}_T \dot{\theta}_H - \text{SIN}\theta_T \text{SIN}\theta_H \ddot{\theta}_T) + r_H^2 \ddot{\theta}_H \Big]$$

$$(23)\quad \frac{\partial L}{\partial \theta_H} = - M_H r_H \Big[ \text{SIN}\theta_H \dot{\theta}_H \dot{X}_L + r_N (\text{COS}\theta_T \text{SIN}\theta_H \dot{\theta}_T \dot{\theta}_H - \text{SIN}\theta_T \text{COS}\theta_H \times$$

$$\dot{\theta}_T \dot{\theta}_H) + M_H g r_H \text{SIN}\theta_H \Big]$$

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

$$(24)\quad (M_L + M_T + M_H) \ddot{X}_L - M_T r_T \text{SIN}\theta_T \dot{\theta}_T^2 - M_H (r_N \text{SIN}\theta_T \dot{\theta}_T^2 + r_H \text{SIN}\theta_H \dot{\theta}_H^2)$$

$$+ M_T r_T \text{COS}\theta_T \ddot{\theta}_T + M_H (r_N \text{COS}\theta_T \ddot{\theta}_T + r_H \text{COS}\theta_H \ddot{\theta}_H) = F_{XL}$$

which is the equation of motion for mass $M_L$.

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

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

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

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

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

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

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

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:

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

$$- COS\theta_T \, SIN\theta_H \, \dot{\theta}_T^2 - SIN\theta_T \, SIN\theta_H \, \ddot{\theta}_T) + r_H^2 \, \ddot{\theta}_H \Big]$$

$$- M_H \, g \, r_H \, SIN\theta_H = F_{\theta H} \quad ,$$

which is the equation of motion for the head mass.

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

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

$$- (M_T \, r_T + M_H r_N) \, \ddot{\theta}_T \, COS\theta_T - M_H \, r_H \, \ddot{\theta}_H \, COS\theta_H \Big\} \quad .$$

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

$$(28) \quad \ddot{\theta}_T = \frac{1}{M_T \, r_T^2 + M_H \, r_N^2} \Big\{ F_{\theta T} - (M_T \, r_T + M_H \, r_N) \, \ddot{X}_L \, COS\theta_T$$

$$- M_H \, r_N \, r_H \Big[ \ddot{\theta}_H \, (COS\theta_H \, COS\theta_T + SIN\theta_H \, SIN\theta_T)$$

$$+ \dot{\theta}_H^2 \, (-SIN\theta_H \, COS\theta_T + COS\theta_H \, SIN\theta_T) \Big]$$

$$+ M_T \, g \, r_T \, SIN\theta_T + M_H \, g \, r_N \, SIN\theta_T \Big\} \quad .$$

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

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

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

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

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

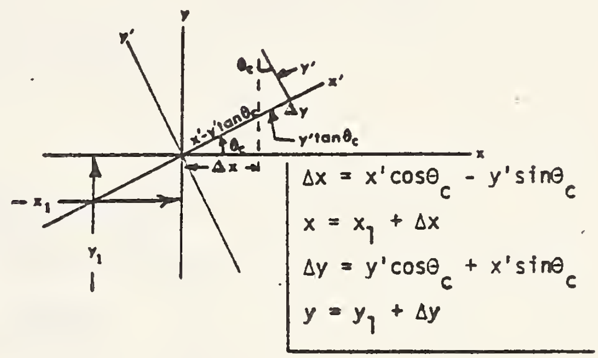
### COORDINATE TRANSFORMATION EQUATIONS

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

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

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

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




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

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

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

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

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

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

Substituting Equation 7 into Equation 6 yields:

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

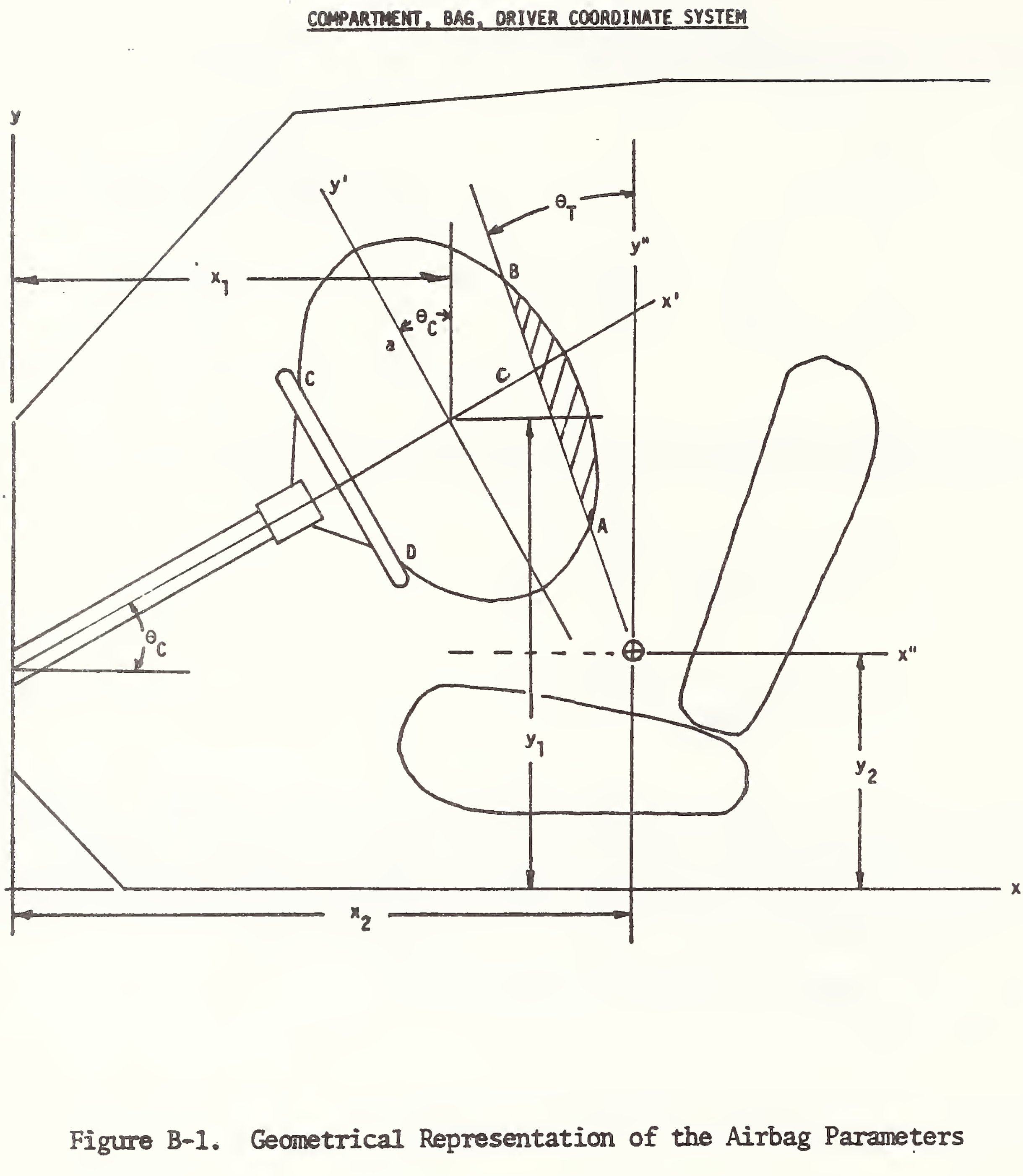



Figure B-1. Geometrical Representation of the Airbag Parameters

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

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

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

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

$$y'\ (\text{COS}\theta_c + m\ \text{SIN}\theta_c) = B + x'\ (m\ \text{COS}\theta_c - \text{SIN}\theta_c)$$

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

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

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

Substituting Equations 10 and 11 and collecting terms:

$$x'^2\,[a^2\,(\text{COS}\theta_c + m\ \text{SIN}\theta_c)^2 + c^2(-\text{SIN}\theta_c + m\ \text{COS}\theta_c)^2]$$

$$+ 2\,Bc^2x'\ (m\ \text{COS}\theta_c - \text{SIN}\theta_c) + B^2\,c^2 - a^2\,c^2\,(\text{COS}\theta_c + m\ \text{SIN}\theta_c)^2 = 0 \quad ,$$

which is a quadratic equation in terms of x'.

Let $A = a^2\,(\text{COS}\theta_c + m\ \text{SIN}\theta_c)^2 + c^2 -(\text{SIN}\theta_c + m\ \text{COS}\theta_c)^2$

$$D = 2\,B\,c^2\,(m\ \text{COS}\theta_c - \text{SIN}\theta_c)$$

$$E = B^2\,c^2 - a^2\,c^2\,(\text{COS}\theta_c + m\ \text{SIN}\theta_c)^2$$

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

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

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

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

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

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

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

The pressure forces act normal to the head and chest:

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

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

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

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

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

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

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

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

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

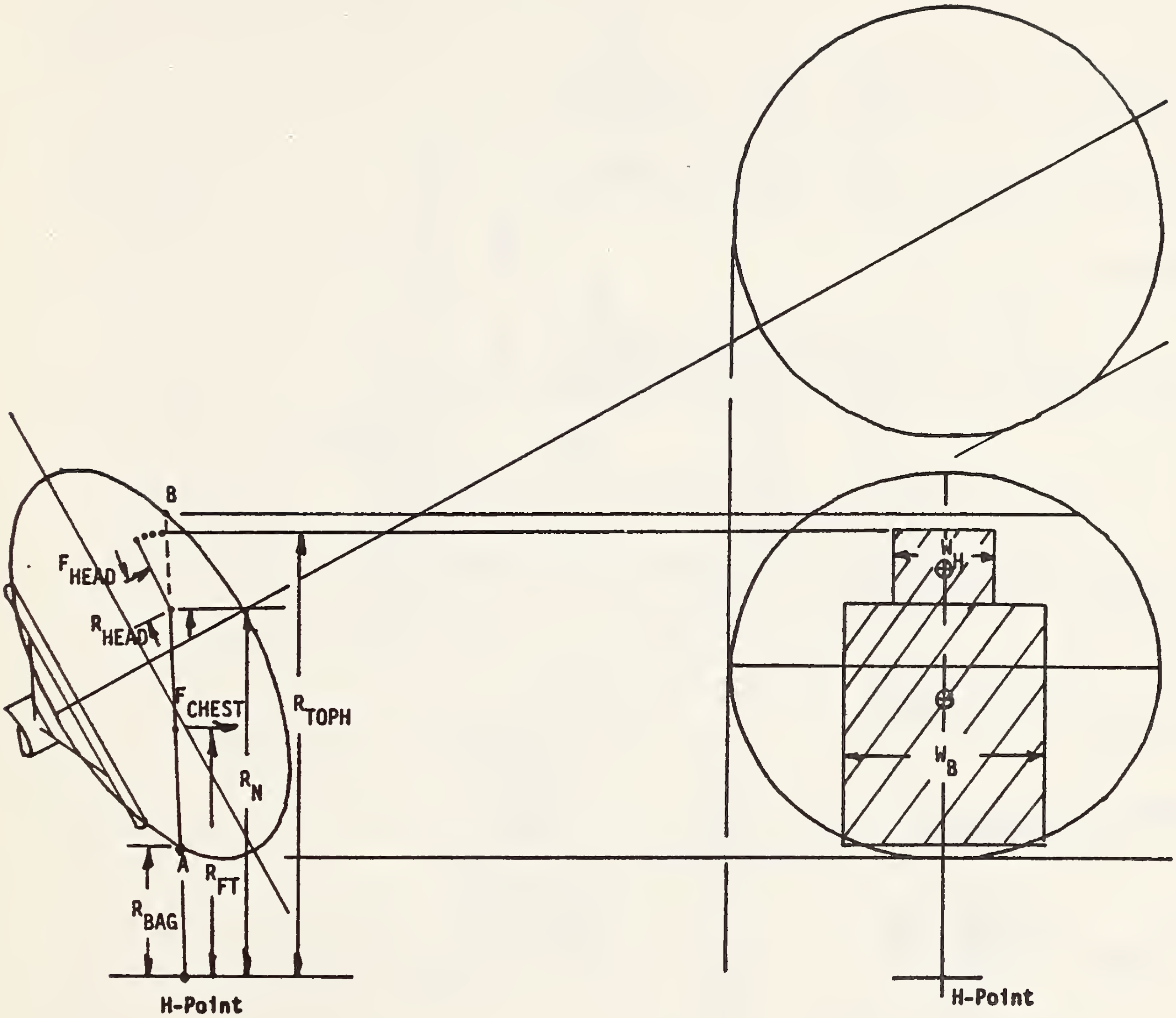



Figure B-2. Head-Bag Interaction Forces Diagram

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

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

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

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

The equation for $R_{FT}$ is:

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

where:

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

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

The equation for $R_{HEAD}$ is:

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

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

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

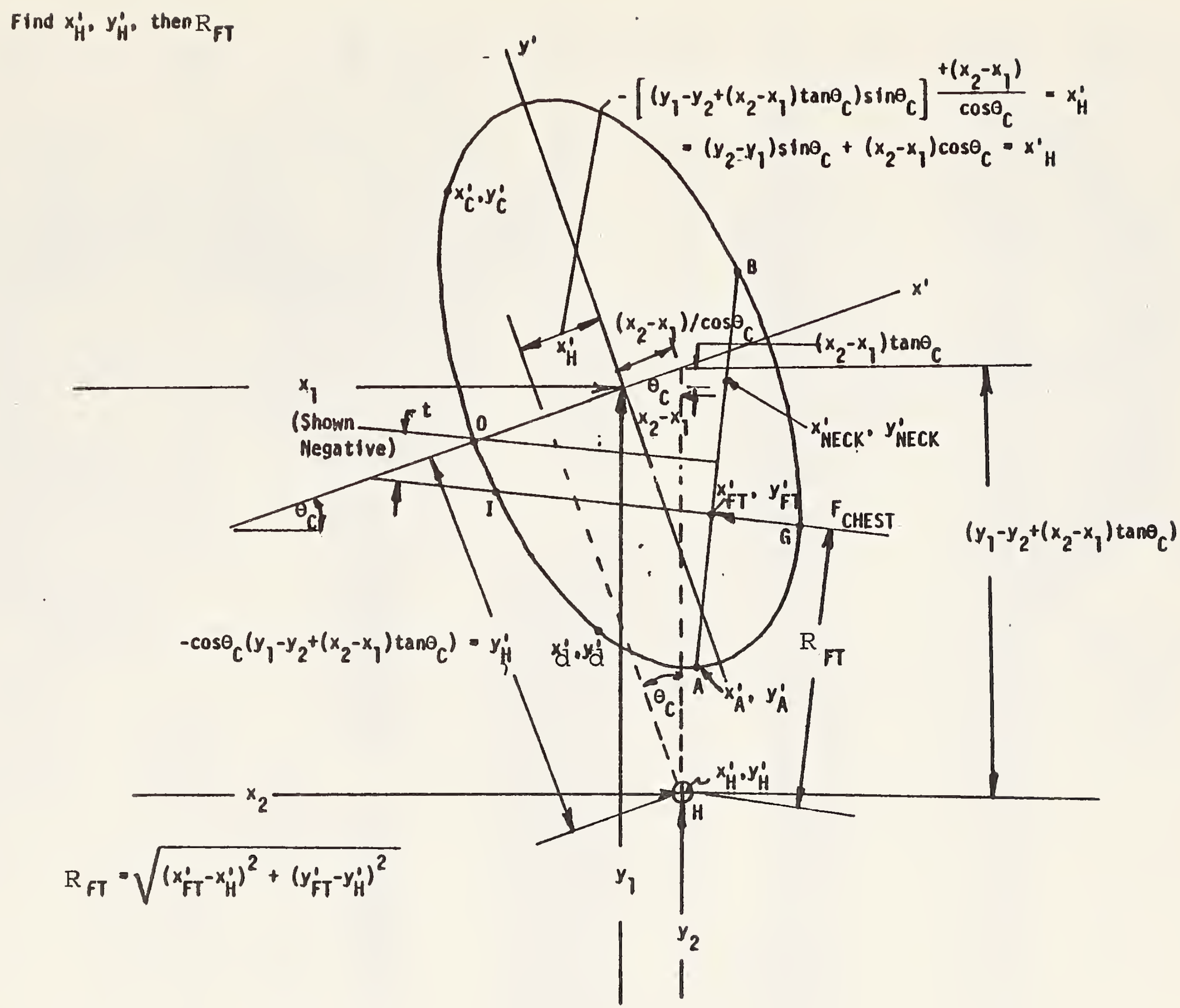
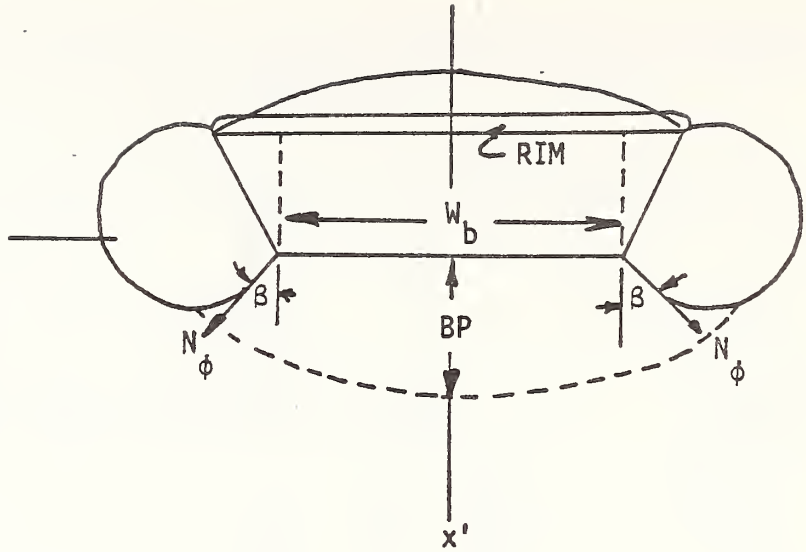



Figure B-3. H-Point Location in x'-y' Coordinate System

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




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

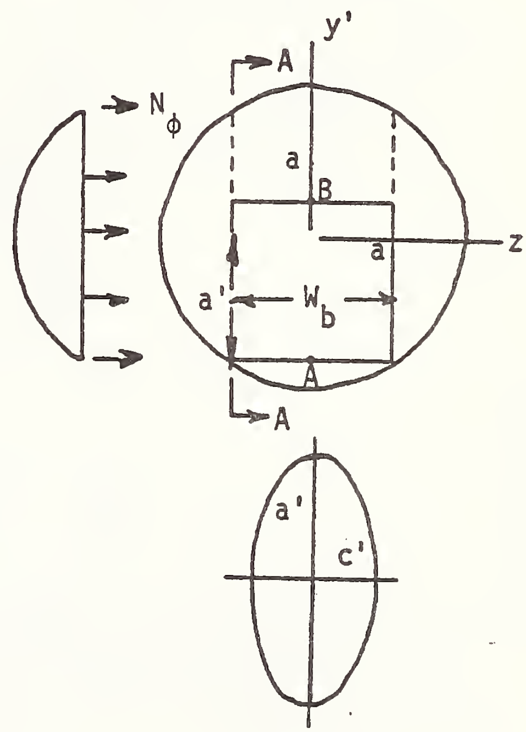
The force $N_\phi$ is the tensile force in the bag.

At $z = \frac{W_b}{2}$, $N_\phi$ is obtained by a force balance.

$N_\phi$ x perimeter of Section A-A = P x Area A-A,

or

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



Sect A-A

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

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

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

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

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

For the x,z plane:

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

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

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

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

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

The perimeter is given by:

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

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

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

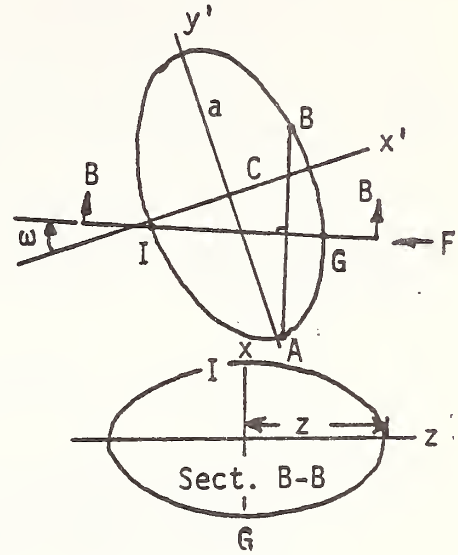
Substituting (28) and (29) into (32):

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

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

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

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



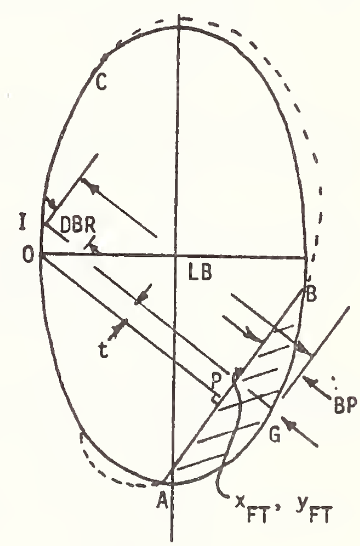

Calculate BP and GI

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

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

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

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




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

or, rewriting the equation,

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

The equation for the mid-plane of the ellipse is

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

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

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

Let

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

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

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

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

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

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

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

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

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

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

In the plane x' y',

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

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

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

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

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

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

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

which is the length of the other axis.

Finally,

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

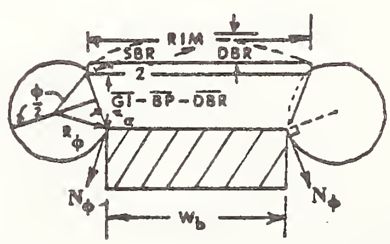
where GI and z are given by Equations 42 and 44, respectively.

For constant perimeter for section B-B,

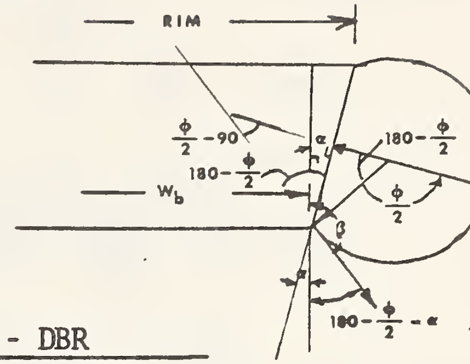
$$SBR \cong 2\sqrt{\left(\frac{RIM}{2}\right)^2 + \overline{DBR}^2} \; .$$

$$(46) \qquad \frac{Per_{BB} - W_b - SBR}{2} = R_\phi \phi$$

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



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




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

Solving (46) & (47) simultaneously gives:

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

Equation (49) must be solved numerically for $\phi$.

The fabric tension force can now be calculated.

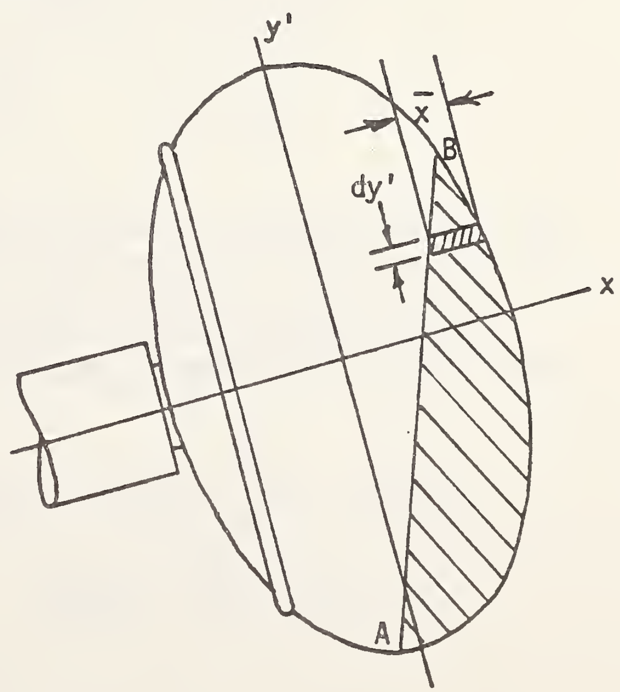
$$\begin{aligned}(50) \quad F_{FT} &= 2N_\phi \overline{AB}\ \text{COS}(180 - (\phi/2 + \alpha)) \\ &= -2N_\phi \overline{AB}\ \text{COS}(\phi/2 + \alpha) \\ &= -2N_\phi \overline{AB}\ \text{COS}\beta,\end{aligned}$$

where $N_\phi$ is given by Equation 33. $\overline{AB}$ is given by $\overline{AB} = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2}$, $\phi$ is given by Equation 49, and $\alpha$ is given by Equation 48.

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

Volume Analysis

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




where,

$$\bar{x} = x_{BAG} - x_{\substack{LINE \\ AB}}$$

for a given $y'$ between $y_B$ and $y_A$.

For $x_{BAG}$,

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

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

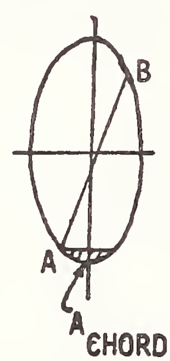
(52) $$BAG = \frac{c}{2a}\left[y'\sqrt{a^2 - y'^2} + a^2 \text{SIN}^{-1}\left(\frac{y'}{a}\right)\right]_{y'_A}^{y'_B} .$$

For $XLINE_{AB}$, using analytic geometry,

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

Therefore,

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




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

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

$$AOI = BAG - LINE + ACHORD$$

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

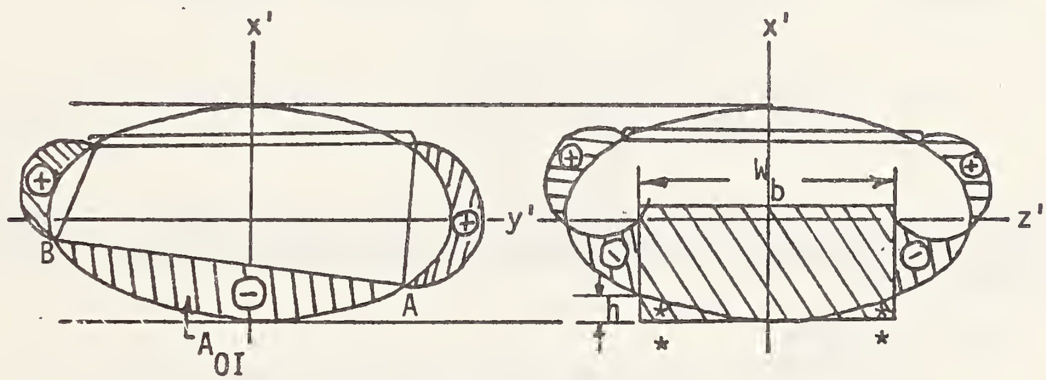
$$\text{VOI} \cong (\text{AOI})W_{AVG} \quad .$$

(54) $$\text{VOI} \cong W_{AVG} \left\{ \frac{c}{2a} \left[ y'\sqrt{a^2 - y'^2} + a^2 \text{SIN}^{-1}\left(\frac{y'}{a}\right) \right] \right.$$

$$\left. \frac{-1}{m\text{COS}\theta_c - \text{SIN}\theta_c} \left[ \frac{(\text{COS}\theta_c + m\text{SIN}\theta_c)y'^2}{2} - By' \right] \right\}_{y'_A}^{y'_B} ,$$

where

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




SIDE VIEW TOP VIEW

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

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

where

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

in

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

so that

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

and,

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

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

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

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

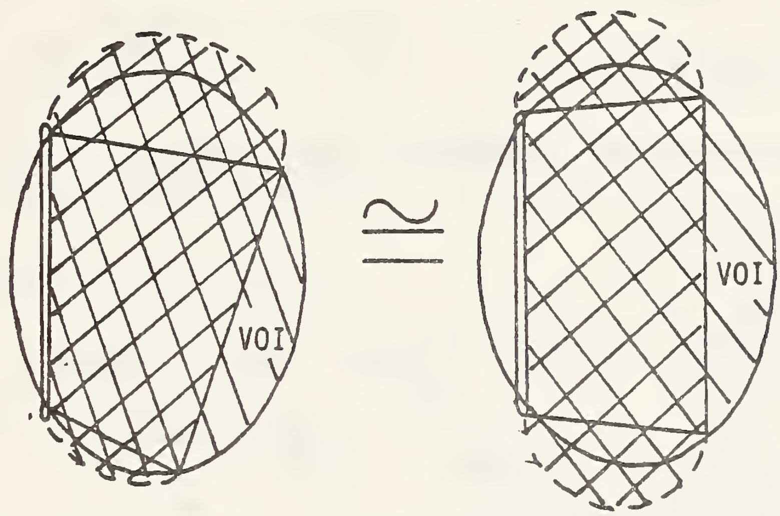
$$V_{BAG,\ ORIG.} = 4/3\pi\ a^2c = 4/3\pi\ (13)^2(6) = 4244 \text{ cubic inches}$$

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

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

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

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




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

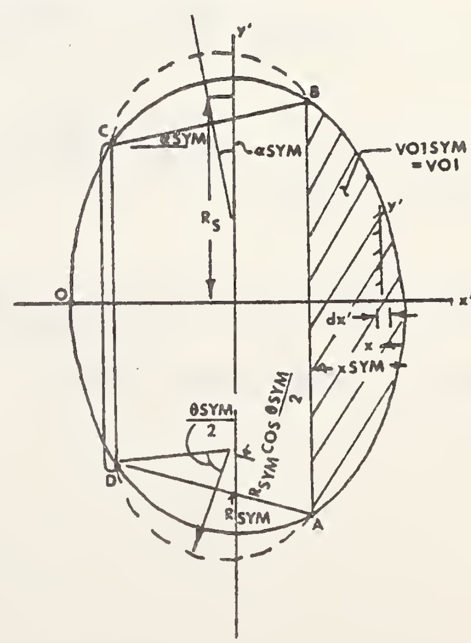
For subsequent volume computations we use the actual volume of intercept for a link in order to change the assymmetrical problem into a symmetrical one.

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

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

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

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



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

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

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

For constant periphery;

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

Rewriting (60);

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

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

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

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

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

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

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

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

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

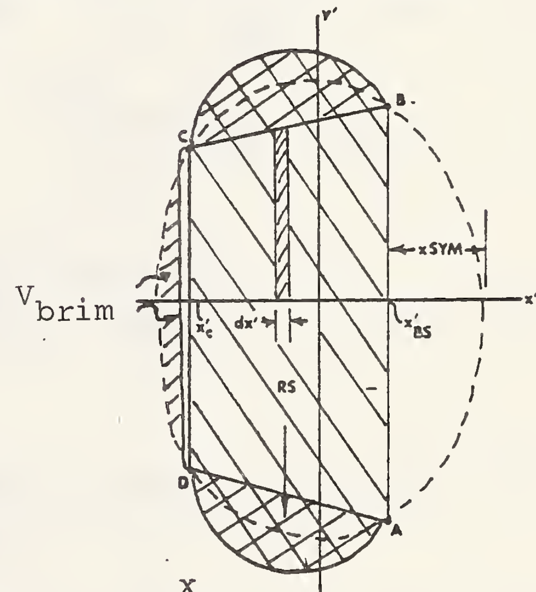
$$(65)\quad \overline{\mathrm{BCSYM}} = \sqrt{(x'_B - x'_C)^2 + (y'_B - y'_C)^2} \qquad \text{(known)}$$

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

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

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

Now to calculate the bag volume.




$$(67)\quad V_{ABCD} = \pi \int_{c-x\mathrm{SYM} = x_B}^{x_C} y'^2\, dx' \qquad \text{where,}$$

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

Substituting (68) into (67):

$$(69)\quad V_{ABCD} = \pi\left[\left(\frac{y_{BS} - y_C}{x_{BS} - x_C}\right)^2 \int_{x_B}^{x_C} (x' - x_C)^2\, dx' + y_C^2 \int_{x_B}^{x_C} dx' + 2y_C\left(\frac{y_{BS} - y_C}{x_{BS} - x_C}\right)\int_{x_B}^{x_C} (x' - x_C)\, dx'\right]$$

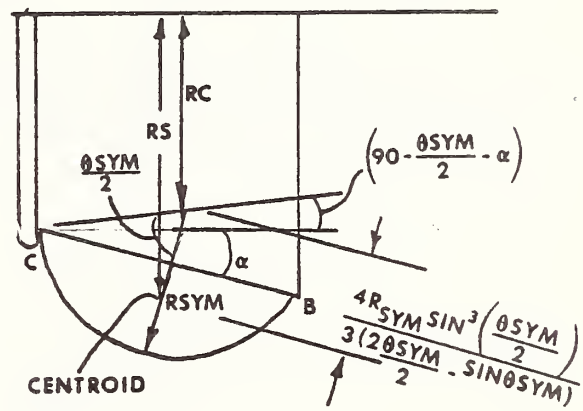
where $V_{ABCD}$ is the volume enclosed by the frustum ABCD.

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

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

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

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




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

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

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

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

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

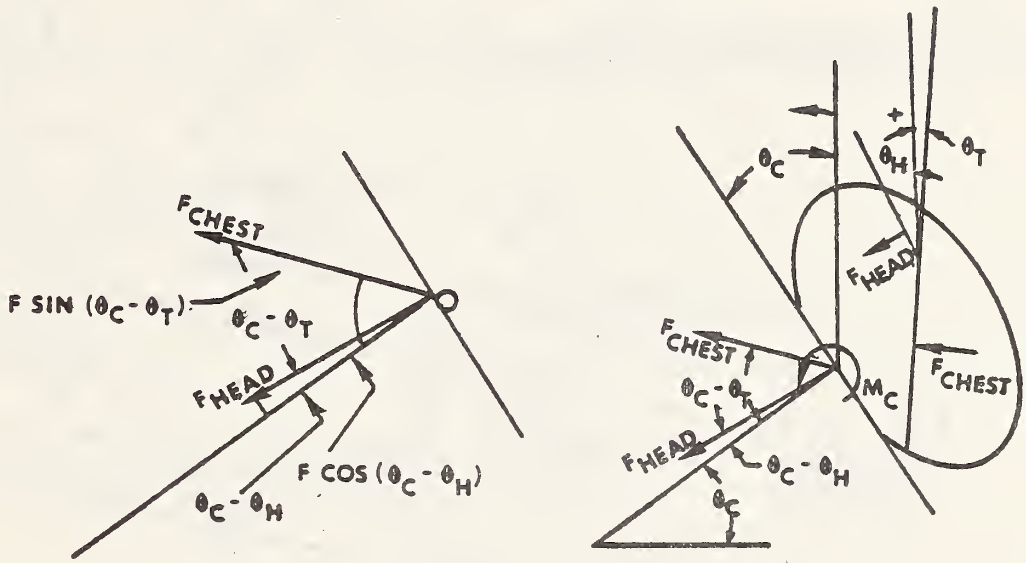
For any $\overline{AB}$ resulting from a calculated volume of intercept, VOI.

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

APPENDIX C

# DERIVATION OF THE STEERING COLUMN ALGORITHM

## COLUMN FORCE CALCULATIONS




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

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

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

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

The total moment acting at point O is given by:

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

GM Type Column

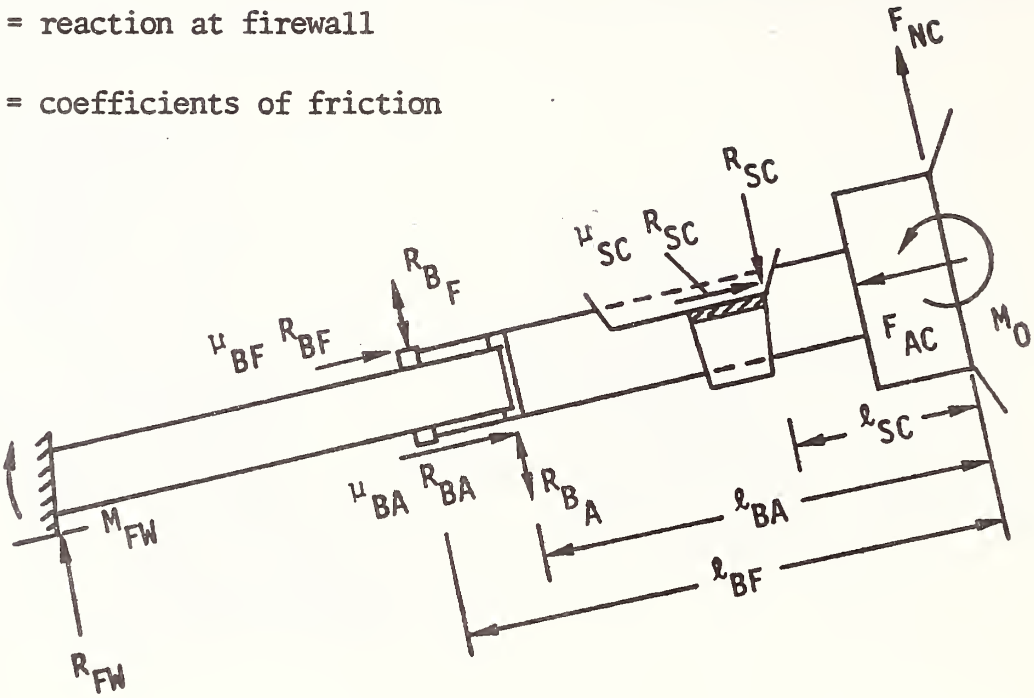
$R_{SC}$ = reaction at shear capsule

$R_{BA}$ = reaction at aft bushing

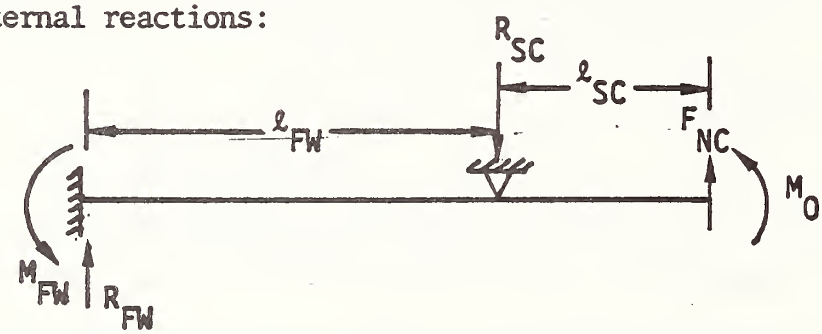
$R_{BF}$ = reaction at forward bushing

$R_{FW}$ = reaction at firewall

μ's = coefficients of friction




Solve for external reactions:




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

(79) $$R_{SC} = F_{NC} + \frac{\frac{3}{2}(M_0 + F_{NC}\,\ell_{SC})}{\ell_{FW}}$$

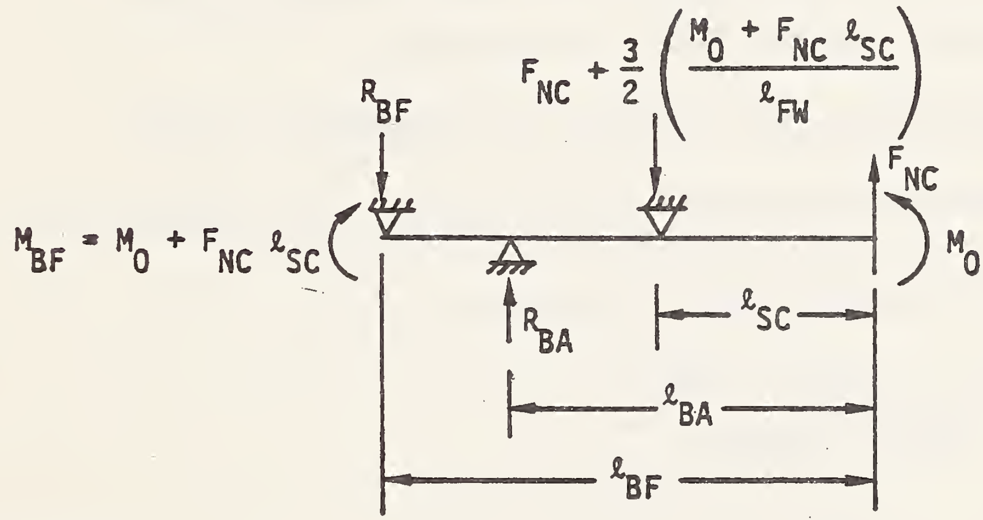
(80) $$R_{FW} = \frac{3}{2}\left(\frac{M_O + F_{NC}\,\ell_{SC}}{\ell_{FW}}\right)$$

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

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

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

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




Solving for $R_{BA}$,

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

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

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

Solving for $R_{BF}$,

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

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

Solve for "t" the moment arm for $F_P$.

The methodology for this calculation is as follows:

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

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

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

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

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

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

$$m' = \frac{m\,COS\theta_C - SIN\theta_C}{COS\theta_C + m\,SIN\theta_C}$$

For a line perpendicular to this line,

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

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

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

Rewriting the equation,

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

The distance t is given by

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

$t > 0$ for $x'_{FT}, y'_{FT}$ above a parallel line through point 0.

$t < 0$ for $x'_{FT}, y'_{FT}$ below a parallel line through point 0.

## Appendix D - DRAC Program Listing



```
DRAC        12/01/81

100C                        *** DRAC ***
110C
120C
130C       THIS PROGRAM PREDICTS THE DRIVER KINEMATICS IN A CRASH SITUATION
140C       IN WHICH THE DRIVER IS RESTRAINED BY AN AIRBAG AND KNEE RESTRAINT.
150C       THE AIRBAG IS ATTACHED TO A STEERING COLUMN AND WHEEL THAT COLLAPSES
160C       ACCORDING TO A PREDETERMINED FORCE-CRUSH CHARACTERISTIC.
170C       THE KNEE RESTRAINT ABSORBS THE KINETIC ENERGY OF THE LOWER BODY AND,
180C       LIKE THE COLUMN, CRUSHES ACCORDING TO A PREDETERMINED FORCE-CRUSH
190C       CHARACTERISTIC.
200C       THE DRIVER IS MODELED BY THREE MASSES-A HEAD MASS, A TORSO MASS AND
210C       A LOWER BODY MASS. THE DRIVER IS CONSTRAINED TO HAVE PLANAR MOTION
220C       SO THAT THE PROGRAM IS STRICTLY APPLICABLE ONLY TO FRONTAL CRASH
230C       SITUATIONS.
240C       EVALUATIONS OF  AIRBAG, STEERING WHEEL, STEERING COLUMN, KNEE
250C       RESTRAINT AND VEHICLE PERFORMANCE CAN BE MADE BY APPROPRIATE CHANGES
260C       IN THE DESIGN PARAMETERS.
270C       TYPICAL DESIGN PARAMETERS THAT CAN BE EVALUATED ARE BAG SIZE, BAG
280C       SHAPE, INFLATION CHARACTERISTICS, VENT AREA, STEERING COLUMN AND/OR
290C       STEERING WHEEL CRUSH CHARACTERISTICS, KNEE RESTRAINT CRUSH CHAR-
300C       ACTERISTICS, STEERING COLUMN SUPPORT STRUCTURE STIFFNESS, AS WELL AS
310C       OTHER SYSTEM PARAMETERS.
320C       THIS PROGRAM IS SELF CONTAINED IN THAT NO EXTERNAL FUNCTIONS OR
330C       SUBROUTINES ARE REQUIRED.
340C
350C            AUTHOR:   MICHAEL FITZPATRICK
360C                      FITZPATRICK ENGINEERING
370C                      WARSAW, INDIANA  46580
380C                      TEL:   (219)-267-4437
390C                      DEC. 1, 1981
400C
410C
420C
430        FILENAME INFILE
440        REAL MU,LSCZ,LFWZ,LBAZ,LBFZ,KRN
450        COMMON/OUT/NPD,T(35),X0(6,35),X1(6,35),X2(6,35),X3(6,35),X4(6,35),
460        &X5(5,35)
470        COMMON/OUT1/N6,X6(4,50),T6(50)
480        COMMON/NAME/INFILE
490        COMMON/AIC/TAIC(175),ARGS(175),PINT1
500   1050 PRINT ,"INPUT FILE NAME"
510        INPUT ,INFILE
520        NPD=0
530        N6=0
540        CALL SOLVE(8)
550        IF(NPD.GT.35)NPD=35
560        IF(N6.GT.50)N6=50
570   1120 FORMAT(1H-)
580   1125 FORMAT(F7.4,2F6.1,2F7.2,2F8.3,F8.1,2F7.2)
590   1130 FORMAT(1X,7F11.2)
```

```
1140 FORMAT(V)
1150 FORMAT(1X,7(4X,"=======")//)
     PRINT 1120
1155 FORMAT(1X,"       TIME      CHEST AP   CHEST SI   HEAD AP
     &    HEAD SI"/1X,"       (MS)        (G'S)        (G'S)        (G'S)
     &       (G'S)")
     PRINT 1155
     PRINT 1150
     DO 1166 K=1,N6
1160 PRINT 1130,T6(K),(X6(J,K),J=1,4)
     PRINT 1120
 1170 FORMAT(1X,"       TIME      VEH G'S     VEH VEL     VEH DISP    BODY
     & G'S  COL DISP    BAG PRESS"/1X,"       (MS)        (G'S)        (MPH)
     &      (INCHES)       (G'S)      (INCHES)    (PSIG)")
     PRINT 1170
     PRINT 1150
      DO 1221 K=1,NPD
1221 PRINT 1130,T(K),(X0(J,K),J=1,6)
     PRINT 1120
1223 FORMAT(1X,"       TIME      H-P DISP   H-P VEL     H-P ACC    FEM FO
     &RCE   SEAT FR.    H-P R.D."/1X,"       (MS)       (INCHES)      (MPH)
     &       (G'S)        (LBS)        (LBS)       (INCHES)")
     PRINT 1223
     PRINT 1150
     DO 1230 K=1,NPD
1230 PRINT 1130,T(K),(X1(J,K),J=1,6)
     PRINT 1120
1250 FORMAT(1X,"       TIME    TORSO DISP  TORSO ANG   TORSO VEL  TORSO
     & ACC  TORSO R.D.  TORSO R.V."/1X,"       (MS)     (INCHES)
     &      (DEG)       (D/SEC)     (D/SEC**2)   (INCHES)      (MPH)")
     PRINT 1250
     PRINT 1150
     DO 1310 K=1,NPD
1310 PRINT 1130,T(K),(X2(J,K),J=1,6)
     PRINT 1120
1330 FORMAT(1X,"       TIME     HEAD DISP    HEAD ANG    HEAD VEL  HEAD
     & ACC    HEAD R.D.   HEAD R.ANG"/1X,"       (MS)     (INCHES)
     &      (DEG)       (D/SEC)     (D/SEC**2)   (INCHES)      (DEG)")
     PRINT 1330
     PRINT 1150
      DO 1380 K=1,NPD
 1380 PRINT 1130,T(K),(X3(J,K),J=1,6)
      PRINT 1120
 1400 FORMAT(1X,"       TIME    COL AX FOR   COL N FOR   COL MOMENT COL
      & RESIST COL STROKE COL ST VEL"/1X,"       (MS)         (LBS)
      &       (LBS)       (IN-LBS)      (LBS)       (INCHES)    (IN/SEC)")
      PRINT 1400
      PRINT 1150
      DO 1460 K=1,NPD
 1460 PRINT 1130,T(K),(X4(J,K),J=1,6)
```

```
      PRINT 1120
 1480 FORMAT(1X,"        TIME      BAG PEN.    BAG VOL.  BAG PRESS.   W/A
     & FORCE   P. FORCE"/1X,"       (MS)      (INCHES)    (CU.IN.)
     &    (PSIG)       (LBS)       (LBS)")
      PRINT 1480
      PRINT 1150
      DO 1540 K=1,NPD
 1540 PRINT 1130,T(K),(X5(J,K),J=1,5)
      PRINT 1120
 1630 PRINT,"ENTER 1 TO CALCULATE HIC"
      INPUT ,NRES
      IF(NRES.NE.1) GO TO 2000
 1640 PEAK=0.
      NSTOP=N6
      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)*PINT1
 1717 CONTINUE
      DELT=THIC(K)
      CHECK=SUM/DELT
      IF(PEAK-CHECK) 1718,1716,1716
 1718 PEAK=CHECK
      TLOW=(L-1)*PINT1
      THIGH=I*PINT1
 1716 CONTINUE
 1715 CONTINUE
      HIC=PEAK**2.5
      PRINT,"THE HIC IS",HIC
      PRINT,"T1=",TLOW
      PRINT,"T2=",THIGH
 2000 STOP
      END
C
C     THIS SUBROUTINE SETS UP THE DIFFERENTIAL EQUATIONS THAT DESCRIBE
C     THE DRIVER KINEMATICS.
      SUBROUTINE DIFEQ(T,Y,DY)
      COMMON/MANDAT/ZL,ZT,ZH,RT,RN,RH,RTOPH,X2Z,Y2Z,WB
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      CALL FORCETH(Y,TNECK)
      CALL DECEL(T,GS)
      CALL BAGSUB(T,Y,TNECK,FTH,FX,FTT,GS)
      SH=SIN(Y(6))
      ST=SIN(Y(7))
      CH=COS(Y(6))
      CT=COS(Y(7))
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      DY(1)=(FX-(ZT*RT+ZH*RN)*(CT*DY(3)-ST*Y(3)*Y(3))
     &-ZH*RH*(CH*DY(2)-SH*Y(2)*Y(2)))/(ZL+ZT+ZH)
      DY(2)=(FTH-ZH*RH*DY(1)*CH-ZH*RN*RH*(CT*CH*DY(3)+CT*SH*Y(3)
     &*Y(3)-ST*CH*Y(3)*Y(3)+ST*SH*DY(3))+ZH*32.17*SH*RH)
     &/(ZH*RH*RH)
      DY(3)=(FTT-(ZT*RT+ZH*RN)*DY(1)*CT-ZH*RN*RH*(CT*CH*DY(2)+Y(2)
     &*Y(2)*(ST*CH-CT*SH)+ST*SH*DY(2))+ZT*32.17*RT*ST+ZH*32.17*RN*ST)
     &/(ZT*RT*RT+ZH*RN*RN)
      DY(4)=-GS
      DY(5)=Y(1)
      DY(6)=Y(2)
      DY(7)=Y(3)
      DY(8)=Y(4)
      RETURN
      END
C
C     THIS SUBROUTINE READS IN THE INPUT DATA, SETS UP THE INPUT DATA
C     FOR DISPLAY AND INITIALIZES KEY VARIABLES.
      SUBROUTINE SETUP(X,Y)
      REAL MU,MC,LSC,LFW,LBA,LBF,LSCZ,LFWZ,LBAZ,LBFZ,KRN
      COMMON/SEATFRIC/NSF,SUN,SFUT,RELSF,SFN(2,24)
      COMMON/KNEEREST/NKR,SKR,RUT,RELKR,KRN(2,24)
      COMMON/NAME/INFILE,OUTFILE
      FILENAME INFILE,OUTFILE
      COMMON/MANDAT/ZL,ZT,ZH,RT,RN,RH,RTOPH,X2Z,Y2Z,WB
      COMMON/NECK/NPN,FNECK(2,24),DCN
      COMMON/VEH/NV,VEHGS(2,20)
      COMMON/GASFLO/NPG,GEN(2,24)
      COMMON/COLFOR/NPC,COL(2,24)
      COMMON/GASDAT/ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
      COMMON/BAGDAT/VC1,VC2,AV,SA,SC,XI,YI
      COMMON/COLDAT/SLIM,THETAC,MU,LSCZ,LFWZ,LBAZ,LBFZ,WC
      COMMON/WHEEL/WA,YO,RIMRAD
      COMMON/PARAM/RFT,THETATZ,THETAHZ
      COMMON/MISC/VCOLCO,SCOLCO,PR8
      COMMON/MMISC/FM2,PA5,GT,FPN,MC,VOLO,GW,LSC,LFW,LBA,LBF
      DOUBLE PRECISION Y(8)
      X=0.
 2070 FORMAT(V)
 2080 FORMAT(1X,"INITIAL VELOCITY:   ",G10.3/1X,
     &"INITIAL HEAD ANGLE:   ",G10.3/1X,"INITIAL TORSO ANGLE:   ",
     &G10.3)
 2100 FORMAT(1X,
     &"        MLEG      MTORSO       MHEAD          RT           RN           RH
     &      RTOPH"/1X,7G10.3)
 2120 FORMAT(1X,"       ATMOP       PGZ        GTZ           U           PN1
     &        PN2        'PN3"/1X,7G10.3)
 2130 FORMAT(1X,"         VC1          VC2          AV           SA           SC
     &          XIZ          YIZ          DCN"/1X,8G10.3)
 2132 FORMAT(1X,"         SLIM        THETAC        MU           LSCZ          LFWZ
```

```
           &       LBAZ        LBFZ         WC"/1X,8G10.3)
      2134 FORMAT(1X,"         WH          YO       RIMRAD       X2Z          Y2Z
           &          WB"/1X,6G10.3)
      2135 FORMAT(1X,"GAS FLOW TIME"/1X,10G10.3)
      2136 FORMAT(1X,"GAS FLOW - LB/SEC"/1X,10G10.3)
      2137 FORMAT(1X,"COLUMN STROKE - INCHES"/1X,10G10.3)
      2138 FORMAT(1X,"COLUMN FORCE - LBS"/1X,10G10.3)
      2140 FORMAT(1X,"NECK ANGLE"/1X,10G10.3)
      2150 FORMAT(1X,"NECK TORQUE"/1X,10G10.3)
      2160 FORMAT(1X,"      NPTS NECK   NPTS KR   NPTS VEH   NPTS SEAT NPTS GAS
           &  NPTS COL    SL:ST     SL:KR"/1X,8G10.3)
      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)
           READ(INFILE,2070)Y(4),Y(6),Y(7)
           READ(INFILE,2070)ZL,ZT,ZH,RT,RN,RH,RTOPH
           READ(INFILE,2070)NPN,NKR,NV,NSF,NPG,NPC,SUN,SKR
           READ(INFILE,2070) (GEN(1,K),K=1,NPG)
           READ(INFILE,2070) (GEN(2,K),K=1,NPG)
           READ(INFILE,2070) (COL(1,K),K=1,NPC)
           READ(INFILE,2070) (COL(2,K),K=1,NPC)
           READ(INFILE,2070)ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
           READ(INFILE,2070)VC1,VC2,AV,SA,SC,X1Z,Y1Z,DCN
           READ(INFILE,2070)SLIM,THETAC,MU,LSCZ,LFWZ,LBAZ,LBFZ,WC
           READ(INFILE,2070)WH,YO,RIMRAD,X2Z,Y2Z,WB
           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)
           MGO=1
           PRINT 2490
           PRINT ,"INPUT VALUES -- INPUT UNITS( MSEC, MPH, DEGREES,
           & INCHES, LBS, FT-LBS, G'S)"
           GO TO 2520
      2480 FORMAT(1X,10G10.3)
      2490 FORMAT(1H-)
      2500 PRINT,"INITIAL VALUES-CONVERTED UNITS(SEC, FT/SEC,
           & RADIANS, FT, LBS, FT-LBS, FT/SEC**2)"
      2520 PRINT 2080,Y(4),Y(6),Y(7)
           PRINT 2100,ZL,ZT,ZH,RT,RN,RH,RTOPH
           PRINT 2160,NPN,NKR,NV,NSF,NPG,NPC,SUN,SKR
           PRINT 2135,(GEN(1,K),K=1,NPG)
           PRINT 2136,(GEN(2,K),K=1,NPG)
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      PRINT 2137, (COL(1,K),K=1,NPC)
      PRINT 2138, (COL(2,K),K=1,NPC)
      PRINT 2265, (SFN(1,K),K=1,NSF)
      PRINT 2267, (SFN(2,K),K=1,NSF)
      PRINT 2140, (FNECK(1,K),K=1,NPN)
      PRINT 2150, (FNECK(2,K),K=1,NPN)
      PRINT 2250, (VEHGS(1,K),K=1,NV)
      PRINT 2260, (VEHGS(2,K),K=1,NV)
      PRINT 2268, (KRN(1,K),K=1,NKR)
      PRINT 2269, (KRN(2,K),K=1,NKR)
      PRINT 2120,ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
      PRINT 2130,VC1,VC2,AV,SA,SC,X1Z,Y1Z,DCN
      PRINT 2132,SLIM,THETAC,MU,LSCZ,LFWZ,LBAZ,LBFZ,WC
      PRINT 2134,WH,YO,RIMRAD,X2Z,Y2Z,WB
      GO TO (2710,3130),MGO
 2710 PRINT 2490
      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)
      ZL=ZL/32.17
      ZT=ZT/32.17
      ZH=ZH/32.17
      RT=RT/12.
      RN=RN/12.
      RH=RH/12.
      RTOPH=RTOPH/12.
      SUN=SUN*12.
      SKR=SKR*12.
      THETAC=THETAC*.01745329
      ADD=SC*SQRT(1.-RIMRAD**2/SA**2)
      X1=X1Z+ADD*COS(THETAC)
      Y1=Y1Z+ADD*SIN(THETAC)
      VCOLCO=0.
      SCOLCO=0.
      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
      MC=WC/386.
      VOLZ=4./3.*3.14159*SA**2*SC
      VOLO=VOLZ
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      GW=(PA*VOLZ)/(U*GTZ)
      LSC=LSCZ
      LFW=LFWZ
      LBA=LBAZ
      LBF=LBFZ
      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=1,30
      VEHGS(1,J)=VEHGS(1,J)/1000.
 3050 VEHGS(2,J)=VEHGS(2,J)*32.17
      SFUT=0.
      RUT=0.
      MGD=2
      GO TO 2500
 3130 CONTINUE
      RETURN
      END
C
C     THIS SUBROUTINE IS A GENERALIZED TABLE LOOKUP AND INTERPOLATION
C     ROUTINE WHICH IS CALLED BY OTHER ROUTINES.
      SUBROUTINE LOOKUP(A,FUN,NPTS,B)
      DIMENSION FUN(2,30)
      DO 3190 J=1,NPTS
 3190 IF(FUN(1,J).GT.A)GOTO3200
 3200 IF(J.EQ.1)J=2
      K=J-1
      B=(A-FUN(1,K))*(FUN(2,J)-FUN(2,K))/(FUN(1,J)-FUN(1,K))+FUN(2,K)
      RETURN
      END
C
C     THIS SUBROUTINE CALCULATES THE NECK TORQUE AS A FUNCTION OF THE
C     NECK ANGLE.
      SUBROUTINE FORCETH(Y,TNECK)
      COMMON/NECK/NPN,FNECK(2,24),DCN
      DOUBLE PRECISION Y(8)
      TNECK=0.
      TDAMP=-DCN*(Y(2)-Y(3))
      VREL=Y(2)-Y(3)
      TREL=Y(6)-Y(7)
      IF(TREL.GT.0.0.AND.VREL.LT.0.)GO TO 10
      IF(TREL.LT.0.0.AND.VREL.GT.0.)GO TO 10
      CALL LOOKUP(TREL,FNECK,NPN,TNECK)
   10 TNECK=TNECK+TDAMP
      RETURN
      END
C
C     THIS SUBROUTINE OBTAINS THE CRASH PULSE G'S AS A FUNCTION OF TIME.
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```
      SUBROUTINE DECEL(T,GS)
      COMMON/VEH/NV,VEHGS(2,30)
      CALL LOOKUP(T,VEHGS,NV,GS)
      RETURN
      END
C
C     THIS SUBROUTINE COMPRISES THE MAJOR PART OF THE DRAC PROGRAM. IT
C     EVALUATES THE BAG SHAPE AS A FUNCTION OF BAG PENETRATION AND TORSO
C     ANGLE, CALCULATES THE FORCES THE BAG APPLIES TO THE DRIVER, CALC-
C     ULATES THE BAG VOLUME AND PRESSURE, DETERMINES THE GAS GENERATOR
C     FLOW CHARACTERISTICS AND CALCULATES THE STEERING COLUMN
C     FORCES, MOMENTS AND STROKE.
      SUBROUTINE BAGSUB(X,Y,TNECK,FTH,FX,FTT,GS)
      REAL MFW,MU,LSC,LFW,LBA,LBF,LFWZ,LSCZ,LBAZ,LBFZ,MD,MC
      REAL KRN
      COMMON/SEATFRIC/NSF,SUN,SFUT,RELSF,SFN(2,24)
      COMMON/MANDAT/ZL,ZT,ZH,RT,RN,RH,RTOPH,X2Z,Y2Z,WB
      COMMON/KNEEREST/AKR,SKR,RUT,RELKR,KRN(2,24)
      COMMON/GASFLO/NPG,GEN(2,24)
      COMMON/COLFOR/NPC,COL(2,24)
      COMMON/GASDAT/ATMOP,PGZ,GTZ,U,PN1,PN2,PN3
      COMMON/BAGDAT/VC1,VC2,AV,SA,SC,X1,Y1
      COMMON/COLDAT/SLIM,THETAC,MU,LSCZ,LFWZ,LBAZ,LBFZ,WC
      COMMON/WHEEL/WH,Y0,RIMRAD
      COMMON/MISC/VCOLCO,SCOLCO,PR8
      COMMON/MMISC/FM2,PA5,GT,FPN,MC,VOLD,GW,LSC,LFW,LBA,LBF
      COMMON/PARAM/RFT,THETATZ,THETAHZ
      COMMON/TIME/STEP,XSTOP
      COMMON/MPARAM/FACOL,SCOLC,PG1,FKNEE,SF,FNCOL,MD,FRCOL,VCOLC
      COMMON/MMPARAM/BP,VOL,FFT,FP
      DOUBLE PRECISION Y(8),B,A,D,E,A1,B1,C1,X2,Y2
    5 FORMAT(1H-)
      DIMENSION DY(8)
      WBACT=WB
      WHACT=WH
      THETAT=Y(7)
      THETAH=Y(6)
C     CHECK TO SEE IF DRIVER SUBMARINING.
      IF(ABS(THETAC-THETAT).GT.1.4) GO TO 500
C     CALCULATE THE SLOPE OF THE DRIVER TORSO.
      OSLOPE=TAN(3.14159/2.+THETAT)
C     CALCULATE THE NEW H-POINT COORDINATES AND THE X-COORDINATE OF THE
C     POINT WHERE THE RIM INTERSECTS THE BAG.
      X2=X2Z-(Y(5)-Y(8))*12.
      Y2=Y2Z
      XC=-SC*SQRT(1.-RIMRAD**2/SA**2)
      B=Y2-Y1-OSLOPE*(X2-X1)
      A=SA**2*(COS(THETAC)+OSLOPE*SIN(THETAC))**2
     &+SC**2*(SIN(THETAC)-OSLOPE*COS(THETAC))**2
      D=2.*B*SC**2*(OSLOPE*COS(THETAC)-SIN(THETAC))
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      E=B**2*(SC**2)-SA**2*(SC**2)*(COS(THETAC)+OSLOPE*SIN(THETAC))**2
C     TEST FOR SIGN OF DISCRIMINATE
    6 IF (B**2-4.*A*E) 80,7,7
C     REAL DISTINCT ROOTS (DEFINITE TORSO AND BAG CONTACT)
    7 DISC=(B**2-4.*A*E)**.5
C     BAG INTERCEPT POINTS, XA,XB AND YA,YB
      XA=(-B-DISC)/(2.*A)
      IF(SC.LE.ABS(XA))XA=ABS(XA)/XA*(SC-.001)
      XB=(-B+DISC)/(2.*A)
      IF(SC.LE.ABS(XB))XB=ABS(XB)/XB*(SC-.001)
      YA=(B+XA*(OSLOPE*COS(THETAC)-SIN(THETAC)))/(COS(THETAC)+OSLOPE*
     &SIN(THETAC))
      IF(SA.LE.ABS(YA))YA=ABS(YA)/YA*(SA-.001)
      YB=(B+XB*(OSLOPE*COS(THETAC)-SIN(THETAC)))/(COS(THETAC)+OSLOPE*
     &SIN(THETAC))
      IF(SA.LE.ABS(YB))YB=ABS(YB)/YB*(SA-.001)
C     ABST=DISTANCE FROM POINT A TO POINT B.
      ABST=SQRT((XA-XB)**2+(YA-YB)**2)
C     X AND Y COORD. OF H-POINT IN XPRIME, YPRIME COORD. SYSTEM
      XH=((Y2-Y1)*SIN(THETAC)+(X2-X1)*COS(THETAC))
      YH=((Y2-Y1)-(X2-X1)*TAN(THETAC))*(+COS(THETAC))
      IF(THETAT-THETAC)8,8,9
    8 YP=YB
      YN=YA
      XP=XB
      XN=XA
      GO TO 10
    9 YP=YA
      YN=YB
      XP=XA
      XN=XB
   10 RBAG=SQRT((XN-XH)**2+(YN-YH)**2)
      IF(ABST+RBAG-12.*RN)11,11,12
   11 XFT=(XA+XB)/2.
      YFT=(YA+YB)/2.
      GO TO 13
   12 XNECK=XN-(RN*12.-RBAG)*SIN(THETAT-THETAC)
      YNECK=YN+(RN*12.-RBAG)*COS(THETAT-THETAC)
      XFT=(XN+XNECK)/2.
      YFT=(YN+YNECK)/2.
C     RFT=DISTANCE FROM H-POINT TO POINT OF FORCE APPLICATION ON TORSO
   13 RFT=SQRT((XH-XFT)**2+(YH-YFT)**2)
C     SLOPE OF LINE PERPENDICULAR TO AB
      PSLOPE=-(COS(THETAC)+OSLOPE*SIN(THETAC))/(OSLOPE*COS(THETAC)
     &-SIN(THETAC))
C     T=MOMENT ARM OF TORSO FORCES
      XO=-SC
      T=(-XFT*PSLOPE+YFT-YO+PSLOPE*XO)/SQRT(PSLOPE**2+1.)
      AI=1./SC**2+PSLOPE**2/SA**2
      BI=2.*PSLOPE/SA**2*(YFT-PSLOPE*XFT)
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      C1=(YFT-PSLOPE*XFT)**2/SA**2-1.
C     POINTS G AND I ARE THE POINTS WHERE THE LINE OF ACTION OF THE FORCE
C     WOULD INTERSECT THE BAG.
      XG=(-B1+SQRT(B1**2-4.*A1*C1))/(2.*A1)
      XI=(-B1-SQRT(B1**2-4.*A1*C1))/(2.*A1)
      YG=PSLOPE*(XG-XFT)+YFT
      YI=PSLOPE*(XI-XFT)+YFT
      YRIM=PSLOPE*(XC-XFT)+YFT
      GI=SQRT((XI-XG)**2+(YI-YG)**2)
C     CALCULATE THE BAG PENETRATION.
      BP=SQRT((XFT-XG)**2+(YFT-YG)**2)
C     DETERMINE THE MIDPOINT OF LINE GI.
      XMGI=(XG+XI)/2.
      YMGI=(YG+YI)/2.
C     CALCULATE MAJOR AXIS LENGTH OF ELLIPSE PERPENDICULAR TO TORSO
      ZP=SQRT(SA**2*(1-XMGI**2/SC**2)-YMGI**2)
C     CALCULATE PERIMETER OF ELLIPSE PERPENDICULAR TO TORSO
      PERBB=2.*3.14159*SQRT(((GI/2.)**2+ZP**2)/2.)
C     SOLVE FOR THE ANGLE(BETA) THAT THE FABRIC TENSION FORCE COMPONENT
C     MAKES WITH RESPECT TO A LINE NORMAL TO THE TORSO. FIRST SOLVE FOR
C     PHI, USING THE NEWTON RAPHSON METHOD OF SOLVING TRANCENDENTAL EQNS.
C     LET PHIO=AN ESTIMATE OF THE ROOT PHI AND EPSLON=THE DESIRED ACC-
C     URACY OF THE ROOT.
      PHIO=3.14
      EPSLON=.00001
      PHI=PHIO
      IF(ABS(YRIM)-RIMRAD)17,16,16
   16 RIM=0.
      GOTO18
C     YRIM" IS THE CHORD LENGTH OF THE RIM AT POINT I.
   17 RIM=SQRT(RIMRAD**2-YRIM**2)*2.
C     FOR BAG PENETRATIONS LESS THAN ONE-HALF THE CHEST THICKNESS, THE
C     BODY WIDTH IN CONTACT WITH THE BAG WILL NOT EXCEED THE LENGTH OF
C     THE BODY IN CONTACT WITH THE BAG.
   18 CHESTT=WBACT/2.5
      IF(BP.LT.CHESTT/2..AND.WBACT.GT.ABST)WB=ABST
      DBR=SQRT((XC-XI)**2+(YRIM-YI)**2)
      SBR=SQRT(.25*RIM**2+DBR**2)*2.
   21 FPHI=(PERBB-WB-SBR)*SIN(PHI/2.)/PHI-(GI-BP-DBR)/(COS(ATAN((WB-RIM)
     &/(2.*(GI-BP-DBR)))))
      DFPHI=(PERBB-WB-SBR)*COS(PHI/2.)/(2.*PHI)-((PERBB-WB-SBR)*SIN(PHI/2.
     &)/PHI**2)
      DEL=-FPHI/DFPHI
      PHI=PHI+DEL
      IF(PHI.GT.2.*3.141593.OR.PHI.LT.0.)GO TO 520
      IF (ABS(DEL).LE.EPSLON) GO TO 22
      GO TO 21
   22 ALPHA=ATAN((WB-RIM)/(2.*(GI-BP-DBR)))
      BETA=PHI/2.+ALPHA
C     SOLVE FOR THE ARC SIN OF YP/SA AND YN/SA.
```

```
C     (comment lines marked C)
   25 ASYPSA=ATAN((YP/SA)/(SQRT(1.-(YP/SA)**2)))
      ASYNSA=ATAN((YN/SA)/(SQRT(1.-(YN/SA)**2)))
C     BAG, TLINE AND ACHORD ARE INTERMEDIATE VALUES REQUIRED FOR THE
C     AREA OF INTERCEPT CALCULATION.
      BAG=SC/(2.*SA)*((YP*SQRT(SA**2-YP**2)+SA**2*ASYPSA)-
     &(YN*SQRT(SA**2-YN**2)+SA**2*ASYNSA))
      TLINE=(XA-(XA-XB)/(YA-YB)*YA)*YP+(XA-XB)/(2.*(YA-YB))*YP**2-
     &(XA-(XA-XB)/(YA-YB)*YA)*YN-(XA-XB)/(2.*(YA-YB))*YN**2
      ACHORD=0.
      IF(XP.LT.0.)ACHORD=SC/SA*(3.141593*SA**2/2.-(YP*SQRT(SA**2-YP**2)
     &+SA**2*ASYPSA))
      IF(XN.LT.0.)ACHORD=ACHORD+SC/SA*(YN*SQRT(SA**2-YN**2)+SA**2*ASYNSA
     &+3.14159*SA**2/2.)
C     SOLVE FOR THE AREA OF INTERCEPT.
      AOI=BAG-TLINE+ACHORD
C     "VOI"=VOLUME OF BAG INTERCEPT.
      WAVG=((RFT-RBAG)*WB+RHEAD*WH)/(RFT-RBAG+RHEAD)
      VOI=WAVG*AOI
C     THE FOLLOWING ROUTINE USES THE NEWTON-RAPHSON METHOD TO SOLVE
C     A CUBIC EQUATION FOR THE BAG PENETRATION THATWOULD EXIST FOR
C     THE SYMMETRICAL CASE WITH A GIVEN VOI.
      ROOTG=0.8*BP
      IF(BP.GE.SC+ABS(XC))ROOTG=SC
      ROOT=ROOTG
   73 FROOT=3.14159*SA**2*(-ROOT**3/(3.*SC**2)+ROOT**2/SC)-VOI
      DFROOT=3.14159*SA**2*(-ROOT**2/SC**2+2.*ROOT/SC)
      DELRT=-FROOT/DFROOT
      ROOT=ROOT+DELRT
      IF(ROOT.GT.2.*SC.OR.ROOT.LT.0.)GO TO 518
      IF (ABS(DELRT).LE.EPSLON) GO TO 74
      GO TO 73
   74 PER=2.*3.14159*SQRT((SA**2+SC**2)/2.)
      BPSYM=ROOT
      ABSYM=2.*SA*SQRT(1.-(SC-BPSYM)**2/SC**2)
      YC=RIMRAD
      OC=SQRT((XC-XO)**2+(YC-YO)**2)
      BCSYMC=(PER-2.*OC-ABSYM)/2.
      XBS=SC-BPSYM
      YBS=ABSYM/2.
C     BEFORE CALCULATING THE LENGTH OF THE LINE BC FOR THE SYMMETRICAL
C     CASE CHECK TO SEE THAT THE HEAD AND CHEST HAVE NOT BOTTOMED
C     OUT ON THE WHEEL RIM. IF THEY HAVE, STOP THE RUN.
      IF(XA.LT.XC.AND.YA.LT.0.) GO TO 510
      IF(XA.LT.XC.AND.YA.GT.0.) GO TO 512
      BCSYMS=SQRT((XBS-XC)**2+(YBS-YC)**2)
C     THE FOLLOWING ROUTINE USES THE NEWTON-RAPHSON METHOD TO SOLVE A
C     TRANCENDENTAL EQUATION SO THAT THE RADIUS AND ANGLE OF THE VERTICAL
C     BAG ENDS CAN BE CALCULATED.
      THEO=3.14
      THE=THEO
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   75 FTHE=BCSYMC*SIN(THE/2.)/THE-BCSYMS/2.
      DFTHE=BCSYMC*COS(THE/2.)/(2.*THE)-BCSYMC*SIN(THE/2.)/THE**2
      DELTH=-FTHE/DFTHE
      THE=THE+DELTH
      IF(THE.GT.2.*3.141593.OR.THE.LT.0.)GO TO 516
      IF (ABS(DELTH).LE.EPSLON) GO TO 76
      GO TO 75
   76 RSYM=BCSYMC/THE
C     THE FOLLOWING STATEMENTS ARE USED TO CALCULATE THE AIRBAG VOLUME.
      SLOPE=(YBS-YC)/(XBS-XC)
      V1=SLOPE**2*(XC**3/3.-XBS**3/3.+XBS**2*XC-XC**2*XBS)
      V2=YC**2*(XC-XBS)
      V3=2.*YC*SLOPE*(XBS*XC-XBS**2/2.-XC**2/2.)
      VABCD=ABS(V1+V2+V3)*3.14159
      ALPHAS=ATAN(SLOPE)
      RC=YC-RSYM*COS(THE/2.+ALPHAS)
      RS=RC+4./3.*(RSYM*SIN(THE/2.)**3)*COS(ALPHAS)/(THE-SIN(THE))
      VBC=2.*3.14159*RS*(RSYM**2/2.*(THE-SIN(THE)))
      VBRIM=3.14159/6.*(SC+XC)*(3.*YC**2+(SC+XC)**2)
      VOL=VABCD+VBC+VBRIM
C     CONFINE BAG VOLUME TO ORIGINAL VOLUME IF THE BAG PRESSURE IS LESS
C     THAN AMBIENT.
      IF(VOL.GE.VOLO.AND.PG1.LE.0.)VOL=VOLO
      GO TO 101
C     COMPLEX ROOTS (NO TORSO AND BAG CONTACT)
   80 VOL=VOLO
      FTT=0.
      FTH=0.
C     COMPUTE GAS FLOW INTO BAG
  101 CALL GASIN(X,QIN)
C     SINCE SUBROUTINE "SOLVE" CALLS "BAGSUB" TWICE PER SOLUTION
C     POINT WE MUST DIVIDE THE TIME STEP BY 2.
      DELTAT=STEP/2.
      GW1=GW+QIN*DELTAT
C     TEST TO SEE IF BAG DEPLOYED YET?IS BAG PRESS.>ATMOS. PRESS.?
      IF(X.EQ.0.)DTIME=.25
      IF(PA.GE.ATMOP.OR.X.GT.DTIME)GO TO 107
      GW=GW1
      PA=GW*GTZ*U/VOL
      PG1=PA-ATMOP
      GT=GTZ
      FFT=0.
      FP=0.
      FTT=0.
      FHEAD=0.
      FTH=0.
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```
      DTIME=X+STEP
      GO TO 150
C     COMPUTE NEW TEMP. AND PRESS. DUE TO NET GAS GAIN IN BAG
  107 GT7=(GW*GT+QIN*GTZ*DELTAT)/GW1
      PNUM=U*GT7*GW1
      PA7=PNUM/VOLD
C     COMPUTE NEW GAS PRESS. AND TEMP. DUE TO POLYTROPIC COMP. OR EXPANS.
      PA8=(PNUM/VOL)**FPN/PA7**(FPN-1.)
      GT8=GT7*(PA8/PA7)**((FPN-1.)/FPN)
C     BAG VENTING COMPUTATIONS; FIRST CALC. PRESS. RATIO ACROSS VENT
      PR7=ATMOP/PA8
C     TEST FOR CHOKED FLOW; ALSO, IF PR7>1,BYPASS QEXH.& SET GW=GW1
      IF (PR7.LT.PR8) GO TO 108
      IF (PR7.GE.1.) GO TO 110
      FM1=VC1*SQRT(PR7**(2./PN1)-PR7**((PN1+1.)/PN1))
      GO TO 109
  108 FM1=FM2
C     COMPUTE EXHAUST FLOW AND RESIDUAL GAS WEIGHT
  109 QEXH=SQRT((772.*PN1)/(PN1-1.))*AV*PA8*FM1/SQRT(U*GT8)
      GW=GW1-QEXH*DELTAT
      GO TO 111
  110 GW=GW1
C     COMPUTE PRESS. AND TEMP. OF GAS AFTER VENTING
  111 RATIO=GW/GW1
      PA=PA8*RATIO**PN1
      GT=GT8*RATIO**(PN1-1)
C     COMPUTE PRESS. RATIO TO DETERMINE WHETHER GAS COMP. OR EXPANDED THIS
C     TIME THRU LOOP; THEN SET PROPER POLYTROPIC EXPONENT.
      PR6=PA8/PA5
      IF (PR6.LT.1.0001) GO TO 112
      FPN=PN2
      GO TO 113
  112 FPN=PN3
C     COMPUTE BAG PRESSURE.
  113 PG1=PA-ATMOP
C     IF THE BAG PRESSURE IS NEGATIVE, CALL IT 0. FOR BAG FORCE CALCS.
      IF(PG1.LT.0.)PG1=0.
C     IF THE TORSO IS NOT IN CONTACT WITH THE BAG, SKIP THE BAG FORCE
C     CALCULATION.
      IF(D**2-4.*A*E)150,150,115
C     THE BAG FORCES ARE CALCULATED IN THE NEXT SEVERAL STATEMENTS.
  115 ENPHI=PG1*SQRT(SA**2-WB**2/4.)*(SQRT(SC**2*(1-WB**2/(4.*
     &SA**2))))*(1-BP/G1)/(2.*SQRT(SA**2-WB**2/4.+SC**2*(1-WB**2
     &/(4.*SA**2))))
      FFT=-2.*ENPHI*ABST*COS(BETA)
      IF (BETA.LE.1.5708) FFT=0.
      FP=PG1*WB*ABST
      IF(RBAG+ABST-RN*12.)140,140,135
  135 IF(ABST+RBAG.GT.RTOPH*12.) GO TO 136
      RHEAD=(ABST+RBAG-RN*12.)/2.
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      GO TO 137
  136 RHEAD=((RTOPH-RN)*12.)/2.
  137 HEADT=WHACT
      IF(BP.LT.HEADT/2..AND.WHACT.GT.2.*RHEAD)WH=2.*RHEAD
      FHEAD=2.*RHEAD*(WH*PGI+FFT/ABST)
      IF(Y(6)-Y(7).LT.0.)FHEAD=FHEAD*COS(Y(6)-Y(7))
      FTH=TNECK-FHEAD*RHEAD/12.
      FP=FP*(RN*12.-RBAG)/ABST
      FFT=FFT*(RN*12.-RBAG)/ABST
      GO TO 141
  140 FHEAD=0.
      FTH=TNECK
  141 FCHEST=FFT+FP
      TRANSTOR=-TNECK
      FTT=-FHEAD*RN*COS(Y(6)-Y(7))+TRANSTOR-RFT*FCHEST/12.
C     COMPUTE THE BENDING MOMENT APPLIED TO THE COLUMN AT THE WHEEL HUB.
      MO=FCHEST*T
C     COMPUTE THE AXIAL FORCE APPLIED TO THE COLUMN.
      FAC=FCHEST*COS(THETAC-THETAT)+FHEAD*COS(THETAC-THETAH)
C     COMPUTE THE NORMAL FORCE APPLIED TO THE COLUMN.
      FNC=FCHEST*SIN(THETAC-THETAT)+FHEAD*SIN(THETAC-THETAH)
      FNCOL=FNC+GS/32.17*WC*SIN(THETAC)
C     COMPUTE THE REACTIONS AT THE COLUMN SUPPORT POINTS.
      RSC=FNCOL+1.5*(MO+FNCOL*LSC)/LFW
      RBA=(RSC*(LBF-LSC)+FNCOL*(LSC-LBF))/(LBF-LBA)
      RBF=(RSC*(LBA-LSC)+FNCOL*(LSC-LBA))/(LBF-LBA)
      FACOL=FAC+GS/32.17*WC*COS(THETAC)
C     THE FOLLOWING ROUTINE COMPUTES THE COLUMN STROKE. "SCOLCO" IS THE
C     STROKE OF THE COLUMN AND "VCOLCO" IS THE STROKING VELOCITY.
C     LOOK UP COLUMN FORCE AS A FUNCTION OF STROKE.
      CALL COLF(SCOLC,FCOL)
C     COMPUTE TOTAL FORCE RESISTING COLUMN STROKE.
      FRCOL=FCOL+MU*ABS(RBF+RBA+RSC)
C     COMPUTE DIFFERENCE BETWEEN FORCE APPLIED TO COLUMN AND THAT FORCE
C     RESISTED BY COLUMN.
      DELF=FACOL-FRCOL
C     COMPARE ACTUAL STROKE TO STROKING LIMIT OF COLUMN.
      IF(SCOLC.GE.SLIM)GO TO 146
      IF(VCOLCO.GE.0.)GO TO 145
      VCOLCO=0.
  145 VCOLC=VCOLCO+DELF/MC*DELTAT
      IF(VCOLC.LT.0.)VCOLC=0.
      SCOLC=SCOLCO+VCOLCO*DELTAT+DELF*DELTAT**2/(2.*MC)
      IF(SCOLC.LT.SCOLCO)SCOLC=SCOLCO
      GO TO 147
  146 VCOLC=0.
      SCOLC=SCOLCO
C     COMPUTE NEW VALUES FOR THE AIRBAG COORDINATES
  147 XI=XI-(SCOLC-SCOLCO)*COS(THETAC)
      YI=YI-(SCOLC-SCOLCO)*SIN(THETAC)
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C          UPDATE OLD VALUES.
      150 VOLO=VOL
          PAS=PA
          LBA=LBAZ-SCOLC
          IF(LBA.LE.0.) GO TO 514
          LFW=LFWZ-SCOLC
          VCOLCO=VCOLC
          SCOLCO=SCOLC
          WB=WBACT
          WA=WAACT
          RELSF=Y(5)-Y(8)
          CALL SPRING(SFN,SFUT,RELSF,SUN,0.0,SF,NSF)
          RELKR=Y(5)-Y(8)
          CALL SPRING(KRN,ROT,RELKR,SKR,0.0,FKNEE,NKR)
          FX=-(SF+FKNEE+FCHEST*COS(Y(7))+FHEAD*COS(Y(6)))
          N=1
          GO TO 540
      500 XSTOP=X
          N=N+1
          PRINT 5
          IF(N.EQ.2)PRINT ,"DRIVER SUBMARINING, NOT RECOVERABLE, RUN STOPPED.
          GO TO 540
      510 XSTOP=X
          N=N+1
          PRINT 5
          IF(N.EQ.2)PRINT ,"CHEST IMPACT WITH LOWER WHEEL RIM, RUN STOPPED."
          GO TO 540
      512 XSTOP=X
          N=N+1
          PRINT 5
          IF(N.EQ.2)PRINT ,"BODY IMPACT WITH UPPER WHEEL RIM, RUN STOPPED."
          GO TO 540
      514 XSTOP=X
          N=N+1
          PRINT 5
          IF(N.EQ.2)PRINT,"COL.STROKE > SHEAR CAP. DIM.(LBAZ), RUN STOPPED"
          GO TO 540
      516 XSTOP=X
          N=N+1
          PRINT 5
          IF(N.EQ.2)PRINT,"THETA NOT CONVERGING, RUN STOPPED."
          GO TO 540
      518 XSTOP=X
          N=N+1
          PRINT 5
          IF(N.EQ.2)PRINT,"BAG PENETRATION SOLUTION NOT CONVERGING, RUN
         &STOPPED."
          GO TO 540
      520 XSTOP=X
          N=N+1
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```
      PRINT 5
      IF(N.EQ.2)PRINT,"PHI NOT CONVERGING, RUN STOPPED."
  540 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 COMPUTES THE COLUMN FORCE AS A FCN OF STROKE.
      SUBROUTINE COLF(SCOLC,FCOL)
      COMMON/COLFOR/NPC,COL(2,24)
      CALL LOOKUP(SCOLC,COL,NPC,FCOL)
      RETURN
      END
C
C     THIS SUBROUTINE PLACES CERTAIN VALUES IN MATRIX FORMAT FOR PRINTING
      SUBROUTINE PRINTI(X,Y,DY)
      COMMON /OUT1/N6,X6(4,50),T6(50)
      COMMON/HIC/THIC(175),ARGS(175),PINT1
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      COMMON/MANDAT/ZL,ZT,ZH,RT,RN,RH,RTOPH,X2Z,Y2Z,WB
      N6=N6+1
      IF(N6.GT.50)RETURN
      CH=COS(Y(6))
      CT=COS(Y(7))
      SH=SIN(Y(6))
      ST=SIN(Y(7))
      X6(1,N6)=(DY(1)*CT+RT*DY(3))/32.17
      X6(2,N6)=-(DY(1)*ST-RT*Y(3)*Y(3))/32.17
      X6(3,N6)=(RH*DY(2)+DY(1)*CH+RN*(DY(3)*(CH*CT+SH*ST)+Y(3)
     &*Y(3)*(SH*CT-CH*ST)))/32.17
      X6(4,N6)=(RH*Y(2)*Y(2)+RN*(Y(3)*Y(3)*(SH*ST+CH*CT)-DY(3)
     &*(SH*CT-CH*ST))-DY(1)*SH)/32.17
      T6(N6)=X*1000.
      THIC(N6)=(N6*PINT1)**0.6
      ARGS(N6)=SQRT(X6(3,N6)**2+X6(4,N6)**2)
      RETURN
      END
C
C     THIS SUBROUTINE SOLVES THE DIFFERENTIAL EQUATIONS THAT DETERMINE
C     THE DRIVER KINEMATICS AND VEHICLE MOTION. THE FOURTH ORDER RUNGE-
C     KUTTA METHOD IS USED TO START THE INTEGRATION, BUT ONCE THE FIRST
C     FOUR POINTS ARE OBTAINED WE SWITCH TO THE MORE ECONOMICAL FOURTH
C     ORDER ADAMS-MOULTON PREDICTOR-CORRECTOR METHOD.
      SUBROUTINE SOLVE(N)
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```
      COMMON/TIME/STEP,XSTOP
      COMMON/HIC/THIC(175),ARGS(175),PINT1
      DOUBLE PRECISION Y(8),YT(8)
      REAL DY
      DOUBLE PRECISION B270,B19,B251
      DIMENSION DY(8),F(3,8),J(3),S(8)
      B251=251.
      B270=270.
      B19=19.
      PRI1=0.
      PRI2=0.
      XSTOP=.140
      STEP=.001
      CALL SETUP(X,Y)
      CALL DIFEQ(X,Y,DY)
      PINT1=.005
      PINT2=.005
      CALL PRINT1(X,Y,DY)
      CALL PRINT2(X,Y,DY)
      IF(XSTOP.GT..25)XSTOP=.25
C     START OF INTEGRATION ROUTINE
C     RUNGE KUTTA START UP
      J(1)=1
      J(2)=2
      J(3)=3
      DO 7270 K=1,N
 7270 F(3,K)=DY(K)
      DO 7550 JK=1,3
      DO 7300 K=1,N
 7300 S(K)=DY(K)*STEP
      XN=X+STEP/2.
      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
           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)GOTO7890
           PRI1=PRI1-PINT1
           CALL PRINT1(X,Y,DY)
      7890 IF(PRI2.LT.PINT2)GOTO7920
           PRI2=PRI2-PINT2
           CALL PRINT2(X,Y,DY)
      7920 IF(X.LT.XSTOP)GOTO7590
      8000 CALL PRINT1(X,Y,DY)
           CALL PRINT2(X,Y,DY)
           RETURN
           END
C
C          THIS SUBROUTINE COMPUTES THE KNEE RESTRAINT CRUSH FORCE AND THE
C          SEAT FRICTION FORCE. HYSTERESIS EFFECTS CAN BE INCLUDED.
           SUBROUTINE SPRING(F,DELTA,DIST,SLOPE1,SLOPE2,FORCE,NPTS)
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              DIMENSION F(2,24)
              R=0.
              IF(DIST.GE.DELTA)GO TO 8340
              M=2
              UT=DIST
              GO TO 8360
        8110  M=3
              UT=DELTA
              GO TO 8360
        8140  F(1,K)=DELTA
              F(2,K)=FORCE
              IF(K.GT.3)GOTO8180
              GO TO (8240,8240,8300),K
        8180  KK=K-3
              R=1.
              DO 8210 L=2,NPTS
              F(1,L)=F(1,L+KK)
        8210  F(2,L)=F(2,L+KK)
              NPTS=NPTS-KK
              GO TO 8300
        8240  KK=3-K
              R=2.
              DO 8280 LL=1,NPTS
              L=NPTS+1-LL
              F(1,L+KK)=F(1,L)
        8280  F(2,L+KK)=F(2,L)
              NPTS=NPTS+KK
        8300  F(1,2)=F(1,3)-F(2,3)/SLOPE1
              F(2,2)=0.
              F(2,1)=-SLOPE2*F(1,2)
              F(1,1)=0.
        8340  M=1
              UT=DIST
        8360  DO 8370 J=2,NPTS
        8370  IF(F(1,J).GT.UT)GOTO8380
        8380  K=J-1
        8390  FORCE=(UT-F(1,K))*(F(2,J)-F(2,K))/(F(1,J)-F(1,K))+F(2,K)
              IF(R.EQ.1.)NPTS=NPTS+KK
              IF(R.EQ.2.)NPTS=NPTS-KK
              GO TO (8450,8410,8140),M
        8410  IF(FORCE.LE.0.)GOTO8450
              IF(ABS((F(2,J)-F(2,K))/(F(1,J)-F(1,K))-SLOPE1).LT..01)
              &GOTO8450
              GO TO 8110
        8450  RETURN
              END
C
C             THIS SUBROUTINE PLACES CERTAIN VALUES IN MATRIX FORMAT FOR PRINTING
              SUBROUTINE PRINT2(X,Y,DY)
              REAL MO
```

DRAC 12/01/81

```
      COMMON/OUT/N,T(35),X0(6,35),X1(6,35),X2(6,35),X3(6,35),X4(6,35)
     &,X5(5,35)
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      COMMON/MANDAT/ZL,ZT,ZA,RT,RN,RA,RTOPA,X2Z,Y2Z,WB
      COMMON/PARAM/RFT,THETATZ,THETAAZ
      COMMON/MPARAM/FACOL,SCOLC,PGI,FKNEE,SF,FNCOL,MO,FRCOL,VCOLC
      COMMON/MMPARAM/BP,VOL,FFT,FP
      DATA F/12./,V/.68181818/,G/32.17/,D/57.295780/
      N=N+1
      IF(N.GT.35)RETURN
      CT=COS(Y(7))
      T(N)=X*1000.
      X0(1,N)=-DY(4)/G
      X0(2,N)=Y(4)*V
      X0(3,N)=Y(8)*F
      X0(4,N)=(DY(1)*CT+RT*DY(3))/G
      X0(5,N)=SCOLC
      X0(6,N)=PGI
      X1(1,N)=Y(5)*F
      X1(2,N(=Y(1)*V
      X1(3,N)=-DY(1)/G
      X1(4,N)=FKNEE/2.
      X1(5,N)=SF
      X1(6,N)=(Y(5)-Y(8))*F
      X2(1,N)=(Y(5)+RT*(SIN(Y(7))-SIN(THETATZ)))*F
      X2(2,N)=Y(7)*D
      X2(3,N)=Y(3)*D
      X2(4,N)=DY(3)*D
      X2(5,N)=X2(1,N)-Y(8)*F
      X2(6,N)=(RT*Y(3)*CT+Y(1)-Y(4))*V
      X3(1,N)=F*(Y(5)+RN*(SIN(Y(7))-SIN(THETATZ))+RA*(SIN(Y(6))-
     &SIN(THETAAZ)))
      X3(2,N)=Y(6)*D
      X3(3,N)=Y(2)*D
      X3(4,N)=DY(2)*D
      X3(5,N)=X3(1,N)-Y(8)*F
      X3(6,N)=(Y(6)-Y(7))*D
      X4(1,N)=FACOL
      X4(2,N)=FNCOL
      X4(3,N)=MO
      X4(4,N)=FRCOL
      X4(5,N)=SCOLC
      X4(6,N)=VCOLC
      X5(1,N)=BP
       X5(2,N)=VOL
       X5(3,N)=PGI
       X5(4,N)=FFT
       X5(5,N)=FP
       RETURN
       END
C
       SUBROUTINE UPDATE(X,Y,DY)
```

```
      DOUBLE PRECISION Y(8)
      DIMENSION DY(8)
      COMMON/KNEEREST/NKR,SKR,RUT,RELKR
      COMMON/SEATFRIC/NSF,SUN,SFUT,RELSF
      SFUT=RELSF
      RUT=RELKR
      RETURN
      END
```

```
DRAC          08:41EST     12/02/81


INPUT FILE NAME?LRSV



INPUT VALUES -- INPUT UNITS( MSEC, MPH, DEGREES, INCHES, LBS, FT-LBS, G'S)
INITIAL VELOCITY:           39.3
INITIAL HEAD ANGLE:          -5.00
INITIAL TORSO ANGLE:          -18.0
       MLEG     MTORSO      MHEAD          RT          RN          RH        RTOPH
       77.0       67.0       11.0        13.8        19.5        4.00        28.0
      NPTS NECK  NPTS KR   NPTS VEH   NPTS SEAT NPTS GAS   NPTS COL    SL.ST      SL.KR
          9          8          6           6          8           6 0.100E+04 0.290E+04
GAS FLOW TIME
      -100.       14.0       16.0        19.0        32.0        65.0        92.0        100.
GAS FLOW - LB/SEC
         0.         0.       4.92        3.86        3.07       0.614          0.          0.
COLUMN STROKE - INCHES
      -100.         0.      0.250       0.500        1.50        8.00
COLUMN FORCE - LBS
         0.         0.       400.        400.  0.160E+04 0.160E+04
SEAT FRICTION DISPLACEMENT
      -100.         0.      0.500        15.0        16.0        100.
SEAT FRICTION FORCE - LBS
         0.         0.       400.        300.          0.          0.
NECK ANGLE
      -90.0      -75.0      -60.0       -30.0          0.        30.0        60.0        75.0
       90.0
NECK TORQUE
       200.       150.       100.        50.0          0.       -50.0       -100.       -150.
      -200.
VEH. PULSE - TIME
      -100.         0.       40.0        102.        115.        150.
VEH. PULSE - DECELERATION
         0.         0.       21.0        22.5          0.          0.
KNEE DISPLACEMENT
      -50.0       3.00       3.75        6.50        7.50        9.00        11.0        50.0
KNEE FORCE - LBS
         0.         0.       400.  0.290E+04 0.290E+04 0.180E+04 0.180E+04 0.100E+04
      ATMOP        PGZ        GTZ           U         PN1         PN2         PN3
       14.7      -14.7  0.116E+04        660.        1.40        1.40        1.40
        VC1        VC2         AV          SA          SC         X1Z         Y1Z         DCN
      0.700      0.700       3.50        11.5        7.50        29.5        23.0        2.50
       SLIM     THETAC         MU        LSCZ        LFWZ        LBAZ        LBFZ          WC
       8.00       17.0      0.160        16.0        14.7        16.0        23.2        18.0
         WH         YO     RIMRAD         X2Z         Y2Z          WB
       9.00         0.       7.75        36.5        9.00        17.0
```

```
INITIAL VALUES-CONVERTED UNITS(SEC, FT/SEC, RADIANS, FT, LBS, FT-LBS, FT/SEC**2)
INITIAL VELOCITY:          57.6
INITIAL HEAD ANGLE:   -0.873E-01
INITIAL TORSO ANGLE:       -0.314
      MLEG     MTORSO      MHEAD          RT          RN          RH       RTOPH
      2.39       2.08      0.342        1.15        1.62       0.333        2.33
     NPTS NECK   NPTS KR   NPTS VEH   NPTS SEAT NPTS GAS   NPTS COL    SL.ST      SL.KR
         9          8          6          6          8          6 0.120E+05 0.348E+05
GAS FLOW TIME
    -0.100 0.140E-01 0.160E-01 0.190E-01 0.320E-01 0.650E-01 0.920E-01      0.100
GAS FLOW - LB/SEC
        0.         0.       4.92        3.86        3.07       0.614          0.          0.
COLUMN STROKE - INCHES
     -100.         0.      0.250       0.500        1.50        8.00
COLUMN FORCE - LBS
        0.         0.       400.        400. 0.160E+04 0.160E+04
SEAT FRICTION DISPLACEMENT
     -8.33         0. 0.417E-01        1.25        1.33        8.33
SEAT FRICTION FORCE - LBS
        0.         0.       400.        300.          0.          0.
NECK ANGLE
     -1.57      -1.31      -1.05      -0.524          0.       0.524        1.05        1.31
      1.57
NECK TORQUE
      200.       150.       100.        50.0          0.       -50.0       -100.       -150.
     -200.
VEH. PULSE - TIME
    -0.100         0. 0.400E-01       0.102       0.115       0.150
VEH. PULSE - DECELERATION
        0.         0.       676.        724.          0.          0.
KNEE DISPLACEMENT
     -4.17      0.250      0.313       0.542       0.625       0.750       0.917        4.17
KNEE FORCE - LBS
        0.         0.       400. 0.290E+04 0.290E+04 0.180E+04 0.180E+04 0.100E+04
     ATMOP        PGZ        GTZ           Q         PN1         PN2         PN3
      14.7      -14.7 0.116E+04        660.        1.40        1.40        1.40
       VC1        VC2         AV          SA          SC         XIZ         YIZ        DCN
     0.700      0.700       3.50        11.5        7.50        29.5        23.0        2.50
      SLIM     THETAC         MU        LSCZ        LFWZ        LBAZ        LBFZ          WC
      8.00      0.297      0.160        16.0        14.7        16.0        23.2        18.0
        WA         YO     RIMRAD         X2Z         Y2Z          WB
      9.00         0.       7.75        36.5        9.00        17.0
```

| TIME (MS) | CHEST AP (G'S) | CHEST SI (G'S) | HEAD AP (G'S) | HEAD SI (G'S) | | |
|---|---|---|---|---|---|---|
| ======= | ======= | ======= | ======= | ======= | ======= | ======= |
| 0. | -0.27 | 0. | -0.46 | 0.09 | | |
| 5.00 | -0.35 | 0.07 | -0.08 | 0.20 | | |
| 10.00 | -0.37 | -0.02 | -0.04 | 0.10 | | |
| 15.00 | -0.39 | -0.25 | 0.01 | -0.18 | | |
| 20.00 | -0.44 | -0.68 | 0.08 | -0.71 | | |
| 25.00 | -0.50 | -1.33 | 0.15 | -1.52 | | |
| 30.00 | -0.45 | -1.33 | -0.07 | -1.54 | | |
| 35.00 | -0.44 | -1.27 | -0.07 | -1.46 | | |
| 40.00 | -6.78 | -1.56 | -0.51 | 0.19 | | |
| 45.00 | -12.55 | -1.87 | -10.42 | 1.73 | | |
| 50.00 | -17.56 | -2.63 | -15.11 | 2.98 | | |
| 55.00 | -20.73 | -5.15 | -19.44 | 1.99 | | |
| 60.00 | -23.19 | -8.42 | -23.46 | -0.16 | | |
| 65.00 | -25.20 | -11.39 | -26.61 | -2.47 | | |
| 70.00 | -26.60 | -11.99 | -29.44 | -2.38 | | |
| 75.00 | -30.03 | -10.80 | -21.43 | 0.82 | | |
| 80.00 | -29.28 | -8.77 | -25.98 | 2.88 | | |
| 85.00 | -28.38 | -6.81 | -24.84 | 4.58 | | |
| 90.00 | -26.30 | -4.95 | -22.71 | 5.19 | | |
| 95.00 | -23.38 | -2.23 | -19.14 | 6.50 | | |
| 100.00 | -20.21 | 0.94 | -15.61 | 8.88 | | |
| 105.00 | -17.30 | 2.85 | -13.12 | 10.25 | | |
| 110.00 | -14.96 | 3.27 | -12.65 | 10.25 | | |
| 115.00 | -13.65 | 2.52 | -13.43 | 9.44 | | |
| 120.00 | -12.67 | 1.81 | -13.16 | 7.90 | | |
| 125.00 | -9.02 | 1.29 | -18.61 | 5.57 | | |
| 130.00 | -8.71 | 0.90 | -8.45 | 4.80 | | |
| 135.00 | -4.14 | 0.65 | -12.72 | 2.56 | | |
| 140.00 | -3.44 | 0.45 | -2.93 | 2.05 | | |
| 140.00 | -3.44 | 0.45 | -2.93 | 2.05 | | |

| TIME (MS) ======= | VEH G'S (G'S) ======= | VEH VEL (MPH) ======= | VEH DISP (INCHES) ======= | BODY G'S (G'S) ======= | COL DISP (INCHES) ======= | BAG PRESS (PSIG) ======= |
|---|---|---|---|---|---|---|
| 0. | 0. | 39.30 | 0. | -0.27 | 0. | -14.70 |
| 5.00 | 2.62 | 39.16 | 3.45 | -0.35 | 0. | -14.70 |
| 10.00 | 5.25 | 38.72 | 6.88 | -0.37 | 0. | -14.70 |
| 15.00 | 7.88 | 38.00 | 10.26 | -0.39 | 0. | -14.25 |
| 20.00 | 10.50 | 37.00 | 13.56 | -0.44 | 0. | -10.31 |
| 25.00 | 13.12 | 35.70 | 16.76 | -0.50 | 0. | -6.95 |
| 30.00 | 15.75 | 34.12 | 19.84 | -0.45 | 0. | -3.76 |
| 35.00 | 18.37 | 32.25 | 22.76 | -0.44 | 0. | -0.60 |
| 40.00 | 21.00 | 30.09 | 25.51 | -6.78 | 0.05 | 1.94 |
| 45.00 | 21.12 | 27.78 | 28.05 | -12.55 | 0.31 | 3.93 |
| 50.00 | 21.24 | 25.45 | 30.39 | -17.56 | 0.81 | 5.37 |
| 55.00 | 21.36 | 23.12 | 32.53 | -20.73 | 1.44 | 6.31 |
| 60.00 | 21.48 | 20.77 | 34.46 | -23.19 | 1.96 | 6.94 |
| 65.00 | 21.60 | 18.41 | 36.19 | -25.20 | 2.32 | 7.32 |
| 70.00 | 21.73 | 16.03 | 37.70 | -26.60 | 2.58 | 7.55 |
| 75.00 | 21.85 | 13.64 | 39.01 | -30.03 | 2.79 | 7.68 |
| 80.00 | 21.97 | 11.24 | 40.10 | -29.28 | 3.00 | 7.62 |
| 85.00 | 22.09 | 8.82 | 40.98 | -28.38 | 3.27 | 7.31 |
| 90.00 | 22.21 | 6.39 | 41.65 | -26.30 | 3.60 | 6.70 |
| 95.00 | 22.33 | 3.95 | 42.11 | -23.38 | 4.00 | 5.88 |
| 100.00 | 22.45 | 1.49 | 42.35 | -20.21 | 4.42 | 5.04 |
| 105.00 | 17.31 | -0.80 | 42.37 | -17.30 | 4.82 | 4.30 |
| 110.00 | 8.65 | -2.23 | 42.23 | -14.96 | 5.11 | 3.78 |
| 115.00 | 0. | -2.70 | 42.01 | -13.65 | 5.20 | 3.54 |
| 120.00 | 0. | -2.70 | 41.77 | -12.67 | 5.20 | 3.32 |
| 125.00 | 0. | -2.70 | 41.53 | -9.02 | 5.20 | 2.87 |
| 130.00 | 0. | -2.70 | 41.30 | -8.71 | 5.20 | 2.26 |
| 135.00 | 0. | -2.70 | 41.06 | -4.14 | 5.20 | 1.57 |
| 140.00 | 0. | -2.70 | 40.82 | -3.44 | 5.20 | 0.91 |
| 140.00 | 0. | -2.70 | 40.82 | -3.44 | 5.20 | 0.91 |

| TIME (MS) | H-P DISP (INCHES) | H-P VEL (MPH) | H-P ACC (G'S) | FEM FORCE (LBS) | SEAT FR. (LBS) | H-P R.D. (INCHES) |
|---|---|---|---|---|---|---|
| 0. | 0. | 39.30 | 0. | 0. | 0. | 0. |
| 5.00 | 3.46 | 39.33 | -0.23 | 0. | 4.26 | 0.01 |
| 10.00 | 6.92 | 39.34 | 0.06 | 0. | 30.42 | 0.04 |
| 15.00 | 10.38 | 39.30 | 0.80 | 0. | 96.46 | 0.12 |
| 20.00 | 13.83 | 39.15 | 2.18 | 0. | 216.87 | 0.27 |
| 25.00 | 17.27 | 38.80 | 4.29 | 0. | 399.99 | 0.50 |
| 30.00 | 20.66 | 38.32 | 4.41 | 0. | 397.79 | 0.82 |
| 35.00 | 24.01 | 37.84 | 4.41 | 0. | 394.83 | 1.25 |
| 40.00 | 27.32 | 37.29 | 5.62 | 0. | 390.96 | 1.81 |
| 45.00 | 30.57 | 36.60 | 6.69 | 0. | 386.09 | 2.52 |
| 50.00 | 33.76 | 35.79 | 9.24 | 96.44 | 380.26 | 3.36 |
| 55.00 | 36.85 | 34.36 | 18.03 | 458.19 | 373.67 | 4.32 |
| 60.00 | 39.77 | 31.79 | 28.95 | 907.54 | 366.85 | 5.31 |
| 65.00 | 42.41 | 28.07 | 38.78 | 1324.97 | 360.52 | 6.22 |
| 70.00 | 44.68 | 23.52 | 42.16 | 1450.00 | 355.29 | 6.98 |
| 75.00 | 46.55 | 18.89 | 41.55 | 1434.40 | 351.43 | 7.54 |
| 80.00 | 48.01 | 14.48 | 38.80 | 1298.39 | 348.87 | 7.91 |
| 85.00 | 49.11 | 10.34 | 36.83 | 1222.22 | 347.44 | 8.12 |
| 90.00 | 49.84 | 6.31 | 36.51 | 1199.12 | 347.01 | 8.18 |
| 95.00 | 50.22 | 2.40 | 33.56 | 1091.67 | 272.90 | 8.11 |
| 100.00 | 50.28 | -0.90 | 25.12 | 830.35 | 92.68 | 7.93 |
| 105.00 | 50.09 | -3.15 | 15.89 | 524.38 | 0. | 7.72 |
| 110.00 | 49.75 | -4.50 | 8.22 | 231.54 | 0. | 7.52 |
| 115.00 | 49.33 | -5.03 | 1.90 | 0. | 0. | 7.32 |
| 120.00 | 48.87 | -5.25 | 1.90 | 0. | 0. | 7.10 |
| 125.00 | 48.40 | -5.46 | 1.84 | 0. | 0. | 6.87 |
| 130.00 | 47.91 | -5.64 | 1.29 | 0. | 0. | 6.62 |
| 135.00 | 47.41 | -5.77 | 1.07 | 0. | 0. | 6.35 |
| 140.00 | 46.90 | -5.86 | 0.47 | 0. | 0. | 6.08 |
| 140.00 | 46.90 | -5.86 | 0.47 | 0. | 0. | 6.08 |

| TIME (MS) | TORSO DISP (INCHES) | TORSO ANG (DEG) | TORSO VEL (D/SEC) | TORSO ACC (D/SEC**2) | TORSO R.D. (INCHES) | TORSO R.V. (MPH) |
|---|---|---|---|---|---|---|
| ======= | ======= | ======= | ======= | ======= | ======= | ======= |
| 0. | -0.00 | -18.00 | 0. | -435.76 | -0.00 | 0. |
| 5.00 | 3.46 | -18.01 | -4.59 | -918.97 | 0.00 | 0.11 |
| 10.00 | 6.91 | -18.04 | -8.41 | -501.06 | 0.03 | 0.51 |
| 15.00 | 10.36 | -18.09 | -8.67 | 589.74 | 0.10 | 1.18 |
| 20.00 | 13.81 | -18.12 | -1.37 | 2611.22 | 0.24 | 2.13 |
| 25.00 | 17.25 | -18.08 | 18.61 | 5732.39 | 0.48 | 3.34 |
| 30.00 | 20.68 | -17.91 | 43.46 | 6011.62 | 0.84 | 4.83 |
| 35.00 | 24.10 | -17.60 | 78.57 | 6035.77 | 1.34 | 6.61 |
| 40.00 | 27.51 | -17.15 | 94.52 | -2273.70 | 2.01 | 8.43 |
| 45.00 | 30.86 | -16.73 | 67.04 | -9857.40 | 2.81 | 9.70 |
| 50.00 | 34.09 | -16.54 | 2.13 | -13959.00 | 3.70 | 10.36 |
| 55.00 | 37.15 | -16.69 | -52.90 | -5545.92 | 4.62 | 10.55 |
| 60.00 | 40.01 | -16.97 | -50.40 | 7203.66 | 5.54 | 10.37 |
| 65.00 | 42.62 | -17.04 | 13.90 | 19035.42 | 6.43 | 9.85 |
| 70.00 | 44.97 | -16.75 | 123.22 | 22094.80 | 7.27 | 9.10 |
| 75.00 | 47.04 | -15.87 | 226.14 | 15928.23 | 8.03 | 8.22 |
| 80.00 | 48.81 | -14.55 | 299.78 | 13268.19 | 8.71 | 7.21 |
| 85.00 | 50.29 | -12.89 | 359.56 | 12060.27 | 9.31 | 6.31 |
| 90.00 | 51.48 | -10.94 | 425.85 | 15295.86 | 9.83 | 5.64 |
| 95.00 | 52.42 | -8.61 | 506.70 | 15713.84 | 10.31 | 5.30 |
| 100.00 | 53.12 | -5.90 | 568.75 | 7667.13 | 10.78 | 5.35 |
| 105.00 | 53.63 | -3.01 | 581.20 | -2298.38 | 11.26 | 5.60 |
| 110.00 | 53.93 | -0.16 | 549.68 | -10808.25 | 11.74 | 5.25 |
| 115.00 | 54.17 | 2.42 | 473.58 | -18843.53 | 12.16 | 4.15 |
| 120.00 | 54.24 | 4.57 | 390.42 | -17271.10 | 12.46 | 2.77 |
| 125.00 | 54.19 | 6.32 | 315.39 | -11522.75 | 12.65 | 1.53 |
| 130.00 | 54.04 | 7.75 | 258.00 | -11910.08 | 12.74 | 0.56 |
| 135.00 | 53.82 | 8.92 | 211.42 | -4940.36 | 12.76 | -0.21 |
| 140.00 | 53.54 | 9.91 | 184.31 | -4776.00 | 12.72 | -0.68 |
| 140.00 | 53.54 | 9.91 | 184.31 | -4776.00 | 12.72 | -0.68 |

| TIME (MS) | HEAD DISP (INCHES) | HEAD ANG (DEG) | HEAD VEL (D/SEC) | HEAD ACC (D/SEC**2) | HEAD R.D. (INCHES) | HEAD R.ANG (DEG) |
|---|---|---|---|---|---|---|
| 0. | -0.00 | -5.00 | 0. | -481.94 | -0.00 | 13.00 |
| 5.00 | 3.46 | -4.97 | 11.73 | 2662.59 | 0.00 | 13.04 |
| 10.00 | 6.91 | -4.88 | 24.94 | 2453.03 | 0.03 | 13.16 |
| 15.00 | 10.37 | -4.73 | 36.26 | 1684.63 | 0.11 | 13.36 |
| 20.00 | 13.83 | -4.53 | 42.32 | 73.74 | 0.27 | 13.59 |
| 25.00 | 17.29 | -4.32 | 38.39 | -2643.35 | 0.52 | 13.76 |
| 30.00 | 20.74 | -4.18 | 17.46 | -4582.11 | 0.91 | 13.73 |
| 35.00 | 24.20 | -4.15 | -5.97 | -4822.17 | 1.44 | 13.45 |
| 40.00 | 27.65 | -4.14 | 52.18 | 38764.65 | 2.15 | 13.01 |
| 45.00 | 31.08 | -3.56 | 171.65 | 25987.80 | 3.03 | 13.17 |
| 50.00 | 34.42 | -2.33 | 326.18 | 33454.61 | 4.02 | 14.22 |
| 55.00 | 37.60 | -0.33 | 462.91 | 18066.09 | 5.07 | 16.36 |
| 60.00 | 40.60 | 2.13 | 504.10 | -2998.66 | 6.14 | 19.10 |
| 65.00 | 43.37 | 4.55 | 450.33 | -19635.76 | 7.19 | 21.64 |
| 70.00 | 45.89 | 6.50 | 316.66 | -30553.84 | 8.19 | 23.25 |
| 75.00 | 48.13 | 7.72 | 206.43 | 36298.40 | 9.12 | 23.58 |
| 80.00 | 50.12 | 8.98 | 266.34 | 5882.24 | 10.01 | 23.52 |
| 85.00 | 51.85 | 10.41 | 308.18 | 4601.08 | 10.87 | 23.31 |
| 90.00 | 53.34 | 11.96 | 305.35 | -2804.76 | 11.69 | 22.90 |
| 95.00 | 54.60 | 13.43 | 276.29 | -4529.29 | 12.50 | 22.03 |
| 100.00 | 55.67 | 14.76 | 259.35 | 3331.91 | 13.32 | 20.66 |
| 105.00 | 56.56 | 16.11 | 291.67 | 13037.84 | 14.18 | 19.12 |
| 110.00 | 57.29 | 17.73 | 354.86 | 15604.06 | 15.05 | 17.89 |
| 115.00 | 57.87 | 19.68 | 427.97 | 17679.61 | 15.86 | 17.27 |
| 120.00 | 58.29 | 21.79 | 376.29 | 13565.59 | 16.51 | 17.22 |
| 125.00 | 58.53 | 23.60 | 334.79 | -42450.76 | 16.99 | 17.28 |
| 130.00 | 58.61 | 24.98 | 231.50 | 13521.71 | 17.31 | 17.22 |
| 135.00 | 58.57 | 26.12 | 214.68 | -43155.14 | 17.51 | 17.20 |
| 140.00 | 58.45 | 27.02 | 173.90 | 7541.57 | 17.62 | 17.11 |
| 140.00 | 58.45 | 27.02 | 173.90 | 7541.57 | 17.62 | 17.11 |

| TIME (MS) | COL AX FOR (LBS) | COL N FOR (LBS) | COL MOMENT (IN-LBS) | COL RESIST (LBS) | COL STROKE (INCHES) | COL ST VEL (IN/SEC) |
|---|---|---|---|---|---|---|
| ======= | ======= | ======= | ======= | ======= | ======= | ======= |
| 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 5.00 | 0. | 0. | 0. | 0. | 0. | 0. |
| 10.00 | 0. | 0. | 0. | 0. | 0. | 0. |
| 15.00 | 0. | 0. | 0. | 0. | 0. | 0. |
| 20.00 | 0. | 0. | 0. | 0. | 0. | 0. |
| 25.00 | 0. | 0. | 0. | 0. | 0. | 0. |
| 30.00 | 0. | 0. | 0. | 0. | 0. | 0. |
| 35.00 | 0. | 0. | 0. | 0. | 0. | 0. |
| 40.00 | 772.90 | 387.91 | 656.46 | 340.16 | 0.05 | 29.05 |
| 45.00 | 1285.14 | 701.75 | 1199.15 | 909.29 | 0.31 | 74.90 |
| 50.00 | 1672.54 | 934.54 | 1620.26 | 1362.64 | 0.81 | 121.72 |
| 55.00 | 1935.55 | 1093.28 | 2035.65 | 2223.30 | 1.44 | 121.83 |
| 60.00 | 2129.16 | 1206.34 | 2382.41 | 2434.49 | 1.96 | 85.39 |
| 65.00 | 2265.40 | 1268.79 | 2563.98 | 2472.42 | 2.32 | 60.09 |
| 70.00 | 2370.96 | 1289.40 | 2578.48 | 2481.77 | 2.58 | 45.03 |
| 75.00 | 2458.79 | 1278.29 | 2458.89 | 2468.76 | 2.79 | 40.88 |
| 80.00 | 2500.58 | 1225.42 | 2229.27 | 2427.16 | 3.00 | 46.85 |
| 85.00 | 2471.84 | 1129.10 | 1903.08 | 2356.20 | 3.27 | 59.60 |
| 90.00 | 2360.08 | 993.91 | 1479.68 | 2259.09 | 3.60 | 73.62 |
| 95.00 | 2181.44 | 835.34 | 973.42 | 2146.19 | 4.00 | 82.85 |
| 100.00 | 1986.14 | 680.42 | 448.03 | 2035.92 | 4.42 | 83.80 |
| 105.00 | 1714.98 | 518.18 | -19.20 | 1922.91 | 4.82 | 72.41 |
| 110.00 | 1431.02 | 368.61 | -389.31 | 1819.78 | 5.11 | 40.64 |
| 115.00 | 1222.71 | 252.13 | -680.00 | 1738.51 | 5.20 | 0. |
| 120.00 | 1154.96 | 193.29 | -881.92 | 1695.63 | 5.20 | 0. |
| 125.00 | 1006.68 | 136.97 | -954.14 | 1658.13 | 5.20 | 0. |
| 130.00 | 797.88 | 88.74 | -890.52 | 1629.69 | 5.20 | 0. |
| 135.00 | 557.77 | 50.74 | -709.62 | 1611.11 | 5.20 | 0. |
| 140.00 | 322.71 | 23.87 | -458.17 | 1601.59 | 5.20 | 0. |
| 140.00 | 322.71 | 23.87 | -458.17 | 1601.59 | 5.20 | 0. |

| TIME (MS) | BAG PEN. (INCHES) | BAG VOL. (CU.IN.) | BAG PRESS. (PSIG) | W/A FORCE (LBS) | P. FORCE (LBS) | |
|---|---|---|---|---|---|---|
| 0. | 2.51 | 4154.75 | -14.70 | 0. | 0. | |
| 5.00 | 2.51 | 4154.75 | -14.70 | 0. | 0. | |
| 10.00 | 2.54 | 4154.75 | -14.70 | 0. | 0. | |
| 15.00 | 2.60 | 4154.75 | -14.25 | 0. | 0. | |
| 20.00 | 2.73 | 4154.75 | -10.31 | 0. | 0. | |
| 25.00 | 2.95 | 4142.26 | -6.95 | 0. | 0. | |
| 30.00 | 3.27 | 4093.99 | -3.76 | 0. | 0. | |
| 35.00 | 3.76 | 3988.83 | -0.60 | 0. | 0. | |
| 40.00 | 4.37 | 3921.41 | 1.94 | 0. | 490.37 | |
| 45.00 | 4.94 | 3844.15 | 3.93 | 14.49 | 992.44 | |
| 50.00 | 5.39 | 3777.82 | 5.37 | 38.42 | 1361.84 | |
| 55.00 | 5.75 | 3722.68 | 6.31 | 60.07 | 1606.56 | |
| 60.00 | 6.19 | 3653.55 | 6.94 | 83.76 | 1765.69 | |
| 65.00 | 6.74 | 3567.05 | 7.32 | 107.19 | 1844.85 | |
| 70.00 | 7.31 | 3470.95 | 7.55 | 126.55 | 1878.58 | |
| 75.00 | 7.84 | 3371.68 | 7.68 | 140.27 | 1889.67 | |
| 80.00 | 8.28 | 3278.70 | 7.62 | 146.30 | 1865.00 | |
| 85.00 | 8.59 | 3199.87 | 7.31 | 144.50 | 1792.18 | |
| 90.00 | 8.75 | 3139.53 | 6.70 | 135.78 | 1663.21 | |
| 95.00 | 8.79 | 3095.78 | 5.88 | 122.34 | 1488.86 | |
| 100.00 | 8.77 | 3060.54 | 5.04 | 107.98 | 1307.05 | |
| 105.00 | 8.76 | 3021.00 | 4.30 | 94.88 | 1141.99 | |
| 110.00 | 8.84 | 2963.54 | 3.78 | 85.09 | 1019.57 | |
| 115.00 | 9.05 | 2877.02 | 3.54 | 80.08 | 961.20 | |
| 120.00 | 9.27 | 2790.33 | 3.32 | 74.47 | 901.74 | |
| 125.00 | 9.40 | 2731.62 | 2.87 | 64.22 | 783.61 | |
| 130.00 | 9.45 | 2699.30 | 2.26 | 50.67 | 620.11 | |
| 135.00 | 9.43 | 2689.55 | 1.57 | 35.46 | 432.93 | |
| 140.00 | 9.36 | 2695.85 | 0.91 | 20.61 | 250.09 | |
| 140.00 | 9.36 | 2695.85 | 0.91 | 20.61 | 250.09 | |

ENTER 1 TO CALCULATE HIC?1

THE HIC IS 1.5820920E+02
T1= 5.0000000E-02
T2= 1.3000000E-01

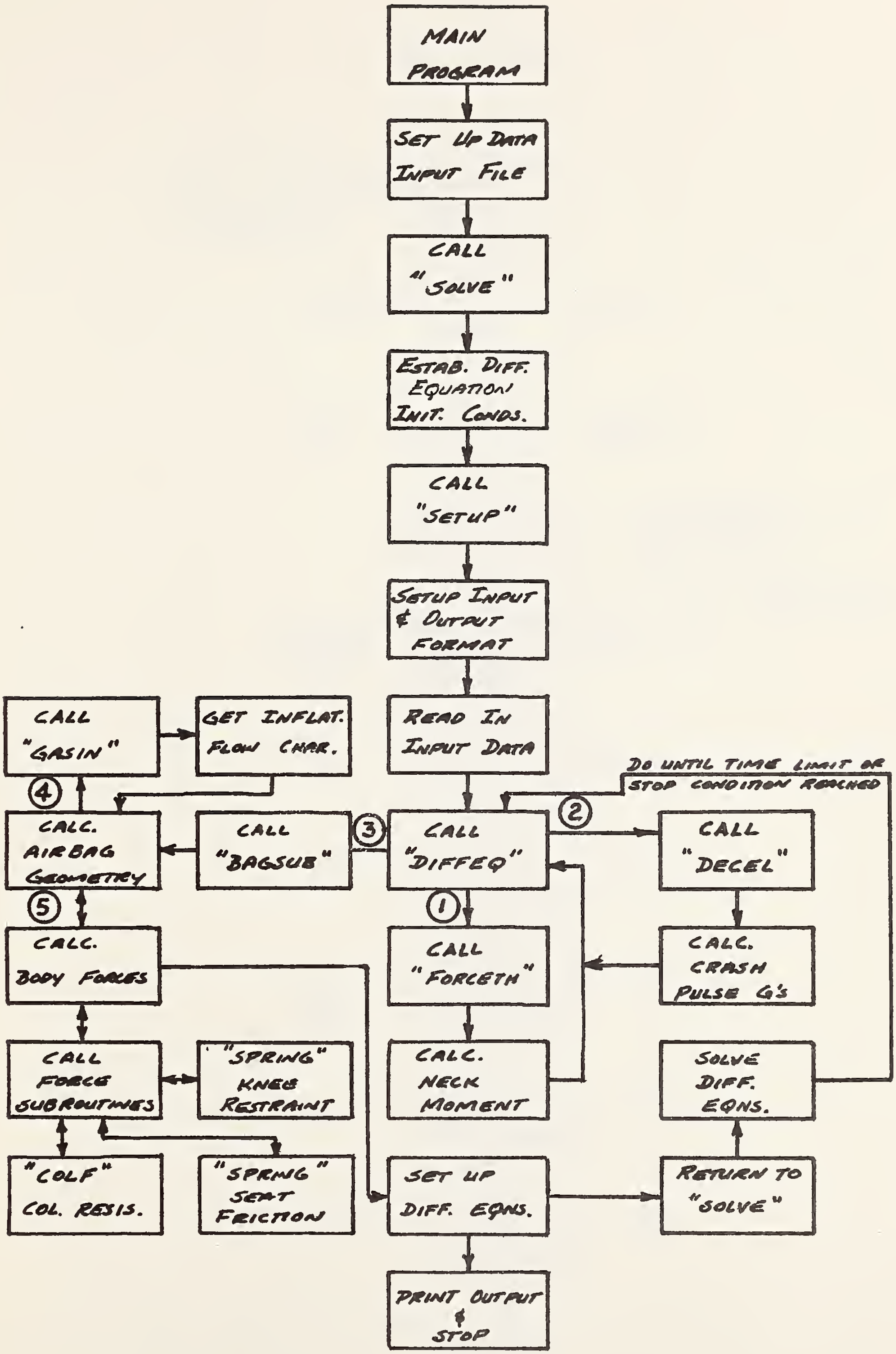
PROGRAM STOP AT 1435

USED 107.82 UNITS

# APPENDIX F

## DRAC Computer Program

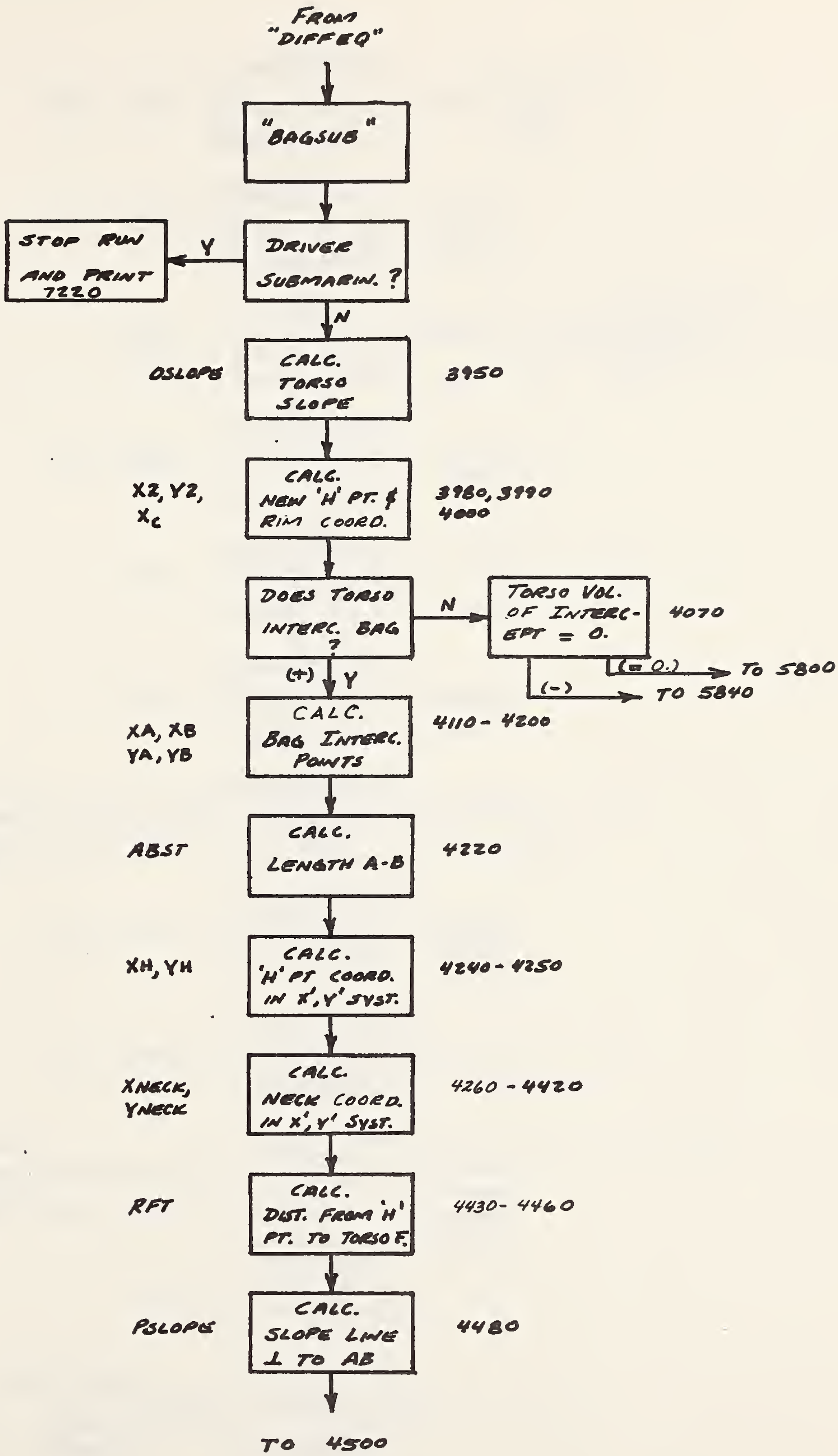
## Overall Flow Chart

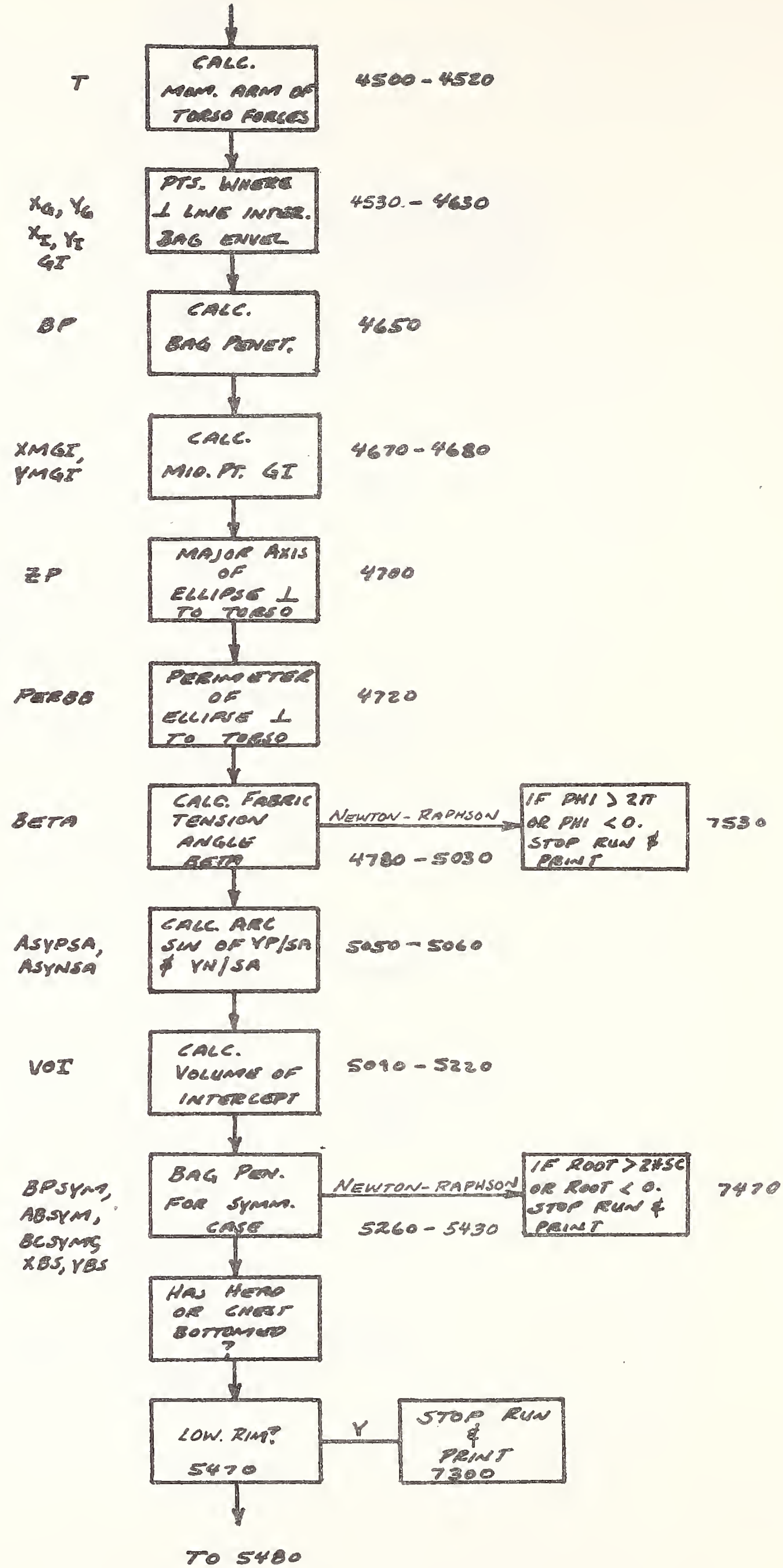

MAIN PROGRAM
SET UP DATA INPUT FILE
CALL "SOLVE"
ESTAB. DIFF. EQUATION INIT. CONDS.
CALL "SETUP"
SETUP INPUT & OUTPUT FORMAT
READ IN INPUT DATA
DO UNTIL TIME LIMIT OR STOP CONDITION REACHED
CALL "GASIN"
GET INFLAT. FLOW CHAR.
CALC. AIRBAG GEOMETRY
CALL "BAGSUB"
CALL "DIFFEQ"
CALL "DECEL"
CALC. BODY FORCES
CALL "FORCETH"
CALC. CRASH PULSE G'S
CALL FORCE SUBROUTINES
"SPRING" KNEE RESTRAINT
CALC. NECK MOMENT
SOLVE DIFF. EQNS.
"COLF" COL. RESIS.
"SPRNG" SEAT FRICTION
SET UP DIFF. EQNS.
RETURN TO "SOLVE"
PRINT OUTPUT & STOP
1
2
3
4
5

APPENDIX G

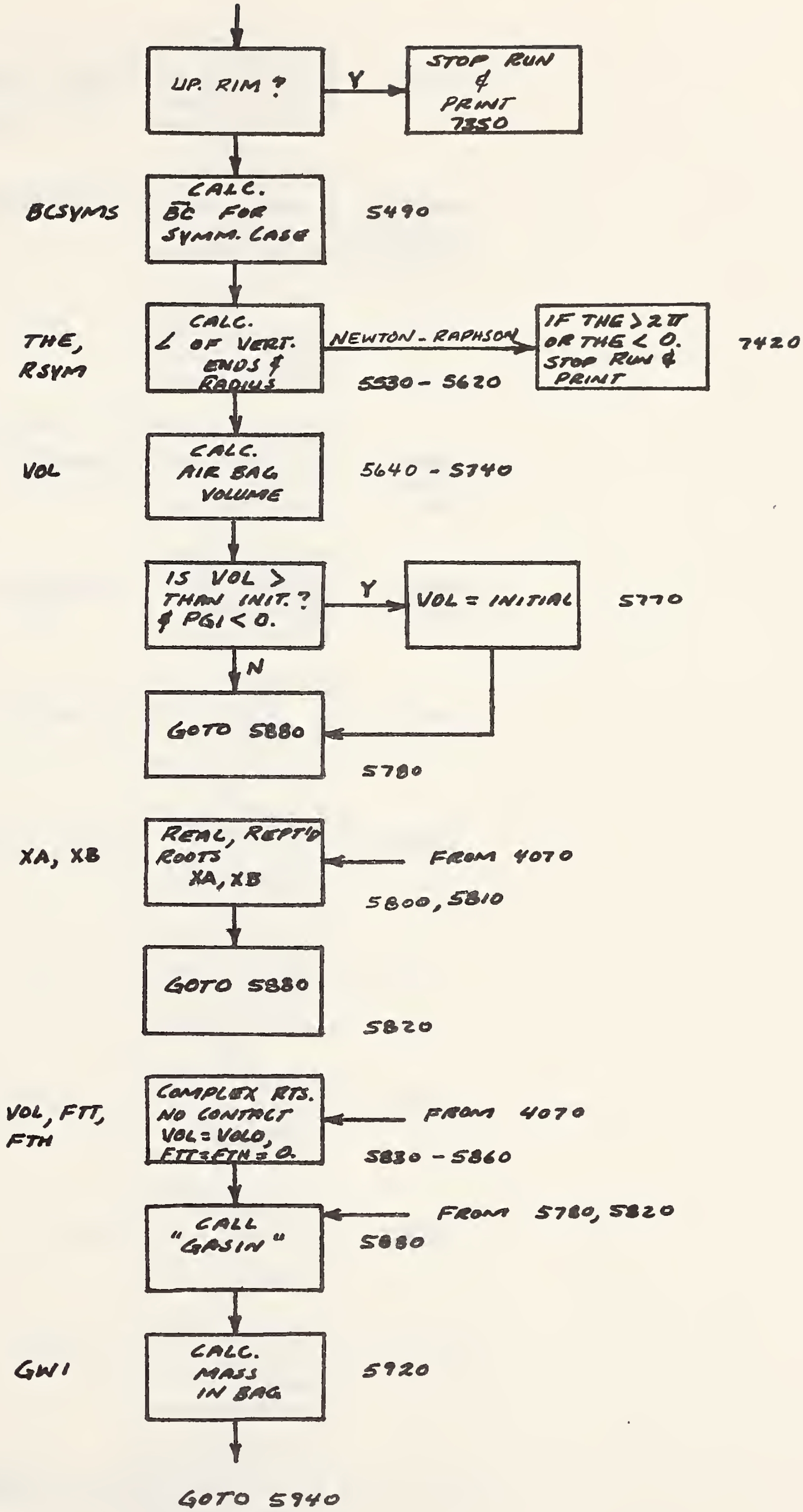
DRAC Subroutine "BAGSUB"

Flowchart

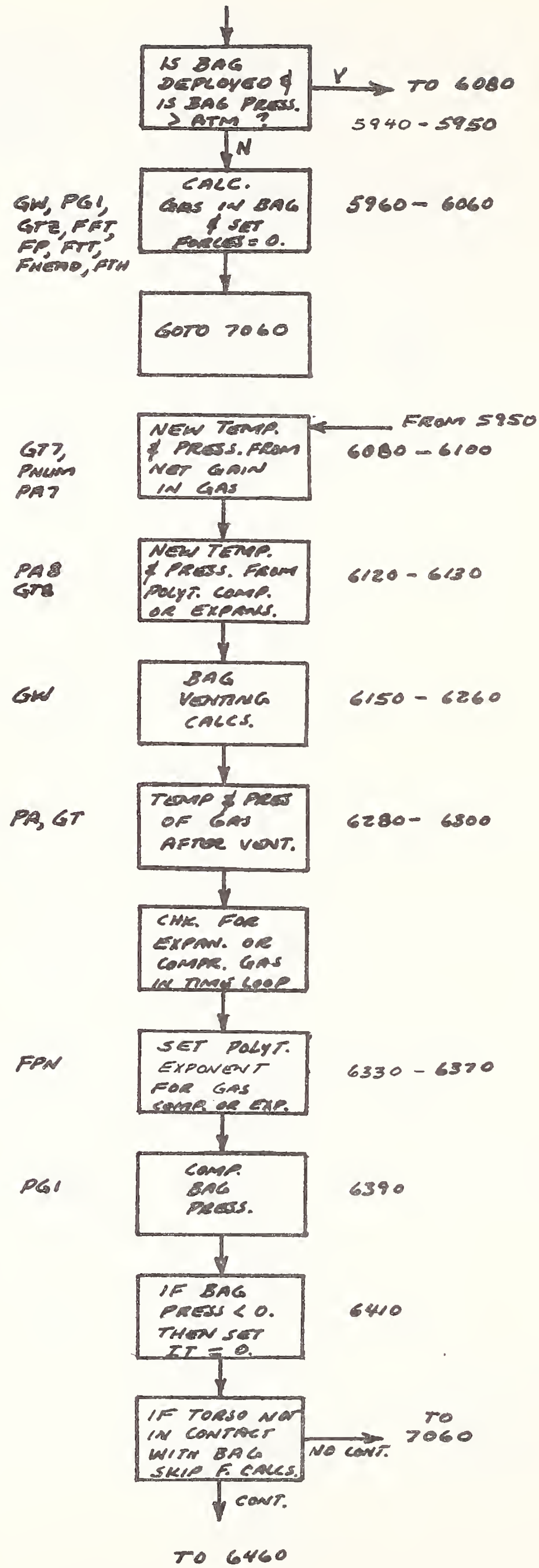

FROM "DIFFEQ"
"BAGSUB"
DRIVER SUBMARIN. ?
Y
STOP RUN AND PRINT 7220
N
OSLOPE
CALC. TORSO SLOPE
3950
X2, Y2, $X_c$
CALC. NEW 'H' PT. & RIM COORD.
3980, 3990 4000
DOES TORSO INTERC. BAG ?
N
TORSO VOL. OF INTERC-EPT = 0.
4070
(= 0.)
TO 5800
(−)
TO 5840
(+) Y
XA, XB YA, YB
CALC. BAG INTERC. POINTS
4110 - 4200
ABST
CALC. LENGTH A-B
4220
XH, YH
CALC. 'H' PT COORD. IN X', Y' SYST.
4240 - 4250
XNECK, YNECK
CALC. NECK COORD. IN X', Y' SYST.
4260 - 4420
RFT
CALC. DIST. FROM 'H' PT. TO TORSO F.
4430 - 4460
PSLOPE
CALC. SLOPE LINE ⊥ TO AB
4480
TO 4500



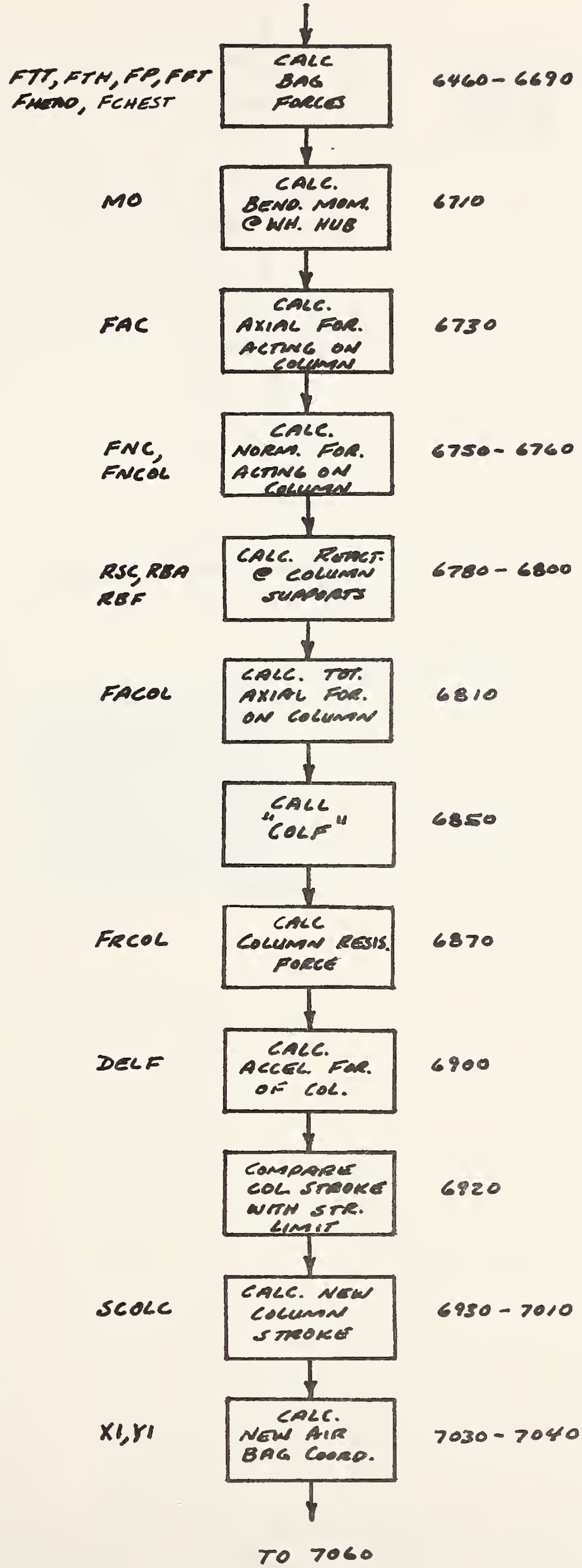
T
CALC. MOM. ARM OF TORSO FORCES
4500 - 4520
XG, YG
XI, YI
GI
PTS. WHERE ⊥ LINE INTER. BAG ENVEL
4530 - 4630
BP
CALC. BAG PENET.
4650
XMGI, YMGI
CALC. MID. PT. GI
4670 - 4680
ZP
MAJOR AXIS OF ELLIPSE ⊥ TO TORSO
4700
PERBB
PERIMETER OF ELLIPSE ⊥ TO TORSO
4720
BETA
CALC. FABRIC TENSION ANGLE BETA
NEWTON - RAPHSON
4780 - 5030
IF PHI > 2π OR PHI < 0. STOP RUN & PRINT
7530
ASYPSA, ASYNSA
CALC. ARC SIN OF YP/SA & YN/SA
5050 - 5060
VOI
CALC. VOLUME OF INTERCEPT
5090 - 5220
BPSYM, ABSYM, BCSYMG, XBS, YBS
BAG PEN. FOR SYMM. CASE
NEWTON-RAPHSON
5260 - 5430
IF ROOT > 2*SC OR ROOT < 0. STOP RUN & PRINT
7470
HAS HEAD OR CHEST BOTTOMED ?
LOW. RIM? 5470
Y
STOP RUN & PRINT 7300
TO 5480

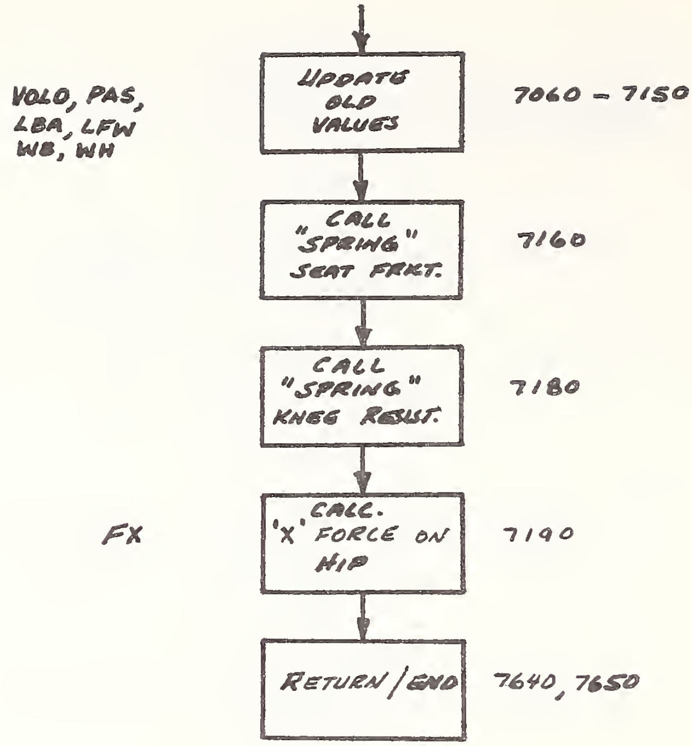


UP. RIM ?
Y
STOP RUN & PRINT 7350
BCSYMS
CALC. BC FOR SYMM. CASE
5490
THE, RSYM
CALC. ∠ OF VERT. ENDS & RADIUS
NEWTON - RAPHSON
IF THE > 2π OR THE < 0. STOP RUN & PRINT
7420
5530 - 5620
VOL
CALC. AIR BAG VOLUME
5640 - 5740
IS VOL > THAN INIT.? & PGI < 0.
Y
VOL = INITIAL
5770
N
GOTO 5880
5780
XA, XB
REAL, REPT'D ROOTS XA, XB
FROM 4070
5800, 5810
GOTO 5880
5820
VOL, FTT, FTH
COMPLEX RTS. NO CONTACT VOL = VOLO, FTT = FTH = 0.
FROM 4070
5830 - 5860
FROM 5780, 5820
CALL "GASIN"
5880
GW1
CALC. MASS IN BAG
5920
GOTO 5940



IS BAG DEPLOYED & IS BAG PRESS. > ATM ?
Y
TO 6080
5940 - 5950
N
GW, PG1, GT2, FET, FP, FTT, FNEMO, FTH
CALC. GAS IN BAG & SET FORCES = 0.
5960 - 6060
GOTO 7060
NEW TEMP. & PRESS. FROM NET GAIN IN GAS
FROM 5950
GT7, PNUM PA7
6080 - 6100
PA8 GT8
NEW TEMP. & PRESS. FROM POLYT. COMP. OR EXPANS.
6120 - 6130
GW
BAG VENTING CALCS.
6150 - 6260
PA, GT
TEMP & PRES OF GAS AFTER VENT.
6280 - 6300
CHK. FOR EXPAN. OR COMPR. GAS IN TIME LOOP
FPN
SET POLYT. EXPONENT FOR GAS COMP. OR EXP.
6330 - 6370
PG1
COMP. BAG PRESS.
6390
IF BAG PRESS < 0. THEN SET IT = 0.
6410
IF TORSO NOT IN CONTACT WITH BAG SKIP F. CALCS.
NO CONT.
TO 7060
CONT.
TO 6460


FTT, FTH, FP, FPT
FHEAD, FCHEST
CALC BAG FORCES
6460 - 6690
MO
CALC. BEND. MOM. @ WH. HUB
6710
FAC
CALC. AXIAL FOR. ACTING ON COLUMN
6730
FNC, FNCOL
CALC. NORM. FOR. ACTING ON COLUMN
6750 - 6760
RSC, RBA
RBF
CALC. REACT. @ COLUMN SUPPORTS
6780 - 6800
FACOL
CALC. TOT. AXIAL FOR. ON COLUMN
6810
CALL "COLF"
6850
FRCOL
CALC COLUMN RESIS. FORCE
6870
DELF
CALC. ACCEL. FOR. OF COL.
6900
COMPARE COL. STROKE WITH STR. LIMIT
6920
SCOLC
CALC. NEW COLUMN STROKE
6930 - 7010
XI, YI
CALC. NEW AIR BAG COORD.
7030 - 7040
TO 7060


VOLD, PAS,
LBA, LFW
WB, WH
UPDATE OLD VALUES
7060 – 7150
CALL "SPRING" SEAT FRKT.
7160
CALL "SPRING" KNEE RESIST.
7180
FX
CALC. 'X' FORCE ON HIP
7190
RETURN/END
7640, 7650

TL 242 .F5837
Fitzpatrick.
"DRAC" user's
Form DOT F 172
FORMERLY FORM D

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