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SUPPLEMENT TO THE HSRI THREE DIMENSIONAL CRASH VICTIM SIMULATION REPORT

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16. Abstract

This report supplements the original HSRI Three-Dimensional Crash Victim Simulation report developed under DOT Contract No. FH-11-6962 (available as NTIS No. PB208242). An airbag model, developed at Wayne State University under NHTSA Contract No. DOT-FH-11-7607, has been installed in the HSRI model and is described. The changes in input data cards due to work accomplished since the original report are presented.

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We are pleased to acknowledge that Dr. Clifford C. Chou of Ford Motor Co., who was one of the original workers on the WSU Airbag Model, served as a consultant during the installation of the WSU Airbag Model in the HSRI Three Dimensional Model.

1.0 INTRODUCTION

This report is a supplement to the original report on the HSRI Three-Dimensional Crash Victim Simulator entitled, "HSRI Three-Dimensional Crash Victim Simulator: Analysis, Verification, Users' Manual, and Pictorial Section," June 30, 1971, by D. H. Robbins, R. O. Bennett, and V. L. Roberts. (Final Report on DOT Contract No. FH-11-6962, NTIS No. PB-208242). This report describes the changes made to the model since the publication of the original report.

These changes include:

1. Input and Output of angular accelerations in radians per second per second instead of degrees per second per second.
2. Numerous formatting changes in printed output.
3. Value of Earth Standard Gravity changed to 32.174.
4. Input and Output in S. I. (Metric) or Anglo-American Units.
5. Incorporation of WSU Airbag Model with minor changes.

Section 2.0 of this report reviews the analysis of the WSU Airbag Model. Section 3.0 of this report consists of an updated version of Table 7 of the original report. Section 4.0 discusses the use of the new features and the restrictions on them.

2.0 ANALYTICAL DESCRIPTION OF THE WSU AIRBAG MODEL

The only known published report on the WSU Airbag Model is SAE Paper No. 720036 entitled, "A Mathematical Model of an Airbag for a Three-Dimensional Simulation," by A. I. King, C. C. Chou, and G. A. Mackinder, dated Jan. 1972.

The description presented here is based on the unpublished WSU final project report to NHTSA (Contract No. DOT-FH-11-7607) and reflects later changes made at both WSU and HSRI.

The WSU Airbag Model was developed to simulate a spherical airbag mounted on a collapsing steering column (driver airbag). Later this model was modified slightly to represent a cylindrical airbag mounted on a collapsing panel (passenger airbag). Both options are available in the current model under switch control. In either case, the airbag model consists of the same basic submodels listed below.

1. The free-expanding airbag submodel
2. The detection of occupant torso contact submodel
3. The contacted airbag submodel
4. The bottomed-out airbag submodel
5. The collapsing column (or panel) submodel
6. Addition of airbag forces into the occupant equations of motion submodel

These submodels are discussed in Sections 2.1 through 2.6, respectively. Section 2.7 discusses the interrelationship between these six submodels.

The basic assumptions made in the derivations of the airbag analysis are listed.

1. Before impact with the occupant, the spherical airbag expands radially due to gas flow.
2. The pressure of the airbag is always uniformly distributed.
3. The gas flow is an adiabatic process.
4. After impact, the airbag deforms as if it were squeezed by two parallel plates.

5. The deformation of the airbag wall follows a linear elastic relation by considering the bag as an axisymmetric elastic thin shell.

2.1 The Free-Expanding Airbag

The differential equations governing the airbag expansion before impact are listed. Figure 1 shows the configuration of the airbag before contact.

$$\dot{R} = \frac{\dfrac{(P_0)^{\frac{1}{k}}}{\rho_0}\left[C - B_1\sqrt{2\rho_0 P\left(\dfrac{\overline{P}}{\overline{P}_0}\right)^{\frac{1}{k}}}\right]}{\dfrac{-B_2}{k}\,(\overline{P})^{(\frac{1}{k}-1)}\,\dfrac{B_5}{B_4} + \pi B_3 R(\overline{P})^{\frac{1}{k}}}$$

$$\dot{P} = -\frac{B_5}{B_4}\dot{R}$$

where

R = bag radius

P = bag gauge pressure

$\overline{P}$ = bag absolute pressure = P + 1 atmosphere

ρ_0 = initial gas density

k = ratio of specific heats (outside to inside)

P_0 = initial bag gauge pressure

$\overline{P}_0$ = initial bag absolute pressure = P_0 + 1 atmosphere

C = gas mass inflow rate

B_1 = gas mass outflow rate, or

$$B_1 = \begin{cases} = 0 \text{ if } P < P_v \\ = A\beta\sqrt{\dfrac{\dfrac{k}{k-1}(B_6)^{\frac{2}{k}}\left[1-(B_6)^{\frac{k-1}{k}}\right](1-B_7)}{(1-B_6)\left(1-B_7(B_6)^{\frac{2}{k}}\right)}} \quad \text{if } P \geq P_v \end{cases}$$

NOTE: 1 atmosphere is the pressure at sea level due to the weight of the atomsphere and has a value of 14.696 lbs/in^2 or 101325 N/m^2

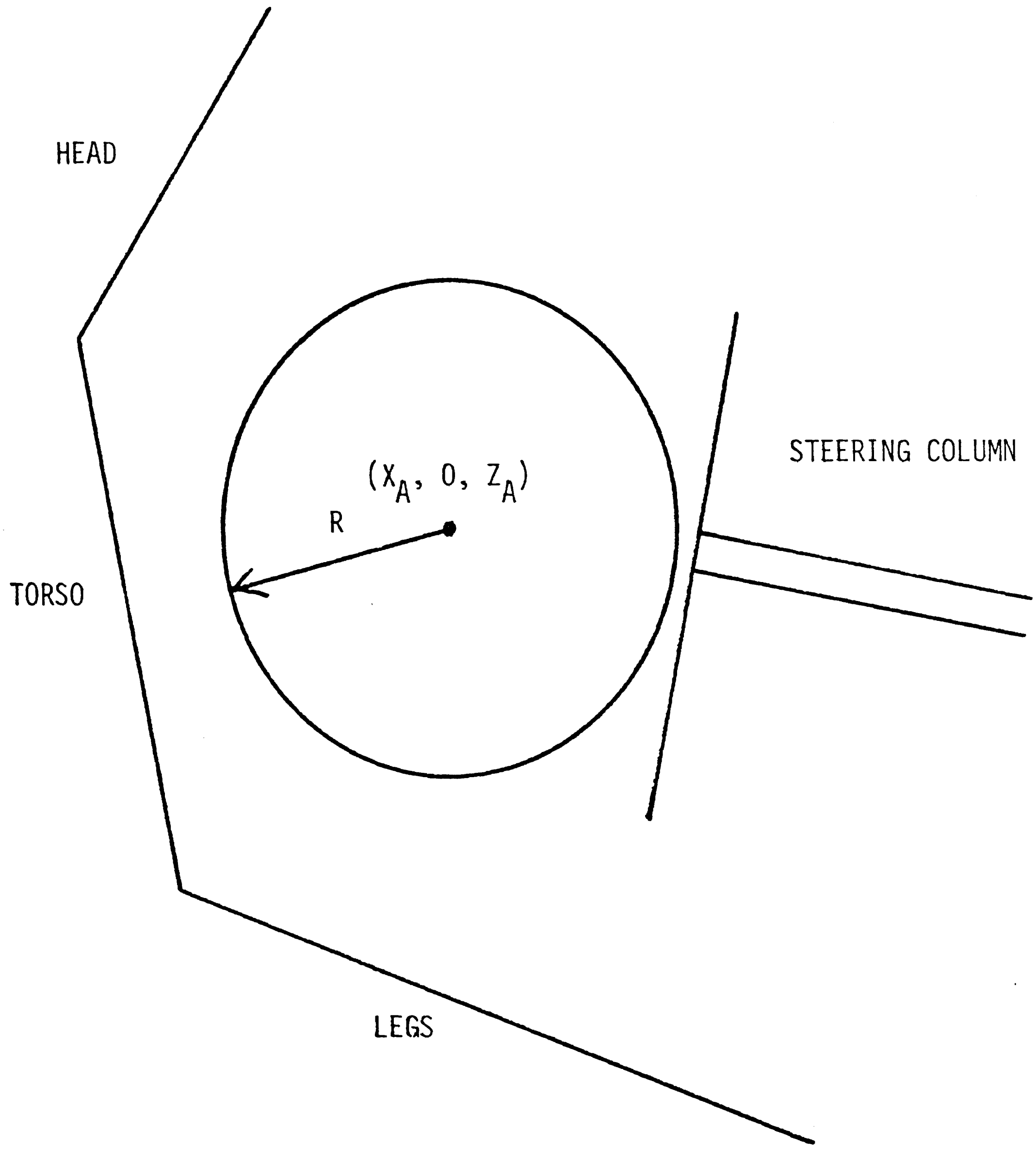

Figure 1. The Free Expanding Airbag

P_v = venting pressure

A = area of vent hole

β = coefficient of discharge

$$B_2 = \text{airbag volume} = \begin{cases} \frac{4}{3}\pi R^3 & \text{for driver airbag} \\ \pi L R^2 & \text{for passenger airbag} \end{cases}$$

L = cylinder length

$$B_3 = \begin{cases} 4R & \text{for driver airbag} \\ 2L & \text{for passenger airbag} \end{cases}$$

$$B_4 = \frac{R}{B_8}$$

$$B_5 = \frac{P}{B_8} - \frac{1}{R}$$

$$B_6 = \text{ratio of pressures (outside to inside)} = \frac{1\ \text{atmosphere}}{\overline{P}}$$

B_7 = ratio of vent hole radius to airbag radius raised to the fourth power =

$$\frac{A^2}{\pi^2 R^4}$$

$$B_8 = \begin{cases} 2hE & \text{for driver airbag} \\ hE & \text{for passenger airbag} \end{cases}$$

h = thickness of airbag wall

E = Young's Modulus of airbag wall

2.2 Detection of Occupant Torso Contact with the Airbag

The time that occupant impact with the airbag occurs (τ) is the first time at which any of the following three inequalities is satisfied. Figure 2 shows the configuration for the testing for occupant-airbag contact.

$$\sqrt{(X_T - X_A)^2 + Y_T^2 + (Y_T - Z_A)^2} < R + C_T$$

$$\sqrt{(X_{TN} - X_A)^2 + Y_{TN}^2 + (Z_{TN} - Z_A)^2} < R + C_T$$

$$\sqrt{(X_{TH} - X_A)^2 + Y_{TH}^2 + (Z_{TH} - Z_A)^2} < R + C_T$$

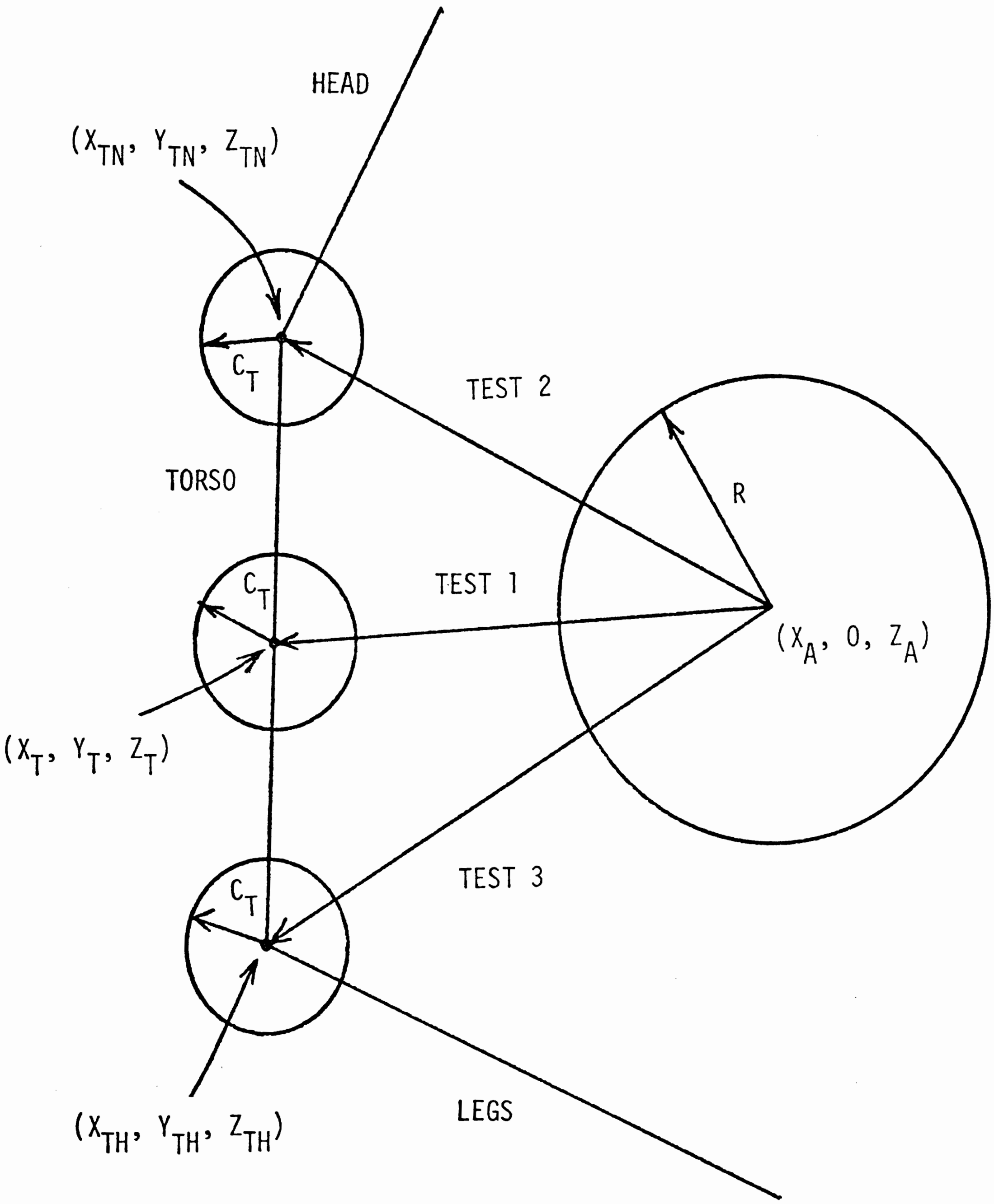

Figure 2. Testing for Occupant-Airbag Contact

where

$(X_A, 0, Z_A)$ is the fixed point in the vehicle where the center of the airbag is mounted.

(X_T, Y_T, Z_T) is the position of the torso center in vehicle coordinates.

(X_{TN}, Y_{TN}, Z_{TN}) is the position of the neck joint in the vehicle coordinates.

(X_{TH}, Y_{TH}, Z_{TH}) is the position of the hip joint in vehicle coordinates.

C_T = 1/2 the thickness of the chest

R = radius of the airbag.

2.3 The Contacted Airbag

The differential equations governing the airbag after impact are listed. Figure 3 shows the configuration for the contacted airbag.

$$\dot{H} = \frac{D_9 A_2 - D_8 A_5}{A_2 A_6 - A_3 A_5}$$

$$\dot{P} = \frac{D_8 - A_3 \dot{H}}{A_2}$$

where

H = the length of the flattened portion of the airbag.

P = gauge pressure of the airbag

$\overline{P}$ = absolute pressure of the airbag = P + 1 atmosphere

$$A_2 = (\overline{P})^{\left(\frac{1}{k} - 1\right)} \cdot \frac{D_1}{k}$$

$$A_3 = (\overline{P})^{\frac{1}{k}} \; D_2 A_1$$

$$A_4 = (\overline{P})^{\frac{1}{k}} \; D_{10} D_3$$

$$A_5 = \frac{(\pi A_1 + H)(2A_1 + H)}{D_4}$$

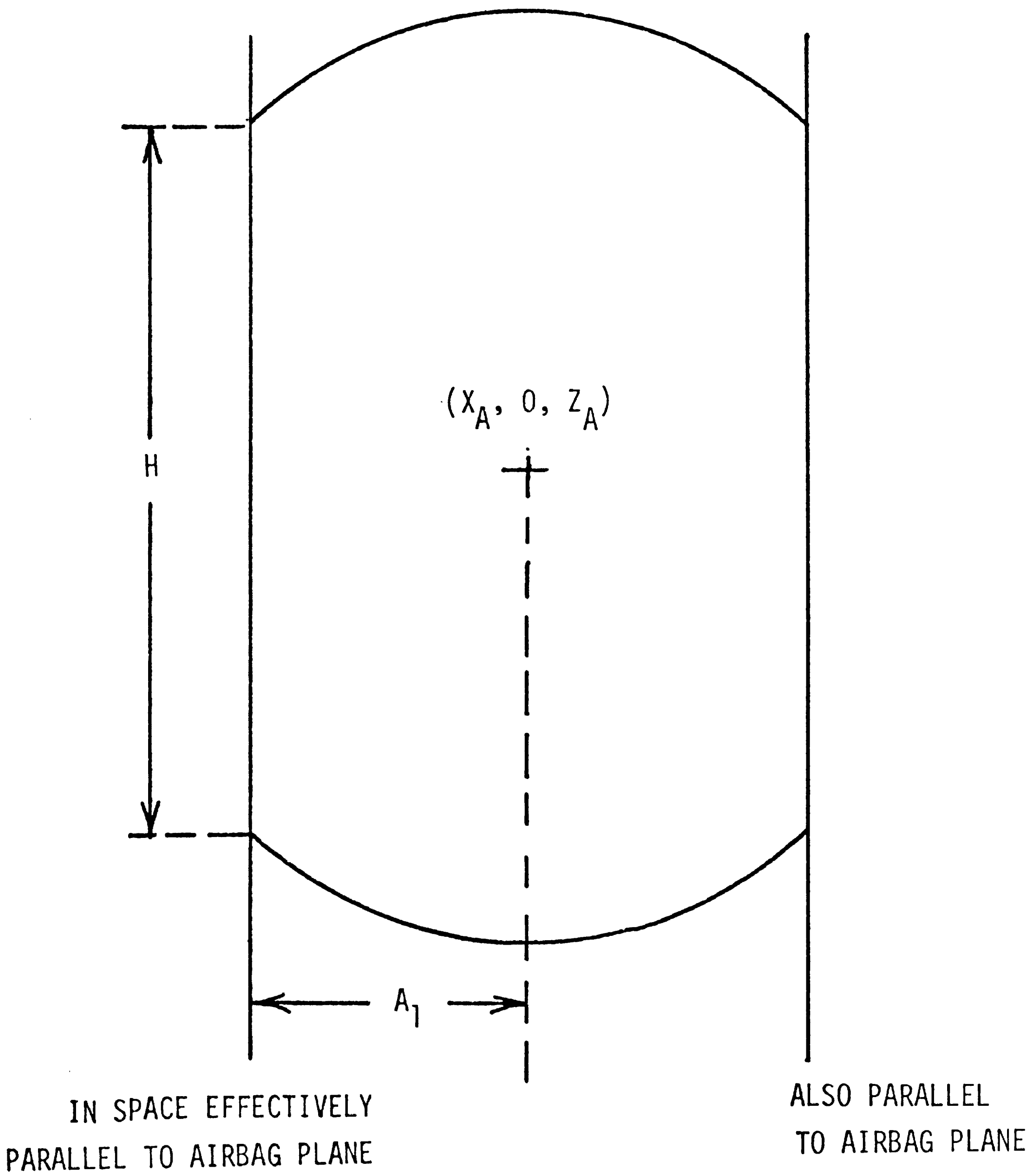

Figure 3. The Contacted Airbag

$$A_6 = \frac{(\pi A_1 + H)\ P}{D_4} - 1$$

A_1 = 1/2 the distance between parallel plates

$$= \begin{cases} R_\tau - \frac{1}{2} D_{11} + \frac{1}{2}(1 - \alpha)\ D_{12} & \text{before rebound begins} \\ A_{1R} - .5\ D_{15} & \text{after rebound begins} \end{cases}$$

R_τ = airbag radius at the time of contact

α = the fraction of torso movement over the last time interval which is allocated to airbag deformation

$$D_1 = \begin{cases} \frac{4}{3}\pi(A_1)^3 + \frac{1}{2}\pi A_1 H^2 & \text{for driver bag} \\ \pi L\ (A_1)^2 + 2LHA_1 & \text{for passenger bag} \end{cases}$$

$$D_2 = \begin{cases} \pi H & \text{for driver bag} \\ 2L & \text{for passenger bag} \end{cases}$$

$$D_3 = \begin{cases} 2\pi(A_1)^2 + \frac{\pi}{4} H^2 & \text{for driver bag} \\ \pi LA_1 + LH & \text{for passenger bag} \end{cases}$$

$$D_4 = \begin{cases} 4hE & \text{for driver bag} \\ hE & \text{for passenger bag} \end{cases}$$

$$D_7 = \begin{cases} 0 \quad \text{if } P < P_V \\ A\beta \sqrt{\dfrac{\frac{k}{k-1}(D_6)^{\frac{2}{k}}\left(1 - (D_6)^{\frac{k-1}{k}}\right)(1 - D_5)}{(1 - D_6)\left(1 - D_5\ (D_6)^{\frac{2}{k}}\right)}} & P \geq P_V \end{cases}$$

$$D_5 = \left(\frac{2\sqrt{\frac{A}{\pi}}}{2A_1 + H}\right)^4$$

$$D_6 = \frac{1 \text{ atmosphere}}{\overline{P}}$$

$$D_8 = \frac{(P_\tau)^{\frac{1}{k}} \; (C - D_7 D_{13})}{\rho_\tau} + A_4$$

P_τ = airbag absolute pressure at time of contact.

$$\rho_\tau = \rho_0 \left(\frac{P_\tau}{\overline{P}_0} \right)^{\frac{1}{k}}$$

$$D_9 = \left[\frac{(\pi A_1 + H) \, P}{D_4} - \frac{\pi}{2} \right] D_{10}$$

$$D_{10} = \alpha V_{CN}$$

V_{CN} = velocity of the torso c.g. relative to the vehicle

$$D_{11} = \sqrt{(X_T - X_\tau)^2 + (Y_T - Y_\tau)^2 + (Z_T - Z_\tau)^2}$$

$$D_{12} = \text{sgn}\,(X_T - X_{cc}) \sqrt{(X_T - X_{cc})^2 + (Y_T - Y_{cc})^2 + (Z_T - Z_{cc})^2}$$

(X_τ, Y_τ, Z_τ) = position in vehicle of torso c.g. at time of contact

(X_{cc}, Y_{cc}, Z_{cc}) = position in vehicle of torso c.g. at time column or panel collapse begins

$$D_{13} = \begin{cases} 0 \text{ if } D_{14} \leq 0 \\ \sqrt{D_{14}} \text{ if } D_{14} > 0 \end{cases}$$

$$D_{14} = 2P \left(\frac{\overline{P}}{P_\tau} \right)^{\frac{1}{k}} \rho_\tau$$

$$D_{15} = \text{sgn}\,(X_T - X_R) \sqrt{(X_T - X_R)^2 + (Y_T - Y_R)^2 + (Z_T - Z_R)^2}$$

(X_R, Y_R, Z_R) = position in vehicle of torso c.g. when rebound begins

A_{1R} = value of A_1 when rebound begins.

Other quantities as defined in Section 2.1

Total force on the occupant torso due to the airbag is computed as as

$$F_T = \frac{\pi}{4} PHG_1G_2$$

where

$$G_1 = \begin{cases} 1 \text{ if } |X_T - X_\tau| \geq C_T \\ \dfrac{|X_T - X_\tau|}{C_T} \text{ if } |X_T - X_\tau| < C_T \end{cases}$$

$$G_2 = \begin{cases} H \text{ if driver airbag} \\ \ell \text{ if passenger airbag} \end{cases}$$

ℓ = width of the occupant torso

2.4 The Bottomed Out Airbag

When $A_1 \leq 0$, the airbag is considered to have bottomed-out. The total force on the occupant is then computed as

$$F_T = F_B + k_B(X_T - X_B)$$

where

F_B is the value of F_T when the airbag bottoms out

k_B = linear spring constant for bottomed-out airbag

(X_B, Y_B, Z_B) is position in vehicle of the torso c.g. when the airbag bottoms out

2.5 The Collapsing Column or Panel

Column or panel collapse begins when the total force on the column or panel due to the airbag exceeds the column or panel collapse force. The column or panel is assumed to collapse in such a way that the airbag force stays constant. An iterative procedure is employed to divide the torso movement between the airbag and steering column in such a way as to maintain the constant force. The Young's Modulus (E) of the airbag wall is changed to a different inputted constant (ECON).

When rebound occurs, the iteration ceases, and the airbag alone responds to torso movement. When the maximum column or panel collapse distance is exceeded (the column or panel bottoms out), the iteration also ceases, and again the airbag alone responds to torso movement.

2.6 Addition of Airbag Forces into the Occupant Equations of Motion

Contributions to the occupant equations of motion due to the airbag are not computed directly in the WSU airbag model. The approach used to get the airbag forces into the occupant equations of motion is to use a slightly modified version of the HSRI occupant contact model. One of the contact planes is assigned to the airbag. In any uninhibited interaction between any body ellipse and the special airbag plane for which the deflection is positive, the prorated force computed by the airbag model is substituted for the standard deflection-dependent ellipse-plane force computation. The proration of force is over the number of expected ellipse-airbag plane interactions. This force is treated by the contact model just as if it were produced by the ellipse-plane interaction and added into the equations of motion for the occupant. This means that the airbag force is always applied to any body ellipse in the direction of the normal to the airbag plane. Figure 4 shows how the airbag force is applied.

HSRI has made two minor additions to the WSU approach outlined above. In order to protect the occupant model integration from potentially large step-functions in force, the prorated airbag force is modified by the following deflection-dependent factor.

$$\eta = \begin{cases} \dfrac{\delta}{\delta_{eff}} & \text{if} \quad \delta < \delta_{eff} \\ 1 & \text{if} \quad \delta \geq \delta_{eff} \end{cases}$$

where

δ = the deflection of the airbag plane by the body ellipse for the current interaction.

δ_{eff} = is the inputted deflection at which the total prorated airbag force is to be felt by the occupant

In order to allow some possibility to model an oblique or lateral collision, the standard handling of planar size and edge effects has been installed with regard to the airbag plane.

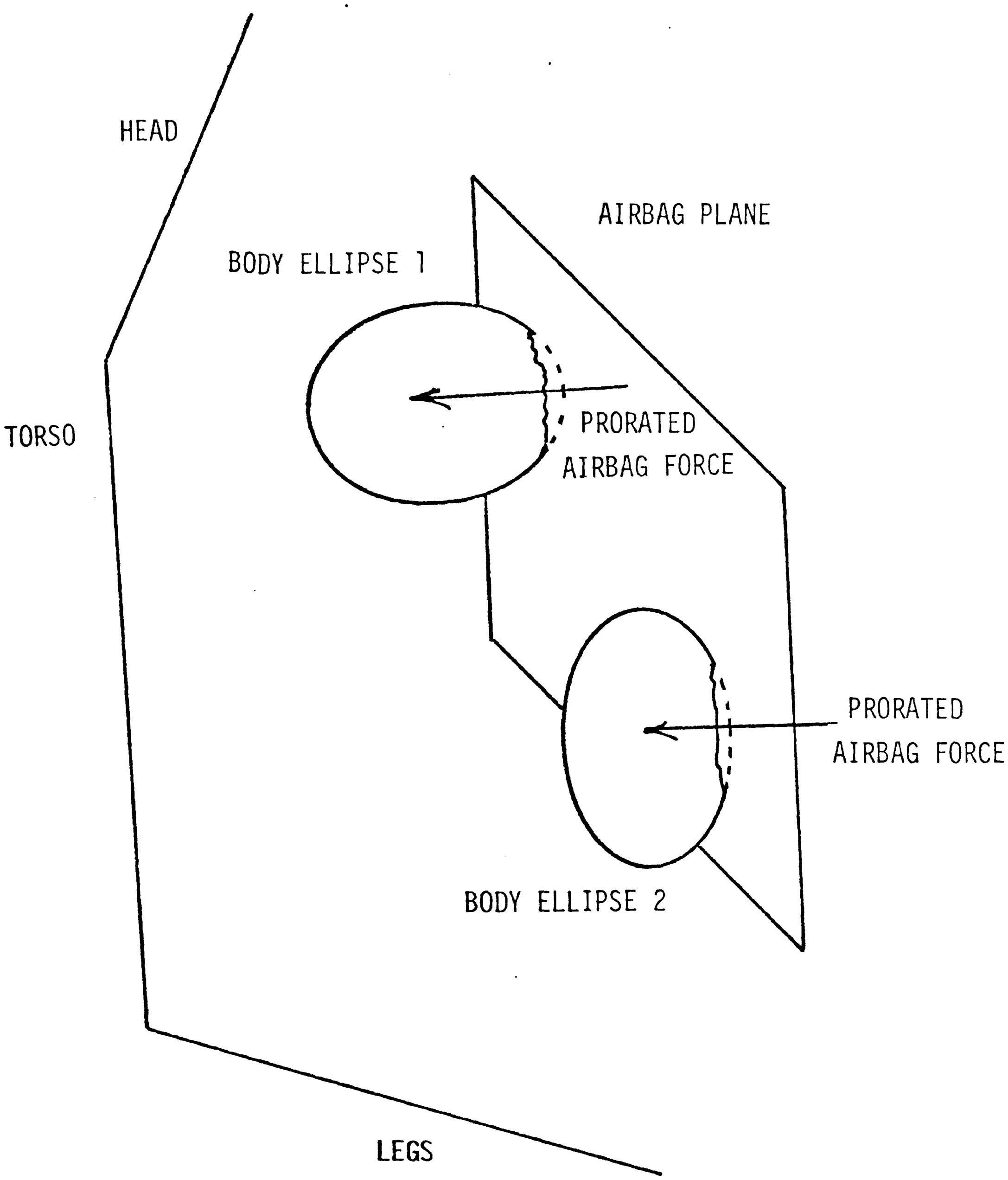

Figure 4. Application of Airbag Force

The properties of the airbag plane are ignored except for position, orientation, size, and edge constants although all properties must be supplied with reasonable values. The user must be very careful to position and move the airbag plane so that it maintains contact with each of the expected body ellipses at the proper angle while the airbag model is predicting non-zero force.

2.7 Submodel Interrelationship

The WSU Airbag Model progresses through the submodels described in Section 2.1 through 2.6 as outlined below. The addition of airbag forces into the occupant equations of motion (2.6) is operational at all times when the airbag option is elected. After the simulated time at which the airbag begins to inflate is reached, the Free-Expanding Airbag Submodel (2.1) and the Detection of Occupant Contact Submodel (2.2) begin to operate. When contact is determined to have occurred, these two submodels are turned off and not used again. At the same time, the Contacted Airbag Submodel (2.3) begins to operate. If the steering column or panel begins to collapse, the Collapsing Column or Panel Submodel (2.5) begins to operate along with the Contacted Airbag. The Collapsing Column or Panel Submodel is turned off if rebound, airbag bottoming out, or column bottoming out occurs. If the airbag bottoms out, the Bottomed-Out Airbag Submodel (2.4) is used. If the airbag pressure goes negative, the Contacted Airbag Submodel is turned off.

3.0 Updated Description of Program Input Data

Table 1 contains a description of the cards required by the WSU Airbag. If the airbag model is not used, only the first card described in Table 1 should be included. Any cards for the airbag must precede all other input cards. Table 2 gives the input cards for the HSRI Three-Dimensional Crash Victim Simulator. The symbols and figure numbers are those used in the original HSRI report. In both these tables, the expected metric untis are enclosed in parentheses and appear next to the expected Anglo-American units. The setting of the switch in field five on Card S determines which set of units is used throughout the input data and also in the output of both the WSU and HSRI Models.

TABLE 1. WSU Airbag Input Cards (1 of 2)

Cards	Field	Symbol	Quantity	Units	
(1st card)	1	NFLAG	Integer switch: NFLAG = 0 Airbag Model is not used NFLAG = 1 Driver Airbag model is used NFLAG = 2 Passenger airbag model is used Note: This number should be punched in column 1.	--	
(2nd card)*	1	ρ_0	Gas density	slug/in^3	(kg/m^3)
	2	R_o	Initial radius of airbag	in	(cm)
	3	P_o	Initial pressure in the airbag	psi	(N/cm^2)
	4	h	Thickness of the airbag membrane	in	(cm)
	5	E	Young's modulus of the membrane	psi	(N/cm^2)
	6	TBEG	Time at which airbag starts to inflate	sec	
	7	C	Inflow mass rate	slug/sec	(kg/sec)
	8	TIEG	Time at which airbag stops inflating	sec	
(3rd card)*	1	k	Ratio of the specific heats (outside to inside)	--	
	2	ℓ	Width of the occupant torso	in	(cm)
	3	C_T	1/2 depth of occupant torso	in	(cm)
	4	X_A	Coordinates of the center of the airbag in vehicle coordinates. Y_A assumed zero.	in	(cm)
	5	Z_A			
	6	L	Length of passenger airbag	in	(cm)
	7	ECON	Young's modulus of membrane on the rebound	lbs/in^2	(N/cm^2)
	8	k_B	Elastic constant of bottomed-out airbag	lbs/in	(N/cm)

TABLE 1. WSU Airbag Input Cards (2 of 2)

Cards	Field	Symbol	Quantity	Units	
(4th Card)*	1	TNE	Total number of ellipsoids which contact the airbag	--	
	2	CDMAX	Maximum column collapse distance	in	(cm)
	3	P_v	Pressure at which vent hole assumed to be open	psi	(N/cm^2)
	4	A	Vent hole area	in^2	(cm^2)
	5	β	Discharge coefficient	--	
	6	VOL	Volume of the airbag when full inflation	in^3	(cm^3)
	7	THETA	Column angle	degrees	
	8	FMAX	Prescribed column collapse load	lbs	(N)
(5th Card)*	1	FOREPS	Convergence criterion for bag-column or panel force balance	lbs	(N)
	2	δ_{eff}	Deflection into airbag plane for full use of airbag force	in	(cm)
	3	LBAGC	Contact Number for airbag plane (1 to 25)	--	

*Include only if NFLAG set to one or two

TABLE 2 INPUT DATA CARDS (3-D MODEL, 4-77) (1 of 16)

Cards	Field	Symbol	Figure	Quantity	Units	
A	1	n	4,5	Body segment number (1.=torso, 2.=head, 3.=legs) If this number is positive, fields 3, 4, 5 will be moments of inertia. If negative, they will be three measurements of body for computing moments of inertia.		
A	2	m_n	4	Mass of body segment	lb sec^2/in	(kg)
A	3	I_{1n} (t_n)	4	Moment of inertia about i-vector (or, 1. anterior-posterior thickness of torso elliptical cylinder 2. anterior-posterior thickness of head ellipsoid 3. inferior-superior thickness of leg elliptical cylinder.)	in lb sec^2 (in.	(kg m^2) (cm))
A	4	I_{2n} (h_n)	4	Moment of inertia about j-vector (or, 1. length of torso elliptical cylinder 2. inferior-superior length of head ellipsoid 3. length of leg elliptical cylinder.)	in lb sec^2 (in.	(kg m^2) (cm))
A	5	I_{3n} (w_n)	4	Moment of inertia about k-vector (or, 1. width of torso elliptical cylinder 2. width of head ellipsoid 3. width of leg elliptical cylinder.)	in lb sec^2 (in.	(kg m^2) (cm))
A	6	ρ_3, ρ_2 or ρ_5	4	Distance from center of gravity to lower joint	in.	(cm)
A	7	ρ_1 ρ_6 or ρ_4	4	Distance from center of gravity to upper joint	in.	(cm)

TABLE 2 INPUT DATA CARDS (3-D MODEL, 4-77) (2 of 16)

Cards	Field	Symbol	Figure	Quantity	Units	
B	1	m	9	Identification number for this ellipsoid must be in range one to ten.		
B	2	n	9	Body segment number to which this ellipsoid is to be attached.		
B	3	x_{em}	9	X coordinate of ellipsoid center relative to body segment system.	in.	(cm)
B	4	y_{em}	9	Y coordinate of ellipsoid center relative to body segment system.	in.	(cm)
B	5	z_{em}	9	Z coordinate of ellipsoid center relative to body segment system.	in.	(cm)
B	6	a_m	9	Ellipsoid semiaxis length parallel to i-vector of body segment.	in.	(cm)
B	7	b_m	9	Ellipsoid semiaxis length parallel to j-vector of body segment.	in.	(cm)
B	8	c_m	9	Ellipsoid semiaxis length parallel to k-vector of body segment.	in.	(cm)
A special card is automatically read after the B card which contacts in columns one through sixteen the alphanumeric name of this ellipsoid. The name should be centered within these sixteen columns.						
C	1	i	13	Joint index (1=neck, 2=hip)		
C	2	$k_{\psi i}$	13	Torsional elastic constant resisting relative yaw.	in lb/rad.	(mN/rad)
C	3	$k_{\psi si}$	13	Torsional elastic constant of relative yaw stop.	in lb/rad.	(mN/rad)

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (3 of 16)

Cards	Field	Symbol	Figure	Quantity	Units
C	4	ψ_{is}	13	Relative yaw angle at which stop is applied.	deg.
C	5	$k_{\phi i}$	13	Torsional elastic constant resisting relative roll.	in lb/rad. (mN/rad)
C	6	$k_{\phi si}$	13	Torsional elastic constant of relative roll stop.	in lb/rad. (mN/rad)
C	7	ϕ_{is}	13	Relative roll angle at which stop is applied.	deg.
C	8	$c_{\psi i}$	13	Relative yaw damping coefficient.	in lb sec/rad (mNsec/rad)
D	1	i	13	Joint index (1.=neck, 2.=neck)	
D	2	$k_{\theta i}$	13	Torsional elastic constant resisting relative pitch.	in lb/rad (mN/rad)
D	3	$k_{\theta usi}$	13	Torsional elastic constant of upper relative pitch stop. Upper = rearward rotation of head relative to torso. = rearward rotation of legs relative to torso.	in lb/rad (mN/rad)
D	4	θ_{usi}	13	Relative pitch angle at which upper stop is applied.	deg.
D	5	$k_{\theta Lsi}$	13	Torsional elastic constant of lower relative pitch stop. lower = forward rotation of head relative to torso. = jacknifing of torso down toward legs.	in lb/rad (mN/rad)

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (4 of 16)

Cards	Field	Symbol	Figure	Quantity	Units
D	6	θ_{LSi}	13	Relative pitch angle at which lower stop is applied.	deg.
D	7	$c_{\theta i}$	13	Relative pitch damping coefficient.	in lb sec/rad. (mNsec/rad)
D	8	$c_{\phi i}$	13	Relative roll damping coefficient.	in lb sec/rad. (mNsec/rad)
E	1	$[x_1]_{t=0}$	5,6	Initial x of torso c.g.*	in. (cm)
E	2	$[\dot{x}_1]_{t=0}$	5,6	Initial forward velocity of torso c.g.*	in/sec. (m/sec)
E	3	$[y_1]_{t=0}$	5,6	Initial y of torso c.g.*	in (cm)
E	4	$[\dot{y}_1]_{t=0}$	5,6	Initial right sideways velocity of torso c.g.	in/sec. (m/sec)
E	5	$[z_1]_{t=0}$	5,6	Initial z of torso c.g.*	in. (cm)
E	6	$[\dot{z}_1]_{t=0}$	5,6	Initial downward velocity of torso c.g.*	in/sec. (m/sec)
E	7	$[\psi_1]_{t=0}$	5,6	Initial torso yaw.*	deg.
E	8	$[\dot{\psi}_1]_{t=0}$	5,6	Initial torso yaw rate.*	deg/sec.
F	1	$[\theta_1]_{t=0}$	5,6	Initial torso pitch.* (may not be exactly ninety degrees in magnitude)	deg.
F	2	$[\dot{\theta}_1]_{t=0}$	5,6	Initial torso pitch rate.*	deg/sec.
F	3	$[\phi_1]_{t=0}$	5,6	Initial torso roll.*	deg.
F	4	$[\dot{\phi}_1]_{t=0}$	5,6	Initial torso roll rate.*	deg/sec.

*These quantities will be interpreted either relative to the inertial system or the vehicle system according to the switch in T-card, field 5.

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (5 of 16)

Cards	Field	Symbol	Figure	Quantity	Units	
F	5	$[\psi_2]_{t=0}$	5,6	Initial head yaw.*	deg.	
F	6	$[\dot{\psi}_2]_{t=0}$	5,6	Initial head yaw rate.*	deg/sec.	
F	7	$[\theta_2]_{t=0}$	5,6	Initial head pitch.* (May not be exactly ninety degrees in magnitude)	deg.	
F	8	$[\dot{\theta}_2]_{t=0}$	5,6	Initial head pitch rate.*	deg/sec.	
G	1	$[\phi_2]_{t=0}$	5,6	Initial head roll.*	deg.	
G	2	$[\dot{\phi}_2]_{t=0}$	5,6	Initial head roll rate.*	deg/sec.	
G	3	$[\psi_3]_{t=0}$	5,6	Initial legs yaw.*	deg.	
G	4	$[\dot{\psi}_3]_{t=0}$	5,6	Initial legs yaw rate.*	deg/sec.	
G	5	$[\theta_3]_{t=0}$	5,6	Initial legs pitch.* (May not be exactly ninety degrees in magnitude)	deg.	
G	6	$[\dot{\theta}_3]_{t=0}$	5,6	Initial legs pitch rate.*	deg/sec.	
G	7	$[\phi_3]_{t=0}$	5,6	Initial legs roll.*	deg.	
G	8	$[\dot{\phi}_3]_{t=0}$	5,6	Initial legs roll rate.*	deg/sec.	
H	1	$[x_4]_{t=0}$	5,6	Initial vehicle x.	in.	(cm)
H	2	$[\dot{x}_4]_{t=0}$	5,6	Initial forward velocity of vehicle.	in/sec.	(m/sec)

*These quantities will be interpreted either relative to the inertial system or the vehicle system according to the switch in T-card, field 5.

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (6 of 16)

Cards	Field	Symbol	Figure	Quantity	Units	
H	3	$[y_4]_{t=0}$	5	Initial vehicle y.	in.	(cm)
H	4	$[\dot{y}_4]_{t=0}$	5	Initial right sideways velocity of vehicle.	in/sec.	(m/sec.)
H	5	$[z_4]_{t=0}$	5	Initial vehicle z.	in.	(cm)
H	6	$[\dot{z}_4]_{t=0}$	5	Initial downward velocity of vehicle.	in/sec.	(m/sec)
I	1	$[\psi_4]_{t=0}$	5,6	Initial vehicle yaw.	deg.	
I	2	$[\dot{\psi}_4]_{t=0}$	5,6	Initial vehicle yaw rate.	deg/sec.	
I	3	$[\theta_4]_{t=0}$	5,6	Initial vehicle pitch. (May not be exactly ninety degrees in magnitude.)	deg.	
I	4	$[\dot{\theta}_4]_{t=0}$	5,6	Initial vehicle pitch rate.	deg/sec.	
I	5	$[\phi_4]_{t=0}$	5,6	Initial vehicle roll.	deg.	
I	6	$[\dot{\phi}_4]_{t=0}$	5,6	Initial vehicle roll rate.	deg/sec.	
J	1	k	10	Identification number for this contact surface. This must be in the range from one to twenty-five.		
J	2	-		The number of times at which the position of this contact relative to the vehicle will be specified. The maximum number of times which can be specified for all contact in total is 300. If this field is zero, this contact will be removed from further consideration.		

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (7-16)

Cards	Field	Symbol	Figure	Quantity	Units
J	3	-		This field is set to any negative quantity if the origin is in back of this contact, or to any positive quantity if the origin is in front of this contact.	
J	4	k_{1k}		Contact linear elastic coefficient.	lb/in. (N/cm)
J	5	k_{2k}		Contact quadratic elastic coefficient.	lb/in^2 (N/cm^2)
J	6	k_{3k}		Contact cubic elastic coefficient.	lb/in^3 (N/cm^3)
J	7	c_k		Contact linear damping coefficient.	lb sec/in. (Nsec/m)
J	8	-		Penetration limit.	in. (cm)

The J card triggers a special reading sequence, the first card of which has the following special format.

Cards	Field	Symbol	Figure	Quantity	Units
-	1	-	-	Alpha-numeric title of contact surface. (centered in columns one through sixteen)	-
-	2	λ_k	11	Edge constant. (columns 21 through 30)	-
-	3	F_{max},k	7	Maximum force to be allowed. (columns 31 through 40)	lbs. (N)
-	4	D_k	7	Saturation unloading slope. Must be steep enough to completely unload before load curve zero force deflection. (columns 41 through 50)	lb/in. (N/cm)

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (8 of 16)

Cards	Field	Symbol	Figure	Quantity	Units	
				The special reading sequence initiated by the J card then concludes by reading one card for each time point specified in field two of the J card. Each of these cards has the following special format.		
-	1	t'	-	Time at which the contact assumes the position and shape specified in the remaining fields on this card. These cards must be in ascending order on time values. (columns 1 through 8)	sec	
-	2	$[\hat{x}_{1k}]_{t=t'}$	10	x coordinate of the middle of the three specified consecutive corner points (columns 9 through 16).	in.	(cm)
-	3	$[\hat{y}_{1k}]_{t=t'}$	10	y coordinate of the middle of the three specified consecutive corner points. (columns 17 through 24).	in.	(cm)
-	4	$[\hat{z}_{1k}]_{t=t'}$	10	z coordinate of the middle of the three specified consecutive corner points (columns 25 through 32).	in.	(cm)
-	5	$[\hat{x}_{2k}]_{t=t'}$	10	x coordinate of one endpoint of the three specified consecutive corner points (columns 33 through 40).	in.	(cm)
-	6	$[\hat{y}_{2k}]_{t=t'}$	10	y coordinate of one endpoint of the three specified consecutive corner points (columns 41 through 48).	in.	(cm)
-	7	$[\hat{z}_{2k}]_{t=t'}$	10	z coordinate of one endpoint of the three specified consecutive corner points (columns 49 through 56).	in.	(cm)
-	8	$[\hat{x}_{3k}]_{t=t'}$	10	x coordinate of the other endpoint of the three specified consecutive corner points (columns 57 through 64).	in.	(cm)

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (9 of 16)

Cards	Field	Symbol	Figure	Quantity	Units
-	9	$[\hat{y}_{3k}]_{t=t'}$	10	y coordinate of the other endpoint of the three specified consecutive corner points (columns 65 through 72).	in. (cm)
-	10	$[\hat{z}_{3k}]_{t=t'}$	10	z coordinate of the other endpoint of the three specified consecutive corner points (columns 73 through 80).	in. (cm)
K	1	-	-	The number of the contact to be used for the seat back in movie making and injury predictions. If zero, fields two through eight are numbers of contacts which comprise the forward vehicle structures.	
K	2	-	-	The number of the contact used as seat cushion.	
K	3	-	-	The number of the ellipsoid used as the chest.	
K	4	-	-	The number of the ellipsoid used as the knee.	
K	5-8	-	-	These fields contain the numbers of contacts which comprise the forward vehicle structure. The first zero or blank field encountered from left to right terminates the card.	
L	1	n	-	Belt segment index (1.=left shoulder belt, 2.=right shoulder belt, 3.=left lap belt, 4.=right lap belt).	
L	2	λ_n	14	x coordinate of anchor point in vehicle.	in. (cm)

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (10 of 16)

Cards	Field	Symbol	Figure	Quantity	Units	
L	3	μ_n	14	y coordinate of anchor point in vehicle.	in.	(cm)
L	4	ν_n	14	z coordinate of anchor point in vehicle.	in.	(cm)
L	5	r_n	14	x coordinate of attachment point on torso.	in.	(cm)
L	6	s_n	14	y coordinate of attachment point on torso.	in.	(cm)
L	7	t_n	14	z coordinate of attachment point on torso.	in.	(cm)
L	8	-	-	Switch. If switch=0., no maximum force is to be specified and will be treated as though infinite. If switch=1., maximum force and unloading slope will be specified on the next card.	-	

If field 8 of card L is non-zero, a special reading sequence is initiated which will read one card immediately **after the L card with the following** special format.

Cards	Field	Symbol	Figure	Quantity	Units	
-	1	$F_{max,n}$	7	Maximum force for belt segment n. (columns 1 through 10).	lbs.	(N)
-	2	D_n	7	Unloading slope in case of saturation. (columns 11 through 20).	lbs/in.	(N/cm)
M	1	n		Belt segment index (See card L, field 1)		
M	2	$_b k_{1n}$		Belt linear spring coefficient.	lb/in.	(N/cm)
M	3	$_b k_{2n}$		Belt quadratic spring coefficient.	lb/in^2	(N/cm^2)

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (11 of 16)

Cards	Field	Symbol	Figure	Quantity	Units	
M	4	$b^{k_3 n}$		Belt cubic spring coefficient.	lb/in^3	(N/cm^3)
M	5	b^{c_n}		Belt linear damping coefficient.	lb.sec/in.	(Nsec/m)
M	6	Δ_n		Belt slack at t=0. (Make negative for pre-loading)	in.	(cm)
M	7			Switch. If switch = 0., belt segment is used. If switch - 1., belt segment is not used.		
M	8			Injury tolerance for body damage from this seat belt segment.	lb.	(N)
N	1	n		Acceleration table number		

n	$\ddot{\sigma}_n$ Special Symbol	Normal Symbol	
1.	vehicle forward acceleration.	$\ddot{x}_4$	See equation (2.5.24 et seq.)
2.	vehicle side acceleration.	$\ddot{y}_4$	
3.	vehicle downward acceleration.	$\ddot{z}_4$	
4.	vehicle yaw acceleration.	$\ddot{\psi}_4$	
5.	vehicle pitch acceleration.	$\ddot{\theta}_4$	
6.	vehicle roll acceleration.	$\ddot{\phi}_4$	

Cards	Field	Symbol	Figure	Quantity	Units
N	2	t'		Time value for acceleration value.	sec.
N	3	$[\ddot{\sigma}_n]_{t=t'}$		Acceleration value.	g's or rad/sec^2
O	1	n		Index of acceleration table to be partially deleted. (See card N field 1).	

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (12 of 16)

Cards	Field	Symbol	Figure	Quantity	Units
O	2	t'_{low}		Lowest value of time for deleting acceleration table values.	sec.
O	3	t'_{high}		Upper value of time for deleting acceleration table values. NOTE: The O-cards do not need to be included if not needed.	sec.
P				The fields of this card are unused with the exception of the "P" in the first column. This card triggers a special reading sequence of debugging control cards immediately following the P card. The format of these special cards follow.	
-	2			Effective time. (negative value terminates special reading sequence.) (columns 11 through 20)	sec.
-	3			8-digit hexadecimal debugging control word. NOTE: See Part 4.3.	These cards must be in ascending order of time values.
Q	1			Logical I/O Unit Number from which the next input record is to be read. If not 0 to 9, program will read from SCARDS next.	
Q	2			Number of input lines to skip before reading. If negative, will rewind 0 to 9.	
R	1	Δt_{max}		Maximum integration step.	sec.
R	2	Δt_{prnt}		Print time step which must be an integral multiple of the maximum step.	sec.

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (13 of 16)

Cards	Field	Symbol	Figure	Quantity	Units
R	3	-		Starting method code: zero is for use of the Euler method, one for modified Runge-Kutta, two for regular Runge-Kutta.	
R	4	-		Predictor-corrector code: zero is use of the Adams-Moulton method, one for Milne-Hamming.	
R	5	$\varepsilon_{\ddot{Z}}$		Acceleration minimum magnitude.	
R	6	-		Recording control code: zero is for no recording, one is for movie, two for precautionary summary recording, three for both.	
R	7	Δv_{lim}		Velocity change limit	
R	8	$\Delta\ddot{Z}_{lim}$		Extrapolation change limit.	
S	1	ε_v		Velocity convergence parameter.	
S	2	ε_t		Time epsilon.	sec.
S	3	N_{max}		Maximum number of subdivisions of the maximum time step to be allowed.	
S	4	-		Execution time limit.	
S	5	MKSSWT		0 = MKS units 1 = Anglo-American units	min.

A special card is automatically read which contains twelve fields of six columns each. These fields contain the relative weights for the twelve generalized coordinates respectively.

Cards	Field	Symbol	Figure	Quantity	Units
T	1	T_{max}		Length of simulation in real time.	sec.
T	2	g		Value of gravity. (negative implies 32.2)	ft/sec^2 (m/sec^2)

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (14 of 16)

Cards	Field	Symbol	Figure	Quantity	Units
T	3	-		Switch. If switch = 0., input data is listed. If switch ≠ 0., input data is not listed.	
T	4	-		Switch. If switch = 0., the tabulated summary output is printed. If switch = 1., the belt angle page is left out. If switch = 2., the two pages of vehicle data are left out also. If switch = 3., the three pages of body angles are left out as well. (Higher levels are inclusive of lower levels.)	
T	5			Switch. If switch = 0., the contents of cards C, D, E and F are considered to be relative to the inertial system. If switch is not zero, the contents of these cards are relative to the vehicle, and the program automatically converts to the inertial.	
T	6			Switch. If switch = 0., body kinetic energies are not computed. If switch is not zero, body kinetic energies are computed and outputed.	
U	1			Multiplying factor to alter sled X-acceleration table.	
U	2			Multiplying factor to alter sled Y-acceleration table.	
U	3			Multiplying factor to alter sled Z-acceleration table.	
U	4			Multiplying factor to alter sled yaw-acceleration table.	
U	5			Multiplying factor to alter sled pitch-acceleration table.	
U	6			Multiplying factor to alter roll-acceleration table.	
V				Title card. Triggers reading of following BCD card.	

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (15 of 16)

Cards	Field	Symbol	Figure	Quantity	Units
W	1	m	9	Ellipsoid number to be inhibited.	
W	2	k	10	Contact number to be inhibited.	
W	3			Switch. If negative, allow no interaction caused by this ellipsoid infringing on this contact. If zero, remove any previous inhibition. If positive, permit interaction, but do not print the forces generated. A maximum of forty ellipsoid-contact combinations can be reported upon in any run.	
X	1			Tolerance specification index. This controls the interpretation of fields two through seven as shown in the table below. Brackets show default values if quantities is left zero or card is left out. The double bracketed values for angular limits represent default values for stiff and flexible torso respectively.	

Field One Value	0.	1.(all units are deg.)	2.(all units are deg.)
Field 2	Sensitivity index limit [1000.]	Neck yaw lower limit [-70.,-87.]	Neck yaw upper limit [70.,87.]
Field 3	Pitch Concussion(rad/sec^2) [2000.]	Neck pitch lower limit [-60.,-100.]	Neck pitch upper limit [60.,90.]
Field 4	Head side acceleration (g-unit)[46.]	Neck roll lower limit [-40.,-57.]	Neck roll upper limit [40.,57.]
Field 5	Chest force (lbs) [1800]*	Hip yaw lower limit [-30.,-47.]	Hip yaw upper limit [30.,47.]
Field 6	Knee force (lbs) [1500]*	Hip pitch lower limit [-90.,-120.]	Hip pitch upper limit [30., 50.]
Field 7	Forward Chest accel. (g-unit) [45.]	Hip roll lower limit [0.,-17.]	Hip roll upper limit [0.,17]
Field 8	Chest S-I g-load [25.]	Switch: 0.=stiff torso, 1.=flexible torso.	

*If metric units indicated, the units are Newtons (N) and the default values the corresponding value.

TABLE 2. INPUT DATA CARDS (3-D MODEL, 4-77) (16 of 16)

Cards	Field	Symbol	Figure	Quantity	Units
Y	1	$P(E_1)$	-	Probability of event one. Must be in range zero to one. (Event one is usually accident type.)	
Y	2	$P(E_2)$	-	Probability of event two. Must be in range zero to one. (Event two is usually occupant position.)	
Y	3	$P(E_3)$	-	Probability of event three. Must be in range zero to one. (Event three is usually restraint system type.)	

The Y card triggers the reading of a card of special format immediately following the Y card.

Cards	Field	Symbol	Figure	Quantity	Units
-	1	-	-	Alphanumeric description of event one. (centered in columns 1 through 24)	
-	2	-	-	Alphanumeric description of event two. (centered in columns 25 through 48)	
-	3	-	-	Alphanumeric description of event three. (centered in columns 49 through 72)	
Z	no fields	-	-	Signals end of data deck.	

4.0 Use of and Restrictions on the New Features

The WSU Airbag Model was developed primarily for the frontal crash simulation. The model may be used for oblique or lateral crash simulation, but only with very great care. The user is referred in particular to the discussion in Section 2.6.

The models are not fully debugged in metric units. The performance of the models in metric is approximately correct but is too much different from a corresponding run in English units to be called acceptable. The user should use the Metric option in these models with suspicion.