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7. Author(s)
D.H. Robbins, R.O. Bennett and B.M. Bowman

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Highway Safety Research Institute
University of Michigan
Huron Parkway and Baxter Road
Ann Arbor, Michigan 48105

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During the past several years, HSRI has developed and validated two and three-dimensional models describing the motions and forces acting on an occupant during a collision. This report describes a new six-mass occupant model combining existing capabilities and possessing the following new features: 1. addition of lower legs to the three-mass model to represent their known restraint capability in frontal impact; 2. remodeling of the vehicle interior contact surfaces to allow any shape for the force-deformation interactions between occupant and vehicle; and 3. simplification of input and output procedures through development of a user-oriented interactive command language. The report is a completely self-contained description of the program and its use.

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HSRI SIX MASS, THREE DIMENSIONAL CRASH VICTIM SIMULATOR

Highway Safety Research Institute
The University of Michigan
Huron Parkway and Baxter Road
Ann Arbor, Michigan 48105

Prepared by:
D. H. Robbins, Research Engineer
R. O. Bennett, Associate Research Mathematician
B. M. Bowman, Associate Research Engineer

Prepared for:
Motor Vehicle Manufacturers Association
Detroit, Michigan

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PART I SUMMARY

During the past several years, HSRI has developed and validated two and three-dimensional models describing the motions and forces acting on an occupant during a collision. These models have performed with approximately ninety percent accuracy in parametric studies of classical crash configurations. A three-mass, three-dimensional model has been used as an inexpensive design tool since early 1970 in studies of integrated seat-restraint systems, door crashworthiness, and head restraints. At the same time, HSRI has developed an "n" degree-of-freedom representation of the torso and neck.

This report describes a new six-mass occupant model combining existing capabilities and possessing the following new features: 1. addition of lower legs to the three-mass model to represent their known restraint capability in frontal inpact; 2. remodeling of the vehicle interior contact surfaces to allow any shape for the force-deformation interactions between occupant and vehicle; and 3. simplification of input and output procedures through development of a user-oriented interactive command language.

The report is organized into three parts and is a completely self-contained description of the program and its use. The main part of the report includes the physical and analytical base of the model, a description of the input requirement and the output generated by the computer program, sample input data and the associated output, and a complete users' guide for model operation.

The first appendix to the main report contains information of particular interest to the computer programmer or to the engineer interested in the internal function of the computer program. The various subroutines are described as well as the integration techneques used in the solution of the equations of motion. Auxiliary output from the program particularly useful in studying program function and physical variables not included in the normal program output is also described. The appendix is concluded by a symbol dictionary. The second appendix contains a listing of the program which is written in Fortran IV.

PART II BACKGROUND AND INTRODUCTION

Three dimensional models of whole body dynamics have been developed to describe human motions including auto occupant dynamics, human gait, and self-generated motions. Beckett (1), Lissner (2), and Weber (3) have modeled motions experienced by the arms and legs during walking. This work is often applied to the design, development, and use of prosthetic devices. In connection with aerospace programs, Kane (4), Hanavan (5), Huston (6), and Passerelo (7) conducted analytical studies of self-generated motions possible in free fall and zero-gravity environments. These are applied to activities such as sky-diving, space-walking, and swimming.

With respect to automobile occupant dynamics, Bartz (8), Furusho (9), Robbins (10,11), Thompson (12), and Young (13) have all developed lumped-mass, multiple-segment whole body models. The model developed by Bartz (8) includes forty degrees of freedom and fifteen rigid body segments connected by ball-and-socket and pinned joints. The Young model (13) includes a similar number of body segments while the others include less: Robbins (10, 11) - three masses (head, torso, lower extremities); Furusho (9) - five masses (head, two torso masses, upper leg, lower leg); and, Thompson (12) - one mass. The last of these is part of a large program invloving vehicle crush characteristics. In all of these models, complex vehicle geometry is introduced to provide an intricate array of forces acting on the segmented occupant.

In developing the new six-mass model which is the main subject of this report, the authors have concentrated on: 1. selection of a minimum number of degrees of freedom consistent with a realistic and economical description of the physical problem; 2. efficient formulation and computational procedures; and, 3. user requirements.

The first assumption which is made is that the main joints of the body are the knees, hips, and neck. The knee is represented by a pinned joint which is a good approximation. The other joints are ball joints with limitations to their free range of motion. The arms have been neglected on the basis of their small mass when compared with the torso and the small effects on overall body dynamics which are generated by the action of external forces on segmented arm masses. The legs have been modeled more completely as right and left upper and lower legs for two reasons. The first is the experimentally observed major effect which the tensing of leg muscles can play in influencing occupant dynamics and the second is the lack of symmetry of most vehicle interiors with the resulting lack of symmetry of the occupant initial position.

Although the number of masses chosen for this simulation is believed the minimum necessary for a realistic approximation of occupant motions and force loadings in most dynamic environments, occupant interactions with the vehicle are modeled in considerable detail. Contact-sensing ellipsoids are attached to the body masses to sense force interactions with the vehicle. These ellipsoids can deform under force representing body compliance.

Because this is a complex initial value problem, the number of equations of motion have a great influence on the cost of exercising the model. Using a minimum number of body linkages combined with a formulation in terms of Euler angle generalized coordinates leads to the smallest possible system of equations. An Euler angle formulation admittedly can lead to solution instabilities, but these problems have been found to be negligible during three years use of the HSRI three-dimensional crash victim simulator, Robbins (11), which is formulated in the same manner.

It is apparent that using a model of this type is difficult due to input data requirements including force-deformation characteristics of the human body, the geometry and strength of an automotive interior, and the crash characteristics which drive the model. In most cases the user is expert in one of those areas and less familiar with others. For example, an automotive designer may be intimate with vehicle characteristics but less familiar with the strength and range of motion of human joints. Sample data sets are stored with the model and are referenced by supervisor programs which query the user and prepare the detailed data set automatically. In this way a user may specify an occupant size such as a 50th percentile male using a single simple command and provide very detailed vehicle geometry input data as another option provided by the interactive supervisor program.

PART III ANALYSIS

Following definition of the coordinate systems describing occupant position, the formulation of the equations of motion using Lagrangian techniques is detailed. The addition of forces to the equations of motion is described in general supplemented by specific analyses of vehicle-occupant contact, gravity, joints, and belt forces.

A. Coordinate Systems Describing Occupant Position

The basic geometry of the new model is shown in Figure 1 while Figure 2 shows the associated coordinate systems fixed on the various elements. Figure 3 defines the motion allowed at each of the pinned knee joints.

The basic inertial coordinate system is

$$e = \begin{bmatrix} I \\ J \\ K \end{bmatrix} \tag{1}$$

with the coordinate systems in the six body masses and the vehicle defined as

$$e_n = \begin{bmatrix} i_n \\ j_n \\ k_n \end{bmatrix} \qquad \text{for } n = 1, \ldots, 7 \tag{2}$$

The generalized coordinates describing the motion of this linkage are chosen to be (x_1, y_1, z_1) describing the translational motions of mass 1, Euler angles describing the motions of masses 1, 2, 3, and 4 and generalized relative pitch describing the motions of masses 5 and 6. The Euler angles are applied in the following order:

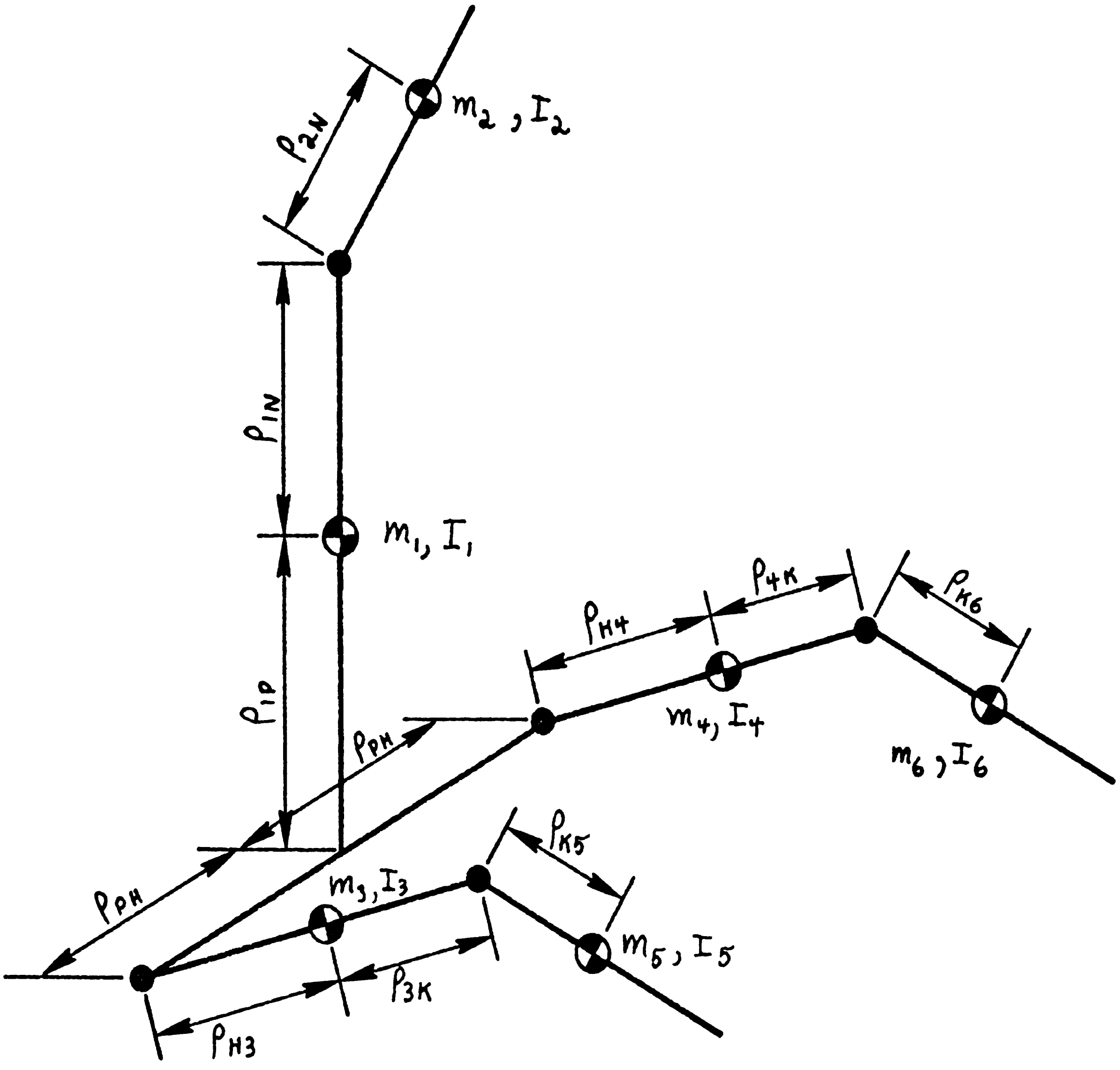


FIGURE 1. MODIFIED HSRI THREE-DIMENSIONAL CRASH VICTIM SIMULATOR.

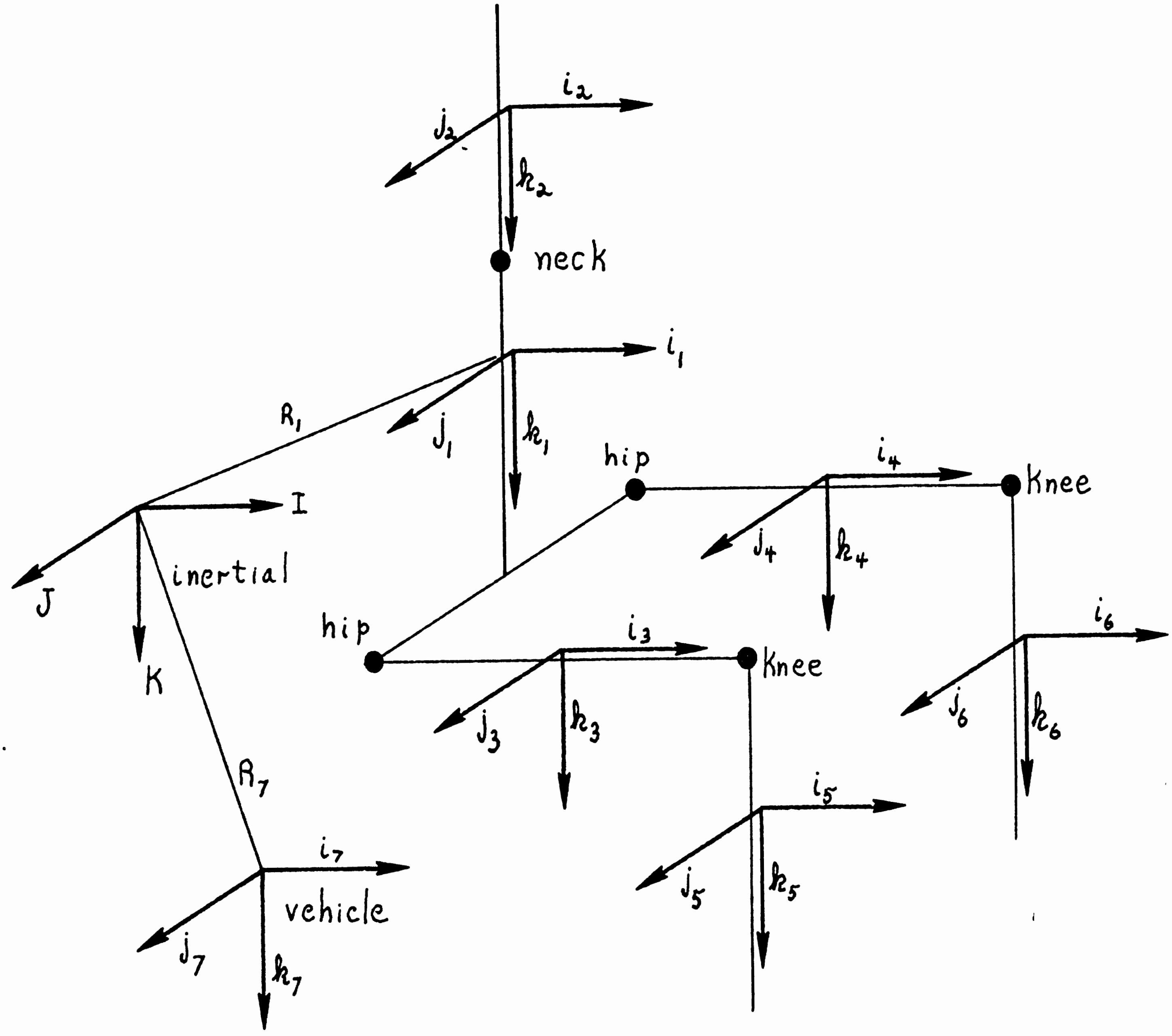


FIGURE 2. COORDINATE SYSTEMS IN MODIFIED HSRI THREE-DIMENSIONAL CRASH VICTIM SIMULATOR.

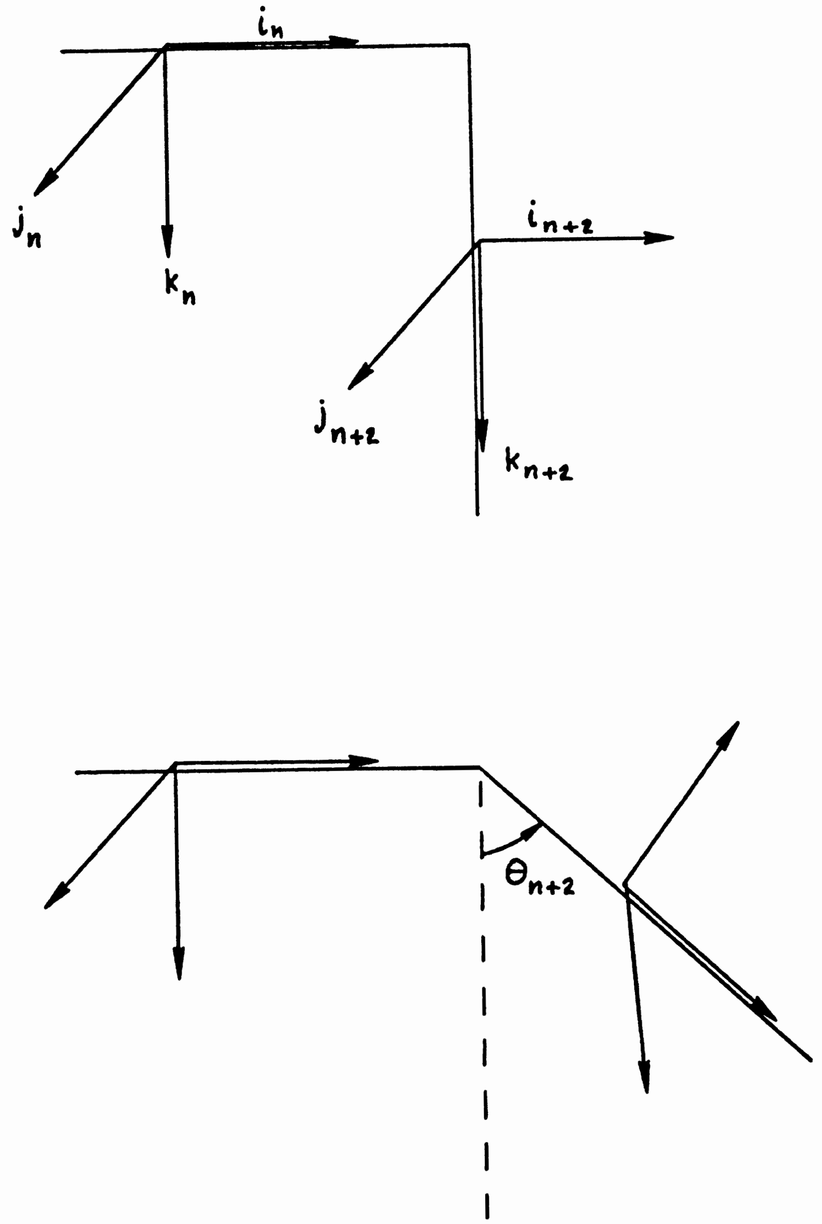


Figure 3. Lower Leg Angle θ_{n+2}.

ψ = yaw and k axis;

θ = pitch about $\bar{j}$ axis;

ϕ = roll about $\bar{\bar{i}}$ axis;

where k is the original axis, $\bar{j}$ is the position reached by the j axis after the ψ-rotations, and $\bar{\bar{i}}$ is the position reached by the i axis after the θ-rotation.

The transformation associated with these motions is

$$e_n = \left[\begin{array}{c|c|c} \cos\psi_n \cos\theta_n & \sin\psi_n \cos\theta_n & -\sin\theta_n \\ \hline \begin{array}{l}\cos\psi_n \sin\theta_n \sin\phi_n \\ -\sin\psi_n \cos\phi_n\end{array} & \begin{array}{l}\sin\psi_n \sin\theta_n \sin\phi_n \\ +\cos\psi_n \cos\phi_n\end{array} & \cos\theta_n \sin\phi_n \\ \hline \begin{array}{l}\cos\psi_n \sin\theta_n \cos\phi_n \\ +\sin\psi_n \sin\phi_n\end{array} & \begin{array}{l}\sin\psi_n \sin\theta_n \cos\phi_n \\ -\cos\psi_n \sin\phi_n\end{array} & \cos\theta_n \cos\phi_n \end{array}\right] e \tag{3}$$

where the subscript n refers to the body segments 1, ..., 4. In a more compact notation,

$$e_n = \begin{bmatrix} T_{11n} & T_{12n} & T_{13n} \\ T_{21n} & T_{22n} & T_{23n} \\ T_{31n} & T_{32n} & T_{33n} \end{bmatrix} e \tag{4}$$

The knee joint is represented as a pinned hinge so that the only motion permitted between the upper and lower leg elements is relative pitch. Thus the position of body elements 5 and 6 is specified if one is given the position of elements 3 and 4 plus a relative pitch angle.

The transformation is given by

$$e_{n+2} = \begin{bmatrix} \cos\theta_{n+2} & 0 & -\sin\theta_{n+2} \\ 0 & 1 & 0 \\ \sin\theta_{n+2} & 0 & \cos\theta_{n+2} \end{bmatrix} e_n \qquad (5)$$

where n=3,4, or in terms of e,

$$e_{n+2} = \begin{bmatrix} \cos\theta_{n+2} & 0 & -\sin\theta_{n+2} \\ 0 & 1 & 0 \\ \sin\theta_{n+2} & 0 & \cos\theta_{n+2} \end{bmatrix} \begin{bmatrix} T_{11n} & T_{12n} & T_{13n} \\ T_{21n} & T_{22n} & T_{23n} \\ T_{31n} & T_{32n} & T_{33n} \end{bmatrix} e \qquad (6)$$

In the compact notation

$$e_n = \begin{bmatrix} T_{11n} & T_{12n} & T_{13n} \\ T_{21n} & T_{22n} & T_{23n} \\ T_{31n} & T_{32n} & T_{33n} \end{bmatrix} e \qquad (7)$$

where n = 1, ..., 7.

In order to form the kinetic energy function for use in the Lagrange equation it is necessary to form the linear and rotational velocities of the various masses. Referring to Figures 1 and 2, the position vectors for the six masses are

$$
\begin{aligned}
R_1 &= x_1 I + y_1 J + z_1 K \\
R_2 &= x_1 I + y_1 J + z_1 K - \rho_{1N} k_1 - \rho_{2N} k_2 \\
R_3 &= x_1 I + y_1 J + z_1 K + \rho_{1P} k_1 + \rho_{PH} j_1 + \rho_{H3} i_3 \\
R_4 &= x_1 I + y_1 J + z_1 K + \rho_{1P} k_1 - \rho_{PH} j_1 + \rho_{H4} i_4 \\
R_5 &= x_1 I + y_1 J + z K + \rho_{1P} k_1 + \rho_{PH} j_1 + \rho_{HK} i_3 + \rho_{K5} k_5 \\
R_6 &= x_1 I + y_1 J + z K + \rho_{1P} k_1 - \rho_{PH} j_1 + \rho_{HK} i_4 + \rho_{K6} k_6 \quad .
\end{aligned}
\tag{8}
$$

Using the position vectors, the locations of the centers of gravity for the six masses are shown to be

$$
\begin{aligned}
x_1 &= x_1 \\
y_1 &= y_1 \\
z_1 &= z_1 \\
\\
x_2 &= x_1 - \rho_{1N} T_{311} - \rho_{2N} T_{312} \\
y_2 &= y_1 - \rho_{1N} T_{321} - \rho_{2N} T_{322} \\
z_2 &= z_1 - \rho_{1N} T_{331} - \rho_{2N} T_{332} \\
\\
x_3 &= x_1 + \rho_{1P} T_{311} + \rho_{PH} T_{211} + \rho_{H3} T_{113} \\
y_3 &= y_1 + \rho_{1P} T_{321} + \rho_{PH} T_{221} + \rho_{H3} T_{123} \\
z_3 &= z_1 + \rho_{1P} T_{331} + \rho_{PH} T_{231} + \rho_{H3} T_{133} \\
\\
x_4 &= x_1 + \rho_{1P} T_{311} - \rho_{PH} T_{211} + \rho_{H4} T_{114} \\
y_4 &= y_1 + \rho_{1P} T_{321} - \rho_{PH} T_{221} + \rho_{H4} T_{124} \\
z_4 &= z_1 + \rho_{1P} T_{331} - \rho_{PH} T_{231} + \rho_{H4} T_{134} \\
\\
x_5 &= x_1 + \rho_{1P} T_{311} + \rho_{PH} T_{211} + \rho_{HK} T_{113} + \rho_{K5} T_{315} \\
y_5 &= y_1 + \rho_{1P} T_{321} + \rho_{PH} T_{221} + \rho_{HK} T_{123} + \rho_{K5} T_{325} \\
z_5 &= z_1 + \rho_{1P} T_{331} + \rho_{PH} T_{231} + \rho_{HK} T_{133} + \rho_{K5} T_{335} \\
\\
x_6 &= x_1 + \rho_{1P} T_{311} - \rho_{PH} T_{211} + \rho_{HK} T_{114} + \rho_{K6} T_{316} \\
y_6 &= y_1 + \rho_{1P} T_{321} - \rho_{PH} T_{221} + \rho_{HK} T_{124} + \rho_{K6} T_{326} \\
z_6 &= z_1 + \rho_{1P} T_{331} - \rho_{PH} T_{231} + \rho_{HK} T_{134} + \rho_{K6} T_{336}
\end{aligned}
\tag{9}
$$

B. Formulation of Equations of Motion Using Lagrangian Techniques

The equations of motion are derived by Lagrangian techniques using the formula

$$\frac{d}{dt}\left[\frac{\partial(KE)}{\partial \dot{q}_i}\right] - \frac{\partial(KE)}{\partial q_i} + \frac{\partial(PE)}{\partial q_i} + \frac{\partial(DE)}{\partial \dot{q}_i} = F_{q_i} \qquad (10)$$

where

KE is the system kinetic energy

PE is the system potential energy

DE is half the system dissipated energy rate

F_{q_i} are the classical generalized forces

q_i are the classical generalized coordinates or degrees of freedom of the model.

Since the only driving force is applied to the vehicle and not directly to the body, the F_{q_i} terms are all zero. After the energy terms have been written, the resulting equations of motion are rearranged so that all the terms containing generalized accelerations appear on the left-hand side and all other terms appear on the right-hand side. Thus rearranged, these equations are of the form

$$m \ddot{\vec{q}} = \vec{Q} \qquad (11)$$

where m is the matrix of generalized acceleration coefficients and $\ddot{\vec{q}}$ is the generalized acceleration vector. In this analysis the right-hand side of the equation, $\vec{Q}$, will be called the "generalized force" and contributions to it from the kinetic, potential, and dissipative energies in Equation (10) will be referred to as the generalized force from that part of the model. The total "generalized force" is the sum of the components from kinetic energy, gravity, joints, belts and contacts. The kinetic energy contributions to the "generalized force" are centrifugal and Coriolis force terms.

Kinetic energy alone determines the left-hand side of the equations of motions. Equation 11 is a set of seventeen simultaneous linear algebraic equations with the generalized accelerations $\ddot{q}_i$ as the unknowns. These equations are solved numerically by Gaussian elimination. The generalized force vector may be expanded to show the various contributions

$$\vec{Q} = \vec{Q}_T + \vec{Q}_G + \vec{Q}_C + \vec{Q}_J + \vec{Q}_B \tag{12}$$

where

$\vec{Q}_T$ is due to kinetic energy

$\vec{Q}_G$ is due to gravity

$\vec{Q}_C$ is due to contact forces

$\vec{Q}_J$ is due to joints

$\vec{Q}_B$ is due to belts

The seventeen generalized coordinates for this problem are the position coordinates for the torso mass, the Euler angles for the torso, head, and upper leg masses, and the pitch angle for the lower leg masses. They are defined in the following order:

$$\begin{array}{ll} q_1 = x_1 & q_{10} = \psi_3 \\ q_2 = y_1 & q_{11} = \theta_3 \\ q_3 = z_1 & q_{12} = \phi_3 \\ q_4 = \psi_1 & q_{13} = \psi_4 \\ q_5 = \theta_1 & q_{14} = \theta_4 \\ q_6 = \phi_1 & q_{15} = \phi_4 \\ q_7 = \psi_2 & q_{16} = \theta_5 \\ q_8 = \theta_2 & q_{17} = \theta_6 \\ q_9 = \phi_2 & \end{array} \tag{13}$$

The derivation of the matrix of generalized acceleration coefficients,m, and the various components of $\vec{Q}$ is given in the next several paragraphs. A variety of geometric, motion, and trigonometric quantities as well as derivatives which are used in the analysis are listed here to provide a central repository. During the computer solution most of these quantities are evaluated as the first step of each integration loop.

Trigonometric quantities making up the transformation matrices have been defined as T_{ijn} in Equations 3 - 7. Other trigonometric quantities which are used are listed as follows.

$$\begin{array}{ll} S_{1n} = \sin\psi_n & ;\ C_{1n} = \cos\psi_n \\ S_{2n} = \sin\theta_n = -T_{13n} & ;\ C_{2n} = \cos\theta_n \\ S_{3n} = \sin\phi_n & ;\ C_{3n} = \cos\phi_n \end{array} \tag{14}$$

The subscript "n" runs from 1-4 on all quantities and also includes 5 and 6 for sines and cosines of theta (θ) and 7 for the vehicle.

$$\begin{array}{ll} T_{14n} = \cos\psi_n \sin\theta_n & T_{5n} = \cos\psi_n \sin\theta_n \sin\phi_n \\ T_{15n} = \sin\psi_n \sin\theta_n & T_{6n} = \sin\psi_n \cos\theta_n \sin\phi_n \\ T_{16n} = \sin\theta_n \cos\phi_n & T_{7n} = \sin\psi_n \sin\theta_n \cos\phi_n \\ T_{17n} = \sin\theta_n \sin\phi_n & T_{8n} = \sin\psi_n \sin\theta_n \sin\phi_n \\ & \\ T_{1n} = \cos\psi_n \cos\theta_n \cos\phi_n & T_{24n} = \cos\psi_n \cos\phi_n \\ T_{2n} = \cos\psi_n \cos\theta_n \sin\phi_n & T_{25n} = \cos\psi_n \sin\phi_n \\ T_{3n} = \cos\psi_n \sin\theta_n \cos\phi_n & T_{26n} = \sin\psi_n \cos\phi_n \\ T_{4n} = \sin\psi_n \cos\theta_n \cos\phi_n & T_{27n} = \sin\psi_n \sin\phi_n \end{array} \tag{15}$$

The first derivatives with respect to time of these quantities which are used elsewhere in the analysis include

$$
\begin{aligned}
\dot{T}_{11n} &= -T_{12n}\dot{\psi}_n - T_{14n}\dot{\theta}_n \\
\dot{T}_{12n} &= T_{11n}\dot{\psi}_n - T_{15n}\dot{\theta}_n \\
\dot{T}_{13n} &= -C_{2n}\dot{\theta}_n \\
\\
\dot{T}_{21n} &= -T_{22n}\dot{\psi}_n + T_{2n}\dot{\theta}_n + T_{31n}\dot{\phi}_n \\
\dot{T}_{22n} &= T_{21n}\dot{\psi}_n + T_{6n}\dot{\theta}_n + T_{32n}\dot{\phi}_n \\
\dot{T}_{23n} &= -T_{17n}\dot{\theta}_n + T_{33n}\dot{\phi}_n \\
\\
\dot{T}_{31n} &= -T_{32n}\dot{\psi}_n + T_{1n}\dot{\theta}_n - T_{21n}\dot{\phi}_n \\
\dot{T}_{32n} &= T_{31n}\dot{\psi}_n + T_{4n}\dot{\theta}_n - T_{22n}\dot{\phi}_n \\
\dot{T}_{33n} &= -T_{16n}\dot{\theta}_n - T_{23n}\dot{\phi}_n \\
\\
\dot{T}_{1n} &= -\dot{\psi}_n T_{4n} - \dot{\theta}_n T_{3n} - \dot{\phi}_n T_{2n} \\
\dot{T}_{2n} &= -\dot{\psi}_n T_{6n} - \dot{\theta}_n T_{5n} + \dot{\phi}_n T_{1n} \\
\dot{T}_{4n} &= \dot{\psi}_n T_{1n} - \dot{\theta}_n T_{7n} - \dot{\phi}_n T_{6n} \\
\dot{T}_{6n} &= \dot{\psi}_n T_{2n} - \dot{\theta}_n T_{8n} + \dot{\phi}_n T_{4n} \\
\\
\dot{T}_{14n} &= -\dot{\psi}_n T_{15n} + \dot{\theta}_n T_{11n} \\
\dot{T}_{15n} &= \dot{\psi}_n T_{14n} + \dot{\theta}_n T_{12n} \\
\dot{T}_{16n} &= \dot{\theta}_n T_{33n} - \dot{\phi}_n T_{17n} \\
\dot{T}_{17n} &= \dot{\theta}_n T_{23n} + \dot{\phi}_n T_{16n}
\end{aligned}
\tag{16}
$$

where n = 1,..., 4.

From the lower legs transformation

$$
\begin{aligned}
\dot{T}_{11,n+2} &= -T_{31,n+2}\,\dot{\theta}_{n+2} + C_{2,n+2}\,\dot{T}_{11n} - S_{2,n+2}\,\dot{T}_{31n} \\
\dot{T}_{12,n+2} &= -T_{32,n+2}\,\dot{\theta}_{n+2} + C_{2,n+2}\,\dot{T}_{12n} - S_{2,n+2}\,\dot{T}_{32n} \\
\dot{T}_{13,n+2} &= -T_{33,n+2}\,\dot{\theta}_{n+2} + C_{2,n+2}\,\dot{T}_{13n} - S_{2,n+2}\,\dot{T}_{33n} \\
\\
\dot{T}_{21,n+2} &= \dot{T}_{21n} \\
\dot{T}_{22,n+2} &= \dot{T}_{22n} \\
\dot{T}_{23,n+2} &= \dot{T}_{23n} \\
\\
\dot{T}_{31,n+2} &= T_{11,n+2}\,\dot{\theta}_{n+2} + S_{2,n+2}\,\dot{T}_{11n} + C_{2,n+2}\,\dot{T}_{31n} \\
\dot{T}_{32,n+2} &= T_{12,n+2}\,\dot{\theta}_{n+2} + S_{2,n+2}\,\dot{T}_{12n} + C_{2,n+2}\,\dot{T}_{32n} \\
\dot{T}_{33,n+2} &= T_{13,n+2}\,\dot{\theta}_{n+2} + S_{2,n+2}\,\dot{T}_{13n} + C_{2,n+2}\,\dot{T}_{33n}
\end{aligned}
\qquad (17)
$$

where n = 3,4.

The second time derivatives of the transformation matrix elements are given by

$$
\begin{aligned}
\ddot{T}_{11n} &= -T_{12n}\ddot{\psi}_n - T_{14n}\ddot{\theta}_n - \dot{T}_{12n}\dot{\psi}_n - \dot{T}_{14n}\dot{\theta}_n \\
\ddot{T}_{12n} &= T_{11n}\ddot{\psi}_n - T_{15n}\ddot{\theta}_n + \dot{T}_{11n}\dot{\psi}_n - \dot{T}_{15n}\dot{\theta}_n \\
\ddot{T}_{13n} &= -C_{2n}\ddot{\theta}_n + S_{2n}\dot{\theta}_n^2 \\
\ddot{T}_{21n} &= -T_{22n}\ddot{\psi}_n + T_{2n}\ddot{\theta}_n + T_{31n}\ddot{\phi}_n - \dot{T}_{22n}\dot{\psi}_n + \dot{T}_{2n}\dot{\theta}_n + \dot{T}_{31n}\dot{\phi}_n \\
\ddot{T}_{22n} &= T_{21n}\ddot{\psi}_n + T_{6n}\ddot{\theta}_n + T_{32n}\ddot{\phi}_n + \dot{T}_{21n}\dot{\psi}_n + \dot{T}_{6n}\dot{\theta}_n + \dot{T}_{32n}\dot{\phi}_n \\
\ddot{T}_{23n} &= -T_{17n}\ddot{\theta}_n + T_{33n}\ddot{\phi}_n - \dot{T}_{17n}\dot{\theta}_n + \dot{T}_{33n}\dot{\phi}_n \\
\ddot{T}_{31n} &= -T_{32n}\ddot{\psi}_n + T_{1n}\ddot{\theta}_n - T_{21n}\ddot{\phi}_n - \dot{T}_{32n}\dot{\psi}_n + \dot{T}_{1n}\dot{\theta}_n - \dot{T}_{21n}\dot{\phi}_n \\
\ddot{T}_{32n} &= T_{31n}\ddot{\psi}_n + T_{4n}\ddot{\theta}_n - T_{22n}\ddot{\phi}_n + \dot{T}_{31n}\dot{\psi}_n + \dot{T}_{4n}\dot{\theta}_n - \dot{T}_{22n}\dot{\phi}_n \\
\ddot{T}_{33n} &= -T_{16n}\ddot{\theta}_n - T_{23n}\ddot{\phi}_n - \dot{T}_{16n}\dot{\theta}_n - \dot{T}_{23n}\dot{\phi}_n
\end{aligned}
\tag{18}
$$

where n = 1, ..., 4 and by

$$
\begin{aligned}
\ddot{T}_{11,n+2} &= -T_{31,n+2}\ddot{\theta}_{n+2} + C_{2,n+2}\ddot{T}_{11n} - S_{2,n+2}\ddot{T}_{31n} \\
&\quad - \dot{T}_{31,n+2}\dot{\theta}_{n+2} - S_{2,n+2}\dot{T}_{11n}\dot{\theta}_{n+2} - C_{2,n+2}\dot{T}_{31n}\dot{\theta}_{n+2} \\
\ddot{T}_{12,n+2} &= -T_{32,n+2}\ddot{\theta}_{n+2} + C_{2,n+2}\ddot{T}_{12n} - S_{2,n+2}\ddot{T}_{32n} \\
&\quad - \dot{T}_{32,n+2}\dot{\theta}_{n+2} - S_{2,n+2}\dot{T}_{12n}\dot{\theta}_{n+2} - C_{2,n+2}\dot{T}_{32n}\dot{\theta}_{n+2} \\
\ddot{T}_{13,n+2} &= -T_{33,n+2}\ddot{\theta}_{n+2} + C_{2,n+2}\ddot{T}_{13n} - S_{2,n+2}\ddot{T}_{33n} \\
&\quad - \dot{T}_{33,n+2}\dot{\theta}_{n+2} - S_{2,n+2}\dot{T}_{13n}\dot{\theta}_{n+2} - C_{2,n+2}\dot{T}_{33n}\dot{\theta}_{n+2} \\
\\
\ddot{T}_{21,n+2} &= \ddot{T}_{21n} \\
\ddot{T}_{22,n+2} &= \ddot{T}_{22n} \\
\ddot{T}_{23,n+2} &= \ddot{T}_{23n} \\
\\
\ddot{T}_{31,n+2} &= T_{11,n+2}\ddot{\theta}_{n+2} + S_{2,n+2}\ddot{T}_{11n} + C_{2,n+2}\ddot{T}_{31n} \\
&\quad + \dot{T}_{11,n+2}\dot{\theta}_{n+2} + C_{2,n+2}\dot{T}_{11n}\dot{\theta}_{n+2} - S_{2,n+2}\dot{T}_{31n}\dot{\theta}_{n+2} \\
\ddot{T}_{32,n+2} &= T_{12,n+2}\ddot{\theta}_{n+2} + S_{2,n+2}\ddot{T}_{12n} + C_{2,n+2}\ddot{T}_{32n} \\
&\quad + \dot{T}_{12,n+2}\ddot{\theta}_{n+2} + C_{2,n+2}\dot{T}_{12n}\dot{\theta}_{n+2} - S_{2,n+2}\dot{T}_{32n}\dot{\theta}_{n+2} \\
\ddot{T}_{33,n+2} &= T_{13,n+2}\ddot{\theta}_{n+2} + S_{2,n+2}\ddot{T}_{13n} + C_{2,n+2}\ddot{T}_{33n} \\
&\quad + \dot{T}_{13,n+2}\dot{\theta}_{n+2} + C_{2,n+2}\dot{T}_{13n}\dot{\theta}_{n+2} - S_{2,n+2}\dot{T}_{33n}\dot{\theta}_{n+2}
\end{aligned}
\tag{19}
$$

where n = 3,4.

The first time derivatives of the positions of the various centers of gravity are

$$
\begin{aligned}
\dot{x}_1 &= \dot{x}_1 \\
\dot{y}_1 &= \dot{y}_1 \\
\dot{z}_1 &= \dot{z}_1 \\[1ex]
\dot{x}_2 &= \dot{x}_1 - \rho_{1N}\dot{T}_{311} - \rho_{2N}\dot{T}_{312} \\
\dot{y}_2 &= \dot{y}_1 - \rho_{1N}\dot{T}_{321} - \rho_{2N}\dot{T}_{322} \\
\dot{z}_2 &= \dot{z}_1 - \rho_{1N}\dot{T}_{331} - \rho_{2N}\dot{T}_{332} \\[1ex]
\dot{x}_3 &= \dot{x}_1 + \rho_{1P}\dot{T}_{311} + \rho_{PH}\dot{T}_{211} + \rho_{H3}\dot{T}_{113} \\
\dot{y}_3 &= \dot{y}_1 + \rho_{1P}\dot{T}_{321} + \rho_{PH}\dot{T}_{221} + \rho_{H3}\dot{T}_{123} \\
\dot{z}_3 &= \dot{z}_1 + \rho_{1P}\dot{T}_{331} + \rho_{PH}\dot{T}_{231} + \rho_{H3}\dot{T}_{133} \\[1ex]
\dot{x}_4 &= \dot{x}_1 + \rho_{1P}\dot{T}_{311} - \rho_{PH}\dot{T}_{211} + \rho_{H4}\dot{T}_{114} \\
\dot{y}_4 &= \dot{y}_1 + \rho_{1P}\dot{T}_{321} - \rho_{PH}\dot{T}_{221} + \rho_{H4}\dot{T}_{124} \\
\dot{z}_4 &= \dot{z}_1 + \rho_{1P}\dot{T}_{331} - \rho_{PH}\dot{T}_{231} + \rho_{H4}\dot{T}_{134} \\[1ex]
\dot{x}_5 &= \dot{x}_1 + \rho_{1P}\dot{T}_{311} + \rho_{PH}\dot{T}_{211} + \rho_{HK}\dot{T}_{113} + \rho_{K5}\dot{T}_{315} \\
\dot{y}_5 &= \dot{y}_1 + \rho_{1P}\dot{T}_{321} + \rho_{PH}T_{221} + \rho_{HK}\dot{T}_{123} + \rho_{K5}\dot{T}_{325} \\
\dot{z}_5 &= \dot{z}_1 + \rho_{1P}\dot{T}_{331} + \rho_{PH}\dot{T}_{231} + \rho_{HK}\dot{T}_{133} + \rho_{K5}\dot{T}_{335} \\[1ex]
\dot{x}_6 &= \dot{x}_1 + \rho_{1P}\dot{T}_{311} - \rho_{PH}\dot{T}_{211} + \rho_{HK}\dot{T}_{114} + \rho_{K6}\dot{T}_{316} \\
\dot{y}_6 &= \dot{y}_1 + \rho_{1P}\dot{T}_{321} - \rho_{PH}\dot{T}_{221} + \rho_{HK}\dot{T}_{124} + \rho_{K6}\dot{T}_{326} \\
\dot{z}_6 &= \dot{z}_1 + \rho_{1P}\dot{T}_{331} - \rho_{PH}\dot{T}_{231} + \rho_{HK}\dot{T}_{134} + \rho_{K6}\dot{T}_{336}
\end{aligned}
\tag{20}
$$

The second time derivatives of the positions of the various centers of gravity are

$$
\begin{aligned}
\ddot{x}_1 &= \ddot{x}_1 \\
\ddot{y}_1 &= \ddot{y}_1 \\
\ddot{z}_1 &= \ddot{z}_1 \\[6pt]
\ddot{x}_2 &= \ddot{x}_1 - \rho_{1N} \ddot{T}_{311} - \rho_{2N} \ddot{T}_{312} \\
\ddot{y}_2 &= \ddot{y}_1 - \rho_{1N} \ddot{T}_{321} - \rho_{2N} \ddot{T}_{322} \\
\ddot{z}_2 &= \ddot{z}_1 - \rho_{1N} \ddot{T}_{331} - \rho_{2N} \ddot{T}_{332} \\[6pt]
\ddot{x}_3 &= \ddot{x}_1 + \rho_{1P} \ddot{T}_{311} + \rho_{PH} \ddot{T}_{211} + \rho_{H3} \ddot{T}_{113} \\
\ddot{y}_3 &= \ddot{y}_1 + \rho_{1P} \ddot{T}_{321} + \rho_{PH} \ddot{T}_{221} + \rho_{H3} \ddot{T}_{123} \\
\ddot{z}_3 &= \ddot{z}_1 + \rho_{1P} \ddot{T}_{331} + \rho_{PH} \ddot{T}_{231} + \rho_{H3} \ddot{T}_{133} \\[6pt]
\ddot{x}_4 &= \ddot{x}_1 + \rho_{1P} \ddot{T}_{311} - \rho_{PH} \ddot{T}_{211} + \rho_{H4} \ddot{T}_{114} \\
\ddot{y}_4 &= \ddot{y}_1 + \rho_{1P} \ddot{T}_{321} - \rho_{PH} \ddot{T}_{221} + \rho_{H4} \ddot{T}_{124} \\
\ddot{z}_4 &= \ddot{z}_1 + \rho_{1P} \ddot{T}_{331} - \rho_{PH} \ddot{T}_{231} + \rho_{H4} \ddot{T}_{134} \\[6pt]
\ddot{x}_5 &= \ddot{x}_1 + \rho_{1P} \ddot{T}_{311} + \rho_{PH} \ddot{T}_{211} + \rho_{HK} \ddot{T}_{113} + \rho_{K5} \ddot{T}_{315} \\
\ddot{y}_5 &= \ddot{y}_1 + \rho_{1P} \ddot{T}_{321} + \rho_{PH} \ddot{T}_{221} + \rho_{HK} \ddot{T}_{123} + \rho_{K5} \ddot{T}_{325} \\
\ddot{z}_5 &= \ddot{z}_1 + \rho_{1P} \ddot{T}_{331} + \rho_{PH} \ddot{T}_{231} + \rho_{HK} \ddot{T}_{133} + \rho_{K5} \ddot{T}_{335} \\[6pt]
\ddot{x}_6 &= \ddot{x}_1 + \rho_{1P} \ddot{T}_{311} - \rho_{PH} \ddot{T}_{211} + \rho_{HK} \ddot{T}_{114} + \rho_{K6} \ddot{T}_{316} \\
\ddot{y}_6 &= \ddot{y}_1 + \rho_{1P} \ddot{T}_{321} - \rho_{PH} \ddot{T}_{221} + \rho_{HK} \ddot{T}_{124} + \rho_{K6} \ddot{T}_{326} \\
\ddot{z}_6 &= \ddot{z}_1 + \rho_{1P} \ddot{T}_{331} - \rho_{PH} \ddot{T}_{231} + \rho_{HK} \ddot{T}_{134} + \rho_{K6} \ddot{T}_{336}
\end{aligned}
\tag{21}
$$

Spatial derivatives are also necessary in forming the equations of motion. The non-zero space derivatives of the positions of the various centers of gravity are

$$\frac{\partial x_1}{\partial x_1} = 1$$

$$\frac{\partial y_1}{\partial y_1} = 1$$

$$\frac{\partial z_1}{\partial z_1} = 1$$

$$\frac{\partial x_2}{\partial x_1} = 1$$

$$\frac{\partial x_2}{\partial \psi_1} = \rho_{1N} T_{321}$$

$$\frac{\partial x_2}{\partial \theta_1} = -\rho_{1N} T_{11}$$

$$\frac{\partial x_2}{\partial \phi_1} = \rho_{1N} T_{211}$$

$$\frac{\partial x_2}{\partial \psi_2} = \rho_{2N} T_{322}$$

$$\frac{\partial x_2}{\partial \theta_2} = -\rho_{2N} T_{12}$$

$$\frac{\partial x_2}{\partial \phi_2} = \rho_{2N} T_{212}$$

$$\frac{\partial y_2}{\partial y_1} = 1$$

$$\frac{\partial y_2}{\partial \psi_1} = -\rho_{1N} T_{311}$$

$$\frac{\partial y_2}{\partial \theta_1} = -\rho_{1N} T_{41}$$

$$\frac{\partial y_2}{\partial \phi_1} = \rho_{1N} T_{221}$$

$$\frac{\partial y_2}{\partial \psi_2} = -\rho_{2N} T_{312}$$

$$\frac{\partial y_2}{\partial \theta_2} = -\rho_{2N} T_{42}$$

$$\frac{\partial y_2}{\partial \phi_2} = \rho_{2N} T_{222}$$

$$\frac{\partial z_2}{\partial z_1} = 1$$

$$\frac{\partial z_2}{\partial \theta_1} = \rho_{1N} T_{161}$$

$$\frac{\partial z_2}{\partial \phi_1} = \rho_{1N} T_{231}$$

$$\frac{\partial z_2}{\partial \theta_2} = \rho_{2N} T_{162}$$

$$\frac{\partial z_2}{\partial \phi_2} = \rho_{2N} T_{232}$$

$$\frac{\partial x_3}{\partial x_1} = 1 \tag{22}$$

$$\frac{\partial x_3}{\partial \psi_1} = -\rho_{1P} T_{321} - \rho_{PH} T_{221}$$

$$\frac{\partial x_3}{\partial \theta_1} = \rho_{1P} T_{11} + \rho_{PH} T_{21}$$

$$\frac{\partial x_3}{\partial \phi_1} = -\rho_{1P} T_{211} + \rho_{PH} T_{311}$$

$$\frac{\partial x_3}{\partial \psi_3} = -\rho_{H3} T_{123}$$

$$\frac{\partial x_3}{\partial \theta_3} = -\rho_{H3} T_{143}$$

continued

$$\frac{\partial y_3}{\partial y_1} = 1$$

$$\frac{\partial y_3}{\partial \psi_1} = \rho_{1P} T_{311} + \rho_{PH} T_{211}$$

$$\frac{\partial y_3}{\partial \theta_1} = \rho_{1P} T_{41} + \rho_{PH} T_{61}$$

$$\frac{\partial y_3}{\partial \phi_1} = -\rho_{1P} T_{221} + \rho_{PH} T_{321}$$

$$\frac{\partial y_3}{\partial \psi_3} = \rho_{H3} T_{113}$$

$$\frac{\partial y_3}{\partial \theta_3} = -\rho_{H3} T_{153}$$

$$\frac{\partial z_3}{\partial z_1} = 1$$

$$\frac{\partial z_3}{\partial \theta_1} = -\rho_{1P} T_{161} - \rho_{PH} T_{171}$$

$$\frac{\partial z_3}{\partial \phi_1} = -\rho_{1P} T_{231} + \rho_{PH} T_{331}$$

$$\frac{\partial z_3}{\partial \theta_3} = -\rho_{H3} C_{23}$$

$$\frac{\partial x_4}{\partial x_1} = 1$$

$$\frac{\partial x_4}{\partial \psi_1} = -\rho_{1P} T_{321} + \rho_{PH} T_{221}$$

$$\frac{\partial x_4}{\partial \theta_1} = \rho_{1P} - \rho_{PH} T_{21}$$

$$\frac{\partial x_4}{\partial \phi_1} = -\rho_{1P} T_{211} - \rho_{PH} T_{311}$$

$$\frac{\partial x_4}{\partial \psi_4} = -\rho_{H4} T_{124}$$

$$\frac{\partial x_4}{\partial \theta_4} = -\rho_{H4} T_{144}$$

$$\frac{\partial y_4}{\partial y_1} = 1$$

$$\frac{\partial y_4}{\partial \psi_1} = \rho_{1P} T_{311} - \rho_{PH} T_{211}$$

$$\frac{\partial y_4}{\partial \theta_1} = \rho_{1P} T_{41} - \rho_{PH} T_{61}$$

$$\frac{\partial y_4}{\partial \phi_1} = -\rho_{1P} T_{221} - \rho_{PH} T_{321}$$

$$\frac{\partial y_4}{\partial \psi_4} = \rho_{H4} T_{114}$$

$$\frac{\partial y_4}{\partial \theta_4} = -\rho_{H4} T_{154}$$

(22)

$$\frac{\partial z_4}{\partial z_1} = 1$$

$$\frac{\partial z_4}{\partial \theta_1} = -\rho_{1P} T_{161} + \rho_{PH} T_{171}$$

$$\frac{\partial z_4}{\partial \phi_1} = -\rho_{1P} T_{231} - \rho_{PH} T_{331}$$

$$\frac{\partial z_4}{\partial \theta_4} = -\rho_{PH} C_{24}$$

$$\frac{\partial x_5}{\partial x_1} = 1$$

$$\frac{\partial x_5}{\partial \psi_1} = \frac{\partial x_3}{\partial \psi_1}$$

$$\frac{\partial x_5}{\partial \theta_1} = \frac{\partial x_3}{\partial \theta_1}$$

$$\frac{\partial x_5}{\partial \phi_1} = \frac{\partial x_3}{\partial \phi_1}$$

continued

$$\frac{\partial x_5}{\partial \Psi_3} = -\rho_{HK} T_{123} - \rho_{K5} T_{325}$$

$$\frac{\partial x_5}{\partial \Theta_3} = -\rho_{HK} T_{143} + \rho_{K5} \left(-S_{25} T_{143} + C_{25} T_{13} \right)$$

$$\frac{\partial x_5}{\partial \Phi_3} = -\rho_{K5} C_{25} T_{213}$$

$$\frac{\partial x_5}{\partial \Theta_5} = \rho_{K5} T_{115}$$

$$\frac{\partial y_5}{\partial y_1} = 1$$

$$\frac{\partial y_5}{\partial \Psi_1} = \frac{\partial y_3}{\partial \Psi_1}$$

$$\frac{\partial y_5}{\partial \Theta_1} = \frac{\partial y_3}{\partial \Theta_1} \tag{22}$$

$$\frac{\partial y_5}{\partial \Phi_1} = \frac{\partial y_3}{\partial \Phi_1}$$

$$\frac{\partial y_5}{\partial \Psi_3} = \rho_{HK} T_{113} + \rho_{K5} T_{315}$$

$$\frac{\partial y_5}{\partial \Theta_3} = -\rho_{HK} T_{153} + \rho_{K5} \left(-S_{25} T_{153} + C_{25} T_{143} \right)$$

$$\frac{\partial y_5}{\partial \Phi_3} = -\rho_{K5} C_{25} T_{223}$$

$$\frac{\partial y_5}{\partial \Theta_5} = \rho_{K5} T_{125}$$

$$\frac{\partial z_5}{\partial z_1} = 1$$

$$\frac{\partial z_5}{\partial \Theta_1} = \frac{\partial z_3}{\partial \Theta_1}$$

$$\frac{\partial z_5}{\partial \Phi_1} = \frac{\partial z_3}{\partial \Phi_1}$$

continued

$$\frac{\partial z_5}{\partial \theta_3} = -\rho_{HK} C_{23} - \rho_{K5} \left(S_{25} C_{23} + C_{25} T_{163} \right)$$

$$\frac{\partial z_5}{\partial \phi_3} = -\rho_{K5} C_{25} T_{233}$$

$$\frac{\partial z_5}{\partial \theta_5} = \rho_{K5} T_{135}$$

$$\frac{\partial x_6}{\partial x_1} = 1$$

$$\frac{\partial x_6}{\partial \psi_1} = \frac{\partial x_4}{\partial \psi_1}$$

$$\frac{\partial x_6}{\partial \theta_1} = \frac{\partial x_4}{\partial \theta_1}$$

$$\frac{\partial x_6}{\partial \phi_1} = \frac{\partial x_4}{\partial \phi_1}$$

(22)

$$\frac{\partial x_6}{\partial \psi_4} = -\rho_{HK} T_{124} - \rho_{K6} T_{326}$$

$$\frac{\partial x_6}{\partial \theta_4} = -\rho_{HK} T_{144} + \rho_{K6} \left(-S_{26} T_{144} + C_{26} T_{14} \right)$$

$$\frac{\partial x_6}{\partial \phi_4} = -\rho_{K6} C_{26} T_{214}$$

$$\frac{\partial x_6}{\partial \theta_5} = \rho_{K6} T_{116}$$

$$\frac{\partial y_6}{\partial y_1} = 1$$

$$\frac{\partial y_6}{\partial \psi_1} = \frac{\partial y_4}{\partial \psi_1}$$

$$\frac{\partial y_6}{\partial \theta_1} = \frac{\partial y_4}{\partial \theta_1}$$

$$\frac{\partial y_6}{\partial \phi_1} = \frac{\partial y_4}{\partial \phi_1}$$

continued

$$\frac{\partial y_6}{\partial \psi_4} = \rho_{HK} T_{114} + \rho_{K6} T_{316}$$

$$\frac{\partial y_6}{\partial \theta_4} = -\rho_{HK} T_{154} + \rho_{K6} \left(-S_{26} T_{154} + C_{26} T_{44} \right)$$

$$\frac{\partial y_6}{\partial \phi_4} = -\rho_{K6} C_{26} T_{224}$$

$$\frac{\partial y_6}{\partial \theta_6} = \rho_{K6} T_{126}$$

$$\frac{\partial z_6}{\partial z_1} = 1 \tag{22}$$

$$\frac{\partial z_6}{\partial \theta_1} = \frac{\partial z_4}{\partial \theta_1}$$

$$\frac{\partial z_6}{\partial \phi_1} = \frac{\partial z_4}{\partial \phi_1}$$

$$\frac{\partial z_6}{\partial \theta_4} = -\rho_{HK} C_{24} - \rho_{K6} \left(S_{26} C_{24} + C_{26} T_{164} \right)$$

$$\frac{\partial z_6}{\partial \phi_4} = -\rho_{K6} C_{26} T_{234}$$

$$\frac{\partial z_6}{\partial \theta_6} = \rho_{K6} T_{136}$$

Similarly, the non-zero spatial derivatives of the various elements of the transformation matrices are

$$
\begin{aligned}
T_{11n,\psi} &= -T_{12n} \\
T_{11n,\theta} &= -T_{14n} \\
T_{12n,\psi} &= T_{11n} \\
T_{12n,\theta} &= -T_{15n} \\
T_{13n,\theta} &= -C_{2n} \\
T_{21n,\psi} &= -T_{22n} \\
T_{21n,\theta} &= T_{2n} \\
T_{21n,\phi} &= T_{31n} \\
T_{22n,\psi} &= T_{21n} \\
T_{22n,\theta} &= T_{6n} \\
T_{22n,\phi} &= T_{32n} \\
T_{23n,\theta} &= -T_{17n} \\
T_{23n,\phi} &= T_{33n} \\
T_{31n,\psi} &= -T_{32n} \\
T_{31n,\theta} &= T_{11n} \\
T_{31n,\phi} &= -T_{21n} \\
T_{32n,\psi} &= T_{31n} \\
T_{32n,\theta} &= T_{4n} \\
T_{32n,\phi} &= -T_{22n} \\
T_{33n,\theta} &= -T_{16n} \\
T_{33n,\phi} &= -T_{23n}
\end{aligned}
\qquad (23)
$$

$$\frac{\partial T_{11,n+2}}{\partial \psi_n} = - T_{12,n+2}$$

$$\frac{\partial T_{11,n+2}}{\partial \theta_n} = - C_{2,n+2} T_{14n} - S_{2,n+2} T_{1n}$$

$$\frac{\partial T_{11,n+2}}{\partial \phi_n} = S_{2,n+2} T_{21n}$$

$$\frac{\partial T_{12,n+2}}{\partial \psi_n} = T_{11,n+2}$$

$$\frac{\partial T_{12,n+2}}{\partial \theta_n} = - C_{2,n+2} T_{15n} - S_{2,n+2} T_{4n}$$

$$\frac{\partial T_{12,n+2}}{\partial \phi_n} = S_{2,n+2} T_{22n} \tag{24}$$

$$\frac{\partial T_{13,n+2}}{\partial \theta_n} = - C_{2,n+2} C_{2n} + S_{2,n+2} T_{16n}$$

$$\frac{\partial T_{13,n+2}}{\partial \phi_n} = S_{2,n+2} T_{23n}$$

$$\frac{\partial T_{21,n+2}}{\partial \psi_n} = - T_{22n}$$

$$\frac{\partial T_{21,n+2}}{\partial \theta_n} = T_{2n}$$

$$\frac{\partial T_{21,n+2}}{\partial \phi_n} = T_{31n}$$

continued

$$\frac{\partial T_{22,n+2}}{\partial \psi_n} = - T_{21n}$$

$$\frac{\partial T_{22,n+2}}{\partial \theta_n} = T_{6n}$$

$$\frac{\partial T_{22,n+2}}{\partial \phi_n} = T_{32n}$$

$$\frac{\partial T_{23,n+2}}{\partial \theta_n} = - T_{17n}$$

$$\frac{\partial T_{23,n+2}}{\partial \phi_n} = T_{33n}$$

$$\frac{\partial T_{31,n+2}}{\partial \psi_n} = - T_{32,n+2} \tag{24}$$

$$\frac{\partial T_{31,n+2}}{\partial \theta_n} = - S_{2,n+2} T_{14n} + C_{2,n+2} T_{1n}$$

$$\frac{\partial T_{31,n+2}}{\partial \phi_n} = - C_{2,n+2} T_{21n}$$

$$\frac{\partial T_{32,n+2}}{\partial \psi_n} = T_{31,n+2}$$

$$\frac{\partial T_{32,n+2}}{\partial \theta_n} = - S_{2,n+2} T_{15n} + C_{2,n+2} T_{4n}$$

$$\frac{\partial T_{32,n+2}}{\partial \phi_n} = - C_{2,n+2} T_{22n}$$

continued

$$\begin{aligned}
\frac{\partial T_{33,n+2}}{\partial \theta_n} &= -S_{2,n+2}\,C_{2n} - C_{2,n+2}\,T_{16n} \\
\frac{\partial T_{33,n+2}}{\partial \phi_n} &= -C_{2,n+2}\,T_{23n} \\
\frac{\partial T_{11,n+2}}{\partial \theta_{n+2}} &= -T_{31,n+2} \\
\frac{\partial T_{12,n+2}}{\partial \theta_{n+2}} &= -T_{32,n+2} \\
\frac{\partial T_{13,n+2}}{\partial \theta_{n+2}} &= -T_{33,n+2} \\
\frac{\partial T_{31,n+2}}{\partial \theta_{n+2}} &= T_{11,n+2} \\
\frac{\partial T_{32,n+2}}{\partial \theta_{n+2}} &= T_{12,n+2} \\
\frac{\partial T_{33,n+2}}{\partial \theta_{n+2}} &= T_{13,n+2}
\end{aligned} \tag{24}$$

The final set of useful quantities used in formulating the equations of motion is of the angular velocities and accelerations. The angular velocities are given by

$$\begin{aligned}
\alpha_{1n} &= \dot{\phi}_n - \dot{\psi}_n S_{2n} \\
\alpha_{2n} &= \dot{\theta}_n C_{3n} + \dot{\psi}_n C_{2n} S_{3n} \\
\alpha_{3n} &= \dot{\psi}_n C_{2n} C_{3n} - \dot{\theta}_n S_{3n}
\end{aligned} \tag{25}$$

where n = 1, ..., 4 and

$$\begin{aligned}
\alpha_{1,n+2} &= \alpha_{1n} C_{2,n+2} - \alpha_{3n} S_{2,n+2} \\
\alpha_{2,n+2} &= \alpha_{2n} + \dot{\theta}_{n+2} \\
\alpha_{3,n+2} &= \alpha_{1n} S_{2,n+2} + \alpha_{3n} C_{2,n+2}
\end{aligned} \tag{26}$$

where n = 3,4.

The angular accelerations are

$$
\begin{aligned}
\dot{\alpha}_{1n} &= \ddot{\phi}_n - \ddot{\psi}_n S_{2n} - \dot{\psi}_n \dot{\theta}_n C_{2n} \\
\dot{\alpha}_{2n} &= \ddot{\theta}_n C_{3n} - \dot{\theta}_n \dot{\phi}_n S_{3n} + \ddot{\psi}_n C_{2n} S_{3n} - \dot{\psi}_n \theta_n S_{2n} S_{3n} + \dot{\psi}_n \dot{\phi}_n C_{2n} C_{3n} \qquad (27) \\
\dot{\alpha}_{3n} &= \ddot{\psi}_n C_{1n} C_{3n} - \dot{\psi}_n \dot{\theta}_n S_{2n} C_{3n} - \dot{\psi}_n \dot{\phi}_n C_{2n} S_{3n} - \ddot{\theta}_n S_{3n} - \dot{\theta}_n \dot{\phi}_n C_{3n}
\end{aligned}
$$

where n = 1, ..., 4 and

$$
\begin{aligned}
\dot{\alpha}_{1,n+2} &= \dot{\alpha}_{1n} C_{2,n+2} - \alpha_{1n} \dot{\theta}_{n+2} S_{2,n+2} \\
&\quad - \dot{\alpha}_{3n} S_{2,n+2} - \alpha_{3n} \dot{\theta}_{n+2} C_{2,n+2} \\
\dot{\alpha}_{2,n+2} &= \dot{\alpha}_{2n} + \ddot{\theta}_{n+2} \qquad (28) \\
\dot{\alpha}_{3,n+2} &= \dot{\alpha}_{1n} S_{2,n+2} + \alpha_{1n} \dot{\theta}_{2,n+2} C_{2,n+2} \\
&\quad + \dot{\alpha}_{3n} C_{2,n+2} - \alpha_{3n} \dot{\theta}_{2,n+2} S_{2,n+2}
\end{aligned}
$$

where n = 3,4.

C. Matrix of Generalized Acceleration Coefficients

The 17 by 17 matrix, m, in Equation 11 is determined from the kinetic energy sections of Lagrange's Equation. The translational kinetic energy is written

$$
KE_T = \frac{1}{2} \sum_{n=1}^{6} m_n (\dot{x}_n^2 + \dot{y}_n^2 + \dot{z}_n^2) \qquad (29)
$$

Substituting this quantity into Equation 10 and using the following relations

$$
\frac{\partial(\dot{x}_n)}{\partial \dot{q}_i} = \frac{\partial x_n}{\partial q_i} , \quad \frac{d}{dt} \left(\frac{\partial \dot{x}_n}{\partial \dot{q}_i} \right) = \frac{\partial \dot{x}_n}{\partial q_i} , \quad \ldots
$$

each term resulting from translational kinetic energy is simply

$$
\sum_{n=1}^{6} m_n \left(\ddot{x}_n \frac{\partial x_n}{\partial q_i} + \ddot{y}_n \frac{\partial y_n}{\partial q_i} + \ddot{z}_n \frac{\partial z_n}{\partial q_i} \right) \qquad (30)
$$

where $i = 1, \ldots, 17$.

The rotational kinetic energy is written

$$KE_R = \frac{1}{2} \sum_{m=1}^{3} \sum_{n=1}^{6} I_{mn} \alpha_{mn}^{2} \tag{31}$$

Substitution of this into Equation 10 yields

$$\sum_{m=1}^{3} \sum_{n=1}^{6} I_{mn} \alpha_{mn} \frac{d}{dt}\left[\frac{\partial \alpha_{mn}}{\partial \dot{\xi}_i} \right] + I_{mn} \dot{\alpha}_{mn} \frac{\partial \alpha_{mn}}{\partial \dot{\xi}_i} - I_{mn} \alpha_{mn} \frac{\partial \alpha_{mn}}{\partial \xi_i} \tag{32}$$

where $i = 1, \ldots, 17$.

The coefficients in m result from expressions 30 and 32. Each Coefficient in each of the seventeen equations is the multiplier of one of the generalized acceleration quantities, $\ddot{x}_1$, $\ddot{y}_1$, ..., $\ddot{\theta}_6$. In their computation a variety of relations are used more than once including

$$\begin{aligned}
a_1 &= m_1 + m_2 + a_{75} \\
a_2 &= -a_{76} + \rho_{1\ell} a_{75} \\
a_3 &= -m_2 \rho_{2n} \\
a_4 &= a_{77} + a_{56} \\
a_5 &= a_{78} + a_{57} \\
a_6 &= m_8 a_{58} \\
a_7 &= m_6 a_{59} \\
a_8 &= a_{60} T_{115} \\
a_9 &= a_{61} T_{116}
\end{aligned} \tag{33}$$

continued

$$
\begin{aligned}
a_{10} &= -a_{60} T_{315} \\
a_{11} &= -a_{61} T_{316} \\
a_{12} &= m_5 a_{73} \\
a_{13} &= m_6 a_{74} \\
a_{14} &= -a_{60} T_{325} \\
a_{15} &= -a_{61} T_{326} \\
a_{16} &= a_{60} T_{125} \\
a_{17} &= a_{61} T_{126} \\
a_{18} &= a_{60} T_{135} \\
a_{19} &= -a_{60} T_{335} \\
a_{20} &= a_{61} T_{136} \\
a_{21} &= -a_{61} T_{336} \\
a_{22} &= 2a_{60} \left(C_{25} C_{23} - S_{25} T_{163} \right) \\
a_{23} &= 2a_{61} \left(C_{26} C_{24} - S_{26} T_{164} \right) \\
a_{24} &= a_{79} + a_{80} \\
a_{25} &= a_{81} + a_{82} \\
a_{26} &= -a_{79} + a_{80} \\
a_{27} &= a_{81} - a_{82} \\
a_{28} &= -a_{24} \\
a_{29} &= a_{25} \\
a_{30} &= a_{26} \\
a_{31} &= a_{27} \\
a_{32} &= \rho_{HK} + a_{73} \\
a_{33} &= \rho_{HK} + a_{74} \\
a_{34} &= \rho_{IP} T_{11} + \rho_{PH} T_{21}
\end{aligned}
\tag{33}
$$

continued

$$
\begin{aligned}
a_{35} &= \rho_{1\rho} T_{41} + \rho_{\rho H} T_{61} \\
a_{36} &= \rho_{1\rho} T_{161} + \rho_{\rho H} T_{171} \\
a_{37} &= \rho_{1\rho} T_{11} - \rho_{\rho H} T_{21} \\
a_{38} &= \rho_{1\rho} T_{41} - \rho_{\rho H} T_{61} \\
a_{39} &= -\rho_{1\rho} T_{161} + \rho_{\rho H} T_{171} \\
a_{40} &= a_4 \\
a_{41} &= a_5 \\
a_{42} &= -\rho_{1\rho} T_{211} + \rho_{\rho H} T_{311} \\
a_{43} &= -\rho_{1\rho} T_{221} + \rho_{\rho H} T_{321} \\
a_{44} &= -\rho_{1\rho} T_{231} + \rho_{\rho H} T_{331} \\
a_{45} &= -\rho_{1\rho} T_{211} - \rho_{\rho H} T_{311} \\
a_{46} &= -\rho_{1\rho} T_{221} - \rho_{\rho H} T_{321} \\
a_{47} &= -\rho_{1\rho} T_{231} - \rho_{\rho H} T_{331} \\
a_{48} &= -(a_{56} T_{123} + a_6 T_{323}) \\
a_{49} &= a_{56} T_{113} + a_6 T_{313} \\
a_{50} &= m_5 (-a_{32} T_{143} + a_{58} T_{13}) \\
a_{51} &= m_5 (-a_{32} T_{153} + a_{58} T_{43}) \\
a_{52} &= -(a_{32} C_{23} + a_{58} T_{163}) \\
a_{53} &= a_8 \\
a_{54} &= a_{16} \\
a_{55} &= a_{18} \\
a_{56} &= m_5 a_{32} \\
a_{57} &= m_6 a_{33} \\
a_{58} &= \rho_{K5} C_{25} \\
a_{59} &= \rho_{K6} C_{26} \\
a_{60} &= m_5 \rho_{K5}
\end{aligned}
\qquad (33)
$$

continued

$$a_{61} = m_6 \rho_{KG}$$

$$a_{62} = a_{76} \rho_{1N}$$

$$a_{63} = m_3 + m_5$$

$$a_{64} = a_{76} \rho_{2N}$$

$$a_{65} = \rho_{1\ell}^2$$

$$a_{66} = a_{62} + 2 a_{63} a_{65}$$

$$a_{67} = \rho_{\ell H}^2$$

$$a_{68} = a_{65} + a_{67}$$

$$a_{69} = -a_3 \rho_{2N}$$

$$a_{70} = \rho_{H3} a_{77}$$

$$a_{71} = \rho_{H4} a_{78}$$

$$a_{72} = 2 a_{63} a_{67}$$

$$a_{73} = \rho_{K5} S_{25} \qquad (33)$$

$$a_{74} = \rho_{K6} S_{26}$$

$$a_{75} = m_4 + m_6 + a_{63}$$

$$a_{76} = m_2 \rho_{1N}$$

$$a_{77} = m_3 \rho_{H3}$$

$$a_{78} = m_4 \rho_{H4}$$

$$a_{79} = \rho_{1\ell} T_{321}$$

$$a_{80} = \rho_{\ell H} T_{221}$$

$$a_{81} = \rho_{1\ell} T_{311}$$

$$a_{82} = \rho_{\ell H} T_{211}$$

$$a_{92} = -(a_{57} T_{124} + a_7 T_{324})$$

$$a_{93} = a_{57} T_{114} + a_7 T_{314}$$

$$a_{94} = m_6(-a_{33} T_{144} + a_{59} T_{14})$$

$$a_{95} = m_6(-a_{33} T_{154} + a_{59} T_{44})$$

$$a_{96} = -(a_{33} C_{24} + a_{59} T_{164})$$

The quantities m_{ij} are given in Equation 34. The first subscript gives the row and the second, the column in m. Only the upper portion and diagonal of this symmetric matrix are given.

$$m_{11} = a_1$$
$$m_{12} = 0$$
$$m_{13} = 0$$
$$m_{14} = -a_2 T_{321}$$
$$m_{15} = a_2 T_{11}$$
$$m_{16} = -a_2 T_{211}$$
$$m_{17} = -a_3 T_{322}$$
$$m_{18} = a_3 T_{12}$$
$$m_{19} = -a_3 T_{212}$$
$$m_{1,10} = -(a_4 T_{123} + a_6 T_{323})$$
$$m_{1,11} = -(a_4 T_{143} - a_6 T_{13})$$
$$m_{1,12} = -a_6 T_{213}$$
$$m_{1,13} = -(a_5 T_{124} + a_7 T_{324}) \qquad (34)$$
$$m_{1,14} = -(a_5 T_{144} - a_7 T_{14})$$
$$m_{1,15} = -a_7 T_{214}$$
$$m_{1,16} = a_8$$
$$m_{1,17} = a_9$$

$$m_{22} = a_1$$
$$m_{23} = 0$$
$$m_{24} = a_2 T_{311}$$
$$m_{25} = a_2 T_{41}$$
$$m_{26} = -a_2 T_{221}$$
$$m_{27} = a_3 T_{312}$$
$$m_{28} = a_3 T_{42}$$
$$m_{29} = -a_3 T_{222}$$
$$m_{2,10} = a_4 T_{113} + a_6 T_{313}$$
$$m_{2,11} = -a_4 T_{153} + a_6 T_{43}$$
$$m_{2,12} = -a_6 T_{223}$$
$$m_{2,13} = a_5 T_{114} + a_7 T_{314}$$
$$m_{2,14} = -a_5 T_{154} + a_7 T_{44}$$
$$m_{2,15} = -a_7 T_{224}$$
$$m_{2,16} = a_{16}$$
$$m_{2,17} = a_{17}$$

continued

$m_{33} = a_1$

$m_{34} = 0$

$m_{35} = -a_2 T_{161}$

$m_{36} = -a_2 T_{231}$

$m_{37} = 0$

$m_{38} = -a_3 T_{162}$

$m_{39} = -a_3 T_{232}$ (34)

$m_{3,10} = 0$

$m_{3,11} = -a_4 C_{23} - a_6 T_{163}$

$m_{3,12} = -a_6 T_{233}$

$m_{3,13} = 0$

$m_{3,14} = -a_5 C_{24} - a_7 T_{164}$

$m_{3,15} = -a_7 T_{234}$

$m_{3,16} = a_{18}$

$m_{3,17} = a_{20}$

$$\begin{aligned} m_{44} = {} & a_{62}(T_{321}^2 + T_{311}^2) + 2a_{63}[a_{65}(T_{321}^2 + T_{311}^2) + a_{67}(T_{221}^2 + T_{211}^2)] \\ & + I_{11} T_{131}^2 + I_{21} T_{231}^2 + I_{31} T_{331}^2 \end{aligned}$$

$$\begin{aligned} m_{45} = {} & a_{62}(-T_{321} T_{11} + T_{311} T_{41}) + a_{63}[-a_{24} a_{34} + a_{25} a_{35} + a_{26} a_{37} \\ & + a_{27} a_{38}] + I_{21} T_{231} C_{31} - I_{31} T_{331} S_{31} \end{aligned}$$

$$\begin{aligned} m_{46} = {} & a_{62}(T_{321} T_{211} - T_{311} T_{221}) + a_{63}(-a_{24} a_{42} + a_{25} a_{43} + a_{26} a_{45} \\ & + a_{27} a_{46}) + I_{11} T_{131} \end{aligned}$$

$m_{47} = a_{64}(T_{321} T_{322} + T_{311} T_{312})$

$m_{48} = a_{64}(-T_{321} T_{12} + T_{311} T_{42})$

$m_{49} = a_{64}(T_{321} T_{212} - T_{311} T_{222})$

$m_{4,10} = a_4 (a_{24} T_{123} + a_{25} T_{113}) + a_6 (a_{24} T_{323} + a_{25} T_{313})$

$m_{4,11} = a_4 (a_{24} T_{143} - a_{25} T_{153}) + a_6 (-a_{24} T_{13} + a_{25} T_{43})$

$m_{4,12} = a_6 (a_{24} T_{213} - a_{25} T_{223})$

$m_{4,13} = a_5 (-a_{26} T_{124} + a_{27} T_{114}) + a_7 (a_{31} T_{314} - a_{30} T_{324})$

$m_{4,14} = -a_5 (a_{26} T_{144} + a_{27} T_{154}) + a_7 (a_{26} T_{14} + a_{27} T_{44})$

$m_{4,15} = -a_7 (a_{26} T_{214} + a_{27} T_{224})$

$m_{4,16} = -a_{24} a_8 + a_{25} a_{16}$

$m_{4,17} = a_{26} a_9 + a_{27} a_{17}$

continued

$$m_{55} = (a_{66} + I_{21})C_{31}^2 + (a_{72} + I_{31})S_{31}^2$$

$$m_{56} = 0$$

$$m_{57} = a_{64}(T_{41}T_{312} - T_{11}T_{322})$$

$$m_{58} = a_{64}(T_{11}T_{12} + T_{41}T_{42} + T_{161}T_{162})$$

$$m_{59} = a_{64}(-T_{11}T_{212} - T_{41}T_{222} + T_{161}T_{232})$$

$$m_{5,10} = -a_{34}(a_6T_{323} + a_{40}T_{123}) + a_{35}(a_6T_{313} + a_{40}T_{113})$$

$$m_{5,11} = a_{34}(a_6T_{13} - a_{40}T_{143}) + a_{35}(a_6T_{43} - a_{40}T_{153}) + a_{36}(a_6T_{163} + a_{40}C_{23})$$

$$m_{5,12} = -a_6(a_{34}T_{213} + a_{35}T_{223} - a_{36}T_{233})$$

$$m_{5,13} = -a_{37}(a_{41}T_{124} + a_7T_{324}) + a_{38}(a_{41}T_{114} + a_7T_{314})$$

$$m_{5,14} = a_{37}(a_7T_{14} - a_{41}T_{144}) + a_{38}(a_7T_{44} - a_{41}T_{154}) - a_{39}(a_7T_{164} + a_{41}C_{24})$$

$$m_{5,15} = -a_7(a_{37}T_{214} + a_{38}T_{224} + a_{39}T_{234})$$

$$m_{5,16} = a_{34}a_8 + a_{35}a_{16} - a_{36}a_{18}$$

$$m_{5,17} = a_{37}a_9 + a_{38}a_{17} + a_{39}a_{20}$$

$$m_{6,6} = a_{66} + a_{72} + I_{11}$$

$$m_{67} = a_{64}(T_{211}T_{322} - T_{221}T_{312})$$

$$m_{68} = a_{64}(T_{211}T_{12} + T_{221}T_{42} - T_{231}T_{162})$$

$$m_{69} = a_{64}(T_{211}T_{212} + T_{221}T_{222} + T_{231}T_{232})$$

$$m_{6,10} = -a_{42}(a_{40}T_{123} + a_6T_{323}) + a_{43}(a_{40}T_{113} + a_6T_{313})$$

$$m_{6,11} = a_{42}(-a_{40}T_{143} + a_6T_{13}) + a_{43}(-a_{40}T_{153} + a_6T_{43}) - a_{44}(a_{40}C_{23} + a_6T_{163})$$

$$m_{6,12} = -a_6(a_{42}T_{213} + a_{43}T_{223} + a_{44}T_{233})$$

$$m_{6,13} = -a_{45}(a_{41}T_{124} + a_7T_{324}) + a_{46}(a_5T_{114} + a_7T_{314})$$

$$m_{6,14} = a_{45}(-a_{41}T_{144} + a_7T_{14}) + a_{46}(-a_5T_{154} + a_7T_{44}) - a_{47}(a_5C_{24} + a_7T_{164})$$

$$m_{6,15} = -a_7(a_{45}T_{214} + a_{46}T_{224} + a_{47}T_{234})$$

$$m_{6,16} = a_{42}a_8 + a_{43}a_{16} + a_{44}a_{18}$$

$$m_{6,17} = a_{45}a_9 + a_{46}a_{17} + a_{47}a_{20}$$

$$m_{7,7} = a_{69}(T_{312}^2 + T_{322}^2) + I_{12}T_{132}^2 + I_{22}T_{232}^2 + I_{32}T_{332}^2$$

$$m_{78} = (a_{69} \qquad\qquad + I_{22})C_{32}T_{232} - I_{32}T_{332}S_{32}$$

$$m_{79} = (a_{69} \qquad\qquad + I_{12})T_{132}$$

$$m_{7,10} = m_{7,11} = m_{7,12} = m_{7,13} = m_{7,14} = m_{7,15} = m_{7,16} = m_{7,17} = 0$$

$$m_{88} = (a_{69} \qquad\qquad + I_{22})C_{32}^2 + I_{32}S_{32}^2$$

$$m_{89} = 0$$

$$m_{8,10} = m_{8,11} = m_{8,12} = m_{8,13} = m_{8,14} = m_{8,15} = m_{8,16} = m_{8,17} = 0$$

continued

$$m_{99} = I_{12} + a_{69}$$

$$m_{9,10} = m_{9,11} = m_{9,12} = m_{9,13} = m_{9,14} = m_{9,15} = m_{9,16} = m_{9,17} = 0$$

$$\begin{aligned}m_{10,10} = {} & a_{70}(T_{123}^2 + T_{113}^2) - I_{13}S_{23}T_{133} + I_{23}T_{233}^2 + I_{33}T_{333}^2 \\ & + a_{32}(-a_{48}T_{123} + a_{49}T_{113}) + a_{58}(-a_{48}T_{323} + a_{49}T_{313}) \\ & + I_{25}T_{223}^2 + I_{15}(S_{23}C_{25} + T_{333}S_{25})^2 + I_{35}(S_{23}S_{25} - T_{333}C_{25})^2\end{aligned}$$

$$\begin{aligned}m_{10,11} = {} & I_{23}T_{233}C_{33} - I_{33}T_{333}S_{33} \\ & - a_{32}(a_{48}T_{143} + a_{49}T_{153}) + a_{58}(a_{48}T_{13} + a_{49}T_{43}) \\ & - I_{15}S_{25}S_{33}(S_{23}C_{25} + T_{333}S_{25}) + I_{25}T_{233}C_{33} \\ & - I_{35}C_{25}S_{33}(-S_{23}S_{25} + T_{333}C_{25})\end{aligned}$$

$$\begin{aligned}m_{10,12} = {} & I_{13}T_{133} - a_{58}(a_{48}T_{213} + a_{49}T_{223}) - I_{15}C_{25}(S_{23}C_{25} + T_{333}S_{25}) \\ & + I_{35}S_{25}(-S_{23}S_{25} + T_{333}C_{25})\end{aligned}$$

$$m_{10,13} = 0$$

$$m_{10,14} = 0$$

$$m_{10,15} = 0$$

$$m_{10,16} = a_{73}(-a_{48}T_{313} - a_{49}T_{323}) + I_{25}T_{233} + a_{58}(a_{48}T_{113} + a_{49}T_{123})$$

$$m_{10,17} = 0$$

$$\begin{aligned}m_{11,11} = {} & a_{70} + m_5 a_{52}^2 - a_{32}(a_{50}T_{143} + a_{51}T_{153}) \\ & + I_{23}C_{33}^2 + I_{33}S_{33}^2 + a_{58}(a_{50}T_{13} + a_{51}T_{43}) + I_{15}S_{33}^2 S_{25}^2 \\ & + I_{25}C_{33}^2 + I_{35}S_{33}^2 C_{25}^2\end{aligned}$$

$$\begin{aligned}m_{11,12} = {} & a_{58}(-a_{50}T_{213} - a_{51}T_{223}) + I_{15}S_{33}S_{25}C_{25} \\ & - I_{35}S_{33}C_{25}S_{25} - a_{52}a_6 T_{233}\end{aligned}$$

$$m_{11,13} = m_{11,14} = m_{11,15} = 0$$

$$\begin{aligned}m_{11,16} = {} & -a_{73}(a_{50}T_{313} + a_{51}T_{323}) + a_{58}(a_{50}T_{113} + a_{51}T_{123}) \\ & + I_{23}C_{23} + a_{52}a_{60}(C_{25}T_{133} - S_{25}T_{333})\end{aligned}$$

$$m_{11,17} = 0$$

$$m_{12,12} = a_{58}a_6 + I_{13} + I_{15}C_{25}^2 + I_{35}S_{25}^2$$

$$m_{12,13} = m_{12,14} = m_{12,15} = m_{12,16} = m_{12,17} = 0$$

continued

$$m_{13,13} = a_{71}(T_{124}^2 + T_{114}^2) - I_{14} S_{24} T_{134} + I_{24} T_{234}^2$$
$$+ I_{34} T_{334}^2 + a_{33}(-a_{92} T_{124} + a_{93} T_{114}) + a_{59}(-a_{92} T_{324} + a_{93} T_{314})$$
$$+ I_{16}(S_{24} C_{26} + T_{334} S_{26})^2 + I_{26} T_{234}^2 + I_{36}(S_{24} S_{26} - T_{334} C_{26})^2$$

$$m_{13,14} = I_{24} T_{234} C_{34} - I_{34} T_{334} S_{34}$$
$$+ a_{33}(-a_{92} T_{144} - a_{93} T_{154}) + a_{59}(a_{92} T_{14} + a_{93} T_{44})$$
$$- I_{16} S_{26} S_{34}(S_{24} C_{26} + T_{334} S_{26}) + I_{26} T_{234} C_{34}$$
$$- I_{36} C_{26} S_{34}(-S_{24} S_{26} + T_{334} C_{26})$$

$$m_{13,15} = I_{14} T_{134} - a_{59}(a_{92} T_{214} + a_{93} T_{224}) - I_{16} C_{26}(S_{24} C_{26} + T_{334} S_{26}$$
$$+ I_{36} S_{26}(-S_{24} S_{26} + T_{334} C_{26})$$

$$m_{13,16} = 0$$

$$m_{13,17} = -a_{74}(a_{92} T_{314} + a_{93} T_{324}) + I_{26} T_{234} + a_{59}(a_{92} T_{114} + a_{93} T_{124})$$

$$m_{14,14} = m_6 a_{96}^2 + a_{71} - a_{33}(a_{94} T_{144} + a_{95} T_{154})$$
$$+ I_{24} C_{34}^2 + I_{34} S_{34}^2 + a_{59}(a_{94} T_{14} + a_{95} T_{44}) + I_{16} S_{34}^2 S_{26}^2$$
$$+ I_{26} C_{34}^2 + I_{36} S_{34}^2 C_{26}^2$$

$$m_{14,15} = -a_{59}(a_{94} T_{214} + a_{95} T_{224}) + (I_{16} - I_{36}) S_{34} S_{26} C_{26}$$
$$- a_{96} a_{61} C_{26} T_{234}$$

$$m_{14,16} = 0$$

$$m_{14,17} = -a_{74}(a_{94} T_{314} + a_{95} T_{324}) + I_{26} C_{34} + a_{59}(a_{94} T_{114} + a_{95} T_{124})$$
$$+ a_{61} a_{96}(C_{26} T_{134} - S_{26} T_{334})$$

$$m_{15,15} = a_{59} a_7 + I_{14} + I_{16} C_{26}^2 + I_{36} S_{26}^2$$

$$m_{15,16} = 0$$

$$m_{15,17} = 0$$

$$m_{16,16} = -\rho_{K5} S_{25}(a_{53} T_{313} + a_{54} T_{323}) + \rho_{K5} C_{25}(a_{53} T_{113} + a_{54} T_{123})$$
$$+ \rho_{K5} a_{55}(C_{25} T_{133} - S_{25} T_{333}) + I_{25}$$

$$m_{16,17} = 0$$

$$m_{17,17} = -a_{74}(a_9 T_{314} + a_{17} T_{324}) + a_{59}(a_9 T_{114} + a_{17} T_{124})$$
$$+ \rho_{K6} a_{20}(C_{26} T_{134} - S_{26} T_{334}) + I_{26}$$

D. Components of Equations of Motion Resulting from Kinetic Energy included in "Generalized Force"

The components of vector $\vec{Q}_T$ defined in Equation 12 are given in this section. In their formulation those portions of $\ddot{T}_{ijn}$, $\ddot{x}_i$, $\ddot{y}_i$, $\ddot{z}_i$, and $\dot{\alpha}_{mn}$ which contain products of first time derivatives of the generalized coordinates are used many times. Those portions of the $\ddot{T}_{ijn}$ as obtained from Equation 18 and 19 are given by

$$
\begin{aligned}
S_{11n} &= -\dot{T}_{12n}\dot{\psi}_n - \dot{T}_{14n}\dot{\theta}_n \\
S_{12n} &= \dot{T}_{11n}\dot{\psi}_n - \dot{T}_{15n}\dot{\theta}_n \quad ; \quad S_{13n} = S_{2n}\dot{\theta}_n^2 \\
S_{21n} &= -\dot{T}_{22n}\dot{\psi}_n + \dot{T}_{2n}\dot{\theta}_n + \dot{T}_{31n}\dot{\phi}_n \\
S_{22n} &= \dot{T}_{21n}\dot{\psi}_n + \dot{T}_{6n}\dot{\theta}_n + \dot{T}_{32n}\dot{\phi}_n \\
S_{23n} &= -\dot{T}_{17n}\dot{\theta}_n + \dot{T}_{33n}\dot{\phi}_n \\
S_{31n} &= -\dot{T}_{32n}\dot{\psi}_n + \dot{T}_{1n}\dot{\theta}_n - \dot{T}_{21n}\dot{\phi}_n \\
S_{32n} &= \dot{T}_{31n}\dot{\psi}_n + \dot{T}_{4n}\dot{\theta}_n - \dot{T}_{22n}\dot{\phi}_n \\
S_{33n} &= -\dot{T}_{16n}\dot{\theta}_n - \dot{T}_{23n}\dot{\phi}_n
\end{aligned}
\tag{35}
$$

where n = 1, ..., 4 and

$$
\begin{aligned}
S_{11,n+2} &= C_{2,n+2}S_{11n} - S_{2,n+2}S_{31n} - \dot{\theta}_{n+2}(\dot{T}_{31,n+2} + S_{2,n+2}\dot{T}_{11n} + C_{2,n+2}\dot{T}_{31n}) \\
S_{12,n+2} &= C_{2,n+2}S_{12n} - S_{2,n+2}S_{32n} - \dot{\theta}_{n+2}(\dot{T}_{32,n+2} + S_{2,n+2}\dot{T}_{12n} + C_{2,n+2}\dot{T}_{32n}) \\
S_{13,n+2} &= C_{2,n+2}S_{13n} - S_{2,n+2}S_{33n} - \dot{\theta}_{n+2}(\dot{T}_{33,n+2} + S_{2,n+2}\dot{T}_{13n} + C_{2,n+2}\dot{T}_{33n}) \\
S_{21,n+2} &= S_{21n} \\
S_{22,n+2} &= S_{22n} \\
S_{23,n+2} &= S_{23n} \\
S_{31,n+2} &= S_{2,n+2}S_{11n} + C_{2,n+2}S_{31n} + \dot{\theta}_{n+2}(\dot{T}_{11,n+2} + C_{2,n+2}\dot{T}_{11n} - S_{2,n+2}\dot{T}_{31n}) \\
S_{32,n+2} &= S_{2,n+2}S_{12n} + C_{2,n+2}S_{32n} + \dot{\theta}_{n+2}(\dot{T}_{12,n+2} + C_{2,n+2}\dot{T}_{12n} - S_{2,n+2}\dot{T}_{32n}) \\
S_{33,n+2} &= S_{2,n+2}S_{13n} + C_{2,n+2}S_{33n} + \dot{\theta}_{n+2}(\dot{T}_{13,n+2} + C_{2,n+2}\dot{T}_{13n} - S_{2,n+2}\dot{T}_{33n})
\end{aligned}
\tag{36}
$$

for n = 3, 4.

The quantities derived from the second derivatives of the position vector (Equation 2.21) can be expressed as

$$
\begin{aligned}
W_{i1} &= 0 \\
W_{i2} &= -\rho_{1N} S_{3i1} - \rho_{2N} S_{3i2} \\
W_{i3} &= \rho_{1\ell} S_{3i1} + \rho_{\ell H} S_{2i1} + \rho_{H3} S_{1i3} \\
W_{i4} &= \rho_{1\ell} S_{3i1} - \rho_{\ell H} S_{2i1} + \rho_{H4} S_{1i4} \\
W_{i5} &= \rho_{1\ell} S_{3i1} + \rho_{\ell H} S_{2i1} + \rho_{HK} S_{1i3} + \rho_{K5} S_{3i5} \\
W_{i6} &= \rho_{1\ell} S_{3i1} - \rho_{\ell H} S_{2i1} + \rho_{HK} S_{1i4} + \rho_{K6} S_{3i6}
\end{aligned}
\qquad (37)
$$

where i = 1,2,3 refer to x, y, z.

From the angular accelerations given in Equations 2.27 and 2.28, the following quantities result.

$$
\begin{aligned}
U_{1n} &= -\dot{\psi}_n \dot{\theta}_n C_{2n} \\
U_{2n} &= -\dot{\theta}_n \dot{\phi}_n S_{3n} - \dot{\psi}_n \dot{\theta}_n T_{17n} + \dot{\psi}_n \dot{\phi}_n T_{33n} \\
U_{3n} &= -\dot{\psi}_n \dot{\theta}_n T_{16n} - \dot{\psi}_n \dot{\phi}_n T_{23n} - \dot{\theta}_n \dot{\phi}_n C_{3n}
\end{aligned}
\qquad (38)
$$

where n = 1, ..., 4 and

$$
\begin{aligned}
U_{15} &= C_{25}(U_{13} - \alpha_{23} \dot{\theta}_5) - S_{25}(\alpha_{13} \dot{\theta}_5 + U_{33}) \\
U_{25} &= U_{23} \\
U_{35} &= S_{25}(U_{13} - \alpha_{33} \dot{\theta}_5) + C_{25}(\alpha_{13} \dot{\theta}_5 + U_{33}) \\
U_{16} &= C_{26}(U_{14} - \alpha_{34} \dot{\theta}_6) - S_{26}(\alpha_{14} \dot{\theta}_6 + U_{34}) \\
U_{26} &= U_{24} \\
U_{36} &= S_{26}(U_{14} - \alpha_{34} \dot{\theta}_6) + C_{26}(\alpha_{14} \dot{\theta}_6 + U_{34})
\end{aligned}
\qquad (39)
$$

Using Equations 35 through 39 the components of the equations of motion resulting from kinetic energy which are included in the "generalized force" as $\vec{Q}_T$ can be written as follows where the subscript n of Q_{Tn} refers to the row in which the term is entered.

$$
\begin{aligned}
Q_{T1} &= m_2 W_{12} + m_3 W_{13} + \ldots + m_6 W_{16} \\
Q_{T2} &= m_2 W_{22} + m_3 W_{23} + \ldots + m_6 W_{26} \\
Q_{T3} &= m_2 W_{32} + m_3 W_{33} + \ldots + m_6 W_{36} \\
Q_{T4} &= a_{76} (T_{321} W_{12} - T_{311} W_{22}) + m_3 (-a_{24} W_{13} + a_{25} W_{23}) \\
&\quad + m_4 (a_{26} W_{14} + a_{27} W_{24}) + m_5 (a_{28} W_{15} + a_{29} W_{25}) \\
&\quad + m_6 (a_{30} W_{16} + a_{31} W_{26}) + I_{11} (\alpha_{11} \dot{T}_{131} + U_{11} T_{131}) \\
&\quad + I_{21} (\alpha_{21} \dot{T}_{231} + U_{21} T_{231}) + I_{31} (\alpha_{31} \dot{T}_{331} + U_{31} T_{331}) \\
\\
Q_{T5} &= -a_{76} (T_{11} W_{12} + T_{41} W_{22} - T_{161} W_{32}) \\
&\quad + m_3 (a_{34} W_{13} + a_{35} W_{23} - a_{36} W_{33}) \\
&\quad + m_4 (a_{37} W_{14} + a_{38} W_{24} + a_{39} W_{34}) \\
&\quad + m_5 (a_{34} W_{15} + a_{35} W_{25} - a_{36} W_{35}) \\
&\quad + m_6 (a_{37} W_{16} + a_{38} W_{26} + a_{39} W_{36}) \\
&\quad + I_{11} C_{21} \alpha_{11} \dot{\psi}_1 + I_{21} (-S_{31} \alpha_{11} \alpha_{21} + C_{31} U_{21}) \\
&\quad + I_{31} (-C_{31} \alpha_{11} \alpha_{31} - S_{31} U_{31}) \\
\\
Q_{T6} &= a_{76} (T_{211} W_{12} + T_{221} W_{22} + T_{231} W_{32}) \\
&\quad + m_3 (a_{42} W_{13} + a_{43} W_{23} + a_{44} W_{33}) \\
&\quad + m_4 (a_{45} W_{14} + a_{46} W_{24} + a_{47} W_{34}) \\
&\quad + m_5 (a_{42} W_{15} + a_{43} W_{25} + a_{44} W_{35}) \\
&\quad + m_6 (a_{45} W_{16} + a_{46} W_{26} + a_{47} W_{36}) \\
&\quad + I_{11} U_{11} + (-I_{21} + I_{31}) \alpha_{21} \alpha_{31} \\
\\
Q_{T7} &= a_3 (-T_{322} W_{12} + T_{312} W_{22}) + I_{12} (\alpha_{12} \dot{T}_{132} + U_{12} T_{132}) \\
&\quad + I_{22} (\alpha_{22} \dot{T}_{232} + U_{22} T_{232}) + I_{32} (\alpha_{32} \dot{T}_{332} + U_{32} T_{332}) \\
Q_{T8} &= a_3 (T_{12} W_{12} + T_{42} W_{22} - T_{162} W_{32}) + I_{12} C_{22} \alpha_{12} \dot{\psi}_2 \\
&\quad + I_{22} (-S_{32} \alpha_{12} \alpha_{22} + C_{32} U_{22}) - I_{32} (C_{32} \alpha_{12} \alpha_{32} + U_{32} S_{32}) \\
\\
Q_{T9} &= -a_3 (T_{212} W_{12} + T_{222} W_{22} + T_{232} W_{32}) + I_{12} U_{12} \\
&\quad + (I_{32} - I_{22}) \alpha_{22} \alpha_{32}
\end{aligned}
\tag{40}
$$

continued

$$\begin{aligned}Q_{T10} = {} & a_{77}(-T_{123}W_{13} + T_{113}W_{23}) + a_{48}W_{15} + a_{49}W_{25} \\ & + I_{13}(\alpha_{13}\dot{T}_{133} + U_{13}T_{133}) + I_{23}(\alpha_{23}\dot{T}_{233} + U_{23}T_{233}) \\ & + I_{33}(\alpha_{33}\dot{T}_{333} + U_{33}T_{333}) + I_{25}(\alpha_{25}\dot{T}_{233} + U_{25}T_{233}) \\ & + I_{15}\{\alpha_{15}(-T_{335}\dot{\theta}_5 + C_{25}\dot{T}_{133} - S_{25}\dot{T}_{333}) + T_{135}U_{15}\} \\ & + I_{35}\{\alpha_{35}(T_{135}\dot{\theta}_5 + S_{25}\dot{T}_{133} + C_{25}\dot{T}_{333}) + T_{335}U_{35}\}\end{aligned} \tag{40}$$

$$\begin{aligned}Q_{T11} = {} & -a_{77}(T_{143}W_{13} + T_{153}W_{23} + C_{23}W_{33}) \\ & + a_{50}W_{15} + a_{51}W_{25} + a_{52}W_{35}m_5 + I_{13}C_{23}\alpha_{13}\dot{\psi}_3 \\ & + I_{23}(-S_{33}\alpha_{13}\alpha_{23} + C_{33}U_{23}) + I_{33}(+C_{33}\alpha_{13}\alpha_{33} + S_{33}U_{33}) \\ & + I_{15}\{\alpha_{15}[S_{25}C_{33}\alpha_{13} + C_{25}(S_{33}\dot{\theta}_5 + C_{23}\dot{\psi}_3)] + S_{33}S_{25}U_{15}\} \\ & + I_{25}\{-S_{33}\alpha_{13}\alpha_{25} + C_{33}U_{25}\} \\ & + I_{35}\{\alpha_{35}[-C_{33}C_{25}\alpha_{13} + S_{25}(S_{33}\dot{\theta}_5 + C_{23}\dot{\psi}_3)] - S_{33}C_{25}U_{35}\}\end{aligned}$$

$$\begin{aligned}Q_{T12} = {} & -a_6(T_{213}W_{15} + T_{223}W_{25} + T_{233}W_{35}) + I_{13}U_{13} \\ & + (-I_{23} + I_{33})\alpha_{23}\alpha_{33} \\ & + \alpha_{25}[-I_{15}S_{25}\alpha_{15} - I_{25}\alpha_{33} + I_{35}C_{25}\alpha_{35}] \\ & + I_{15}C_{25}U_{15} + I_{35}S_{25}U_{35}\end{aligned}$$

$$\begin{aligned}Q_{T13} = {} & a_{78}(-T_{124}W_{14} + T_{114}W_{24}) + a_{92}W_{16} + a_{93}W_{26} \\ & + I_{14}(-C_{24}\alpha_{14}\dot{\theta}_4 - S_{24}U_{14}) + I_{24}(\alpha_{24}\dot{T}_{234} + U_{24}T_{234}) \\ & + I_{34}(\alpha_{34}\dot{T}_{334} + U_{34}T_{334}) + I_{26}(\alpha_{26}\dot{T}_{234} + U_{26}T_{234}) \\ & + I_{16}\{\alpha_{16}(-T_{336}\dot{\theta}_6 + C_{26}\dot{T}_{134} - S_{26}\dot{T}_{334}) + U_{16}T_{136}\} \\ & + I_{36}\{\alpha_{36}(T_{136}\dot{\theta}_6 + S_{26}\dot{T}_{134} + C_{26}\dot{T}_{334}) + U_{36}T_{336}\}\end{aligned}$$

$$\begin{aligned}Q_{T14} = {} & -a_{78}(T_{144}W_{14} + T_{154}W_{24} + C_{24}W_{34}) + a_{94}W_{16} + a_{95}W_{26} \\ & + a_{96}W_{36}m_6 + I_{14}C_{24}\alpha_{14}\dot{\psi}_4 + I_{24}[-S_{34}\alpha_{14}\alpha_{24} + C_{34}U_{24}] \\ & + I_{34}[-C_{34}\alpha_{14}\alpha_{34} - S_{34}U_{34}] \\ & + I_{16}\{\alpha_{16}[C_{34}S_{26}\alpha_{14} + C_{26}(S_{34}\dot{\theta}_6 + C_{24}\dot{\psi}_4)] + S_{34}S_{26}U_{16}\} \\ & + I_{26}\{-S_{34}\alpha_{14}\alpha_{26} + C_{34}U_{26}\} \\ & + I_{36}\{\alpha_{36}[-C_{34}C_{26}\alpha_{14} + S_{26}(S_{34}\dot{\theta}_6 + C_{24}\dot{\psi}_4)] - S_{34}C_{26}U_{36}\}\end{aligned}$$

$$\begin{aligned}Q_{T15} = {} & -a_7(T_{214}W_{16} + T_{224}W_{26} + T_{234}W_{36}) + I_{14}U_{14} \\ & + (-I_{24} + I_{34})\alpha_{24}\alpha_{34} + \alpha_{26}[-I_{16}S_{26}\alpha_{16} - I_{26}\alpha_{34} + I_{36}C_{26}\alpha_{36}] \\ & + I_{16}C_{26}U_{16} + I_{36}S_{26}U_{36}\end{aligned}$$

$$Q_{T16} = a_{53}W_{15} + a_{54}W_{25} + a_{55}W_{35} + (I_{15} - I_{35})\alpha_{15}\alpha_{35} + I_{25}U_{25}$$

$$Q_{T17} = a_9W_{16} + a_{17}W_{26} + a_{20}W_{36} + (I_{16} - I_{36})\alpha_{16}\alpha_{36} + I_{26}U_{26}$$

E. Addition of Forces to the Equations of Motion

Three different force-producting features of the model add to the complexity of the equations of motion -- contact, belts, and joints. The determination of force is unique to each of these features but the way in which the resulting force is applied to the equations of motions in common to all and will be discussed here.

Consider a typical force-producer and call it feature F. In this simulation, the magnitude of the force produced by F will be a function of deflection and deflection rate where deflection is defined appropriately for each feature. For example, belt deflection is elongation of the belt beyound the zero slack condition. The direction of the force in each case is that which will tend to maximally decrease deflection. The force produced can be separated into deflection-dependent terms which may be called a"spring" force and a collection of deflection rate-dependent terms which may be called a dissipative force.

$$F_F = {}_S F_F + {}_D F_F \tag{41}$$

where

F_F is the total force produced by feature F

${}_S F_F$ is the "spring" force for feature F

${}_D F_F$ is the dissipative force for feature F

In general

$$\left| {}_S \vec{F}_F \right| = f(\delta)$$

and,

$$\left| {}_D \vec{F}_F \right| = g(\dot{\delta}) \tag{42}$$

where $f(\delta)$ is a polynomial or tabular function of displacement, δ, and $g(\dot{\delta})$ is a function of displacement rate, $\dot{\delta}$. The deflection and deflection rate (δ and $\dot{\delta}$) are computed as functions of the seventeen generalized coordinates. A general description of the functions f and g is given in Figure 4.

The spring force, ${}_S\vec{F}_F$, will do work in the classical sense and yield a potential energy

$$V_F = \int_0^{\delta} f(x)\,dx \tag{43}$$

and the contributions to (41) will be of the form

$$\frac{\partial V}{\delta q_i} = \frac{\partial V}{\partial \delta}\,\frac{\partial \delta}{\partial q_i} = \left| {}_S\vec{F}_F \right| \frac{\partial \delta}{\partial q_i} \tag{44}$$

for $i = 1,\ldots,17$.

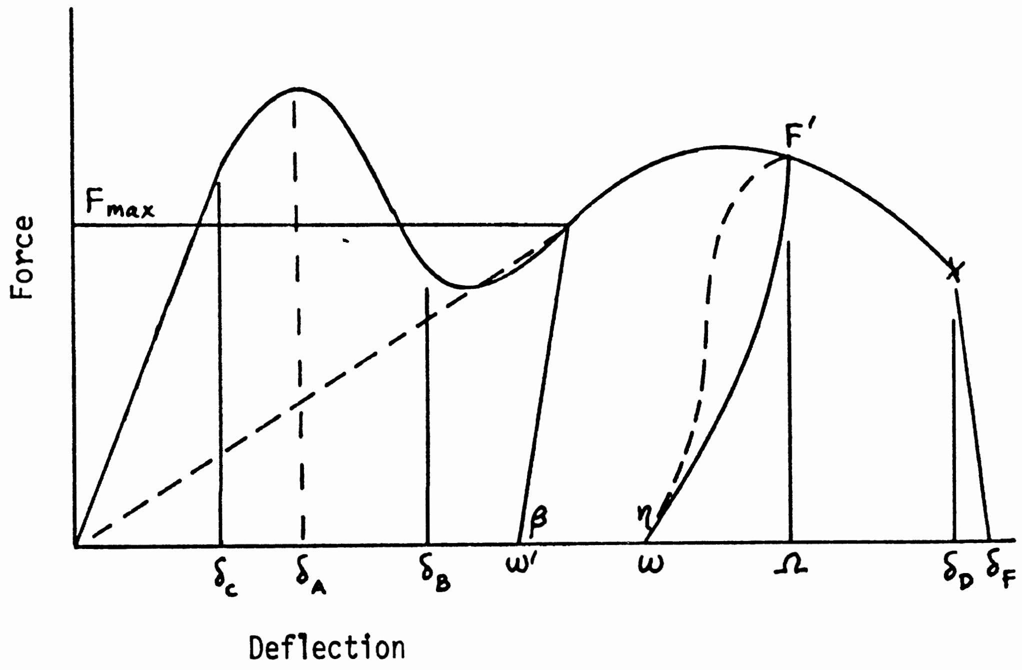
The quantity $\frac{\partial \delta}{\partial q_i}$ will be referred to as the "lever arm." If the generalized coordinate is rotational and the force for the feature F such that it tends to push or pull the body segment in a direction perpendicular to the line joining the center of rotation to the point of application of the force, then this quantity will be the actual length of that line and hence, the lever arm. In other cases, it contains factors which yield the perpendicular component of the force as well and is an "effective lever arm". In general, since

$${}_S Q_{F_i} = \left| {}_S\vec{F}_F \right| \frac{\partial \delta}{\partial q_i} \tag{45}$$

(where ${}_S Q_F$ is the generalized force vector contribution due to the "spring" force of feature F) strongly resembles the relation,

Torque = Force x Lever arm

this nomenclature has been adopted.



where

δ_A = deflection at peak inertial force

δ_C = elastic limit (yield point)

δ_B = termination of use of auxiliary polynomial

F_{max} = saturation force limit

Ω = deflection at which unloading begins, that is, the maximum deflection for the particular load-unload cycle

ω = calculated permanent deflection for cycle (unsaturated)

ω = calculated permanent deflection for cycle (saturated)

β = slope of saturation unloading curve

δ_D = breaking point

δ_F = endpoint of break down curve

η = total permanent deformation

F = force at maximum deflection

Figure 4. HSRI Representation of Force-Deflection Curves

The quantity ${}_D\vec{F}_F$ is dissipative in nature and will yield a dissipative energy rate.

$$D_F = \int_0^{\dot{\delta}} g(x)\,dx \tag{46}$$

and the contributions to (41) will be of the form

$$\frac{\partial D}{\partial \dot{q}_i} = \frac{\partial D}{\partial \dot{\delta}}\,\frac{\partial \dot{\delta}}{\partial \dot{q}_i} = \left|{}_D\vec{F}_F\right| \frac{\partial \dot{\delta}}{\partial \dot{q}_i} \tag{47}$$

for i = 1,...,17

But it is also true that

$$\frac{\partial \dot{\delta}}{\partial \dot{q}_i} = \frac{\partial}{\partial \dot{q}_i}\left(\sum_{j=1}^{17} \frac{\partial \delta}{\partial q_j}\,\dot{q}_j\right) = \frac{\partial \delta}{\partial q_i} + \sum_{j=1}^{17} \dot{q}_j \frac{\partial}{\partial \dot{q}_i}\left(\frac{\partial \delta}{\partial q_j}\right) = \frac{\partial \delta}{\partial q_i} \tag{48}$$

since δ is a function only of the generalized corrdinates and not their rates.

Therefore (47) will take the form of (45) and recalling (41) as well as correcting signs, it can be shown that

$$Q_{Fi} = \left|\vec{F}_F\right| \frac{\partial \delta}{\partial q_i} \tag{49}$$

where $\vec{Q}_F$ is the generalized force vector contribution for feature F.

Equation (49) will hold true if it is agreed that the magnitude may reverse signs when the force reverses directions.

One last property of lever arms should be noted. Using the chain rule,

$$\frac{d}{dt}\left[\delta(q_1,\cdots,q_N)\right] = \sum_{k=1}^{N} \frac{\partial \delta}{\partial q_K}\,\frac{dq_K}{dt} \tag{50}$$

where the q's are the parameters including generalized coordinate upon which deflection depends.

Hence the terms of $\dot{\delta}$ due to body motion can be computed by summing up each lever arm times the corresponding generalized velocity. In most cases, this is the actual technique employed.

So the labor of either deriving or presenting the implications of feature F on the equations of motion can be simplified to the consideration of deflection and lever arms. In the sections which follow concerning the individual force-producers, deflection, and lever arms will be explicitly defined.

Deflection rate will be discussed in terms of body motion, vehicle motion, and motion relative to the vehicle. The exact form of equation (50) which applies for the feature under consideration will also be presented.

The load-deflection properties which are installed in the model and which are used to define the functions f and g (See Equation 42) have been developed using the ideas presented in Danforth and Randall (14) together with certain useful extensions. For purposes of explanation, let us assume that a completely rigid ball is being gradually impressed upon a planar panel of some flexible material such as sheet metal. The description to the model of the load-deflection properties of the panel centers around seven input constants: δ_A, δ_B, δ_C, δ_D, δ_F, F_{max}, and β. The first three quantities are defined as shown in Figure 4 and have been suggested by the work of Danforth and Randall. The other four quantities control extensions of that work. The first six quantities must be non-negative. The first two quantities together with the fourth and fifth must form a monotonically increasing sequence. The fourth and fifth must not be equal.

Before undertaking a physical description of these seven quantitites, it is necessary to glance over the balance of the model input quantities. These are four in number. The first will be referred to as the Static Loading Curve and consists of the seven coefficients of a seventh order polynomial in deflection (the constant coefficient is assumed zero) or a table of Force versus Deflection which is linearly interpolated between points.

The second of these input quantities will be referred to as the Inertial Spike Curve and may also be a polynomial or a table as described above. An additional restriction that this curve assume a zero value at deflection equal to δ_B must be adhered to in order to avoid possible premature termination of the model run.

The third input quantity is the G-factor which is defined as the fraction of permanent deflection over maximum deflection. The G-factor must be in a closed interval from zero to one and can be supplied to the model as either a constant value or a table of G-Factor versus Deflection as above.

The last input quantity is the R-factor which is defined as the fraction of conserved energy over total energy. It too must be in the closed interval from zero and one and can be supplied as a constant value or a table of R-Factor versus Deflection. It should be understood that G and R factors include all the accumulated effects for a particular deflection and are used only at the beginning of the unloading part of each cycle.

The quantity δ_A can be described as the deflection at which the inertial effects of the panel begin to break down irreparably. Usually this quantity is set to the deflection at which occurs the maximum of the Inertial Spike Curve although this is not a requirement. If unloading begins before this point is passed and the elastic yield point δ_C is also not passed, loading, unloading, and reloading are all along the Combined Curve. The Combined Curve is defined as the sum of the Inertial Spike Curve and the Static Curve at each point. If the elastic yield point has been passed, regular unloading (explained below) takes place but reloading is again to the Combined Curve.

The quantity δ_B can be described as the deflection at which all inertial effects cease. If δ_A has been exceeded and δ_B has not been exceeded, regular loading is on the Combined Curve. If unloading begins and the elastic yield point has not been passed, unloading is along a linear segment connecting the point of maximum deflection (Ω) with the origin and reloading will be to the Static Curve at Ω . If the yield point has been passed, unloading is regular and reloading will also be to the Static Curve at Ω.

The quantity δ_D can be described as the deflection at which massive breakdown of the whole panel begins. If δ_B has been exceeded and δ_D has not been reached, regular loading is on the Static Curve. If the yield point has not been reached, unloading and reloading are also along the Static Curve. If the yield point has been passed, regular unloading takes place and reloading is to the Static Curve at Ω.

δ_F can be described as the deflection at which complete failure takes place. Once δ_F has been exceeded, the model will always produce zero force. If δ_D has been exceeded and δ_F has not been reached, loading is along a linear segment connecting the point of the Static Curve at δ_D with a zero at δ_F. If unloading takes place before failure is complete and if the yield point has not been reached, unloading and reloading are along the minimum of the Static Curve and the value of the linear segment at Ω. If the yield point has been passed, normal unloading takes place and reloading is to the linear segment at Ω.

F_{max} is called the Saturation Force Limit and is intended to model special materials which exhibit the property of breaking down in such a way as to maintain a specific maximum force until reaching the breaking point. This feature is applied only to the Static Curve. Whenever the Saturation Force Limit is exceeded by the Static Curve, the regular loading sequence is superceded. Note that the Inertial Spike Curve is unaffected, and if the Combined Curve is being used, the Inertial Spike Curve will continue to be added until δ_B is reached. Once static curve saturation comes into play, the force for loading on the Static Curve is set to F_{max} until δ_D is reached. If unloading takes place on the saturated Static Curve, normal unloading is replaced by the use of the seventh input constant, β which is called the Saturation Unloading Slope. If β is negative, the G factor is used to determine the permanent deformation. If β is positive, it is taken as a linear slope to determine the permanent deformation. In either case, if the new permanent deformation fails to exceed the old permanent deformation or β is zero, the old permanent deformation is used. Unloading and reloading are along a linear segment connecting a zero at the point of permanent deformation to F_{max} at Ω. If this unloading takes place in the range where the Combined Curve is used, the same rules apply as were explained above except the F_{max} replaces the Static Curve. Note that the elastic yield point has effect before saturation and during break down after saturation but not during saturation.

Normal unloading is modeled by determination of permanent deformation and conserved energy using the G and R factors evaluated at the maximum deflection (Ω). Let ω be the permanent deformation, F^{ℓ} be the force at Ω, and E^{ℓ} be the conserved energy. Then, as was done in the

HSRI two dimensional model, a parabola is fitted which unloads to the permanent deformation with the proper conserved energy. It will occasionally happen that the curvature of a parabola is not adequate to achieve this result without the physically unrealistic effect of a negative force loop. If this contingency arises, unloading and reloading are computed from two linear segments which maintain the proper permanent deformations and conserved energy.

Normal reloading is modeled by fitting a cubic which maintains continuity in both force and force slope.

It should be recalled at this time that both occupant ellipsoids and vehicle contact surfaces can deform. This property of sharing deflection between two interacting surfaces is also shared by belts where two interconnected segments must reach force equilibrium. In these two cases total deflection, lever arms, etc. are known while the force is not known. To compute the force (equal in both interacting elements) the amount of deflection occuring in each must be solved by an iterative procedure. When this procedure is completed, deflections in the individual elements are known and the force computed within a small error range which is specified in the input data to the program.

F. Vehicle-Occupant Contact

The force interactions between the crash victim and his environment are modeled by impingement of ellipsoids attached to body segments into planar surfaces attached to a moving vehicle reference frame or attached to the inertial reference frame. This general model is illustrated in Figure 5. Both the ellipsoid and the planar surfaces can deform as each one may have its own unique set of force-deformation characteristics. In addition to this, forces may be generated when an ellipsoid attached to one body segment interacts with an ellipsoid attached to another body element (e.g., head on chest).

The normal force generated during such an encounter is taken to be deflection and deflection-rate dependent where deflection is defined as the maximum perpendicular distance, δ, the ellipsoid extends into the contact surface or other ellipsoid. This force acts to push the ellipsoid outward perpendicular to the contact point at the location of maximum impingement. A tangential force also may be generated during contact, which is considered to be a frictional force. Hence, its value is proportional to the value of the normal force. The direction of this force depends on the tangential velocity vector which exists between the ellipsoid and the other surface.

The storage capacity of the computer program has been chosen to hold approximately twenty body ellipsoids and thirty planar contact surfaces. More contact surfaces may be chosen if the number of ellipsoids is suitably reduced. Also, it is assumed that most of the ellipsoids are reduced to spheres, that most of the contact surfaces do not move with respect to their reference frame, and that no inhibitions of force generation are included.

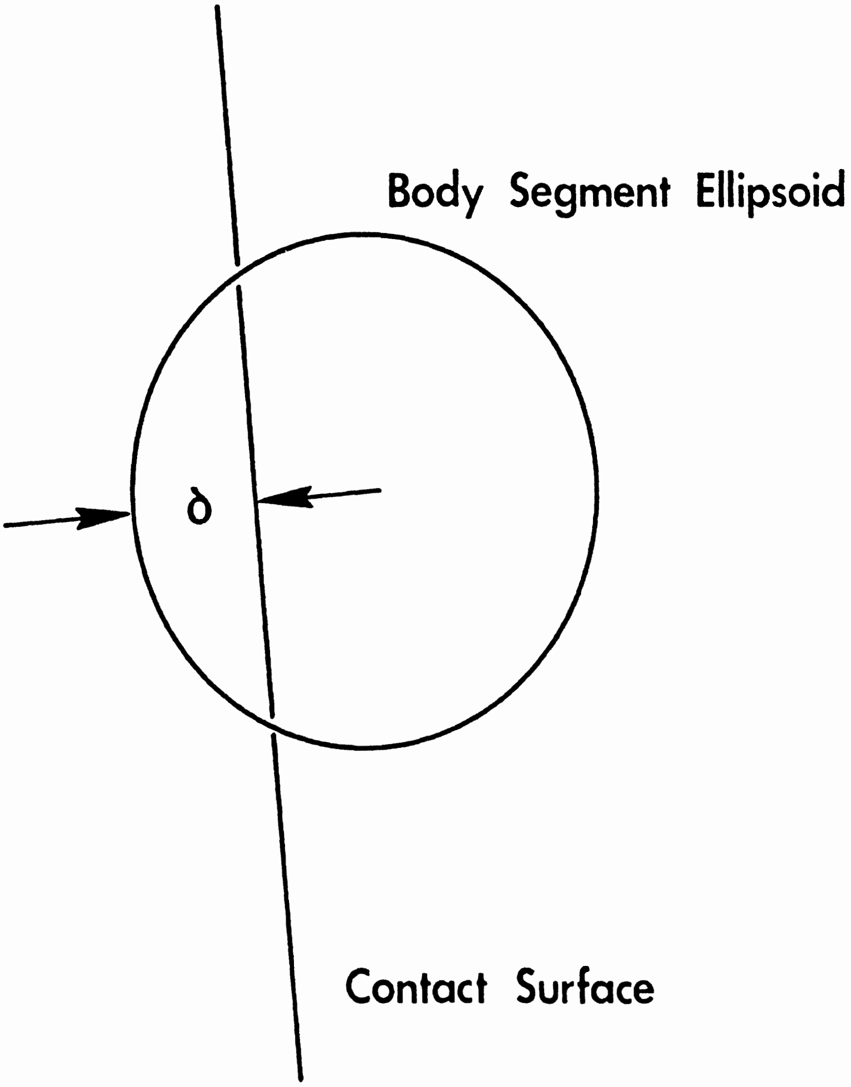


Figure 5. Contact Force

The relative storage requirements are: 1. spheres - 18 locations; 2. ellipsoids - 31 locations; and, 3. contact surfaces - 55 locations with 10 locations necessary for each time point for which location is specified. Approximately 2200 locations are available in two storage arrays. The logic of the program has been chosen for any number of ellipsoids and contact surfaces. If an application requires more surfaces or ellipsoids than are currently available, a trivial change to the program could be made.

Each of the ellipsoids can be attached to any of the six body segments, centered at an arbitrary displacement from the body segment center of gravity, but always located with principal axes parallel to the body segment coordinate system as shown in Figure 6. The planar contact surfaces, which are in the shape of parallelograms, can be attached to the vehicle (or to the inertial coordinate frame) and moved relative to the reference coordinate system as a function of time to represent such physical events as occupant compartment deformation or intrusion. Each contact surface is specified by three corner points, given as a function of time in tabular form relative to the reference coordinate system as shown for a vehicle in Figure 7. Only the initial location need be specified if the surface is stationary with respect to the reference coordinate system.

F. 1. Specifications, Edges, and Thickness of Contact Surfaces.

Contact surfaces are endowed with other special properties, some of which are illustrated in Figure 8. The three points in Figure 8 which define the shape of the contact surface are specified in the following order:

(1) Point 1. Any of the four corner points;

(2) Point 2. Either adjacent corner point; and,

(3) Point 3. The other corner point adjacent to Point 1.

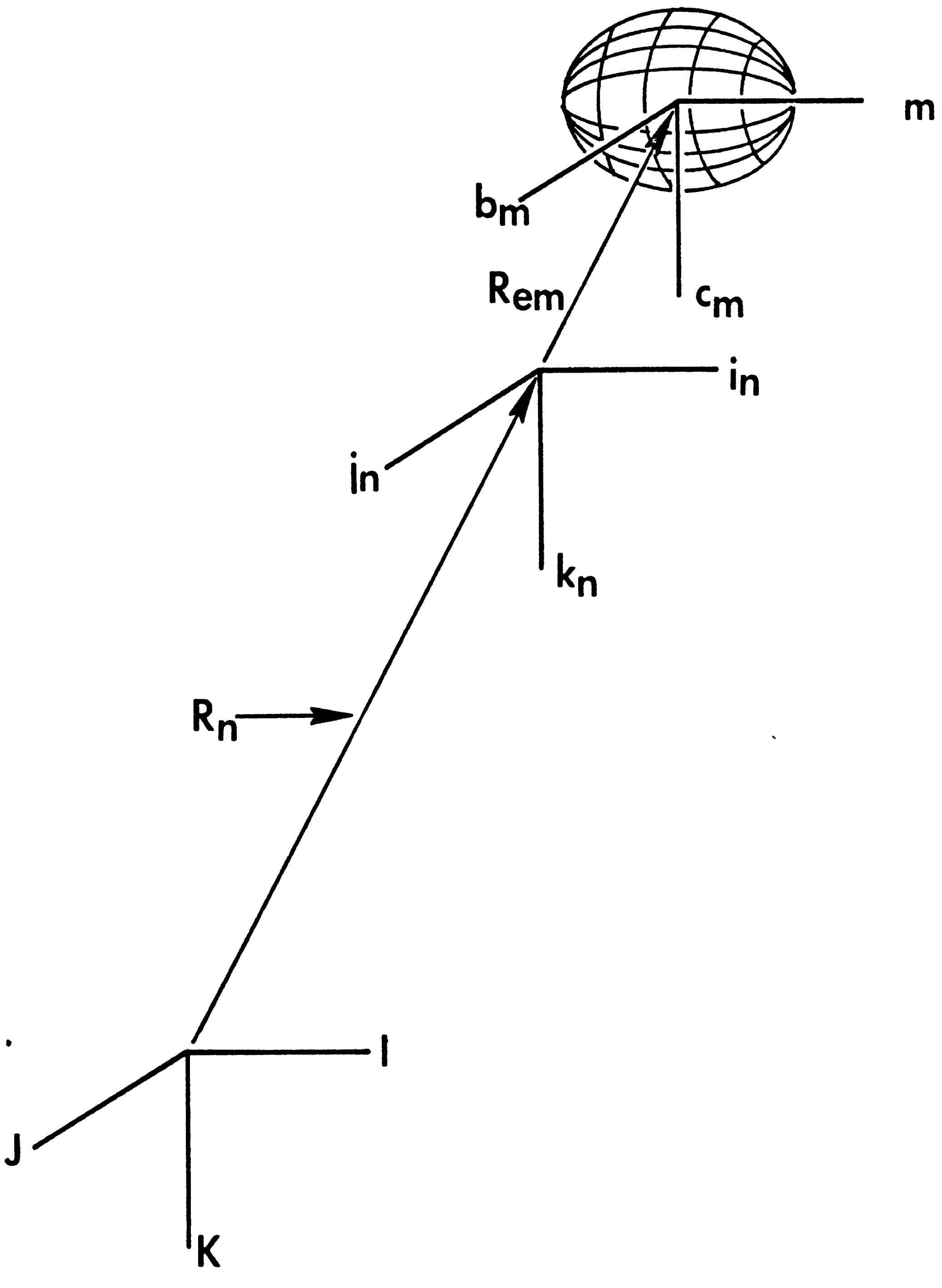


Figure 6. Ellipsoid 'm' Attached to Body Segment 'n'.

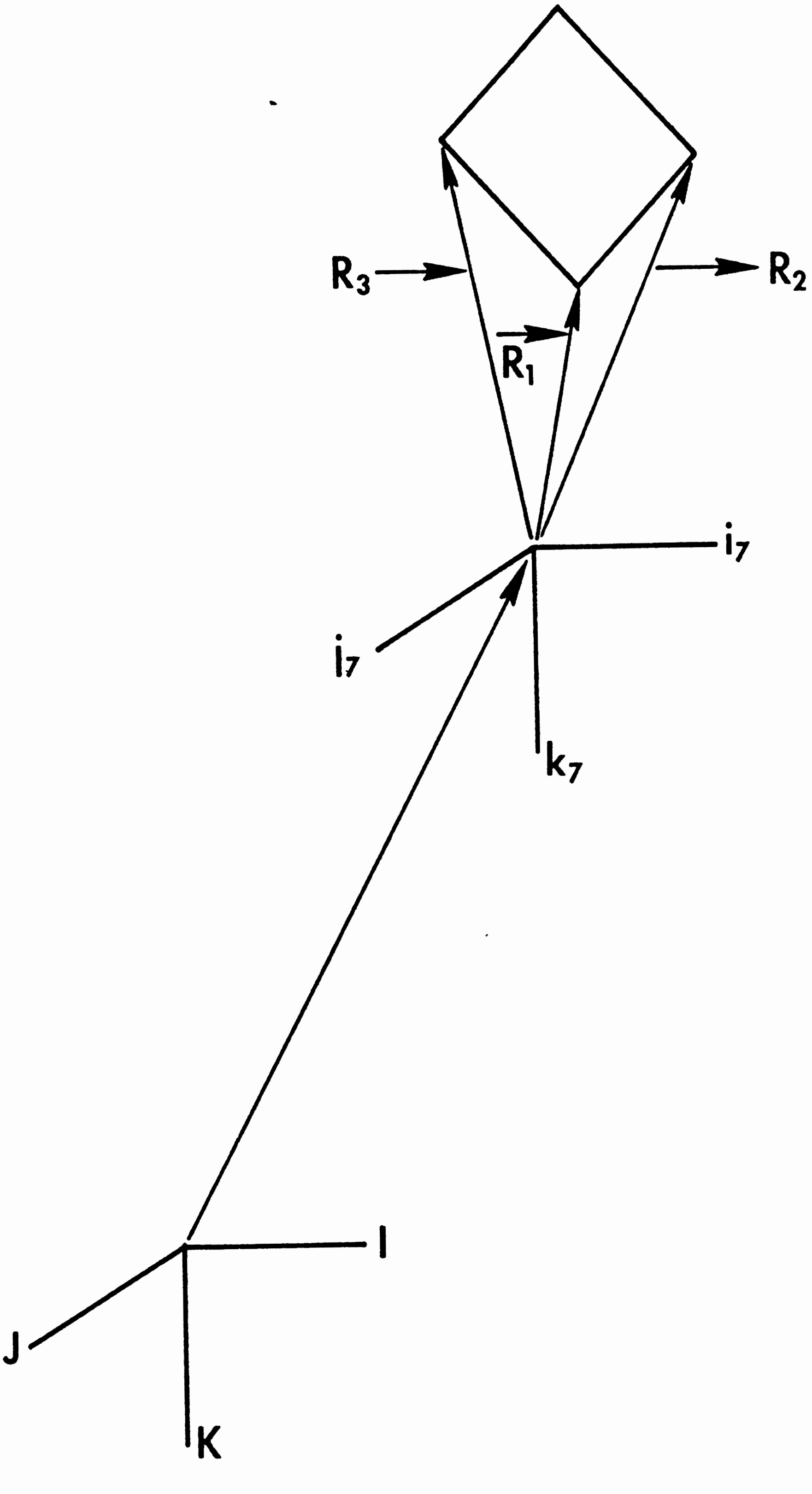


Figure 7. Contact Surface Attached to the Vehicle

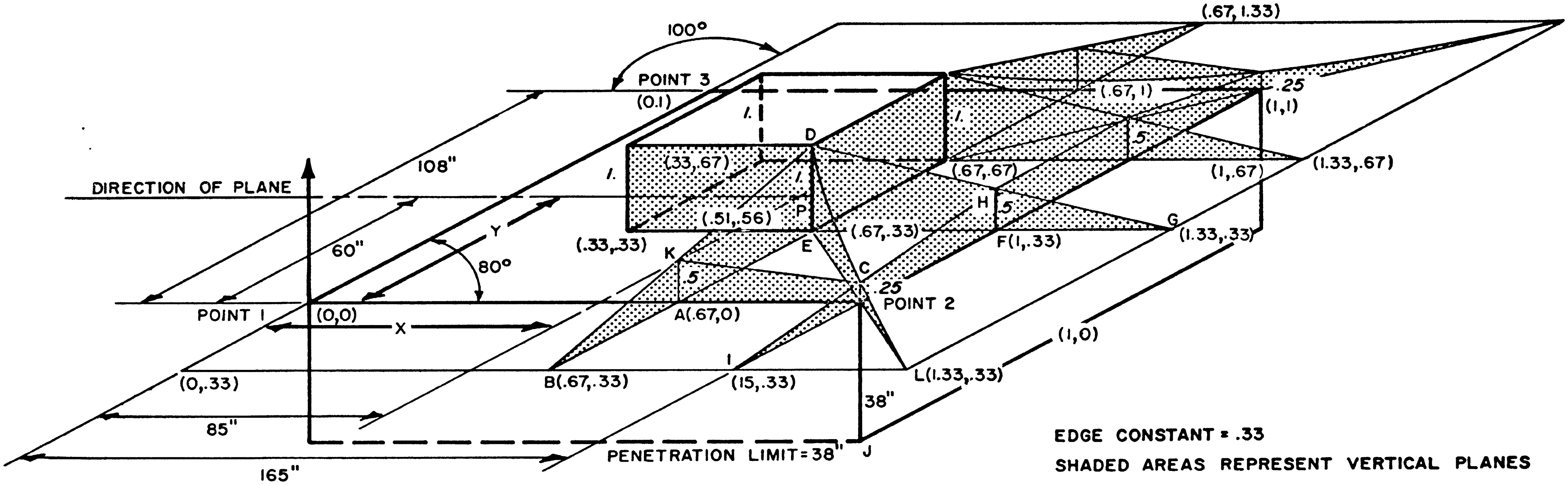


Figure 8. Contact Surface Special Parameters

The contact surface illustrated is 165 inches from Point 1 to Point 2 and 108 inches from Point 1 to Point 3. The included angle is eighty degrees. A surface coordinate system is set up by the computer program with Point 1 serving as the origin, Point 2 as Point (1,0) and Point 3 as Point (0,1) with the axes taken parallel to the edges. This coordinate system sees all contact surfaces as a unit square regardless of shape or size. The point on the contact surface at which the maximum impingement takes place is represented in this system. When the coordinates of the point are reported in the printed output, each of the coordinates are multiplied by the length of its respective side so that printed results are in inches. Thus, if Point P represents the point of maximum impingement, it has internal surface coordinates of (.51,.56) and will be reported as (85,60).

Since the total interaction of the ellipsoid with the parallelogram is represented by what happens at the point of maximum impingement, a quantity called the "edge constant" was introduced to handle cases where an ellipsoid interacted with the edge of a contact surface or at a corner where contact surfaces meet. In this case, maximum impingement lies outside the region defined by the parallelogram but yet the ellipsoid makes firm contact with the surface. It is assumed in developing an analytical tool to handle this problem that the contact force decreases as the point of maximum impingement moves away from the edge of the contact surface. The computer simulation approximately resolves these edge problems by employing the following device. The force is computed using the deflection and deflection rate in the normal manner. The resulting force is multiplied by an "effectiveness factor" which ranges from one in a region in the middle of the contact surface down to zero in the regions outside the contact surface. The effectiveness factor is illustrated in Figure 8 by plotting its value corresponding to the various points on and near the contact surface above the level of the plane. For example:

(1) Effectiveness factor for contact surface Point P is shown as Point P' above the surface and has the value of unity;

(2) Effectiveness factor for Point E is represented by Point D, also unity;

(3) Point A on the edge of the contact surface has an effectiveness factor of 1/2 shown as Point K; and,

(4) Outside the contact surface at Point B, the effectiveness factor is reduced to zero indicating that no contact will be predicted between an ellipsoid and a contact surface.

The line BKD is a trace of the values of the factor as the point of maximum impingement of an ellipsoid into the surface moves toward and beyond the edge of the contact surface along line EAB. The result is that for a given deflection, force will be reduced to zero as the ellipsoid moves off the edge of the surface. The effectiveness factor is linear along lines such as BKD, GHD, KC, and HCI but parabolic along DCL. The exact definition of the effectiveness factor is given below:

$$E = R \cdot S \tag{51}$$

where

E is the effectiveness factor

$$R = \begin{cases} 0 \text{ for } X \leqq -\lambda \\ 0.5 + \dfrac{0.5X}{\lambda} \text{ for } -\lambda < X < \lambda \\ 1.0 \text{ for } \lambda \leqq X \leqq 1-\lambda \\ 0.5 + 0.5\left(\dfrac{1-X}{\lambda}\right) \text{ for } 1-\lambda < X < 1+\lambda \\ 0 \text{ for } X \geqq 1+\lambda \end{cases} \tag{52}$$

$$S = \begin{cases} 0 \text{ for } Y \leqq -\lambda \\ 0.5 + \dfrac{0.5\,Y}{\lambda} \text{ for } -\lambda < Y < \lambda \\ 1.0 \text{ for } \lambda \leqq Y \leqq 1-\lambda \\ 0.5 + 0.5\left(\dfrac{1-Y}{\lambda}\right) \text{ for } 1-\lambda < Y < 1+\lambda \\ 0 \text{ for } Y \geqq 1+\lambda \end{cases} \qquad \text{(52) concluded}$$

where X, Y are the contact surface coordinates of the maximum impingement

λ is the edge constants specified as input to the computer program, which must lie in the range $0 < \lambda \leqq 0.5$.

The edge constant is the mechanism by which a user of the HSRI model specifies the interaction of a body ellipsoid with the edge of a contact surface and must be provided as input data for each contact surface in order to exercise the model. It should be selected on the basis of a comparison of the geometries of a particular contact surface and the body ellipsoid which is most likely to interact with the surface. For instance, the surface shown in Figure 8 is 165 inches long along its x-coordinate. If it is assumed that a body ellipsoid with a semi-major axis length of 54.45 inches is the most likely or important interaction, then the edge constant should be selected as

$$\lambda = 54.45/165. \simeq 0.33$$

If this value is used, a contact force equal to zero will be predicted if the contact ellipsoid just misses the surface, but when any part of the ellipsoid touches an edge of the contact surface, a small force will be computed. This force will be at a maximum when the contact ellipsoid interacts with the center region of the contact surface.

Occasionally a body ellipsoid can approach a contact surface from either side. Consider the case of a contact surface representing the top of a dash panel and a body ellipsoid attached to the knee of an unrestrained occupant.

In some vehicles the top of the dash panel is directly above the knees. Consider a hypothetical case where the vehicle is impacted in the rear and is pushed into the path of an oncoming truck. During the rear-end part of the collision, the occupant is often propelled upward along the slope of the seat back. During the frontal collision, the occupant then moves forward. In this series of events it is possible that the knees of the occupant could impact very high on the instrument panel due to the unusual initial positioning for the frontal crash event. It is desired in this case that the knee feel a force from contact with the top of the dash panel and not a large force due to the initial seating position where the knee is below the panel. Another example of this kind of problem is the rear seat passenger which vaults the front seat, striking the front seat back.

This simulation resolves this kind of difficulty by requiring the user to assign a positive or front side to each contact surface. No force will be generated unless the ellipsoid approaches from the front side. In order to determine simply whether an ellipsoid has approached from the front or back, the user is required to specify the "penetration limit," a parameter which represents the maximum penetration into the surface which can occur in one integration time step. Then, if an ellipsoid's first deflection into the surface is greater than this value, the ellipsoid is assumed to be coming up from behind and no force is computed until the ellipsoid gets totally in front of the contact surface and then comes back and hits the surface.

The penetration limit is illustrated in Figure 8 by a plane in dotted lines drawn underneath the contact plane. CJ represents the penetration limit. The value of 38 inches is about ten times the normal size of this parameter and is exaggerated only for illustrative purposes.

The positive side specification is made by telling the program whether the inertial origin lies behind or in front of the contact surface. The inertial origin should not lie exactly on the infinite extension of any of the contact surfaces although it is permissible to get arbitrarily close. The front of the contact surface is shown in Figure 8 by an arrow passing through Point 1.

F.2. Calculation of Deflection for Ellipsoid-Plane Contact

The analytical expression for deflection is based on the distance from a point in space to a plane. It is

$$\delta = \frac{A x_0 + B y_0 + C z_0 + D}{\pm\sqrt{A^2 + B^2 + C^2}} \tag{53}$$

where (x_0, y_0, z_0) is the location of that point in inertial coordinates on the ellipsoid, which is tangent to a surface, parallel to the contact surface, and which represents the point of maximum penetration of the ellipsoid into the contact surface. The quantities A, B, C, D which are the coefficients of the plane

$$A x + B y + C z + D = 0 \tag{54}$$

in inertial space, are computed from the generalized motion coordinates at each time point in the simulation. With respect to a moving (vehicle) coordinate system this plane can be described by

$$r x' + q y' + p z' + s = 0 \tag{55}$$

The transformation between the inertial system "e" and the vehicle system "e_7" is given by

$$e_7 = T_{ij7}\, e \tag{56}$$

as defined previously.

Input data to the program defines each contact surface with respect to the vehicle coordinate system, e_7, by locating three corner points, $(\hat{x}_1, \hat{y}_1, \hat{z}_1)$, $(\hat{x}_2, \hat{y}_2, \hat{z}_2)$, and $(\hat{x}_3, \hat{y}_3, \hat{z}_3)$. The surface coefficients in equation (55) can be written in terms of this specified input data as

$$\begin{aligned} p &= \hat{x}_1(\hat{y}_2-\hat{y}_3)+\hat{x}_2(\hat{y}_3-\hat{y}_1)+\hat{x}_3(\hat{y}_1-\hat{y}_2) \\ q &= \hat{x}_1(\hat{z}_3-\hat{z}_2)+\hat{x}_2(\hat{z}_1-\hat{z}_3)+\hat{x}_3(\hat{z}_2-\hat{z}_1) \\ r &= \hat{y}_1(\hat{z}_2-\hat{z}_3)+\hat{y}_2(\hat{z}_3-\hat{z}_1)+\hat{y}_3(\hat{z}_1-\hat{z}_2) \\ s &= \hat{z}_1(\hat{x}_3\hat{y}_2-\hat{x}_2\hat{y}_3)+\hat{z}_2(\hat{x}_1\hat{y}_3-\hat{x}_3\hat{y}_1) \\ &\quad +\hat{z}_3(\hat{x}_2\hat{y}_1-\hat{x}_1\hat{y}_2) \end{aligned} \tag{57}$$

Using the rotation transformation of coordinates (Equation 56) as well as the formulas for the plane (Equations 54 and 55), the quantities A, B, C, D may be expressed

$$\begin{aligned} A &= T_{117}\,r+T_{217}\,q+T_{317}\,p \\ B &= T_{127}\,r+T_{227}\,q+T_{327}\,p \\ C &= T_{137}\,r+T_{237}\,q+T_{337}\,p \\ D &= s-Ax_7-By_7-Cz_7 \end{aligned} \tag{58}$$

where (x_7, y_7, z_7) is the specified location of the origin of the vehicle coordinate system with respect to the inertial system. This completely defines the quantities A, B, C, D at any point in time. If it is desired to attach the contact surface to the inertial system rather than the moving system, the quantities A, B, C, D in equation (3.8) replace p, q, r, s in equation 57 and the points $(\hat{x}_1, \hat{y}_1, \hat{z}_1)$, $(\hat{x}_2, \hat{y}_2, \hat{z}_2)$, $(\hat{x}_3, \hat{y}_3, \hat{z}_3)$ are defined in inertial space.

The position in space of (x_0, y_0, z_0) depends on the location of the body segment mass and the location of the ellipsoid in the coordinate system associated with the particular body segment mass. It is given by

$$\begin{aligned} x_o &= \mu_7 + k\,(\mu_2 A + \mu_1 B + \mu_3 C) \\ y_o &= \mu_8 + k\,(\mu_1 A + \mu_4 B + \mu_5 C) \\ z_o &= \mu_9 + k\,(\mu_3 A + \mu_5 B + \mu_6 C) \end{aligned} \tag{59}$$

where

$$\begin{aligned} \mu_1 &= \tfrac{1}{2}\left[c_m^2 T_{31n} T_{32n} + b_m^2 T_{21n} T_{22n} + a_m^2 T_{11n} T_{12n}\right] \\ \mu_2 &= \tfrac{1}{2}\left[c_m^2 T_{31n}^2 + b_m^2 T_{21n}^2 + a_m^2 T_{11n}^2\right] \\ \mu_3 &= \tfrac{1}{2}\left[c_m^2 T_{31n} T_{33n} + b_m^2 T_{21n} T_{23n} + a_m^2 T_{11n} T_{13n}\right] \\ \mu_4 &= \tfrac{1}{2}\left[c_m^2 T_{32n}^2 + b_m^2 T_{22n}^2 + a_m^2 T_{12n}^2\right] \\ \mu_5 &= \tfrac{1}{2}\left[c_m^2 T_{32n} T_{33n} + b_m^2 T_{22n} T_{23n} + a_m^2 T_{12n} T_{13n}\right] \\ \mu_6 &= \tfrac{1}{2}\left[c_m^2 T_{33n}^2 + b_m^2 T_{23n}^2 + a_m^2 T_{13n}^2\right] \end{aligned} \tag{60}$$

and

$$\begin{aligned} \mu_7 &= x_n + x_{em} T_{11n} + y_{em} T_{21n} + z_{em} T_{31n} \\ \mu_8 &= y_n + x_{em} T_{12n} + y_{em} T_{22n} + z_{em} T_{32n} \\ \mu_9 &= z_n + x_{em} T_{13n} + y_{em} T_{23n} + z_{em} T_{33n} \\ k &= \pm \sqrt{\frac{2}{\mu_2 A^2 + \mu_4 B^2 + \mu_6 C^2 + 2\mu_1 AB + 2\mu_3 AC + 2\mu_5 BC}} \end{aligned} \tag{61}$$

The quantities for μ_7, μ_8, μ_9 are the inertial coordinates of the ellipsoid center. The remaining quantities are defined as

m is the ellipsoid number,

n is the number of the body segment,

a_m, b_m, c_m are the semi-axes of ellipsoid m,

x_{em}, y_{em}, z_{em} are the coordinates of the ellipsoid center in the body segment coordinate system.

These formulas are derived using the equation describing a plane tangent to a quadratic surface (ellipsoid) and the fact that parallel planes have proportional coefficients.

These formulas simplify for the case of a sphere and the simplified formulas have been implemented in the computer program to reduce the cost of exercising the model. Equations (59) and (60) become

$$\begin{aligned} x_0 &= \mu_7 + k \mu A \\ y_0 &= \mu_8 + k \mu B \\ z_0 &= \mu_9 + k \mu C \end{aligned} \tag{62}$$

where

$$\begin{aligned} k &= \pm \frac{2}{R} \sqrt{\frac{1}{A^2+B^2+C^2}} \\ \mu_1 &= \mu_3 = \mu_5 = 0 \\ \mu_2 &= \mu_4 = \mu_6 = \frac{R^2}{2} \equiv \mu \end{aligned} \tag{63}$$

where R = the radius of the sphere.

F.3. Calculation of Lever Arms for Ellipsoid-Plane Contact

Lever arms, as defined in Part III E. of this report, are required for computation of the force actions to be included in the equations of motion. Differentiation of the deflection as given in equation 53 and considerable simplification leads to following expression for the lever arm, L,

$$\begin{aligned} L_{im} &\equiv \pm \sqrt{p^2+q^2+r^2} \, \frac{\partial \delta}{\partial q_i} \\ &= A \frac{\partial \mu_7}{\partial q_i} + B \frac{\partial \mu_8}{\partial q_i} + C \frac{\partial \mu_9}{\partial q_i} \\ &+ \frac{k}{2} \Big\{ c_m^2 \left(A T_{31n} + B T_{32n} + C T_{33n} \right)\left(A T'_{31n} + B T'_{32n} + C T'_{33n} \right) \\ &+ b_m^2 \left(A T_{21n} + B T_{22n} + C T_{23n} \right)\left(A T'_{21n} + B T'_{22n} + C T'_{23n} \right) \\ &+ a_m^2 \left(A T_{11n} + B T_{12n} + C T_{13n} \right)\left(A T'_{11n} + B T'_{12n} + C T'_{13n} \right) \Big\} \end{aligned} \tag{64}$$

where (') implies a partial derivative with respect to q_i.

Equation 64 holds for all 17 degrees of freedom, and reduces to simpler forms for particular combinations of q_i, ellipsoid index m, and body segment index n. The factors

$$\frac{\partial \mu_7}{\partial q_i}, \quad \frac{\partial \mu_8}{\partial q_i}, \quad \frac{\partial \mu_9}{\partial q_i}$$

come immediately from equation 61 For the special case of a sphere, equation 64 simplifies to

$$L_{im} = \pm \sqrt{p^2+q^2+r^2}\left[A\frac{\partial \mu_7}{\partial q_i} + B\frac{\partial \mu_8}{\partial q_i} + C\frac{\partial \mu_9}{\partial q_i}\right] \tag{65}$$

The deflection time rate is dependent on not only the movement of the crash victim but also on both the movement of the vehicle and the movement of the contact surface with respect to the vehicle. Therefore, Equation (50) here becomes

$$\dot{\delta} = \sum_{k=1}^{17} \frac{\partial \delta}{\partial q_k}\dot{q}_k + \sum_{i=1}^{6} \frac{\partial \delta}{\partial \sigma_i}\dot{\sigma}_i + \sum_{j=1}^{4} \frac{\partial \delta}{\partial \xi_j}\dot{\xi}_j \tag{66}$$

The first term of (66) represents the movement of the body and is the sum of each lever arm already presented times the corresponding generalized velocity. The second term of (66) represents the movement of the vehicle where

$$\vec{\sigma} = \begin{bmatrix} x_7 \\ y_7 \\ z_7 \\ \psi_7 \\ \theta_7 \\ \phi_7 \end{bmatrix} \tag{67}$$

The vehicle "lever arms" are given below.

$$\frac{\partial \delta}{\partial \sigma_1} = - \frac{A}{\sqrt{p^2 + q^2 + r^2}}$$

$$\frac{\partial \delta}{\partial \sigma_2} = - \frac{B}{\sqrt{p^2 + q^2 + r^2}}$$

$$\frac{\partial \delta}{\partial \sigma_3} = - \frac{C}{\sqrt{p^2 + q^2 + r^2}}$$

$$\frac{\partial \delta}{\partial \sigma_4} = \frac{(y_0 - y_7) A - (x_0 - x_7) B}{\sqrt{p^2 + q^2 + r^2}} \tag{68}$$

$$\begin{aligned} \sqrt{(p^2 + q^2 + r^2)}\,\frac{\partial \delta}{\partial \sigma_5} = {} & (x_0 - x_7)(T_{17} p + T_{27} q - T_{147} r) \\ & + (y_0 - y_7)(T_{47} p + T_{67} q - T_{157} r) \\ & - (z_0 - z_7)(T_{167} p + T_{177} q + C_{27} r) \end{aligned}$$

$$\begin{aligned} \sqrt{(p^2 + q^2 + r^2)}\,\frac{\partial \delta}{\partial \sigma_6} = {} & (x_0 - x_7)(T_{317} q - T_{217} p) \\ & + (y_0 - y_7)(T_{327} q - T_{227} p) \\ & + (z_0 - z_7)(T_{337} q - T_{237} p) \end{aligned}$$

The third term of (66) represents the motion of the contact with respect to the vehicle where

$$\vec{\xi} = \begin{bmatrix} p \\ q \\ r \\ s \end{bmatrix} \tag{69}$$

These contact coefficients or "lever arms" are defined below.

$$\begin{aligned}
\left(\sqrt{p^2+q^2+r^2}\right)\frac{\partial\delta}{\partial\xi_1} &= (x_0-x_7)T_{317}+(y_0-y_7)T_{327}+(z_0-z_7)\,T_{337}-\frac{p\delta}{\sqrt{p^2+q^2+r^2}}\\
\left(\sqrt{p^2+q^2+r^2}\right)\frac{\partial\delta}{\partial\xi_2} &= (x_0-x_7)T_{217}+(y_0-y_7)T_{227}+(z_0-z_7)T_{237}-\frac{q\delta}{\sqrt{p^2+q^2+r^2}}\\
\left(\sqrt{p^2+q^2+r^2}\right)\frac{\partial\delta}{\partial\xi_3} &= (x_0-x_7)T_{117}+(y_0-y_7)T_{127}+(z_0-z_7)T_{137}-\frac{r\delta}{\sqrt{p^2+q^2+r^2}}\\
\frac{\partial\delta}{\partial\xi_4} &= \frac{1}{\sqrt{p^2+q^2+r^2}}
\end{aligned}\tag{70}$$

The motion of any of the contact surfaces is specified as input data to the crash victim simulator by presenting the positions of the three defining corner points at a sequence of time points. Implicit in this type of specification is the ability to change size, shape and orientation as well as position of a contact surface as a function of time. Figure 9 illustrates this general type of motion in a contact surface specified at three time points. The arrow emanating from the contact surface shows the forward side of the surface.

The sample contact surface starts out in the form of a square in the plane of the figure at t=0, moves forward, sideways, rotates, and becomes a rectangle by $t=t_1$, and moves back into the plane of the figure as a diamond shape oriented in the other direction by $t=t_2$. The three defining points are numbered with arrows showing their movements during the intervening times between specifications.

Each of the nine coordinates defining the position of the corner points are treated as piece-wise linear functions of time. A typical coordinate, the x-coordinate of Point 1, is shown in Figure 10. The coordinate rate is

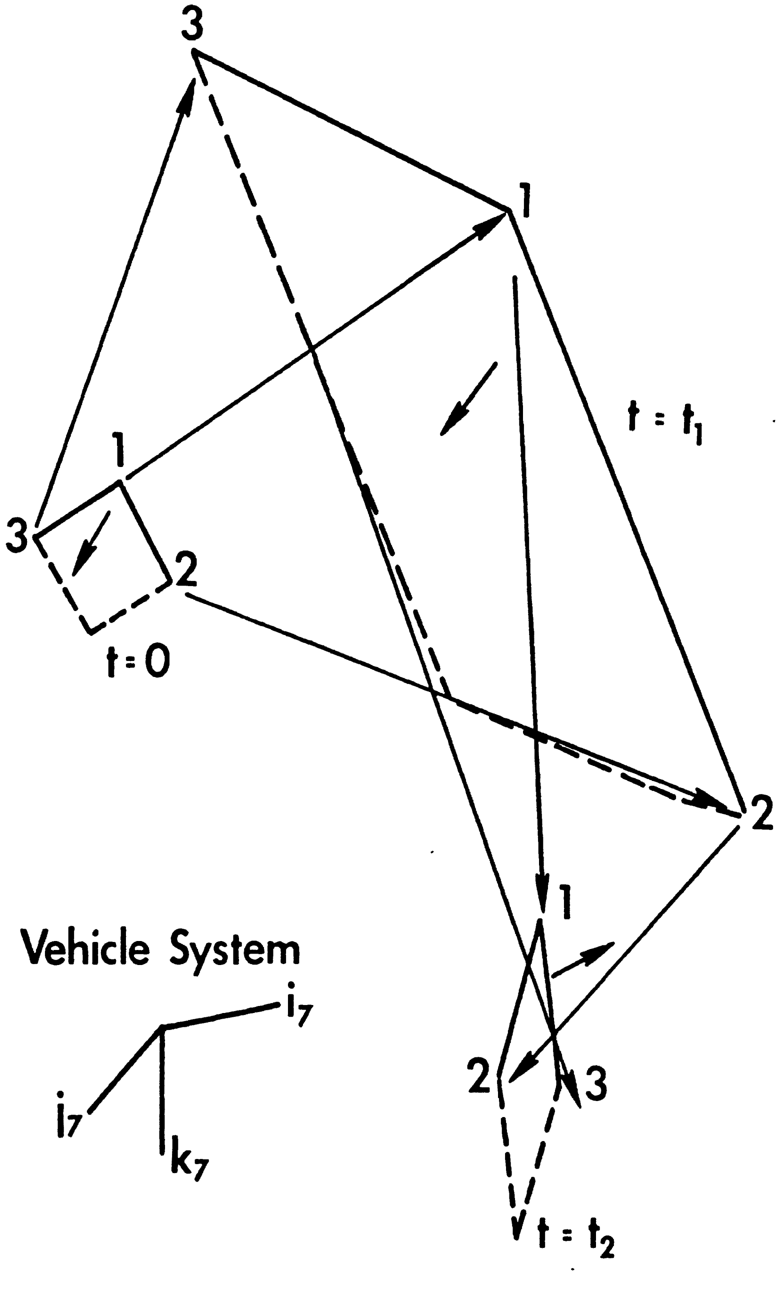


Figure 9. A Moving Contact at Three Time Points

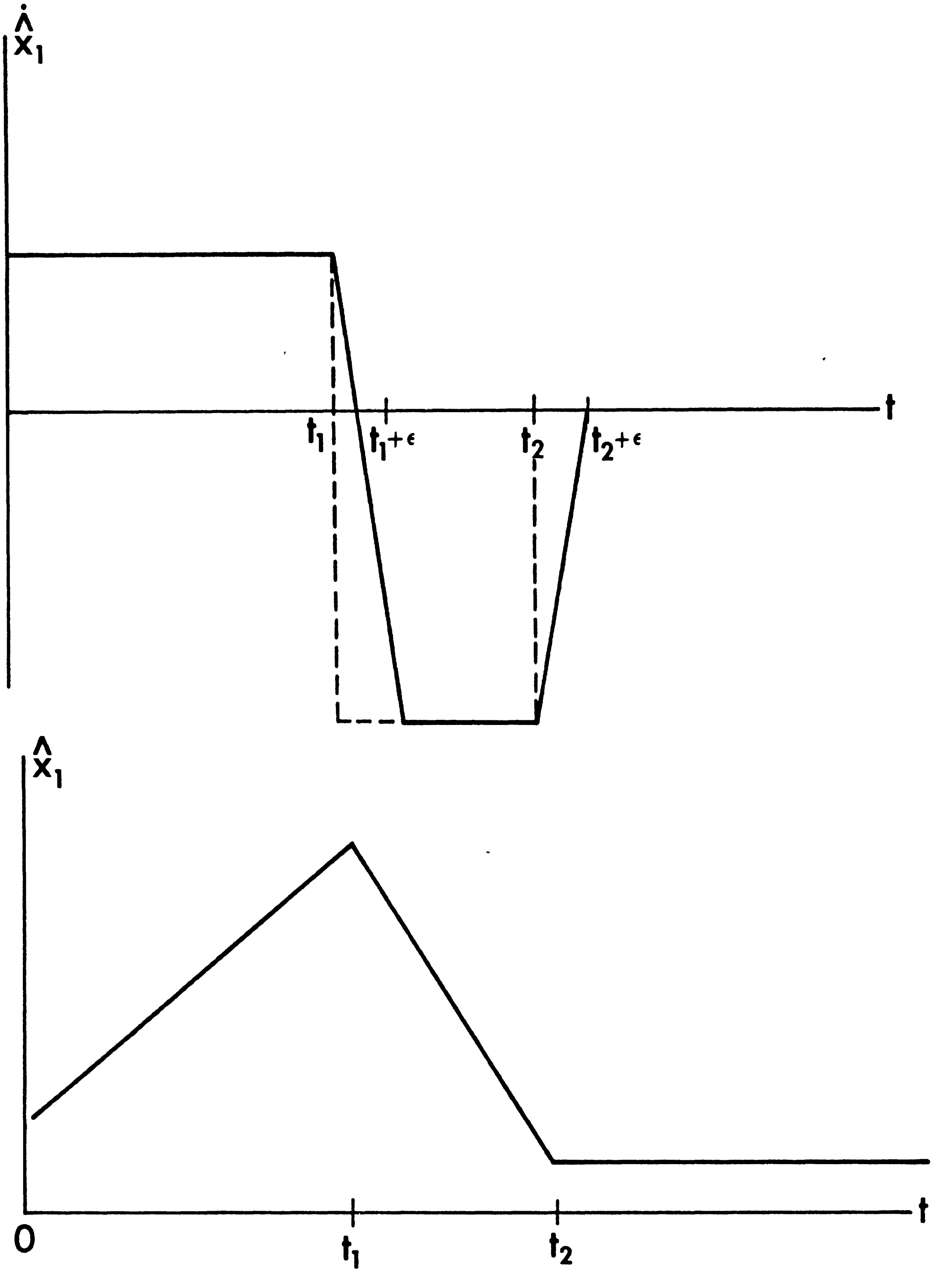


Figure 10. A Corner Coordinate Value and Rate as a Function of Time

a step function but is made continuous by adding ramps from one level to the next within a small time interval. Values for corner coordinates and coordinate rates together with the derivatives of Equation (57) determine the $\dot{\xi}_j$ for j=1-4 used in Equation (66).

F.4. Tangential Forces

The forces which are generated tangential to a surface when a body element ellipsoid contacts a planar vehicle contact surface are modeled by tangential Coulomb friction forces, T,

$$\vec{T} = - C \mu F \frac{\vec{\dot{\eta}}}{\dot{\eta}} \tag{71}$$

where

$\vec{\dot{\eta}}$ = velocity of contact point over surface; $\dot{\eta}$ is inherently positive

F = normal force

μ = coefficient of friction

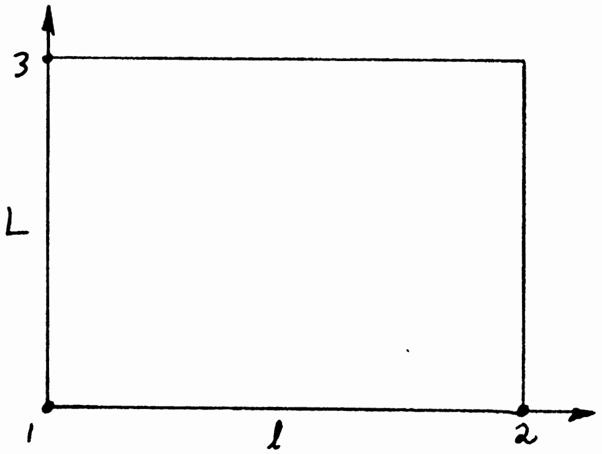
C = 1 if $\dot{\eta} > \nu$ and a linear ramp from 0 to 1 if $\dot{\eta} < \nu$

ν = ramp length (in/sec).

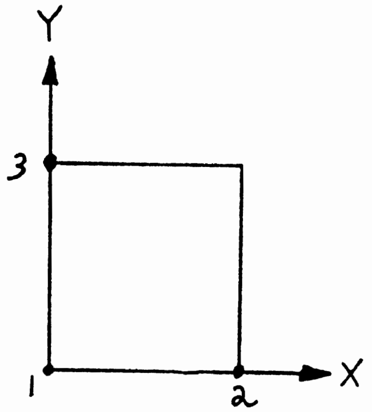
As the tangential forces are chosen to be dissipative in nature, their contribution to the right hand sides of the equations of motion are given in the terms,

$$\begin{aligned} Q_i &= - \frac{\partial}{\partial \dot{q}_i} \int \vec{T} \cdot \vec{\delta \eta} \\ &= - \frac{\partial}{\partial \dot{q}_i} \int - C \mu F \frac{\vec{\dot{\eta}}}{\dot{\eta}} \cdot \vec{\delta \dot{\eta}} \\ &= - C \mu F \frac{\partial \dot{\eta}}{\partial \dot{q}_i} \end{aligned} \tag{72}$$

$\dot{\eta}$ is the speed of the motion of the contact point across the contact surface. The extent of the contact surface with corner points (1, 2, 3) and side lengths (ℓ ,L) is shown below.



The Computations in the program are based on a unit square so that the same logic may be used for each contact. The coordinates of this same surface are (X, Y).



The velocity of the contact point in unit square coordinates is

$$\dot{\eta} = \sqrt{l^2 \dot{X}^2 + L^2 \dot{Y}^2} \tag{73}$$

The equation (72) may now be written in terms of the individual contact planes as

$$\frac{\partial \dot{\eta}}{\partial \dot{q}_i} = \frac{1}{\dot{\eta}} \left(l^2 \dot{X} \frac{\partial \dot{X}}{\partial \dot{q}_i} + L^2 \dot{Y} \frac{\partial \dot{Y}}{\partial \dot{q}_i} \right) \tag{74}$$

Because $X = X(q_i)$ and $Y = Y(q_i)$,

$$\frac{\partial \dot{X}}{\partial \dot{q}_i} = \frac{\partial X}{\partial q_i} \quad ; \quad \frac{\partial \dot{Y}}{\partial \dot{q}_i} = \frac{\partial Y}{\partial q_i} \tag{75}$$

and thus,

$$\frac{\partial \dot{\eta}}{\partial \dot{q}_i} = \frac{1}{\dot{\eta}} \left(l^2 \dot{X} \frac{\partial X}{\partial q_i} + L^2 \dot{Y} \frac{\partial Y}{\partial q_i} \right) \tag{76}$$

Because the X, Y are points on a plane for which analytical expressions have already been presented, it is relatively easy from this point to compute the contributions to the right hand sides of the equations of motion resulting from tangential contact surface forces.

F.5. Ellipsoid-Ellipsoid Interactions

Allowance is made in the model for contact interaction between body segment "ellipsoids." Regardless of whether the user provides spheres or true ellipsoids, each interaction is modeled as one sphere against another.

A user-supplied ellipsoid is replaced either by a sphere fixed to the body element or by a sphere which can migrate along the major axis of the ellipsoid to a position of minimum distance from an approaching sphere. Whether the fixed sphere or the migrating sphere is used depends on whether the ellipsoid does or does not approximate a sphere. The definition of this criterion, the selection of sphere radii, and definition of the extreme allowed positions on either side of the ellipsoid center for a migrating sphere are discussed in the following text.

Since a sphere migrating along the major axis essentially reduces an ellipsoid to a circular cylinder with a hemispherical cap at each end, the approximation is best for ellipsoids with $a \gg b = c$.

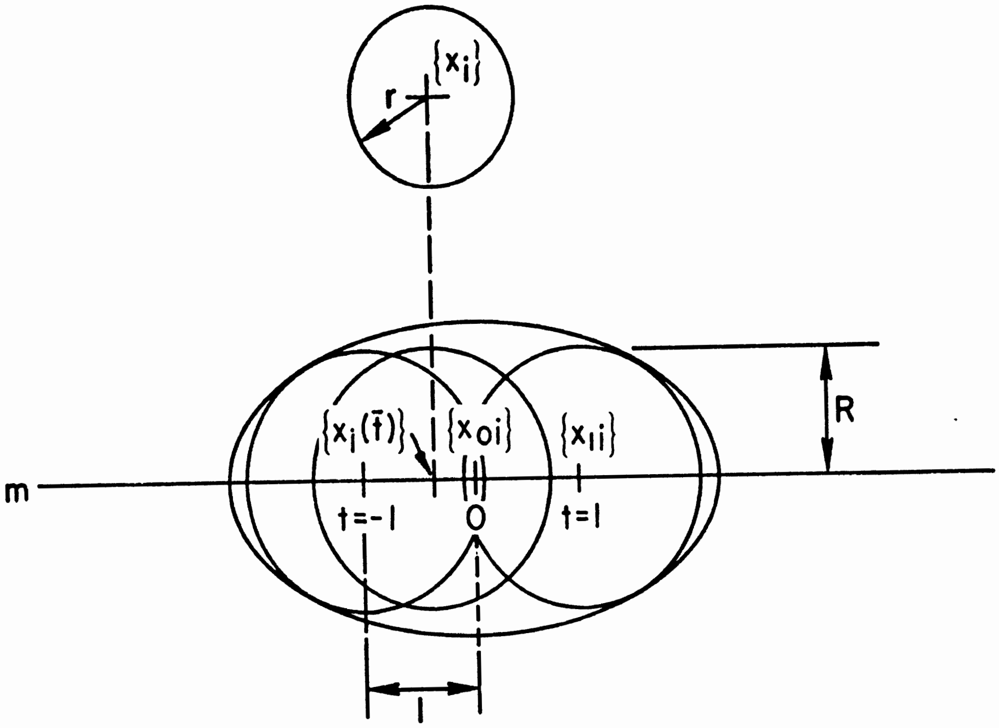
Figure 11 is a schematic showing the approach of a sphere to a contact ellipsoid.

The parametric equations for line m are

$$x_i = x_{oi} + \lambda_i t \, , \qquad i = 1, 2, 3, \tag{77}$$

where

$$\lambda_i = x_{1i} - x_{oi}$$



$\{x_{oi}\}$ is the inertial center position of the ellipsoid.

$\{x_{1i}\} = f(\{x_{oi}\}, l,$ direction cosines of major axis).

Figure 11. Approach of Sphere to Ellipsoid

The distance between the center of an approaching sphere and points on the line m is given by

$$d^2 = \sum_{i=1}^{3} (x_i - X_i)^2 = \sum_{i=1}^{3} (x_{oi} - X_i + \lambda_i t)^2 \qquad (78)$$

The shortest distance is found from

$$\left.\frac{\partial d^2}{\partial t}\right|_{t=\bar{t}} = 0 = \sum_{i=1}^{3} 2\,(x_{oi} - X_i - \lambda_i \bar{t})\,\lambda_i \qquad (79)$$

or

$$\sum_{i=1}^{3} \lambda_i (x_{oi} - X_i) + \sum_{i=1}^{3} \lambda_i^2 \bar{t} = 0$$

which gives

$$\bar{t} = \frac{\sum_{i=1}^{3} \lambda_i (X_i - x_{oi})}{\sum_{i=1}^{3} \lambda_i^2} \qquad (80)$$

Now, $\{x_i(\bar{t})\}$ is the position of the center of a sphere slid along the major axis to a point opposite the approaching sphere as long as $-1 \leq t \leq 1$. If $|\bar{t}| > 1$, then the sphere may be positioned at $\bar{t} = \pm 1$. The ellipsoid is thus represented by a circular cylinder with a hemisphere at each end.

If $\bar{t} < -1$, set $t = -1$.

If $\bar{t} > 1$, set $t = 1$.

Then evaluate

$$(R + r)^2 - \sum_{i=1}^{3} (x_{oi} - X_i + \lambda_i \bar{t})^2$$

If this is positive then the spheres intersect and

$$\delta = R + r - \sqrt{\sum_{i=1}^{3} (x_{oi} - X_i + \lambda_i \bar{t})^2} \qquad (81)$$

The derivative is

$$\frac{\partial \delta}{\partial q_j} = \frac{\sum_{i=1}^{3} (x_{oi} - X_i + \lambda_i \bar{t}) \left(\frac{\partial x_{oi}}{\partial q_j} - \frac{\partial X_i}{\partial q_j} + \lambda_i \frac{\partial \bar{t}}{\partial q_j} + \bar{t} \frac{\partial \lambda_i}{\partial q_j} \right)}{\delta - (R + r)} \tag{82}$$

Since

$$\sum_{i=1}^{3} 2 (x_{oi} - X_i + \lambda_i \bar{t}) \lambda_i = 0,$$

we have that

$$\sum_{i=1}^{3} (x_{oi} - X_i + \lambda_i \bar{t}) \lambda_i \frac{\partial \bar{t}}{\partial q_j} = 0 .$$

Therefore,

$$\frac{\partial \delta}{\partial q_j} = \frac{\sum_{i=1}^{3} (x_{oi} - X_i + \lambda_i \bar{t}) \left(\frac{\partial x_{oi}}{\partial q_j} - \frac{\partial X_i}{\partial q_j} + \bar{t} \frac{\partial \lambda_i}{\partial q_j} \right)}{\delta - (R + r)} \tag{83}$$

where

$$\frac{\partial x_{oi}}{\partial q_j} = \frac{\partial x_n}{\partial q_j} + x_{em} \frac{\partial T_{1in}}{\partial q_j} + y_{em} \frac{\partial T_{2in}}{\partial q_j} + z_{em} \frac{\partial T_{3in}}{\partial q_j} \tag{84}$$

$$i = 1, 2, 3$$

This has the same form as the derivatives of Equations 61 as does $\frac{\partial X_i}{\partial q_j}$.

Since body ellipsoids must be attached parallel to body element axes, $\mathbf{X}_{1i}$ is as follows using the fact that m from Figure 11 must be along body axes i_n, j_n, or k_n. Let

$$j = \begin{Bmatrix} 1 \\ 2 \\ 3 \end{Bmatrix} \text{ if the major axis is along } \begin{Bmatrix} i_n \\ j_n \\ k_n \end{Bmatrix} . \tag{85}$$

Then,

$$x_{01}\, i + x_{02}\, j + x_{03}\, k + l \cdot \left\{ \begin{matrix} i_n \\ \text{or} \\ j_n \\ \text{or} \\ k_n \end{matrix} \right\} = x_{11}\, i + x_{12}\, j + x_{13}\, k \qquad (86)$$

$$= x_{01}\, i + x_{02}\, j + x_{03}\, k + l \left(T_{j1,n}\, i + T_{j2,n}\, j + T_{j3,n}\, k \right) \qquad (87)$$

Thus,

$$x_{1i} = x_{0i} + l\, T_{jin} \qquad (88)$$

Hence, by Equation 77,

$$\lambda_i = l\, T_{jin} \qquad (89)$$

and

$$\frac{\partial \lambda_i}{\partial q_k} = l \frac{\partial T_{jin}}{\partial q_k} \qquad (90)$$

Figure 12 is a schematic showing the approach between two body ellipsoids

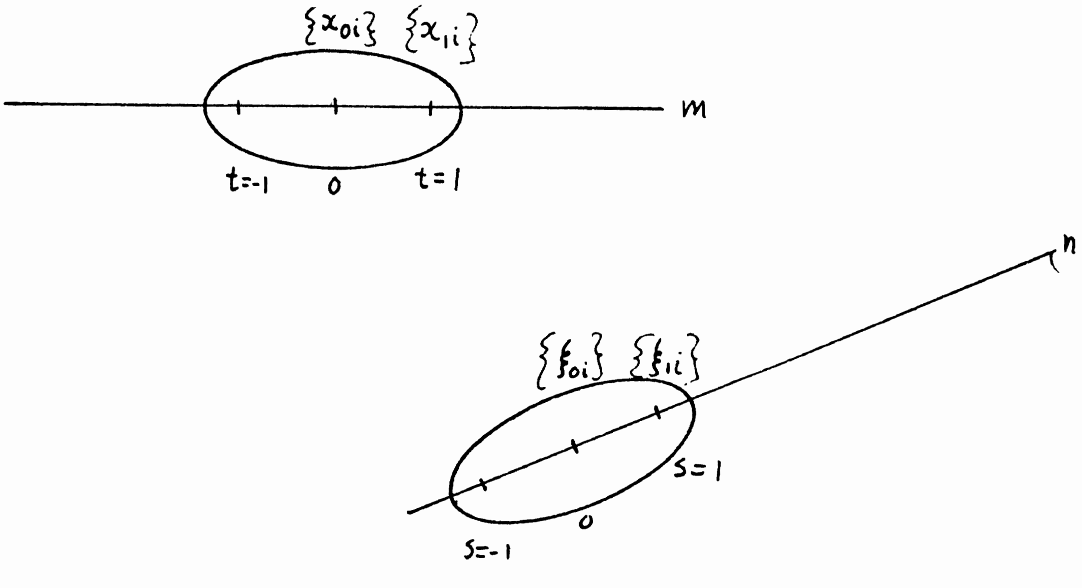


Figure 12. Approach of Ellipsoid to elllipsoid

The parametric equations for lines m and n are

$$x_i = x_{oi} + \lambda_i t$$

$$\xi_i = \xi_{oi} + \mu_i s \qquad , i = 1, 2, 3 \tag{91}$$

where

$$\lambda_i = x_{1i} - x_{oi} \quad , \quad \mu_i = \xi_{1i} - \xi_{oi} \tag{92}$$

The distance between two points on the lines is

$$d^2 = \sum_{i=1}^{3} (x_i - \xi_i)^2 = \sum_{i=1}^{3} (x_{oi} - \xi_{oi} + \lambda_i t - \mu_i s)^2 \tag{93}$$

The shortest distance is found by minimizing d with respect to t and s and is

$$\bar{t} = \frac{\left[\sum_{i=1}^{3} \lambda_i (x_{oi} - \xi_{oi})\right]\left[\sum_{i=1}^{3} \mu_i^2\right] - \left[\sum_{i=1}^{3} \mu_i (x_{oi} - \xi_{oi})\right]\left[\sum_{i=1}^{3} \mu_i \lambda_i\right]}{\left[\sum_{i=1}^{3} \mu_i \lambda_i\right]^2 - \left[\sum_{i=1}^{3} \lambda_i^2\right]\left[\sum_{i=1}^{3} \mu_i^2\right]}$$

$$\bar{s} = \frac{\left[\sum_{i=1}^{3} \lambda_i (x_{oi} - \xi_{oi})\right]\left[\sum_{i=1}^{3} \mu_i \lambda_i\right] - \left[\sum_{i=1}^{3} \mu_i (x_{oi} - \xi_{oi})\right]\left[\sum_{i=1}^{3} \lambda_i^2\right]}{\left[\sum_{i=1}^{3} \mu_i \lambda_i\right]^2 - \left[\sum_{i=1}^{3} \lambda_i^2\right]\left[\sum_{i=1}^{3} \mu_i^2\right]} \tag{94}$$

If $\{\bar{t} < -1, \bar{t} > 1 ; \bar{s} < -1 ; \bar{s} > 1\}$, then $\bar{t}$ and $\bar{s}$ are set to $\{\bar{t} = -1, \bar{t} = 1 ; \bar{s} = -1 ; \bar{s} = 1\}$.

If

$$(R + r)^2 - \sum_{i=1}^{3} (x_{oi} - \xi_{oi} + \lambda_i \bar{t} - \mu_i \bar{s})^2 \tag{95}$$

is positive, then

$$\delta = R + r - \sqrt{\sum_{i=1}^{3} (x_{oi} - \xi_{oi} + \lambda_i \bar{t} - \mu_i \bar{s})^2} \tag{96}$$

and its derivative is

$$\frac{\partial \delta}{\partial q_n} = \frac{\sum_{i=1}^{3} (x_{oi} - \xi_{oi} + \lambda_i \bar{t} - \mu_i \bar{s})\left(\frac{\partial x_{oi}}{\partial q_n} - \frac{\partial \xi_{oi}}{\partial q_n} + \bar{t}\frac{\partial \lambda_i}{\partial q_n} - \bar{s}\frac{\partial \mu_i}{\partial q_n}\right)}{\delta - (R + r)} \tag{97}$$

The form of the derivative quantities are similar to those for the sphere-ellipsoid contact discussed previously.

If the denominators of Equation 94 are zero, then the major axes of the ellipsoids are parallel and the problem must be treated as a special case. The details are not presented here.

A body ellipsoid is replaced by a sphere for the purpose of "ellipsoid-ellipsoid" interaction if it is sufficiently like a sphere. The criterion is as follows: Where $a \geq b \geq c$, the ellipsoid is replaced by a sphere if $\frac{c}{a} \geq \beta \geq 0.75$, where β is an input parameter. If this condition is satisfied, then R=c and the sphere will be positioned at the center of the ellipsoid. Alternative definitions of R, such as $R=(a+b+c)/3$ or $R=[(a^2+b^2+c^2)/3]^{1/2}$ were considered, but R=c is felt to be the best selection.

If an ellipsoid fails the sphere-replacement test just outlined, then a radius must be assigned for a sphere which migrates along the major axis. This radius is taken as R=c, where $a \geq b \geq c$.

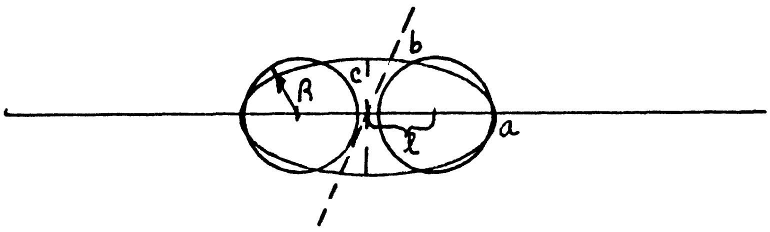


Figure 13. Selection of ℓ for Migrating Sphere.

Given R for the migrating sphere, how should ℓ be selected? The following form is used:

$$\ell = \gamma \, (a - R)$$

Here, $\gamma \leq 1$ is an input parameter. Note that $\gamma=1$ puts the sphere flush to the end of the ellipsoid.

"Ellipsoid-ellipsoid" interaction will not in general be allowed between joining body segments. It is assumed that the JOINT subroutine can be used to represent adequately such interactions. The standard inhibit switch settings allow only the following interactions.

1. head vs. either upper leg
2. lower leg vs. lower leg

3. upper leg _vs_. upper leg
4. left upper leg _vs_. right lower leg
5. right upper leg _vs_. left lower leg

Thus, the major function played by the ellipsoid-ellipsoid contacts is between the various leg elements.

G. Gravity Components of Equations of Motion

The potential energy due to gravity acting on the six masses is given by

$$V_g = -g \sum_{i=1}^{6} m_i z_i \tag{98}$$

When this is substituted into Lagrange's Equation, terms are calculated in the form

$$Q_{gi} = \frac{\partial V}{\partial q_i} = -g \sum_{n=1}^{6} m_n \frac{\partial z_n}{\partial q_i} \tag{99}$$

for each of the 17 generalized coordinates. The addition to the right hand side of each of the equations of motion due to gravity is given by

$$\begin{aligned}
Q_{g1} &= Q_{g2} = Q_{g4} = Q_{g7} = Q_{g10} = Q_{g13} = 0 \\
Q_{g3} &= -g \sum_{n=1}^{6} m_n \\
Q_{g5} &= -g \left[m_2 \rho_{1N} T_{161} - (m_3 + m_5) a_{36} + (m_4 + m_6) a_{39} \right] \\
Q_{g6} &= -g \left[m_2 \rho_{1N} T_{231} + (m_3 + m_5) a_{44} + (m_4 + m_6) a_{47} \right] \\
Q_{g8} &= -g\, m_2\, \rho_{2N}\, T_{162} \\
Q_{g9} &= -g\, m_2\, \rho_{2N}\, T_{232} \\
Q_{g11} &= -g \left(-m_3 \rho_{H3} C_{23} + m_5 a_{52} \right) \\
Q_{g12} &= g\, m_5\, a_{58}\, T_{233} \\
Q_{g14} &= -g \left(m_4 \rho_{H4} C_{24} + m_6 a_{96} \right) \\
Q_{g15} &= g\, m_6\, a_{59}\, T_{234} \\
Q_{g16} &= -g\, m_5\, \rho_{K5}\, T_{135} \\
Q_{g17} &= -g\, m_6\, \rho_{K6}\, T_{136}
\end{aligned} \tag{100}$$

H. Occupant Joint Model

The model for the motion resisting torques which exist at the five joint structures (neck, hip, knees) includes the following features:

1. linear elastic torsional springs which tend to restore the body position to a neutral rest orientation. (The neutral rest position does not necessarily have to be the initial body configuration at the beginning of the simulation. This allows application of a non-zero joint torque at time = 0);

2. stiff linear elastic torsional springs (joint stops) which are applied only at the end of the practical range of joint motion (The joint stops are also supplemented with joint damping); and,

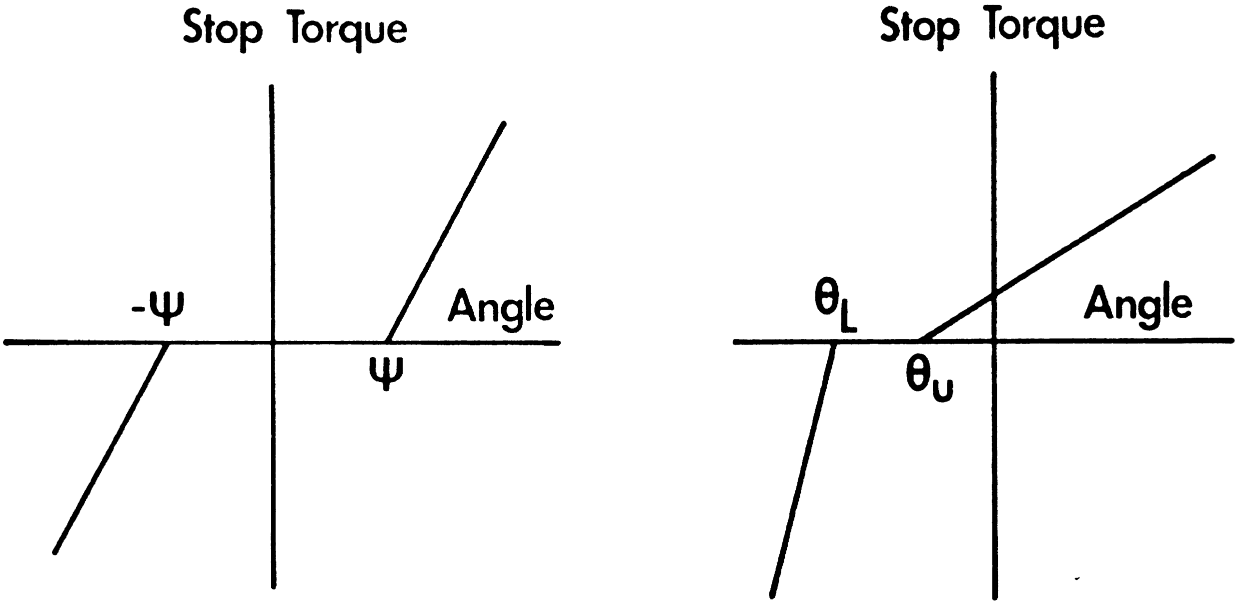
3. coupling between relative yaw, pitch, and roll motions between adjacent body segments to provide a realistic representation for joint range of motion (For example, the amount a person can roll his head to the side on a voluntary basis is influenced by the degree of extension or hyperextension of the neck). Figure 14 shows the model for joints.

The motion resisting torques are computed from relative angular motions between the various body segments. These are represented as a series of relative Euler angles shown in Figure 15 which transforms the system of coordinates parallel to the torso coordinate system to a system of coordinates parallel to the head coordinate system. This same scheme is used for the hip joint. At the knee the generalized coordinate used to locate the lower leg relative to the upper leg is already defined relative to the upper leg and is used to calculate the knee joint torque directly. The relative angles are named

$\Delta\psi_{ij}$ = relative yaw,

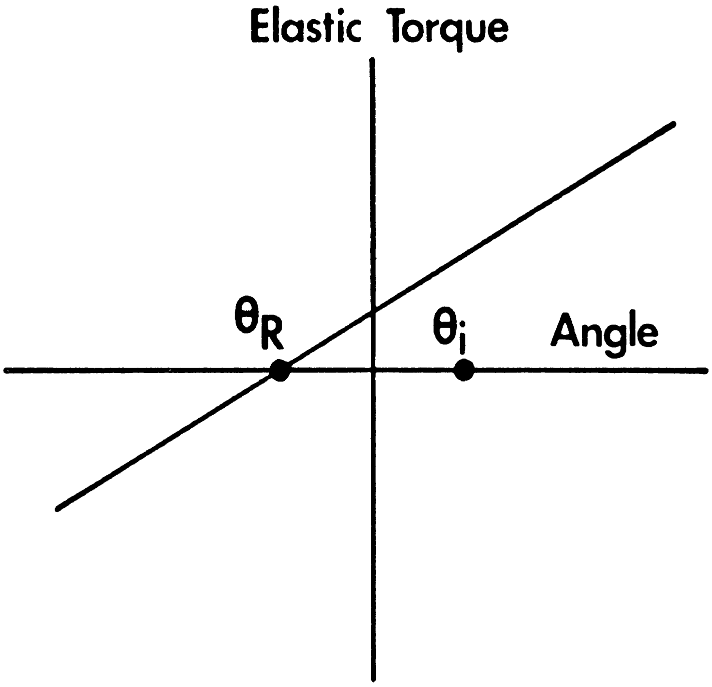
$\Delta\theta_{ij}$ = relative pitch, and

$\Delta\phi_{ij}$ = relative roll,



Symmetric Stop
(shown for yaw)

Pitch Stop



θ_R = Rest angle
θ_i = Initial relative angle

Figure 14. Joints

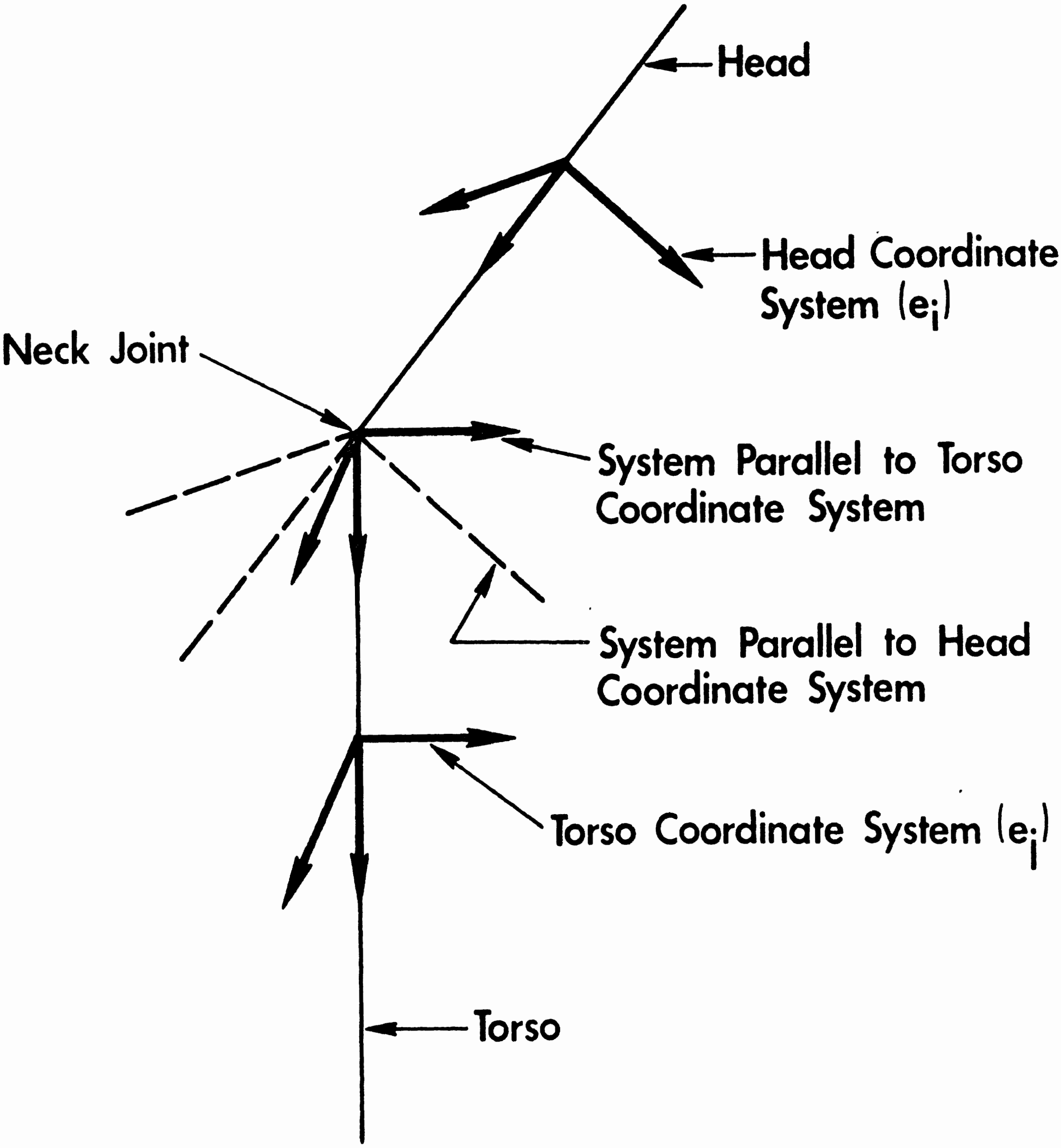


Figure 15. Relative Euler angles for computing joint torques (head-torso- joint)

where the subscripts define the two body elements, i and j, between which the motions take place. The order of application of these angles is yaw, pitch, then roll.

To describe the relative joint angles in terms of the generalized coordinates, reference is made to the body coordinate transformations given originally as Equations 3 and 4. The inertial system, e, rotates into one of the body segment systems by

$$e_i = \begin{bmatrix} \cos\psi_i \cos\theta_i & \sin\psi_i \cos\theta_i & -\sin\theta_i \\ \cos\psi_i \sin\theta_i \sin\phi_i - \sin\psi_i \cos\phi_i & \sin\psi_i \sin\theta_i \sin\phi_i + \cos\psi_i \cos\phi_i & \cos\theta_i \sin\phi_i \\ \cos\psi_i \sin\theta_i \cos\phi_i + \sin\psi_i \sin\phi_i & \sin\psi_i \sin\theta_i \cos\phi_i - \cos\psi_i \sin\phi_i & \cos\theta_i \cos\phi_i \end{bmatrix} e$$

$$= \begin{bmatrix} T_{11i} & T_{12i} & T_{13i} \\ T_{21i} & T_{22i} & T_{23i} \\ T_{31i} & T_{32i} & T_{33i} \end{bmatrix} e \qquad (101)$$

For body element j

$$e_j = A_j \; e \qquad (102)$$

and for body element i

$$e_i = A_i \, e \qquad (103)$$

For orthogonal transformations the inverse of A_j is the same as the transpose.

$$A_j^{-1} = A_j^T \qquad (104)$$

and thus

$$e = A_j^{-1} e_j = A_j^T e_j \qquad (105)$$

The system of relative Euler angles $\Delta\psi_{ij}$, $\Delta\theta_{ij}$, and $\Delta\phi_{ij}$ is defined from a transformation of the same form as Equation (101) which rotates a system parallel to e_j into a system parallel to e_i as illustrated in Figure 15 Substituting Equation (105) into Equation (106),

$$e_i = A_i A_j^T e_j \tag{106}$$

where

$$A_i A_j^T = \begin{bmatrix} \cos\Delta\psi_{ij}\cos\Delta\theta_{ij} & \sin\Delta\psi_{ij}\cos\Delta\theta_{ij} & -\sin\Delta\theta_{ij} \\ \cos\Delta\psi_{ij}\sin\Delta\theta_{ij}\sin\Delta\phi_{ij} - \sin\Delta\psi_{ij}\cos\Delta\phi_{ij} & \sin\Delta\psi_{ij}\sin\Delta\theta_{ij}\sin\Delta\phi_{ij} + \cos\Delta\psi_{ij}\cos\Delta\phi_{ij} & \cos\Delta\theta_{ij}\sin\Delta\phi_{ij} \\ \cos\Delta\psi_{ij}\sin\Delta\theta_{ij}\cos\Delta\phi_{ij} + \sin\Delta\psi_{ij}\sin\Delta\phi_{ij} & \sin\Delta\psi_{ij}\sin\Delta\theta_{ij}\cos\Delta\phi_{ij} - \cos\Delta\psi_{ij}\sin\Delta\phi_{ij} & \cos\Delta\theta_{ij}\cos\Delta\phi_{ij} \end{bmatrix} \tag{107}$$

Because A_j and A_i^T are known, it is now possible to describe the relative joint angles in terms of generalized coordinates.

$$A_i = \begin{bmatrix} T_{11i} & T_{12i} & T_{13i} \\ T_{21i} & T_{22i} & T_{23i} \\ T_{31i} & T_{32i} & T_{33i} \end{bmatrix} \quad ; \quad A_j^T = \begin{bmatrix} T_{11j} & T_{21j} & T_{31j} \\ T_{12j} & T_{22j} & T_{32j} \\ T_{13j} & T_{23j} & T_{33j} \end{bmatrix} . \tag{108}$$

Needed components of the matrix $(A_i A_j^T)_{nm}$, are

$$\begin{aligned} (A_i A_j^T)_{11} &= T_{11i}T_{11j} + T_{12i}T_{12j} + T_{13i}T_{13j} \\ (A_i A_j^T)_{12} &= T_{11i}T_{21j} + T_{12i}T_{22j} + T_{13i}T_{23j} \\ (A_i A_j^T)_{13} &= T_{11i}T_{31j} + T_{12i}T_{32j} + T_{13i}T_{33j} \\ (A_i A_j^T)_{23} &= T_{21i}T_{31j} + T_{22i}T_{32j} + T_{23i}T_{33j} \\ (A_i A_j^T)_{33} &= T_{31i}T_{31j} + T_{32i}T_{32j} + T_{33i}T_{33j} \end{aligned} \tag{109}$$

The elements of Equation (109) can now be used with Equation (107) to write the relative joint angles in terms of generalized coordinates

$$\Delta \psi_{ij} = \tan^{-1}\left[\frac{(A_i A_j^T)_{12}}{(A_i A_j^T)_{11}}\right]$$

$$\Delta \theta_{ij} = -\sin^{-1}\left[(A_i A_j^T)_{13}\right] \qquad (110)$$

$$\Delta \phi_{ij} = \tan^{-1}\left[\frac{(A_i A_j^T)_{23}}{(A_i A_j^T)_{33}}\right]$$

The contribution to the right hand sides of the equations of motion, Q_i, arise from elastic joint and stop forces as well as a dissipative force in the joint stop.

$$Q_k = \left|\vec{F}_s + \vec{F}_D\right| \frac{\partial \delta}{\partial q_k} \quad , k = 1, \cdots, 17 \qquad (111)$$

as defined in Equation (111) where

$\vec{F}_s$ = elastic spring force,

$\vec{F}_D$ = dissipative force,

δ = deflection associated with a given set of forces,

q_k = one of the seventeen generalized coordinates.

Let the body segment indices i and j now be called m and n respectively and let i (1, 2, 3, 4, or 5) indicate the joint between segments m and n.

Let the neutral "rest" position within the joint range of motion about which elastic torsional spring forces are generated be defined by $(\Delta\psi_{mn})_r$, $(\Delta\theta_{mn})_r$, and $(\Delta\phi_{mn})_r$. The locations of the stops are given for each joint, i, by

$\eta_{1i} = \alpha_{\psi+}$ = yaw stop location,
$\eta_{2i} = \alpha_{\theta+}(0)$ = positive pitch stop location with zero yaw,
$\eta_{3i} = \alpha_{\theta+}(\alpha_{\psi+})$ = positive pitch stop location in the presence of full yaw,
$\eta_{4i} = \alpha_{\theta-}(0)$ = negative pitch stop location with zero yaw,
$\eta_{5i} = \alpha_{\theta-}(\alpha_{\psi+})$ = negative pitch stop location in the presence of full yaw,
$\eta_{6i} = \alpha_{\phi-}(0, \alpha_{\theta+}(0))$ = positive roll stop in the presence of zero yaw and full positive pitch,
$\eta_{7i} = \alpha_{\phi+}(0, 0)$ = pure roll stop,
$\eta_{8i} = \alpha_{\phi+}(0, \alpha_{\theta-}(0))$ = positive roll stop in the presence of zero yaw and full negative pitch,
$\eta_{9i} = \alpha_{\phi+}(\alpha_{\psi+}, 0)$ = positive roll stop in the presence of full yaw and zero pitch,
$\eta_{10i} = \alpha_{\phi-}(\alpha_{\psi+}, 0)$ = negative roll stop in the presence of full yaw and zero pitch,
$\eta_{11i} = \alpha_{\phi+}(\alpha_{\psi+}, \alpha_{\theta+}(\alpha_{\psi+}))$ = positive roll stop in the presence of full yaw and positive pitch,
$\eta_{12i} = \alpha_{\phi-}(\alpha_{\psi+}, \alpha_{\theta+}(\alpha_{\psi+}))$ = negative roll stop in the presence of full yaw and positive pitch,
$\eta_{13i} = \alpha_{\phi+}(\alpha_{\psi+}, \alpha_{\theta-}(\alpha_{\psi+}))$ = positive roll stop in the presence of full yaw and negative pitch,
$\eta_{14i} = \alpha_{\phi-}(\alpha_{\psi+}, \alpha_{\theta-}(\alpha_{\psi+}))$ = negative roll stop in the presence of full yaw and negative pitch.

In the case of the knee joints, only the positive and negative pitch stops, η_{2i} and η_{4i}, are used. These fourteen quantities η_{ki}, which are used to define joint range of motion, are based on observations of coupling between the rotational modes of relative motion at a joint; the verbal descriptions above serve as definitions for the η_{ki}. Preliminary values have been determined for human neck structures through human volunteer studies of head-torso relative motion. Only estimates are available for the hip joint. If experimental values are not provided as input data for the computer program, default values are provided by the program to insure proper program function.

General formulas for stop location combine the quantities just presented.

$$A_{\psi i} = \text{yaw stop} = \eta_{1i} \quad \text{for all } \Delta\psi_{mn},\ \Delta\theta_{mn}, \text{and } \Delta\phi_{mn} \tag{112}$$

$$A_{\theta i} = \text{pitch stop} = \begin{cases} \eta_{2i} + \dfrac{|\Delta\psi_{mn}|}{\eta_{1i}}\left(\eta_{3i} - \eta_{2i}\right) \\ \qquad \text{for } \Delta\theta_{mn} \geq 0 \text{ and all } \Delta\psi_{mn},\ \Delta\phi_{mn} \\ \eta_{4i} + \dfrac{|\Delta\psi_{mn}|}{\eta_{1i}}\left(\eta_{5i} - \eta_{4i}\right) \\ \qquad \text{for } \Delta\theta_{mn} \leq 0 \text{ and all } \Delta\psi_{mn},\ \Delta\phi_{mn} \end{cases} \tag{113}$$

$$A_{\phi i} = \text{roll stop} = \mu_{1i} + \frac{|\Delta\psi_{mn}|}{\eta_{1i}}\left(\mu_{2i} - \mu_{1i}\right) \tag{114}$$

where:

$$\mu_{1i} = \begin{cases} \eta_{7i} \operatorname{sgn} \Delta\phi_{mn} + \dfrac{\Delta\theta_{mn}}{\eta_{2i}}\left(\eta_{6i} \operatorname{sgn} \Delta\phi_{mn} - \eta_{7i} \operatorname{sgn} \Delta\phi_{mn}\right) & \text{for } \Delta\theta_{mn} \geqslant 0 \\ \eta_{7i} \operatorname{sgn} \Delta\phi_{mn} + \dfrac{\Delta\theta_{mn}}{\eta_{4i}}\left(\eta_{8i} \operatorname{sgn} \Delta\phi_{mn} - \eta_{7i} \operatorname{sgn} \Delta\phi_{mn}\right) & \text{for } \Delta\theta_{mn} < 0 \end{cases} \tag{115}$$

and,

$$\mu_{2i} = \begin{cases} \nu_{1i} + \dfrac{\Delta\theta_{mn}}{\eta_{3i}}\left(\nu_{2i} - \nu_{1i}\right) & \text{for } \Delta\theta_{mn} \geqslant 0 \\ \nu_{1i} + \dfrac{\Delta\theta_{mn}}{\eta_{5i}}\left(\nu_{3i} - \nu_{1i}\right) & \text{for } \Delta\theta_{mn} < 0 \end{cases} \tag{116}$$

for

$$\begin{aligned} \nu_{1i} &= \begin{cases} \eta_{9i} & \Delta\Psi_{mn} > 0, \ \Delta\phi_{mn} > 0 \\ \eta_{10i} & \Delta\Psi_{mn} > 0, \ \Delta\phi_{mn} < 0 \\ -\eta_{10i} & \Delta\Psi_{mn} < 0, \ \Delta\phi_{mn} > 0 \\ -\eta_{9i} & \Delta\Psi_{mn} < 0, \ \Delta\phi_{mn} < 0 \end{cases} \\ \nu_{2i} &= \begin{cases} \eta_{11i} & \Delta\Psi_{mn} > 0, \ \Delta\phi_{mn} > 0 \\ \eta_{12i} & \Delta\Psi_{mn} > 0, \ \Delta\phi_{mn} < 0 \\ -\eta_{12i} & \Delta\Psi_{mn} < 0, \ \Delta\phi_{mn} > 0 \\ -\eta_{11i} & \Delta\Psi_{mn} < 0, \ \Delta\phi_{mn} < 0 \end{cases} \\ \nu_{3i} &= \begin{cases} \eta_{13i} & \Delta\Psi_{mn} > 0, \ \Delta\phi_{mn} > 0 \\ \eta_{14i} & \Delta\Psi_{mn} > 0, \ \Delta\phi_{mn} < 0 \\ -\eta_{14i} & \Delta\Psi_{mn} < 0, \ \Delta\phi_{mn} > 0 \\ -\eta_{13i} & \Delta\Psi_{mn} < 0, \ \Delta\phi_{mn} < 0 \end{cases} \end{aligned} \tag{117}$$

The elastic torsional forces acting at any joint, i, are $(\vec{F}_s)_{\psi_i}$ for relative yaw, $(\vec{F}_s)_{\theta_i}$ for relative pitch, and $(\vec{F}_s)_{\phi_i}$ for relative roll.

$$(\vec{F}_s)_{\psi_i} = \begin{cases} E_{\psi_i}\left[\Delta\psi_{mn} - (\Delta\psi_{mn})_r\right], & -A_{\psi_i} \leq \Delta\psi_{mn} \leq A_{\psi_i} \\ E_{\psi_i}\left[\Delta\psi_{mn} - (\Delta\psi_{mn})_r\right] + S_{\psi_i}\left[\Delta\psi_{mn} - A_{\psi_i} \operatorname{sgn} \Delta\psi_{mn}\right], & \\ \qquad \Delta\psi_{mn} > A_{\psi_i} \text{ or } \Delta\psi_{mn} < -A_{\psi_i} & \end{cases} \tag{118}$$

$$(\vec{F}_s)_{\theta_i} = \begin{cases} E_{\theta_i}\left[\Delta\theta_{mn} - (\Delta\theta_{mn})_r\right], & A_{\theta_{li}} \leq \Delta\theta_{mn} \leq A_{\theta_{ui}} \\ E_{\theta_i}\left[\Delta\theta_{mn} - (\Delta\theta_{mn})_r\right] + S_{\theta ui}\left[\Delta\theta_{mn} - A_{\theta_{ui}}\right] & \\ \qquad \Delta\theta_{mn} > A_{\theta_{ui}} & \\ E_{\theta_i}\left[\Delta\theta_{mn} - (\Delta\theta_{mn})_r\right] + S_{\theta_{li}}\left[\Delta\theta_{mn} - A_{\theta_{li}}\right] & \\ \qquad \Delta\theta_{mn} < -A_{\theta_{li}} & \end{cases} \tag{119}$$

$$(\vec{F}_s)_{\phi_i} = \begin{cases} E_{\phi_i}\left[\Delta\phi_{mn} - (\Delta\phi_{mn})_r\right], & |\Delta\phi_{mn}| \leq |A_{\phi_i}| \\ E_{\phi_i}\left[\Delta\phi_{mn} - (\Delta\phi_{mn})_r\right] + S_{\phi_i}\left[\Delta\phi_{mn} - A_{\phi_i}\right] & \\ \qquad |\Delta\phi_{mn}| > |A_{\phi_i}| & \end{cases} \tag{120}$$

where

E_{ψ_i} = elastic yaw constant

E_{θ_i} = elastic pitch constant

E_{ϕ_i} = elastic roll constant

S_{ψ_i} = elastic yaw stop constant

$S_{\theta_{ui}}$ = elastic pitch upper stop constant

$S_{\theta_{li}}$ = elastic pitch lower stop constant

S_{ϕ_i} = elastic roll stop constant

The only torsional forces which are generated for the knee joints are the pitch forces. In those cases $\Delta \theta_{mn} = \theta_5$ or θ_6.

The dissipative forces, which are applied simultaneously with the elastic stops, are described in general by the expression

$$\vec{F}_D = -C\dot{\delta}\ \min\left(\frac{\delta}{0.1}, 1.\right) \tag{121}$$

where

C = damping coefficient

δ = angular penetration into a stop, and

$\dot{\delta}$ = angular rate.

When $0<\delta<0.1$, where δ is measured in radians, a ramp is used to build up the dissipative force. For each joint (except the knee joints), three dissipative forces will be applied resisting yaw, pitch, and roll. In the case of the knees only pitch is applied.

$$(\vec{F}_D)_{\psi_i} = - C_{\psi_i} \left(\Delta \dot{\psi}_{mn}\right) \min\left[\frac{\Delta \psi_{mn} - A_{\psi_i} \operatorname{sgn} \Delta \psi_{mn}}{0.1} , 1.0 \right]$$

$$\Delta \psi_{mn} > A_{\psi_i} \quad \text{or} \quad \Delta \psi_{mn} < - A_{\psi_i}$$

(122)

$$(\vec{F}_D)_{\theta_i} = \begin{cases} - C_{\theta_i} \left(\Delta \dot{\theta}_{mn}\right) \min\left[\dfrac{\Delta \theta_{mn} - A_{\theta_{ui}}}{0.1} , 1.0 \right] \\ \qquad \Delta \theta_{mn} > A_{\theta_{ui}} \\ - C_{\theta_i} \left(\Delta \dot{\theta}_{mn}\right) \min\left[\dfrac{\Delta \theta_{mn} - A_{\theta_{li}}}{0.1} , 1.0 \right] \\ \qquad \Delta \theta_{mn} < - A_{\theta_{li}} . \end{cases}$$

(123)

$$(\vec{F}_D)_{\phi_i} = - C_{\phi_i} \left(\Delta \dot{\phi}_{mn}\right) \min\left[\frac{\Delta \phi_{mn} - A_{\phi_i}}{0.1} , 1.0 \right]$$

$$\left|\Delta \phi_{mn}\right| > \left|A_{\phi_i}\right|$$

(124)

Equation (111) requires computation of a quantity, $\frac{\partial \delta}{\partial q_k}$, where δ generally represents a deflection associated with a force. In examining Equations (118, 119, 120, 122, 123, 124), it is seen that all $\frac{\partial \delta}{\partial q_k}$ are included in

$$\left.\begin{array}{c} \dfrac{\partial \; \Delta \psi_{mn}}{\partial \; q_k} \\[2ex] \dfrac{\partial \; \Delta \theta_{mn}}{\partial \; q_k} \\[2ex] \dfrac{\partial \; \Delta \phi_{mn}}{\partial \; q_k} \end{array}\right\} \quad \text{where} \quad \begin{array}{l} k = 1, \cdots, 17 \\ mn = 21, 31, 41, 53, 64 \, . \end{array}$$

Recalling Equations (110),

$$\frac{\partial \psi_{mn}}{\partial q_k} = \frac{\partial}{\partial q_k}\left(\tan^{-1}\left[\frac{(A_m A_n^T)_{12}}{(A_m A_n^T)_{11}}\right]\right)$$

$$= \frac{1}{(A_m A_n^T)_{12}^2 + (A_m A_n^T)_{11}^2}\left[(A_m A_n^T)_{11}\frac{\partial}{\partial q_k}(A_m A_n^T)_{12} - (A_m A_n^T)_{12}\frac{\partial}{\partial q_k}(A_m A_n^T)_{11}\right] \qquad (125)$$

Similar equations are generated for the other two quantities. This shows the basic relationship between the "lever arm" quantities and the original transformation matrices which have been given in detail along with all spatial and time derivatives in Part III E. of this report.

These formulas will not be given in complete detail because of their excessive length.

In summary Equation (111) shows the basic relationship to be used in forming the components of the right hand sides of the equations of motion which deal with forces generated due to joint elasticity, stops, and damping. The elastic and dissipative forces ($\vec{F}_S$ and $\vec{F}_D$) are given for each joint in Equations (118, 119, 120, 122, 123, 124). The deflection δ and lever arm $\frac{\partial \delta}{\partial q_k}$ expressions are given in terms of quantities earlier defined explicitly in terms of generalized coordinates (Equations (110, 125). In general,

$$Q_k = \sum_{i=1}^{5} \left| (\vec{F}_S)_{\psi_i} + (\vec{F}_D)_{\psi_i} \right| \frac{\partial \Delta \psi_{mn}}{\partial q_k} + \left| (\vec{F}_S)_{\theta_i} + (\vec{F}_D)_{\theta_i} \right| \frac{\partial \Delta \theta_{mn}}{\partial q_k}$$

$$+ \left| (\vec{F}_S)_{\phi_i} + (\vec{F}_D)_{\phi_i} \right| \frac{\partial \Delta \phi_{mn}}{\partial q_k} \qquad (126)$$

where $k = 1, \ldots, 17$

$mn=21$ when $i=1$ (neck joint)

$mn=31$ when $i=2$ (right hip)

$mn=41$ when $i=3$ (left hip)

$mn=53$ when $i=4$ (right knee)

$mn=64$ when $i=5$ (left knee)

I. Addition of Belt Forces to the Equations of Motion

The belt model is illustrated in Figure 16. The belts are represented by four independent segments, each anchored to the vehicle at an arbitrary point and pinned to the torso at an arbitrary point. Deflection is defined as elongation beyond the unrestrained belt length and is formulated as

$$\delta_n = \ell_n(t) - \ell_n(o) \tag{127}$$

where

$\ell_n(o) = \left| \vec{R}_1 + \vec{\beta}_n - \vec{R}_7 - \vec{\alpha}_n \right|_{t=o} + \Delta_n$

$\ell_n(t) = \left| \vec{R}_1 + \vec{\beta}_n - \vec{R}_7 - \vec{\alpha}_n \right|$

n is belt segment number

$\vec{\alpha}_n$ is anchor position vector (see Figure 16)

$\vec{\beta}_n$ is attachment position vector

Δ_n is the specified slack in the belt (negative for initial belt tension)

TABLE I. TYPICAL BELT INDEX SPECIFICATIONS

Belt Index	Belt Segment Name
1	Left Shoulder
2	Right Shoulder
3	Left Lap
4	Right Lap

Belt material properties are defined on M-cards in terms of either force-deflection relationships or force-strain relationships, as declared after the K-card. Strain is taken as deflection δ_n divided by the unrestrained belt length $\ell_n(0)$.

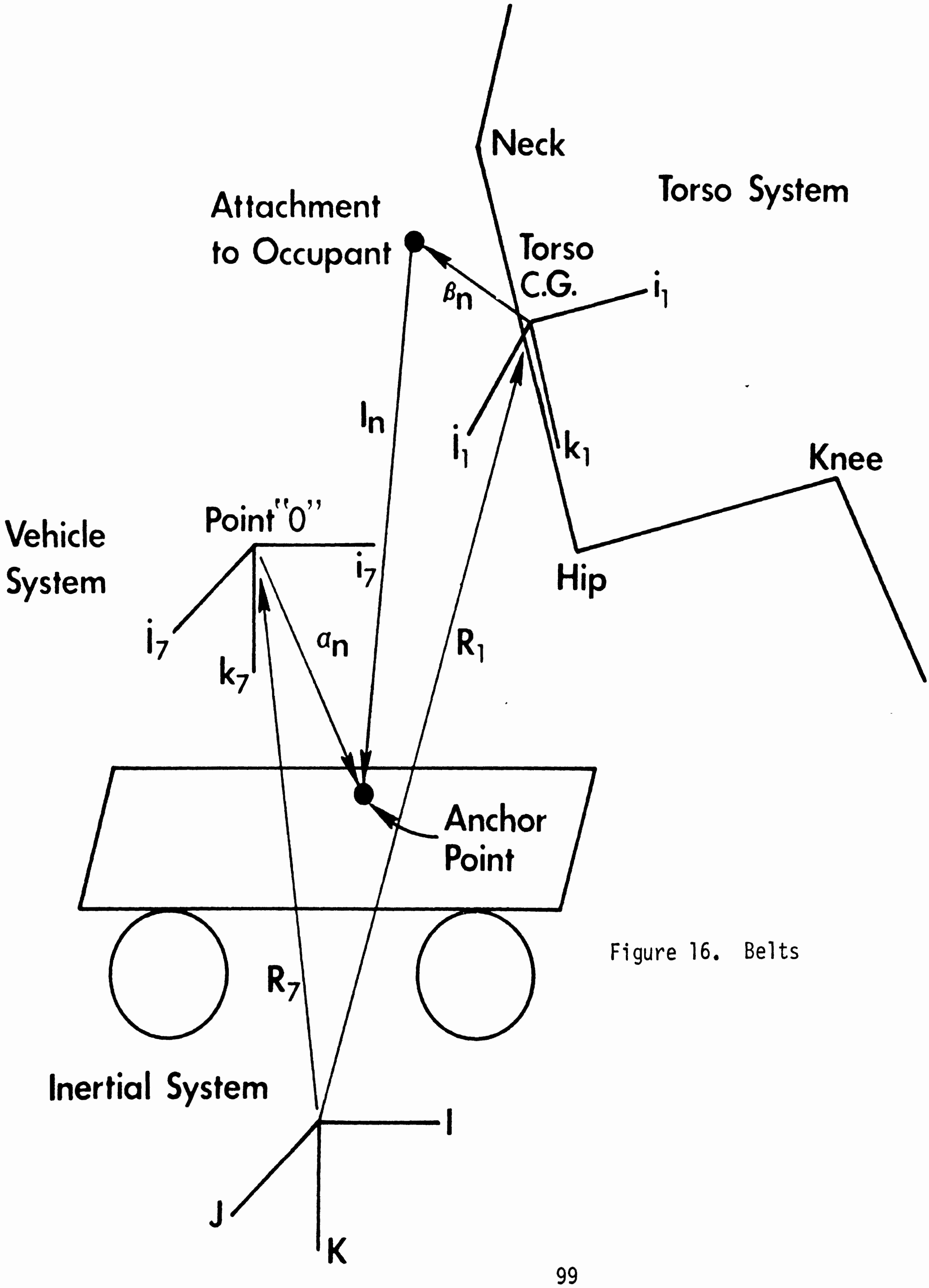


Figure 16. Belts

The components of $\vec{\alpha}_n$ and $\vec{\beta}_n$ are taken relative to vehicle and torso respectively as shown in Eq. (128).

$$\vec{\alpha}_n = \lambda_n \vec{i}_7 + \mu_n \vec{j}_7 + \nu_n \vec{k}_7 \qquad (128)$$

$$\vec{\beta}_n = r_n \vec{i}_1 + s_n \vec{j}_1 + t_n \vec{k}_1$$

Then the inertial position of the anchor point is

$$\hat{X}_n = x_7 + \lambda_n \cos\psi_7 \cos\theta_7 + \mu_n \sin\psi_7 \cos\theta_7 - \nu_n \sin\theta_7$$

$$\hat{Y}_n = y_7 + \lambda_n (\cos\psi_7 \sin\theta_7 \sin\phi_7 - \sin\psi_7 \cos\phi_7) + \mu_n (\sin\psi_7 \sin\theta_7 \sin\phi_7 + \cos\psi_7 \cos\phi_7) + \nu_n \cos\theta_7 \sin\phi_7$$

$$\hat{Z}_n = z_7 + \lambda_n (\cos\psi_7 \sin\theta_7 \cos\phi_7 + \sin\psi_7 \sin\phi_7) + \mu_n (\sin\psi_7 \sin\theta_7 \cos\phi_7 - \cos\psi_7 \sin\phi_7) + \nu_n \cos\theta_7 \cos\phi_7 \qquad (129)$$

and the inertial position of the attachment point on the torso is

$$\hat{x}_n = x_1 + r_n \cos\psi_1 \cos\theta_1 + s_n \sin\psi_1 \cos\theta_1 - t_n \sin\theta_1$$

$$\hat{y}_n = y_1 + r_n (\cos\psi_1 \sin\theta_1 \sin\phi_1 - \sin\psi_1 \cos\phi_1) + s_n (\sin\psi_1 \sin\theta_1 \sin\phi_1 + \cos\psi_1 \cos\phi_1) + t_n \cos\theta_1 \sin\phi_1$$

$$\hat{z}_n = z_1 + r_n (\cos\psi_1 \sin\theta_1 \cos\phi_1 + \sin\psi_1 \sin\phi_1) + s_n (\sin\psi_1 \sin\theta_1 \cos\phi_1 - \cos\psi_1 \sin\phi_1) + t_n \cos\theta_1 \cos\phi_1 \qquad (130)$$

and

$$l_n = \sqrt{(\hat{X}_n - \hat{x}_n)^2 + (\hat{Y}_n - \hat{y}_n)^2 + (\hat{Z}_n - \hat{z}_n)^2} \qquad (131)$$

Further, lever arms take the form

$$\frac{\partial \delta}{\partial q_j} = \frac{\hat{x}_n - \hat{X}_n}{l_n} \frac{\partial \hat{x}_n}{\partial q_j} + \frac{\hat{y}_n - \hat{Y}_n}{l_n} \frac{\partial \hat{y}_n}{\partial q_j} + \frac{\hat{z}_n - \hat{Z}_n}{l_n} \frac{\partial \hat{z}_n}{\partial q_j} \qquad (132)$$

where the non-zero derivatives are

$$\frac{\partial \hat{x}_n}{\partial x_1} = 1$$

$$\frac{\partial \hat{x}_n}{\partial \psi_1} = (s_n \cos \psi_1 - r_n \sin \psi_1) \cos \theta_1$$

$$\frac{\partial \hat{x}_n}{\partial \theta_1} = -(s_n \sin \psi_1 + r_n \cos \psi_1) \sin \theta_1 - t_n \cos \theta_1$$

$$\frac{\partial \hat{y}_n}{\partial y_1} = 1$$

$$\begin{aligned}\frac{\partial \hat{y}_n}{\partial \psi_1} = {} & (s_n \cos \psi_1 - r_n \sin \psi_1) \sin \theta_1 \sin \phi_1 \\ & - (s_n \sin \psi_1 + r_n \cos \psi_1) \cos \phi_1\end{aligned}$$

$$\frac{\partial \hat{y}_n}{\partial \theta_1} = \left[(s_n \sin \psi_1 + r_n \cos \psi_1) \cos \theta_1 - t_n \sin \theta_1\right] \sin \phi_1$$

$$\begin{aligned}\frac{\partial \hat{y}_n}{\partial \phi_1} = {} & (s_n \sin \psi_1 + r_n \cos \psi_1) \sin \theta_1 \cos \phi_1 - (s_n \cos \psi_1 - r_n \sin \psi_1) \sin \phi_1 \\ & + t_n \cos \theta_1 \cos \phi_1\end{aligned}$$

$$\frac{\partial \hat{z}_n}{\partial z_1} = 1$$

$$\begin{aligned}\frac{\partial \hat{z}_n}{\partial \psi_1} = {} & (s_n \cos \psi_1 - r_n \sin \psi_1) \sin \theta_1 \cos \phi_1 + (s_n \sin \psi_1 \\ & + r_n \cos \psi_1) \sin \phi_1\end{aligned}$$

$$\frac{\partial \hat{z}_n}{\partial \theta_1} = \left[(s_n \sin \psi_1 + r_n \cos \psi_1) \cos \theta_1 - t_n \sin \theta_1\right] \cos \phi_1$$

$$\begin{aligned}\frac{\partial \hat{z}_n}{\partial \phi_1} = {} & -(s_n \sin \psi_1 + r_n \cos \psi_1) \sin \theta_1 \sin \phi_1 - (s_n \cos \psi_1 - r_n \sin \psi_1) \cos \phi_1 \\ & - t_n \cos \theta_1 \sin \phi_1\end{aligned}$$

(133)

For belts, deflection rate is computed by Equation 134.

$$\dot{\delta} = \sum_{k=1}^{17} \frac{\partial \delta}{\partial q_k} \dot{q}_k + \sum_{i=1}^{6} \frac{\partial \delta}{\partial \sigma_i} \dot{\sigma}_i \qquad (134)$$

where the second term represents vehicle motions ($\sigma_1 = x_7$, $\sigma_2 = y_7$, $\sigma_3 = z_7$, $\sigma_4 = \psi_7$, $\sigma_5 = \theta_7$, and $\sigma_6 = \phi_7$).

Then

$$\frac{\partial \delta}{\partial \sigma_j} = \frac{\hat{x}_n - \hat{X}_n}{l_n} \frac{\partial \hat{X}_n}{\partial \sigma_j} + \frac{\hat{y}_n - \hat{Y}_n}{l_n} \frac{\partial \hat{Y}_n}{\partial \sigma_j} + \frac{\hat{z}_n - \hat{Z}_n}{l_n} \frac{\partial Z_n}{\partial \sigma_j} \qquad (135)$$

where

$$\frac{\partial \hat{X}_n}{\partial \sigma_j} = \left\{ \begin{array}{l} 1 \\ 0 \\ 0 \\ -\lambda_n \sin \psi_7 \cos \theta_7 + \mu_n \cos \psi_7 \cos \theta_7 \\ -\lambda_n \cos \psi_7 \sin \theta_7 - \mu_n \sin \psi_7 \sin \theta_7 - \nu_n \cos \theta_7 \\ 0 \end{array} \right. \qquad (136)$$

$$\frac{\partial \hat{Y}_n}{\partial \sigma_j} = \left\{ \begin{array}{l} 0 \\ 1 \\ 0 \\ -\lambda_n T_{227} + \mu_n T_{217} \\ \lambda_n T_{27} + \mu_n T_{67} - \nu_n T_{177} \\ \lambda_n T_{317} + \mu_n T_{327} + \nu_n T_{337} \end{array} \right. \qquad (137)$$

$$\frac{\partial \hat{Z}_n}{\partial \sigma_j} = \left\{ \begin{array}{l} 0 \\ 0 \\ 1 \\ -\lambda_n T_{327} + \mu_n T_{317} \\ \lambda_n T_{17} + \mu_n T_{47} - \nu_n T_{167} \\ -\lambda_n T_{217} - \mu_n T_{227} - \nu_n T_{237} \end{array} \right. \qquad (138)$$

Equation (127) defines belt deflection, Equation (132) gives lever arms and Equation (134) gives belt deflection rate. This is all the information which is necessary to determine the additions to the right hand sides of the equations of motion produced by the four belt forces

$$Q_{Bi} = \sum_{j=1}^{4} |\vec{F}_{Bj}| \frac{\partial \delta_{Bj}}{\partial q_i} \quad \text{for } i = 1, \cdots, 17 \tag{139}$$

The deflections which have been derived in this section generate the forces $\vec{F}_{Bj}$ in the computer program using the material property options explained in detail in Part III E. of this report.

A series of options are available to the program user to represent slipping belts, friction, and force influences among the various belts. If these options, which are described in the following text, are chosen, the force contributions, $|\vec{F}_{Bj}|$, to the right hand sides of the equations of motion are modified accordingly. Even though the deflections which are used to compute the belt forces may be modified in these special options, the "deflection" δ_{Bj} does not change. This quantity is calculated based on the attachment points of the belt on the occupant and on the vehicle. Because migration of the belt is not allowed on the body, these lever arm quantities will not change even if the associated forces are modified to account for slipping belts, friction, etc.

I.1 Force Equalization (Free slipping)

Any two belts (maximum of two pair) may be chosen to slip freely thus equalizing the forces in the belts. A schematic of this is given in Figure 17. The following simple procedure yields equal forces in the two belts.

The unstretched belt length is given by

$$L_t = \ell_{10} + \Delta_1 + \ell_2 + \ell_{30} + \Delta_3 \tag{140}$$

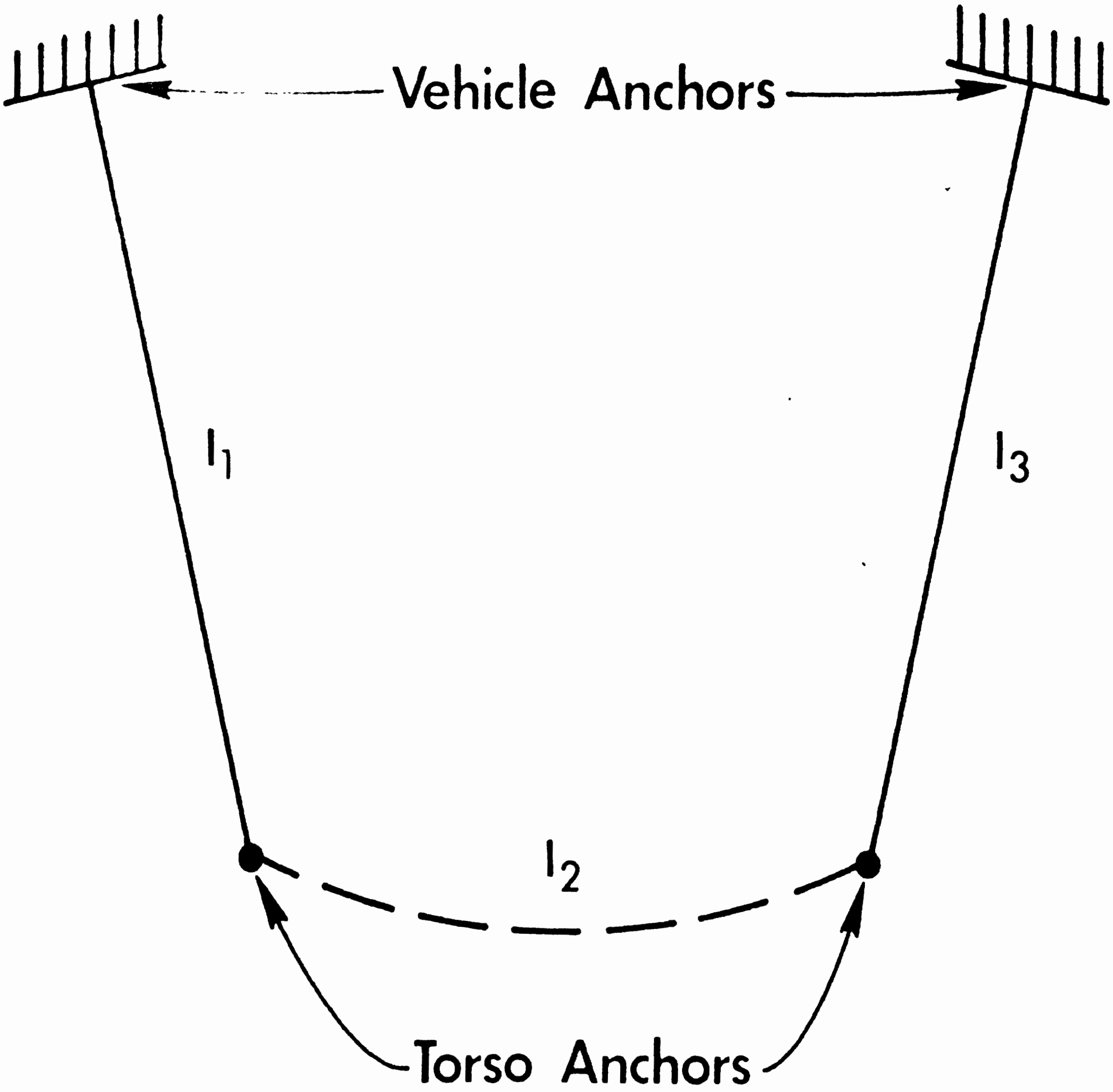


Figure 17. Slipping Belts.

where ℓ_{10} is the initial length of one belt element, ℓ_{30} is the initial length of the other belt element, ℓ_2 is the distance between body anchor points across the body (does not have to be the linear distance between the points), Δ_1 is the slack in the belt 1, and Δ_3 is the slack in belt 3. At each point in time, belt length is

$$L = \ell_1 + \ell_2 + \ell_3 \quad . \tag{141}$$

The quantity

$$L_t - L = (\ell_{10} + \Delta_1 - \ell_1) + (\ell_{30} + \Delta_3 - \ell_3) \tag{142}$$

is then determined. If

$$L_t - L \geq 0,$$

then $\vec{F}_{Bj} = 0$.

If not, the belt elongation is determined as

$$\delta = L - L_t \quad . \tag{143}$$

This deflection is then used to generate a force based on special material properties which reflect the structural deformation properties of the entire belt loop and the restrained occupant.

To use this option the appropriate belts must be introduced to the simulation via complete belt specification (K) cards. The belt pair (L) cards then specify which belt pairs are to be force-equalized. If the belt switch = -1., then a special material name must be entered on the appropriate card following the L card in the 4th field. If the belt switch is chosen to be = -3., then the average value for the two forces (computed using the materials indicated on the K-cards) is applied for each belt segment.

I.2. Inter-belt Influence

In more complex belt and harness arrangements, friction and geometric considerations lead to unequal belt tensions. Three optional methods have been supplied with this model to allow the forces in one belt (the influencer) to influence the forces in another belt (the influencee). They are described in the following three sections. The computer program logic allows any of these three influences to be applied to belt pairs which have previously been force equalized by the method of Section I.1. However, examination of the equations of the following three sections shows that equalized force values will be further modified only by the method of Section I.2.C.

I.2.A. Normal-force Friction. The first irter-belt influence option (INFL = 1 on the L card) is intended to simulate the effect of static and sliding friction between belts and the occupant. Consider a belt pair (i,j) with belt tensions $F_i^{(o)} > F_j^{(o)}$. Then belt i is considered to be the influencer and belt j the influencee. The force $F_i^{(o)}$ is adjusted downward and $F_j^{(o)}$ is adjusted upward by an amount estimated to represent the friction effect with the restriction that the influencee tension is never made to exceed the influencer tension.

Specifically, F_i and F_j replace $F_i^{(o)}$ and $F_j^{(o)}$ and

$$\begin{aligned} F_i &= F_i^{(o)} - \lambda\left(F_i^{(o)} - F_j^{(o)}\right) \\ F_j &= F_j^{(o)} + \lambda\left(F_i^{(o)} - F_j^{(o)}\right)\varsigma \end{aligned} \tag{144}$$

where λ is a friction-dependent influence factor described below. ς is an input quantity (8th field of L card), $0 \leq \varsigma \leq 1$. Values much less than 1 are considered most reasonable; the default is zero. The following considerations go into selection of the analytical form of λ.

$F_i^{(o)}$ and $F_j^{(o)}$ should be unchanged if there is no inter-belt influence, i.e., if the belt attachment points on the occupant are considered as fixed end points of separate and independent belt segments. This is a limiting case, and by Equation 144, corresponds to $\lambda = 0$. As the opposing limit, consider $\lambda = 1/2$ and $\varsigma = 1$; then $F_i = F_j$, i.e., the belt segments have equal tension. Thus, this will be considered the free-slipping case.

Further, since one belt must have more influence or less influence on the other depending on whether the segment L_2 (see Figure 18) is less tight or more tight to the occupant, λ must depend on the normal force of the belts at L_2.

Thus let

$$F_s = \mu_s N \tag{145}$$

be a force saturation level for static friction, where μ_s is an inputted static coefficient of friction for the belt pair and N is a computed normal force at L_2. If the difference between the tangential components of $\vec{F}_i$ and $\vec{F}_j$ is less than this saturation level, then belt slippage is assumed not to occur and therefore $\lambda = 0$. The resultant tangential component is estimated as being in the direction of the unit vector $\hat{e}_{ij}$ between the belt attachment points on the occupant (see Figure 18). The normal force N is approximated by adding the components of $\vec{F}_i$ and $\vec{F}_j$ normal to $\hat{e}_{ij}$ and in the planes $(\vec{F}_i, \hat{e}_{ij})$ and $(\vec{F}_j, \hat{e}_{ij})$. (Clearly, the approximation is best when the belt anchors and attachment points lie in the same plane.) Finally, λ should approach the free-slipping case ($\lambda = 1/2$) as an inputted sliding coefficient of friction, μ_k, approaches zero.

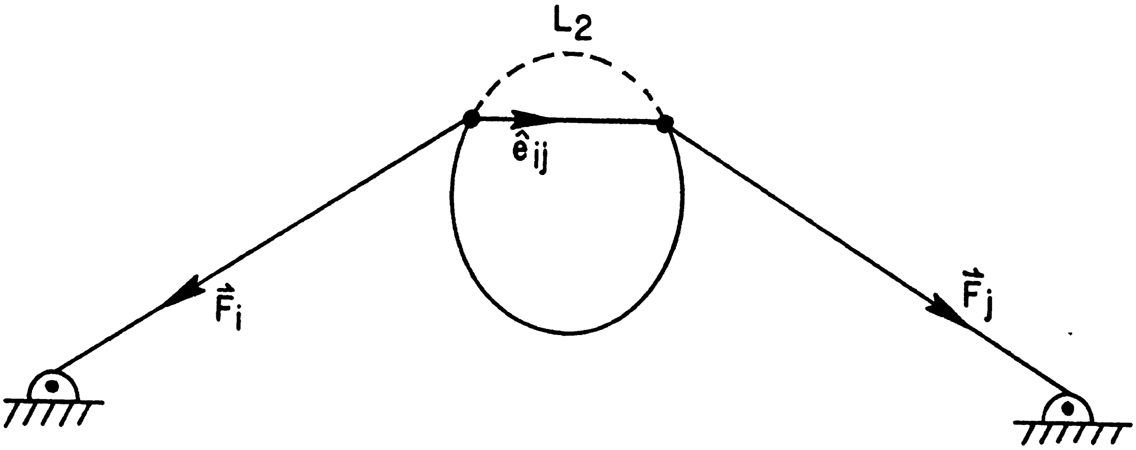


Figure 18. Belt Friction

In accordance with these observations, the influence factor for use in Equations 144 is defined as follows:

$$\lambda = 0 \qquad \text{if} \quad \left|(\vec{F}_i - \vec{F}_j)\cdot\hat{e}_{ij}\right| < F_s = \mu_s N \tag{146}$$

$$\lambda = \frac{1}{2}\left(1 - \frac{\mu_K N}{\left|(\vec{F}_i - \vec{F}_j)\cdot\hat{e}_{ij}\right|}\right) \qquad \text{otherwise,}$$

where, in general, $\mu_k \leq \mu_s$. Note that free slipping results for μ_k and μ_s inputted as 0; a non-slip condition is guaranteed by inputting μ_s as a very large number.

The remainder of this section is concerned with the estimated tangential and normal forces, $\left|(\vec{F}_i - \vec{F}_j)\cdot\hat{e}_{ij}\right|$ and N, as described in the foregoing text. In terms of the notation used in Equations 129, 130, and 131, the belt force vectors are

$$\vec{F}_n = \left|\vec{F}_n\right| \frac{(\hat{X}_n - \hat{x}_n)i + (\hat{Y}_n - \hat{y}_n)j + (\hat{Z}_n - \hat{z}_n)k}{\ell_n} \tag{147}$$

where n = i and j. The unit vector $\hat{e}_{ij}$ is

$$\hat{e}_{ij} = \frac{i(\hat{x}_j - \hat{x}_i) + j(\hat{y}_j - \hat{y}_i) + k(\hat{z}_j - \hat{z}_i)}{\sqrt{(\hat{x}_j - \hat{x}_i)^2 + (\hat{y}_j - \hat{y}_i)^2 + (\hat{z}_j - \hat{z}_i)^2}} \ . \tag{148}$$

Thus, Equations 147 and 148 completely determine the tangential force. The complete analysis for the normal force is lengthy and will not be presented here. Suffice it to say that $\vec{N}$ is determined as

$$\vec{N} = (\vec{F}_i \cdot \hat{e}^{(i)})\hat{e}^{(i)} + (\vec{F}_j \cdot \hat{e}^{(j)})\hat{e}^{(j)},$$

where $\hat{e}^{(i)}$ is the unit vector which is both in the plane $(\vec{F}_i, \hat{e}_{ij})$ and inwardly normal to $\hat{e}_{ij}$; $\hat{e}^{(j)}$ is defined similarly.

I.2.b. Force Difference Saturation An inter-belt influence option can be selected which will simulate the effect of belt friction in an entirely different manner. Here, a "saturation force difference" is inputted by the user (card L) for the influencer-influencee pair. Whenever the difference in tension between the two belts exceeds this force saturation value, the influencee is modified by an amount such that the difference in the tensions is equal to the saturation value. The influencer maintains its force level. This adjustment of the force difference is intended to represent partial slipping against static friction.

Thus, where F_i is the tension in the influencer, $F_j^{(o)}$ is the unadjusted tension in the influencee, F_j is the adjusted tension in the influencee, and $F_{s,ij}$ is the inputted force saturation level, the following analysis applies.

If $\left|F_i - F_j^{(o)}\right| \leq F_{s,ij}$, then no modification of the influencee tension is required. However, if $\left|F_i - F_j^{(o)}\right| > F_{s,ij}$, then we seek the adjustment Δ_{ij} to $F_i^{(o)}$ such that

$$\left|F_i - F_j\right| = F_{s,ij},$$

where

$$F_i = F_j^{(o)} + \Delta_{ij}. \tag{149}$$

There are two cases to be considered. Case "a" arises when $F_i > F_j^{(o)}$. The adjustment Δ_{ij} must be positive in order that the difference in the tensions will be modified downward to $F_{s,ij}$. Since

$$F_{s,ij} = F_i - F_j,$$

we obtain

$$F_j = F_j^{(o)} + (F_i - F_{s,ij} - F_j^{(o)}),$$

i.e.,

$$\Delta_{ij} = F_i - F_{s,ij} - F_j^{(o)} > 0. \qquad (150)$$

Case "b" occurs when $F_i < F_j^{(o)}$. The adjustment Δ_{ij} must be negative. Since

$$F_{s,ij} = F_j - F_i,$$

we obtain

$$F_j = F_j^{(o)} + (F_i + F_{s,ij} - F_j^{(o)}),$$

i.e.,

$$\Delta_{ij} = F_i + F_{s,ij} - F_j^{(o)} < 0. \qquad (151)$$

I.2.C. Percentage Influence The third inter-belt influence option allows the user to specify the positive or negative percentage of the influencer tension which will be applied as an additive adjustment to the influencee. In conjunction with this option, the user supplies a "maximum influence force bound" (L card). If the percentage adjustment, in absolute value, is greater than this bound, then the bound itself is applied as the adjustment to the influencee (with proper sign).

Thus, where $F_{B,ij} > 0$ is the influence bound, p_{ij} is the fractional, percentage influence factor, F_i is the influencer, and $F_j^{(o)}$ is the unadjusted influencee force, the modified forces are determined as follows. If

$$|p_{ij} F_i| \leq F_{B,ij},$$

then the adjustment to belt j due to belt i is

$$\Delta_{ij} = p_{ij} F_i \quad . \qquad (152)$$

Otherwise,

$$\Delta_{ij} = F_{B,ij} \operatorname{sgn} p_{ij} \quad . \tag{153}$$

Finally, adjustments to $F_j^{(o)}$ are summed over all specified influencers so that

$$F_j = F_j^{(o)} + \sum_i \Delta_{ij} \quad . \tag{154}$$

If the resulting influencee tension F_j is less than zero, then it is set equal to zero.

PART IV. PROGRAM INPUT AND OUTPUT

This part of the report commences with a detailed description of the input data required to operate the model. A typical data set is included. A discussion and sample of the output generated by the program follows.

A summary of the types of exercises used to check model operation is next with appropriate input and output included. This information is of special interest to those groups installing the model in computer systems remote from the University of Michigan.

A preliminary comparison of model predictions with experimental results is included. Comparisons are also made with the older HSRI 3-mass, 3-D model and the 2-D model.

The final section of this part of the report describes a user-oriented command language (OVERLORD) which can be used as an aid in preparation of input data sets. This language, written in FORTRAN IV, can be implemented for both terminal and batch use.

A. Description of Input Data File

Input to the HSRI six-mass, three-dimensional model consists of a series of eighty character lines which will be called cards in this discussion. Many of the cards have a common format which is shown in Table 2.

Eight of the standard input cards trigger special reading sequences of information which does not fit easily into the standard format. These special reading sequences are summarized in Table 3 and presented in detail in Table 5.

Table 4 contains a typical complete data set for the model. The numbers at the left are file line numbers and are not part of the data. In line 1103, the letter "A" represents the position of the first column and so on. Note the special reading sequences beginning at lines 1132, 1134, 1136, 1138, 1140, 1142, 1144, 1148, 1152, 1156, 1158, 1160, 1162, 1164, 1168, 1172, 1176, 1180, 1185, 1188, 1191, 1229, and 1234. Table 5 contains a detailed explanation of each card type together with all the special reading sequences. The reader is urged to use this table to decode the run specification contained in Table 5 and then check his impression against Table 6 in Section 4.B which contains the summary output generated using this data set.

Order of cards is irrelevant except that the Z-card must always be last and special reading sequences must be together in proper order. When the program finishes operation using a first data deck, it will look for a second. If it finds more data, it will continue; otherwise, it will sign off. Each data deck is independent and must be complete including a Z-card.

TABLE 2. STANDARD INPUT CARD FORMAT

Field	Card Columns	Description
ID	1	A letter, A through Z, which acts to identify the information being specified on this card.
I	2-10	Numeric data in floating point format. The decimal point must be explicitly included except for right-adjusted integers. "D-format" is permissible but must be right-adjusted. Normally left-adjusted "F-format" is used for convenience.
2	11-20	Numeric Data
3	21-30	Numeric Data
4	31-40	Numeric data
5	41-50	Numeric data
6	51-60	Numeric data
7	61-70	Numeric data
8	71-80	Numeric data

TABLE 3. SPECIAL READING SEQUENCES

Standard Card Which Triggers Sequence	Length of Sequence	Termination of Sequence	Description of Information Contained
H	Fixed	Card count of one.	Name and material of contact sensing ellipsoids.
I	Variable consisting of one card plus two times the number of time points specified in I2.	Card count of (1+ 2n) where n is the number of time points,	Name, material, titling information and location as a function of time of contact surfaces.
J	Variable	Blank card terminates sequence.	Series of cards containing ellipsoid-contact pairs for force inhibition.
K	Fixed	Card count of one.	Name and material of belts.
L	Sequence of one card included for each interbelt influence pair selected.	Card count equal to number of interbelt influences.	Force limitation, friction coefficient, percent influence or other quantities relating to interbelt influences.
M	Variable consisting of one card plus a possibility of two more if polynomial coefficients are used to define force-deformation	Card count of one plus one if Field 5 of card after M card = 0, plus one more if Field 6 of card after Mcard = 0.	Material specification cards including name, saturation data, if any, specification whether F-δ curves are tabular or polynomial, and polynomial coefficients if that optio is chosen.
T	Variable	Negative number on card.	Table of debug code words versus effective time.
U	Variable	Card count of one or two based on 0 or 1 in field 1 of U card.	Alpha-numeric run title.

```
>  1103   A1.     .234    12.78   11.5    3.65    8.375   11.5    3.75
>  1104   A2.     .0408   .3672   .442    .221    6.
>  1105   A3.     .0522   .197    1.31    1.31    0.      7.5
>  1106   A4.     .0522   .197    1.31    1.31    0.      7.5
>  1107   A5.     .0254   1.2     1.2     .0508           10.125
>  1108   A6.     .0254   1.2     1.2     .0508           10.125
>  1109   B0.     18.4    0.      10.     0.      -335.   0.
>  1110   B1.     0.      20.     0.      0.      0.      0.
>  1111   B2.     1.4     6.8     -31.6   0.      0.      0.
>  1112   B3.     0.      13.     0.      0.      0.      0.
>  1113   B4.     0.      13.     0.      0.      0.      0.
>  1114   B5.     0.      17.     0.      0.      0.      0.
>  1115   B6.     0.      17.     0.      0.      0.      0.
>  1116   C0.     0.      0.      0.      0.      0.      0.
>  1117   C1.     0.      -335.   0.      0.      0.      0.
>  1118   D1.     600.    -13.2   150000. 150000. 2.      70.     -70.
>  1119   D2.     800.    -7.     150000. 150000. 2.      45.     -30.
>  1120   D3.     800.    -7.     150000. 150000. 2.      45.     -30.
>  1121   D4.     250.    17.     100000. 100000. 2.      70.     -30.
>  1122   D5.     250.    17.     100000. 100000. 2.      70.     -30.
>  1123   E1.     600.    1.4     110000. 2.      60.     70.     -70.
>  1124   E2.     800.    0.      110000. 2.      45.     45.     -30.
>  1125   E3.     800.    0.      110000. 2.      45.     45.     -30.
>  1126   F1.     600.    -32.1   110000. 2.      50.     50.     50.
>  1127   F2.     800.    0.      110000. 2.      30.     30.     30.
>  1128   F3.     800.    0.      110000. 2.      30.     30.     30.
>  1129   G1.     50.     50.     50.     50.     50.     50.     1.
>  1130   G2.     30.     30.     30.     30.     30.     30.     1.
>  1131   G3.     30.     30.     30.     30.     30.     30.     1.
>  1132   H1.     0.      -5.3    -7.1    3.87                    1.
>  1133   LEFT CHEST
>  1134   H1.     0.      5.3     -7.1    3.87                    1.
>  1135   RIGHT CHEST
>  1136   H1.     0.      -5.3    7.1     3.8                     1.
>  1137   LEFT HIP
>  1138   H1.     0.      5.3     7.1     3.8                     1.
>  1139   RIGHT HIP
>  1140   H5.     0.      0.      6.      3.807                   1.
>  1141   RIGHT FOOT
>  1142   H6.     0.      0.      6.      3.807                   1.
>  1143   LEFT FOOT
>  1144   I0.     1.      -1.     15.     .00     1.
>  1145   SEAT BACK       MAT1
>  1146   0.      0.      11.     11.     10.     11.     -30.    10.
>  1147   0.      1.      22.1    11.     30.0
>  1148   I0.     1.      1.      15.     .00     1.
```

TABLE 4. TYPICAL INPUT DATA SET (Page 1 of 3)

```
>  1149    SEAT CUSHION         MAT1
>  1150    0.         0.        8.4        11.        32.3       8.4        -30.       32.3
>  1151    0.         1.        36.        11.        26.
>  1152    10.        1.        1.         15.        .00        1.
>  1153    FLOOR                MAT1
>  1154    0.         0.        30.        11.        41.        30.        -30.       41.
>  1155    0.         1.        60.        11.        41.
>  1156    K1.        0.        -9.5       0.         0.         -2.5       -11.       0.
>  1157    LEFT SHOULDER                   LEFT SHOULDER
>  1158    K2.        14.5      11.        36.        0.         5.3        1.7        1.5
>  1159    RIGHT SHOULDER                  RIGHT SHOULDER
>  1160    K3.        14.5      -11.       36.        0.         -7.1       7.2        0.
>  1161    LEFT LAP                        LEFT LAP
>  1162    K4.        14.5      11.        36.        0.         7.1        7.2        1.5
>  1163    RIGHT LAP                       RIGHT LAP
>  1164    M0.        0.        1000.      2000.      3000.      0.         1.         1.
>  1165    MAT1                 100000.    500.       0.         0.
>  1166    500.
>  1167    0.
>  1168    M0.        0.        1000.      2000.      3000.      0.         1.         1.
>  1169    LEFT SHOULDER        100000.    240.       0.         0.
>  1170    240.
>  1171    0.
>  1172    M0.        0.        1000.      2000.      3000.      0.         1.         1.
>  1173    RIGHT SHOULDER       100000.    240.       0.         0.
>  1174    240.
>  1175    0.
>  1176    M0.        0.        1000.      2000.      3000.      0.         1.         1.
>  1177    LEFT LAP             100000.    467.       0.         0.
>  1178    467.
>  1179    0.
>  1180    M0.        0.        1000.      2000.      3000.      0.         1.         1.
>  1181    RIGHT LAP            100000.    300.       0.         0.
>  1182    300.
>  1183    0.
>  1184    N1.        1.        0.
>  1185    J
>  1186    LEFT FOOT            RIGHT FOOT
>  1187
>  1188    J
>  1189    LEFT FOOT            SEAT CUSHION
>  1190
>  1191    J
>  1192    RIGHT FOOT           SEAT CUSHION
>  1193
>  1194    01.        0.        0.
```

TABLE 4. TYPICAL INPUT DATA SET (Page 2 of 3)

```
>  1195   01.     2.       0.
>  1196   02.     0.       0.
>  1197   02.     .0078    0.
>  1198   02.     .01      22.
>  1199   02.     .012     14.
>  1200   02.     .016     26.
>  1201   02.     .02      14.
>  1202   02.     .022     13.
>  1203   02.     .026     6.
>  1204   02.     .028     12.
>  1205   02.     .03      10.
>  1206   02.     .034     15.
>  1207   02.     .04      13.
>  1208   02.     .044     10.
>  1209   02.     .05      12.
>  1210   02.     .054     12.
>  1211   02.     .06      15.
>  1212   02.     .064     15.
>  1213   02.     .07      0.
>  1214   02.     .074     6.
>  1215   02.     .08      3.
>  1216   02.     .084     0.
>  1217   02.     2.       0.
>  1218   03.     0.       0.
>  1219   03.     2.       0.
>  1220   04.     0.       0.
>  1221   04.     2.       0.
>  1222   05.     0.       0.
>  1223   05.     2.       0.
>  1224   06.     0.       0.
>  1225   06.     2.       0.
>  1226   Q0.     1.       0.       0.        0.      0.
>  1227   R1.     1.       .0005    .005      10.     1.        .5       .0000001
>  1228   S.2     .005     10.      .000001   32.2              1.       100.
>  1229   T
>  1230   0.      00000000
>  1231   .05     00000000
>  1232   2.      00000000
>  1233   -1.
>  1234   J1.
>  1235   DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.
>  1236   REFERENCE 3-111,3-128, AND 101.
>  1237   V.2     .02      1000.    800000.   6.      .05       10.      10.
>  1238   W.75    .0       0.       0.        .1      .0000001  0.       0.
>  1239   Z
```

TABLE 4. TYPICAL INPUT DATA SET (Page 3 of 3)

Table 5. 6 Mass - 3D Model Input. Page 1 of 7

	Field	1	2	3	4	5	6	7	8
Inertial Properties	A	segment mass ID number	mass of body segment, lb.sec^2/in.	I about i-axis, in.lb.sec^2	I about j-axis, in.lb.sec^2	I about k-axis, in.lb.sec^2	$n=1.$ (ρ_{1P})	$n=1.$ (ρ_{1N})	$n=1.$ (ρ_{PH})
		1.=torso 2.=head 3.=right upper leg 4.=left upper leg 5.=right lower leg 6.=left lower leg					$n=2.$ (ρ_{2N})		(all inches)
							$n=3.$ (ρ_{3K})	$n=3.$ (ρ_{H3})	
							$n=4.$ (ρ_{4K})	$n=4.$ (ρ_{H4})	
								$n=5.$ (ρ_{K5})	
								$n=6.$ (ρ_{K6})	
Body Initial Conditions	B	segment mass ID number	$X_1(0)$ or $\psi_i(0)$	$Y_1(0)$ or $\theta_i(0)$	$Z_1(0)$ or $\phi_i(0)$	$\dot{X}_1(0)$ or $\dot{\psi}_i(0)$	$\dot{Y}_1(0)$ or $\dot{\theta}_i(0)$	$\dot{Z}_1(0)$ or $\dot{\phi}_i(0)$	
		0.=linear coordinates of torso 1.,...,6.=as on A card	inches or degrees						
			yaw	pitch (For masses 5 and 6, this column, relative pitch, is the only entry).	roll		(For masses 5 and 6, this column, relative pitch velocity is used).		
Vehicle Initial Conditions	C	n=0.	X_7	Y_7	Z_7	Ψ_7	Θ_7	Φ_7	
		n=1.	$\dot{X}_7$ in. or in/sec	$\dot{Y}_7$	$\dot{Z}_7$	$\dot{\Psi}_7$ deg. or deg/sec	$\dot{\Theta}_7$	$\dot{\Phi}_7$	

Table 5. 6 Mass - 3D Model Input. Page 2 of 7

	Field 1	2	3	4	5	6	7	8
Joints (pitch)	D joint number 1.=neck 2.=right hip 3.=left hip 4.=right knee 5.=left knee	pitch elastic coefficient, in.lb/rad.	pitch elastic rest angle, degrees. Position about which elastic torque is applied (see G-card, field 8)	upper pitch stop coefficient, in.lb/rad (angular motion positive)	lower pitch stop coefficient, in.lb/rad (angular motion negative)	pitch stop damping coefficient, in.lb.sec/rad	location of positive pitch stop, $\alpha_{\theta_+}(0)$ (applied yaw is zero) (degrees) η_2	location of negative pitch stop, $\alpha_{\theta_-}(0)$ (applied yaw is zero) (degrees) η_4
Joints (yaw)	E joint number 1.=neck 2.=right hip 3.=left hip	yaw elastic coefficient, in.lb/rad	yaw elastic rest angle, degrees Position about which elastic torque is applied (see G-card, field 8)	yaw stop coefficient, in.lb/rad	yaw damping coefficient, in.lb.sec/rad	location of positive yaw stop, degrees α_{ψ_+} η_1	maximum positive pitch with positive yaw stop applied, degrees $\alpha_{\theta_+}(\alpha_{\psi_+})$ η_3	minimum pitch with negative yaw stop applied, degrees $\alpha_{\theta_-}(\alpha_{\psi_-})$ η_5
Joints (roll)	F joint number 1.=neck 2.=right hip 3.=left hip	roll elastic coefficient, in.lb/rad	roll elastic rest angle, degrees Position about which elastic torque is applied (see G-card, field 8)	roll stop coefficient, in.lb/rad	roll damping coefficient, in.lb.sec/rad	positive roll at positive pitch, degrees $\alpha_{\phi_+}(0,\alpha_{\theta_+})$ η_6	maximum roll stop, degrees α_{ϕ_+} η_7	positive roll at negative pitch, degrees $\alpha_{\phi_+}(0,\alpha_{\theta_-})$ η_8
Joint (stop coupling)	G joint number 1.=neck 2.=right hip 3.=left hip	maximum positive roll at maximum positive yaw, degrees $\alpha_{\phi_+}(\alpha_{\psi_+},0)$ η_9	maximum negative roll with maximum positive yaw, degrees $\alpha_{\phi_-}(\alpha_{\psi_+},0)$ η_{10}	maximum positive roll with maximum positive yaw and pitch, degrees $\alpha_{\phi_+}(\alpha_{\psi_+},\alpha_{\theta_+})$ η_{11}	maximum negative roll with maximum positive yaw and pitch, degrees $\alpha_{\phi_-}(\alpha_{\psi_+},\alpha_{\theta_+})$ η_{12}	maximum positive roll with maximum positive yaw and maximum negative pitch, degrees $\alpha_{\phi_+}(\alpha_{\psi_+},\alpha_{\theta_-})$ η_{13}	maximum negative roll with maximum positive yaw and maximum negative pitch, degrees $\alpha_{\phi_-}(\alpha_{\psi_+},\alpha_{\theta_-})$ η_{14}	Switch: 0.= elastic rest angles D3, E3, F3 are relative to initial relative angles. 1.= relative to body orientation with zero relative angles

Table 5. 6 Mass - 3D Model Input. Page 3 of 7

	Field	1	2	3	4	5	6	7	8
Ellipsoid Contacts	H	body segment number 1.=torso 2.=head 3.=rul 4.=lul 5.=rll 6.=lll	x-coordinate of ellipsoid c.g. relative to body coordinates, in.	y-coordinate of ellipsoid c.g. relative to body coordinates, in.	z-coordinate of ellipsoid c.g. relative to body coordinates, in.	length of semi-axis in x-direction, a_m, in.	length of semi-axis in y-direction, b_m, in. (If sphere, leave blank)	length of semi-axis in z-direction, c_m, in. (If sphere, leave blank)	friction class $1. \leq n \leq 5.$
Ellipsoid Name	After each H card insert special card. Ellipsoid name (1-16)		▨	(Blank if rigid) (21-36)	Material name	▨			
Contact Surface Specification	I	1.=contact in inertial space. 0.=contact relative to vehicle.	n.=number of time points for which the location of this contact is specified.	Field set to negative number if origin on back side of contact and set to positive number if origin on front side of contact.	Penetration limit. (If ellipsoid center greater than this distance behind contact, initially, the logic waits for the ellipsoid to get out in front and begin a second penetration before applying force.	Edge constant. Choose based on most important assumed contact= $\left(\frac{\text{ellipsoid largest axis-semi}}{\text{length of contact surface}}\right)$ $0 < \lambda \leq .5$	friction class $1. \leq n \leq 10$		
Contact Surface Name	Contact name (1-16)		▨	Material name (21-36) (Blank if rigid)		Optional description of surface axes, etc. for page heading			
Contact Surface Name	time		switch 0.	center point x_1	y_1	z_1	outer point x_2	y_2	z_2
			1.	outer point, x_3	y_3	z_3			
			(2n cards will be read here, ordered in time)						

Table 5. 6 Mass - 3D Model Input. Page 4 of 7

	Field 1	2	3	4	5	6	7	8
Contact Inhibition Sequence	J Starts reading sequence							
	Ellipsoid name (1-16)		Ellipsoid or contact name (21-36)		Any pairs listed here will reverse default condition			
	Blank card to conclude contact inhibition sequence							
Belt Specification Cards	K n=1.≤n≤4.	x=belt anchor in vehicle, inches	y=belt anchor in vehicle, inches	z=belt anchor in vehicle, inches	x=belt point on body, inches	y=belt point on body, inches	z=belt point on body, inches	slack, inches
	Belt Name (1-24) (center for centered column headings)			Material Name (31-46) (center for centered column heading)		Body Material Name (51-66) if shared deflection between belt and torso; otherwise, blank (must be blank if eighth field is non-zero)		MBELT (0.) 0.= force based on belt deflection Non-zero = force based on belt strain
Belt Pairings	L belts 1-2 switch	belts 1-3 switch 1.=influencer influencee pair 2.=influencee influencer pair	belts 1-4 switch 0.=no coupling	belts 2-3 switch -1.=free slipping (force equalization) (A maximum of two pairs, 1-2, 3-4 or 1-3, 2-4 or 1-4, 2-3 may slip) and then influencer-influencee combination.	belts 2-4 switch is applied. -2.=same as -1. except influencee-influencer applied. -3.=pure free slipping	belts 3-4 switch	INFL Influence type 0.=no influence 1.=friction 2.=saturation based on force difference 3.=percent influence	ZINFL (needed only for INFL = 1). Enter value from 0. to 1. Zero or a value near zero is recommended. (See Section I.2.A.)
	pair number 1.=1-2 2.=1-3 3.=1-4 4.=2-3 5.=2-4 6.=3-4 (in order)	For influencer-influencee pair, if INFL is 1.=static friction coefficient, 2.=ΔF, the saturation force difference 3.=percent influence (fractional)	For influencer-influencee pair, if INFL is 1.=kinetic friction coefficient 2.=(not used) 3.=maximum influence force, lbs.	Material name for free slipping (31-46) (center for centered column heading)	(This card must be added for each pair having coupling).			

Table 5. 6 Mass - 3D Model Input. Page 5 of 7

	Field	1	2	3	4	5	6	7	8
Material Property Cards	M	$\delta_\alpha = \delta_A =$ deflection at peak inertial force, inches	$\delta_\beta = \delta_B =$ stop use of auxiliary polynomial, inches	$\delta_\gamma = \delta_C =$ elastic limit, inches	$\delta_b = \delta_D =$ breaking point, inches	$\delta_F =$ endpoint of break down curve, inches	G=ratio of permanent deformation to maximum deflection in plastic region G=positive constant from 0. to 1. If -n is put in where n $\geq$ 8., then G is read from Table n.	R=ratio of conserved energy to total energy R=positive constant from 0. to 1. If -n is put in where n$\geq$8., then R is read from Table n.	ϵ_p=convergence epsilon for shared deflection interactions, lbs. (Compares forces on the two surfaces. Differences should be less than this number, e.g., 1 lb.)
		(for belt materials the first five fields must be strain values, non-dimensional, if force strain option has been selected for belts) $(0 \leq \delta_A \leq \delta_B \leq \delta_D < \delta_F \, ; \quad \delta_C \geq 0)$							
		Material name (1-16) (must be centered if material name is centered on belt cards)		F_{max} = saturation force limit, pounds	β = slope of saturation unloading curve, lb/in (or lb/unit strain; see M-card)	n=0. Next card is read for polynomial coefficients of static F-δ curve) n$\geq$ 8. (Static curve specified as Table n)	n=0. (Next card is read for polynomial coefficients of inertia spike. n$\geq$ 8. (Inertia spike specified as Table n)		
		C_1	C_2	C_3	C_4	C_5	C_6		
		There may be two cards here defining the two possible polynomials $F = C_1\delta + C_2\delta^2 + C_3\delta^3 + C_4\delta^4 + C_5\delta^5 + C_6\delta^6$							
Contact Friction Specification	N	Ellipsoid friction class 1.$\leq$ n$\leq$ 5.	contact friction class 1.$\leq$ n$\leq$10.	friction coefficient					

Table 5. 6 Mass - 3D Model Input. Page 6 of 7

	Field	1	2	3	4	5	6	7	8
Tables Vehicle Acceleration, Debug, G and R, F-δ	O	Table number 1-6=acceleration 7=debug ≥8=material (There may be up to 60 tables)	Time G and R tables needs Ω =maximum deflection before unload, inches F-δ table, deflection, in.	Acceleration g's for tables 1-3 Tables 4-6, rad/sec^2 G or R in this column F-δ table, Force, lbs.		Table numbers 1.= $\ddot{x}_7$ 2.= $\ddot{y}_7$ 3.= $\ddot{z}_7$ 4.= $\dot{\psi}_7$ 5.= $\ddot{\theta}_7$ 6.= $\ddot{\phi}_7$			
Table Delete	P	Table number from 0-card	First point in time to partially delete 0-table.	Final point in time to partially delete 0-table.					
	Q	Modify Table 1 by constant multiplier given here.	Modify Table 2	Modify Table 3	Modify Table 4	Modify Table 5	Modify Table 6		
Integration Control	R	starting integration method 0.=Euler 1.=modified Runge-Kutta 2.=regular Runge-Kutta. (1.)	predictor corrector method 0.=Adams 1.=Milne (Euler and Adams are more stable) (1.)	maximum integration time step (.0005)	velocity convergence parameter (.005)	maximum number of subdivisions of maximum time step (10.)	velocity change limit (1.)	extrapolation change limit (.5)	acceleration minimum magnitude (.0000001)
Miscellaneous Control	S	real time interval for simulation, sec. (.2)	time step between tabular output items, sec. (.005)	execution time limit (10.)	time epsilon, sec. (.000001)	gravity, ft/sec (32.2)	Time output switch 0.= sec; Non-zero = msec (0.)	linear integration weights (1.)	angular integration weights (100.)

Table 5. 6 Mass - 3D Model Input. Page 7 of 7

	Field	1	2	3	4	5	6	7	8
Debug Control Cards	T	Triggers debug cards.							
		effective time (negative value terminates sequence)	hexadecimal debug control word						
Title Card	U	n=0.=one card read n=1.=two cards read							
		(The eighty columns on this card comprise the first part (or all) of the title.							
		(The first 52 columns comprise (if used) the rest of the title.							
	V	DSTEPX (.2) Maximum step to search for balance in shared deflection, inches	DSTEPN (.02) Minimum step to search for balance in shared deflection, inches	FORLIM (1000.) Limit of change in force for rigid-rigid contact before halving, lbs.	HARDCN (15,000.) Linear elastic coefficient for use in rigid-rigid contact, lb/in.	LIMCNT (6.) Limit on number of iterations for force balancing in shared deflection.	TPC (.05) Fractional of current ramp length in moving contacts.	EPSFAC (10.) Number of maximum integration time steps for maximum ramp length in moving contacts.	FNU (10.) Length of friction ramp in in/sec. (contact friction)
	W	BETELP (.75) Minimum ratio of shortest to longest semi-major axis to be treated as sphere for ellipsoid contacts.	GAMELP (.9) Fractional position of sphere center along semi-major axis relative to position for sphere-ellipsoid tangency at end of semi-major axis.	ILONG (0.) Non-zero switch causes non-sequential paging of output.	ISTAT (0.) Switch for output units of vehicle velocities and accelerations. 0. = in/sec and G's neg.= in/sec and in/sec^2 pos.= mph and G's	ZERA (.1) Proximity epsilon for nearness to pole at $\pi/2$ in radians for pitch.	ZERB (.000001) Proximity epsilon for sine of pitch near pole at $\pi/2$.	IUIS (0.) Printing of body segment c.g. displacement and velocity, feet, knees, H-point, and ellipsoid centers. 0. = relative to vehicle origin. -1. = inertial. 1.= relative to time zero H-point.	IACC (0.) Zero yields body acceleration in G's. One yields body acceleration in in/sec^2 (all absolute.)
	Z	(GO card)							

B. DESCRIPTION OF NORMAL PROGRAM OUTPUT

The printed output of this model is divided into three general categories. The first category is normal output, that which emerges from a successful run when no special information is required. The second category is auxiliary or debugging output, which is extensive information on the inner workings of the program under control of the input data. The third category is messages which appear only when certain error conditions arise. This section deals with the first category. Section IV of Appendix A presents the other two categories.

Normal output is divided into two parts. The first part is one or more pages at the beginning and presents the input data which has been supplied by the user. The second part is the bulk of the normal output and records the simulated model parameters over the time interval of interest.

Each page of normal output begins with a heading. The first line identifies the model, the part of normal output in which this page is included, the date of the run, and the page number. The second line is a descriptive run title supplied by the user (See Table 5, V-card). The next lines are unique to each page and define units and reference coordinate systems as appropriate.

Table 6, consisting of 29 pages, contains a sample output from the model. The input data used to generate this result is included in Table 4. Also, this is the same run as has been used in the preliminary experimental verification discussed in Part IV C. This run was designed to duplicate an impact sled test. The 50th percentile Sierra dummy was seated in an automotive bucket seat and restrained by a single diagonal harness and lap belt combination. The deceleration pulse represents a direct side impact.

The first three pages of Table 6 list the data which has been read by the input section of the model. Line numbers are provided and the data file is broken up into nine columns. The first column contains card identification letters and the second contains other numeric information included in the first field of the particular card.

Pages 4 through 15 of Table 6 contain body kinematics. Two sheets of data are provided for each segment consisting of x, y, and z displacements, velocities, and accelerations of the center of gravity plus the same quantities for pitch, roll and yaw. The lower legs are handled a bit differently than the other body segments because there is only one angular degree of freedom. In addition to x, y, z, and pitch displacements, velocities, and accelerations, the location of the knee and foot are given. It should be noted that center of gravity displacement and velocities can be printed out relative to the vehicle origin, relative to the H-point, or inertial. This has particular application both to pedestrian motions and vehicle occupant motions.

Pages 15 through 18 of Table 6 deal with joint relative Euler angles and angular velocities about the coordinate axes of each body segment. This gives an indication of the level of motion occuring between the various body segments. The neck, right hip, and left hip joints are included on page 16 of Table 6. It should be recalled that knee pitch is a degree of freedom and has been included with the particular lower leg element.

Vehicle kinematics are included on pages 19 and 20 of Table 6. Displacements, velocities, and accelerations for forward, side, upward, pitching, spinning, and rollover motions are included.

Information on belts is included on page 21 of Table 6. It should be recalled that each belt segment which is used has been given a name and assigned a material on the input data card following the K-card (See Tables 4 and 5). These names are used in dynamic labelling of the belt tabular output. For each belt, its elongation, elongation rate, and the resulting force are given or, optionally, strain and strain rate.

Pages 22 through 24 of Table 6 are concerned primarily with torques applied at the various joints. Page 22 lists elastic joint moments while page 23 lists stop moments for neck, right hip, and left hip. Knee elastic and stop moments are given on page 24. This is supplemented by potential energy stored in the knee structures as well as H-point location. Location of the H-point is inertial, relative to the vehicle, or relative to the initial H-point position in the vehicle.

Pages 25 and 26 of Table 6 summarize energy and momentum quantities. Kinetic energies are listed for each body segment as well as potential energy quantities stored in individual joints, all belts, and all contacts. A total is computed. Total moments are given on page 26. The linear quantities are self-explanatory. The three columns under the heading "ANGULAR," are total angular momenta. The three columns under the heading "COMPONENT ABOUT C.G. " are the portions of total angular momenta resulting from angular velocity $(I \cdot \omega)$, as opposed to $m(\vec{r} \times \vec{v})$ terms.

Page 27 of Table 6 is a summary of the integration performance. The heading "CPU TIME," represents the total computer time used in seconds.

The numbers under "EVAL" give the total number of calls to the subroutine "ACCEL." This refers to the total number of computations of the derivatives, forces moments, etc. necessary for solving the equations of motion. "DENS" is a measure of the integration and is a computation of the number of integration steps since the last print time divided by the minimum possible number of steps which could occur in the particular print time interval. The numbers under "STEPS" represent the total number of integration steps accumulated up to a particular point in simulation time. The remaining columns refer to the number of integration steps of a particular size which have been accumulated up to a point in time. "WHOLE" refers to the number of times the integration time step is the maximum allowed. "HALF" refers to the number of times it has been cut in half, etc.

The last two pages of Table 6 are samples of printout occurring when contact forces are generated. The dynamic titling includes a body ellipsoid and its material on the first line. Another body ellipsoid or a contact surface and its material are included on the other line. If no contact is sensed between two eligible surfaces, this page will not be produced. A tabulation of the quantities listed on this page is included as Table 7 completing the description of normal program output.

```
 1 A          1.0000000     0.2340000    12.7800000    11.5000000      3.6500000      8.3750000     11.5000000      3.7500000
 2 A          2.0000000     0.0408000     0.3672000     0.4420000      0.2210000      6.0000000      0.0            0.0
 3 A          3.0000000     0.0522000     0.1970000     1.3100000      1.3100000      9.0000000      7.5000000      0.0
 4 A          4.0000000     0.0522000     0.1970000     1.3100000      1.3100000      9.0000000      7.5000000      0.0
 5 A          5.0000000     0.0254000     1.2000000     1.2000000      0.0508000      0.0           10.1250000      0.0
 6 A          6.0000000     0.0254000     1.2000000     1.2000000      0.0508000      0.0           10.1250000      0.0
 7 B          0.0          18.4000000     0.0          19.0000000      0.0         -335.0000000      0.0            0.0
 8 B          1.0000000     0.0          20.0000000     0.0            0.0            0.0            0.0            0.0
 9 B          2.0000000     1.4000000     0.8000000   -31.6000000      0.0            0.0            0.0            0.0
10 B          3.0000000     0.0          13.0000000     0.0            0.0            0.0            0.0            0.0
11 B          4.0000000     0.0          13.0000000     0.0            0.0            0.0            0.0            0.0
12 B          5.0000000     0.0          17.0000000     0.0            0.0            0.0            0.0            0.0
13 B          6.0000000     0.0          17.0000000     0.0            0.0            0.0            0.0            0.0
14 C          0.0           0.0           0.0           0.0            0.0            0.0            0.0            0.0
15 C          1.0000000     0.0        -335.0000000     0.0            0.0            0.0            0.0            0.0
16 D          1.0000000   600.0000000   -13.2000000 150000.0000000 150000.0000000      2.0000000     70.0000000    -70.0000000
17 D          2.0000000   800.0000000    -7.0000000 150000.0000000 150000.0000000      2.0000000     45.0000000    -30.0000000
18 D          3.0000000   800.0000000    -7.0000000 150000.0000000 150000.0000000      2.0000000     45.0000000    -30.0000000
19 D          4.0000000   250.0000000    17.0000000 100000.0000000 100000.0000000      2.0000000     70.0000000    -30.0000000
20 D          5.0000000   250.0000000    17.0000000 100000.0000000 100000.0000000      2.0000000     70.0000000    -30.0000000
21 E          1.0000000   600.0000000     1.4000000 110000.0000000      2.0000000     60.0000000     70.0000000    -70.0000000
22 E          2.0000000   800.0000000     0.0      110000.0000000      2.0000000     45.0000000     45.0000000    -30.0000000
23 E          3.0000000   800.0000000     0.0      110000.0000000      2.0000000     45.0000000     45.0000000    -30.0000000
24 F          1.0000000   600.0000000   -32.1000000 110000.0000000      2.0000000     50.0000000     50.0000000     50.0000000
25 F          2.0000000   800.0000000     0.0      110000.0000000      2.0000000     30.0000000     30.0000000     30.0000000
26 F          3.0000000   800.0000000     0.0      110000.0000000      2.0000000     30.0000000     30.0000000     30.0000000
27 G          1.0000000    50.0000000    50.0000000    50.0000000     50.0000000     50.0000000     50.0000000      1.0000000
28 G          2.0000000    30.0000000    30.0000000    30.0000000     30.0000000     30.0000000     30.0000000      1.0000000
29 G          3.0000000    30.0000000    30.0000000    30.0000000     30.0000000     30.0000000     30.0000000      1.0000000
30 H          1.0000000     0.0          -3.3000000    -7.1000000      3.8700000      0.0            0.0            1.0000000
31      LEFT CHEST
32 H          1.0000000     0.0           3.3000000    -7.1000000      3.8700000      0.0            0.0            1.0000000
33      RIGHT CHEST
34 H          1.0000000     0.0          -3.3000000     7.1000000      3.8000000      0.0            0.0            1.0000000
35      LEFT HIP
36 H          1.0000000     0.0           3.3000000     7.1000000      3.8000000      0.0            0.0            1.0000000
37      RIGHT HIP
38 H          5.0000000     0.0           0.0           6.0000000      3.8970000      0.0            0.0            1.0000000
39      RIGHT FOOT
40 H          6.0000000     0.0           0.0           6.0000000      3.8970000      0.0            0.0            1.0000000
41      LEFT FOOT
42 I          0.0           1.0000000    -1.0000000    15.0000000      0.0900000      1.0000000      0.0            0.0
43      SEAT BACK                MAT1
44            0.0           0.0          11.0000000    11.0000000     10.0000000     11.0000000    -30.0000000     10.0000000
45            0.0           1.0000000    22.1000000    11.0000000     39.9000000      0.0            0.0            0.0
46 I          0.0           1.0000000     1.0000000    15.0000000      0.0900000      1.0000000      0.0            0.0
47      SEAT CUSHION             MAT1
48            0.0           0.0           3.4000000    11.0000000     32.3000000      8.4000000    -30.0000000     32.3000000
49            0.0           1.0000000    36.0000000    11.0000000     26.0000000      0.0            0.0            0.0
50 I          0.0           1.0000000     1.0000000    15.0000000      0.0900000      1.0000000      0.0            0.0
51      FLOOR                    MAT1
52            0.0           0.0          30.0000000    11.0000000     41.0000000     30.0000000    -30.0000000     41.0000000
53            0.            1.0000000    60.0000000    11.0000000     41.0000000      0.0            0.0            0.0
54 K          1.0000000     0.0          -3.5000000     0.0            0.0           -2.5000000    -11.0000000      0.0
55      LEFT SHOULDER                   LEFT SHOULDER
56 K          2.0000000    14.5000000    11.0000000    36.0000000      0.0            5.3000000      1.7000000      1.5000000
57      RIGHT SHOULDER                  RIGHT SHOULDER
58 K          3.0000000    14.5000000   -11.0000000    36.0000000      0.0           -7.1000000      7.2000000      0.0
59      LEFT LAP                        LEFT LAP
```

TABLE 6. SAMPLE PROGRAM OUTPUT (Page 1 of 29)

```
 60 K        4.0000000   14.5000000     11.0000000    36.0000000     0.0           7.1000000     7.2000000      1.5000000
 61    RIGHT LAP                       RIGHT LAP
 62 A              0.0   0.0           1000.0000000  2000.0000000  3000.0000000     0.0          1.0000000      1.0000000
 63    MAT1                          1000000.0000000       500.0000000          0.0                0.0
 64        500.0000000   0.0              0.0           0.0          0.0            0.0
 65                0.0   0.0              0.0           0.0          0.0            0.0
 66 A              0.0   0.0           1000.0000000  2000.0000000  3000.0000000     0.0          1.0000000      1.0000000
 67    LEFT SHOULDER                 1000000.0000000       240.0000000          0.0                0.0
 68        240.0000000   0.0              0.0           0.0          0.0            0.0
 69                0.0   0.0              0.0           0.0          0.0            0.0
 70 A              0.0   0.0           1000.0000000  2000.0000000  3000.0000000     0.0          1.0000000      1.0000000
 71    RIGHT SHOULDER                1000000.0000000       240.0000000          0.0                0.0
 72        240.0000000   0.0              0.0           0.0          0.0            0.0
 73                0.0   0.0              0.0           0.0          0.0            0.0
 74 A              0.0   0.0           1000.0000000  2000.0000000  3000.0000000     0.0          1.0000000      1.0000000
 75    LEFT LAP                      1000000.0000000       467.0000000          0.0                0.0
 76        467.0000000   0.0              0.0           0.0          0.0            0.0
 77                0.0   0.0              0.0           0.0          0.0            0.0
 78 A              0.0   0.0           1000.0000000  2000.0000000  3000.0000000     0.0          1.0000000      1.0000000
 79    RIGHT LAP                     1000000.0000000       300.0000000          0.0                0.0
 80        300.0000000   0.0              0.0           0.0          0.0            0.0
 81                0.0   0.0              0.0           0.0          0.0            0.0
 82 N        1.0000000   1.0000000        0.0           0.0          0.0            0.0          0.0            0.0
 83 J              0.0   0.0              0.0           0.0          0.0            0.0          0.0            0.0
 84    LEFT FOOT                RIGHT FOOT
 85
 86 J              0.0   0.0              0.0           0.0          0.0            0.0          0.0            0.0
 87    LEFT FOOT                SEAT CUSHION
 88
 89 J              0.0   0.0              0.0           0.0          0.0            0.0          0.0            0.0
 90    RIGHT FOOT               SEAT CUSHION
 91
 92 J        1.0000000   0.0              0.0           0.0          0.0            0.0          0.0            0.0
 93 J        1.0000000   2.0000000        0.0           0.0          0.0            0.0          0.0            0.0
 94 J        2.0000000   0.0              0.0           0.0          0.0            0.0          0.0            0.0
 95 J        2.0000000   0.0078000        0.0           0.0          0.0            0.0          0.0            0.0
 96 J        2.0000000   0.0100000      22.0000000      0.0          0.0            0.0          0.0            0.0
 97 J        2.0000000   0.0120000      14.0000000      0.0          0.0            0.0          0.0            0.0
 98 J        2.0000000   0.0160000      25.0000000      0.0          0.0            0.0          0.0            0.0
 99 J        2.0000000   0.0200000      14.0000000      0.0          0.0            0.0          0.0            0.0
100 J        2.0000000   0.0220000      13.0000000      0.0          0.0            0.0          0.0            0.0
101 J        2.0000000   0.0260000        6.0000000     0.0          0.0            0.0          0.0            0.0
102 J        2.0000000   0.0280000      12.0000000      0.0          0.0            0.0          0.0            0.0
103 J        2.0000000   0.0300000      10.0000000      0.0          0.0            0.0          0.0            0.0
104 J        2.0000000   0.0340000      15.0000000      0.0          0.0            0.0          0.0            0.0
105 J        2.0000000   0.0400000      13.0000000      0.0          0.0            0.0          0.0            0.0
106 J        2.0000000   0.0440000      10.0000000      0.0          0.0            0.0          0.0            0.0
107 J        2.0000000   0.0500000      12.0000000      0.0          0.0            0.0          0.0            0.0
108 J        2.0000000   0.0540000      12.0000000      0.0          0.0            0.0          0.0            0.0
109 J        2.0000000   0.0600000      15.0000000      0.0          0.0            0.0          0.0            0.0
110 J        2.0000000   0.0640000      15.0000000      0.0          0.0            0.0          0.0            0.0
111 J        2.0000000   0.0700000        9.0000000     0.0          0.0            0.0          0.0            0.0
112 J        2.0000000   0.0740000        5.0000000     0.0          0.0            0.0          0.0            0.0
113 J        2.0000000   0.0800000        3.0000000     0.0          0.0            0.0          0.0            0.0
114 J        2.0000000   0.0840000        0.0           0.0          0.0            0.0          0.0            0.0
115 J        2.0000000   2.0000000        0.0           0.0          0.0            0.0          0.0            0.0
116 J        3.0000000   0.0              0.0           0.0          0.0            0.0          0.0            0.0
117 J        3.0000000   2.0000000        0.0           0.0          0.0            0.0          0.0            0.0
118 J        4.0000000   0.0              0.0           0.0          0.0            0.0          0.0            0.0
119 J        4.0000000   2.0000000        0.0           0.0          0.0            0.0          0.0            0.0
```

TABLE 6. SAMPLE PROGRAM OUTPUT (Page 2 of 29)

```
 120 0         5.0000000       0.0             0.0            0.0            0.0            0.0            0.0            0.0
 121 0         5.0000000       2.0000000       0.0            0.0            0.0            0.0            0.0            0.0
 122 0         5.0000000       0.0             0.0            0.0            0.0            0.0            0.0            0.0
 123 0         6.0000000       2.0000000       0.0            0.0            0.0            0.0            0.0            0.0
 124 2         0.0             1.0000000       0.0            0.0            0.0            0.0            0.0            0.0
 125 8         1.0000000       1.0000000       0.0025000      0.0025000      10.0000000     1.0000000      0.5000000      0.0000001
 126 3         1.2000000       0.0050000      10.0000000      0.0000010      32.2000000     0.0            1.0000000    100.0000000
 127 4         0.0             0.0             0.0            0.0            0.0            0.0            0.0            0.0
 128                 0.0                 00000000
 129                 0.0500000           00000000
 130                 2.0000000           00000000
 131                -1.0000000           00000000
 132 0         1.0000000       0.0             0.0            0.0            0.0            0.0            0.0            0.0
 134
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                             REFERENCE 3-111,3-128, AND 191.
 135 4         0.2000000       0.0200000    1000.0000000 80000.0000000      6.0000000      0.0500000     10.0000000     10.0000000
 136 4         0.7500000       0.9000000       0.0            0.0            0.1000000      0.0000010      0.0            0.0
 137 4         0.0             0.0             0.0            0.0            0.0            0.0            0.0            0.0
```

TABLE 6. SAMPLE PROGRAM OUTPUT (Page 3 of 29)

```
                         THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                NOV 15, 1972   PAGE   1
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                     REFERENCE 3-111,3-128, AND 191.
                          UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                 DISPLACEMENTS AND VELOCITIES ARE RELATIVE TO THE ORIGIN OF THE VEHICLE COORDINATE SYSTEM.
                                      ACCELERATIONS IN G'S

                                       BODY KINEMATICS


                                             HEAD

   TIME          X-DISP.   X-VEL.  X-ACCEL.     Y-DISP.    Y-VEL.  Y-ACCEL.     Z-DISP.    Z-VEL.  Z-ACCEL.

0.0                13.94     0.0      -0.0       -3.16      0.0       -0.3        3.12      0.0        0.3
0.0050             13.94   -0.03      -0.0       -3.16     -0.52      -0.3        3.12      0.63       0.3
0.0100             13.94   -0.16      -0.0       -3.17    -10.39      -0.3        3.13      1.27       0.3
0.0150             13.94   -0.23      -0.0       -3.31    -46.26      -0.3        3.13      1.89       0.3
0.0200             13.94   -0.35      -0.1       -3.65    -87.14      -0.3        3.14      2.51       0.3
0.0250             13.93   -0.43      -0.1       -4.15   -110.10      -0.3        3.16      3.09       0.3
0.0300             13.93   -0.56      -0.1       -4.74   -128.71      -0.3        3.18      3.62       0.3
0.0350             13.93   -0.71      -0.1       -5.45   -154.25      -0.3        3.19      4.09       0.2
0.0400             13.92   -0.86      -0.1       -6.29   -181.47      -0.3        3.22      4.49       0.2
0.0450             13.92   -0.97       0.0       -7.25   -203.44       0.3        3.24      5.10       0.8
0.0500             13.91   -0.70       0.3       -8.32   -223.25       1.6        3.27      8.26       2.4
0.0550             13.91    0.10       0.6       -9.48   -242.23       2.9        3.33     14.43       3.9
0.0600             13.92    1.66       1.0      -10.74   -262.10       4.1        3.42     23.09       5.0
0.0650             13.93    4.30       1.7      -12.10   -282.23       4.8        3.56     33.67       5.9
0.0700             13.96    8.27       2.4      -13.55   -294.49       5.5        3.76     45.67       6.5
0.0750             14.02   13.40       2.9      -15.03   -296.95       6.3        4.02     58.79       7.1
0.0800             14.10   18.76       2.4      -16.51   -291.45       8.1        4.35     73.29       8.0
0.0850             14.20   22.46       1.3      -17.93   -275.54      10.9        4.76     89.84       9.1
0.0900             14.32   23.84       0.1      -19.25   -250.94      14.8        5.25    108.62      10.4
0.0950             14.44   23.12      -0.8      -20.42   -216.98      20.8        5.85    130.53      12.5
0.1000             14.55   21.56      -0.7      -21.40   -168.97      29.3        6.56    156.98      14.8
0.1050             14.65   19.80      -4.3      -22.08   -102.81      41.0        7.42    185.62       5.2
0.1100             14.67  -23.54     -33.8      -22.38    -13.59      44.8        8.19     90.51     -86.6
0.1150             14.42  -65.32       0.1      -22.24     67.71      36.2        8.27    -32.26      -9.4
0.1200             14.11  -57.43       3.9      -21.74    126.75      27.5        8.13    -25.04       4.1
0.1250             13.84  -49.53       4.7      -20.98    178.58      27.2        8.02    -16.57       4.9
0.1300             13.62  -39.62       5.6      -19.95    232.73      28.8        7.97     -5.17       6.8
0.1350             13.45  -27.59       7.4      -18.65    287.89      27.8        7.98      9.76       9.7
0.1400             13.36   -5.01      15.6      -17.06    348.20      32.5        8.08     33.60      12.2
0.1450             13.39   14.71      22.7      -15.20    388.92      10.2        8.01    -66.27      27.4
0.1500             13.61   53.13       4.2      -13.22    410.24      12.6        7.80   -101.20     -38.1
0.1550             13.85   45.33       0.9      -11.10    435.73      16.8        7.14   -162.55     -83.5
0.1600             14.11   58.03       6.6       -8.84    463.35       8.9        6.08   -215.67       7.6
0.1650             14.42   66.11       2.1       -6.48    477.25       5.9        5.04   -201.80       6.6
0.1700             14.76   67.53      -0.4       -4.07    487.02       4.2        4.06   -189.55       6.5
0.1750             15.09   66.17      -0.7       -1.62    494.40       3.5        3.15   -173.65      10.9
0.1800             15.42   66.03       0.2        0.87    500.40       2.0        2.35   -142.68      21.6
0.1850             15.75   64.73      -2.1        3.37    497.62      -6.2        1.76    -89.16      34.2
0.1900             16.06   57.51      -5.1        5.81    470.14     -23.7        1.51     -7.94      49.7
0.1950             16.32   46.53      -6.3        8.01    403.13     -45.0        1.72     94.64      53.0
0.2000             16.53   49.66      23.3        9.78    306.43     -52.6        2.44    195.10      56.4
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 4 of 29)

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                         THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA             NOV 15, 1972  PAGE  3
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                   REFERENCE 3-111,3-128, AND 191.
                        UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                                  ACCELERATIONS IN RAD/SEC/SEC

                                         BODY KINEMATICS


                                              HEAD


                             YAW                             PITCH                           ROLL

   TIME            DISP.     VEL.     ACCEL.      DISP.     VEL.     ACCEL.      DISP.     VEL.      ACCEL.

0.0                1.40      0.0       -4.8       6.80      0.0        5.5      -31.60      0.0       -32.5
0.0050             1.40     -1.33      -4.9       6.80      1.55       5.2      -31.62     -9.27      -32.0
0.0100             1.39     -2.53      -5.1       6.82      2.98       4.8      -31.69    -18.27      -31.2
0.0150             1.37     -4.30      -5.4       6.83      4.24       4.0      -31.81    -27.03      -29.9
0.0200             1.34     -5.83      -5.7       6.86      5.22       2.8      -31.96    -35.35      -28.2
0.0250             1.31     -7.59      -6.1       6.89      5.85       1.6      -32.16    -43.18      -26.4
0.0300             1.27     -9.40      -6.6       6.92      6.13       0.4      -32.39    -50.50      -24.7
0.0350             1.21    -11.33      -7.1       6.95      6.29      -0.5      -32.66    -57.33      -23.0
0.0400             1.15    -13.51      -7.9       6.98      5.88      -0.9      -32.97    -63.67      -21.3
0.0450             1.08    -16.14     -11.7       7.00      6.01       4.1      -33.30    -70.40      -34.2
0.0500             0.99    -20.04     -14.4       7.04      8.72      15.5      -33.68    -85.09      -68.8
0.0550             0.88    -24.06     -15.0       7.10     16.53      45.3      -34.17   -110.38     -109.8
0.0600             0.75    -23.43     -15.3       7.23     37.09     101.6      -34.81   -148.86     -160.4
0.0650             0.59    -34.23     -26.8       7.50     78.44     190.7      -35.67   -192.87     -134.1
0.0700             0.40    -43.71     -36.5       8.05    144.91     266.5      -36.72   -226.36     -104.1
0.0750             0.15    -55.07     -37.4       8.98    224.96     277.9      -37.92   -256.16     -112.3
0.0800            -0.14    -54.17      74.4      10.27    284.10      87.2      -39.31   -302.42     -242.0
0.0850            -0.31     -7.30     255.8      11.68    264.39    -232.6      -41.05   -406.65     -504.4
0.0900            -0.12     91.53     428.8      12.76    151.91    -540.3      -43.52   -600.10     -855.2
0.0950             0.68    233.11     546.9      13.08    -32.38    -715.4      -47.22   -895.77    -1194.3
0.1000             2.22    378.63     414.8      12.42   -223.60    -561.4      -52.62  -1273.03    -1406.7
0.1050             4.35    454.47    -177.4      10.97   -346.31    -650.4      -59.99  -1662.10     -463.5
0.1100             5.54   -174.93   -4338.6       7.46  -1330.35   -6154.6      -66.39   -549.67     6595.1
0.1150             0.82  -1713.07   -3540.2      -3.74  -2918.43    -654.2      -64.96    840.47      608.6
0.1200            -9.14  -2188.03    -859.7     -17.43  -2532.88    1401.9      -61.29    603.45     -970.7
0.1250           -20.34  -2217.91     698.1     -29.09  -2128.15    1479.5      -59.06    255.35    -1613.1
0.1300           -30.45  -1727.37    2784.4     -38.61  -1661.39    1845.6      -59.13   -320.40    -2447.0
0.1350           -36.65   -695.47    3843.2     -45.41  -1005.53    2928.2      -62.67  -1093.17    -2439.7
0.1400           -37.75    159.31    1930.5     -48.06    -20.20    3581.9      -69.51  -1570.95     -971.6
0.1450           -46.07  -4071.30    6185.8     -57.74  -3680.34   18777.6      -67.44   2973.11    -3477.7
0.1500           -51.26  -4475.43  -22939.8     -61.05  -2758.05      17.0      -64.76   4082.43    22992.0
0.1550           -57.82    663.62  -36424.3     -55.1    3474.78  -22785.1      -58.30   -223.73    35987.7
0.1600           -67.29  -1523.14    7703.1     -46.49   1850.89    3759.9      -47.21   2008.76    -5692.4
0.1650           -69.85    378.67    5337.6     -34.96   2680.39    2052.6      -40.35    939.34    -1581.3
0.1700           -64.60   1648.43    3847.1     -20.48   3032.50     394.8      -35.91    994.28     1715.1
0.1750           -53.64   2746.93    4004.1      -5.51   2849.27   -1845.0      -29.16   1804.82     3778.9
0.1800           -36.95   3327.03    3932.8       6.63   1867.24   -5131.4      -17.13   3005.99     4216.1
0.1850           -15.08   4650.06     376.7      11.44   -124.57   -6429.4        0.37   3869.27     1109.4
0.1900             7.10   3977.03   -4621.7       4.58  -2597.81   -7974.1       19.28   3455.24    -3688.5
0.1950            23.37   2481.83   -5153.2     -13.24  -4347.41   -4038.9       33.46   2178.76    -4544.3
0.2000            26.64  -4650.84  -50479.4     -32.83   -534.44   45218.3       44.64   4643.16    29874.0
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 5 of 29)

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                          THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA              NOV 15, 1972   PAGE  5
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                               REFERENCE 3-111,3-128, AND 191.
                          UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                 DISPLACEMENTS AND VELOCITIES ARE RELATIVE TO THE ORIGIN OF THE VEHICLE COORDINATE SYSTEM.
                                             ACCELERATIONS IN G'S

                                               BODY KINEMATICS


                                                    TORSO

    TIME          X-DISP.    X-VEL.  X-ACCEL.    Y-DISP.    Y-VEL.  Y-ACCEL.     Z-DISP.    Z-VEL.  Z-ACCEL.

  0.0              18.40     0.0        0.1       0.0        0.0        0.1       19.00      0.0        0.0
  0.00500          18.40     0.26       0.1       0.00       0.10       0.0       19.00      0.04       0.0
  0.01000          18.40     0.43       0.1      -0.01      -9.16       0.0       19.00      0.09       0.0
  0.01500          18.41     0.67       0.1      -0.14     -44.43       0.0       19.00      0.17       0.0
  0.02000          18.41     0.77       0.0      -0.47     -84.72       0.0       19.00      0.27       0.1
  0.02500          18.41     0.80      -0.0      -0.95    -107.09       0.0       19.00      0.38       0.1
  0.03000          18.42     0.75      -0.0      -1.53    -125.12       0.0       19.01      0.49       0.0
  0.03500          18.42     0.64      -0.1      -2.21    -150.10       0.0       19.01      0.56       0.0
  0.04000          18.42     0.50      -0.1      -3.03    -176.76       0.0       19.01      0.59       0.0
  0.04500          18.43     0.24      -0.3      -3.97    -198.16       0.6       19.01      0.88       0.7
  0.05000          18.42    -0.74      -0.7      -5.01    -217.19       2.1       19.02      3.71       2.3
  0.05500          18.42    -2.34      -0.8      -6.14    -234.54       4.1       19.06      9.39       3.5
  0.06000          18.40    -3.72      -0.5      -7.36    -251.03       6.4       19.12     17.09       4.3
  0.06500          18.36    -4.26      -0.1      -8.65    -264.44       9.7       19.23     26.66       5.7
  0.07000          18.36    -3.83       0.5      -9.98    -264.12      13.7       19.39     38.52       6.5
  0.07500          18.34    -2.36       1.1     -11.26    -247.17      18.1       19.62     50.93       6.2
  0.08000          18.34    -0.54       0.6     -12.43    -216.31      22.4       19.90     61.14       4.0
  0.08500          18.34    -0.15      -0.2     -13.40    -171.80      25.9       20.22     65.39       0.3
  0.09000          18.33    -1.09      -0.8     -14.13    -119.52      27.9       20.54     61.87      -4.0
  0.09500          18.32    -2.90      -1.0     -14.59     -65.41      27.7       20.82     50.23      -8.0
  0.10000          18.31    -3.63       0.7     -14.79     -13.98      25.1       21.03     31.29     -11.5
  0.10500          18.29    -0.09       3.6     -14.74      30.47      19.8       21.13      7.47     -11.4
  0.11000          18.32    12.20       2.8     -14.52      55.94       5.4       21.14      3.41       7.2
  0.11500          18.37    -1.70     -15.3     -14.22      63.43       7.7       21.20     17.88       0.4
  0.12000          18.29   -22.84      -2.6     -13.85      88.00      17.0       21.27      8.64      -9.0
  0.12500          18.19   -15.62       7.9     -13.32     123.26      17.8       21.26    -13.66     -13.1
  0.13000          18.15     0.35       8.2     -12.63     152.98      13.3       21.13    -37.95     -12.4
  0.13500          18.20    19.53      11.0     -11.60     177.16      11.1       20.88    -58.69      -2.7
  0.14000          18.33    25.70      -8.9     -10.87     188.67      -3.1       20.62    -40.15      14.1
  0.14500          18.39     0.25      -4.6      -9.97     173.55      -1.5       20.49    -21.73     -13.7
  0.15000          18.41    10.95      10.3      -9.07     185.92       6.8       20.33    -30.30      -2.7
  0.15500          18.52    33.64       4.7      -8.13     192.90       5.3       20.15    -41.59       3.3
  0.16000          18.71    42.35       4.2      -7.14     203.60       6.2       19.93    -51.15     -10.4
  0.16500          18.94    46.94       0.7      -6.09     214.86       5.2       19.63    -70.80      -9.9
  0.17000          19.17    45.47      -2.4      -5.00     222.62       2.7       19.23    -88.72      -7.6
  0.17500          19.38    37.40      -6.6      -3.88     224.19      -1.7       18.75    -98.78      -2.9
  0.18000          19.52    15.73     -14.4      -2.78     211.95      -9.9       18.25   -100.80       0.5
  0.18500          19.53   -13.12     -13.9      -1.77     190.59     -10.8       17.75    -97.90       2.3
  0.19000          19.41   -33.12      -6.6      -0.86     175.49      -4.1       17.28    -92.40       3.5
  0.19500          19.21   -44.73      -5.3      -0.00     171.18      -0.3       16.83    -84.01       5.2
  0.20000          18.96   -54.43      -6.9       0.86     172.59       1.9       16.44    -74.55       2.5
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TABLE 6. SAMPLE OUTPUT DATA (Page 6 of 29)

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                    THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA              NOV 15, 1972  PAGE  7
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                              REFERENCE 3-111,3-128, AND 191.
                   UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                                  ACCELERATIONS IN RAD/SEC/SEC

                                        BODY KINEMATICS


                                            TORSO


                          YAW                             PITCH                           ROLL

   TIME          DISP.      VEL.     ACCEL.       DISP.     VEL.     ACCEL.       DISP.     VEL.     ACCEL.

  0.0             0.0       0.0        0.1        20.00      0.0        3.9        0.0       0.0        3.5
  0.0050          0.00     -0.06      -0.3        20.00      1.11       3.7        0.00      0.98       3.2
  0.0100         -0.00     -0.13      -0.2        20.01      2.08       3.1        0.01      1.80       2.9
  0.0150         -0.00     -0.17       0.1        20.02      2.85       2.3        0.02      2.61       2.6
  0.0200         -0.00     -0.16      -0.0        20.04      3.37       1.4        0.04      3.25       1.9
  0.0250         -0.00     -0.19      -0.1        20.06      3.64       0.6        0.05      3.69       1.1
  0.0300         -0.00     -0.24      -0.2        20.08      3.71      -0.1        0.07      3.90       0.3
  0.0350         -0.01     -0.32      -0.3        20.09      3.60      -0.7        0.09      3.87      -0.5
  0.0400         -0.01     -0.42      -0.3        20.11      3.32      -1.3        0.11      3.60      -1.3
  0.0450         -0.01      5.43      92.0        20.13      1.97     -15.3        0.13      5.47      35.2
  0.0500          0.14     60.33     282.0        20.12     -6.72     -45.3        0.20     26.45     106.6
  0.0550          0.67    161.50     413.6        20.04    -24.14     -78.1        0.42     63.30     143.5
  0.0600          1.79    286.62     438.4        19.86    -51.63    -112.9        0.84    103.27     124.6
  0.0650          3.49    378.24     150.4        19.51    -90.54    -156.6        1.41    113.20     -87.7
  0.0700          5.39    362.79    -263.1        18.94   -136.23    -151.7        1.84     47.61    -370.2
  0.0750          6.92    231.14    -638.3        18.16   -172.30     -94.0        1.75    -93.83    -599.6
  0.0800          7.55     12.03    -840.2        17.26   -183.49      33.4        0.83   -278.19    -640.7
  0.0850          7.02   -222.37    -754.3        16.40   -152.41     182.4       -0.99   -441.21    -471.0
  0.0900          5.43   -398.82    -446.8        15.80    -78.45     337.5       -3.47   -537.04    -186.8
  0.0950          3.22   -465.56      -6.2        15.70     43.42     516.1       -6.21   -545.98     122.4
  0.1000          1.02   -379.92     637.5        16.32    209.56     624.6       -8.78   -463.37     463.6
  0.1050         -0.27   -111.26    1197.2        17.82    390.69     615.1      -10.68   -282.17     682.9
  0.1100         -0.04     60.63   -2155.0        20.14    482.33    -715.8      -11.84   -243.73    -771.3
  0.1150         -2.75  -1283.86   -4987.5        21.36    -98.47   -2799.1      -13.99   -619.70    -709.6
  0.1200        -11.12  -1665.96    2879.6        19.23   -611.70    -114.5      -16.80   -361.15    2259.8
  0.1250        -16.40   -350.59    5155.3        16.65   -371.75    1148.6      -16.87    324.58    2200.4
  0.1300        -14.61   1022.97    4306.7        15.49   -122.36     510.6      -13.85    843.48    1426.7
  0.1350         -6.88   1863.71    -354.7        15.06    -97.39    -523.1       -8.84   1086.12    -154.3
  0.1400         -0.02    513.77   -7795.1        13.94   -387.70   -1241.5       -3.94    829.86   -1085.5
  0.1450         -2.82  -1413.41   -3831.1        11.83   -365.14     365.8       -0.51    608.04     389.8
  0.1500        -11.04  -1547.95    1717.4        10.64     22.06    1438.8        3.02    741.15     159.0
  0.1550        -17.25   -683.92    2763.6        11.23    206.64    1230.5        6.68    716.55    -463.0
  0.1600        -19.67    -73.34    2753.4        12.79    329.35    -157.9       10.03    669.84     130.8
  0.1650        -18.21    630.13    2157.3        14.24    236.03    -468.9       13.49    714.64     163.9
  0.1700        -13.70   1128.15    1178.1        15.04     78.63    -574.5       17.16    742.18     -63.4
  0.1750         -7.56   1257.57    -459.3        15.06    -58.08    -282.4       20.70    651.20    -609.0
  0.1800         -2.44    651.23   -3341.3        14.81      3.61     663.5       23.34    371.63   -1266.8
  0.1850         -1.80   -433.83   -3534.5        15.42    253.60     903.0       24.19    -45.59   -1596.3
  0.1900         -5.92  -1133.36   -1471.9        17.18    408.63      69.8       22.82   -490.08   -1381.1
  0.1950        -12.56  -1493.03    -913.5        19.14    349.09    -472.7       19.47   -827.86    -890.3
  0.2000        -20.17  -1335.23    2400.9        20.33     87.62   -1304.3       14.95   -900.29     534.3
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TABLE 6. SAMPLE OUTPUT DATA (Page 7 of 29)

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                          THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                 NOV 15, 1972  PAGE  9
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                REFERENCE 3-111,3-128, AND 191.
                           UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                  DISPLACEMENTS AND VELOCITIES ARE RELATIVE TO THE ORIGIN OF THE VEHICLE COORDINATE SYSTEM.
                                             ACCELERATIONS IN G'S

                                               BODY KINEMATICS


                                                RIGHT UPPER LEG

   TIME         X-DISP.   X-VEL.  X-ACCEL.    Y-DISP.   Y-VEL.  Y-ACCEL.    Z-DISP.    Z-VEL.  Z-ACCEL.

  0.0            28.57     0.0       0.3        3.75      0.0      -0.0      25.18      0.0        0.2
  0.0050         28.57     0.53      0.3        3.75     -0.02     -0.0      25.18      0.46       0.2
  0.0100         28.58     1.04      0.2        3.74     -9.39     -0.0      25.19      0.86       0.2
  0.0150         28.58     1.33      0.1        3.61    -44.75     -0.0      25.19      1.18       0.1
  0.0200         28.59     1.57      0.1        3.28    -85.13      0.0      25.20      1.42       0.1
  0.0250         28.60     1.66      0.0        2.79   -107.58      0.0      25.21      1.63       0.1
  0.0300         28.61     1.66     -0.0        2.21   -125.67      0.0      25.22      1.87       0.1
  0.0350         28.62     1.60     -0.0        1.52   -150.68      0.0      25.23      2.21       0.2
  0.0400         28.62     1.51     -0.1        0.70   -177.36      0.0      25.24      2.66       0.3
  0.0450         28.63     0.84     -1.4       -0.24   -198.92      0.2      25.25      3.53       1.1
  0.0500         28.62    -4.62     -4.2       -1.20   -219.57      0.8      25.28      7.26       2.8
  0.0550         28.58   -14.73     -6.1       -2.44   -240.53      1.6      25.33     14.04       4.2
  0.0600         28.47   -27.50     -6.8       -3.70   -262.87      2.8      25.42     22.78       4.7
  0.0650         28.30   -39.67     -5.5       -5.07   -284.28      5.1      25.56     31.81       4.5
  0.0700         28.08   -48.07     -3.1       -6.52   -293.67      8.3      25.74     39.56       3.4
  0.0750         27.83   -51.33     -0.4       -7.98   -288.23     11.6      25.95     44.76       1.9
  0.0800         27.57   -50.03      1.8       -9.38   -271.43     14.0      26.18     46.79       0.2
  0.0850         27.33   -45.71      2.3      -10.68   -245.28     15.2      26.41     45.87      -0.9
  0.0900         27.12   -42.61      0.5      -11.83   -215.28     15.8      26.64     44.12      -0.7
  0.0950         26.90   -45.00     -3.2      -12.83   -183.77     17.0      26.86     43.83       0.5
  0.1000         26.65   -56.41     -8.5      -13.66   -148.41     19.9      27.08     46.53       2.4
  0.1050         26.32   -76.07    -11.5      -14.30   -106.31     24.4      27.33     52.68       3.9
  0.1100         25.89   -86.55     17.1      -14.69    -48.12     31.8      27.61     57.36      -6.6
  0.1150         25.62   -15.77     43.1      -14.81     -0.30     14.1      27.83     24.22     -21.3
  0.1200         25.69    32.10      0.3      -14.74     28.17     24.2      27.87      1.55       0.4
  0.1250         25.79    -0.16    -24.9      -14.45     89.68     35.0      27.91     20.03      14.6
  0.1300         25.67   -47.01    -23.7      -13.84    148.74     22.2      28.09     50.20      16.5
  0.1350         25.34   -81.03     -3.1      -13.04    160.25    -19.3      28.42     77.75      -2.8
  0.1400         24.99   -33.23     66.0      -12.39    102.04    -12.0      28.58    -42.35     -90.4
  0.1450         25.21   109.36     26.8      -11.86    110.71    -16.2      28.11   -109.07      -0.5
  0.1500         25.69    63.44    -28.6      -11.49     42.58    -19.0      27.47   -147.93     -13.9
  0.1550         25.92    31.37     -7.5      -11.27     52.28     12.1      26.73   -144.12       5.9
  0.1600         26.03     5.76    -15.1      -10.94     80.95     16.0      26.04   -132.88       5.5
  0.1650         26.00   -13.33    -10.9      -10.46    110.36     13.8      25.40   -123.22       4.3
  0.1700         25.86   -35.55     -6.7       -9.85    132.91      9.7      24.81   -116.35       3.1
  0.1750         25.66   -44.53      0.2       -9.14    148.49      7.4      24.24   -110.42       3.1
  0.1800         25.51    -2.64     38.3       -8.35    170.99     15.8      23.70   -104.19       3.8
  0.1850         25.69    76.24     35.6       -7.41    204.16     16.6      23.20    -93.53       7.4
  0.1900         26.13   109.34     -2.3       -6.33    227.71      7.0      22.77    -77.95       7.7
  0.1950         26.72   102.33     -5.0       -5.16    237.95      3.9      22.42    -63.32       7.7
  0.2000         27.19    74.41    -31.1       -3.94    256.32     17.9      22.15    -43.43      10.7
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 8 of 29)

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                    THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                 NOV 15, 1972  PAGE 11
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                 REFERENCE 3-111,3-128, AND 191.
                              UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                                        ACCELERATIONS IN RAD/SEC/SEC

                                              BODY KINEMATICS


                                              RIGHT UPPER LEG


                             YAW                                PITCH                              ROLL

   TIME           DISP.      VEL.     ACCEL.      DISP.      VEL.     ACCEL.       DISP.      VEL.     ACCEL.

 0.0              0.0       0.0         0.8      13.00      0.0      -11.8        0.0       0.0          0.6
 0.00500          0.00      0.21        0.7      12.99     -3.27     -10.7        0.00      0.16         0.5
 0.01000          0.00      0.39        0.5      12.97     -5.95      -7.9        0.00      0.30         0.5
 0.01500          0.00      0.51        0.3      12.93     -7.74      -4.7        0.00      0.42         0.3
 0.02000          0.01      0.55       -0.0      12.89     -8.73      -2.5        0.01      0.49         0.2
 0.02500          0.01      0.43       -0.4      12.85     -9.39      -2.6        0.01      0.51        -0.0
 0.03000          0.01      0.31       -0.8      12.80    -10.43      -5.1        0.01      0.47        -0.2
 0.03500          0.01      0.01       -1.3      12.74    -12.46      -9.2        0.01      0.36        -0.5
 0.04000          0.01     -0.41       -1.7      12.67    -15.74     -13.6        0.01      0.19        -0.7
 0.04500          0.01     -1.73      -15.4      12.58    -18.93       2.4        0.01     -0.68       -11.2
 0.05000         -0.02    -11.83      -58.1      12.50    -12.52      40.9       -0.00     -8.28       -44.2
 0.05500         -0.14    -36.62     -117.0      12.47      3.03      64.3       -0.09    -27.34       -91.2
 0.06000         -0.42    -80.31     -190.5      12.54     23.80      77.4       -0.30    -61.88      -152.8
 0.06500         -0.99   -154.72     -346.0      12.71     46.29      76.5       -0.75   -122.73      -287.7
 0.07000         -2.06   -283.91     -562.4      12.99     64.61      45.2       -1.61   -232.65      -488.2
 0.07500         -3.94   -478.11     -789.9      13.34     68.27     -27.2       -3.18   -405.28      -717.2
 0.08000         -6.94   -730.33     -950.2      13.63     43.50    -155.4       -5.77   -639.49      -903.3
 0.08500        -11.28  -1010.53     -984.2      13.70    -23.62    -315.9       -9.64   -912.57      -981.7
 0.09000        -17.02  -1279.53     -869.0      13.32   -137.78    -478.9      -14.90  -1189.03      -926.9
 0.09500        -23.99  -1495.32     -617.3      12.25   -295.08    -610.8      -21.48  -1433.45      -766.6
 0.10000        -31.83  -1620.46     -237.9      10.32   -480.21    -661.3      -29.14  -1622.01      -546.0
 0.10500        -40.00  -1628.95      139.4       7.46   -658.61    -563.8      -37.59  -1750.26      -389.5
 0.11000        -48.00  -1527.41     1039.5       3.84   -742.68     381.8      -46.56  -1745.51      1535.9
 0.11500        -54.53  -1020.87     2418.4       0.73   -449.74    1486.5      -53.37   -851.17      4229.1
 0.12000        -57.79   -282.54     2420.9      -0.43    -32.66    1089.5      -54.53    363.20      3767.3
 0.12500        -57.75    239.51     1373.7      -0.13     90.47     -86.7      -50.41   1222.28      2790.4
 0.13000        -55.67    566.75      801.4       0.10    -29.95    -778.8      -41.90   2279.26      4778.1
 0.13500        -52.60    565.24    -1368.4      -0.76   -318.39    -302.2      -26.50   4010.04      7392.4
 0.14000        -51.08    169.56      990.9      -0.78    581.15    4860.9       -2.09   5402.23       454.6
 0.14500        -48.80    730.96      595.7       4.16   1056.71    -699.4       22.54   4000.87    -13121.9
 0.15000        -46.41     76.11    -2084.7       9.71   1232.49     234.2       29.14   -838.87     -5972.7
 0.15500        -46.71   -152.21     -955.9      15.46   1031.34    -717.2       24.63   -767.29       401.1
 0.16000        -48.05   -345.34     -438.0      20.03    779.59    -941.1       21.10   -623.31       512.8
 0.16500        -50.06   -451.01     -278.6      23.29    530.25    -796.7       18.29   -507.42       349.2
 0.17000        -52.47   -502.13     -111.5      25.41    324.03    -629.0       16.00   -408.79       326.6
 0.17500        -55.04   -523.17      123.2      26.62    171.38    -458.2       14.18   -318.06       544.1
 0.18000        -56.98   -155.34     2156.4      27.14     34.59    -505.9       13.74    262.39      3062.3
 0.18500        -56.14    478.01     1803.1      25.92   -129.89    -647.1       17.27   1111.56      2290.7
 0.19000        -52.97    677.33     -373.1      25.82   -301.01    -454.7       23.80   1356.17      -479.4
 0.19500        -49.81    595.03     -186.9      24.02   -410.77    -307.9       30.26   1230.86      -403.6
 0.20000        -46.89    594.52       47.2      21.79   -472.86     -30.2       36.12   1080.57     -1547.7
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 9 of 29)

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                       THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                    NOV 15, 1972  PAGE 13
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                    REFERENCE 3-111,3-128, AND 191.
                     UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                DISPLACEMENTS AND VELOCITIES ARE RELATIVE TO THE ORIGIN OF THE VEHICLE COORDINATE SYSTEM.
                                               ACCELERATIONS IN G'S

                                                 BODY KINEMATICS


                                                    LEFT UPPER LEG

   TIME              X-DISP.    X-VEL.  X-ACCEL.      Y-DISP.    Y-VEL.  Y-ACCEL.       Z-DISP.    Z-VEL.  Z-ACCEL.

0.0                   28.57      0.0        0.3        -3.75      0.0       -0.0          25.18      0.0         0.2
0.0050                28.57      0.51       0.2        -3.75     -0.02      -0.0          25.18      0.41        0.2
0.0100                28.58      0.93       0.2        -3.76     -9.39      -0.0          25.19      0.77        0.2
0.0150                28.58      1.23       0.1        -3.89    -44.75      -0.0          25.19      1.04        0.1
0.0200                28.59      1.43       0.1        -4.22    -85.13       0.0          25.20      1.23        0.1
0.0250                28.60      1.52       0.0        -4.71   -107.58       0.0          25.20      1.41        0.1
0.0300                28.60      1.51      -0.0        -5.29   -125.67       0.0          25.21      1.64        0.1
0.0350                28.61      1.44      -0.0        -5.98   -150.68       0.0          25.22      1.98        0.2
0.0400                28.62      1.34      -0.1        -6.80   -177.36       0.0          25.23      2.45        0.3
0.0450                28.63      1.34       0.2        -7.74   -198.92       0.2          25.24      3.09        0.5
0.0500                28.63      2.13       0.6        -8.79   -219.56       0.8          25.26      4.44        0.9
0.0550                28.65      3.66       0.9        -9.94   -240.45       1.7          25.29      6.72        1.4
0.0600                28.67      5.46       0.9       -11.13   -262.51       3.0          25.33      9.95        2.0
0.0650                28.70      4.36      -2.3       -12.56   -283.36       5.4          25.39     15.69        4.3
0.0700                28.70     -4.03      -6.6       -14.01   -292.25       8.4          25.50     26.79        7.2
0.0750                28.65    -20.63     -10.5       -15.46   -286.68      11.6          25.67     42.70        9.1
0.0800                28.49    -43.43     -12.4       -16.85   -269.53      14.5          25.93     60.62        8.9
0.0850                28.21    -65.97     -10.5       -18.14   -241.67      16.6          26.27     75.58        6.4
0.0900                27.84    -82.33      -6.2       -19.26   -208.66      17.4          26.67     84.69        3.0
0.0950                27.40    -83.36      -1.2       -20.22   -175.45      16.8          27.11     87.33       -0.2
0.1000                26.96    -86.83       3.6       -21.02   -144.30      15.4          27.54     84.33       -2.8
0.1050                26.55    -77.74       5.2       -21.67   -114.95      16.7          27.94     77.72       -2.6
0.1100                26.18    -74.46     -10.1       -22.13    -60.82      47.0          28.34     84.01        6.6
0.1150                25.73   -107.03     -17.0       -22.18     41.12      46.3          28.78     87.38       -5.4
0.1200                25.15   -116.64      11.1       -21.80    101.42       9.5          29.18     75.03       -6.5
0.1250                24.66    -69.73      31.7       -21.30     92.12     -11.9          29.51     54.23      -14.1
0.1300                24.48     -0.63      37.0       -20.88     76.21      -4.3          29.70     14.33      -22.6
0.1350                24.61     31.86     -18.9       -20.53     60.31     -10.5          29.66    -36.51      -46.5
0.1400                24.59    -49.53     -46.1       -20.26     55.81       9.0          29.24   -129.03      -39.3
0.1450                24.24    -70.94       7.3       -19.86    114.22      38.2          28.49   -160.44       -7.9
0.1500                23.95    -27.63      29.8       -19.14    166.55      14.6          27.66   -160.67        4.3
0.1550                23.93     21.53      36.7       -18.25    182.26      -1.3          26.89   -152.06        5.7
0.1600                24.19     78.73      23.8       -17.36    172.04      -7.5          26.14   -149.94       -2.2
0.1650                24.69    118.93      17.4       -16.54    157.75      -6.7          25.38   -153.55       -1.2
0.1700                25.36    143.44       5.5       -15.78    148.18      -2.5          24.61   -152.90        2.3
0.1750                26.07    134.43     -16.6       -15.04    148.87       3.8          23.86   -145.14        6.2
0.1800                26.60     65.74     -43.4       -14.26    164.49      10.9          23.18   -126.87       12.0
0.1850                26.68    -30.11     -45.0       -13.33    189.57      15.1          22.61    -99.78       15.8
0.1900                26.36    -91.33     -19.1       -12.36    219.85      14.8          22.19    -70.27       13.2
0.1950                25.81   -124.14     -12.2       -11.18    249.98      16.5          21.89    -49.76        5.7
0.2000                25.16   -124.73      10.6        -9.86    272.30       3.8          21.65    -51.33       -6.6
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 10 of 29)

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                      THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                  NOV 15, 1972  PAGE 15
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                  REFERENCE 3-111,3-128, AND 191.
                       UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                                   ACCELERATIONS IN RAD/SEC/SEC

                                          BODY KINEMATICS


                                          LEFT UPPER LEG

                            YAW                                PITCH                               ROLL

  TIME           DISP.       VEL.     ACCEL.      DISP.      VEL.     ACCEL.       DISP.      VEL.      ACCEL.

0.0               0.0        0.0        0.8      13.00       0.0      -13.7        0.0        0.0        0.6
0.0050            0.00       0.21       0.7      12.99      -3.81     -12.5        0.00       0.16       0.5
0.0100            0.00       0.33       0.5      12.96      -6.96      -9.4        0.00       0.30       0.5
0.0150            0.00       0.51       0.3      12.92      -9.15      -5.9        0.00       0.42       0.3
0.0200            0.01       0.55      -0.0      12.87     -10.43      -3.3        0.01       0.49       0.2
0.0250            0.01       0.46      -0.4      12.82     -11.28      -3.0        0.01       0.50      -0.0
0.0300            0.01       0.31      -0.8      12.76     -12.39      -5.1        0.01       0.46      -0.3
0.0350            0.01       0.02      -1.3      12.69     -14.38      -9.0        0.01       0.36      -0.5
0.0400            0.01      -0.42      -1.7      12.61     -17.54     -13.0        0.01       0.19      -0.7
0.0450            0.01      -1.73     -15.4      12.52     -20.76      -0.7        0.01      -0.68     -11.2
0.0500           -0.02     -11.37     -59.1      12.42     -15.92      35.1       -0.00      -8.32     -44.8
0.0550           -0.14     -37.74    -124.5      12.38      -0.61      71.4       -0.09     -27.91     -94.8
0.0600           -0.44     -85.53    -213.7      12.43      24.48     102.5       -0.31     -64.30    -162.1
0.0650           -1.05    -168.53    -378.7      12.64      62.45     167.0       -0.77    -127.19    -287.3
0.0700           -2.21    -305.03    -575.1      13.08     117.13     204.7       -1.65    -231.24    -441.1
0.0750           -4.19    -495.93    -758.4      13.82     174.66     182.2       -3.16    -380.75    -603.3
0.0800           -7.26    -733.93    -885.5      14.79     208.31      26.0       -5.54    -576.36    -761.8
0.0850          -11.58    -997.66    -940.9      15.80     180.91    -226.7       -9.00    -816.92    -914.2
0.0900          -17.24   -1263.43    -896.4      16.47      76.21    -502.6      -13.77   -1096.09   -1023.7
0.0950          -24.17   -1500.23    -737.8      16.43    -103.63    -743.3      -20.00   -1394.86   -1044.1
0.1000          -32.14   -1673.73    -499.2      15.34    -342.96    -914.4      -27.71   -1684.98    -964.7
0.1050          -40.82   -1781.07    -263.4      12.94    -618.22    -941.7      -36.78   -1937.26    -804.2
0.1100          -49.89   -1750.84    2002.4       9.34    -764.89     442.4      -46.91   -1985.86    2213.5
0.1150          -56.12    -602.44    4857.6       6.37    -365.78    1551.1      -54.07    -731.65    5201.4
0.1200          -56.38     291.35     748.7       5.19    -210.15    -582.2      -54.68     278.76     895.9
0.1250          -54.94     240.64    -474.8       3.58    -438.25    -757.8      -53.34     200.53    -674.1
0.1300          -53.97     159.54    -291.7       1.05    -537.39    -197.2      -51.55     842.90    5099.5
0.1350          -53.89    -257.53   -2358.0      -1.79    -478.00    2045.4      -44.94    1681.41    3765.9
0.1400          -56.05    -342.63    2844.6      -2.02     496.50    3238.2      -32.63    3434.76    7683.4
0.1450          -54.94     827.33    3786.5       1.77     652.30    -743.9      -10.95    4881.71     734.2
0.1500          -49.37    1130.23    -459.0       5.25     587.41    -907.6       11.08    3481.06   -6403.4
0.1550          -44.17     914.46   -1317.1       7.59     364.46    -247.3       24.60    2038.27   -4376.4
0.1600          -40.47     594.83    -961.7       9.18     235.25    -625.7       32.32    1186.84   -1938.0
0.1650          -38.19     323.27    -954.0       9.91      59.54    -609.5       37.10     765.06   -1099.0
0.1700          -37.26      50.34    -953.9       9.78    -108.61    -474.9       40.26     514.67    -854.0
0.1750          -37.68    -207.67    -699.9       9.01    -177.33      -8.3       42.12     215.42   -1144.8
0.1800          -38.88    -207.63     622.9       8.20    -126.77     341.4       42.42     -87.89    -967.6
0.1850          -39.31      48.33     903.0       7.87      -0.35     503.1       41.38    -303.11    -435.1
0.1900          -38.61     179.31     -45.4       8.24     150.29     536.3       39.70    -364.96    -208.0
0.1950          -37.78     152.93     -92.3       9.36     300.74     576.9       37.72    -436.57    -427.8
0.2000          -37.11      96.42    -282.7      11.28     453.21     297.7       35.10    -635.82    -973.9
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 11 of 29)

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                       THREE DIMENSIONAL CRASH VICTIM SIMULATOR    OUTPUT DATA                 NOV 15, 1972  PAGE 17
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                   REFERENCE 3-111,3-128, AND 191.
                       UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
             DISPLACEMENTS AND VELOCITIES ARE RELATIVE TO THE ORIGIN OF THE VEHICLE COORDINATE SYSTEM.
                                        ACCELERATIONS IN G'S

                                          BODY KINEMATICS


                                          RIGHT LOWER LEG

   TIME          X-DISP.    X-VEL.  X-ACCEL.    Y-DISP.    Y-VEL.  Y-ACCEL.    Z-DISP.    Z-VEL.  Z-ACCEL.

0.0               42.40       0.0       0.5       3.75       0.0       0.0      31.93       0.0       0.4
0.0050            42.41      0.98       0.5       3.75      0.01       0.0      31.93      0.77       0.4
0.0100            42.41      2.02       0.6       3.74     -9.34       0.0      31.93      1.31       0.2
0.0150            42.43      3.13       0.6       3.61    -44.70      -0.0      31.94      1.48      -0.0
0.0200            42.45      4.35       0.6       3.28    -85.08      -0.0      31.95      1.32      -0.1
0.0250            42.47      5.56       0.6       2.79   -107.54      -0.0      31.95      0.99      -0.2
0.0300            42.50      6.69       0.6       2.21   -125.67      -0.0      31.96      0.74      -0.1
0.0350            42.54      7.66       0.5       1.52   -150.74      -0.0      31.96      0.79       0.1
0.0400            42.58      8.45       0.4       0.70   -177.49      -0.0      31.97      1.25       0.3
0.0450            42.62      8.83      -0.3      -0.24   -199.25      -0.1      31.98      2.00       0.3
0.0500            42.66      6.32      -1.7      -1.29   -221.10      -0.2      31.99      2.44       0.2
0.0550            42.69      2.53      -2.9      -2.46   -245.04      -0.5      32.00      2.85       0.3
0.0600            42.68     -3.36      -3.3      -3.75   -272.73      -0.7      32.01      3.35       0.2
0.0650            42.65     -9.77      -3.0      -5.19   -303.39      -1.3      32.03      3.68       0.2
0.0700            42.59    -14.94      -2.3      -6.77   -328.87      -2.1      32.05      4.15       0.4
0.0750            42.50    -18.83      -1.8      -8.47   -347.61      -3.0      32.07      5.17       0.7
0.0800            42.40    -22.44      -2.0     -10.24   -362.23      -3.6      32.11      7.11       1.3
0.0850            42.28    -27.63      -3.7     -12.08   -371.50      -3.5      32.15     10.16       1.8
0.0900            42.12    -37.82      -7.1     -13.95   -377.26      -2.3      32.21     14.01       2.1
0.0950            41.88    -53.74     -11.6     -15.85   -379.40       0.3      32.29     18.08       2.0
0.1000            41.54    -82.93     -16.6     -17.74   -374.97       4.5      32.39     21.43       1.3
0.1050            41.04   -119.03     -20.7     -19.58   -361.55       9.4      32.50     22.42      -0.4
0.1100            40.34   -154.62      -0.2     -21.33   -335.49      19.7      32.60     16.75      -7.5
0.1150            39.65   -103.16      41.0     -22.91   -296.03      18.0      32.64     -4.59     -13.1
0.1200            39.29    -45.33      12.0     -24.31   -262.67      20.3      32.55    -30.47     -13.1
0.1250            39.04    -63.13     -28.2     -25.51   -213.58      30.8      32.34    -53.68     -12.0
0.1300            38.54   -131.64     -33.3     -26.41   -143.10      41.5      32.01    -79.87     -14.6
0.1350            37.75   -178.12      -6.0     -26.92    -62.55      44.3      31.54   -106.84      -9.6
0.1400            36.90   -152.31      17.6     -27.01     17.76      29.6      31.03    -83.29      23.2
0.1450            36.15   -155.07      -8.9     -26.80     62.52      23.8      30.67    -75.44      -4.5
0.1500            35.39   -147.26      -0.5     -26.32    132.41      36.0      30.32    -61.16       6.4
0.1550            34.60   -163.43     -10.4     -25.51    186.66      18.1      30.01    -60.87      -0.9
0.1600            33.72   -184.82      -6.4     -24.49    218.07      13.7      29.71    -59.43       2.0
0.1650            32.77   -193.53      -2.9     -23.35    238.65       8.2      29.43    -54.50       2.9
0.1700            31.79   -196.56      -0.5     -22.12    251.22       5.1      29.17    -49.18       2.5
0.1750            30.81   -196.02       3.0     -20.84    259.54       4.8      28.93    -45.43       1.1
0.1800            29.89   -162.53      28.5     -19.50    282.96      17.8      28.70    -49.45      -5.1
0.1850            29.23   -103.32      27.0     -17.99    320.06      18.0      28.42    -63.33      -8.1
0.1900            28.80    -75.22       1.9     -16.32    342.20       4.0      28.07    -74.69      -2.6
0.1950            28.44    -69.81       3.6     -14.59    349.57       3.8      27.68    -79.66      -2.5
0.2000            28.10    -63.37      10.2     -12.82    363.23      16.3      27.28    -76.76      14.4
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 12 of 29)

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                         THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                    NOV 15, 1972  PAGE 19
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                    REFERENCE 3-111,3-128, AND 191.
                           UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                  DISPLACEMENTS AND VELOCITIES ARE RELATIVE TO THE ORIGIN OF THE VEHICLE COORDINATE SYSTEM.
                                            ACCELERATIONS IN RAD/SEC/SEC

                                                  BODY KINEMATICS


                                                  RIGHT LOWER LEG


                              PITCH                               KNEE                               FOOT

  TIME              DISP.      VEL.      ACCEL.        X          Y          Z           X          Y          Z

0.0                 17.00       0.0       18.72      35.88       3.75      23.50       47.47       3.75      40.70
0.0050              17.01       5.42      19.37      35.88       3.75      23.50       47.47       3.75      40.70
0.0100              17.05      11.21      21.27      35.89       3.74      23.50       47.48       3.74      40.70
0.0150              17.13      17.07      23.87      35.89       3.61      23.51       47.50       3.61      40.70
0.0200              17.23      24.38      26.40      35.90       3.28      23.53       47.53       3.28      40.71
0.0250              17.38      32.74      28.34      35.91       2.79      23.54       47.57       2.79      40.70
0.0300              17.56      41.34      29.42      35.92       2.21      23.55       47.62       2.21      40.69
0.0350              17.79      49.33      29.73      35.93       1.52      23.57       47.68       1.52      40.68
0.0400              18.06      58.32      29.63      35.94       0.70      23.59       47.75       0.70      40.67
0.0450              18.37      67.05      46.67      35.95      -0.24      23.62       47.83      -0.24      40.66
0.0500              18.75      86.08      80.42      35.95      -1.29      23.65       47.91      -1.29      40.64
0.0550              19.24     112.07     100.42      35.90      -2.46      23.71       48.01      -2.45      40.61
0.0600              19.88     142.20     103.84      35.79      -3.75      23.79       48.11      -3.74      40.56
0.0650              20.66     167.33      67.30      35.62      -5.19      23.91       48.22      -5.16      40.49
0.0700              21.53     179.33      18.86      35.38      -6.78      24.05       48.33      -6.71      40.39
0.0750              22.43     179.34     -17.02      35.11      -8.48      24.22       48.44      -8.35      40.28
0.0800              23.32     172.70     -27.00      34.81     -10.26      24.41       48.54     -10.05      40.15
0.0850              24.16     166.33      -8.02      34.48     -12.10      24.64       48.64     -11.77      40.01
0.0900              25.00     172.22      53.94      34.09     -13.96      24.91       48.74     -13.51      39.85
0.0950              25.93     202.71     167.03      33.60     -15.81      25.27       48.84     -15.29      39.63
0.1000              27.10     275.32     357.79      32.92     -17.55      25.74       48.91     -17.14      39.31
0.1050              28.78     401.33     495.68      32.02     -19.08      26.35       48.92     -19.13      38.84
0.1100              31.13     530.23     329.36      30.90     -20.25      27.11       48.78     -21.30      38.20
0.1150              34.17     732.17    1291.32      29.97     -20.91      27.73       48.46     -23.69      37.56
0.1200              39.06    1273.28    2435.03      29.69     -21.08      27.93       48.09     -26.26      37.16
0.1250              47.19    1954.36    2184.81      29.80     -20.79      27.93       47.48     -28.95      36.74
0.1300              58.41    2497.10    1432.80      29.90     -20.04      28.08       46.34     -31.54      35.94
0.1350              71.51    2600.17   -3168.39      29.89     -19.00      28.52       44.69     -33.65      34.54
0.1400              77.49    -830.39 -15644.80      29.70     -18.23      28.69       43.15     -34.63      33.36
0.1450              65.46   -3158.49   -1547.01      30.14     -17.49      27.57       41.17     -34.99      33.87
0.1500              49.52   -3075.34    1245.99      30.73     -16.84      26.21       38.97     -34.73      34.68
0.1550              35.29   -2599.06    1640.64      30.88     -16.53      24.73       37.34     -33.43      35.70
0.1600              23.53   -2099.75    1712.41      30.74     -16.18      23.47       35.75     -31.76      36.46
0.1650              14.17   -1662.49    1329.29      30.42     -15.74      22.44       34.23     -29.90      37.01
0.1700               6.71   -1338.46     940.45      29.99     -15.22      21.59       32.77     -27.95      37.39
0.1750               0.61   -1116.31     584.42      29.57     -14.64      20.88       31.35     -25.95      37.66
0.1800              -4.75   -1057.27     -44.67      29.14     -13.95      20.28       29.91     -23.93      37.80
0.1850             -10.10   -1088.36     -85.65      29.42     -12.97      19.81       28.29     -21.90      37.71
0.1900             -15.31   -1049.03     386.24      30.26     -11.72      19.51       26.53     -19.85      37.28
0.1950             -20.52    -952.33     215.19      31.14     -10.39      19.37       24.85     -17.75      36.61
0.2000             -25.17    -865.78     605.42      31.95      -9.03      19.36       23.31     -15.60      35.75
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 13 of 29)

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                                  THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA              NOV 15, 1972   PAGE 21
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                        REFERENCE 3-111,3-128, AND 191.
                                 UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                   DISPLACEMENTS AND VELOCITIES ARE RELATIVE TO THE ORIGIN OF THE VEHICLE COORDINATE SYSTEM.
                                                 ACCELERATIONS IN G'S

                                                    BODY KINEMATICS


                                                     LEFT LOWER LEG

     TIME           X-DISP.    X-VEL.  X-ACCEL.    Y-DISP.    Y-VEL.  Y-ACCEL.     Z-DISP.    Z-VEL.  Z-ACCEL.

   0.0               42.40      0.0        0.5      -3.75      0.0       0.0        31.93      0.0        0.4
   0.0050            42.41      0.98       0.5      -3.75      0.01      0.0        31.93      0.79       0.4
   0.0100            42.41      2.04       0.6      -3.76     -9.34      0.0        31.93      1.34       0.2
   0.0150            42.43      3.16       0.6      -3.89    -44.70     -0.0        31.94      1.52      -0.0
   0.0200            42.45      4.37       0.6      -4.22    -85.08     -0.0        31.95      1.35      -0.2
   0.0250            42.47      5.56       0.6      -4.71   -107.54     -0.0        31.95      1.01      -0.2
   0.0300            42.50      6.74       0.6      -5.29   -125.67     -0.0        31.96      0.74      -0.1
   0.0350            42.54      7.69       0.5      -5.98   -150.74     -0.0        31.96      0.78       0.1
   0.0400            42.58      8.48       0.4      -6.80   -177.49     -0.0        31.97      1.25       0.3
   0.0450            42.62      9.11       0.3      -7.74   -199.25     -0.1        31.98      2.03       0.4
   0.0500            42.67      9.74       0.3      -8.79   -221.10     -0.2        31.99      2.63       0.2
   0.0550            42.72     10.31       0.3      -9.96   -245.07     -0.5        32.00      2.76      -0.1
   0.0600            42.77     10.73       0.1     -11.25   -272.88     -0.8        32.01      2.38      -0.3
   0.0650            42.82      9.53      -1.6     -12.69   -303.77     -1.4        32.02      1.36      -0.7
   0.0700            42.86      4.06      -4.2     -14.28   -329.31     -2.0        32.03     -0.06      -0.6
   0.0750            42.86     -6.36      -6.6     -15.97   -347.46     -2.4        32.02     -1.20      -0.6
   0.0800            42.79    -21.06      -8.3     -17.74   -360.42     -2.4        32.02     -1.74       0.1
   0.0850            42.64    -37.83      -9.0     -19.57   -367.21     -2.1        32.01     -0.43       1.2
   0.0900            42.41    -55.46      -9.2     -21.41   -370.82     -1.5        32.02      2.90       2.2
   0.0950            42.09    -73.84      -9.9     -23.27   -372.93     -0.5        32.04      7.73       2.8
   0.1000            41.67    -93.87     -11.0     -25.14   -372.63      1.0        32.09     13.39       3.1
   0.1050            41.14   -117.63     -14.7     -26.99   -368.17      4.1        32.18     19.35       2.7
   0.1100            40.47   -152.23      -8.7     -28.80   -346.07     29.9        32.28     18.75      -6.5
   0.1150            39.74   -126.41      26.9     -30.34   -269.12     38.5        32.32     -6.08     -15.2
   0.1200            39.19   -105.93     -11.0     -31.54   -218.81     10.4        32.23    -26.48      -3.0
   0.1250            38.60   -129.38      -9.8     -32.61   -214.00     -0.8        32.09    -24.99       2.5
   0.1300            37.89   -153.43     -15.2     -33.69   -215.71      1.6        31.99    -13.15       7.2
   0.1350            37.04   -187.04     -10.6     -34.70   -165.03     70.0        31.95     -3.80       4.1
   0.1400            36.14   -162.61      28.4     -35.09     22.73    110.3        31.93    -10.07     -10.9
   0.1450            35.44   -125.21       0.9     -34.51    188.40     59.2        31.81    -36.93      -9.3
   0.1500            34.74   -162.66     -20.3     -33.38    243.59     11.0        31.60    -47.72      -4.9
   0.1550            33.84   -190.53      -6.3     -32.11    260.61     -0.1        31.34    -57.56      -5.6
   0.1600            32.87   -195.94      -0.2     -30.81    262.65      2.2        31.02    -66.13      -3.7
   0.1650            31.89   -193.96       2.0     -29.43    268.49      4.0        30.67    -74.06      -4.6
   0.1700            30.93   -183.84       3.5     -28.11    278.99      8.2        30.28    -83.71      -4.7
   0.1750            30.01   -178.23       7.2     -26.66    303.80     17.9        29.85    -88.30       0.2
   0.1800            29.16   -163.76       7.7     -25.04    350.56     27.7        29.41    -83.31       4.2
   0.1850            28.37   -153.24       1.4     -23.16    388.92     19.3        29.02    -77.02       0.8
   0.1900            27.60   -155.63      -1.9     -21.1     421.81      6.9        28.63    -79.23      -0.9
   0.1950            26.81   -154.96      10.7     -18.96    432.41      3.3        28.23    -79.15       0.2
   0.2000            26.13   -103.84      46.8     -16.70    424.13    -23.1        27.83    -76.91       8.2
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 14 of 29) TABLE 6.

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                           THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                 NOV 15, 1972  PAGE 23
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                   REFERENCE 3-111,3-128, AND 131.
                         UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
               DISPLACEMENTS AND VELOCITIES ARE RELATIVE TO THE ORIGIN OF THE VEHICLE COORDINATE SYSTEM.
                                       ACCELERATIONS IN RAD/SEC/SEC

                                              BODY KINEMATICS


                                              LEFT LOWER LEG


                            PITCH                               KNEE                               FOOT

  TIME            DISP.      VEL.      ACCEL.        X          Y         Z           X          Y         Z

  0.0             17.00       0.0      20.88       35.88      -3.75     23.50       47.47      -3.75     40.70
  0.0050          17.02       6.35     21.62       35.88      -3.75     23.50       47.47      -3.75     40.70
  0.0100          17.06      12.30     23.31       35.89      -3.76     23.50       47.48      -3.76     40.70
  0.0150          17.14      19.48     25.52       35.89      -3.89     23.51       47.50      -3.89     40.70
  0.0200          17.26      27.11     27.67       35.90      -4.22     23.53       47.53      -4.22     40.71
  0.0250          17.41      35.47     29.16       35.91      -4.71     23.54       47.57      -4.71     40.70
  0.0300          17.61      43.72     29.72       35.92      -5.29     23.55       47.62      -5.29     40.69
  0.0350          17.85      52.22     29.45       35.93      -5.98     23.57       47.68      -5.98     40.68
  0.0400          18.13      60.36     28.75       35.94      -6.80     23.59       47.75      -6.80     40.67
  0.0450          18.45      67.38      7.06       35.95      -7.74     23.62       47.83      -7.74     40.66
  0.0500          18.78      62.43    -40.64       35.96      -8.79     23.65       47.91      -8.79     40.65
  0.0550          19.06      44.40    -83.56       35.97      -9.96     23.68       48.00      -9.95     40.64
  0.0600          19.21      16.01   -111.79       36.00     -11.25     23.72       48.08     -11.24     40.63
  0.0650          19.21     -14.48    -92.63       36.02     -12.70     23.75       48.17     -12.66     40.62
  0.0700          19.09     -33.77    -35.87       36.00     -14.29     23.80       48.26     -14.21     40.59
  0.0750          18.91     -29.03     72.83       35.91     -15.99     23.88       48.35     -15.84     40.53
  0.0800          18.85      14.18    233.48       35.68     -17.77     24.01       48.46     -17.53     40.40
  0.0850          19.12      98.52    344.82       35.28     -19.59     24.23       48.59     -19.26     40.20
  0.0900          19.88     202.33    359.33       34.71     -21.39     24.55       48.74     -21.00     39.91
  0.0950          21.13     294.84    272.87       33.97     -23.17     24.99       48.89     -22.79     39.52
  0.1000          22.76     349.66    100.90       33.08     -24.87     25.55       49.03     -24.63     39.03
  0.1050          24.55     357.43    -80.70       32.08     -26.45     26.26       49.10     -26.58     38.42
  0.1100          26.21     373.75   1531.22       30.95     -27.79     27.12       49.03     -28.67     37.68
  0.1150          30.25    1404.35   4851.68       29.88     -28.37     27.95       48.76     -31.07     36.85
  0.1200          40.29    2440.10   1448.18       29.28     -28.02     28.51       48.27     -33.81     36.08
  0.1250          52.86    2520.93   -194.22       28.96     -27.42     29.05       47.37     -36.57     35.23
  0.1300          65.29    2444.77   -346.62       28.89     -26.95     29.56       46.01     -39.21     34.46
  0.1350          76.27    1445.77  -5247.11       29.03     -26.59     29.90       44.18     -41.60     33.96
  0.1400          76.26   -1310.01  -6698.34       28.77     -26.48     29.51       42.66     -42.46     34.30
  0.1450          66.95   -2062.24   -442.76       28.54     -26.00     28.26       41.47     -41.80     35.42
  0.1500          56.04   -2374.01   -706.00       28.81     -24.81     26.98       39.69     -40.82     36.36
  0.1550          43.98   -2418.23   -275.08       29.26     -23.43     25.90       37.35     -39.75     36.97
  0.1600          31.90   -2364.07    505.45       29.83     -22.17     24.94       34.78     -38.48     37.34
  0.1650          20.49   -2191.38    697.92       30.50     -21.11     24.09       32.12     -36.94     37.52
  0.1700          10.07   -1963.05    898.77       31.24     -20.25     23.34       29.45     -35.08     37.48
  0.1750           0.93   -1694.19    934.18       31.93     -19.57     22.69       26.92     -32.86     37.24
  0.1800          -6.43   -1460.24    543.65       32.33     -18.92     22.11       24.78     -30.22     36.93
  0.1850         -13.99   -1366.37    274.14       32.43     -18.09     21.58       23.16     -27.29     36.65
  0.1900         -20.61   -1273.30    339.70       32.16     -16.99     21.11       21.88     -24.28     36.35
  0.1950         -26.72   -1151.03    658.96       31.66     -15.72     20.67       20.79     -21.29     36.03
  0.2000         -31.91    -881.45   1726.22       31.03     -14.30     20.18       20.06     -18.40     35.78
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TABLE 6. SAMPLE OUTPUT DATA (Page 15 of 29)

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                          THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                    NOV 15, 1972  PAGE 25
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                  REFERENCE 3-111,3-128, AND 191.
                          UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.

                                             BODY KINEMATICS


                                         JOINT RELATIVE EULER ANGLES


                              NECK                             RIGHT HIP                            LEFT HIP

   TIME             YAW     PITCH      ROLL          YAW     PITCH      ROLL          YAW     PITCH      ROLL

 0.0               1.43    -13.19    -32.09          0.0     -7.00      0.0           0.0     -7.00      0.0
 0.0050            1.42    -13.19    -32.12         0.00     -7.01     -0.00         0.00     -7.01     -0.00
 0.0100            1.42    -13.19    -32.19         0.00     -7.04     -0.01         0.00     -7.05     -0.01
 0.0150            1.40    -13.18    -32.31         0.01     -7.09     -0.02         0.01     -7.10     -0.02
 0.0200            1.38    -13.18    -32.47         0.01     -7.15     -0.03         0.01     -7.17     -0.03
 0.0250            1.35    -13.17    -32.67         0.02     -7.21     -0.05         0.02     -7.24     -0.05
 0.0300            1.31    -13.15    -32.91         0.02     -7.28     -0.07         0.02     -7.32     -0.07
 0.0350            1.27    -13.14    -33.19         0.03     -7.35     -0.09         0.03     -7.40     -0.09
 0.0400            1.21    -13.13    -33.49         0.03     -7.44     -0.10         0.03     -7.50     -0.10
 0.0450            1.14    -13.11    -33.81         0.03     -7.54     -0.12         0.03     -7.61     -0.12
 0.0500            0.92    -13.07    -34.19        -0.13     -7.62     -0.15        -0.13     -7.70     -0.15
 0.0550            0.31    -12.84    -34.67        -0.74     -7.58     -0.23        -0.74     -7.67     -0.23
 0.0600           -0.67    -12.64    -35.31        -2.07     -7.34     -0.39        -2.08     -7.44     -0.39
 0.0650           -2.64    -12.33    -36.12        -4.23     -6.84     -0.66        -4.29     -6.92     -0.66
 0.0700           -4.68    -10.87    -36.94        -7.11     -6.02     -1.03        -7.26     -5.93     -1.02
 0.0750           -6.49     -9.26    -37.56       -10.45     -4.84     -1.53       -10.69     -4.35     -1.44
 0.0800           -7.52     -6.94    -37.84       -14.05     -3.30     -2.31       -14.29     -2.12     -1.99
 0.0850           -7.28     -4.46    -37.99       -17.80     -1.60     -3.61       -17.86      0.51     -2.89
 0.0900           -5.59     -2.64    -38.55       -21.86     -0.05     -5.71       -21.56      3.10     -4.52
 0.0950           -2.74     -2.22    -40.32       -26.59      1.01     -8.81       -25.83      5.13     -7.25
 0.1000            0.57     -4.03    -44.16       -32.46      1.25    -12.95       -31.35      6.16    -11.37
 0.1050            3.23     -7.22    -50.67       -40.02      0.55    -18.04       -38.94      5.99    -17.02
 0.1100            2.93    -13.48    -56.24       -49.42     -0.67    -23.74       -49.02      5.13    -23.87
 0.1150           -2.66    -25.21    -50.94       -54.49     -0.99    -28.07       -53.51      4.78    -28.64
 0.1200           -9.98    -35.32    -41.32       -49.80     -0.75    -29.19       -46.13      3.73    -29.30
 0.1250          -20.86    -41.67    -34.60       -44.06     -0.93    -26.90       -40.00      1.35    -29.89
 0.1300          -35.59    -46.70    -33.08       -43.31     -2.10    -21.34       -41.39     -1.61    -31.07
 0.1350          -49.62    -51.46    -37.90       -47.71     -4.70     -9.51       -49.25     -5.30    -27.85
 0.1400          -54.39    -55.00    -48.96       -52.38     -6.37     11.30       -57.52     -6.40    -18.79
 0.1450          -61.01    -64.70    -47.33       -46.00     -3.72     31.39       -52.46     -5.08     -1.28
 0.1500          -52.54    -70.64    -51.02       -34.80     -0.73     32.79       -38.04     -4.97     15.28
 0.1550          -44.96    -67.66    -52.60       -28.86      2.42     24.27       -26.28     -5.43     23.66
 0.1600          -50.93    -62.40    -41.81       -27.86      4.07     18.25       -19.81     -6.26     27.39
 0.1650          -52.93    -54.25    -36.15       -31.15      4.19     14.16       -18.42     -7.91     29.12
 0.1700          -48.89    -43.14    -35.41       -37.56      3.12     11.71       -21.21    -10.57     30.23
 0.1750          -41.83    -30.53    -33.83       -45.57      1.43     10.75       -26.87    -13.97     31.20
 0.1800          -30.23    -18.15    -28.94       -52.00     -0.19     11.52       -32.50    -17.04     31.61
 0.1850          -10.47     -8.38    -19.33       -51.56     -1.42     14.87       -33.15    -18.51     30.60
 0.1900           16.68     -5.14     -6.94       -44.34     -2.24     20.07       -28.25    -17.94     28.83
 0.1950           46.09    -14.54      5.61       -34.78     -2.66     25.76       -21.32    -15.74     27.55
 0.2000           65.69    -31.77     14.38       -24.78     -2.90     31.57       -14.16    -12.26     26.35
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 16 of 29)

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                              THREE DIMENSIONAL CRASH VICTIM SIMULATOR    OUTPUT DATA                   NOV 15, 1972  PAGE 27
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                      REFERENCE 3-111,3-128, AND 191.
                              UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.

                                                 BODY KINEMATICS


                                   ANGULAR VELOCITIES ABOUT BODY SEGMENT AXES

                                   TORSO                              HEAD                            RIGHT UPPER LEG

 TIME                 X          Y          Z          X          Y          Z          X          Y          Z

0.0                  0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0050               0.98       1.11      -0.00      -9.10       2.04      -0.36       0.11      -3.27       0.21
0.0100               1.87       2.38      -0.17     -17.94       4.00      -0.80       0.22      -5.95       0.38
0.0150               2.67       2.65      -0.16     -26.52       5.85      -1.40       0.30      -7.74       0.50
0.0200               3.31       3.37      -0.16     -34.65       7.53      -2.20       0.36      -8.73       0.54
0.0250               3.75       3.64      -0.18     -42.27       8.97      -3.26       0.40      -9.39       0.48
0.0300               3.98       3.71      -0.23     -49.37      10.17      -4.60       0.40     -10.43       0.30
0.0350               3.98       3.60      -0.31     -55.95      11.21      -6.20       0.36     -12.46       0.01
0.0400               3.75       3.32      -0.40     -62.03      12.23      -8.05       0.28     -15.74      -0.40
0.0450               3.63       1.57       5.17     -68.47      13.79     -10.07      -0.30     -18.89      -1.75
0.0500               5.79      -5.32      56.44     -82.63      18.29     -11.72      -5.70     -12.52     -11.61
0.0550               7.94     -23.03     151.89    -107.41      27.09     -10.47     -19.43       3.09     -35.75
0.0600               5.90     -47.68     270.32    -145.28      46.58      -2.03     -44.45      24.22     -78.27
0.0650             -13.12     -91.76     358.64    -188.41      83.50      18.19     -88.68      48.26    -150.31
0.0700             -70.15    -125.14     347.35    -220.24     142.03      51.95    -168.81      72.37    -274.71
0.0750            -165.88    -165.49     224.79    -247.57     210.89      95.36    -295.00      93.97    -460.71
0.0800            -281.75    -183.36      14.17    -292.76     253.60     138.72    -467.45     114.61    -701.51
0.0850            -378.43    -148.70    -215.92    -405.18     204.09     168.23    -673.25     141.14    -971.87
0.0900            -428.41     -55.08    -387.78    -620.33      48.64     169.38    -894.35     187.05   -1238.69
0.0950            -420.02      91.68    -440.89    -948.54    -188.65     130.45   -1116.20     260.41   -1467.86
0.1000            -356.65     262.74    -328.39   -1354.47    -429.58      46.85   -1331.79     356.94   -1626.30
0.1050            -248.03     403.55     -31.68   -1749.35    -559.61     -76.32   -1538.82     463.53   -1681.57
0.1100            -264.61     460.39     154.68    -526.94    -373.78   -1288.50   -1643.15     595.79   -1587.17
0.1150            -150.23     194.34   -1188.53     728.78     313.76   -3367.63    -838.14     550.83    -969.98
0.1200             188.04    -131.37   -1682.50     -51.92     614.00   -3224.35     361.09     211.14    -190.56
0.1250             425.06    -258.31    -429.42    -823.08     568.17   -2821.77    1223.12    -126.98     222.44
0.1300             570.23    -354.63     927.83   -1398.63     306.40   -2118.80    2278.26    -400.78     401.88
0.1350             601.87    -372.62    1763.35   -1568.44     -27.95   -1117.45    4017.41    -536.92     363.80
0.1400             706.10    -421.01     470.86   -1452.09    -107.13      18.47    5404.55     574.59     190.60
0.1450             899.12    -352.62   -1392.41    -469.70     595.01   -4232.39    3947.90    1255.44     268.33
0.1500            1026.91     -53.16   -1520.42     166.13     783.55   -3418.38    -851.71    1113.06    -534.56
0.1550             889.73     103.75    -890.01     275.45    1529.46    3139.45    -726.71     876.41    -563.10
0.1600             657.12     311.06    -132.32     904.14    2026.92     645.84    -505.01     610.53    -583.34
0.1650             559.64     371.59     538.92    1156.30    1841.87    1971.89    -329.09     373.44    -559.75
0.1700             449.48     396.53    1017.84    1570.90    1550.56    3029.29    -193.35     186.43    -525.33
0.1750             324.53     374.35    1156.14    2068.32    1156.12    3776.01     -83.25      51.60    -495.09
0.1800             205.19     252.74     576.68    2548.60     631.34    4277.95     333.49       0.66    -142.92
0.1850              61.80      71.76    -459.05    2946.95     -94.76    4558.41     895.12       2.48     445.54
0.1900            -154.54     -44.23   -1158.91    3137.66   -1143.25    4599.71    1061.66     -29.21     679.97
0.1950            -336.57    -142.76   -1450.88    2747.33   -2289.43    4408.39     988.35     -80.65     676.96
0.2000            -435.19    -238.33   -1231.85    2115.99   -3110.54   -2432.26     859.87     -56.60     724.67
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 17 of 29)

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                THREE DIMENSIONAL CRASH VICTIM SIMULATOR    OUTPUT DATA                NOV 15, 1972  PAGE 29
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                          REFERENCE 3-111,3-128, AND 191.
                UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.

                                  BODY KINEMATICS


                        ANGULAR VELOCITIES ABOUT BODY SEGMENT AXES


                         LEFT UPPER LEG                    RIGHT LOWER LEG                  LEFT LOWER LEG

   TIME            X          Y          Z          X          Y          Z          X          Y          Z

0.0               0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0050            0.11      -3.31       0.21       0.05       2.15       0.23       0.05       2.25       0.23
0.0100            0.22      -6.96       0.38       0.09       5.26       0.43       0.09       5.54       0.43
0.0150            0.30      -9.15       0.50       0.14       9.93       0.57       0.14      10.33       0.57
0.0200            0.36     -10.43       0.54       0.19      16.16       0.62       0.19      16.68       0.62
0.0250            0.40     -11.28       0.47       0.24      23.35       0.57       0.24      23.99       0.57
0.0300            0.40     -12.39       0.30       0.29      30.60       0.41       0.29      31.34       0.41
0.0350            0.36     -14.38       0.01       0.34      37.07       0.12       0.34      37.83       0.12
0.0400            0.28     -17.34      -0.40       0.39      42.29      -0.29       0.39      43.02      -0.30
0.0450           -0.30     -20.73      -1.75       0.27      48.77      -1.75       0.27      46.61      -1.76
0.0500           -5.75     -15.32     -11.70      -1.67      73.55     -12.83      -1.68      46.52     -12.92
0.0550          -19.82      -0.36     -36.34      -6.56     115.46     -40.16      -6.71      43.90     -41.30
0.0600          -45.88      24.34     -83.45     -15.18     166.42     -88.72     -15.86      40.95     -93.90
0.0650          -90.31      64.07    -163.61     -29.95     215.78    -171.93     -31.44      50.19    -184.21
0.0700         -162.18     125.65    -293.64     -56.21     252.20    -317.50     -57.25      91.88    -330.53
0.0750         -262.10     201.32    -472.08     -96.86     273.51    -538.43     -94.92     171.34    -531.55
0.0800         -388.95     275.62    -686.25    -151.62     287.31    -829.24    -146.30     289.98    -775.12
0.0850         -545.33     323.39    -919.85    -216.45     307.96   -1162.31    -213.88     427.71   -1047.75
0.0900         -737.82     362.45   -1158.66    -286.98     359.27   -1500.62    -299.96     564.78   -1340.48
0.0950         -970.45     394.70   -1387.69    -362.08     463.12   -1808.15    -405.00     689.55   -1644.21
0.1000        -1240.96     443.58   -1592.33    -444.68     633.45   -2054.45    -528.07     798.74   -1948.91
0.1050        -1538.36     544.17   -1760.41    -539.15     865.06   -2214.71    -668.05     901.66   -2240.38
0.1100        -1701.83     739.25   -1738.73    -585.91    1126.12   -2208.11    -758.86    1113.00   -2311.61
0.1150         -664.85     270.14    -647.53    -148.74    1283.00   -1273.27    -248.17    1674.49    -894.28
0.1200          252.40    -358.23      -3.08     400.47    1490.42      79.55     194.92    2081.85     160.39
0.1250          185.59    -454.38    -206.11     668.03    1827.60    1048.44     277.95    2066.68      22.29
0.1300          839.97    -459.09    -321.65     851.17    2096.32    2151.16     643.33    1985.68     628.60
0.1350         1673.39    -156.30    -519.85     929.16    2062.74    3925.38     902.12    1289.25    1502.22
0.1400         3422.71     560.65     -47.59     984.22    -256.01    5317.60     859.11    -749.96    3313.48
0.1450         4856.14     673.33     973.87    1395.66   -1913.05    3702.71    1005.53   -1382.61    4849.69
0.1500         3377.59     792.74     991.70    -146.27   -1963.27    -994.67    1064.31   -1581.56    3355.42
0.1550         1917.48     738.07     672.51    -267.84   -1722.96    -879.46     912.79   -1709.56    1815.43
0.1600         1091.96     512.31     370.49    -230.16   -1489.23    -736.44     731.30   -1851.26     891.54
0.1650          709.93     237.30     215.70    -182.06   -1289.05    -623.28     589.55   -1953.78     450.51
0.1700          505.89     -50.31     107.98    -130.61   -1152.04    -544.33     479.20   -2013.87     194.81
0.1750          247.97    -269.32     -33.08     -77.94   -1064.54    -495.96     248.47   -1963.18     -29.06
0.1800          -58.23    -232.36     -66.33     320.52   -1056.61    -170.02     -65.81   -1702.21     -58.82
0.1850         -309.81      31.76      36.58     953.41   -1086.08     281.58    -291.77   -1334.61     110.39
0.1900         -390.73     223.48      41.15    1204.85   -1079.10     371.25    -351.24   -1048.87     176.06
0.1950         -461.46     330.33     -64.53    1162.95   -1043.60     287.49    -441.19    -820.69     149.88
0.2000         -654.70     425.19    -183.21    1086.41    -922.39     290.22    -652.60    -456.25     190.54
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 18 of 29)

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                              THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                  NOV 15, 1972  PAGE 31
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                    REFERENCE 3-111,3-128, AND 191.
                              UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                                          ACCELERATIONS IN G'S

                                             VEHICLE KINEMATICS

      TIME             X-DISP.    X-VEL.  X-ACCEL.     Y-DISP.     Y-VEL.  Y-ACCEL.      Z-DISP.    Z-VEL.   Z-ACCEL.

0.0                      0.0        0.0       0.0        0.0     -335.00      0.0          0.0        0.0        0.0
0.0050                   0.0        0.0       0.0      -1.67     -335.00      0.0          0.0        0.0        0.0
0.0100                   0.0        0.0       0.0      -3.34     -325.65     22.0          0.0        0.0        0.0
0.0150                   0.0        0.0       0.0      -4.89     -290.29     23.0          0.0        0.0        0.0
0.0200                   0.0        0.0       0.0      -6.23     -249.91     14.0          0.0        0.0        0.0
0.0250                   0.0        0.0       0.0      -7.41     -227.46      7.7          0.0        0.0        0.0
0.0300                   0.0        0.0       0.0      -8.51     -209.34     10.0          0.0        0.0        0.0
0.0350                   0.0        0.0       0.0      -9.50     -184.29     14.7          0.0        0.0        0.0
0.0400                   0.0        0.0       0.0     -10.35     -157.57     13.0          0.0        0.0        0.0
0.0450                   0.0        0.0       0.0     -11.08     -135.86     10.3          0.0        0.0        0.0
0.0500                   0.0        0.0       0.0     -11.71     -114.29     12.0          0.0        0.0        0.0
0.0550                   0.0        0.0       0.0     -12.22      -91.01     12.5          0.0        0.0        0.0
0.0600                   0.0        0.0       0.0     -12.61      -64.44     15.0          0.0        0.0        0.0
0.0650                   0.0        0.0       0.0     -12.86      -35.66     14.0          0.0        0.0        0.0
0.0700                   0.0        0.0       0.0     -12.98      -13.44      9.0          0.0        0.0        0.0
0.0750                   0.0        0.0       0.0     -13.01        0.38      5.5          0.0        0.0        0.0
0.0800                   0.0        0.0       0.0     -12.99        8.59      3.0          0.0        0.0        0.0
0.0850                   0.0        0.0       0.0     -12.94       10.91      0.0          0.0        0.0        0.0
0.0900                   0.0        0.0       0.0     -12.88       10.91      0.0          0.0        0.0        0.0
0.0950                   0.0        0.0       0.0     -12.83       10.91      0.0          0.0        0.0        0.0
0.1000                   0.0        0.0       0.0     -12.77       10.91      0.0          0.0        0.0        0.0
0.1050                   0.0        0.0       0.0     -12.72       10.91      0.0          0.0        0.0        0.0
0.1100                   0.0        0.0       0.0     -12.66       10.91      0.0          0.0        0.0        0.0
0.1150                   0.0        0.0       0.0     -12.61       10.91      0.0          0.0        0.0        0.0
0.1200                   0.0        0.0       0.0     -12.55       10.91      0.0          0.0        0.0        0.0
0.1250                   0.0        0.0       0.0     -12.50       10.91      0.0          0.0        0.0        0.0
0.1300                   0.0        0.0       0.0     -12.45       10.91      0.0          0.0        0.0        0.0
0.1350                   0.0        0.0       0.0     -12.39       10.91      0.0          0.0        0.0        0.0
0.1400                   0.0        0.0       0.0     -12.34       10.91      0.0          0.0        0.0        0.0
0.1450                   0.0        0.0       0.0     -12.28       10.91      0.0          0.0        0.0        0.0
0.1500                   0.0        0.0       0.0     -12.23       10.91      0.0          0.0        0.0        0.0
0.1550                   0.0        0.0       0.0     -12.17       10.91      0.0          0.0        0.0        0.0
0.1600                   0.0        0.0       0.0     -12.12       10.91      0.0          0.0        0.0        0.0
0.1650                   0.0        0.0       0.0     -12.06       10.91      0.0          0.0        0.0        0.0
0.1700                   0.0        0.0       0.0     -12.01       10.91      0.0          0.0        0.0        0.0
0.1750                   0.0        0.0       0.0     -11.96       10.91      0.0          0.0        0.0        0.0
0.1800                   0.0        0.0       0.0     -11.90       10.91      0.0          0.0        0.0        0.0
0.1850                   0.0        0.0       0.0     -11.85       10.91      0.0          0.0        0.0        0.0
0.1900                   0.0        0.0       0.0     -11.79       10.91      0.0          0.0        0.0        0.0
0.1950                   0.0        0.0       0.0     -11.74       10.91      0.0          0.0        0.0        0.0
0.2000                   0.0        0.0       0.0     -11.68       10.91      0.0          0.0        0.0        0.0
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 19 of 29)

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                                THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                     NOV 15, 1972  PAGE 33
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                     REFERENCE 3-111,3-128, AND 191.
                              UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                                              ACCELERATIONS IN RAD/SEC/SEC

                                                   VEHICLE KINEMATICS


                                   YAW                               PITCH                              ROLL

     TIME            DISP.       VEL.     ACCEL.       DISP.       VEL.     ACCEL.       DISP.       VEL.     ACCEL.

   0.0               0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0050            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0100            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0150            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0200            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0250            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0300            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0350            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0400            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0450            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0500            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0550            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0600            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0650            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0700            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0750            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0800            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0850            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0900            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.0950            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1000            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1050            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1100            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1150            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1200            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1250            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1300            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1350            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1400            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1450            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1500            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1550            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1600            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1650            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1700            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1750            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1800            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1850            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1900            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.1950            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
   0.2000            0.0         0.0         0.0       0.0         0.0         0.0       0.0         0.0         0.0
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 20 of 29)

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                            THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                    NOV 15, 1972  PAGE 35
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                     REFERENCE 3-111,3-128, AND 191.
                            UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.

                                                   BELT LOADS

          LEFT SHOULDER                 RIGHT SHOULDER                LEFT LAP                     RIGHT LAP
                MADE OF                       MADE OF                        MADE OF                      MADE OF
           LEFT SHOULDER                 RIGHT SHOULDER               LEFT LAP                     RIGHT LAP

 TIME   ELONGATION   RATE    FORCE   ELONGATION   RATE    FORCE   ELONGATION   RATE   FORCE   ELONGATION   RATE    FORCE

0.0         0.0        0.       0.      0.0         0.       0.      0.0         0.      0.      0.0          0.       0.
0.0050      0.00       0.       0.      0.0         0.       0.      0.00        0.      0.      0.0          0.       0.
0.0100      0.0        0.       0.      0.0         0.       0.      0.00       -2.      0.      0.0          0.       0.
0.0150      0.0        0.       0.      0.0         0.       0.      0.0         0.      0.      0.0          0.       0.
0.0200      0.0        0.       0.      0.0         0.       0.      0.0         0.      0.      0.0          0.       0.
0.0250      0.0        0.       0.      0.0         0.       0.      0.0         0.      0.      0.0          0.       0.
0.0300      0.0        0.       0.      0.0         0.       0.      0.0         0.      0.      0.0          0.       0.
0.0350      0.0        0.       0.      0.0         0.       0.      0.0         0.      0.      0.0          0.       0.
0.0400      0.0        0.       0.      0.0         0.       0.      0.0         0.      0.      0.0          0.       0.
0.0450      0.0        0.       0.      0.20      101.      48.      0.0         0.      0.      0.24       108.      72.
0.0500      0.0        0.       0.      0.74      115.     178.      0.0         0.      0.      0.82       122.     245.
0.0550      0.0        0.       0.      1.34      125.     322.      0.0         0.      0.      1.45       131.     435.
0.0600      0.0        0.       0.      1.99      135.     477.      0.0         0.      0.      2.13       141.     639.
0.0650      0.0        0.       0.      2.65      146.     646.      0.38       97.    177.      2.86       152.     859.
0.0700      0.0        0.       0.      3.44      153.     826.      0.87       97.    408.      3.64       157.    1092.
0.0750      0.0        0.       0.      4.20      149.    1008.      1.31       73.    611.      4.41       149.    1324.
0.0800      0.50     146.     120.      4.92      136.    1180.      1.58       33.    737.      5.11       129.    1533.
0.0850      1.25     149.     299.      5.54      112.    1330.      1.63      -11.    762.      5.68        97.    1704.
0.0900      1.95     128.     467.      6.03       81.    1446.      1.48      -48.    690.      6.08        64.    1824.
0.0950      2.49      86.     597.      6.35       49.    1524.      1.18      -68.    552.      6.32        34.    1897.
0.1000      2.78      33.     668.      6.52       17.    1564.      0.84      -63.    393.      6.43         9.    1930.
0.1050      2.82     -16.     677.      6.52      -15.    1566.      0.60      -31.    278.      6.42       -16.    1925.
0.1100      2.72     -16.     653.      6.39      -35.    1533.      0.51      -17.    240.      6.27       -37.    1881.
0.1150      2.62     -39.     628.      6.27       -8.    1504.      0.12     -159.     55.      6.20        20.    1861.
0.1200      2.25     -99.     540.      6.26       -7.    1503.      0.0         0.      0.      6.42        40.    1925.
0.1250      1.73    -100.     415.      6.04      -90.    1449.      0.0         0.      0.      6.35       -79.    1905.
0.1300      1.30     -69.     312.      5.37     -171.    1289.      0.0         0.      0.      5.63      -201.    1690.
0.1350      1.04     -36.     251.      4.42     -194.    1062.      0.0         0.      0.      4.49      -234.    1346.
0.1400      0.88     -38.     211.      3.34     -155.     850.      0.0         0.      0.      3.52      -143.    1057.
0.1450      0.58     -80.     140.      2.90      -99.     696.      0.0         0.      0.      3.10       -27.     929.
0.1500      0.22     -59.      52.      2.51      -72.     602.      0.0         0.      0.      3.16        31.     948.
0.1550      0.13      17.      30.      2.17      -69.     521.      0.0         0.      0.      3.30        16.     989.
0.1600      0.29      53.      69.      1.77      -91.     425.      0.0         0.      0.      3.26       -34.     978.
0.1650      0.64      83.     153.      1.23     -111.     303.      0.0         0.      0.      2.95       -88.     885.
0.1700      1.10      93.     253.      0.65     -113.     164.      0.39      207.    184.      2.41      -123.     724.
0.1750      1.59      98.     383.      0.12     -104.      28.      1.50      226.    699.      1.77      -129.     532.
0.1800      2.04      75.     489.      0.0         0.       0.      2.53      172.   1180.      1.21       -86.     364.
0.1850      2.31      33.     555.      0.0         0.       0.      3.12       63.   1458.      0.96       -17.     287.
0.1900      2.37     -10.     568.      0.0         0.       0.      3.20      -21.   1495.      1.03        40.     308.
0.1950      2.25     -33.     540.      0.15       94.      37.      2.99      -57.   1396.      1.32        77.     396.
0.2000      2.08     -34.     499.      0.64       83.     154.      2.73      -34.   1273.      1.73        64.     518.
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 21 of 29)

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                              THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA              NOV 15, 1972   PAGE 37
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                REFERENCE 3-111,3-128, AND 191.
                         UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.

                                          JOINT ELASTIC MOMENTS

                                 NECK                               RIGHT HIP                          LEFT HIP

  TIME             YAW        PITCH        ROLL         YAW       PITCH        ROLL         YAW       PITCH        ROLL

0.0              -0.29        -0.46       -0.09         0.0        0.00        0.0          0.0        0.00        0.0
0.0050           -0.26        -0.37        0.17        -0.01       0.16        0.03        -0.01       0.17        0.03
0.0100           -0.17        -0.11        0.93        -0.05       0.59        0.12        -0.05       0.67        0.12
0.0150           -0.02        -0.17        2.18        -0.11       1.25        0.27        -0.11       1.41        0.27
0.0200            0.21        -0.26        3.89        -0.19       2.05        0.46        -0.19       2.32        0.46
0.0250            0.52        -0.37        6.02        -0.27       2.93        0.69        -0.27       3.32        0.69
0.0300            0.92        -0.49        8.53        -0.34       3.87        0.94        -0.34       4.40        0.94
0.0350            1.41        -0.62       11.38        -0.41       4.92        1.20        -0.41       5.58        1.20
0.0400            2.01        -0.75       14.53        -0.46       6.14        1.44        -0.46       6.93        1.44
0.0450            2.77        -0.89       17.95        -0.41       7.58        1.68        -0.42       8.50        1.68
0.0500            5.07        -1.34       21.89         1.79       8.63        2.12         1.79       9.73        2.12
0.0550           11.46        -2.70       26.92        10.35       8.03        3.23        10.38       9.39        3.24
0.0600           23.80        -5.84       33.57        28.87       4.71        5.47        29.09       6.20        5.50
0.0650           42.28       -12.37       42.95        59.08      -2.18        9.17        59.94      -1.16        9.24
0.0700           63.07       -23.33       50.69        99.23     -13.62       14.32       101.31     -14.91       14.18
0.0750           82.63       -41.22       57.15       145.97     -30.21       21.42       149.28     -37.03       20.07
0.0800           93.42       -65.34       60.13       196.20     -51.62       32.27       199.52     -68.10       27.78
0.0850           90.87       -91.30       61.69       248.59     -75.35       50.37       249.44    -104.90       40.41
0.0900           73.19      -110.80       67.57       305.26     -97.09       79.70       301.03    -141.06       63.05
0.0950           43.37      -113.97       86.08       371.24    -111.87      123.03       360.67    -169.38      101.19
0.1000            8.71       -96.08      126.25       453.24    -115.20      180.80       437.70    -183.69      158.75
0.1050          -19.16       -59.49      194.49       558.83    -105.38      251.86       543.74    -181.31      237.62
0.1100          -16.06         2.88      252.83       690.05     -88.42      331.54       684.40    -169.31      333.28
0.1150           42.56       125.76      197.32       760.77     -83.91      391.99       747.16    -164.52      399.91
0.1200          119.22       233.34       96.51       695.35     -87.28      407.60       644.08    -149.80      409.15
0.1250          233.08       300.19       26.20       615.21     -84.75      375.53       558.56    -116.59      417.33
0.1300          387.38       350.78       10.31       604.76     -68.41      297.98       577.92     -72.53      433.85
0.1350          534.29       400.59       60.76       666.13     -32.17      132.83       637.60     -23.73      388.91
0.1400          584.25       437.75      176.52       731.34      -8.82     -157.73       803.19      -8.43      262.43
0.1450          653.51       539.35      159.45       642.25     -45.82     -438.32       732.44     -26.76       17.94
0.1500          564.84       601.46      198.11       485.85     -87.59     -457.82       531.08     -28.28     -213.34
0.1550          485.44       572.62      214.67       462.91    -131.51     -338.89       366.95     -21.97     -330.42
0.1600          548.02       515.19      101.64       389.01    -154.58     -254.81       276.55     -10.30     -382.50
0.1650          568.98       423.36       42.42       434.99    -156.20     -197.66       257.22      12.74     -406.62
0.1700          526.62       313.49       34.63       524.46    -141.33     -163.47       296.10      49.84     -422.05
0.1750          452.72       191.44       18.12       636.24    -117.75     -150.16       375.18      97.34     -435.69
0.1800          331.20        51.86      -33.12       726.01     -95.10     -160.89       453.82     140.20     -441.37
0.1850          124.35       -48.30     -127.44       719.86     -77.90     -207.59       462.90     160.66     -427.26
0.1900         -162.10       -73.88     -263.45       619.08     -66.48     -280.18       394.50     152.76     -402.54
0.1950         -467.97        13.23     -394.90       485.67     -60.55     -359.70       297.65     122.03     -384.70
0.2000         -673.13       194.43     -491.97       345.97     -57.20     -440.77       197.72      73.41     -367.86
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 22 of 29)

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                               THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                  NOV 15, 1972  PAGE 39
DEBUG SERIES 73. OLD 3-D VS. NEW 3-D.                                      REFERENCE 3-111,3-128, AND 191.
                               UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.

                                                JOINT STOP MOMENTS

                                    NECK                               RIGHT HIP                              LEFT HIP

TIME              YAW         PITCH        ROLL         YAW       PITCH        ROLL         YAW       PITCH        ROLL

0.0               0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0050            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0100            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0150            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0200            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0250            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0300            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0350            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0400            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0450            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0500            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0550            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0600            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0650            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0700            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0750            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0800            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0850            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0900            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.0950            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.1000            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.1050            0.0          0.0       1297.15         0.0        0.0          0.0          0.0        0.0          0.0
0.1100            0.0          0.0      11992.16      8538.61       0.0          0.0       7759.84       0.0          0.0
0.1150            0.0          0.0       1798.13     18210.04       0.0          0.0      16323.42       0.0          0.0
0.1200            0.0          0.0          0.0       9175.71       0.0          0.0       2154.96       0.0          0.0
0.1250            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.1300            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0       2057.51
0.1350            0.0          0.0          0.0       5220.06       0.0          0.0       8205.87       0.0          0.0
0.1400            0.0          0.0          0.0      14168.80       0.0          0.0      24066.91       0.0          0.0
0.1450         1960.21         0.0          0.0       1900.83       0.0      -2699.25      14231.59       0.0          0.0
0.1500            0.0       1674.00      1917.15         0.0        0.0      -5325.42         0.0        0.0          0.0
0.1550            0.0          0.0       5037.12         0.0        0.0          0.0          0.0        0.0          0.0
0.1600            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.1650            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.1700            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0       -435.97
0.1750            0.0          0.0          0.0       1095.04       0.0          0.0          0.0        0.0      -2312.38
0.1800            0.0          0.0          0.0      13458.19       0.0          0.0          0.0        0.0      -3092.24
0.1850            0.0          0.0          0.0      14555.68       0.0          0.0          0.0        0.0      -1151.59
0.1900            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.1950            0.0          0.0          0.0          0.0        0.0          0.0          0.0        0.0          0.0
0.2000        -10809.19        0.0          0.0          0.0        0.0      -3020.82         0.0        0.0          0.0
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 23 of 29)

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                         THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                NOV 15, 1972  PAGE 41
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                               REFERENCE 3-111,3-128, AND 191.
                        UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
                   DISPLACEMENTS AND VELOCITIES ARE RELATIVE TO THE ORIGIN OF THE VEHICLE COORDINATE SYSTEM.


                 ELASTIC MOMENTS       STOP MOMENTS        POTENTIAL ENERGY              H-POINT

   TIME          RT KNEE   LT KNEE   RT KNEE    LT KNEE    RT KNEE   LT KNEE      X         Y         Z

0.0                 0.0      0.0      0.0        0.0       -0.0      -0.0      21.26      0.0      26.87
0.0050             -0.06    -0.07     0.0        0.0        0.00      0.00     21.27     -0.00     26.87
0.0100             -0.24    -0.47     0.0        0.0        0.00      0.00     21.27     -0.01     26.87
0.0150             -0.55    -0.81     0.0        0.0        0.00      0.00     21.27     -0.14     26.87
0.0200             -1.02    -1.14     0.0        0.0        0.00      0.00     21.28     -0.48     26.87
0.0250             -1.64    -1.30     0.0        0.0        0.01      0.01     21.29     -0.96     26.87
0.0300             -2.45    -2.66     0.0        0.0        0.01      0.01     21.29     -1.54     26.87
0.0350             -3.44    -3.71     0.0        0.0        0.02      0.03     21.30     -2.23     26.87
0.0400             -4.61    -4.94     0.0        0.0        0.04      0.05     21.30     -3.05     26.88
0.0450             -5.97    -6.45     0.0        0.0        0.07      0.08     21.31     -3.99     26.88
0.0500             -7.63    -7.79     0.0        0.0        0.12      0.12     21.30     -5.03     26.89
0.0550             -9.78    -8.96     0.0        0.0        0.19      0.16     21.29     -6.17     26.92
0.0600            -12.56    -9.65     0.0        0.0        0.32      0.19     21.25     -7.39     27.00
0.0650            -15.96    -9.66     0.0        0.0        0.51      0.19     21.18     -8.68     27.12
0.0700            -19.77    -9.16     0.0        0.0        0.78      0.17     21.09     -9.99     27.31
0.0750            -23.71    -8.35     0.0        0.0        1.12      0.14     20.97    -11.20     27.57
0.0800            -27.56    -8.39     0.0        0.0        1.52      0.13     20.82    -12.22     27.90
0.0850            -31.25    -9.47     0.0        0.0        1.95      0.17     20.67    -12.97     28.25
0.0900            -34.92   -12.55     0.0        0.0        2.44      0.31     20.55    -13.41     28.58
0.0950            -38.95   -18.01     0.0        0.0        3.03      0.65     20.52    -13.56     28.84
0.1000            -44.07   -25.14     0.0        0.0        3.89      1.26     20.61    -13.47     28.97
0.1050            -51.40   -32.94     0.0        0.0        5.28      2.17     20.82    -13.20     28.96
0.1100            -61.66   -40.19     0.0        0.0        7.60      3.23     21.15    -12.80     28.83
0.1150            -74.90   -57.30     0.0        0.0       11.22      6.68     21.42    -12.34     28.77
0.1200            -96.24  -101.66     0.0        0.0       18.52     20.65     21.35    -11.98     28.84
0.1250           -131.72  -156.46     0.0        0.0       34.70     48.96     21.08    -11.64     28.94
0.1300           -180.68  -210.76     0.0        0.0       65.29     88.79     20.76    -11.23     28.97
0.1350           -237.84  -258.64 -2656.78  -10996.71    148.11    735.63     20.49    -10.78     28.87
0.1400           -263.96  -258.38 -13050.72 -10882.09    992.84    728.31     20.34    -10.30     28.73
0.1450           -211.44  -217.33     0.0        0.0       89.41     94.99     20.11     -9.98     28.69
0.1500           -141.91  -170.24     0.0        0.0       40.28     58.03     19.84     -9.80     28.55
0.1550            -79.81  -117.74     0.0        0.0       12.74     27.72     19.78     -9.54     28.31
0.1600            -28.48   -65.30     0.0        0.0        1.62      8.45     19.94     -9.13     27.97
0.1650             12.35   -15.41     0.0        0.0        0.31      0.46     20.23     -8.57     27.52
0.1700             44.89    30.44     0.0        0.0        4.03      1.83     20.60     -7.89     26.95
0.1750             71.50    70.13     0.0        0.0       10.22      9.84     21.01     -7.08     26.32
0.1800             94.88   104.43     0.0        0.0       18.01     21.81     21.34     -6.18     25.69
0.1850            118.27   135.44     0.0        0.0       27.97     36.57     21.45     -5.27     25.12
0.1900            141.85   164.11     0.0        0.0       40.25     53.86     21.34     -4.33     24.65
0.1950            163.73   190.78     0.0        0.0       53.61     72.80     21.13     -3.29     24.29
0.2000            183.99   213.41     0.0     3343.43      67.70     35.37     20.86     -2.14     24.03
```

TABLE 6. SAMPLE PROGRAM OUTPUT (Page 24 of 29)

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                                   THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                     NOV 15, 1972  PAGE 43
DEBUG SERIES 73. OLD 3-D VS. NEW 3-D.                                   REFERENCE 3-111,3-128, AND 191.
                              UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.

                                                  ENERGY VALUES

                              BODY         KINETIC                                 POTENTIAL*

                                                                                                        BELTS AND
  TIME        HEAD       TORSO     RT U LEG   LT U LEG   RT L LEG    LT L LEG     NECK      RT HIP     LT HIP   CONTACTS    TOTAL

 0.0         2283.      13130.      2929.      2929.      1425.      1425.         0.         0.        0.         7.     24135.
 0.0050      2297.      13123.      2929.      2929.      1425.      1425.         0.         0.        0.         7.     24135.
 0.0100      2304.      13116.      2930.      2930.      1425.      1425.         0.         0.        0.         7.     24136.
 0.0150      2311.      13108.      2930.      2930.      1425.      1425.         0.         0.        0.         7.     24136.
 0.0200      2318.      13101.      2930.      2930.      1426.      1426.         0.         0.        0.         7.     24137.
 0.0250      2325.      13095.      2930.      2930.      1426.      1426.         0.         0.        0.         7.     24138.
 0.0300      2332.      13089.      2929.      2929.      1426.      1426.         0.         0.        0.         7.     24139.
 0.0350      2339.      13083.      2929.      2929.      1427.      1427.         0.         0.        0.         7.     24140.
 0.0400      2346.      13077.      2928.      2928.      1427.      1427.         0.         0.        0.         7.     24141.
 0.0450      2349.      13054.      2925.      2926.      1428.      1428.         0.         0.        0.        21.     24132.
 0.0500      2326.      12859.      2911.      2910.      1430.      1430.         0.         0.        0.       175.     24043.
 0.0550      2270.      12425.      2880.      2869.      1437.      1436.         1.         0.        0.       549.     23868.
 0.0600      2138.      11724.      2831.      2795.      1449.      1447.         1.         1.        1.      1208.     23645.
 0.0650      2037.      10705.      2744.      2676.      1470.      1465.         3.         2.        2.      2283.     23434.
 0.0700      1982.       9293.      2580.      2479.      1504.      1495.         6.         6.        7.      3945.     23299.
 0.0750      1875.       7560.      2331.      2253.      1554.      1540.        10.        14.       15.      6126.     23278.
 0.0800      1759.       5699.      2033.      2036.      1620.      1602.        14.        26.       28.      8560.     23379.
 0.0850      1617.       3872.      1749.      1852.      1699.      1681.        17.        44.       47.     10996.     23576.
 0.0900      1450.       2274.      1526.      1695.      1781.      1773.        18.        68.       72.     13143.     23804.
 0.0950      1278.       1110.      1364.      1558.      1857.      1872.        19.       103.      106.     14772.     24042.
 0.1000      1137.        546.      1233.      1440.      1919.      1973.        21.       157.      157.     15686.     24278.
 0.1050      1076.        612.      1139.      1346.      1976.      2071.        27.       242.      241.     15753.     24489.
 0.1100       259.       1062.       972.      1193.      1977.      2098.      -600.        42.      108.     15081.     22204.
 0.1150       653.       1580.       294.       681.      1499.      1580.        32.     -1045.     -747.     14877.     19421.
 0.1200       842.       2887.        87.       859.      1278.      1500.        65.        26.      357.     16305.     24245.
 0.1250      1116.       2728.       333.       532.      1320.      1541.       121.       329.      312.     16802.     25217.
 0.1300      1510.       4043.      1009.       287.      1491.      1633.       228.       287.      310.     13759.     25312.
 0.1350      2022.       7263.      1652.       336.      1636.      1216.       375.       166.       86.      8946.     24593.
 0.1400      2773.       6330.      1355.      1030.       801.       674.       470.      -562.    -2184.      5988.     18399.
 0.1450      3934.       5306.      1803.      2201.      1577.      1437.       602.       395.     -590.      5055.     23571.
 0.1500      4321.       7398.      1094.      2179.      1293.      1939.       574.       413.      205.      5311.     25431.
 0.1550      5144.       7135.       904.      1890.      1465.      2151.       394.       184.      153.      5732.     25252.
 0.1600      5342.       6933.       832.      1738.      1564.      2224.       480.       150.      139.      5389.     25466.
 0.1650      6215.       7821.       832.      1763.      1617.      2302.       425.       156.      145.      4110.     25440.
 0.1700      6432.       6733.       983.      1818.      1642.      2393.       314.       201.      169.      2581.     25393.
 0.1750      6723.       5965.      1083.      1705.      1653.      2476.       199.       275.      237.      1985.     25316.
 0.1800      6544.       7407.      1154.      1348.      1687.      2518.        95.      -470.      306.      2589.     23616.
 0.1850      6795.       6025.      1051.      1336.      1963.      2848.        28.      -364.      270.      3206.     23738.
 0.1900      6143.       5983.      2083.      1755.      2275.      2993.        84.       291.      213.      3249.     25096.
 0.1950      5153.       6305.      2116.      2272.      2240.      3039.       313.       231.      157.      3001.     25015.
 0.2000      3332.       6243.      2185.      2624.      2275.      2732.      1146.       240.      112.      3184.     24832.
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 25 of 29)

* NOTE: Some potential energies have been calculated incorrectly as evidenced by the appearance of negative values. The coding error causing this has been corrected.

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                         THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                  NOV 15, 1972  PAGE 45
DEBUG SERIES 73. OLD 3-D VS. NEW 3-D.                                   REFERENCE 3-111,3-128, AND 191.
                      UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.

                                            MOMENTA

                         LINEAR                            ANGULAR                    COMPONENT ABOUT C.G.

    TIME          X         Y         Z          X          Y          Z          X          Y          Z

    0.0          0.0    -144.35      0.0     2956.11       0.0    -3353.80       0.0        0.0        0.0
    0.0050       0.16   -144.35      0.12    2955.77       0.79   -3353.68       0.15       0.16      -0.07
    0.0100       0.31   -144.35      0.23    2955.25       1.93   -3353.34       0.28       0.37      -0.14
    0.0150       0.44   -144.35      0.31    2954.62       3.77   -3352.78       0.40       0.64      -0.20
    0.0200       0.55   -144.35      0.37    2953.95       5.96   -3352.16       0.48       0.97      -0.25
    0.0250       0.62   -144.35      0.42    2953.20       7.92   -3351.59       0.52       1.30      -0.30
    0.0300       0.66   -144.35      0.48    2952.28       8.89   -3351.18       0.52       1.57      -0.33
    0.0350       0.67   -144.35      0.56    2951.03       8.28   -3350.98       0.48       1.73      -0.35
    0.0400       0.66   -144.35      0.65    2949.34       5.93   -3351.03       0.38       1.75      -0.37
    0.0450       0.59   -143.98      0.36    2944.72      -1.03   -3350.27       0.42       1.55      -0.09
    0.0500       0.09   -143.23      1.95    2915.07     -36.15   -3340.04       1.68       0.63       2.38
    0.0550      -0.30   -141.46      4.01    2848.51    -101.46   -3314.75       3.56      -1.10       6.87
    0.0600      -1.77   -138.43      6.60    2740.52    -185.36   -3266.80       4.68      -3.86      12.16
    0.0650      -2.66   -133.78     10.22    2577.79    -283.45   -3189.62       1.20      -7.98      15.42
    0.0700      -3.57   -126.50     14.44    2334.42    -403.11   -3077.70     -12.89     -13.85      13.05
    0.0750      -4.41   -117.46     18.98    2011.04    -531.80   -2923.88     -38.25     -20.00       4.08
    0.0800      -5.35   -105.41     23.04    1629.41    -652.18   -2730.95     -71.21     -22.65     -10.92
    0.0850      -6.61    -90.34     25.55    1231.71    -738.16   -2505.30    -103.17     -15.07     -29.39
    0.0900      -8.17    -74.65     26.06     854.43    -776.97   -2253.27    -126.35       5.62     -48.01
    0.0950     -10.04    -57.23     24.58     522.60    -771.26   -1986.29    -135.18      38.86     -64.14
    0.1000     -11.93    -39.74     21.44     247.66    -730.05   -1706.84    -127.21      78.48     -75.09
    0.1050     -13.25    -22.46     17.19      26.20    -664.25   -1406.05    -103.11     113.11     -78.51
    0.1100     -14.30     -5.77     12.77    -168.67    -605.52   -1102.97     -90.14     127.29     -83.70
    0.1150     -15.44     10.37      8.42    -338.21    -566.20    -810.95     -48.79      38.36    -156.61
    0.1200     -15.94     24.99      3.55    -454.51    -510.71    -480.51      29.99     -56.42    -178.79
    0.1250     -14.39     39.45     -2.00    -540.70    -399.52     -66.06     100.29     -83.46    -110.89
    0.1300     -11.24     52.61     -8.08    -599.12    -242.32     369.33     155.81     -99.66     -36.20
    0.1350      -8.40     63.62    -13.99    -639.90     -76.87     725.21     183.36     -92.57      15.98
    0.1400      -6.51     72.21    -19.34    -674.46      88.92     963.43     179.83    -118.24     -37.11
    0.1450      -4.42     79.26    -24.71    -692.64     270.66    1158.62     192.01    -148.07    -153.35
    0.1500      -1.01     85.40    -30.09    -705.73     476.03    1367.79     194.54     -90.38    -157.56
    0.1550       3.37     91.21    -34.33    -738.05     675.86    1656.03     186.07     -49.97    -113.60
    0.1600       7.07     95.65    -38.72    -790.57     835.86    1912.70     157.52     -22.98     -64.25
    0.1650       9.09    101.21    -42.51    -833.64     958.20    2113.62     137.01     -11.53     -16.93
    0.1700       9.24    104.79    -45.32    -867.07    1034.43    2240.93     113.92      -5.74      19.35
    0.1750       6.64    107.15    -46.94    -942.87    1007.82    2273.62      79.05      -0.08      36.19
    0.1800       1.39    108.50    -44.94   -1069.81     856.72    2217.42      41.05      -6.81      13.54
    0.1850      -4.55    108.40    -40.20   -1225.65     655.69    2126.94       1.10     -24.95     -31.93
    0.1900     -10.38    107.71    -33.59   -1393.35     432.87    2027.45     -50.28     -30.95     -58.43
    0.1950     -15.43    105.53    -25.73   -1554.27     197.77    1944.11     -93.85     -28.21     -69.27
    0.2000     -17.59    105.17    -18.33   -1674.69      50.57    1939.67    -111.56      -6.78     -67.59
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TABLE 6. SAMPLE PROGRAM OUTPUT (Page 26 of 29)

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                        THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                NOV 15, 1972  PAGE 47
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                                REFERENCE 3-111,3-128, AND 191.
                        UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.

                                      INTEGRATION PERFORMANCE MEASURES

   TIME        CPU TIME    EVAL.  DENS.    STEPS   WHOLE   HALF  QUARTER  1/8   1/16   1/32   1/64  1/128  1/256  1/512

 0.0             0.0          1    0.0       4       0      0      0       0     0      0      0     0      0      0
 0.0050          7.154       31    1.4      14       7      7      0       0     0      0      0     0      0      0
 0.0100         10.003       41    1.0      24      17      7      0       0     0      0      0     0      0      0
 0.0150         12.654       51    1.0      34      27      7      0       0     0      0      0     0      0      0
 0.0200         15.249       61    1.0      44      37      7      0       0     0      0      0     0      0      0
 0.0250         17.845       71    1.0      54      47      7      0       0     0      0      0     0      0      0
 0.0300         20.455       81    1.0      64      57      7      0       0     0      0      0     0      0      0
 0.0350         23.082       91    1.0      74      67      7      0       0     0      0      0     0      0      0
 0.0400         25.735      101    1.0      84      77      7      0       0     0      0      0     0      0      0
 0.0450         28.468      111    1.0      94      87      7      0       0     0      0      0     0      0      0
 0.0500         31.265      121    1.0     104      97      7      0       0     0      0      0     0      0      0
 0.0550         33.923      131    1.0     114     107      7      0       0     0      0      0     0      0      0
 0.0600         36.466      141    1.0     124     117      7      0       0     0      0      0     0      0      0
 0.0650         38.999      151    1.0     134     127      7      0       0     0      0      0     0      0      0
 0.0700         41.598      161    1.0     144     137      7      0       0     0      0      0     0      0      0
 0.0750         44.129      171    1.0     154     147      7      0       0     0      0      0     0      0      0
 0.0800         46.756      181    1.0     164     157      7      0       0     0      0      0     0      0      0
 0.0850         49.369      191    1.0     174     167      7      0       0     0      0      0     0      0      0
 0.0900         52.013      201    1.0     184     177      7      0       0     0      0      0     0      0      0
 0.0950         54.555      211    1.0     194     187      7      0       0     0      0      0     0      0      0
 0.1000         57.247      221    1.0     204     197      7      0       0     0      0      0     0      0      0
 0.1050         61.938      240    1.3     217     206      7      4       0     0      0      0     0      0      0
 0.1100         71.572      279    2.7     244     208     20     16       0     0      0      0     0      0      0
 0.1150         88.280      349    4.0     284     208     30     46       0     0      0      0     0      0      0
 0.1200        100.667      401    3.4     318     210     41     64       3     0      0      0     0      0      0
 0.1250        106.659      427    2.0     326     211     60     64       3     0      0      0     0      0      0
 0.1300        113.151      456    2.0     338     215     76     64       3     0      0      0     0      0      0
 0.1350        123.121      499    3.1     339     215     87     84       3     0      0      0     0      0      0
 0.1400        149.940      618    6.8     437     215     90    107      45     0      0      0     0      0      0
 0.1450        187.504      731   10.7     564     215     90    118      95    46      0      0     0      0      0
 0.1500        244.361     1049   15.6     720     215     90    120     135   143     17      0     0      0      0
 0.1550        285.793     1232   11.4     834     215     91    131     179   191     27      0     0      0      0
 0.1600        312.207     1351    7.4     906     215     96    152     199   219     27      0     0      0      0
 0.1650        318.891     1383    2.0     926     219    112    152     199   219     27      0     0      0      0
 0.1700        324.538     1410    1.8     946     224    125    152     199   219     27      0     0      0      0
 0.1750        328.833     1430    1.4     966     232    131    152     199   219     27      0     0      0      0
 0.1800        334.734     1459    2.0     980     236    147    152     199   219     27      0     0      0      0
 0.1850        343.981     1506    2.6    1006     239    151    161     199   219     27      0     0      0      0
 0.1900        350.134     1538    2.0    1026     243    177    161     199   219     27      0     0      0      0
 0.1950        354.506     1561    2.0    1046     244    196    161     199   219     27      0     0      0      0
 0.2000        383.710     1701    7.7    1143     247    203    164     221   261     27      0     0      0      0
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TABLE 6 SAMPLE PROGRAM OUTPUT (Page 27 of 29)

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                    THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                 NOV 15, 1972  PAGE 49
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                          REFERENCE 3-111,3-128, AND 191.
                    UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
             CONTACT TANGENCY POINT COORDINATES ARE RELATIVE TO THE VEHICLE SYSTEM ORIGIN.

                                CONTACT INTERACTION BETWEEN

                          ELLIPSOID LEFT CHEST       ASSUMED TO BE RIGID

                                            AND

                          PLANE SEAT BACK          MADE OF MAT1

 TIME    DEFLECTION   RATE     FORCE    FRICTION  X-PLANE * Y-PLANE*   VEL.     X-PL VEL. Y-PL VEL. X-TAN PT  Y-TAN PT  Z-TAN PT

0.0         0.02      -0.        9.7       0.0     0.0       0.0        0.        0.        0.     12.34     -5.30     13.68
0.0050      0.02      -0.        9.6       0.0     0.0       0.0        0.        0.        0.     12.34     -5.30     13.68
0.0100      0.02      -0.        9.3       0.0     0.0       0.0        0.        0.        0.     12.34     -5.30     13.68
0.0150      0.02      -0.        8.8       0.0     0.0       0.0        0.        0.        0.     12.35     -5.44     13.68
0.0200      0.02      -0.        8.3       0.0     0.0       0.0        0.        0.        0.     12.35     -5.77     13.68
0.0250      0.02      -0.        7.9       0.0     0.0       0.0        0.        0.        0.     12.35     -6.25     13.68
0.0300      0.02      -0.        7.6       0.0     0.0       0.0        0.        0.        0.     12.35     -6.82     13.68
0.0350      0.02       0.        7.6       0.0     0.0       0.0        0.        0.        0.     12.35     -7.50     13.68
0.0400      0.02       0.        8.0       0.0     0.0       0.0        0.        0.        0.     12.35     -8.32     13.68
0.0450      0.02      -3.        9.4       0.0     0.0       0.0        0.        0.        0.     12.35     -9.26     13.68
0.0500      0.01      -4.        4.0       0.0     0.0       0.0        0.        0.        0.     12.36    -10.29     13.69
0.0550      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.0600      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.0650      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.0700      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.0750      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.0800      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.0850      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.0900      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.0950      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.1000      0.31      73.      157.4       0.0     0.0       0.0        0.        0.        0.     13.05    -21.14     16.42
0.1050      0.57      57.      333.2       0.0     0.0       0.0        0.        0.        0.     12.80    -21.26     16.77
0.1100      0.86      33.      431.0       0.0     0.0       0.0        0.        0.        0.     12.67    -21.16     16.98
0.1150      1.27     142.      632.7       0.0     0.0       0.0        0.        0.        0.     12.37    -20.97     17.32
0.1200      2.11     158.     1054.7       0.0     0.0       0.0        0.        0.        0.     11.59    -20.51     17.65
0.1250      2.54       3.     1269.4       0.0     0.0       0.0        0.        0.        0.     11.10    -19.74     17.57
0.1300      2.14    -159.     1067.9       0.0     0.0       0.0        0.        0.        0.     11.34    -18.87     17.06
0.1350      1.34    -259.      518.2       0.0     0.0       0.0        0.        0.        0.     12.21    -17.89     16.24
0.1400      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.1450      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.1500      0.13      70.       66.8       0.0     0.0       0.0        0.        0.        0.     12.50    -13.64     14.43
0.1550      0.30      -1.      150.6       0.0     0.0       0.0        0.        0.        0.     12.15    -11.92     13.97
0.1600      0.21     -47.      106.4       0.0     0.0       0.0        0.        0.        0.     12.09    -10.30     13.56
0.1650      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.1700      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.1750      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.1800      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.1850      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.1900      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.1950      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
0.2000      0.0        0.        0.0       0.0     0.0       0.0        0.        0.        0.      0.0       0.0       0.0
```

TABLE 6. SAMPLE PROGRAM OUTPUT (Page 28 of 29)

* NOTE: Positions of contact on X-PLANE and Y-PLANE are printed "0.0" They are non-zero and the error causing the problem has been corrected.

```
                    THREE DIMENSIONAL CRASH VICTIM SIMULATOR   OUTPUT DATA                    NOV 15, 1972   PAGE 51
DEBUG SERIES 7B. OLD 3-D VS. NEW 3-D.                              REFERENCE 3-111,3-128, AND 191.
                     UNITS ARE INCHES, DEGREES, POUNDS, AND SECONDS UNLESS NOTED.
              CONTACT TANGENCY POINT COORDINATES ARE RELATIVE TO THE VEHICLE SYSTEM ORIGIN.

                                     CONTACT INTERACTION BETWEEN


                              ELLIPSOID RIGHT CHEST         ASSUMED TO BE RIGID

                                                  AND

                                PLANE SEAT BACK          MADE OF MAT1

  TIME    DEFLECTION   RATE      FORCE    FRICTION  X-PLANE*  Y-PLANE*   VEL.     X-PL VEL. Y-PL VEL. X-TAN PT  Y-TAN PT  Z-TAN PT

0.0          0.02       -0.        9.7      0.0      0.0       0.0       0.         0.        0.      12.34      5.30     13.68
0.0050       0.02       -0.        9.6      0.0      0.0       0.0       0.         0.        0.      12.34      5.30     13.68
0.0100       0.02       -0.        9.2      0.0      0.0       0.0       0.         0.        0.      12.35      5.30     13.68
0.0150       0.02       -0.        8.7      0.0      0.0       0.0       0.         0.        0.      12.35      5.16     13.68
0.0200       0.02       -0.        8.2      0.0      0.0       0.0       0.         0.        0.      12.35      4.83     13.68
0.0250       0.02       -0.        7.6      0.0      0.0       0.0       0.         0.        0.      12.35      4.35     13.69
0.0300       0.01       -0.        7.3      0.0      0.0       0.0       0.         0.        0.      12.35      3.78     13.69
0.0350       0.01        0.        7.2      0.0      0.0       0.0       0.         0.        0.      12.36      3.10     13.70
0.0400       0.01        0.        7.4      0.0      0.0       0.0       0.         0.        0.      12.36      2.28     13.70
0.0450       0.02        1.        8.0      0.0      0.0       0.0       0.         0.        0.      12.36      1.34     13.71
0.0500       0.13        6.       15.8      0.0      0.0       0.0       0.         0.        0.      12.35      0.31     13.72
0.0550       0.09       17.       43.9      0.0      0.0       0.0       0.         0.        0.      12.31     -0.82     13.77
0.0600       0.20       29.      100.5      0.0      0.0       0.0       0.         0.        0.      12.22     -2.03     13.86
0.0650       0.37       36.      183.4      0.0      0.0       0.0       0.         0.        0.      12.10     -3.33     14.01
0.0700       0.54       33.      272.0      0.0      0.0       0.0       0.         0.        0.      11.97     -4.69     14.19
0.0750       0.67       17.      336.8      0.0      0.0       0.0       0.         0.        0.      11.91     -6.05     14.37
0.0800       0.70       -5.      352.2      0.0      0.0       0.0       0.         0.        0.      11.93     -7.34     14.54
0.0850       0.63      -23.      314.9      0.0      0.0       0.0       0.         0.        0.      12.06     -8.51     14.67
0.0900       0.50      -28.      248.1      0.0      0.0       0.0       0.         0.        0.      12.24     -9.48     14.76
0.0950       0.38      -15.      191.4      0.0      0.0       0.0       0.         0.        0.      12.38    -10.22     14.82
0.1000       0.38       14.      187.8      0.0      0.0       0.0       0.         0.        0.      12.41    -10.68     14.87
0.1050       0.53       49.      266.2      0.0      0.0       0.0       0.         0.        0.      12.25    -10.84     14.90
0.1100       0.85       61.      422.9      0.0      0.0       0.0       0.         0.        0.      11.93    -10.78     14.94
0.1150       0.85      -77.      422.9      0.0      0.0       0.0       0.         0.        0.      11.93    -10.66     14.94
0.1200       0.20     -149.       38.7      0.0      0.0       0.0       0.         0.        0.      12.55    -10.35     14.75
0.1250       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1300       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1350       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1400       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1450       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1500       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1550       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1600       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1650       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1700       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1750       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1800       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1850       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1900       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.1950       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
0.2000       0.0         0.        0.0      0.0      0.0       0.0       0.         0.        0.       0.0       0.0       0.0
```

TABLE 6. SAMPLE PROGRAM OUTPUT (Page 29 of 29)

* NOTE: Positions of contact on X-PLANE and Y-PLANE are printed "0.0" They are non-zero and the error causing the problem has been corrected.

TABLE 7 DESCRIPTION OF CONTACT FORCE

NORMAL OUTPUT

ITEM	DESCRIPTION
TIME	Real time in seconds.
DEFLECTION	Penetration of ellipsoid into another ellipsoid or contact surface.
RATE	Rate of penetration.
FORCE	Normal force generated.
FRICTION	Friction force tangential to contact surface.
X-PLANE Y-PLANE	Location in contact plane coordinates of the point of application of the friction force.
VEL.	Velocity at which the computed friction force vector is moving along the contact plane.
X-PL. VEL. Y-PL. VEL.	X- and Y- components of VEL. in contact surface coordinates.
X-TAN PT. Y-TAN PT. Z-TAN PT.	The x, y, and z components of the location of the point of application of the normal force relative to the vehicle origin, relative to the occupant's H-point, or inertial. The coordinate system depends on IDIS as specified in field 7 of the W card (See Table 5).

C. PRELIMINARY EXPERIMENTAL VERIFICATION

In developing the earlier HSRI Three-Dimensional crash victim simulator described by Robbins (11), validation experiments were carried out on an impact sled. The 50th percentile Sierra dummy was seated in an automotive bucket seat and restrained by a single diagonal harness and lap belt combination. The deceleration pulse (See Figure 19) represented a direct side impact. The photographic and transducer data was processed to provide comparisons with quantities predicted using the model. Portions of the verification exercise are included in Section 4 B of this report describing normal program output.

Several comparisons between the experimental results, the predictions of the older 3-mass model, and the predictions of the new 6-mass model are given in Figures 20-26. It will be noticed that the two analyses give similar results in all cases. This is explained by the fact that the data set used with the new analysis was based on the data set used with the 3-mass model to serve as a check on results.

The major difference observed between predicted and experimental results is in angular head motions with predicted motions being too large. The older 3-mass model does not allow coupling between yaw, pitch, and roll stops. The new model was exercised to simulate the responses of the old models. When the input data is changed to represent a more realistic set of stops, the results given in Figures 24, 25, and 26 for the 6-mass model should correspond much more closely to the experimental case.

A series of exercises of the new model should be conducted for comparison with the various other two and three-dimensional models which are under development or in use today. A more complete assessment of accuracy, flexibility, ease of use, operational cost, etc., will be possible when that work is complete. Of particular interest will be the accuracy of the new joint model which is believed to be the most realistic yet proposed.

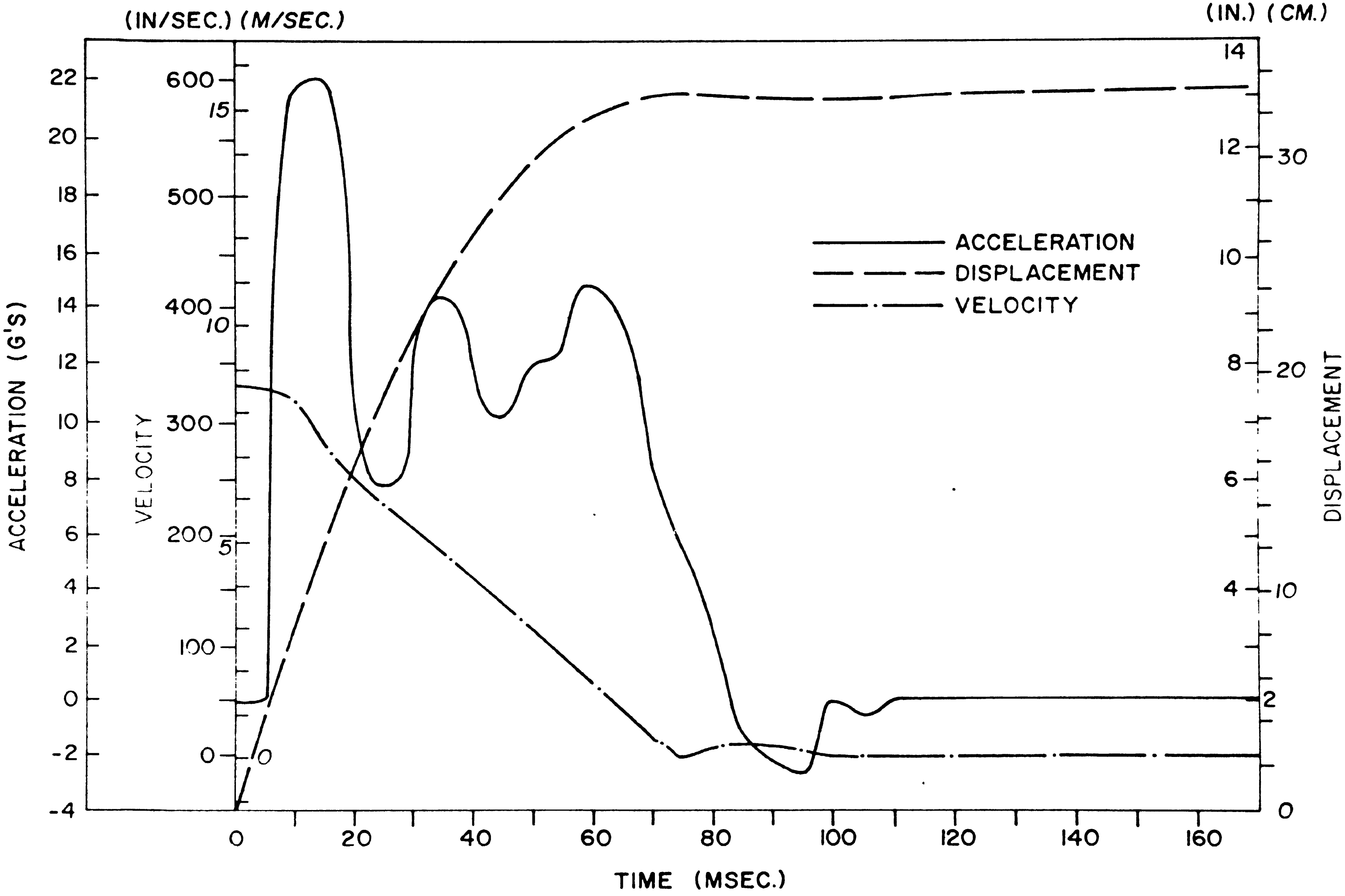

Figure 19. Vehicle Kinematics

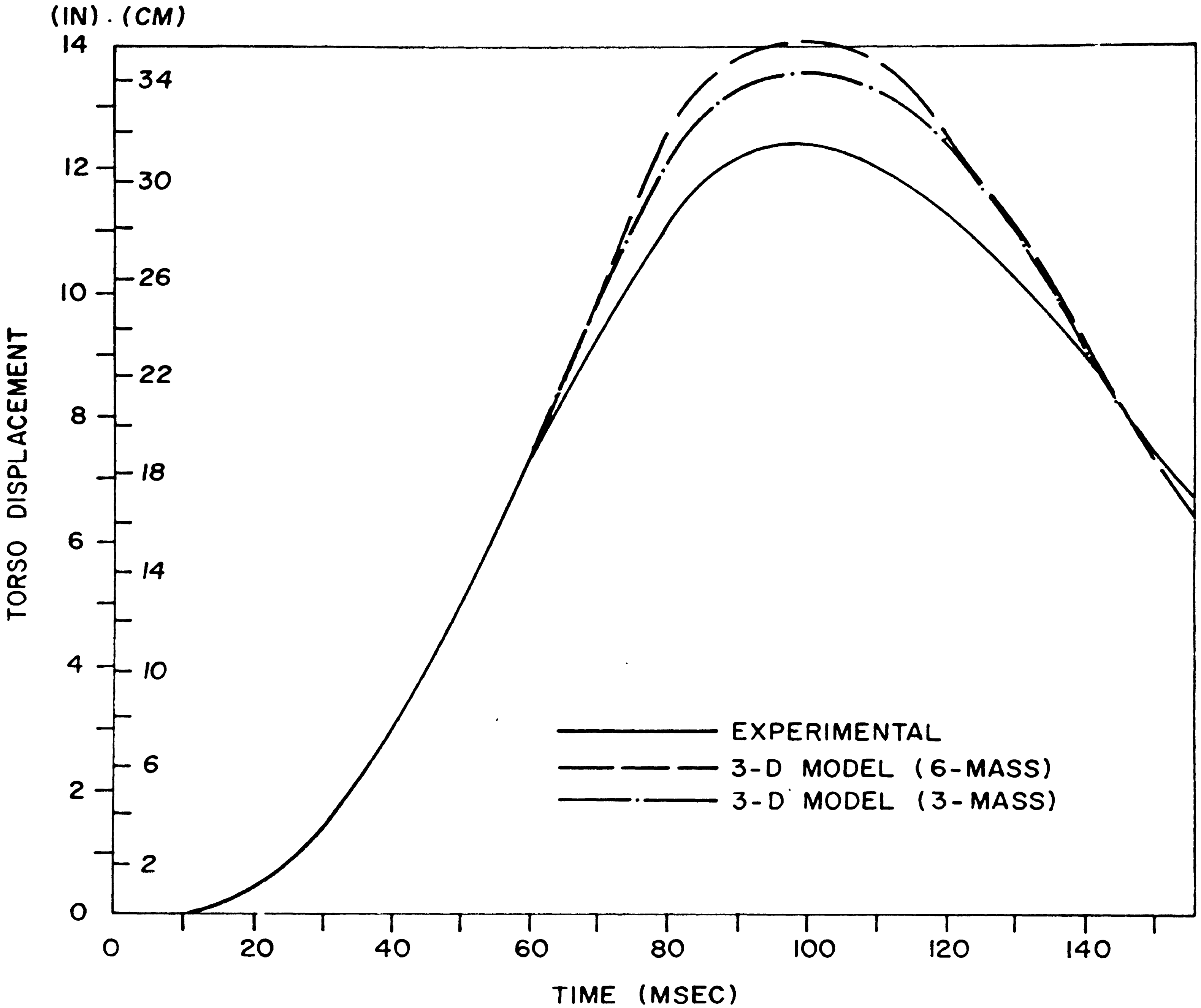

Figure 20. Torso Displacement to Side

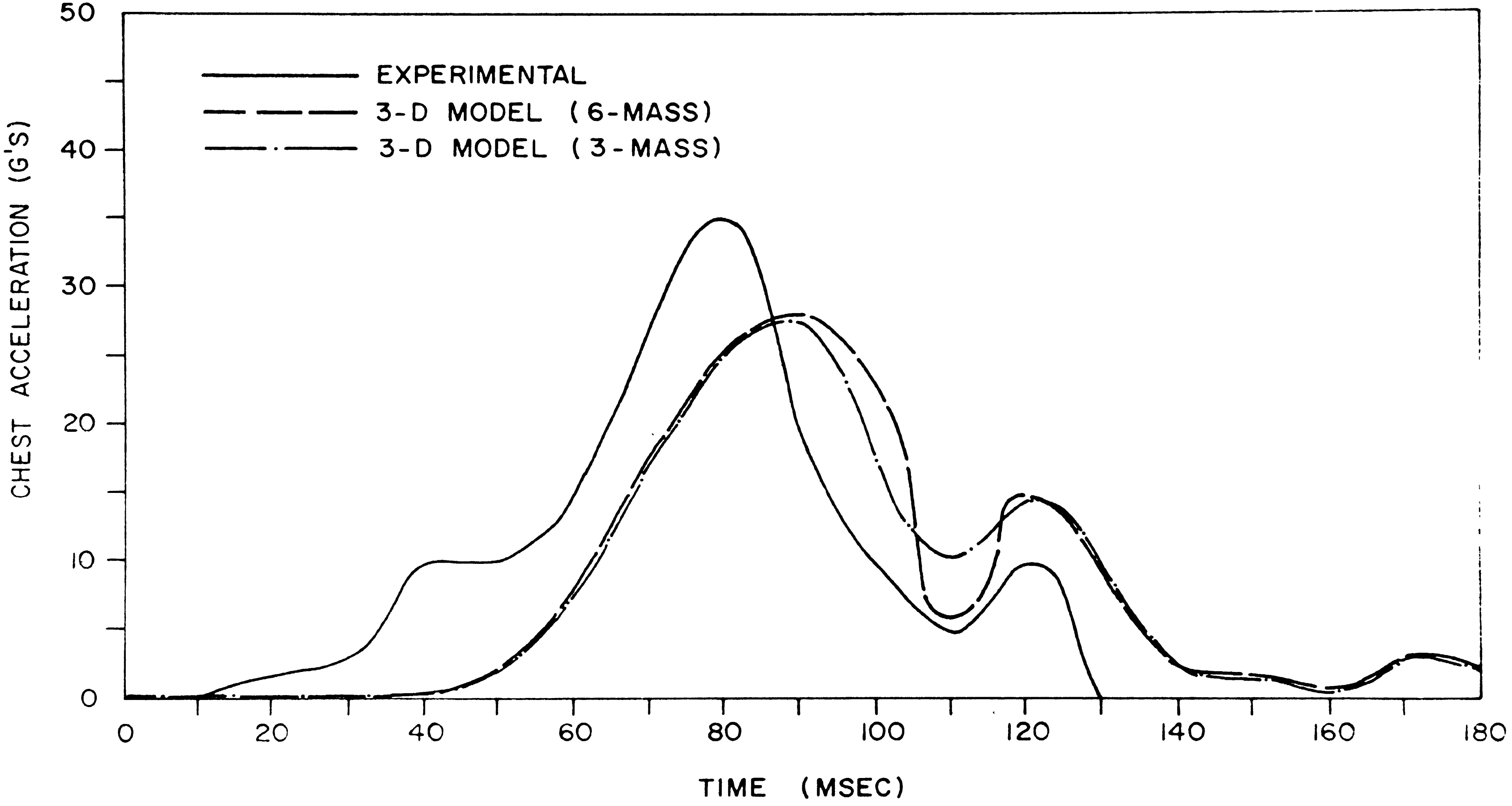

Figure 21. Lateral Torso Acceleration

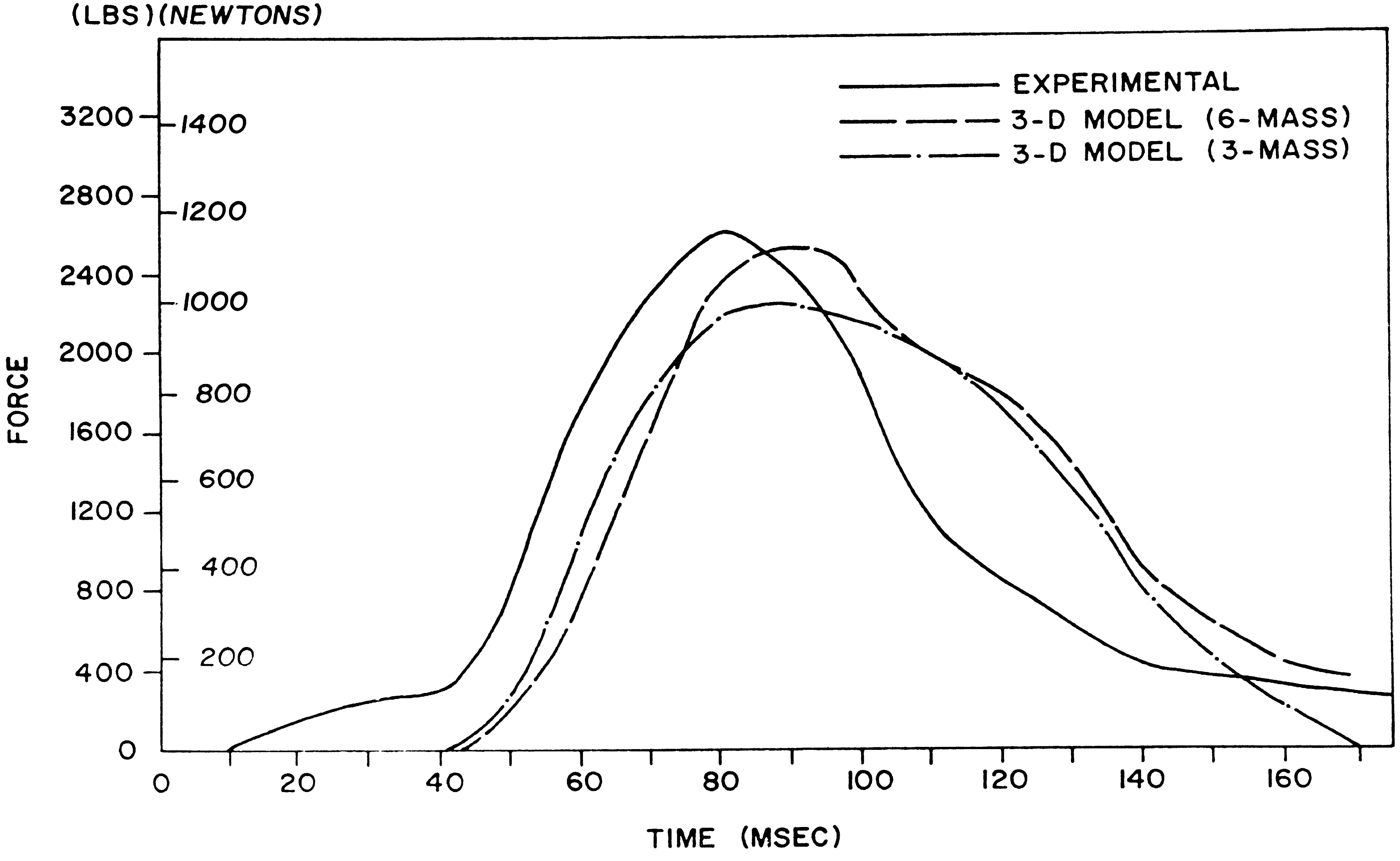

Figure 22. Sum of Seat Belt Loads

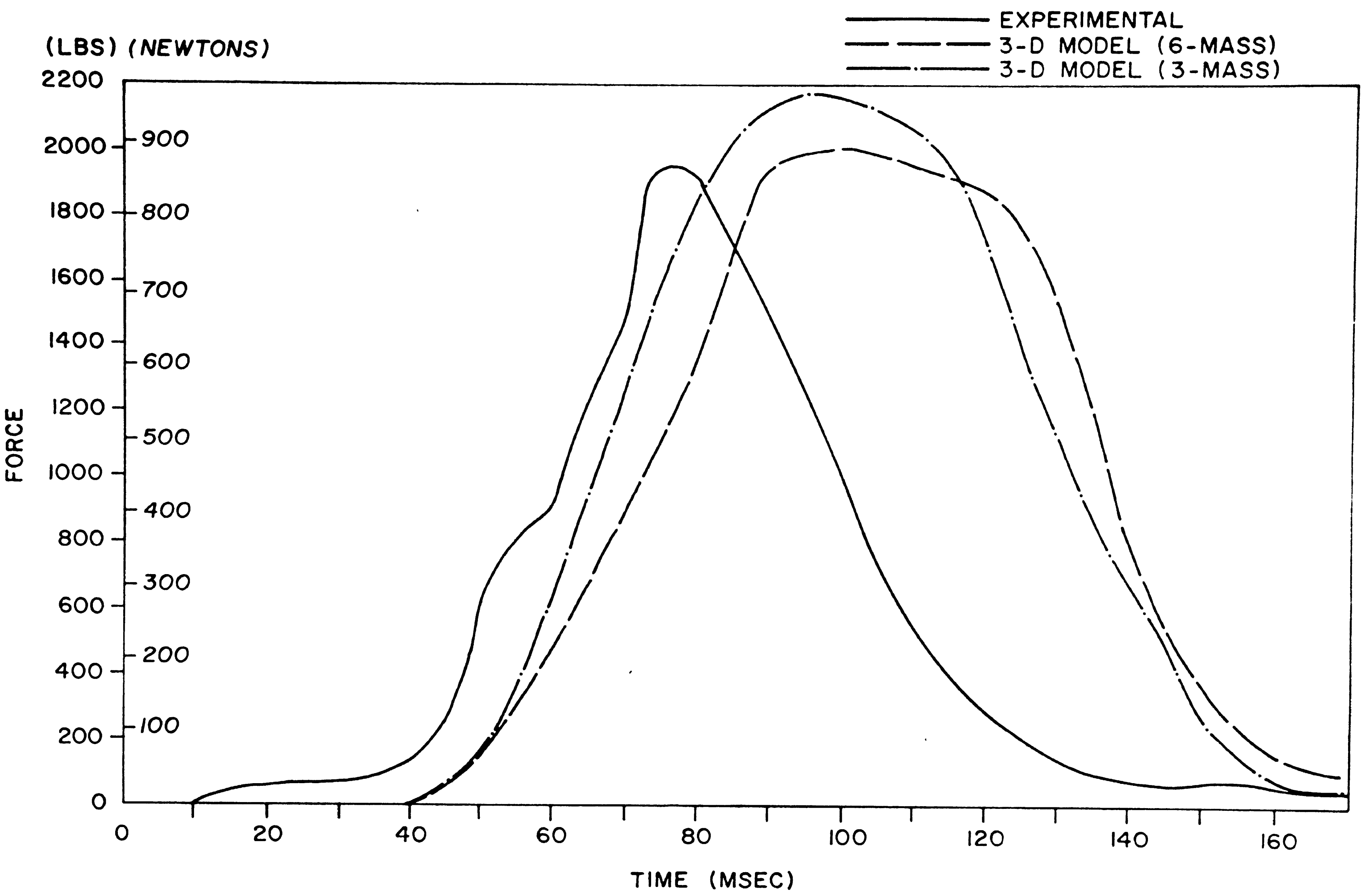

Figure 23. Sum of Shoulder Belt Loads.

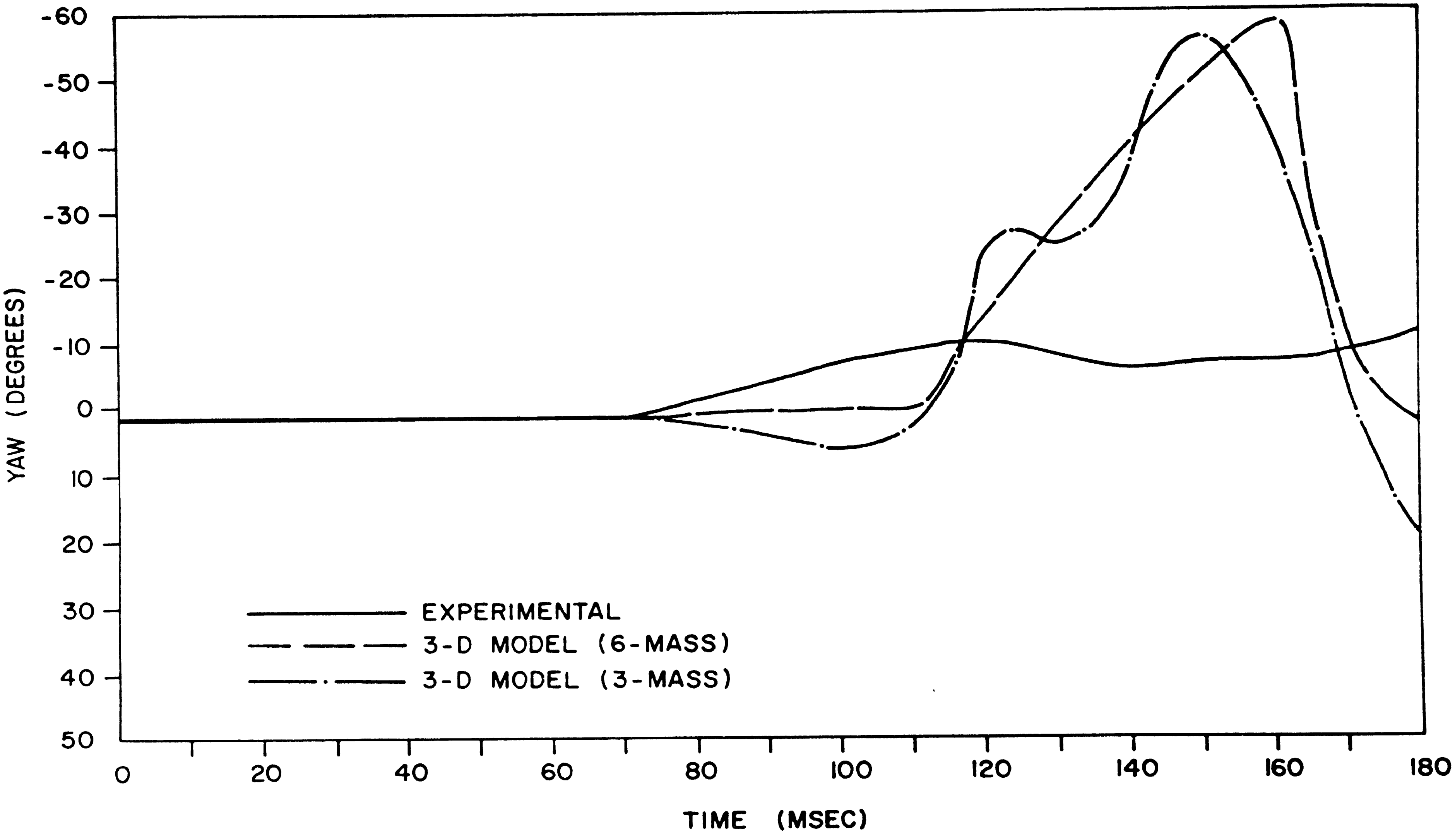

Figure 24. Head Yaw

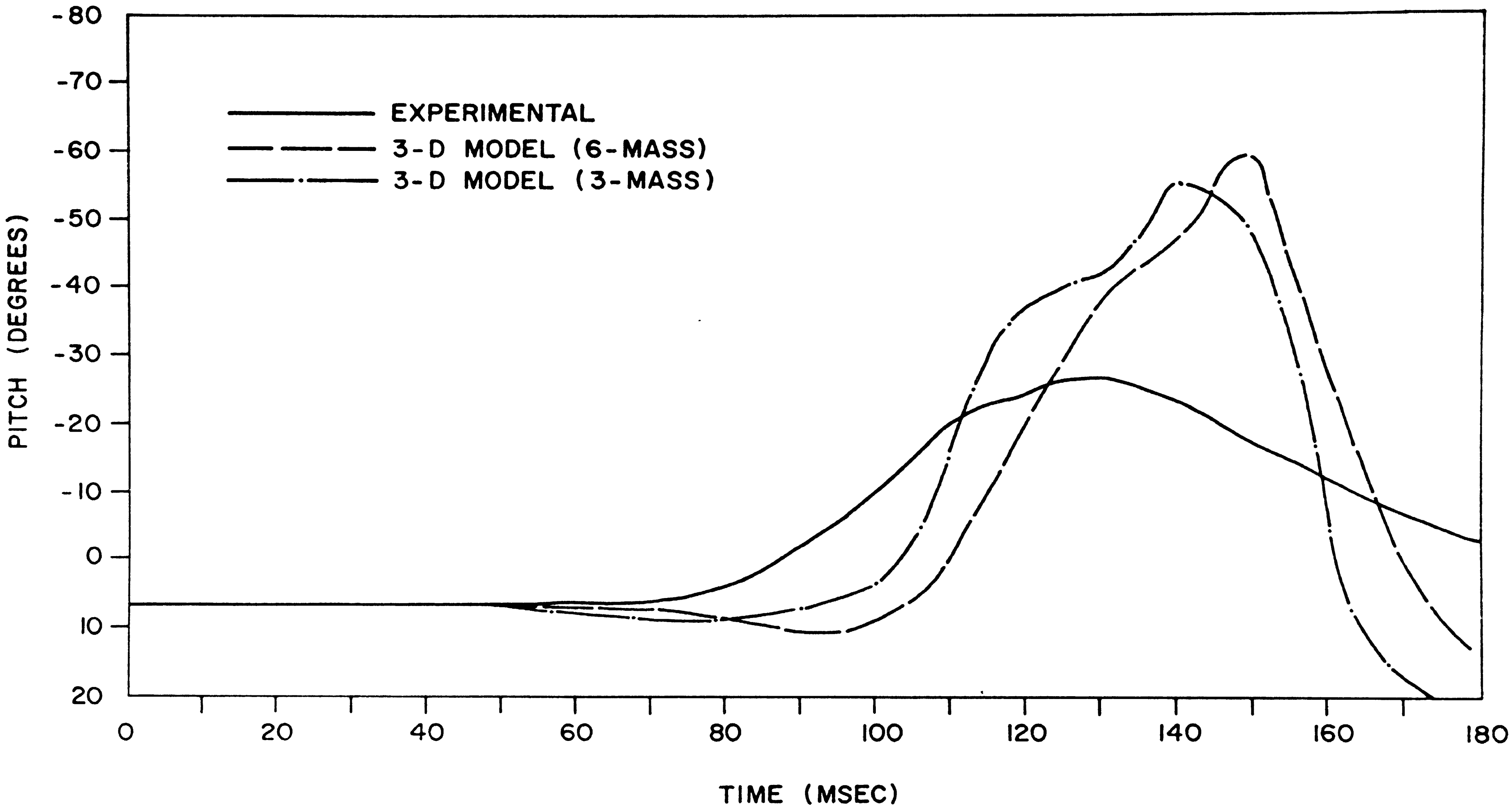

Figure 25. Head Pitch

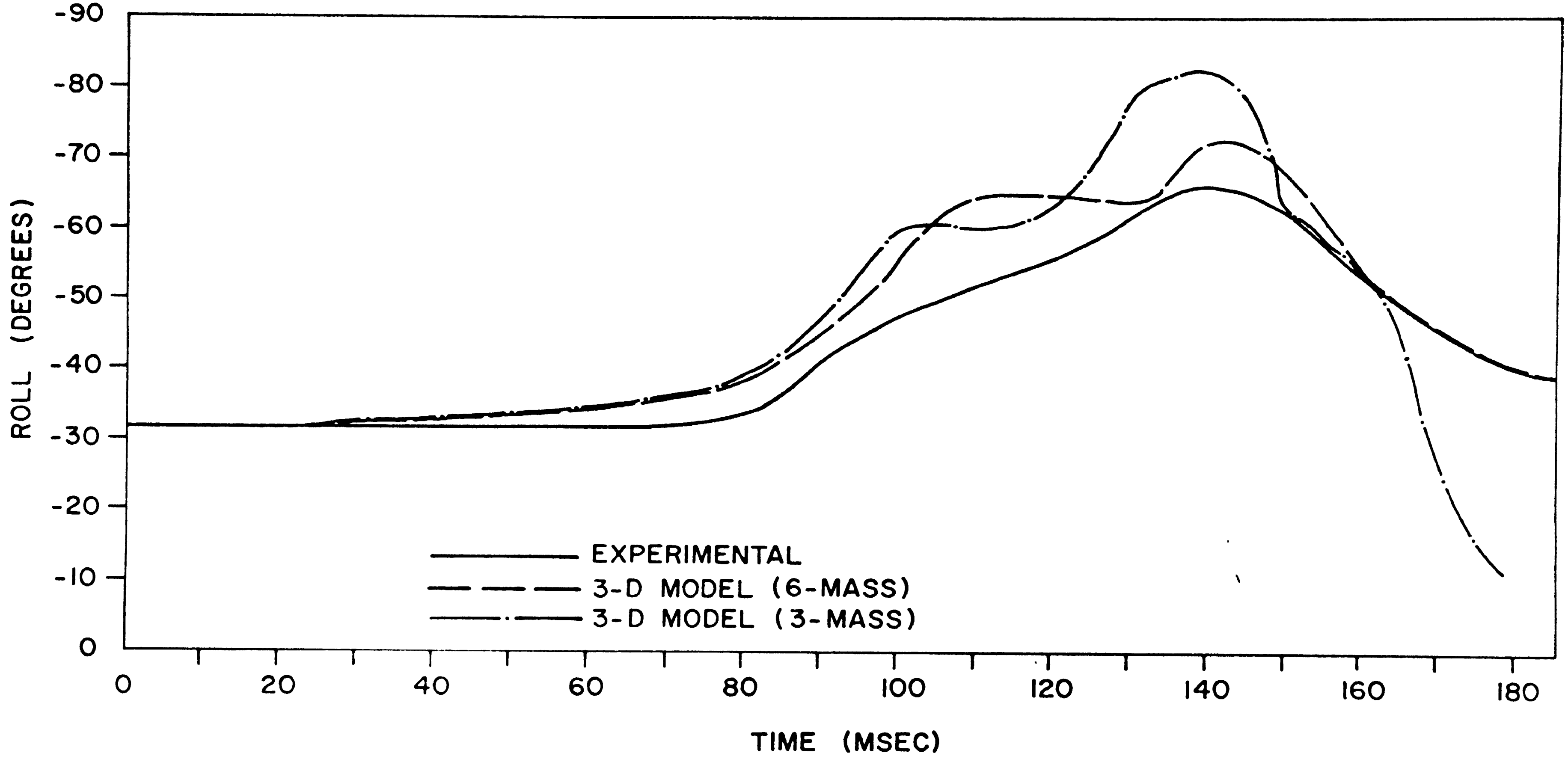

Figure 26. Head Roll

D. USERS' GUIDE FOR MODEL OPERATION

This program is designed to be used normally in batch mode. It is also possible to make data sets for this model with the use of a companion program, OVERLORD. The bulk of this section constitutes a description of OVERLORD in its present form. A listing of OVERLORD is included at the end of Appendix B but no further information is included in Appendix A. Another companion program called BAIL for obtaining partial normal printout in the case of a machine aborted run is also described at the end of this section.

The normal batch mode execution of the program in the Michigan Terminal System (MTS) has input coming in on logical device number (l.d.n.) one, normal output coming out on SPRINT, debugging output coming out on l.d.n. six, and a summary scratch file attached to l.d.n. nine. The full run statement for the program in MTS is

```
$RUN SXXX:3DE 1=DATA 6=DEBUG 9=SUMMARY SPRINT=PRINTOUT
```

where

DATA is a file containing the input data deck

DEBUG is an empty file to hold the auxillary output

PRINTOUT is an empty file to hold the normal output

SUMMARY is an empty file to hold the special binary output which is used to produce the standard normal printout.

Normal batch operation calls for the run statement:

```
$RUN SXXX:3DE 1=DATA 9=SUMMARY
```

Here both l.d.n. six and SPRINT default to *SINK* (the normal print stream.)

D.1 Introduction to OVERLORD

Since the production of data sets for this and other models is both tedious and often routine, there is a need for computer aided data making.

Previously, programs had been developed to carry out some of the steps involved in obtaining complete data sets, but it was felt at HSRI that the development of a program for the overall control of the data making and model running processes was mandatory before the working engineer would benefit from these large computer models. Lack of manpower has made necessary the curtailment of all but the rudiments of such a program. Even still, we feel that this version of OVERLOAD will be very helpful.

OVERLORD is currently a command language which deals with the construction and handling of portions of data sets. It is for conversational or batch use. It allows the user to elect one of certain standard options in each major section of the data, to construct certain selected pieces of information using the program to help, or to make use of a portion of one of his own old data sets. A command is typed in as one or more characters followed optionally by a blank and a four character data set name. Only the first letter of a command need be right for recognition.

D.2 OVERLORD Commands

OVERLORD begins with a statement printed on the teletype or printer as follows:

```
ENTER OVERLORD COMMAND LANGUAGE, TYPE S PLUS EOL FOR INFORMATION.
```

EOL stands for whatever is the End Of Line character for your terminal. OVERLORD prompts for a command with a ".". The proper response would be at least the first letter of a command and perhaps a data set name. The "S" command is the Summary command and asks for an abbreviated summary of the command language to be printed. This is shown below:

```
COMMAND
 SHORT
 FORM    DESCRIPTION
C DATA  WORK ON SIMULATION CONTROL DATA.
D DATA  WORK ON ACCELERATION DATA.
E DATA  SUBMIT A CONCURRENT RUN.
F       OUTPUT DATA DECK ON 8 AND STOP.
I DATA  WORK ON VEHICLE INTERIOR DATA.
L DATA  LOAD WHOLE DATA SET FOR MODIFICATION.
M MODL  SET UP FOR SPECIFIED MODEL.
                     OPTIONS: HS2D,HS3D,HS3E,CGH2.
O DATA  WORK ON OCCUPANT DATA.
P DATA  WORK ON INITIAL CONDITIONS DATA.
R DATA  SAVE IN LIBRARY UNDER NAME.
W DATA  VERIFY DATA SET IN LIBRARY.

     IF DATA IS BLANK, CAUSES PROMPTING (EXCEPT W=ALL).
     IF DATA IS =00M WHERE M IS DIGIT (0,...,9),
        TAKE NEXT SET ON LOGICAL DEVICE NUMBER M.
     IF DATA IS NAME IN LIBRARY, LOADS FROM OLD SET.
     IF DATA IS NONE OF THESE, COMMAND IGNORED.
```

Table 8 contains a more complete description of the command. The sections which immediately follow this table deal with the organization of OVERLORD and certain of the commands individually. The Execute and Model commands will do nothing but print comments at this time.

D.3. OVERLORD Organization

OVERLORD uses six logical devices together with SPRINT in its MTS version. L.d.n. one is used for input of the old master which contains thirty-five standard data sets used by OVERLORD together with any of the user's data sets which he has recorded in earlier runs or added by hand. The data sets which are on the master are in a special format called library format which is described in a later section. The old master is unchanged. An updated version of the master incorporating any new data sets recorded is produced on l.d.n.2. A copy of the data set current when the FINISH command is given is output in regular

TABLE 8. OVERLORD COMMAND LANGUAGE

Commands		Argument	Explanation
1.	CONTROL	Data Set Name	Work on program control section of the data.
2.	DECELERATION	Data Set Name	Work on vehicle acceleration section of the data.
3.	EXECUTE	Data Set Name	Submit the compiled data set for a run while you wait.
4.	FINISH	No Argument	Data set is finished, put together copy of updated master file and output the data set in regular card format for later running.
5.	INTERIOR	Data Set Name	Work on vehicle interior section of data deck.
6.	LOAD	Data Set Name	Load all of an old data set on old master in the library format for modification.
7.	MODEL	Model Name	Code for model for which data set is produced. Currently for this model only.
8.	OCCUPANT	Data Set Name	Work on occupant section of data.
9.	POSITION	Data Set Name	Work on initial position and velocity data section.
10.	RECORD	Data Set Name	Save current data set in library format on new master for future reference.
11.	SUMMARY	No Argument	Print summary of command language.
12.	WHAT	Data Set Name	Verify data set in library or list all that are.

card format on l.d.n.8. Input commands and responses to prompts are expected on l.d.n.5. Both l.d.n.7 and l.d.n.9 have scratch files attached to them. Prompting and other printout is done using SPRINT.

Throughout Table 8, one of three responses is expected where a "Data Set Name" is called for. The first such response is either an EOL or blanks followed by EOL. This response signifies that prompting is to be made for which of the standard options is to be elected. If a four character name of a data set present on the old master plus an EOL is given, the applicable part of the data set is used. The third expected possibility is of the form "=OOM" plus EOL which directs OVERLORD to use the applicable part of the next data set on l.d.n."m". This data set must also be in the library format.

D.4. The Control Command

When prompting is requested, the Control Command begins with:

```
 START WITH STANDARD VALUES?
 PROPER RESPONSES ARE:
 YES
 NO
?
```

If it is desired to make small changes in previously submitted control information, respond "no," otherwise respond "yes" since you will not have the opportunity to supply all needed values in the prompting which follows. OVERLORD always lists the possible responses when there are certain expected responses. The first such response is always the default if simply an EOL is given. The first character of any response plus EOL is sufficient for recognition. When an answer is expected, OVERLORD ends the prompts with a question mark.

After the answer is received and acted upon, prompting continues with:

```
 ENTER MAXIMUM REAL TIME FOR SIMULATION.
 RESPONSE NOT TO EXCEED 5 DIGITS.
?.2
        (answer shown)
```

This time the answer is shown as well, then continues:

```
 ENTER SPACING OF PRINTED TIMES.
 RESPONSE NOT TO EXCEED 8 DIGITS.
?.005

 ENTER EXECUTION TIME LIMIT.
 RESPONSE NOT TO EXCEED 5 DIGITS.
?.2
```

D.5. The Deceleration Command

```
 WANT STANDARD 30 M.P.H. BARRIER CRASH PROFILE?
 PROPER RESPONSES ARE:
 NO
 YES
?

 ENTER DESCRIPTIVE TITLE.
 RESPONSE NOT TO EXCEED 40 DIGITS.
?

 TYPE CODE LETTER FOR ONE OF PROFILE TYPES.
 PROPER RESPONSES ARE:
 A. FRONTAL IMPACT
 B. REAR IMPACT
 C. LEFT SIDE IMPACT
 D. RIGHT SIDE IMPACT
 E. UPWARD ACCEL.
 F. DOWNWARD ACCEL.
 G. FRONT PITCH ACCEL.
 H. REAR PITCH ACCEL.
 I. LEFT SPIN ACCEL.
 J. RIGHT SPIN ACCEL.
 K. LEFT ROLL ACCEL.
 L. RIGHT ROLL ACCEL.
 M.     DONE
```

This prompt will be repeated as each acceleration table is completed until an "M" is responded. The prompting continues.

```
TYPE CODE LETTER FOR ONE OF PULSE SHAPES.
PROPER RESPONSES ARE:
A. TRAPEZOID
B. TRIANGLE
C. SINE
D. NO MORE
```

A profile is made up of the sum of one or more of the elementary pulses. These pulses are individually prompted for until a "D" is responded. Then the necessary cards for that table or profile are added to the data set and prompting for the next profile begins. Continuing prompting for each pulse seeks numerical quantities necessary to describe the particular pulse shape and is self-explanatory.

D.6. The Interior Command

```
 ENTER CODE LETTER FOR STANDARD INTERIOR YOU WANT.
 PROPER RESPONSES ARE:
 A. DRIVER SEAT WITHOUT SIDE CONTACTS.
 B. DRIVER SEAT WITH SIDE CONTACTS.
 C. PASSENGER SEAT W/O SIDE CONTACTS.
 D. PASSENGER SEAT WITH SIDE CONTACTS.
 E. PASSENGER SEAT WITH FLOOR ONLY.
?
```

These five standard options are all that are currently offered.

D.7. The Occupant Command

```
ENTER CODE LETTER FOR STANDARD OCCUPANT YOU WANT.
PROPER RESPONSES ARE:
A. 95TH MALE.
B. 50TH MALE.
C. 5TH FEMALE.
D. 6 YEAR CHILD.
```

These four standard options are all that are currently offered.

D.8. The Position Command

This command requests vehicle velocities in the six-degrees-of-freedom and then inquires:

```
ENTER BELTS USED.
PROPER RESPONSES ARE:
A. LAP BELT ONLY.
B. LAP BELT AND TORSO HARNESS.
C. NO BELTS.
```

At this point the slack for each belt segment announced is inquired about and then prompting continues with:

```
CHOOSE CONNECTION TYPE FOR (LAP BELT OR TORSO HARNESS).
PROPER RESPONSES ARE:
A. FREE SLIPPING.
B. PERCENT INFLUENCE.
C. NO COUPLING.
D. SATURATION.
E. FRICTION.
```

Depending on the choice made, the remaining information is prompted for. The rest of the position information is picked from standard values based on the current situation.

D.9. The What Command

If no data set name is provided, this command causes the total list of data sets on the old master to be printed as below.

```
DATA SET NAMES ON OLD MASTER.
      1   *50M
      2   *95M
      3   *05F
      4   *6YC
      5   *CON
      6   *DEC
      7   *PAF
      8   *DST
      9   *DWS
     10   *PST
     11   *PWS
     12   *D95
     13   *P95
```

```
14   *D50
15   *P50
16   *D5F
17   *P5F
18   *D6C
19   *P6C
20   *LD9
21   *LP9
22   *LD0
23   *LP0
24   *LD5
25   *LP5
26   *LD6
27   *LP6
28   *HD9
29   *HP9
30   *HD0
31   *HP0
32   *HD5
33   *HP5
34   *HD6
35   *HP6
```

If a data set name is supplied, this command prints a statement about whether or not a data set with that name is present on the old master. The printed response is for example:

```
DATA SET *HDP IS NOT ON OLD MASTER.
```

or

```
DATA SET *HP9 IS IN POSITION 29 ON OLD MASTER.
```

D.10. Library Format for Data Set

Library format is regular card format modified so that the "U" and "Z" cards are dropped. The deck is preceded with two or three title cards which are described in Table 9, and each lettered card which starts a special reading sequence is preceded by a card as described in Table 10. The data sections present need not be complete, but if any part of a data section is present, it must be acknowledged. Table 11 specifies which cards are in which data sections.

TABLE 9 SPECIFICATION OF TITLE CARDS OF LIBRARY FORMAT

<table>
<tr><th>Card No.</th><th>Columns</th><th>Description</th></tr>
<tr><td>1</td><td>1</td><td>"."</td></tr>
<tr><td></td><td>2-5</td><td>Data Set Name (no blanks allowed)</td></tr>
<tr><td></td><td>6-8</td><td>Number of cards in data deck (150 maximum) except this card.</td></tr>
<tr><td></td><td>9</td><td>Data Set Type
1 if contains a Control Data section only
2 if contains a acceleration data section only
5 if interior data section only
8 if occupant data section only
9 if position data section only
0 if any combination of these</td></tr>
<tr><td></td><td>10</td><td>Control Data Section Switch: 0 if absence, 1 if present</td></tr>
<tr><td></td><td>11</td><td>Decel Date Section Switch: 0 if absence, 1 if present</td></tr>
<tr><td></td><td>12</td><td>Interior Data Section Switch: 0 if absence, 1 if present</td></tr>
<tr><td></td><td>13</td><td>Occupant Data Section Switch: 0 if absence, 1 if present</td></tr>
<tr><td></td><td>14</td><td>Position Data Section Switch: 0 if absence, 1 if present</td></tr>
<tr><td></td><td>15</td><td>Model code.
0 if HSRI Extended 3-D model
1 if HSRI Regular 3-D model
2 if Extended MODROS model
3 if HSRI Regular 2-D model</td></tr>
<tr><td>2</td><td>see description</td><td><table>
<tr><th>Data Set Type</th><th>Title contained in columns</th></tr>
<tr><td>1</td><td>1-40</td></tr>
<tr><td>2</td><td>1-40</td></tr>
<tr><td>5</td><td>1-12</td></tr>
<tr><td>8</td><td>1-8</td></tr>
<tr><td>9</td><td>1-24</td></tr>
<tr><td>0</td><td>1-80</td></tr>
</table></td></tr>
<tr><td>3</td><td>1-40</td><td>present if and only if data set type is zero and contains Deceleration Title</td></tr>
</table>

NOTE: If Data set type zero, the format of title expected is

Cols.	Contents
7-8	Occupant Title
9-12	" IN "
13-24	Interior title
25-36	" POSITIONED "
37-60	Position title
61-80	" AND SUBJECTED TO "

TABLE 10 SPECIFICATION OF LENGTH CARDS OF LIBRARY FORMAT

Columns	Explanation
1	"."
2-3	Number of cards in reading sequence including the lettered card but not including this one.
4	Blank or Data Section Type (See Table 11). This must be filled in for cards which may occur in more than one data section.

TABLE 11 SPECIFICATION OF CARD I.D. FOR DATA SECTION TYPE

Data Section Type	Description	Card I.D.
1	Control Section	R, S, T, V, W
2	Deceleration Section	"0" cards for tables 1-6
5	Interior Section	I, K fields 2-4, N and matching M's and O's.
8	Occupant Section	A, D, E, F, G, H, and matching M's and O's.
9	Position Section	B, C, J, L and K fields 5-8.

D.11. BAIL Program

The BAIL Program is designed to cause the SUMARY routine of the regular model package to read the binary file and produce normal printed output up to the point that the run aborted and information was recorded. In MTS, the run statement is:

```
$RUN SXXX: BAIL  9=SUMMARY  SPRINT=PRINTOUT
```

where SUMMARY and PRINTOUT are defined at the beginning of this section.

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14. J. P. Danforth and C. D. Randall, "Treatment of Single and Multiple Loading and Unloading of Contact Surfaces in Vehicle Interiors," Unpublished memo, 33 p., 1971.

APPENDIX A DETAILED PROGRAM INFORMATION

I. OVERALL PROGRAM ORGANIZATION AND FLOW

The overall functional layout of the program is implied by the integration techniques employed (see Part III of this Appendix). The program is segmented so that the solution of Equation 11 for the generalized accelerations is accomplished by subroutine ACCEL when it is provided with the current time, generalized coordinates, and generalized velocities. CARTIN is a subroutine which when given time produces the vehicle coordinates, velocities, and accelerations. Figure 27 shows the overall flow of the program in terms of calls to these two subroutines.

All variables are first initialized and accelerations are computed at time zero. A time step is then chosen and new accelerations computed. Based on this predicted value, a corrected value is obtained using a different mathematical forward prediction rule. This iterative predictor-corrector method is used until a convergence test is passed. An additional procedure which is applied is the limiting procedures discussed in Section III of this Appendix. These tests occur in the flow diagram within the boxes which state that one or the other integration should be done. After acceptable accelerations are determined, the equations are integrated to give final values for velocities, displacements, and other quantities as required and the information stored for later output.

II. SUBPROGRAM DESCRIPTIONS AND FLOW

The physical organization of the program consists of a main program, forty-two subprograms, and twenty-six Fortran and MTS utility routines. In what follows, the main program will be treated as a subprogram which is named MAIN and is simply called first.

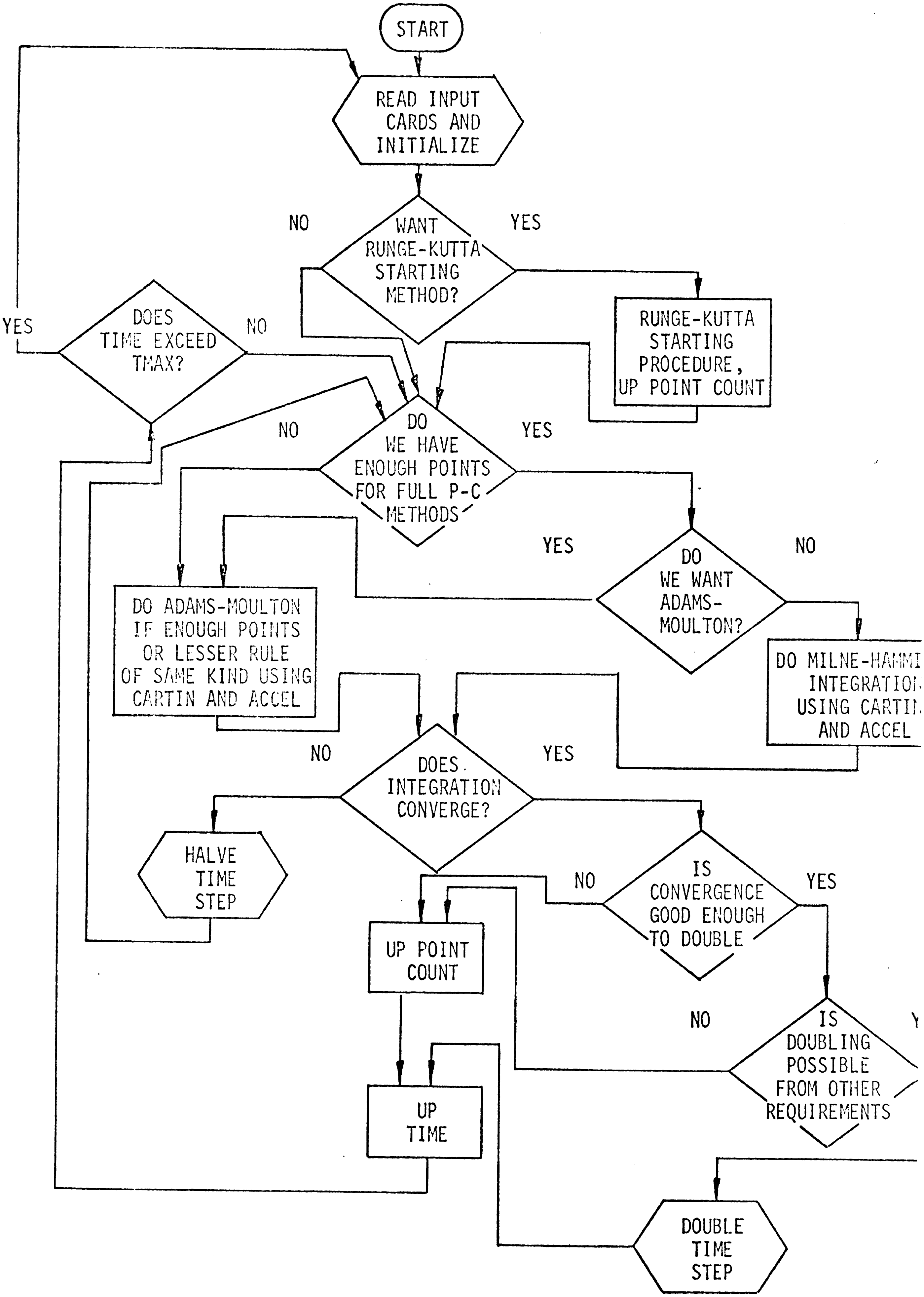

Figure 27 Flow Diagram for Three-Dimensional Victim Simulator

Table 12 contains a short description of each of the forty-three subprograms together with four columns of information about interactions and communication between them. The Flow Sequence is a series of statements about parts of a program which indicate the steps that are taken and in what order and can be considered a flow diagram that has been written out. A flow sequence can be as elaborate as the whole program given step by step in English or as simple as a general description of purpose. In order to facilitate identification of which parts of the program code which correspond to each of the flow sequence statements, a "Statement Location" column has been provided. The statement location consists of a range of Fortran statement numbers which includes the code which is being talked about. Often there will be no statement number on the ends of the code to be discussed. This problem is handled by appending a suffix of "B" or "F" (which means "before" or "after" respectively) to a nearby statement number. "END" designates the physical last statement of the subprogram ("SRT" the first).

The "Commons" column lists in alphabetical order all the labeled commons used for communication between this subprogram and others. The "Subprograms Called" column lists all the other subprograms in alphabetical order which this one uses followed by a list of all the library functions used. "Subprograms Calling" lists all the subprograms which use this one. "Special Output" lists all the auxillary output which eminates from this subprogram. A prefix of "DB" indicates the debug switch number found in Tables 33 and 34. A prefix of "E" indicates the number of the error message in the order found in Table 35.

Table 13 lists each of the library functions used and gives a brief description of each. Table 14 presents all the labeled commons, the subprograms which share each one, and an indication about the type of information each contains.

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 1 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
1	ACCEL	SRT - 45	Initialization	BQ, BUG, CART, CNT DUM, IO, KC, MC, QQ, QV, T	CONTAC BELT JOINT SLE1	MAIN RK	DB12 - DB25 E21
		50 - 90B	Compute rotation matrices and associated quantities.				
		90B - 9989F	Compute body segment c.g. quantities.				
		94 - 9987F	Compute kinetic energy generalized force quantities.				
		111 - 9986F	Compute generalized mass matrix.				
		51 - 900B	Compute generalized forces due to kinetic energy and gravity				
		900 - 901	Compute generalized forces due to contacts, belts, and joints by calling separate routines and accumulate total generalized forces.				
		901F - END	Solve system of equations for generalized accelerations.				
2	BELT	SRT - 120B	Compute inertial anchor and attachment positions and associated quantities for each belt.	BC, BQ, BUG, BV, CART, FEC, IO, QQ, QV, T	SETACT LODFEL	ACCEL	DB1 - DB11
		120 - 130B	Compute belt length, components, and derivations for each belt.				
		130 - 150	Compute lever arms and belt angles for each belt.				
		150F - 155	For each pair of free slipping belts, compute effective deflection and call LODFEL for force using effictive load-deflection properties. Apply force to both belts.				
		155F - 170	For all belts not paired in free slipping, compute individual force by calling LODFEL using individual load-deflection properties.				

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 2 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
2 (cont.)	BELT	172-216	If interbelt influence of friction type is chosen, compute new belt forces using equation 147. Then skip to 219.				
		230-240	If interbelt influence of either force difference or percentage type is chosen, compute new belt forces using equation 154.				
		219-END	Compute contributions to generalized forces.				
3	CARTIN		Integrate the piece-wise linear acceleration profile segment by segment up to the current time using the exact solution. Certain tables are used which are computed in READAT for efficiency sake.	BUG, CART, DUM, IO, T, TAB, VX	GETY	MAIN RK	DB30
4	CMIL		Compute Milne corrector with Hamming's modification using the last four formulas in Equation 155.	C, QQ, T, XX	NONE	MAIN	NONE
5	CONTAC	SRT-40	Initialization	BQ, BUG, CART, CON, DUM, FEC, IO, IT, OUT, QQ, QV, T, TT	SETACT LODFEL	ACCEL	DB39-DB70
		50-60B	Unpack contact ellipsoid information for each ellipsoid.				
		60B-190F	Pack computed ellipsoid information for each ellipsoid.				
		210-1490	For each contact plane, determine all forces, generalized forces, etc., resulting from all interacting ellipsoids.				

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 3 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
5 (cont.)	CONTAC	210-210F	Unpack contact plane controls. If plane has more than one inputted position in time history, go to 250.				
		210F-250B	For plane with only one inputted position in time history, unpack corner point coordinates parallelogram side lengths, etc. Go to 410.				
		250-320	Determine corner point positions and velocities interpolating if necessary.				
		330-430B	Compute contact plane coefficients and rates in inertial and vehicle coordinates.				
		430F-460B	Compute corner point positions and velocities relative to vehicle if the inputted time history is inertial.				
		470F-600	Compute intermediate contact plane quantities.				
		600F-1480	Check all body segments for ellipsoids interacting with the plane; compute deflections, forces, and lever arms.				
		620F-1470	Loop on ellipsoids for particular plane and particular body segment. Nested inside 600F-1480.				
		640-650B	Unpack ellipsoid information.				
		650F-690B	Compute inertial coordinates of point of deepest penetration against plane.				
		710-790	Compute contact edge lengths and edge effectiveness factors.				
		800F-990	Determine lever arms if ellipsoid.				
		1000-1100	Determine lever arms if sphere.				
		1110-1130	Determine deflection rate.				
		1140-1150	Determine normal contact force and contributions to generalized force vector.				

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 4 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
5 (cont.)	CONTAC	1220F-1450	Tangential force loop for the plane-ellipsoid interaction.				
		1220F-1225B	Determine whether there will be a non-zero tangential force.				
		1225B-1410	Determine velocity components of the contact point on the plane.				
		1420-1450	Compute tangential force and contributions to generalized force vector.				
		1550B-2250F	Loop for ellipsoid-ellipsoid interactions; outermost loops match body segment against body segment; innermost loops match ellipsoids.				
		1560B-1580B	If segment has no ellipsoids, consider next segment. Otherwise, unpack ellipsoid quantities.				
		1580-1640B	If opposing segment has no ellipsoids or if contact between the segments is inhibited, consider the next ellipsoid. Otherwise, unpack ellipsoid quantities.				
		1560F-2240	Ellipsoid loop for first compared body segment.				
		1580F-2220	Ellipsoid loop for body segment compared against.				
		1650-1740	Compute lever arms for interacting spheres or sphere-like ellipsoids.				
		1750-1890	Compute lever arms for ellipsoid interacting with sphere or sphere-like ellipsoid.				
		1900-2030	Compute lever-arms for interacting ellipsoids.				
		1940-1980B	Define $\overline{s}$ and $\overline{t}$ so as to resolve the degeneracy for the case of ellipsoids with parallel major axes.				
		2040-2070B	Compute deflection rate, force, contributions to the generalized force vector, and output quantities.				

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 5 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
6	CONTRL		Check to see if there are seven good points and that the doubled time step will not skip over next print time. If not all so, set switch which will prevent doubling.	DUM, EP, LT, T, TT	NONE	MAIN	NONE
7	CORK		Compute Moulton corrector using the second or the fourth pair of formulas in Equation 156 or if fewer points, the second, fourth, or sixth pair of formulas in Equation 158 depending on the number of points	C, QQ, T, XX	NONE	MAIN	NONE
8	DATE		Obtain month, day, and year of current run.	NONE	TIME	READAT	NONE
9	DEBUG		Obtain hexadecimal control word from Table 7 using GETY, extract the 16 two bit fields and shift to become integers and store in debug switch array.	BUG, IO, T	GETY SHFTR LAND	MAIN READAT	NONE
10	DETAB		Copy one of the acceleration tables back on itself leaving out any points which fall in the specified closed time interval.	TAB	SERTAB	READAT	NONE
11	ENTAB		Enter a new point in one of the acceleration tables.	TAB	SERTAB MOVTAB	READAT	E18 E19
12	ENTER		Enter a newly established set of generalized coordinates, velocities and accelerations together with the current time in the time history. If a normal entry, push down the values currently in the time history before entering the new ones.	QQ, T, XX	NONE	MAIN	NONE

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 6 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
13	EVAL		Compute the force produced given the material properties, deflection, and deflection rate for a single interaction	BUG, DUM, FEC, IO, LC, LF, LP, T	GETY SLOPE	LODEFEL	DB71-DB74 E25
14	EXTIM		Call a system routine to obtain execution time since initialization.	NONE	TIME	MAIN	NONE
15	FINDM		Find or set up material property storage for given name of material.	FEC	MATCH PUSHER	READAT	NONE
16	GETY		Determine correct piecewise interval for current time and deceleration table and interpolate to current time. Don't interpolate if debug control word.	TAB	SERTAB	CARTIN DEBUG EVAL	NONE
17	INTAB		Sort deceleration tables into order and then compute slope and intercept for each of the linear segments of each table.	TAB	NONE	READAT	NONE
18	JOINT	5F-230 5F-7F 8F-15B 15-19	Determine angles, moments, and generalized forces for the five joints. Determine relative angles at neck or hip joint. If t = 0, make sure that quadrants are properly selected for the relative angles. For relative pitch equal to ±π/2 (singular case), determine lever arms, relative angles, and relative angle velocities.	BQ, BUG, DEF, DUM, IO, IT, JC, JV, MC, QQ, QV, T	NONE	ACCEL	DB32-DB38

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 7 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
18 (cont.)	JOINT	20-20F	Guarantee continuity of relative angle in time with respect to quadrant charge.				
		30-60	Compute lever arms and relative angle velocities for neck or hip joint.				
		65F-70B	Save the neck or hip relative angle values at t=0.				
		70-85F	Define relative angles and velocities for knee joint.				
		95-220	Determine deflection, moment, and contribution to generalized force vector at the joint for each angular mode of relative angulation.				
		95-95F	Compute elastic moment for relative yaw, pitch, or roll.				
		100-140B	Compute joint stop angles for neck or hip based on coupling between yaw, pitch, and roll modes of relative angulation.				
		140-180F	Compute angular deformation against joint stop and also the joint stop moment and total moment.				
		180F-185B	For knee joint, determine generalized force contribution.				
		185-210	For neck or hip joint, determine contributions to generalized force vector.				
19	LIMIT		Carry out tests described in Part III on predicted accelerations.	BUG, DUM, EP, IO, QQ, T, XX	NONE	MAIN	DB28 DB29

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 8 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
20	LODFEL		Carry out the unpacking of material properties for an interaction and manage the shared deflection iteration if necessary.	FEC, LC, LD, LF, LP, OUT, T	EVAL	BELT CONTAC	E22-E24
21	MAIN		Flow in the main program is shown by Figure 27.	BUG, CNT, EP, IO, LT, QQ, T TT, XX	TRAPER GETIHC READAT EXTIM DEBUG CARTIN ACCEL ENTER STASH UPDATE RK PRED LIMIT CORK SUMRY PMIL CMIL CONTRL ZILTCH SYSTEM MINO	NONE	DB26 DB27 DB31 E1-E7
		30-100B	Compute starting values with a Runge-Kutta method using subroutine RK and Equation 157.				
		100-END	Compute continuing time steps using a predictor-corrector method.				
		160-210B	Halve the time step using Equation 158.				
		265-285B	Double the time step using Equation 159.				
		285-END	Print error messages if corresponding conditions have arisen.				
22	MATCH		Match an inputted name against a stored name and return location if match found.	FEC	NONE	FINDM READAT	NONE

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 9 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
23	MOVTAB		Move table entries around to make room for a new table entry.	TAB	NONE	ENTAB	E20
24	NUPAGE		Check to see if output page is full and insert page eject and title if so.	NONE	NONE	NONE	NONE
25	PEEK		Take a preliminary look at each input data card to be sure that no illegal characters are present.	ERR, IO,	SETSA	READAT	E17
26	PMIL		Compute Milne predictor with Hamming's modification using the first four formulas in Equation 155.	C, QQ, T, XX	NONE	MAIN	NONE
27	PRED		Compute Adams predictor using the first or third pair of formulas in Equation 156 or if fewer points, the first, third, or fifth pair of formulas in Equation 158 depending on the number of points.	C, T, XX	NONE	MAIN	NONE
28	PUSHER		Adjusts stored indices to compensate for new entry in middle of array.	BC, FEC, OUT, VX	NONE	FINDM READAT SETACT	NONE

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 10 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
29	READAT		Carry out run initialization and real and convert input data deck.	BC, BUG, CART, CON, DUM, EP, ERR, FEC, IO, IT, JC, JV, KC, LD, LT, MC, OUT, QQ, RSS, T, TAB, TL, TT, VX, XX	XSWTCH FCVTHB SIOEER REDTAB DATE PEEK FINDM PUSHER MATCH ENTAB DETAB INTAB DEBUG	MAIN	E8-E16
30	REDTAB		Initialize all deacceleration tables to zero and set size parameters.	TAB	NONE	READAT	NONE
31	RELTIV		Compute cartesian coordinates for output, relative to cart origin or relative to H-point position in cart at t=0.	QV	NONE	STASH	NONE
32	RK		Set up constants for desired Runge-Kutta method and integrate a starting point using Equation 117.	EP, QQ, T, XX	CARTIN ACCEL	MAIN	NONE
33	SERTAB		Search for the table entry corresponding to a particular argument.	TAB	NONE	DETAB ENTAB GETY	NONE

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 11 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
34	SETACT		Find or create the control entry in KACT for a given interaction.	BC, FEC, OUT	PUSHER	BELT CONTAC	NONE
35	SLOPE		Look up the ramp slope in a table given a particular argument.	TAB	SERTAB	EVAL	NONE
36	STASH	5	If t is not a print time, continue the integration.	BC, BV, CART, CNT, CON, DEF, EP, FEC, IO, IT, JC, JV, KC, LD, LT, MC, OUT, QQ, QV, RSS, T, TAB, TL, TT, VX, XX	RELTIV	MAIN SUMRY	NONE
		5F-10B	During first call to STASH, unpack titling and identification addresses of planes and ellipsoids and write constants into a file for use by SUMRY.				
		20-70	Compute energies and momenta.				
		70F-110	Compute the terms in $(\ddot{x}_k, \ddot{y}_k, \ddot{z}_k)$ not containing any generalized acceleration.				
		110F-700	Compute all output quantities in the units and coordinate systems specified by the user.				
		135B-700	Convert linears to relative coordinates if required.				
		700F-END	Write output variables into a file for use by SUMRY.				
37	SUMRY	SRT-END	Read output labeling, constants, and variables from file where they have been stored by STASH. Print all categories of output quantities, with continuous paging or with a "break" after each 41 time points. (See text of report.)	TL	STASH TITLE	MAIN	E26 E27

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 12 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
37 (CONT.)		SRT-8 10B-30B 19-41 50-2410 2500-2540B 2540-2610 2618-2630 2640-END	Initialization. Read constants. Read output variables for 41 time points. Save last line of output to be printed as first line of next page for each category of output quantities. Print all output except for contacts. Set up and print proper headings for contact output pages. Establish contact variable values to be printed. Print contact variable output. Recycle for continuation of printing if not done.				
38	TITLE		Increment page count, insert page eject, and print the three-line title for the new page of normal printout.	TL	NONE	SUMRY	NONE
39	TRAPER		Initialize the trap intercept system routines. Now dummied.	NONE	NONE	MAIN	NONE
40	UPDATE		Update special arrays which contain the values of certain quantities at the last established time point in final preparation for accepting the current time point as established.	BUG, FEC, IO, JV, T, TT	ERROR	MAIN	NONE
41	XSWITCH		Set error switch when transmission error intercepted.	ERR	NONE	READAT	NONE

TABLE 12 SUBPROGRAM SPECIFICATIONS AND APPEARANCES (Page 13 of 13)

Number	Subprogram Name	Statement Location	Flow Sequence or Description	Commons	Subprograms Called	Subprograms Calling	Special Output
42	ZILTCH		Skip to the beginning of a new data deck.	ERR, IO,	NONE	MAIN	E28

TABLE 13. LIBRARY FUNCTION DESCRIPTIONS

DABS	Double precision absolute value of a double precision argument.
DARCOS	Double precision arccosine of a double precision argument.
DARSIN	Double precision arcsine of a double precision argument.
DATAN2	Double precision arctangent of two double precision arguments.
DCOS	Double precision cosine of a double precision argument.
DFLOAT	Convert integer argument to double precision.
DMAX1	Obtain maximum of two or more double precision arguments.
DMIN1	Obtain minimum of two or more double precision arguments.
DMOD	Obtain double precision argument one modulo double precision argument two.
DSIGN	Obtain sign of double precision argument two times the magnitude of double precision argument one.
DSIN	Double precision sine of a double precision argument.
DSQRT	Double precision square root of a double precision argument (which must be positive).
ERROR	Return control to MTS to terminate execution and trigger a hexadecimal memory dump if that has been permitted by the user. (MTS Vol. 3, page 87)
FCVTHB	Control I/O blank conversion default. (MTS Vol. 3, page 91)
GETIHC	Set up IHC trap catcher. (MTS Vol. 3, page 103)
IABS	Integer absolute value of an integer argument.
ISIGN	Integer magnitude of first argument and sign of second argument.
LAND	Obtain a bitwise logical "and" of two full word arguments (i.e., the result has bits on only if the corresponding bits of both arguments are on). (MTS Vol. 3, page 39)
MAXO	Integer maximum of two or more integer arguments.
MINO	Integer minimum of two or more integer arguments.
SETSTA	Set up rereading of input cards with different formats. (MTS Vol. 3, page 221)
SHFTR	The first full word argument is shifted right by the number of bits specified by the second integer argument. (MTS Vol. 3, page 39)
SIOERR	Set up transmission error intercept. (MTS Vol. 3, page 229)
SLE1	Solve the set of simultaneous linear equations AX=B by Gaussian elimination. (MTS Vol. 3, page 235)
SYSTEM	Return to executive system as successful run. (MTS Vol. 3, page 255)
TIME	Allow the user easy access to the elapsed time, CPU time used, time of day, and the date in convenient units. (MTS Vol. 3, page 257)

TABLE 14. LABELED COMMON DESCRIPTIONS (page 1)

Number	Common Name	Subprograms Which Use	Description
1	BC	BELT,PUSHER,READAT,SETACT, STASH	Physical properties of belts.
2	BQ	ACCEL,BELT,CONTAC,JOINT	Contributions to the generalized force vector.
3	BUG	ACCEL,BELT,CARTIN,CONTAC, DEBUG,EVAL,JOINT,LIMIT, MAIN,READAT,UPDATE	Debug printout control switches.
4	BV	BELT,STASH	Belt forces and subsidiaries.
5	C	CMIL,CORK,PMIL,PRED	Integration rule constants.
6	CART	ACCEL,BELT,CARTIN,CONTAC, READAT,STASH	Vehicle coordinates, velocities, and accelerations.
7	CNT	ACCEL,STASH	Integration step counters.
8	CON	CONTAC,READAT,STASH	Contact friction coefficients.
9	DEF	JOINT,STASH	Joint stop angle deformations.
10	DUM	ACCEL,CARTIN,CONTAC,CONTRL, EVAL,JOINT,LIMIT,READAT	Temporary storage and profile modifiers.
11	EP	CONTRL,LIMIT,MAIN,READAT, STASH	Program control input parameters.
12	ERR	PEEK,READAT, XSWTCH,ZILTCH	Transmission error switch.
13	FEC	BELT,CONTAC,EVAL,FINDM, LODFEL,MATCH,PUSHER,READAT, SETACT,STASH,UPDATE	Ellipsoid, contact, belt and material properties, quantities and controls.
14	IO	ACCEL,BELT,CARTIN,CONTAC, DEBUG,EVAL,JOINT,LIMIT, MAIN,PEEK,READAT,STASH, UPDATE,ZILTCH	Device numbers for debug output, input, and standard output.
15	IT	CONTAC,JOINT,READAT,STASH	Iteration controls.
16	JC	JOINT,READAT,STASH	Joint input parameters.
17	JV	JOINT,READAT,STASH,UPDATE	Joint forces and angles.
18	KC	ACCEL,READAT,STASH	Physical properties of body segments.
19	LC	EVAL,LODFEL	New values of material dependent load-deflection quantities.
20	LD	LODFEL,READAT,STASH	Load-deflection force balance search controls.
21	LF	EVAL,LODFEL	Position dependent load-deflection quantities.
22	LP	EVAL,LODFEL	Old values of material dependent load-deflection quantities.
23	LT	CONTRL,MAIN,READAT,STASH	Integer equivalent of time control parameters.
24	MC	ACCEL,JOINT,READAT,STASH	Numerical constants.
25	OUT	CONTAC,PUSHER,READAT, SETACT,STASH	Storage for contact output.
26	QQ	ACCEL,BELT,CMIL,CONTAC, CORK,ENTER,JOINT,LIMIT, MAIN,PMIL,READAT,RK,STASH	Generalized coordinates, velocities, and accelerations.

TABLE 14. LABELED COMMON DESCRIPTIONS (page 2)

Number	Common Name	Subprograms Which Use	Description
27	QV	ACCEL,BELT,CONTAC,JOINT, RELTIV,STASH	Building blocks for kinetic energy contributions to the equations of motion.
28	RSS	READAT,STASH	Inputted controls and headings for output.
29	T	ACCEL,BELT,CARTIN,CMIL, CONTAC,CONTRL,CORK,DEBUG, ENTER,EVAL,JOINT,LIMIT, LODFEL,MAIN,PMIL,PRED, READAT,RK,STASH,UPDATE	Time and integration step size.
30	TAB	CARTIN,DETAB,ENTAB,GETY, INTAB,MOVTAB,READAT,REDTAB, SERTAB,SLOPE,STASH	Input table storage for profiles, debug, and material properties.
31	TL	READAT,STASH,SUMRY,TITLE, BELT	Printout page title, print controls, and belt quantities.
32	TT	CONTAC,CONTRL,MAIN,READAT, STASH,UPDATE	Time control parameters.
33	VX	CARTIN,PUSHER,READAT,STASH	Storage for deceleration table computed velocities and displacements.
34	XX	CMIL,CORK,ENTER,LIMIT,MAIN, PMIL,READAT,RK,STASH	Time history of established values of generalized coordinates, velocities, and accelerations.

III. INTEGRATION TECHNIQUES AND PROGRAM CONTROLS

The equations of motion arising in the simulation of the three-dimensional crash victim are, in form, a system of twelve simultaneous, nonlinear, second-order, ordinary differential equations in seventeen unknowns. In this system the second derivatives of the seventeen unknowns appear only linearly, so that it is possible to solve for them in terms of the first derivatives, the unknowns, and various constants.

Hence this system of equations is integrated by employing predictor-corrector techniques for an initial value problem, together with a starting method for initializing the required history of established values. Two separate predictor-corrector methods are available in the HSRI Extended Three-Dimensional Crash Victim Simulator. The one most commonly used is the classical Milne method as modified by Hamming for faster convergence. With the Milne-Hamming method, and much of the logic which surrounds its use, we have followed the approach taken in the SSP subroutines, HPCG and DHPCG.[1] The Milne-Hamming method can be summarized by Equation 155.

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[1] System/360 Scientific Subroutine Package (360-CM-03X) Version II H20-0205-2, pp. 122-128.

For k = 1,17:

$$\dot{P}_{k,1} = \dot{Z}_{k,-3} + \frac{4\Delta t}{3}(2\ddot{Z}_{k,0} - \ddot{Z}_{k,1} + 2\ddot{Z}_{k,-2})$$

$$P_{k,1} = Z_{k,-3} + \frac{4\Delta t}{3}(2\dot{Z}_{k,0} - \dot{Z}_{k,-1} + 2\dot{Z}_{k,-2})$$

$$\dot{H}_{k,1} = \dot{P}_{k,1} - \frac{112}{121}(\dot{P}_{k,0} - \dot{C}_{k,0})$$

$$H_{k,1} = P_{k,1} - \frac{112}{121}(P_{k,0} - C_{k,0})$$

$$\dot{C}_{k,1} = \frac{1}{8}[9\ddot{Z}_{k,0} - \dot{Z}_{k,-2} + 3\Delta t(\ddot{H}_{k,1} + 2\ddot{Z}_{k,0} - \ddot{Z}_{k,-1})]$$

$$C_{k,1} = \frac{1}{8}[9Z_{k,0} - Z_{k,-2} + 3\Delta t(\dot{C}_{k,1} + 2\dot{Z}_{k,0} - \dot{Z}_{k,-1})]$$

$$\dot{Z}_{k,} = \frac{1}{121}(112\dot{C}_{k,1} + 9\dot{P}_{k,1})$$

$$Z_{k,1} = \frac{1}{121}(112C_{k,1} + 9P_{k,1})$$

where

$Z_{k,j}$ is the value of the k-th generalized coordinate in the recorded history of established values which corresponds to time t - jΔt where t is the last recorded established time and Δt is the current integration time step. Note: where k appears as a subscript in a formula, that formula is evaluated for values of k from one to seventeen before anything else is done.

$\dot{Z}_{k,j}, \ddot{Z}_{k,j}$ are respectively first and second derivatives of the corresponding generalized coordinates.

$P_{k,j}, \dot{P}_{k,j}$ are the results of the Milne predictor for the corresponding generalized coordinates and velocities.

$H_{k,1}, \dot{H}_{k,1}$ are the predictions for the corresponding generalized coordinates and velocities used including the Hamming modification.

$\ddot{H}_{k,1}$ are computed by evaluation of Equation 11 using the values $H_{k,1}$ and $\dot{H}_{k,1}$ as generalized coordinates and velocities.

$C_{k,j}, \dot{C}_{k,j}$ are the results of the Milne corrector for the generalized coordinates and velocities. Note: the k implies that $\ddot{H}_{1,1}, \ddot{H}_{2,1}, \ldots, \ddot{H}_{17,1}$ are all being referred to here.

$Z_{k,1}, \dot{Z}_{k,1}$ are the corrected values of the generalized coordinates and velocities after the Hamming modification has been applied. These are the values tested for convergence. If convergence fails with the single correction, the integration time step is halved immediately.

The alternate predictor-corrector is the classical Adams-Moulton method which exhibits much greater stability. When this option is employed, up to ten corrections are permitted to obtain convergence before the time step is halved. The Adams-Moulton method is used both in four-point and five-point forms based on how many established prints are available in the time history. The two forms are presented in Equation 156 .

Four-point, for k = 1,17:

$$\dot{P}_{k,1} = \dot{Z}_{k,0} + \Delta t(c_8\ddot{Z}_{k,0} + c_9\ddot{Z}_{k,-1} + c_{10}\ddot{Z}_{k,-2} - c_{11}\ddot{Z}_{k,-3})$$

$$P_{k,1} = Z_{k,0} + \Delta t(c_{19}\dot{P}_{k,1} + c_{20}\dot{Z}_{k,0} + c_{21}\dot{Z}_{k,-1} + c_{22}\dot{Z}_{k,-2} + c_{23}\dot{Z}_{k,-3}) \qquad 156$$

$$\dot{C}_{k,1} = \dot{Z}_{k,0} + \Delta t(c_{19}\ddot{P}_{k,1} + c_{20}\ddot{Z}_{k,0} + c_{21}\ddot{Z}_{k,-1} + c_{22}\ddot{Z}_{k,-2} + c_{23}\ddot{Z}_{k,-3})$$

(Continued on next page)

$$C_{k,1} = Z_{k,0} + \Delta t(c_{19}\dot{C}_{k,1} + c_{20}\dot{Z}_{k,0} + c_{21}\dot{Z}_{k,-1} + c_{22}\dot{Z}_{k,-2} + c_{23}\dot{Z}_{k,-3})$$

(156 continued)

Five-point, for k = 1,17:

$$\dot{P}_{k,1} = \dot{Z}_{k,0} + \Delta t(c_{15}\ddot{Z}_{k,0} + c_{16}\ddot{Z}_{k,-1} + c_{17}\ddot{Z}_{k,-2} + c_{18}\ddot{Z}_{k,-3} + c_{19}\ddot{Z}_{k,-4})$$

$$P_{k,1} = Z_{k,0} + \Delta t(c_{24}\dot{P}_{k,1} + c_{25}\dot{Z}_{k,0} + c_{26}\dot{Z}_{k,-1} + c_{27}\dot{Z}_{k,-2} + c_{28}\dot{Z}_{k,-3} + c_{29}\dot{Z}_{k,-4})$$

$$\dot{C}_{k,1} = \dot{Z}_{k,0} + \Delta t(c_{24}\ddot{P}_{k,1} + c_{25}\ddot{Z}_{k,0} + c_{26}\ddot{Z}_{k,-1} + c_{27}\ddot{Z}_{k,-2} + c_{28}\ddot{Z}_{k,-3} + c_{29}\ddot{Z}_{k,-4})$$

$$C_{k,1} = Z_{k,0} + \Delta t(c_{24}\dot{C}_{k,1} + c_{25}\dot{Z}_{k,0} + c_{26}\dot{Z}_{k,-1} + c_{27}\dot{Z}_{k,-2} + c_{28}\dot{Z}_{k,-3} + c_{29}\dot{Z}_{k,-4})$$

where

$P_{k,1}, \dot{P}_{k,1}, C_{k,1}, \dot{C}_{k,1}, Z_{k,j}, \dot{Z}_{k,j}$, and $\ddot{Z}_{k,j}$ have corresponding definitions as in Equation 155.

$\ddot{P}_{k,1}$ are computed by evaluation of Equation 11 using the values $P_{k,1}$ and $\dot{P}_{k,1}$ as coordinates and velocities.

c_i are the constants presented in Table 15.

Actual experience with the computer program indicates that the Milne-Hamming method failed only once to achieve good results. A corresponding run using the Adams-Moulton method did produce good results but at considerable expense. On straightforward runs, the two methods are approximately equivalent in efficiency with a slight advantage to the Milne-Hamming. On runs of moderate difficulty, the Milne-Hamming method is much better.

Three starting methods are available. The normal method is a Runge-Kutta procedure as specially modified by Ralston[1] to gain maximum convergence. This method is highly unstable, but with a partial second iteration for improvement of results, it has never failed in our actual experience. The second integration starting method offered is a classical Runge-Kutta method

[1] Ralston "Runge-Kutta Methods with Minimum Error Bounds, " MTAC, Vol. 16, No. 80 (1962), pp. 431-437.

TABLE 15 INTEGRATION RULE COEFFICIENTS

i	c_i	Ralston Version
1	1.5	Independent of choice of Runge-Kutta method.
2	0.5	
3	1.9166666666666667	
4	- 1.3333333333333333	
5	0.41666666666666667	
6	0.66666666666666667	
7	- 0.083333333333333333	
8	2.2916666666666667	
9	- 2.4583333333333333	
10	1.5416666666666667	
11	0.375	
12	0.79166666666666667	
13	- 0.20833333333333333	
14	0.041666666666666667	
15	2.6402777777777778	
16	- 3.8527777777777778	
17	3.6333333333333333	
18	- 1.7694444444444444	
19	0.3486111111111111	
20	0.8972222222222222	
21	- 0.3666666666666667	
22	0.1472222222222222	
23	- 0.02638888888888889	
24	0.3465277777777778	
25	0.9076388888888889	
26	- 0.3375	
27	0.1680555555555556	
28	- 0.36805555555555556	
29	0.0020833333333333333	
30	0.5	0.4
31	0.5	0.45573725421878943
32	0.0	0.29697760924775360
33	0.5	0.15875964497103583
34	1.0	1.0
35	0.0	0.21810038822592047
36	0.0	- 3.0509651486929308
37	1.0	3.8328647604670103
38	0.16666666666666667	0.17476028226269037
39	0.33333333333333333	- 0.55148066287873294
40	0.33333333333333333	1.2055355993965235
41	0.16666666666666667	0.17118478121951903
42	$c_{32} + c_{33}$	These are computed after the appropriate values are assigned c_{30} through c_{41}.
43	$c_{30}c_{31}$	
44	$c_{35} + c_{36} + c_{37}$	
45	$c_{30}c_{36} + c_{32}c_{37}$	
46	$c_{33}c_{37}$	
47	$c_{38} + c_{39} + c_{40} + c_{41}$	
48	$c_{30}c_{39} + c_{32}c_{40} + c_{35}c_{41}$	
49	$c_{33}c_{40} + c_{36}c_{41}$	
50	$c_{37}c_{41}$	

with greater stability and less accuracy. Equation 157 presents a general four-point Runge-Kutta method for second-order equations. Specific Runge-Kutta methods are obtained by an appropriate set of constants c_{30} through c_{41} and the computed constants c_{42} through c_{51}. The constants needed for the normal Runge-Kutta are presented in Table 15 in the left column and those needed for the Ralston modification are in the right column.

For k = 1,17:

$$
\begin{aligned}
t_1 &= t \\
K_{k,1} &= Z_{k,0} \\
\dot{K}_{k,1} &= \dot{Z}_{k,0} \\
t_2 &= t + c_{30}\Delta t \\
K_{k,2} &= Z_{k,0} + c_{30}\Delta t\dot{Z}_{k,0} \\
\dot{K}_{k,2} &= \dot{Z}_{k,0} + c_{30}\ddot{K}_{k,1}\Delta t \\
t_3 &= t + c_{31}\Delta t \\
K_{k,3} &= Z_{k,0} + c_{42}\Delta t\dot{Z}_{k,0} + c_{43}(\Delta t)^2\ddot{K}_{k,1} \\
\dot{K}_{k,3} &= \dot{Z}_{k,0} + c_{32}\Delta t\ddot{K}_{k,1} + c_{33}\Delta t\ddot{K}_{k,2} \\
t_4 &= t + c_{34}\Delta t \\
K_{k,4} &= Z_{k,0} + \Delta t c_{44}\dot{Z}_{k,0} + c_{45}(\Delta t)^2\ddot{K}_{k,1} + c_{46}(\Delta t)^2\ddot{K}_{k,2} \\
\dot{K}_{k,4} &= \dot{Z}_{k,0} + \Delta t c_{35}\ddot{K}_{k,1} + c_{36}\Delta t\ddot{K}_{k,2} + c_{37}\Delta t\ddot{K}_{k,3} \\
Z_{k,1} &= Z_{k,0} + \Delta t c_{47}\dot{Z}_{k,0} + (\Delta t)^2(c_{48}\ddot{K}_{k,1} + c_{49}\ddot{K}_{k,2} + c_{50}\ddot{K}_{k,3}) \\
\dot{Z}_{k,1} &= \dot{Z}_{k,0} + \Delta t(c_{38}\ddot{K}_{k,1} + c_{39}\ddot{K}_{k,2} + c_{40}\ddot{K}_{k,3} + c_{41}\ddot{K}_{k,4})
\end{aligned}
\tag{157}
$$

where

$Z_{k,0}, \dot{Z}_{k,0}, t, \Delta t, c_m, Z_{k,1}$, and $\dot{Z}_{k,1}$ are as defined with Equations 155 and 156, and $\ddot{K}_{k,1}, \ddot{K}_{k,2}, \ddot{K}_{k,3}$, and $\ddot{K}_{k,4}$ are all computed by evaluations of Equation 11 using the corresponding $t_m, \dot{K}_{k,m}, K_{k,m}$ given above as coordinates and velocities.

The third starting method uses the Euler method to establish the second point, the trapezoidal rule to establish the third point, and Simpson's rule to establish the fourth point. This third option uses a regular predictor-corrector type iteration to establish convergence at each of the levels. Equation 158 shows the formulas used.

Modified Euler Method (one point)

$$\dot{P}_{k,1} = \dot{Z}_{k,0} + \Delta t \ddot{Z}_{k,0}$$

$$P_{k,1} = Z_{k,0} + c_2 \Delta t(\dot{Z}_{k,0} + \dot{P}_{k,1})$$

$$\dot{C}_{k,1} = \dot{Z}_{k,0} + c_2 \Delta t(\ddot{P}_{k,1} + \ddot{Z}_{k,0})$$

$$C_{k,1} = Z_{k,0} + c_2 \Delta t(\dot{C}_{k,1} + \dot{Z}_{k,0})$$

Modified Trapezoidal Rule (two points)

$$\dot{P}_{k,1} = \dot{Z}_{k,0} + \Delta t(c_1 \ddot{Z}_{k,0} - c_2 \ddot{Z}_{k,-1}) \tag{158}$$

$$P_{k,1} = Z_{k,0} + \Delta t(c_5 \dot{P}_{k,1} + c_6 \dot{Z}_{k,0} + c_7 \dot{Z}_{k,-1})$$

$$\dot{C}_{k,1} = \dot{Z}_{k,0} + \Delta t(c_5 \ddot{P}_{k,1} + c_6 \ddot{Z}_{k,0} + c_7 \ddot{Z}_{k,-1})$$

$$C_{k,1} = Z_{k,0} + \Delta t(c_5 \dot{C}_{k,1} + c_6 \dot{Z}_{k,0} + c_7 \dot{Z}_{k,-1})$$

Modified Simpson's Rule (three points)

$$\dot{P}_{k,1} = \dot{Z}_{k,0} + \Delta t(c_3 \ddot{Z}_{k,0} + c_4 \ddot{Z}_{k,-1} + c_5 \ddot{Z}_{k,-2})$$

$$P_{k,1} = Z_{k,0} + \Delta t(c_{11} \dot{P}_{k,1} + c_{12} \dot{Z}_{k,0} + c_{13} \dot{Z}_{k,-1} + c_{14} \dot{Z}_{k,-2})$$

(Continued on Next Page)

$$\dot{C}_{k,1} = \dot{Z}_{k,0} + \Delta t(c_{11}\ddot{P}_{k,1} + c_{12}\ddot{Z}_{k,0} + c_{13}\ddot{Z}_{k,-1} + c_{14}\ddot{Z}_{k,-2})$$

$$C_{k,1} = Z_{k,0} + \Delta t(c_{11}\dot{C}_{k,1} + c_{12}\dot{Z}_{k,0} + c_{13}\dot{Z}_{k,-1} + c_{14}\dot{Z}_{k,-2}) \qquad 158 \text{ Concluded}$$

where definitions are similar to those in Equation 156.

Determination of convergence is uniform among all the various methods employed. The absolute error of the weighted averages of first derivatives obtained by two seperate calculations of the solution to the system of equations at a particular time is required to have less magnitude than a specified value. The convergence test can be expressed by the following inequality.

$$\hat{N} \sum_{k=1}^{17} \bar{\mu}_k \left| \dot{Z}_{k,1}^{(n)} - \dot{Z}_{k,1}^{(n-1)} \right| \leqq \varepsilon_V \qquad 159$$

where $\hat{N}$ is a method scaling constant.

$\bar{\mu}_k$ are the absolute integration weights. These are the relative integration weights computed from last two fields of the S-card so they are normalized to add to one

$\dot{Z}_{k,1}^{(n)}$ are defined as the current trial values of generalized velocities at the new time

$\dot{Z}_{k,1}^{(n-1)}$ are defined as the previous trial values of generalized velocities at the new time

If the Milne-Hamming method is being employed, $\hat{N}=1$, $\dot{Z}_{k,1}^{(n)} = \dot{Z}_{k,1}$ and $\dot{Z}_{k,1}^{(n-1)} = \dot{H}_{k,1}$ (see Equation 155). If the test fails, the integration time step is immediately halved.

If either Runge-Kutta method is being employed, $N = \frac{1}{15}$, $\dot{Z}_{k,1}^{(n)} = \dot{Z}_{k,1}$ determined at the original time step and $\dot{Z}_{k,1}^{(n)} = \dot{Z}_{k,1}$ determined by two applications of the rule at half the original time step. If the test fails, the time step is halved, the $\dot{Z}_{k,1}^{(n-1}$ are set to the $\dot{Z}_{k,1}^{(n)}$, and the new $\dot{Z}_{k,1}^{(n)}$ are determined by two applications of the rule at half the current time step. This iteration is continued until convergence is attained or until the allowed number of halvings is exceeded. Once convergence has been achieved, three points of the required four points in the time history have been established. The fourth point is calculated by one more application of the rule at the half integration step. A single iteration is then taken to improve the four established values by using four-point interpolation formulas for the displacements and velocities and a revaluation of the accelerations for the second, third, and fourth points of the history, each in turn. If the current time is considered to be that of the last of the four established points, and Δt is the half time step, then the equations used in order of application in the iteration are those presented in Equation 160 .

For k = 1,17,

$$\begin{aligned}
\dot{Z}_{k,-2} &= \dot{Z}_{k,-3} + \frac{\Delta t}{24} (9\, \ddot{Z}_{k,-3} + 19\, \ddot{Z}_{k,-2} - 5\, \ddot{Z}_{k,-1} + \ddot{Z}_{k,0}) \\
Z_{k,-2} &= Z_{k,-3} + \frac{\Delta t}{24} (9\, \dot{Z}_{k,-3} + 19\, \dot{Z}_{k,-2} - 5\, \dot{Z}_{k,-1} + \dot{Z}_{k,0}) \\
\dot{Z}_{k,-1} &= \dot{Z}_{k,-3} + \frac{\Delta t}{3} (\ddot{Z}_{k,-3} + 4\, \ddot{Z}_{k,-2} + \ddot{Z}_{k,-1}) \\
Z_{k,-1} &= Z_{k,-3} + \frac{\Delta t}{3} (\dot{Z}_{k,-3} + 4\, \dot{Z}_{k,-2} + \dot{Z}_{k,-1}) \\
\dot{Z}_{k,0} &= \dot{Z}_{k,-3} + \frac{3}{8} \Delta t\, (\ddot{Z}_{k,-3} + 3\, \ddot{Z}_{k,-2} + 3\, \ddot{Z}_{k,-1} + \ddot{Z}_{k,0}) \\
Z_{k,0} &= Z_{k,-3} + \frac{3}{8} \Delta t\, (\dot{Z}_{k,-3} + 3\, \dot{Z}_{k,-2} + 3\, \dot{Z}_{k,-1} + \dot{Z}_{k,0}) \qquad 160
\end{aligned}$$

where $\ddot{Z}_{k,-2}$ are recomputed after the first two equations and the new values are throughout the rest of the equations. $\ddot{Z}_{k,-1}$ are recomputed after the fourth equation, and $\ddot{Z}_{k,0}$ are recomputed after the sixth equation.

If any of the methods set forth in Equations 156 and 158 is being employed, $\hat{N} = 1$, $\dot{Z}_{k,1}^{(n-1)} = \dot{P}_{k,1}$, and $\dot{Z}_{k,1}^{(n)} = \dot{C}_{k,1}$. If the test fails, the $P_{k,1}$, $\dot{P}_{k,1}$ are set to the $C_{k,1}$, $\dot{C}_{k,1}$, and the corresponding corrector equations are used again. This iteration is tried ten times to obtain convergence before the time step is halved.

In all cases, when convergence fails and the time step interval is halved, the missing points in the time history are supplied by use of sixth-order Bessel central difference interpolation formulas[1] and a single iteration. The number of halvings is incremented and checked against the limit. Then the following iteration is employed.

$$\Delta t = \frac{\Delta t}{2}$$

for k = 1,17,

$$\dot{Z}_{k,-\frac{1}{2}} = \frac{1}{256}\left(80\dot{Z}_{k,0} + 135\dot{Z}_{k,-1} + 40\dot{Z}_{k,-2} + \dot{Z}_{k,-3}\right) + \frac{15}{128}\Delta t\left(\ddot{Z}_{k,-2} + 6\ddot{Z}_{k,-1} - \ddot{Z}_{k,0}\right)$$

$$Z_{k,-\frac{1}{2}} = \frac{1}{256}\left(80Z_{k,0} + 135Z_{k,-1} + 40Z_{k,-2} + Z_{k,-3}\right) + \frac{15}{128}\Delta t\left(\dot{Z}_{k,-2} + 6\dot{Z}_{k,-1} - \dot{Z}_{k,0}\right) \qquad 161$$

$$\dot{Z}_{k,-\frac{3}{2}} = \frac{1}{256}\left(12\dot{Z}_{k,0} + 135\dot{Z}_{k,-1} + 108\dot{Z}_{k,-2} + \dot{Z}_{k,-3}\right) + \frac{3}{128}\Delta t\left(9\ddot{Z}_{k,-2} - 18\ddot{Z}_{k,-1} - \ddot{Z}_{k,0}\right)$$

(Continued on Next Page)

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[1] Scarborough, J. B. "Numerical Mathematical Analysis," John Hopkins Press pp. 84, 1962.

$$Z_{k,-\frac{3}{2}} = \frac{1}{256}\left(12Z_{k,0} + 135Z_{k,-1} + 108Z_{k,-2} + Z_{k,-3}\right) + \frac{3}{128}\Delta t\left(9\ddot{Z}_{k,-2} - 18\ddot{Z}_{k,-1} - \ddot{Z}_{k,0}\right)$$

$$\ddot{Z}_{k,-4} = \ddot{Z}_{k,-2}$$

$$\dot{Z}_{k,-4} = \dot{Z}_{k,-2}$$

$$Z_{k,-4} = Z_{k,-2}$$

$$\ddot{Z}_{k,-2} = \ddot{Z}_{k,-1}$$

$$\dot{Z}_{k,-2} = \dot{Z}_{k,-1}$$

$$Z_{k,-2} = Z_{k,-1}$$

$$\ddot{Z}_{k,-1} = \ddot{Z}_{k,-\frac{1}{2}}\text{ , etc.}$$

$$\ddot{Z}_{k,-3} = \ddot{Z}_{k,-\frac{3}{2}}\text{ , etc.}$$

$$\dot{P}_{k,0} - \dot{C}_{k,0} = \frac{242}{27}\left(\dot{Z}_{k,0} - \dot{Z}_{k,-3}\right) - \frac{121}{36}\Delta t\left(\ddot{Z}_{k,0} + 3\ddot{Z}_{k,-1} + 3\ddot{Z}_{k,-2} + \ddot{Z}_{k,-3}\right)$$

$$P_{k,0} - C_{k,0} = \frac{242}{27}\left(Z_{k,0} - Z_{k,-3}\right) - \frac{121}{36}\Delta t\left(\dot{Z}_{k,0} + 3\dot{Z}_{k,-1} + 3\dot{Z}_{k,-2} + \dot{Z}_{k,-3}\right)$$

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Concluded

If convergence succeeds by a factor of fifty better than required, the time step is doubled if other conditions are met. These conditions are that the current integration time step size is smaller than Δt_{max}, that the time history contains at least seven good points, and that the new larger step will not jump over the next increment of Δt_{prnt}. If these conditions are all met, the following reshuffling and calculation takes place.

$\Delta t = 2\Delta t$

for $k = 1,17$,

$$\ddot{Z}_{k,-1} = \ddot{Z}_{k,-2}$$

$$\dot{Z}_{k,-1} = \dot{Z}_{k,-2}$$

$$Z_{k,-1} = Z_{k,-2}$$

$$\ddot{Z}_{k,-2} = \ddot{Z}_{k,-4} \text{ , etc.} \tag{162}$$

$$\ddot{Z}_{k,-3} = \ddot{Z}_{k,-6} \text{ , etc.}$$

$$\ddot{Z}_{k,-4} = \ddot{Z}_{k,-8} \text{ , etc.}$$

$$\dot{P}_{k,0} - \dot{C}_{k,0} = \frac{242}{27} (\dot{Z}_{k,0} - \dot{Z}_{k,-3}) - \frac{121}{36} \Delta t\, (\ddot{Z}_{k,0} + 3\ddot{Z}_{k,-1} + 3\ddot{Z}_{k,-2} + \ddot{Z}_{k,-3})$$

$$P_{k,0} - C_{k,0} = \frac{242}{27} (Z_{k,0} - Z_{k,-3}) - \frac{121}{36} \Delta t\, (\dot{Z}_{k,0} + 3\dot{Z}_{k,-1} + 3\dot{Z}_{k,-2} + \dot{Z}_{k,-3})$$

Experience dictates that convergence by itself is not sufficient to guarantee good results in all impact situations. Since initial value procedures seldom are capable of regaining any lost accuracy, it is of utmost importance to prevent the solution from deviating from the true solution. During a time interval in which impact occurs, the solution is smooth both before and during the impact, but changes shape abruptly shortly after the moment of impact. Calculation of a good solution often requires decreasing the integration time step before the convergence test is violated. This situation is recognized by extrapolating the value of second derivatives at a particular time, based on the time history of their established values, and comparing these against their predicted values. If the disagreement is too great, the time step is halved. This test is formalized in Equation 163 .

For $k = 1,17$,

$$ {}_E\ddot{Z}_{k,1} = 4\ddot{Z}_{k,0} - 6\ddot{Z}_{k,-1} + 4\ddot{Z}_{k,-2} - \ddot{Z}_{k,-3} $$

$$ \tilde{\varepsilon} = \sum_{k=1}^{17} \bar{\mu}_k \left| {}_E\ddot{Z}_{k,1} - \ddot{Z}_{k,1}^{(n-1)} \right| \leqq \Delta\tilde{\ddot{Z}}_{lim} $$

or failing that

$$ \hat{\varepsilon} = \sum_{k=1}^{17} \bar{\mu}_k \left| \ddot{Z}_{k,1}^{(n-1)} \right| \neq 0 \quad \text{and} \quad \frac{\tilde{\varepsilon}}{\hat{\varepsilon}} \leqq \Delta\tilde{\ddot{Z}}_{lim} $$

$$ \text{or} \qquad \hat{\varepsilon} = 0 \quad \text{and} \quad \frac{\tilde{\varepsilon}}{\sum_{k=1}^{12} \bar{\mu}_k \left| {}_E\ddot{Z}_{k,1} \right|} \leqq \Delta\tilde{\ddot{Z}}_{lim} \qquad 163 $$

where $\ddot{Z}_{k,1}^{(n-1)}$ is defined as it was for Equation 159 except this test is used only when the Milne-Hamming method or the Adams-Moulton method is being employed and $\Delta\tilde{\ddot{Z}}_{lim}$ is the extrapolation change limit. To pick up sudden changes, a two-point extropolation is also used in the same way.

Further, it has been noted that occasionally the level of activity can become too great for computation of good results at a particular time step without convergence failing. A test has been incorporated to limit the value of the weighted average of the second derivatives multiplied by the integration step. This weighted average velocity change has been taken as a measure of the "activity load" during the time step. If the activity load is too great, the time step is halved.

$$ \Delta t \sum_{k=1}^{17} \bar{\mu}_k \left| \ddot{Z}_{k,1}^{(n-1)} \right| \leqq \Delta V_{lim} \qquad 164 $$

where ΔV_{lim} is the velocity change limit

$\ddot{Z}_{k,1}^{(n-1)}$ is defined here as in Equation 163

Both these tests are applied only after prediction in the two predictor-corrector methods and must be passed before correction is begun. Either of these tests will be skipped if the corresponding limit is specified as zero.

The least important feature of the integration scheme used in the computer solution is intended mainly to keep out the introduction of small errors in the solutions and normal printout. The computed values of the second derivatives are scanned and set at zero if they are smaller in magnitude than a specified value. If this option is not desired, the acceleration minimum magnitude parameter is set at zero. This option helps the accuracy in some extreme cases, but mostly it acts to remove irrelevant detail from the regular printout.

The basic integration control parameter is the maximum integration time step. Under certain conditions, which already have been discussed in this section, the program will cut down the size of the integration time step by halving it up to a specified number of times. Regular printout occurs at multiples of the print time step parameter which itself must be an integral multiple of the maximum time step.

The time epsilon parameter is the absolute difference between two computed times which must be exceeded for them to be treated as distinct by the program. When the execution time limit parameter is non-zero, it causes the program to keep track of how much central processing unit (C.P.U.) time it has used and sign off when this limit is exceeded.

An excellent overall treatment of the topics considered in this section is found in Hamming, R. W., "Numerical Methods for Scientists and Engineers," Chapters 14, 15 and 16, McGraw-Hill, 1962.

IV PACKING AND UNPACKING SPECIFICATIONS

The Extended Three-Dimensional Model incorporates features which require potentially many tables of which one or more may be quite long. In order to achieve this flexibility without using a huge amount of storage for the tables, a free format storage of tables was adopted. This implies that each table or group of tables contains a fixed format section (called the control section) which contains formatting information about the free section. The free section is organized in terms of "typical entries," the number, location, and length of which will be specified in the control section.

The array KCON serves as the control section for the STOMAT array which holds the physical input data describing contacts, ellipsoids, belts, and the materials of which they are made. KCON itself has a free section and a control section called the Standard Area. Table 16 specifies the standard area. The first seventeen locations are fixed format. Starting in 18 are the beginning indices of all the contact planes connected to the vehicle, followed by the contact planes connected to the inertial frame, and followed by all the materials specified. The rest of the table is in terms of typical entries which occur in the order they are formed in reading of the input data. These contain both control and some physical information and are specified in Tables 17 through 20. Five kinds of typical entries occur in STOMAT and are specified in Tables 21 through 25. These are all referenced from KCON.

The load-deflection contact force, and belt force routines all require temporary storage for values and references to past values. Another free format storage system was developed to handle this information. KACT contains control information and time history information for certain switches used in the computation. The first entry in KACT is the number of control entries which are present. They typical control entry is specified in Table 26. The control entries occur starting index two in the order in which the corresponding force-producing interaction took place. Then follows the time history entries for switches which are shown in Table 27. The rest of the time history information (mostly physical information) occurs in typical entries specified in Table 28 in the STOACT array. Output of force and other quantities for the interaction is stored in the CONOUT array in terms of typical entries and specified in Tables 29 and 30.

In addition, the table routines for acceleration profiles have been extended to tabular load-deflection information and also are in free format. The control information is in the MSTOR array (see the Symbol Dictionary) and the table information is specified in Table 31.

TABLE 16 THE STANDARD AREA OF THE KCON ARRAY

Index	Description
1-6	Beginning index of all ellipsoids for each segment
7	Beginning index of belt 1 in STOMAT, 0 if absent
8	Beginning index of belt 1 material control in KCON
9,10	Same for belt 2
11,12	Same for belt 3
13,14	Same for belt 4
15	Number of relative planes (m_r)
16	Number of inertial planes (m_i)
17	Number of materials (m_m)
18 $17+m_r$	Beginning Index of plane controls for each of all of the planes.
$18+m_r$ $17+m_r+m_i$	Beginning index of plane control for each of all of the inertial planes
$18+m_r+m_i$ $17+m_r+m_i+m_m$	Beginning index for each of all of the material controls

TABLE 17 THE TYPICAL ELLIPSOID CONTROL ENTRY OF THE KCON ARRAY

Relative Index	Description
1	Beginning index in STOMAT of ellipsoid parameter section
2	Beginning index in KCON of material control section, 0 if rigid
3	Body segment number attached to
4-7	Ellipsoid name
8	Sphere switch: 0 if sphere, -1 if sphere like, 2 ellipsoid
9	Number of inhibitions against planes
10	Number of inhibitions against ellipsoids
11	Friction class: 1 through 5
12	JX: 1,2,3 if maximum axis is along i,j,k; 0 pre initialization
13	Beginning index of list of inhibited planes
14	Beginning index of list of inhibited ellipsoids.

TABLE 18 THE TYPICAL BODY SEGMENT ENTRY OF THE KCON ARRAY

Relative Index	Description
1	Number of ellipsoids for body segment (N_e)
2 (N_e+1)	Beginning index for ellipsoid control

TABLE 19 THE TYPICAL MATERIAL CONTROL ENTRY OF THE KCON.ARRAY

Relative Index	Description
1	Beginning index of material properties in STOMAT
2-5	Material Name (4A4 format)

TABLE 20 THE TYPICAL CONTACT PLANE CONTROL ENTRY OF THE KCON ARRAY

Relative Index	Description
1	Beginning index in STOMAT of plane parameter section
2	Beginning index in KCON of material control section, 0 if rigid
3	Attachment 0 if inertial , 7 if vehicle
4-7	Plane name (4A4 format)

TABLE 20 THE TYPICAL CONTACT PLANE CONTROL ENTRY OF THE KCON ARRAY (CONT.)

Relative Index	Description
8	Number of times specified in STOMAT
9	Current index in STOMAT
10	Last index in STOMAT
11	Friction class - 0 if no friction
12	Beginning index in STOMAT

TABLE 21 THE TYPICAL BELT ENTRY OF THE STOMAT ARRAY

Relative Index	Contents
1	x attachment
2	y attachment
3	z attachment
4	x anchor
5	y anchor
6	z anchor
7	slack

TABLE 22 THE TYPICAL MATERIAL ENTRY OF THE STOMAT ARRAY

Relative Index	Description
1	δ_A
2	δ_B
3	δ_C
4	δ_D
5	δ_F
6	F max
7	β
8	G constant or table number if negative
9	R constant or table number if negative
10	FOREPS force epsilon for shared convergence
11	Title location
12	Static curve: table number or coefficient location if negative
13	Inertial curve: table number or coefficient location if negative
14	Static and/or inertial coefficients if any

TABLE 23 THE TYPICAL CONTACT PLANE ENTRY OF THE STOMAT ARRAY

Relative Index	Contents
1	penetration limit
2	edge constant
3	direction factor input
4	direction factor (inertial)
5	r vehicle relative version of plane coefficients
6	q
7	p
8	s
9-20	BB(1) - BB(12)
21	x surface side length
22	y surface side length

TABLE 24 THE TYPICAL PLANE POSITION ENTRY OF THE STOMAT ARRAY

Relative Index	Contents
1	t
2-4	$\hat{x}_1$, $\hat{y}_1$, $\hat{z}_1$
5-7	$\hat{x}_2$, $\hat{y}_2$, $\hat{z}_2$
8-10	$\hat{x}_3$, $\hat{y}_3$, $\hat{z}_3$

TABLE 25 THE TYPICAL ELLIPSOID ENTRY OF THE STOMAT ARRAY

Relative Index	Contents	
1	x_{em}	
2	y_{em}	
3	z_{em}	
4	x_{em} inert	
5	y_{em} inert	
6	z_{em} inert	
	If ellipsoid	If sphere
7	max of a_m, b_m, and c_m	R^2
8	a^2_m	R
9	b^2_m	$R^2/2$
10	c^2_m	absent
11	R	absent
12	ℓ	absent
13-18	μ_1-μ_6	absent

TABLE 26 THE TYPICAL CONTROL ENTRY OF THE KACT ARRAY

Relative Index	Description
1	Beginning index of ellipsoid in KCON or if negative belt beginning index in KCON (IKC) (IA)
2	Beginning index of contact in KCON or if negative beginning index of ellipsoid in KCON; if belt 1,2, 3, or 4, shared deflection on a corresponding belt segment; if 5, 6, 7, or 8, shared deflection on a corresponding belt segment of material 1; if 9, 10, 11, or 12, shared deflection on a corresponding belt segment of material 2; if 0, no shared deflection; -1 or -2 is material 1 or 2 only (JKC) (IB)
3	Beginning index of entry for interactions in STOACT 0 if none (ISACT) (IACT)
4	Beginning index of entry for interaction in CONOUT 0 if none (ICNOUT)
5	Beginning index of time history entry for interaction in KACT, zero if none (IKACT)
6	Beginning index of ellipsoid in STOMAT if both soft, of the soft one if only one soft, or zero if both rigid (KNA)
7	Beginning index of contact or ellipsoid in STOMAT if both soft, 0 otherwise (KNB)

TABLE 27 THE TYPICAL TIME HISTORY OF THE KACT ARRAY

Relative Index	Description
1-4	IALF history
5-8	I history
9-12	J history
13-16	NPRENG
17-20	Secondary computed coefficient switch (Lx(1))
21-24	Saturation switch history (ISP)
25-28	Lx(2)
29-32	Lx(3)
33-36	Lx(4)

NOTE: 1-36 repeated as 37-72 for second soft material if present.

TABLE 28 THE TYPICAL TIME HISTORY ENTRY OF THE STOACT ARRAY

Relative Index	Description
1	Beginning index for this interaction in KACT
2-6	t history: current, the last three previous times, 0
7-10	δ history D
11-14	$\dot{\delta}$ history DD
15-18	ω history OG
19-22	Ω history BOG
23-26	E history E
27-30	$F(\omega)$ FOG
31-34	$F'(\omega)$ FBOG
35-38	$F(\delta)$ FD
39-42	$F'(\delta)$ FDD
43-46	coefficient history 1 PX(1)
47-50	coefficient history 2 PX(2)
51-54	coefficient history 3 PX(3)
55-58	coefficient history 4 PX(4)
59-62	coefficient history δ_{cut} PX(6)
63-66	coefficient history 0 1 PX(7)
67-70	coefficient history 0 2 PX(8)
71-74	coefficient history 0 3 PX(9)
75-78	coefficient history 0 4 PX(10)
79-150	for other soft material if present

TABLE 29 THE TYPICAL ELLIPSOID-PLANE ENTRY OF THE CONOUT ARRAY

Relative Index	Description	
1	δ	deflection
2	$\dot{\delta}$	deflection rate
3	F	normal force
4	T	tangential force
5	ℓx	x position on plane
6	Ly	y position on plane
7	$\dot{\eta}$	resultant tangential velocity on plane
8	$\ell\dot{x}$	x component tangential velocity on plane
9	$L\dot{y}$	y component tangential velocity on plane
10	x_0	tangential point in inertial coordinates on ellipsoid
11	y_0	
12	z_0	

TABLE 30 THE TYPICAL ELLIPSOID-ELLIPSOID ENTRY OF THE CONOUT ARRAY

Relative Index	Description	
1	δ deflection	
2	$\dot{\delta}$ deflection rate	
3	F normal force	
4	XE(1,1)	center of 1stellipsoid in inertial coordinates
5	XE(2,1)	
6	XE(3,1)	
7	XE(1,2)	center of 2ndellipsoid in inertial coordinates
8	XE(2,2)	
9	XE(3,2)	

TABLE 31 ORGANIZATION OF TABLE ENTRIES IN THE STOR ARRAY

Relative Index	Description
0	Period if scan type is periodic otherwise absent
1 to n	Table Abscissas for n points
n+1 to 2n	Table Ordinates for n points
2n+1 to 3n-1	Computed slopes for each table interval
3n to 4n-2	Computed intercepts for each table interval

NOTE: The MSTOR Index reference points to relative index one whether or not the period is present.

V DESCRIPTION OF AUXILIARY PROGRAM OUTPUT

Auxiliary or debugging printout for this program is organized in terms of sixteen four-level switches. Each switch corresponds to a particular section of the program. The levels of a particular switch control the depth of detail of the debugging printout from the section of the program which the switch covers. Higher levels of a switch include all the printout from lower levels from the switch.

The four levels are represented by integers zero through three. Zero represents no debugging printout, and high levels are represented by larger integers as described in Table 32.

TABLE 32 DEBUG SWITCH DEFINITION

0 = summary output only

1 = primary debugging information such as forces

2 = secondary debugging information such as the contributions to the generalized force vector of each force component.

3 = tertiary debugging information to allow a detailed inspection of the inner workings of the program.

To avoid needless volume of printing, each of the sixteen switches is allowed to vary its level as a function of simulated time during a run of the program. In order to avoid inputting sixteen separate tables of debug level versus effective time, advantage is taken of the binary characteristics of the IBM 360/67 computer. The four levels of a debugging switch can be represented by two binary bits. The possibilities for all sixteen switches can then be represented by thirty-two bits. Eight hexadecimal digits also represent thirty-two bits. Hence, debugging control is achieved by use of a table of eight hexadecimal digit control words versus effective time. When any or all of the switches change levels, a new control work in the table is needed. The switches correspond to groups of two bits from the left of the word, i.e., switch one is controlled by the left-most two bits, switch two by the next two, and so on. The switch will take on the specified level at the first time step in simulated time beyond the effective time specified.

As an example setup of the hexadecimal debugging control word, consider the case where printout of the quantity "PDA," the joint force lever arms, is desired. This is specified under debug switch 4, debug level 2. As each digit of the hexadecimal word covers two debug switches, this printout will be covered by the second two bits of the second digit. Because no special printout is desired from debug switch 3, the first two bits describing the second hexadecimal digit must be "00." Because the desired debug level is 2, the last two bits of the second digit must be "10." Therefore the second digit takes on the value "0010" or "2." Thus, the hexadecimal word will be "02000000" at the effective time.

The table of effective times and control words is specified to the program by means of the T-card described in Table 5. The total span of simulated time for the run should be covered by effective times of control words if the T-card is used at all. Removals from control word tables can be made by use of the P-card with a table number of seven and new additions by the T-card again.

The user is warned that the volume of printout is startlingly huge and hence utmost discretion must be exercised in the use of this feature.

Table 33 contains a detailed list of the sixteen debug switches and the quantities which will be printed for each debug level of each switch. Table 33 should be used in conjunction with the Symbol Dictionary (see part VI), Table 37 and (in some cases) the listing of the program (Appendix B). Each line in Table 33 corresponds to one line in the printed output so this table can be used to identify individual quantities. In some cases, it has been necessary because of space to enter more than one line for a single printed line in the output. Such "continuation" lines are marked with a *.

Under the column entitled "Quantity" there appears a facsimile of each output line including the line identification and showing the Fortran name of each printed quantity. The name of the subroutine from which this printout is made is given in the column labelled "Subroutine."

These printouts are organized on Block Number (which is printed as identification) on the order in which they appear.

Table 34 contains a summary of the material presented in Table 33 for the convenience of the user. A short description of each set of quantities is given instead of the explicit format. Table 35 gives Block Numbers in terms of debug levels.

Error messages produced by this simulator are shown in Table 36, which is self explanatory.

TABLE 33. DEBUG FORMATS (page 1)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
1	1	1	J DELB(J) DELD(J) FB(J) for J = 1 to 4	BELT
1	1	2	J BXA(1,J) BYA(1,J) BZA(1,J) BXA(2,J) BYZ(2,J) BZA(2,J) (blocks 2, 3, 4, 5 inside a 4-deep loop on J)	BELT
1	2	3	J BX(J) BY(J) BZ(J) BXD BYD BZD	BELT
1	3	4	J BC(1) BC(2) BC(3) BC(4) BC(5) BC(6) BC(7) BC(8) BC(9) BC(10) BC(11) BC(12)	BELT
1	3	5	J PDB(J,1) PDB(J,2) PDB(J,3) PDB(J,4) PDB(J,5) PDB(J,6)	BELT
2	1	6	I IR IE FAC(I) AB(I) FS(I) FN(I) FE(1) FE(2) CTHETA (blocks 6, 7, 8 inside a 0- to 6-deep loop on I)	BELT
2	2	7	I AA(1) BB(1) CC(1) DD(1) AA(2) BB(2) CC(2) DD(2) AAP(1) BBP(1) CCP(1) DDP(1) AAP(2) BBP(2) CCP(2) DDP(2)	BELT
2	3	8	I DC(1) DC(2) DC(3) TSD XX(1) YY(1) ZZ(1) XX(2) YY(2) ZZ(2) XX(3) YY(3) ZZ(3) XX(4) YY(4) ZZ(4)	BELT
3	1	9	FB(1) FB(2) FB(3) FB(4) FBMOD(1) FBMOD(2) FBMOD(3) FBMOD(4) INFL	BELT
3	2	10	I FMOD(I,1) FMOD(I,2) FMOD(I,3) FMOD(I,4) for I = 1 to 6	BELT
3	3	11	BR(1) BR(2) BR(3) BR(4) BR(5) BR(6) BR(7) BR(8) BR(9) BR(10) BR(11) BR(12) BR(13) BR(14) BR(15) BR(16) BR(17)	BELT

TABLE 33. DEBUG FORMATS (page 2)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
11	1	12	Q(1,1) Q(1,2) . . . . Q(1,9) Q(1,10) . . . . Q(1,17) Q(2,1) . . . . Q(2,9) Q(2,10) . . . . Q(2,17) Q(3,1) . . . . Q(3,9) Q(3,10) . . . . Q(3,17) CQ(1,1) . . . . CQ(1,6) CQ(2,1) . . . . CQ(2,6) CQ(3,1) . . . . CQ(3,6) X(1,1) X(2,1) X(3,1) X(1,2) X(2,2) X(3,2) X(1,3) X(2,3) X(3,3) X(1,4) . . . . X(3,6)	ACCEL
11	2	13	S(1,1) C(1,1) S(2,1) C(2,1) S(3,1) C(3,1) S(1,2) C(1,2) S(2,2) C(2,2) *S(3,2) C(3,2) S(1,3) . . . . *. . C(3,4) S(2,5) C(2,5) S(2,6) C(2,6)	ACCEL
11	2	14	N R(1,1,N) R(1,2,N) R(1,3,N) R(2,1,N) R(2,2,N) R(2,3,N) R(3,1,N) R(3,2,N) R(3,3,N) for N = 1 to 7 A(1) A(2) . . . . A(9) A(10) . . . . A(18) ⋮ A(91) . . . . A(96)	ACCEL

TABLE 33. DEBUG FORMATS (page 3)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
11	3	15	K DX(1,1,K) DX(2,1,K) DX(3,1,K) DX(1,2,K) . . . . . . DX(3,3,K) DX(1,4,K) DX(2,4,K) . . . . DX(3,6,K) for K = 1 to 18	ACCEL
11	3	16	N DR(1,N,1) DR(2,N,1) . . . . DR(9,N,1) DR(1,N,2). . . . . DR(1,N,3). . . . . DR(1,N,4). . . . . DR(9,N,4) for N = 1 to 7	ACCEL
11	3	17	DRL(1,1) DRL(2,1) . . . . DRL(9,1) DRL(1,2) DRL(2,2) . . . . DRL(9,2)	ACCEL
11	3	18	N R14(N) R15(N) R16(N) R17(N) R24(N) R25(N) R26(N) R27(N) for N = 1 to 7	ACCEL
11	3	19	N TR(1,N) TR(2,N). . . . . TR(8,N) for N = 1 to 7	ACCEL
11	3	20	N DTR(1,N). . . . . DTR(8,N) for N = 1 to 7	ACCEL
12	1	21	AL(1,1) AL(1,2). . . . . . . AL(1,6) AL(2,1) . . . . AL(2,6) AL(3,1) . . . . AL(3,6)	ACCEL
12	1	22	QA(1) . . . . QA(9) QA(10) . . . . QA(17)	ACCEL
12	2	23	(EMAT (I,J), J = I,1,17), I = 1,17 These are the rows of the upper triangular matrix from the symmetric matrix EMAT. Rows are separated by blank fields.	ACCEL

TABLE 33. DEBUG FORMATS (page 4)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
12	2	24	BT(1) BT(2) . . . . BT(9) BT(10) . . . . BT(17) BG(1) . . . . BG(9) BG(10) . . . . BG(17) BS(1) . . . . BS(9) BS(10) . . . . BS(17) BF(1) . . . . BF(9) BF(10) . . . . BF(17) BR(1) . . . . BR(9) BR(10) . . . . BR(17) BJ(1) . . . . BJ(9) BJ(10) . . . . BJ(17) B(1) . . . . B(9) B(10) . . . . B(17)	ACCEL
12	3	25	N SS(1,1,N) SS(1,2,N) SS(1,3,N) SS(2,1,N) . . . . . . SS(3,3,N) for N = 1 to 6 U(1,1) U(1,2) . . . . U(1,6) U(2,1) . . . . U(2,6) U(3,1) . . . . U(3,6) W(1,1) W(1,2) . . . . W(1,6) W(2,1) . . . . W(2,6) W(3,1) . . . . W(3,6)	ACCEL
9	1	26	MT IT ILIM TT(1) MILL LTIME LTDCUR LTPRNT MAXTIM	MAIN

TABLE 33. DEBUG FORMATS (page 5)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
9	2	27	I XXX(1,I,1) XXX(1,I,2) XXX(1,I,3) PCV(I) PCX(I) for I = 1 to 17	MAIN
9	3	31	J TT(J) XXX(J,1,1) XXX(J,2,1) . . . . XXX(J,9,1) XXX(J,10,1) . . . . XXX(J,17,1) XXX(J,1,2) . . . . XXX(J,9,2) XXX(J,10,2) . . . . XXX(J,17,2) XXX(J,1,3) . . . . XXX(J,9,3) XXX(J,10,3) . . . . XXX(J,17,3) for J = 2 to 10	MAIN
13	2	28	1 Q(3,1) DUM(1) DUM(18) 2 Q(3,2) DUM(2) DUM(19) 3 Q(3,3) *DUM(3) DUM(20) 4 . . . . * . . . . 7 . . . . * . . . . 10 . . . . * . . . . 13 . . . . * . . . . 16 Q(3,16) DUM(16) DUM(3) 17 Q(3,17) DUM(17) DUM(34)	LIMIT
13	1	29	II DEL TS TSA TSB TSC	LIMIT
8	1	30	CQ(1,J) CQ(2,J) CQ(3,J) for J = 1 to 6	CARTIN

TABLE 33. DEBUG FORMATS (page 6)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
4	3	38	RNM13 RNM12 RNM11 RNM23 RNM33 (blocks 32-38 inside a 5-deep loop on K)	JOINT
4	2	32	AGL(1,1) AGL(2,1) AGL(3,1) AGL(1,2) AGL(2,2) AGL(3,2)	JOINT
4	1	33	K DA(K,1) DD(K,1) DA(K,2) DD(K,2) DA(K,3) DD(K,3) KPW PC	JOINT
4	2	34	PDA(1,1) PDA(1,2) . . . . PDA(1,6) PDA(2,1) . . . . PDA(2,6) PDA(3,1) . . . . PDA(3,6)	JOINT
4	1	35	EJ(K,1) SJ(K,1) EJ(K,2) SJ(K,2) EJ(K,3) SJ(K,3)	JOINT
4	2	36	BJ(1). . . . . BJ(9) BJ(10) . . . . BJ(17)	JOINT
4	3	37	DUM(9) DUM(10) DUM(11) DUM(1) DUM(2) DUM(3) DUM(4)	JOINT
5	1	39	JKC XHAT(1) . . . . XHAT(9) DHAT(1) . . . . DHAT(9)	CONTAC
5	1	40	JKC BC(4) . . . . BC(12) BC(1) BC(2) BC(3) BC(13) BC(31)	CONTAC
5	2	41	JKC BB(1) . . . . BB(9) BB(10). . . BB(12) BC(14) . . . . . . BC(19) BC(20). . . BC(23)	CONTAC
5	3	42	JKC DDC DMC(1) DMC(2) DMC(3) DDS	CONTAC

TABLE 33. DEBUG FORMATS (page 7)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
14	3	62	JKC XDDC XDMC(1) XDMC(2) XDMC(3) YDDC YDMC(1) YDMC(2) YDMC(3) XYDDS	CONTAC
6	1	44	IKC J ISM STOMAT(ISM+12) . . STOMAT(ISM+17) *STOMAT(ISM+3) . . STOMAT(ISM+5)	CONTAC
6	1	45	IKC J ISM STOMAT(ISM+3) . . STOMAT(ISM+5)	CONTAC
7	3	46	IKC JKC XZ YZ ZZ ETA FK XZA YZA ZZA TSP XZB YZB ZZB TSQ	CONTAC
7	1	47	IKC JKC ETA ETAD FT TSQ SFAC TSR RFAC	CONTAC
7	3	48	IKC JKC BS(1) . . . . BS(9) BS(10) . . . . BS(17)	CONTAC
7	3	49	IKC JKC DD(1) . . . . DD(9) DD(10) . . . . DD(17)	CONTAC
7	3	50	IKC JKC K XEM YEM ZEM HALFK GUM(1,1). . . . . GUM(1,9) GUM(1,10) . . . . GUM(1,17) GUM(2,1). . . . . GUM(2,9) GUM(2,10) . . . . GUM(2,17) GUM(3,1). . . . . GUM(3,9) GUM(3,10) . . . . GUM(3,17) DUM(1) . . . . . DUM(6) DDD(1) DDD(2) DDD(3) IGCHK(1). . . IGCHK(17) IDDCHK(1) . . IDDCHK(3) IFCHK	CONTAC

TABLE 33. DEBUG FORMATS (page 8)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
7	3	51	IKC JKC K XEM YEM ZEM BC(8) BC(9) BC(10) BC(31) SUM(1) SUM(2) SUM(3) DDD(1) . . DDD(3) IDDCHK(1) . . *IDDCHK(3)	CONTAC
14	2	52	IKC JKC DD(1) . . . . DD(9) DD(10) . . . . DD(17) DUM(1) . . . . DUM(9) DUM(10) . . . . DUM(17)	CONTAC
14	3	53	IKC JKC DXYZZ(1,1) . . . . DXYZZ(1,9) DXYZZ(1,10) . . . . DXYZZ(1,17) DXYZZ(2,1) . . . . DXYZZ(2,9) DXYZZ(2,10) . . . . DXYZZ(2,17) DXYZZ(3,1) . . . . DXYZZ(3,9) DXYZZ(3,10) . . . . DXYZZ(3,17) DXDQ(1) . . . . DXDQ(9) DXDQ(10). . . . . DXDQ(17) DYDQ(1) . . . . DYDQ(9) DYDQ(10). . . . . DYDQ(17) BC(15) BC(16) BC(17) BC(18) BC(19) BC(20) BC(21) BC(31)	CONTAC
14	2	54	IKC JKC XDOT YDOT	CONTAC
14	2	55	IKC JKC XDOT XDDC XDMC(1) XDMC(2) XDMC(3) YDOT YDDC YDMC(1) YDMC(2) YDMC(3)	CONTAC
14	2	56	IKC JKC XDOT YDOT DDS WS WT	CONTAC

TABLE 33. DEBUG FORMATS (page 9)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
14	2	57	IKC JKC XDOT YDOT XZ YZ ZZ CQ(1,1) CQ(1,2) CQ(1,3)	CONTAC
14	3	58	IKC JKC DUM(1) . . . . DUM(9) DUM(10) DUM(11) DUM(12) SUM(1). . SUM(3) BC(4) . . BC(6)	CONTAC
14	1	59	IKC JKC FTAN CFTAN FT FNU BC(22) BC(23) DE(18) DE(1) . . . . DE(9) DE(10) . . . . . . DE(17)	CONTAC
14	3	60	IKC JKC BF(1) . . . . BF(9) BF(10) . . . . . . BF(17)	CONTAC
14	2	61	BF(1) . . . . BF(9) BF(10) . . . . . . BF(17)	CONTAC
7	2	43	BS(1) . . . . BS(6) BS(7) . . . . BS(12) BS(13) . . . . . . BS(17)	CONTAC
15	1	63	IKC JKC DUM(1) . DUM(3) RE(IE) KTYPE(IE) DUM(4) . DUM(6) RE(IS) *KTYPE(IS) XDEL FEE KKK	CONTAC
15	2	64	IKC JKC XE(1,1) XE(2,1) XE(3,1) STOMAT(K) STOMAT(K+1) STOMAT(K+2) K XE(1,2) XE(2,2) XE(3,2) STOMAT(M) STOMAT(M+1) STOMAT(M+2) M DDE(1) . . . . DDE(9) DDE(10) . . . . DDE(18)	CONTAC

TABLE 33. DEBUG FORMATS (page 10)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
15	3	65	IKC JKC DER(1,L,1) . . . . DER(1,L,9) DER(1,L,10) . . . . DER(1,L,17) DER(2,L,1) . . . . DER(2,L,9) DER(2,L,10) . . . . DER(2,L,17) DER(3,L,1) . . . . DER(3,L,9) DER(3,L,10) . . . . DER(3,L,17) for L = 1 to 2 BE(1). . . . . BE(9) BE(10) . . . . BE(17)	CONTAC
15	2	66	IKC JKC XLAM(1,1) XLAM(2,1) XLAM(3,1) TBAR(1) XL(IE) JX(IE) KKK	CONTAC
15	2	67	IKC JKC XLAM(1,1) XLAM(2,1) XLAM(3,1) TBAR(1) XL(IE) JX(IE) KKK XLAM(1,2) XLAM(2,2) XLAM(3,2) TBAR(2) XL(IS) JX(IS) DET	CONTAC
15	2	68	IKC JKC KASE A1 A2 B1 B2 B3 B4 TBBAR(1) TBBAR(2) XDEL	CONTAC
15	3	69	IKC JKC DLAM(1,K,1) . . . . DLAM(1,K,9) DLAM(1,K,10) . . . . DLAM(1,K,17) DLAM(2,K,1) . . . . DLAM(2,K,9) DLAM(2,K,10) . . . . DLAM(2,K,17) DLAM(3,K,1) . . . . DLAM(3,K,9) DLAM(3,K,10) . . . . DLAM(3,K,17) for K = 1 to KKK-1	CONTAC
5	1	70	JKC BC(8) . . . BC(11) BC(3) BC(2) BC(1) BC(13) XHAT(1) . . . . XHAT(9) DHAT(1) . . . . DHAT(9)	CONTAC

TABLE 33 . DEBUG FORMATS (page 11)

Debug Switch	Debug Level	Block Number	Quantity	Subroutine
10	1	71	K L IA(L) II(L) JJ(L) IS(L) LLXX(4,L) D(L) DD(L) FORCE FDEV	EVAL
10	3	72	OG(L) BOG(L) E(L) PX(1,L) PX(2,L) *PX(3,L) PX(4,L) PX(5,L) PX(6,L) PX(7,L) PX(8,L) PX(9,L) PX(10,L) TM(L) FOG(L) *FBOG(L) DP(K) DDP(K) OGP(K) BOGP(K) EP(K) TMP(K) FOGP(K) FBOGP(K) DA(K) *DB(K) DC(K) DE(K) FM(K) DF(K) GI(K) RI(K) DM(K) FD(K)	EVAL
10	3	73	1 LL(1,K) LLXX(1,L) 2 LL(2,K) LLXX(2,L) 3 LL(3,K) LLXX(3,L) 4 LL(4,K) LLXX(4,L)	EVAL
10	3	74	(KCON(I), I = 951 to 1000)	UPDATE
16	3	--	If debug switch 16 is equal to 3, execution will be terminated prior to SUMRY by "CALL ERROR," which can produce a dump of core.	UPDATE

TABLE 34. SUMMARY OF DEBUG FORMATS (page 1)

Debug Switch	Debug Level	Debug Block Number	Description	Subroutine
1	1	1	Belt deflection, rate, and unmodified force	BELT
1	1	2	Components of vectors to belt attachment and anchor points	BELT
1	2	3	Components of belt anchor-to-attachment vector	BELT
1	3	4	Belt intermediate results in rate calculation	BELT
1	3	5	Belt lever arms (direction cosines)	BELT
2	1	6	Forces and other quantities used in determining interbelt influence for friction case (inputted INFL = 1)	BELT
2	2	7	Coefficients for planes used in determining interbelt influence for friction case (inputted INFL = 1)	BELT
2	3	8	Inertial coordinates of belt attachment and anchor points	BELT
3	1	9	Belt forces and interbelt influence modified forces	BELT
3	2	10	Belt force modifications from interbelt influence	BELT
3	3	11	Belt generalized force contributions	BELT
4	1	33	Relative Euler angles and rates	JOINT
4	1	35	Joint elastic and joint stop moments	JOINT
4	2	32	Relative Euler angles	JOINT
4	2	34	Joint lever arms	JOINT
4	2	36	Joint generalized force contributions	JOINT

TABLE 34. SUMMARY OF DEBUG FORMATS (page 2)

Debug Switch	Debug Level	Debug Block Number	Description	Subroutine
4	3	37	Joint stop angles, deflection, and moment	JOINT
4	3	38	Relative direction cosines for appendages	JOINT
5	1	39	Calculated inertial contact surface corner point coordinates	CONTAC
5	1	40	Coefficients of contact surface plane	CONTAC
5	1	70	Inputted contact surface corner point coordinates, relative or inertial	CONTAC
5	2	41	Contact surface intermediate results	CONTAC
5	3	42	Terms in vehicle contribution to contact deflection rate	CONTAC
6	1	44	Inertial coordinates of ellipsoid center and intermediate results for ellipsoid-contact calculations	CONTAC
6	1	45	Inertial coordinates of sphere center	CONTAC
7	1	47	Deflection, force, and associated quantities for ellipsoid-contact interaction	CONTAC
7	2	43	Total generalized force contribution from ellipsoid contact forces at a surface	CONTAC
7	3	46	Inertial coordinates of possible contact points on ellipsoid	CONTAC
7	3	48	Partial sums (through the IKC contact ellipsoid) for the generalized force contribution of contact forces for a surface	CONTAC
7	3	49	Contact force lever arms for an ellipsoid-plane interaction	CONTAC
7	3	50	Intermediate results for determining ellipsoid-contact lever arms	CONTAC
7	3	51	Intermediate results for determining sphere-contact lever arms	CONTAC

TABLE 34. SUMMARY OF DEBUG FORMATS (page 3)

Debug Switch	Debug Level	Debug Block Number	Description	Subroutine
8	1	30	Vehicle coordinates, velocities, and accelerations	CARTIN
9	1	26	Current integration step level, last established time, execution time and integer versions of time	MAIN
9	2	27	Last integrated values and corrections	MAIN
9	3	31	Time history of integrated values	MAIN
10	1	71	Principal switches together with input and output of load-deflection evaluation	EVAL
10	3	72	Current values of load-deflection quantities	EVAL
10	3	73	Special unloading switches	EVAL
10	3	74	Control table storage check	UPDATE
11	1	12	Body and vehicle kinetics	ACCEL
11	2	13	Sines and cosines of angle generalized coordinates	ACCEL
11	2	14	Rotation matrix elements for vehicle and each body segment and building blocks for kinetic energy contributions	ACCEL
11	3	15	Partial and time derivatives of body segment CG coordinates	ACCEL
11	3	16	Partial and time derivatives of rotation matrix elements	ACCEL
11	3	17	Partial derivatives of rotation matrix elements	ACCEL
11	3	18	Building blocks for kinetic energy contributions	ACCEL
11	3	19	Building blocks for kinetic energy contributions	ACCEL
11	3	20	Velocity dependent building blocks for kinetic energy contributions	ACCEL

TABLE 34. SUMMARY OF DEBUG FORMATS (page 4)

Debug Switch	Debug Level	Debug Block Number	Description	Subroutine
12	1	21	Body segment angular velocity components	ACCEL
12	1	22	Generalized acceleration values before possible editing	ACCEL
12	2	23	Coefficient matrix for generalized acceleration vector	ACCEL
12	2	24	The generalized force vector and contributing terms	ACCEL
12	3	25	Parts of acceleration quantities which do not have a generalized acceleration factor	ACCEL
13	1	29	Summary of limit quantities	LIMIT
13	2	28	Detail of limit quantities	LIMIT
14	1	59	Contact surface friction force, lever arms, and associated quantities	CONTAC
14	2	52	Contact force lever arms and corresponding values calculated from approximated quantities used in determining friction contributions	CONTAC
14	2	54	Contribution of inertial motion of body segments to surface tangential coordinate velocity components for ellipsoid	CONTAC
14	2	55	Block 54 plus contribution of vehicle motion	CONTAC
14	2	56	Block 55 plus contribution from contact surface position	CONTAC
14	2	57	Block 56 plus additional contribution from contact surface position	CONTAC
14	2	61	Total generalized force contribution from ellipsoid friction forces at a surface	CONTAC
14	3	53	Partial derivatives of contact point coordinates (approximate for ellipsoid, exact for sphere)	CONTAC
14	3	58	Contributing factors of values in block 57	CONTAC

TABLE 34. SUMMARY OF DEBUG FORMATS (page 5)

Debug Switch	Debug Level	Debug Block Number	Description	Subroutine
14	3	60	Partial sums (through the IKC contact ellipsoid) for the generalized force contribution of friction forces on a surface	CONTAC
14	3	62	Vehicle motion contribution to tangential velocity at contact surface	CONTAC
15	1	63	Ellipsoid-ellipsoid deflection, force, and center coordinates of migrating spheres	CONTAC
15	2	64	Center coordinates of interacting contact ellipsoids, inertial and relative to body segment CG; lever arms for ellipsoid-ellipsoid force	CONTAC
15	2	66	Migrating sphere position parameters for sphere-sphere case or sphere-ellipsoid	CONTAC
15	2	67	Migrating sphere position parameters for ellipsoid-ellipsoid case	CONTAC
15	2	68	Quantities calculated for case of interacting parallel ellipsoids	CONTAC
15	3	65	Ellipsoid center coordinate contributions to ellipsoid-ellipsoid force lever arms and partial sum of generalized force vector elements (through the IKC-JKC ellipsoid-ellipsoid interaction)	CONTAC
15	3	69	Semi-major axis direction numbers contributions to ellipsoid-ellipsoid force lever arms	CONTAC
16	3	-	Triggers a hexidecimal memory dump if that has been permitted by the user	UPDATE

TABLE 35. DEBUG BLOCK NUMBER, DEBUG SWITCH, AND SUBROUTINE CORRESPONDENCE

Debug Block Number	Debug Switch	Subroutine
1-5	1	BELT
6-8	2	BELT
9-11	3	BELT
12-20	11	ACCEL
21-25	12	ACCEL
26-27	9	MAIN
28-29	13	LIMIT
30	8	CARTIN
31	9	MAIN
32-38	4	JOINT
39-42	5	CONTAC
43	7	CONTAC
44-45	6	CONTAC
46-51	7	CONTAC
52-62	14	CONTAC
63-69	15	CONTAC
70	5	CONTAC
71-74	10	EVAL
-	16	UPDATE

TABLE 36. ERROR MESSAGES (page 1)

Number	Message	Condition and Action Required	Subroutine
1	time limit in AT TIME = XX.XXXX RUN LIMIT EXCEEDED msec XXXXX * msec of execution XXXXX	The user's specified execution time limit has been exceeded. Execution will be stopped. If not deliberate, recheck input for bad control values.	MAIN
2	time AT TIME = XX.XXXX FATAL ERROR, MAXIMUM NUMBER OF *INTERVAL SUBDIVISION EXCEEDED.	Recheck input data looking for parameters that would cause unusually large forces such as misplaced contact planes, ellipsoids, belt anchors, or initial body positions.	MAIN
3	time AT TIME = XX.XXXX FATAL ERROR RETURN.	An error has occurred which makes continuation of the run impossible. A prior error message will state the cause.	MAIN
4	INTERVAL HALVING PROCEDURE FAILS.	It has become impossible to evaluate the accelerations in procedure for halving integration step size. If due to other than convergence, reason stated. Look for excessive forces.	MAIN
5	DATA NOT PROPERLY READ IN, SKIP DATA SET.	A mispunched card has been encountered. Vital information is assumed lost and the data deck is not processed. Check your input data.	MAIN
6	Program States Word PROGRAM TRAP XXXXXXXXXX XXXXXXXXXX	A program trap has occurred such as a division by zero, overflow, or underflow. Check your data deck.	MAIN
7	time IHC AT TIME = XX.XXXX ICH ERROR NO. Number FATAL ERROR XXXX	A Fortran supplied routine has received an illegal argument. Check your data deck.	MAIN

TABLE 36. ERROR MESSAGES (page 2)

Number	Message	Condition and Action Required	Subroutine
8	ILLEGAL CARD SKIPPED.	An input card with an illegal I.D. field has been encountered. This card is skipped and execution is not interrupted.	READAT
9	BELT PAIRING CARDS OUT OF ORDER Pair No. Expected XXXXX Pair No. Read XXXXX	Belt input cards which specify pairing properties out of order or one is missing. Check your data deck.	READAT
10	KCON FILLED, RUN ABORTED.	Alotted storage for contact control information is exceeded. The number of contacts, ellipsoids, or material properties must be cut down. Revise your data deck.	READAT
11	STOMAT FILLED, RUN ABORTED.	Alotted storage for contact quantities is exceeded. The amount of information and/or the number of contacts, ellipsoids, belts, or material properties must be cut down. Revise your data deck.	READAT
12	CUR FILLED, RUN ABORTED.	Too many entries in input vehicle acceleration tables (nos. 1 through 6). Revise your data deck to include fewer time points.	READAT
13	END OF FILE.	There is no more input data to be processed. Normal termination.	READAT
14	CONVERSION ERROR.	An I/O error has occurred. Check your data deck for bad cards. If no errors, try again.	READAT
15	TRANSMISSION ERROR.	A transmission error has occurred. Check your data deck for bad cards. If no errors, try again.	READAT

TABLE 36. ERROR MESSAGES (page 3)

Number	Message	Condition and Action Required	Subroutine
16	MASS OR INERTIA ZERO.	At least one of the inertial properties of the occupant were set zero. Program will not operate properly so this input deck skipped. Revise data deck.	READAT
17	ID field 8 Numeric Fields XXXX XXXXXXXXXX XXXXXXXXXX . . XXXXXXXXXX ILLEGAL PUNCHING, RUN ABORTED.	Illegal character punched in a numeric field. Revise data deck.	PEEK
18	now set to 60 MORE THAN XXX TABLES REQUESTED.	Too many tables (see $\overline{0}$-card) specified in data deck. This includes profiles, material properties, and debugging. This table skipped. Revise data deck.	ENTAB
19	now set to 3000 MORE THAN XXXXX TABLE ENTRIES REQUESTED.	Too many entries (see $\overline{0}$-card) specified in the tables specified. Revise data deck. This entry skipped.	ENTAB
20	Table No. Entry No. NO ROOM FOR TABLE XXX EXPANSION AT XXXXXX	Impossible to update table for lack of room. Revise data deck. This entry skipped.	MOVTAB
21	ERROR RETURN.	Termination of run due to error. This will be accompanied by a statement about cause.	ACCEL
22	time AT TIME XX.XXXX LOAD-DEFLECTION TIME HISTORY EXHAUSTED.	Search for appropriate base entry in load-deflection time histories fails. Let us know; this should normally never happen. You may try small changes in data deck since this can occur only in very special circumstances.	LODFEL

TABLE 36 . ERROR MESSAGES (page 4)

Number	Message	Condition and Action Required	Subroutine
23	time AT TIME XX.XXXX INCOMPATIBLE LOAD-DEFLECTIONS IN SHARED *CASE.	Force balance search fails for shared case. If fatal, check load-deflection curves for ambiguous force balances. Time interval halved and execution continued.	LODFEL
24	time AT TIME XX.XXXX EXCESSIVE FORCE CHANGE Ellipsoid Name *AGAINST Ellipsoid or Contact Name BOTH RIGID.	Too large of a time step for the contact of two rigid bodies. If fatal, supply material properties for one of the bodies. Normally leads to time interval halving and execution continued.	LODFEL
25	time AT TIME X.XXXXXX BAD UNLOADING CURVE, ENERGY NOT RIGHT * Static Control Spike Control XXXXX XXXXX * Permanent deformation Maximum deflection Force at maximum deflection Conserved energy XXXXXXXX.XXX XXXXXXXX.XXX XXXXXXXX.XXX XXXXXXXX.XXX	Conserved energy too much to fit under reasonable unloading curve. Unloading curve replaced by a straight line segment from maximum to permanent deformation. Execution continues.	EVAL
26	CONTACT ERROR No. of contact in storage Ellipsoid index Contact index Conout index * Ellipsoid name index Contact name index	Incompatibility in storage of contact surfaces for printing. Printing discontinued. If persists with repeat run, contact us.	SUMRY
27	INCOMPLETE DATA RECORD.	End of summary file reached without normal file termination sequence. Printing discontinued. If otherwise all right, repeat run.	SUMRY

TABLE 36 . ERROR MESSAGES (page 5)

Number	Message	Condition and Action Required	Subroutine
28	REPEATED INPUT TRANSMISSION ERRORS, JOB ABORTED.	Ten transmission errors in reading input data deck. Run abandoned. Check data deck then rerun.	ZILTCH
29	MBELT MUST BE EITHER ZERO FOR ALL BELTS OR NON-ZERO FOR ALL BELTS.	Check cards following K-cards (eighth field). Belt forces must be based either on deflection or on strain (a combination is not allowed). Revise data deck. Make sure that M-cards for belt materials are for deflection or strain, accordingly.	READAT
30	TOO MANY SLIPPING PAIRS.	A maximum of two belt pairs are allowed to slip freely: 1-2, 3-4 or 1-3, 2-4 or 1-4, 2-3. Revise data deck.	READAT
31	SHARED DEFLECTION HAS BEEN DISALLOWED.	Shared deflection between belts and torso is not allowed if belt forces are based on strain. Processing of data deck was continued after negation of shared deflection input.	READAT

VI SYMBOL DICTIONARY

This section consists of three tables which offer an aid to a more detailed examination of the program code and its correspondence to the analysis behind the code.

Table 37 is the main symbol dictionary which is ordered on the Fortran name given to each quantity. The "Symbol" column contains the analytical symbol used in Part III. The third column gives either the label of the common in which this variable resides or the name of the subprogram in which it is used if it is not shared between subprograms. Columns four and five are used together to detail quantities which have been stored in arrays instead of individual variables. If a number appears in column five, it refers to the corresponding value in the first column of Table 39 which defines the quantity or type of information for each value of the subscript up to the number in the "Dimension" column.

Table 38 is provided to ease getting from the analysis to the program code and is ordered on symbol. Table 39 specifies the meanings of most of the subscripts used in arrays.

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
A	-	ACCEL	96	-	Building blocks for kinetic energy terms in equations of motion
A	-	SUMRY	41 150	43 -	The first 150 values in DYN
A1	-	CONTAC	1	-	Test parameter for ellipsoid-ellipsoid
A2	a^2	CONTAC	1	-	Square of semi-x-axis ellipsoid
AA	-	BELT	2	21	X-coefficient for plane determined by two attachments and an anchor point
AAP	-	BELT	2	21	X-coefficient for plane perpendicular to AAx+BBy+CCz+DD=0 and through two attachment points
AB	-	BV	6	12	Absolute tangential component of net belt force for each pair of belts
AB	-	SUMRY	41 53	43 -	DYN(151) to DYN(203)
ABC	-	SUMRY	41 9	43 -	DYN(204) to DYN(212)
ACCM	$\Delta\ddot{\tilde{Z}}_{lim}$	EP	1	-	Extrapolation change limit
AF	$\Delta t\ddot{K}_{k,1}$	RK	17	3	First Runge-Kutta acceleration evaluation times the time step
AFSAT	$F_{s,\nu}$	BC	4 4	11 11	Absolute influence force limit for belt i on belt j
AGL	Δx_{nm}	JOINT	3 2	28 31	Relative joint angles
AL	-	QV	3 6	10 18	Body segment angular velocity components
AP	-	STASH,RELTIV	6	-	Temporary storage
ARE	R	EVAL	1	-	Fraction of conserved energy to total energy
AX	-	CONTACT	2	-	Vestigial
B	$\vec{Q}$	BQ	17	3	Total generalized force vector.
B	-	SUMRY	41 516	43 -	The first 516 values in CON
B1 to B4		CONTAC	1	-	Test parameters for ellipsoid-ellipsoid

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
B2	b^2	CONTAC	1	_	Square of semi-y-axis of ellipsoid
BA1	λ_n	BELT	1	-	Anchor or attachment x-coordinate in cart or torso system
BA2	μ_n	BELT	1	-	y-coordinate (see BA1)
BA3	ν_n	BELT	1	-	z-coordinate (see BA1)
BANG	-	BV	4 3	11 2	Belt projected angles
BB	-	BELT	2	21	y-coefficient (see AA)
BB	-	CONTAC	12	-	Contact surface intermediate results
BB	-	SUMRY	41 30	43 -	CON (517) to CON (546)
BBP	-	BELT	2	21	y-coefficient (see AAP)
BC	-	BELT	12	in.	Belt intermediate results in rate calculation
BC	-	CONTAC	31	13	Contact surface information array
BC	-	SUMRY	41 36	43 -	CON (547) to CON (582)
BC27	λ	CONTAC	1	-	Edge parameter
BD	-	SUMRY	41 32	43 -	CON (583) to CON (614)
BE	-	BQ	17	3	Ellipsoid-ellipsoid generalized force vector
BE	-	SUMRY	41 6	43 -	CON (615) to CON (620)
BETELP	-	IT	1	-	Minimum ratio of shortest to longest semi-axis to be treated as sphere for ellipsoid contacts
BF	-	BQ	17	3	Contact friction generalized force vector
BF	$\Delta t\ddot{K}_{k,2}$	RK	17	3	Second Runge-Kutta acceleration evaluation times the time step
BF	-	SUMRY	41 5	43 -	CON (621) to CON (625)
BG	$\vec{Q}_G$	BQ	17	3	Gravity generalized force vector
BG	-	SUMRY	41 65	43 -	CON (626) to CON (690)
BJ	$\vec{Q}_J$	BQ	17	3	Joint generalized force vector
BL	$\ell_n(t)$	BELT	4	11	Belt segment lengths
BLC	-	BELT	6	12	Belt-pair length across body.

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
BLZ	$\ell_n(o)$	TL	4	11	Initial belt segment lengths including slack.
BMVK	μ_k	BC	6	12	Kinetic friction coefficient for each belt pairing
BMUS	μ_s	BC	6	12	Static friction coefficient for each belt pairing
BOG	Ω	LF	6	48	Maximum deflection array for EVAL. Units are inches.
BOGP	Ω	LP	2	50	Last value of BOG for this interaction
BR	$\vec{Q}_B$	BQ	17	3	Belt generalized force vector
BS	$\vec{Q}_C$	BQ	17	3	Contact generalized force vector
BT	$\vec{Q}_T$	BQ	17	3	Centrifugal generalized force vector
BX	-	BELT	4	11	Inertial x-component of belt vector, anchor to attachment
BXA	$\hat{x}_n,\hat{\underline{X}}_n$	BELT	2 4	9 11	Inertial x-component of torso CG-to-belt attachment vector or of cart origin-to-anchor vector
BXD	-	BELT	1	in/sec	Rate of change of belt length inertial X-component
BY	-	BELT	4	11	Y-component (see BX)
BYA	$\hat{y}_n,\hat{\underline{Y}}_n$	BELT	2 4	9 11	Y-component (see BXA)
BYD	-	BELT	1	in/sec	Rate of change of belt length inertial Y-component
BZ	-	BELT	4	11	Z-component (see BX)
BZA	$\hat{z}_n,\hat{\underline{Z}}_n$	BELT	2 4	9 11	Z-component (see BXA)
BZD	-	BELT	1	in/sec	Rate of change of belt length inertial Z-component
C	c_i	C	29	-	Integration rule coefficients for predictor-correctors, Table 15 lines one through twenty-nine
C	-	QV	3 7	6 18	Cosines of generalized angles
C	c_i+29	RK	21	-	Integration rule coefficients for Runge-Kutta methods, Table 15, lines thirty through fifty

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
C2	C^2	CONTAC	1	-	Square of semi-z-axis of ellipsoid
CARD	-	READAT	8	-	Temporary storage for numerical fields of input data cards.
CATC	-	LIMIT	1	-	Difference between accleration and four point extropolation
CATD	-	LIMIT	1	-	Difference between two point and four point extropolations
CC	-	BELT	2	21	Z-coefficient (see AA)
CCP	-	BELT	2	21	Z-coefficient (see AAP)
CE	-	EVAL	1	in.lbs.	Conserved energy
CETA	-	READAT	14	33	Coupled neck joint stop angles
CF	$\Delta t\ddot{K}_{k,3}$	RK	17	3	Third Runge-Kutta acceleration evaluation times the time step
CFTAN	-	CONTAC	1	-	Tangential friction force
CGF	-	EVAL	1	lbs	Force at COG
CM	-	EVAL	1	lbs/in	Force slope at COG
CMASS	-	READAT	4 6	32 18	Masses and moments of inertia for 50th percentile male
CMU	-	CON	5 10	22 23	Friction coefficients for ellipsoids against planes
CMUG	-	CONTAC	1	-	Friction coefficient
COG	-	EVAL	1	in.	Maximum deflection last loading
COMP	-	UPDATE	1	-	Three times maximum time step
CON	-	STASH	690	-	Output vector for contact interaction values
CONOUT	-	OUT	690	-	Contact output storage array
COST	-	JOINT	1	-	Relative pitch cosine
COSTSY	-	JOINT	1	-	Square of relative yaw cosine
COSTSR	-	JOINT	1	-	Square of relative roll cosine
CQ	-	CART	3 6	19 20	Vehicle kinematics
CTHETA	-	BELT	1	-	Cosine of angle between two planes, for debug output (belt friction); value near to 1 indicates good approximation in analysis
CUR	-	VX	1200	-	Storage for deceleration table computed velocities and displacements for each linear segment
D	-	C	4	-	Milne integration coefficients

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
D	δ	LF	6	48	Deflection array for EVAL. Units are inches
DA	δ_A	LC	2	50	Deflection at peak of inertial spike. Units are inches
DA	Δx_{nm}	JV	5 3	26 28	Relative Euler angles
DAMPJ	C	JC	5 3	26 28	Joint stop damping coefficients
DAZ	-	JOINT	2 3	5 6	Initial joint relative angles
DB	δ_B	LC	2	50	Deflection at end of inertial spike. Units are inches
DC	-	BELT	3	2	Direction cosines
DC	δ_c	LC	2	50	Elastic limit. Units are inches
DD	-	BELT	2	21	Coefficient for plane (see AA)
DD	-	CONTAC	18	42	Lever arms and deflection rate for contacts
DD	$\dot{\delta}$	LF	6	48	Deflection rate array for EVAL. Units are inches per second
DD	$\Delta\dot{x}_{nm}$	JV	5 3	26 28	Relative Euler angle velocities
DDC	-	BELT	3 2	2 21	Direction cosines for a contribution to normal force for belt pair
DDC	-	CONTAC	1	-	Vehicle contribution to contact deflection rate
DDD	-	CONTAC	3	16	Saved contact lever arm values
DDE	-	CONTAC	18	42	Lever arms and deflection rate for ellipsoid-ellipsoid force
DDP	-	BELT	2	21	Coefficient for plane (see AAP)
DDP	δ	LP	2	50	Last value of DD for this interaction
DDS	-	CONTAC	1	-	Contact surface contribution to contact deflection rate
DE	-	CONTAC	18	42	Lever arms and tangential speed for friction force

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
DE	δ_D	LC	2	50	Breaking point - Units are inches
DEF	-	DEF	5 3	26 28	Joint stop deformation
DEL	δ	EVAL, LODFEL	1	inches	Input deflection to evaluation section
DEL	-	LIMIT, MAIN	1	-	Weighted averages of various test quantitities
DELB	δ_n	BV	4	11	Belt elongations
DELD	$\dot{\delta}_n$	BV	4	11	Belt elongation rates
DELD	-	LODFEL	1	in./sec.	Deformation rate
DELDEL	-	LODFEL	1	inches	Change in total deflection between last evaluation and now
DELDLA	-	LODFEL	3	inches	Evaluation of deflection change for first material from last deflection
DELDLB	-	LODFEL	3	-	vestigial
DELTAT	Δt_{max}	TT	1	sec.	Maximum time step
DELTIM	Δt	LODFEL	1	sec.	Time increment from last force evaluation for this interaction
DER	-	CONTAC	3 2 17	10 25 42	Partial derivatives of ellipsoid center coordinates (XE)
DET	-	CONTAC	1	-	A determinant
DF	δ_F	LC	2	50	Deflection at which completely broken. Units are inches
DF	$\Delta t\ddot{K}_{k,4}$	RK	17	3	Fourth Runge-Kutta acceleration evaluation times the time step
DFAC	-	VX	6	20	Factor to change the amplitude of deceleration table
DFORE	-	LODFEL	3	pounds	Evaluations of force unbalance of first material force minus second material force
DH	-	SUMRY	20	-	Temporary storage for contact interaction information to be printed
DHAT	-	CONTAC	9	1 in/sec	Contact surface corner coordinat rates

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
DK	-	CONTACT	1	-	Part of the contact normalizin factor
DLAM	-	CONTAC	3 2 17	10 25 42	Partial derivatives of XLAM
DM	β	LC	2	50	Slope of saturation unloading line. Units are pounds/inch
DMC	-	CONTAC	3	-	Intermediate results in computing DDC
DP	δ	LP	2	50	Last value of D for this interaction
DPIT	-	JOINT	1	-	Difference between appendage pitch and torso pitch
DPR	-	STASH	1	deg/rad	Value of $180/\pi$
DR	-	QV	9 7 4	4 18 5	Partial and time derivatives of R
DR14	-	QV	7	18	Time derivative of R14
DR15	-	QV	7	18	Time derivative of R15
DR16	-	QV	7	18	Time derivative of R16
DR17	-	QV	7	18	Time derivative of R17
DRL	-	QV	9 2	4 7	Partial derivatives of R for lower leg angles
DSTEPN	-	LD	1	in.	Minimum step to search for balance in shared deflection
DSTEPX	-	LD	1	in.	Maximum step to search for balance in shared deflection
DTMIN	ε_t	EP	1	sec.	Inputted time epsilon
DTPRNT	Δt_{prnt}	TT	1	sec.	Inputted print time interval
DTR	-	QV	8 7	- 18	Time derivative of TR
DUM	-	DUM	48	-	Temporary storage array
DUR	-	JOINT	1	-	Partial derivative of relative direction cosine
DUY	-	JOINT	1	-	Partial derivative of relative direction cosine
DVR	-	JOINT	1	-	Partial derivative of relative direction cosine
DVY	-	JOINT	1	-	Partial derivative of relative direction cosine
DX	-	QV	3 6 18	10 18 42	Partial and time derivatives of X

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
DXDQ	-	CONTAC	17	42	Partial derivatives of WS
DXYZZ	-	CONTAC	3 17	10 42	Partial derivatives of XZ, YZ, ZZ (Or approximations if not sphere)
DYAW	-	JOINT	1	-	Difference between appendage yaw and torso yaw
DYDQ	-	CONTAC	17	42	Partial derivatives of WT
DYN	-	STASH	212	-	Output vector for body kinetics and dynamics
E	E	LF	6	48	Total energy on loading phase or conserved energy on unloading phase array for EVAL. Units are inch- pounds
EDEPS	$\varepsilon_{\ddot{Z}}$	KC	1	-	Inputted acceleration minimum magnitude
EI	I_{in}	KC	3 6	10 18	Body segment principle axis moments of inertia
EIT	-	STASH	3 3	10 10	Inertia tensor with respect to inertial coordinate frame
EJ	-	JV	5 3	26 28	Joint elastic moment
ELAS	E_{Xi}	JC	5 3	26 28	Joint elastic coefficients
EL1	-	CONTAC	1	-	Same as A2
EL2	-	CONTAC	1	-	Same as B2
EL3	-	CONTAC	1	-	Same as C2
EL21 to EL26	-	CONTAC	1	-	Intermediate results in calculation of FK
EL27	-	CONTAC	1	-	Inertial X of ellipsoid center
EL28	-	CONTAC	1	-	Inertial Y of ellipsoid center
EL29	-	CONTAC	1	-	Inertial Z of ellipsoid center
EM	m_i	KC	6	18	Body segment mass
EMAT	m	ACCEL	17 17	3 3	Generalized mass matrix
EP	E	LP	2	50	Last value of E for this interaction
EPS	ε	CONTAC	1	sec	Parameter for linearizing contact surface corner point velocities
EPSFAC	-	IT	1	-	Number of maximum time steps for maximum ramp length in moving contacts

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
EPZA	ΔV_{lim}	EP	1	-	Inputted velocity change limit
EPZV	ε_v	EP	1	-	Inputted velocity convergence parameter
EREST	(Δx_{mn})	JC	5 3	26 28	Rest position for elastic joint forces (or switch)
ESG	g	MC	1	in/sec^2	Earth standard gravity (386.4 in/sec^2)
ETA	δ	CONTAC	1	in.	Deflection of contact surface by body ellipsoid
ETA	η_{ij}	JC	12 3	30 26	Joint stop limits
ETAD	$\dot{\delta}$	CONTAC	1	in/sec	Deflection rate
FA	-	EVAL	1	pounds	Static force
FAA	-	EVAL	1	lbs/in.	Static force slope
FAC	λ	BV	6	12	Fractional influence factor for adjustment of smaller force toward larger force, and vice versa, for each belt pair (belt friction)
FB	$\vec{F}_i$	BV	4	11	Unmodified force for belt i
FB	-	EVAL	1	pounds	Inertial spike force
FBB	-	EVAL	1	lbs/in.	Inertial spike force slope
FBMOD	-	BV	4	11	Modified force for belt i
FBOG	$F(\Omega)$	LF	6	48	Force at maximum deflection array for EVAL. Units are pounds
FBOGP	$F(\Omega)$	LP	2	50	Last value of FBOG for this interaction
FD	F	LC	2	50	Last value of force for this interaction
FDD	F'	LODFEL	2	50	Force slope for interaction Units are pounds per inch
FDEL	-	LODFEL	1	lbs.	Difference of two evaluations of the force difference for the two materials
FDEV	F'	EVAL	1	pounds/inch	Output force slope from evaluation section
FE	-	BELT	2	21	Contributions to normal force for belt pair
FEE	-	CONTAC	1	-	Ellipsoid-ellipsoid force

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
FK	k	CONTAC	1	-	Normalization factor in contact calculations for deflection
FM	F_{max}	LC	2	50	Static curve saturation force limit. Units are pounds
FMOD	-	BELT	6 4	12 11	Additive modification of belt force FB
FMU	-	CONTAC	1	-	Half of square of sphere radius
FN	N	BV	6	12	Normal force to body from belt pair i
FNU	-	CON	1	in/sec.	Length of velocity ramp from zero relative velocity for surface friction coefficients
FOG	$F'(\Omega)$	LF	6	48	Slope of force at maximum deflection array for EVAL. Units are pounds per inch
FOGP	$F'(\Omega)$	LP	2	50	Last value of FOG for this interaction
FORA	-	LODFEL	3	pounds	Evaluations of force for first material
FORAP	-	LODFEL	3	lbs/in.	Evaluations of force slope for first material
FORB	-	LODFEL	3	pounds	Evaluations of force for second material
FORBP	-	LODFEL	3	lbs/in.	Evaluations of force slope for second material
FORCE	F	EVAL, LODFEL	1	pounds	Output force from evaluation section
FOREPS	-	LODFEL	1	pounds	Minimum of the force convergence epsilon for the two materials
FORLIM	-	LD	1	pounds	Limit to force change for rigid on rigid case before halving
FPSUM1	-	LODFEL	1	lbs/in.	Sum of force slopes for both materials
FPSUM2	-	LODFEL	1	lbs/in.	Sum of force slopes for both materials
FRIC	-	CONTAC	1	-	Switch, sum of all friction coefficients
FS	-	BV	6	12	Tangential force to body from belt pair i in static case
FT	-	CONTAC	1	lb.	Total contact force

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
FT	-	READAT	1	-	A conversion factor, inches to inches or degrees to radians
FTAN	-	CONTAC	1	-	Friction coefficient times normal force
FUM	-	CONTAC	3	-	Intermediate results in evaluation of contact lever arms
GAMELP	-	IT	1	-	Ratio of sphere center position on semi-major axis to that position which would cause the sphere and ellipsoid to be flush at the extremity
GEE	G	EVAL	1	-	Fraction of permanent deformation over maximum deflection
GI	G	LC	2	50	Fraction of permanent deformation over maximum deflection for current loading cycle
GRAV	g	MC	1	in/sec^2	Local gravity constant
GSE	-	STASH	1	-	g's per unit acceleration, 1/ESG
GUM	-	CONTAC	3 17	- 42	Intermediate results in evaluation of contact lever arms
HALFK	-	CONTAC	1	-	Half of FK
HARDCN	-	LD	1	lbs/in.	Linear elastic coefficient for use in rigid on rigid case
HIPZ	-	STASH	3	10	Cart relative H-point coordinates at t=0
I	i	MANY	1	-	General index
IA	-	CONTROL	1	-	General index
IA	-	LF	6	48	IALF switch array for EVAL
IA	-	SETACT	1	-	Ellipsoid control index for interaction
IA	-	TRAPER	18	-	Vestigial
IAA	-	JOINT	1	-	General Index
IAB	-	JOINT	1	-	General Index
IACC	-	RSS, SUMRY	1	-	Switch which specifies units for output of body segment linear accelerations
IACT	-	LODFEL	1	-	Beginning index of entry for interaction in STOACT
IALPH	-	READAT	26	-	Input card identification letter storage
IAP	-	LP	2	50	Last value of IA for this interaction

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
IB	-	CONTRL, DETAB	1	-	General Index
IB	-	LODFEL	1	-	Index of current large side evaluation
IB	-	SETACT	1	-	Plane or Ellipsoid control index for interaction
IBEG	-	PUSHER	1	-	Index of where insertion is to be made
IBLANK	-	READAT	1	-	EBCD for blanks used in making formats
IBLNK	-	MATCH	1	-	EBDC for blanks used for comparing with A1 format input
IBUG	-	BUG	16	-	Debug output control switch array
IC	-	DEBUG	16	-	Shift control array in debug unpacking
IC	-	LODFEL	1	-	Index of current evaluation
IC	-	NUPAGE	1	-	Argument which is set non-zero if new page was required
IC1	-	CONTAC	1	-	Moving contact switch
IC2	-	CONTAC	1	-	Starting index for storage for corner point coordinates of contact surfaces
IC4	-	CONTAC	1	-	Pointer for storage for corner point coordinates of contact surfaces
ICF	-	SUMRY	1	-	General Index
ICHOP	-	JOINT	1	-	Indicator of relative roll sign
ICNOUT	-	LODFEL, SETACT	1	-	Beginning index in CONOUT for interaction
ICOUNT	-	CNT	21	-	Number of time steps at each of the possible halving levels.
ICOUNT	-	CONTAC	1	-	A counter
ICOUNT	-	SUMRY	1	-	General Index
ID	-	READAT	1	-	Input card identification letter
IDATE	-	TL	3	-	Date label storage
IDC	-	SUMRY	8	-	EBCD for plane or ellipsoid name and material
IDCON	-	RSS, SUMRY	20	40	Beginning addresses in KCON for contact planes
IDDCHK	-	CONTAC	3	16	Switch for minimizing calculations for ellipsoid lever arms

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
IDESCR	-	RSS, SUMRY	10 20	- 40	EBCD for optional input describing planes
IDI	-	SUMRY	10	-	EBCD for ellipsoid name and material
IDIR	-	MATCH, PUSHER	1	-	Input argument which controls subroutine options
IDIS	-	RSS, SUMRY	1	-	Switch which specifies coordinate system for output of body segment CG displacements and velocities and position of feet, knees, H-point, and ellipsoid centers
IDT	-	PUSHER	1	-	Index of array into which insertion is to be made
IDUMM	-	BELT	1	-	Dummy argument
IE	-	BELT	1	-	Belt number of influencee
IE	-	CONTAC	1	-	Index for ellipsoid (or sphere)
IE	-	STASH	1	-	General Index
IEND	-	SUMRY	1	-	Index of last location in CON to be printed for a particular line of output
IENRG	-	TL	1	-	Output times in msec if non-zero
IEOF	-	STASH, SUMRY	1	-	Causes END OF FILE in place of STASH output if non-zero
IEP	-	EVAL	1	-	Switch which when non-zero causes total energy to be accumulated
IERR	-	ENTAB	1	-	Error switch: non-zero if not enough room in table storage for new point
IERR	-	MOVTAB	1	-	Switch set non-zero if not enough room to make space for new entry
IERSWT	-	ERR	1	-	Switch set non-zero if I/O error has occurred in reading card
IFCHK	-	CONTAC	1	-	Switch, for minimizing calculations for ellipsoid lever arms
IGCHK	-	CONTAC	17	42	Switch, for minimizing calculations for ellipsoid lever arms
IHCERR	-	MAIN	1	-	Number of IHC error which has been intercepted
IHCLIS	-	MAIN	5	-	List of IHC errors to intercept
IHIB	-	IT	6 6	18 18	Switch, non-zero inhibits force production between body segments i and j

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
II	-	LF	6	48	Operational index for static curve array for EVAL. Negative is table index, positive and greater than LENMAT is computed polynomial index in STOACT. Otherwise is input polynomial index in STOMAT
II	-	MANY	1(or 4)	-	General index
II	-	SUMRY, TITLE	1	-	Control for page heading
IIA	-	LODFEL	1	-	Index of current small side evaluation
IIACT	-	LODFEL	1	-	Beginning index of entry for interaction in KACT
IIF	-	SUMRY	1	-	General Index
IIP	-	LP	2	50	Last value of II for this interaction
IJ	-	MANY	1	-	General index
IJKC	-	STASH	1	-	General index
IK	-	DETAB	1	-	Current entry index for deletion
IK	-	FINDM, MATCH	1	-	Switch, negative if new material entry
IKA	-	LODFEL	1	-	Push down copy loop index
IKA	-	MANY	1	-	General index
IKACT	-	CONTAC	1	-	Control index
IKACT	-	LODFEL	1	-	Beginning index of time history entry for interaction in KACT
IKACT	-	SETACT	1	-	Beginning index of time history entry for interaction in KACT, 0 if none
IKAT	-	SETACT	1	-	Beginning index in KACT of interact entry which has been created
IKB	-	MANY	1	-	General index
IKC	-	CONTAC	1	-	Control index
IKC	-	MANY	1		General index
IKC	-	SUMRY	1		Same as IMC
IKD	-	MANY	1	-	General Index
IKF	-	PUSHER, READAT	1	-	General index
IKG	-	PUSHER, READAT	1	-	General index

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
IKH	-	READAT	1	-	General Index
IKHH	-	READAT	1	-	General Index
IKI	-	PUSHER READAT UPDATE	1	-	General Index
IKJ	-	PUSHER READAT UPDATE	1	-	General index
IKJJ	-	READAT	1	-	General index
IKK	-	PUSHER	1	-	General index
IKM	-	CARTIN, READAT	1	-	General index
IKN	-	SUMRY	1	-	Beginning address in KCON for an interaction
IKONT	-	SETACT	1	-	Number of locations needed in KACT for interaction
IKOUT	-	SETACT	1	-	Beginning index of CONOUT entry or zero if none
IKX	-	READAT	1	-	General index
IKY	-	CARTIN, READAT	1	-	General index
IKZ	-	UPDATE	1	-	Beginning address of entry for interaction in KACT
ILIM	-	CNT	1	-	Current time step halving level
ILONG	-	IT, SUMRY	1	-	Inputted switch: zero for continuous paging of output when there are more than 41 time poin to be printed; non-zero for discontinuous paging
IM	-	BELT, CONTAC	1	-	Impingement history index
IM	-	STASH	1	-	General index
IM	-	UPDATE	1	-	General index
IMAT	-	BC	6	52	Index of material properties for slipping belts
IMC	-	SUMRY	60	39	Plane-ellipsoid (see ITOT) number for plane (or ellipsoid) involved in an interaction
IN	-	BELT CONTAC	1	-	Interaction control index
IN	-	STASH SUMRY	1	-	Device number (9) for storage of results printed by SUMRY
IN	-	TITLE	3 3	- -	EBCD of printout part subtitle labels

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
IN	-	ZILTCH	1	-	General index
INAME	-	RSS, SUMRY	6 4	- 11	EBCD for belt names
INAMEZ	-	READAT	6 4	- 11	EBCD for column heading in case a belt is not present (belt name)
INF	-	BC	4 4	11 11	Influence belt connections
INFL	-	BC	1	-	Influence type for all belt pairs
INFLPR	-	BC	6 2	12 14	Belt number of jth member of ith belt pair, zero if inactive
INR	-	STASH	1	-	One to three for displacements, four to six for velocities
INS	-	STASH, SUMRY	1	-	Number of planes plus ellipsoids in excess of 24
INSERT	-	ENTAB, GETY, MOVTAB, PUSHER, SERTAB, SLOPE	1	-	Relative index of table entry at or just in front of where insertion is to be made
INT	-	STASH, SUMRY	1	-	Same as ITOT, or 24 if ITOT greater than 24
INTRAC	-	FEC	1	-	Seven times the number of interactions having occurred
INZ	-	LODFEL	1	-	Switch set non-zero if no established time history in STOACT
INZ		PMIL, PRED, UPDATE	1	-	Switch to recognize the first time through these routines afte loading to initialize constants
IOK	-	PEEK	20	-	Storage array for allowable characters for input card
IOUT	-	STASH, SUMRY	60	39	Beginning address in CONOUT for an interaction
IOVER	-	STASH	1	-	Argument which is non-zero cause by-passing of the normal print time test in order to record data for printing
IP	-	SUMRY	1	-	Zero for non-continuous paging if there are more than 41 time points; non-zero for continuous paging

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
IPAGE	-	TL	1	-	Printout page counter
IPAIR	-	READAT	6 2	12 14	Internally defined data statin belt pairings
IPC	-	EP	1	-	Inputted predictor-corrector selection switch
IPENG	-	CONTAC	1	-	Switch which records if an interaction produced force or was approached from behind
IPERM	-	ACCEL	24	-	Temporary storage required by SLE1
IPIK	-	MOVTAB	1	-	Pushdown ending index
IPN	-	SETACT	1	-	Switch set negative if plane approached from rear or positive if produced force
IPUT	-	ENTAB	1	-	Absolute index in STOR of entry at or just in front of where insertion is to be made.
IQ	-	JOINT	1	-	Appendage angle coordinate number
IR	-	BELT	1	-	Belt number of influencer
IREG	-	MAIN	18	-	Storage region for PSW information in case of processing interrupt
IREW	-	SUMRY	1	-	Switch to control inserting ending record on binary file
IRIG	-	SUMRY	1	-	EBCD for bbRI (rigid material)
IRIGID	-	STASH	4	-	EBCD for "Rigid Material"
IRK	-	EP	1	-	Inputted integration starting method selection switch
IS	-	CONTAC	1	-	Index for sphere (or ellipsoid)
IS	-	LF	6	48	Saturation switch array for EVAL Non-zero if saturation has taken place
ISA or ISAA	-	MANY	1 (or 14)	-	Number for identifying blocks of debug output
ISACT	-	SETACT	1	-	Beginning index of entry for interaction in STOACT
ISFT	-	MATCH	1	-	Index which contains proper offset to pick up name from various tables
ISIZE	-	PUSHER	1	-	Number of locations to be added to table
ISLPPR	-	BC	2 2	15 14	Belt number of jth member of ith pair of slipping belts

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
ISM	-	BELT	1	-	Control index for belt materi
ISM	-	CONTAC	1	-	Control index
ISOFT	-	STASH	1	-	The number of non-rigid participants of a force-producing interaction pair
ISP	-	LP	2	50	Last value of IS for this interaction
ISTAT	-	IT, SUMRY	1	-	Switch controlling units for outputted vehicle velocities and accelerations (W-card)
ISUM	-	DEBUG	1	-	General index
ISUM	-	STASH	6	-	Partial sum of ellipsoids on body segments through the ith
ISW	-	MATCH	1	-	Switch which is non-zero if inertial planes being dealt with
ISW	-	UPDATE	1	-	Switch set non-zero if working in second material region
IT	-	DEBUG	1	-	General index
IT	-	MAIN	1	-	Correction number index in the Adams-Moulton type of predictor corrector
IT	-	SUMRY	1	-	Non-zero if print time history has not been exhausted, for continuous paging of output groups
ITABL	-	SLOPE	1	-	Index of current input table
ITHRU	-	READAT	1	-	Similar to INZ but for READAT
ITITLE	-	TL	33	-	Inputted subtitle storage
ITOT	-	STASH, SUMRY	1	-	Number of planes plus ellipsoids
ITRY	-	ZILTCH	1	-	Count of number of read errors which occurred
IUPA	-	BELT, CONTAC	1	-	Control index for location of ISM
IUPB	-	BELT, CONTAC	1	-	Control index for location of IUPC AND IUPD
IUPC	-	BELT, CONTAC	1	-	Control index for slipping pairs
IUPD	-	BELT, CONTAC	1	-	Control index for slipping pairs
IUPE	-	BELT, CONTAC	1	-	Control index
IUPF	-	CONTAC	1	-	Control index

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
IUPG	-	CONTAC	1	-	Control Index
IUPH	-	CONTAC	1	-	Control Index
IUPI	-	CONTAC	1	-	Control Index
IUPM	-	CONTAC	1	-	Control Index
IUSEA	-	FEC	1	-	Number of locations in STOACT which are used
IUSEC	-	VX	1	-	Number of locations of CUR which are used
IUSEK	-	FEC	1	-	Number of locations in KCON which are used
IUSEKA	-	FEC	1	-	Number of locations in KACT which are used
IUSEM	-	FEC	1	-	Number of locations in STOMAT which are used
IUSEO	-	OUT	1	-	Number of locations in CONOUT which are used
IX	-	GETY, SLOPE	1	-	General index
IZ	-	ZILTCH	1	-	EBCD for 'Z'
J	-	DEBUG	2	-	Equivalenced to double precision table value to enable access to last 32 bits
J	j	MANY	1	-	General index
JA	-	DETAB	1	-	Table entry index for beginning of deletion interval
JA	-	LODFEL	1	-	Second material index corresponding to IIA
JB	-	DETAB	1	-	Table entry index for ending of deletion interval
JB	-	LODFEL	1	-	Second material index corresponding to IB
JC	-	LODFEL	1	-	Second material index corresponding to IC
JC	-	STASH, SUMRY	1	-	Maximum index used for a subdivision of a storage array for contact interaction values
JCHOP	-	JOINT	1	-	Indicator of relative pitch sign
JD	-	STASH, SUMRY	1	-	Similar to JC
JE	-	STASH, SUMRY	1	-	Similar to JC

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
JEL	-	SUMRY	1	-	Zero if ellipsoid-ellipsoid, one if plane-ellipsoid
JELL	-	STASH	60	39	Zero if contact interaction is ellipsoid-ellipsoid, one if ellipsoid-plane
JF	-	STASH, SUMRY	1	-	Similar to JC
JG	-	STASH, SUMRY	1	-	Similar to JC
JISWT	-	LODFEL	1	-	Depository for KISWT
JJ	-	LF	6	48	Operational index for inertial spike array for EVAL. Negative is table index. Otherwise is input polynomial index in STOMAT
JJ	-	MANY	1	-	General index
JJJ	-	CONTAC	1	-	General index
JJP	-	LP	2	50	Last value of JJ for this interaction
JKC	-	CONTAC	1	-	Control Index
JKC	-	SUMRY	1	-	Same as JMC
JKONT	-	SETACT	1	-	Number of Evaluations needed in STOACT for interaction
JMC	-	SUMRY	60	39	Plane-ellipsoid number (see ITOT) for ellipsoid involved in an interaction
JNZ	-	LODFEL	1	-	Switch non-zero if necessary to quarter interval to get started
JQ	-	JOINT	1	-	Torso angle coordinate number
JSM	-	CONTAC	1	-	Control Index
JUPA	-	CONTAC	1	-	Control Index
JUPB	-	CONTAC	1	-	Control Index
JUPC	-	CONTAC	1	-	Control Index
JUPD	-	CONTAC	1	-	Control Index
JUPE	-	CONTAC	1	-	Control Index
JUPF	-	CONTAC	1	-	Control Index
JUPG	-	CONTAC	1	-	Control Index
JUPH	-	CONTAC	1	-	Control Index
JX	-	CONTAC	2	25	Major axis indicator, one for x, two for y, three for z
K	-	JOINT	1	-	Joint number, 1 to 5 for neck, right hip, left hip, right knee, left knee
K	k	MANY	1	-	General Index

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
K	-	SUMRY	41 14	43 34	Same as KK in STASH
KA	-	SETACT	1	-	General Index
KACT	-	FEC	3472	-	Control indices for storage of interaction quantities in STOACT, CONOUT, and STOMAT
KASE	-	CONTAC	1	-	Switch indicating relative position of parallel ellipsoids
KB	-	SETACT	1	-	General Index
KBUG	-	BELT	1	-	Sum of debug switches for BELT debug
KC	-	STASH	1	-	Zero for ellipsoid, one for plane
KCHA	-	JOINT	1	-	General Index
KCHB	-	JOINT	1	-	General Index
KCHOP	-	JOINT	1	-	Indicator of relative yaw sign
KCON	-	FEC	835	-	Control indices for ellipsoids, contacts, belts and materials in STOMAT and within KCON
KELL	-	CONTAC	2	25	Control Index
KG	-	EVAL	1	-	Table index if G-factor from table
KI	-	CONTAC	1	-	Body segment index
KISWT	-	LODFEL	1	-	Vestigial
KJ	-	CONTAC	1	-	Body segment index
KK	-	CONTAC	1	-	General index
KK	-	STASH	14	34	Output vector for integration performance measures
KKA	-	UPDATE	1	-	General index
KKB	-	UPDATE	1	-	General index
KKK	-	CONTAC	1	-	Switch, one if sphere-sphere, two if sphere-ellipsoid, three if ellipsoid-ellipsoid
KKONT	-	SETACT	1	-	Number of locations needed in CONOUT
KNA	-	LODFEL	1	-	Beginning index in STOMAT if bot soft, of soft one if one soft, or zero if neither
KNA	-	SETACT	1	-	Beginning index of ellipsoid in STOMAT if both interacting ellipsoids (or ellipsoid and contact plane) are soft, of the soft one if only one, 0 if both rigid

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
KNB	-	LODFEL	1	-	Beginning index of contact or second ellipsoid if both soft otherwise zero
KNB	-	SETACT	1	-	Beginning index of contact or ellipsoid in STOMAT if both soft, 0 otherwise
KNTACC	-	CNT	1	-	Number of times ACCEL has been called
KNTDUB	-	CNT	1	-	Number of times convergence has been good enough to double the time step but other requirements were not met
KNTOT	-	CNT	1	-	Total number of time steps of all sizes
KONECT	-	JOINT	5 2	26 24	Digitized description of which segments each joint connects
KPW	-	JOINT	1	-	Indicates quadrant for relative pitch and the corresponding set of relative angles
KR	-	EVAL	1	-	Table index if R-factor from Table .
KSEG	-	CONTAC	2	25	Body segment number for ellipsoid
KSEG	-	STASH.	40	37	Body segment number for ellipsoid
KT	-	ENTER	1	-	General index
KTA	-	ENTER	1	-	General index
KTYPE	-	CONTAC	2	25	Ellipsoid type
L	1	MANY	1	-	General index
LA	-	DETAB	1	-	Lower copy down index limit for deletion
LA	-	LODFEL	1	-	STOACT index for second material corresponding to IACT
LA	-	SETACT	1	-	General index
LA	-	STASH	5 2 40	35 36 37	EBCD names and material names for planes and ellipsoids, and control indices
LAA	-	SUMRY	5 2 24	35 36 37	Part of LA (for the first 24 planes and ellipsoids

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
LAB	-	SUMRY	5 2 16	35 36 47	Part of LA (for planes and ellipsoids after the 24th)
LAALAB	-	SUMRY	40	37	LAA for the first 24 and LAB for the last 16
LADD	-	ENTAB	1	-	Period spacer index for new table
LAP	-	EVAL	1	-	Last value of IA
LAST	-	STASH	1	-	The number of equivalent full integration steps at the preceding call to STASH
LB	-	DETAB	1	-	Upper copy down index limit for deletion
LB	-	INTAB	1	-	General index
LB	-	SETACT	1	-	Absolute value of IKACT
LBD	-	ACCEL, CONTAC	1	-	Same as LDB
LC	-	SUMRY	1	-	Number of time point for a given page of output
LDB	-	IO	1	-	Output device number for debug printout
LDTPRT	-	LT	1	-	Integer equivalent of DTPRNT
LENACT	-	FEC	1	-	Length of STOACT, 6432
LENCUR	-	VX	1	-	Length of CUR, 1200
LENKAT	-	FEC	1	-	Length of KACT, 3472
LENKON	-	FEC	1	-	Length of KCON, 835
LENMAT	-	FEC	1	-	Length of STOMAT, 2258
LENOUT	-	OUT	1	-	Length of CONOUT, 690
LI	-	LODFEL	1	-	Ending index of time history of times for interaction
LIMENT	-	LD	1	-	Limit of number of iterations for balance in shared deflection
LIMENT	-	TAB	1	-	Maximum number of entries allowed for all deceleration tables (3000).
LIMTAB	-	TAB	1	-	Maximum number of input tables both deceleration and others (60).
LJ	-	LODFEL	1	-	Beginning index of time history of times for interaction

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
LK	-	LODFEL	1	-	KACT index for second material corresponding to IKACT
LKA	-	JOINT, UPDATE	1	-	General index
LKACT	-	LODFEL	1	-	Index of proper IALF entry in KACT time history entry for interaction
LKB	-	JOINT, UPDATE	1	-	General Index
LL	-	EVAL	1	-	Input material number index
LLX	-	LC	4 2	51 50	Last value of LLXX for this interaction
LLXX	-	LC	4 6	51 48	Current values of computed polynomial control switches
LM	-	INTAB	1	-	Absolute index of slope in STOR
LOOK	-	PEEK	80	-	Storage array for first look at a new card in 80A1 format
LQ	-	JOINT	1	-	General index
LTDCUR	-	LT	1	-	Integer equivalent of TDCUR
LTIME	-	LT	1	-	Integer equivalent of T
LTPRNT	-	LT	1	-	Integer equivalent of TPRINT
LU	-	JOINT	1	-	General index
LX	-	LODFEL	1	-	Index of matched time just prior to current time in STOACT time history
LY	-	INTAB	1	-	Absolute index of ordinate in STOR
LZ	-	LODFEL	1	-	Index of STOACT entry for second material in time history
LZKACT	-	LODFEL	1	-	Index of KACT entry for second matiral in time history
M	m	MANY	1	-	General index
MA	-	SETACT	1	-	Absolute value of IA
MASK	-	DEBUG	16	-	Two bit masks for extracting each switch value from the total control word
MAXCON	-	STASH	1	-	Number of locations in CONOUT which are used
MAXTDC	-	LT	1	-	Integer equivalent of DELTAT
MAXTIM	-	LT	1	-	Integer equivalent of TMAX
MB	-	GETY	1	-	Absolute index of slope in STOR
MB	-	SETACT	1	-	Absolute Value of IB
MBELT	-	TL	1	-	Non-zero if force-strain relationship is used for belts instead of force deflection.

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
MC	-	STASH, SUMRY	1	-	Interaction number
ME	-	STASH	1	-	Beginning index in KCON for ellipsoids on a particular body segment
MIKC	-	STASH, SUMRY	60	39	Beginning address in KCON for ellipsoid in force-producing interaction
MILL	-	CNT	1	msec	Total CPU time of execution so far
MJKC	-	STASH, SUMRY	60	39	Beginning address in KCON for plane or ellipsoid in force producing interaction
MKA	-	UPDATE	1	-	General index
MKB	-	UPDATE	1	-	General index
ML	-	CONTAC	1	-	General index
MLIM	N_{max}	EP	1	-	Inputted maximum number of halvings which will be permitted
MM	-	CONTAC, GETY, SUMRY	1	-	General index
MN	-	CONTAC	1	-	General index
MNAME	-	RSS, SUMRY	4 4	- 11	EBCD for belt material names
MNAME2	-	READAT	4 4	- 11	EBCD for column heading in case belt is not present (belt material)
MOVE	-	UPDATE	1	-	General index
MSTOR	-	TAB	60 5	44 45	Input table information
MT	-	CONTRL, CORK, MAIN, PRED	1	-	Number of estimated points in time history
MX	-	EP	1	msec	Inputted CPU execution time limit
N	n	MANY	1	-	General index
N	-	RELTIV	1	-	Zero if relative velocities are not to be determined
N	-	SUMRY	1	-	Same as NNN in STASH
NA	-	EVAL	1	-	Current value of II

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
NA	-	JOINT	1	-	General Index
NADD	-	MOVTAB	1	-	Index which contains proper number locations for adding one new entry
NAM	-	FINDM, MATCH	4	-	EBCD storage array for 16 character name in 4A4 format
NAMES	-	READAT	8	-	EBCD ellipsoid, contact, or material names
NB	-	DETAB, ENTAB, GETY, INTAB, MOVTAB, SERTAB, SLOPE	1	-	Beginning address in STOR for table NTAB
NB	-	EVAL	1	-	Current value of JJ
NCOUNT	-	LODFEL	1	-	Total number of evaluations
NE	-	INTAB, SERTAB.	1	-	General index
NE	-	STASH	1	-	General index
NELL	-	STASH	1	-	Total number of body ellipsoids (or spheres)
NEND	-	ENTAB	1	-	Temporary value of last index used in STOR
NEWT	-	MOVTAB	1	-	New value of NUMENT after one new entry added to table
NID	-	IO	1	-	Input device number
NIX	-	EVAL	1	-	Return control index from force evaluation section
NKA	-	UPDATE	1	-	General index
NKB	-	UPDATE	1	-	General index
NL	-	CONTAC	1	-	General index
NM	-	CONTAC, INTAB, MOVTAB	1	-	General index
NN	-	CONTAC	1	-	General index
NN	-	ENTAB	1	-	Input table number
NN	-	STASH, SUMRY	1	-	Number of force-producing interaction combinations
NNB	-	INTAB	1	-	General index
NNN	-	STASH	1	-	Similar to JC
NOD	-	IO	1	-	Standard output device number
NPLANE	-	STASH	1	-	Total number of contact planes

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
NPNT	-	INTAB	1	-	Pointer index at current X in scanning, flagged negative if table needs reordering
NPOINT	-	SERTAB	1	-	Index of pointer for current place in table scan
NQR	-	CONTAC	17 2	42 24	Internally supplied data used by ellipsoid-ellipsoid logic
NR	-	STASH	6 9	17 41	Indices of displacement and velocity elements of the DYN vector
NS	-	MOVTAB	1	-	Index of slope at point of insertion
NSC	-	ENTAB	1	-	Input table scan switch
NSCAN	-	ENTAB, DETAB, GETY, MOVTAB, SERTAB	1	-	Input table switch. Only types used are piecewise-linear and piecewise constant
NSWT	-	STASH, SUMRY	1	-	Similar to JC
NTAB	-	DETAB, ENTAB, GETY, MOVTAB, SERTAB, SLOPE	1	-	Index of current input table
NTOP	-	MOVTAB	1	-	Index of last location to be moved in current push down loop
NTOT	-	DETAB, ENTAB, GETY, INTAB, MOVTAB, SERTAB, SLOPE	1	-	Number of points in table NTAB
NUMC	-	PEEK, READAT	1	-	Number of input card
NUMCON	-	READAT, SUMRY	1	-	Contact plane number
NUMENT	-	TAB	1	-	Number of table entries in STOR
NUMTAB	-	TAB	1	-	Number of tables in MSTOR

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
NX	-	MOVTAB	1	-	Index of X at point of inserti
NY	-	MOVTAB	1	-	Index of Y at point of inserti
OG	ω	LF	6	48	Permanent deformation array fo EVAL. Units are inches
OGP	ω	LP	2	50	Last value of OG for this interaction
OR	-	JV	5 3	26 28	Relative Euler angles from preceding time point.
P	p_{ij}	KC	12	8	Body segment center of gravity to joint distance
PC	-	JOINT	1	-	Sign factor for relative pitch cosine
PCV	-	XX	17	3	Difference between predicted and corrected velocities
PCX	-	XX	17	3	Difference between predicted and corrected generalized coordinates
PDA	-	JOINT	3 6	16 27	Joint lever arms
PDB	-	BELT	4 6	11 20	Belt lever arms (direction cosines)
PE	-	STASH	5 3	26 28	Joint potential energies
PERCNT	p_{ij}	BC	4 4	11 11	Positive or negative percentage of influencer force i to be added to influencee force j (for belts)
PERD	-	ENTAB	1	sec	Vestigial, period of a periodic table
PETA	η_{ij}	JC	2 5	29 26	Upper and lower stop limits
PI	π	MC	1	-	Value of π
PITWO	$\pi/2$	MC	1	-	Value of $\pi/2$
PPX	-	STASH	1	-	i component of total linear momentum
PV	$\dot{p}_{k,1}$	XX	17	3	Predicted generalized velocities
PX	-	LF	10 6	49 48	Computed polynomial array for EVAL
PX	$p_{k,1}$	XX	17	3	Predicted generalized coordinates
PY	-	STASH	1	-	j component of total linear momentum

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
PZ	-	STASH	1	-	k-component of total linear momentum
Q	q_k	QQ	3 17	19 3	Generalized coordinates, velocities, and accelerations
Q1	-	ACCEL, STASH	1	-	Temporary storage
Q2	-	ACCEL, STASH	1	-	Temporary storage
Q3	-	ACCEL, STASH	1	-	Temporary storage
QA	$\ddot{q}_k$	ACCEL	17	3	Generalized acceleration values before possible editing (see EDEPS)
QQ	-	ACCEL	1	-	Temporary storage
QI	-	READAT	2 17	19 3	Body initial conditions
R	-	QV	3 3 7	- - 18	Rotation matrix elements
R14	-	QV	7	18	Trigonometric combination
R15	-	QV	7	18	Trigonometric combination
R16	-	QV	7	18	Trigonometric combination
R17	-	QV	7	18	Trigonometric combination
R24	-	QV	7	18	Trigonometric combination
R25	-	QV	7	18	Trigonometric combination
R26	-	QV	7	18	Trigonometric combination
R27	-	QV	7	18	Trigonometric combination
RE	-	CONTAC	2	25	Radius for contact sphere associated with ellipsoid
RFAC	R	CONTAC	1	-	Contact surface edge effect factor
RFSAT	-	BC	4 4	11 11	Magnitude of maximum allowed difference between force i and force j for belt influences
RI	R	LC	2	50	Fraction of conserved energy over total energy for current loading cycle
RKE	-	STASH	6	18	Rotational kinetic energy for body segments
ROLLJ	-	JOINT	1	-	Torso roll angle
RNM11	-	JOINT	1	-	Direction cosine with respect to torso
RNM12	-	JOINT	1	-	Direction cosine with respect to torso

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
RNM13	-	JOINT	1	-	Direction cosine with respect to torso
RNM21	-	JOINT	1	-	Direction cosine with respect to torso
RNM23	-	JOINT	1	-	Direction cosine with respect to torso
RNM31	-	JOINT	1	-	Direction cosine with respect to torso
RNM33	-	JOINT	1	-	Direction cosine with respect to torso
RPD	-	MC	1	-	Value of $\pi/180$
S	-	QV	3 7	6 18	Sines of generalized angles
SAVE	-	MAIN	17	3	Temporary storage for first attempt with Runge-Kutta
SFAC	S	CONTAC	1	-	Contact surface edge effect factor
SGF	-	EVAL	1	lbs.	Force at SOG
SJ	-	JV	5 3	26 28	Joint stop moment
SLOPE	-	SLOPE	1	-	Calculated slope for abscissa X for table NTAB
SM	-	EVAL	1	lbs/in.	Force slope at SOG
SOG	-	EVAL	1	in.	Last unloading deflection before reloading
SS	S_{ijn}	ACCEL, STASH	3 3 6	- - 18	The part of $\ddot{R}$ - elements containing no generalized acceleration factors
STEPS	-	STASH SUMRY	1	-	Ratio of print time interval to maximum integration step sine
STOACT	-	FEC	6432	-	Time histories for force-producing interactions
STOMAT	-	FEC	2258	-	Ellipsoid, contact plane, bel and material constants and kinematics
STOP	S_{x_i}	JC	5 3	26 28	Joint stop coefficients
STOR	-	TAB	3000	-	Storage for input table time points
STP	-	JC	5	26	Upper pitch stop coefficient
SUM	-	BELT, CONTAC	11	-	Temporary storage

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
SUMRKE	-	STASH	1	-	Total rotational kinetic energy
SUMTKE	-	STASH	1	-	Total translational kinetic energy
T	t	T	1	sec	Simulated time
TBAR	-	CONTAC	2	25	Position parameter for migrating sphere
TBBAR	-	CONTAC	2	25	Parameters for evaluation of TBAR for parallel ellipsoids
TDCUR	Δt	T	1	sec.	Current integration time step
TINEST	-	LT	1	-	Smallest possible time step under integration scheme
TKE	-	STASH	6	18	Translational kinetic energy for body masses
TM	t	LF	6	48	Current time array for EVAL. Units are seconds
TMAX	T_{max}	TT	1	sec.	Program run simulated time duration
TMP	t	LP	2	50	Last value of TM for this interaction
TN	-	UPDATE	1	sec.	Current time recorded in STOACT entry
TNEXT	-	SUMRY	1	-	Value of time for the first new record of the next page of continuously paged output; negative if none
TOG	ω'	EVAL	1	in.	Permanent deformation computed from saturation unloading
TOTLKE	-	STASH	1	-	Total kinetic energy
TOTLX	-	STASH	1	-	i component of total angular momentum
TOTLY	-	STASH	1	-	j component of total angular momentum
TOTLZ	-	STASH	1	-	k component of total angular momentum
TPC	-	IT	1	-	Fraction of next time segment during which the contact surface corner point velocity is to be linearized
TPRINT	-	TT	1	sec	Computed next print time
TQ	-	CARTIN, READAT	1	sec^2	Factor used in vehicle integration
TS	-	LIMIT	1	-	Temporary storage

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
TR	-	QV	8 7	- 18	Trigonometric combination
TS	-	BELT	6	17	Inertial components and rates of change of cart origin-to-torso CG vector
TSA	-	MANY	1	-	Temporary storage
TSB	-	MANY	1	-	Temporary storage
TSC	-	MANY	1	-	Temporary storage
TSD	-	CONTAC, BELT	1	-	Temporary storage
TSE	-	CONTAC	1	-	Temporary storage
TSF	-	CONTAC	1	-	Temporary storage
TSG	-	CONTAC	1	-	Temporary storage
TSH	-	CONTAC	1	-	Temporary storage
TSI	-	CONTAC	1	-	Temporary storage
TSN	-	CONTAC	1	-	Temporary storage
TSP	-	CONTAC	1	-	Temporary storage
TSQ	-	CONTAC	1	-	Temporary storage
TSR	-	CONTAC	1	-	Temporary storage
TSS	-	CONTAC	1	-	Temporary storage
TSXZ	-	CONTAC	1	in.	Factor in contact calculations
TSYZ	-	CONTAC	1	in.	Factor in contact calculations
TSZ	-	LIMIT	1	-	The maximum of the weighted average of CATC and CATD's
TSZZ	-	CONTAC	1	in.	Factor in contact calculations
TT	-	CARTIN	1	sec.	Time on current deceleration table segment
TT	-	XX	10	38	Time history time storage
TTT	-	READAT	1	sec.	Length of current deceleration table segment
U	u_{in}	ACCEL	3 6	10 18	The parts of $\dot{\alpha}$'s containing no generalized acceleration factors
VALUE	-	SERTAB	1	-	Abscissa of input table
VI	-	READAT	2 6	19 20	Vehicle initial conditions
VX	-	STASH	1	-	Contribution to i component o total angular momentum from linear velocities
VY	-	STASH	1	-	Similar to VX for j component
VZ	-	STASH	1	-	Similar to VX for k component

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
W	w_{in}	ACCEL, STASH	3 6	10 18	The part of body segment linear accelerations containing no generalized acceleration factor
WGT	$\bar{\mu}_k$	EP	17	3	Weighting factors
WS	X	CONTAC	1	-	X-coordinate of special contact surface system, see Equation 52
WT	Y	CONTAC, SLOPE, SERTAB	1	-	Y-coordinate of special contact surface system, see Equation 52
WX	-	STASH	1	-	Contribution to i component of total angular momentum from angular velocities
WY	-	STASH	1	-	Similar to WX, for j component
WXYZ	-	STASH	3	10	Inertial components of angular velocity vector
X	-	ENTAB, GETY	1	sec.	Abscissa of input table
X	-	QV	3 6	10 18	Body segment CG coordinates
XA	-	RELTIV, STASH	6	17	Inertial coordinates and velocities returned by RELTIV as relative quantities
XA	-	DETAB, SERTAB	1	sec.	Lower endpoint of time range for deletion or search
XB	-	DETAB, SERTAB	1	sec.	Upper endpoint of time range for deletion or search
XAA	-	DETAB	1	-	Either endpoint of time range to be deleted (with XBB, defines a closed interval)
XBB	-	DETAB	1	-	Either endpoint of time range to be deleted (with XAA, defines a closed interval)
XC	-	RELTIV, STASH	6	17	Inertial coordinates and velocities for cart origin or time-zero H-point in cart
XDDC	-	CONTAC	1	-	Vehicle contribution to x-component of tangential velocity
XDEL	-	CONTAC	1	-	Ellipsoid-ellipsoid deformation
XDMC	-	CONTAC	3	-	Intermediate results in computing XDDC
XDOT	-	CONTAC	1	in/sec.	Time derivative of WS

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
XE	-	CONTAC	3 2	10 25	Inertial coordinates of ellipsoid center
XEM	x_{em}	CONTAC	1	-	X-coordinate of ellipsoid center in body segment system
XHAT	-	CONTAC	9	1	Contact surface corner point coordinates
XLAM	-	CONTAC	3 2	10 25	Direction numbers of semi-major axis
XL	-	CONTAC	2	25	Distance along semi-major axis between ellipsoid center and migrating sphere center
XX	r_n	BELT	4	11	Inertial X-coordinates of belt attachments and anchors
XX	-	GETY, ENTAB, SLOPE	1	sec.	Abscissa of input table
XXX	-	XX	10 17 3	38 3 19	Time history of body kinematics
XYDDS	-	CONTAC	1	-	Factor in contact surface contribution to components of tangential velocity
XZ	x_o	CONTAC	1	in.	X-coordinate of actual contact point
XZA	-	CONTAC	1	in.	X-coordinate of first possible contact point
XZB	-	CONTAC	1	in.	X-coordinate of second possible contact point
Y	-	DEBUG, ENTAB. GETY	1	-	Ordinate of input table
YY	s_n	BELT	4	11	Inertial Y-coordinates of belt attachments and anchors
YDDC	-	CONTAC	1	-	Vehicle contribution to y-component of tangential velocity
YDMC	-	CONTAC	3	-	Intermediate results in computing YDDC
YDOT	-	CONTAC	1	in/sec.	Time derivatives of WT
YEM	y_{em}	CONTAC	1	-	Y-coordinate of ellipsoid center in body segment system
YZ	y_o	CONTAC	1	in.	Y-coordinate of actual contact point
YZA	-	CONTAC	1	in.	Y-coordinate of first possible contact point
YZB	-	CONTAC	1	in.	Y-coordinate of second possible contact point

TABLE 37. SYMBOL DICTIONARY

Fortran Name	Symbol	Subprogram or Common	Dimension	Units or Subscript Reference	Definition
ZEM	z_{em}	CONTAC	1	-	Z-coordinate of ellipsoid center in body segment system
ZERA	-	IT	1	rad.	Inputted proximity epsilon for nearness to pole at π/2 for pitch
ZERB	-	IT	1	rad.	Inputted proximity epsilon for sine of pitch near pole at π/2
ZINFL	ζ	Z	1	-	Input factor which modifies adjustment to influencee force for belt friction (INFL=1); default = 0.
ZZ	t_n	BELT	4	11	Inertial Z-coordinates of belt attachments and anchors
ZZ	z_o	CONTAC	1	in.	Z-coordinate of actual contact point
ZZA	-	CONTAC	1	in.	Z-coordinate of first possible contact point
ZZB	-	CONTAC	1	in.	Z-coordinate of second possible contact point

TABLE 38. SYMBOL AND FORTRAN NAME CORRESPONDENCE

Symbol	Fortran Name	Symbol	Fortran Name	Symbol	Fortran Name	Symbol	Fortran Name
a^2	A2	N	FN	X	WS	Δx_{nm}	AGL,OA
b^2	B2	N_{max}	MLIM	y_{em}	YEM	$(\Delta x_{nm})_r$	EREST
c	DAMPJ	p_{ij}	PERCNT	y_o	YZ	Δx_{nm}	DD
c^2	c2	$P_{k,1}$	PX	$\hat{y}_n$	BYA	ε	EPS
c_i	c	$\dot{P}_{k,1}$	PV	Y	WT	ε_t	DTMIN
E	E,EP	q_k	Q	z_{em}	ZEM	ε_v	EPZV
E_{x_i}	ELAS	$\vec{Q}$	B	z_o	ZZ	$\varepsilon_{\ddot{z}}$	EDEPS
F	FD,FORCE	$\vec{Q}_B$	BR	$\hat{z}_n$	BZA	η_{ij}	ETA,PETA
F'	FDD,FDEV	$\vec{Q}_c$	BS	β	DM	λ	BC27,FAC
$\vec{F}_i$	FB	$\vec{Q}_G$	BG	δ	ETA,D, DEL,DP	λ_n	BA1
F_{max}	FM	$\vec{Q}_J$	BJ	$\dot{\delta}$	DD,DDP, ETAD	μ_k	BMUK
$F_{s,\nu}$	AFSAT	$\vec{Q}_T$	BT	δ_A	DA	$\bar{\mu}_k$	WGT
$F(\Omega)$	FOG,FBOGP	r_n	XX	δ_B	DB	μ_n	BA2
$F'(\Omega)$	FOG,F$\overline{\text{O}}$GP	R	ARE,RFAC, RI	δ_c	DC	μ_s	BMUS
g	ESG,GRAV	s_n	YY	δ_D	DE	ν_n	BA3
G	GEE,GI	S	SFAC	δ_F	DF	π	PI PITWO
i	I	S_{ijn}	SS	δ_n	DELB	ρ_{ij}	P
$I_{\hat{i}n}$	EI	S_{x_i}	STOP	$\dot{\delta}_n$	DELD	ω	OG,OGP
j	J	t	T,TM,TMP	$\Delta t\ddot{K}_{k,1}$	AF	ω'	TOG
k	FK,K	t_n	ZZ	$\Delta t\ddot{K}_{k,2}$	BK	Ω	BOG,BOGP
l	L	T_{max}	TMAX	$\Delta t\ddot{K}_{K,3}$	CK		
$l_{n(t)}$	BL	u_{l_n}	U	$\Delta t\ddot{K}_{k,4}$	DF		
$l_{n(o)}$	BLZ	w_{in}	W	Δ_t	TDCUR, DELTIM		
m	EMAT,M	x_{em}	XEM	Δt_{max}	DELTAT		
m_i	EM	x_o	XZ	Δt_{prnt}	DTPRNT		
n	N	$\hat{x}_n$	BXA	Δv_{lim}	EPZA		

TABLE 39. SUBSCRIPT REFERENCE EXPLANATIONS

SUBSCRIPT REFERENCE NUMBER	SUBSCRIPT VALUES	SUBSCRIPT EXPLANATION	UNITS	SYMBOL
1	1	X-coordinate of first corner point of contact surface.	in.	$\hat{x}_1$
	2	Y-coordinate of first corner point of contact surface	in.	$\hat{y}_1$
	3	Z-coordinate of first corner point	in.	$\hat{z}_1$
	4	X-coordinate of one adjacent corner point.	in.	$\hat{x}_2$
	5	Y-coordinate of one adjacent corner point.	in.	$\hat{y}_2$
	6	Z-coordinate of one adjacent corner point.	in.	$\hat{z}_2$
	7	X-coordinate of other adjacent corner point.	in.	$\hat{x}_3$
	8	Y-coordinate of other adjacent corner point.	in.	$\hat{y}_3$
	9	Z-coordinate of other adjacent corner point.	in.	$\hat{z}_3$
	10	Time at which contact surface assumes this position. If the dimension is nine, this one is omitted.	sec.	t'
2	1	For projected angle with inertial i	-	-
	2	For projected angle with inertial j	-	-
	3	For projected angle with inertial k	-	-
3	1	Inertial X-coordinate for torso center of gravity.	in.or lb.	x_1
	2	Inertial Y-coordinate for torso center of gravity	in. or lb.	y_1
	3	Inertial Z-coordinate for torso center of gravity.	in. or lb.	z_1
	4	Inertial torso yaw angle.	rad or in.lb	ψ_1
	5	Inertial torso pitch angle.	rad or in.lb	θ_1
	6	Inertial torso roll angle.	rad or in.lb	ϕ_1
	7	Inertial head yaw angle.	rad or in.lb	ψ_2
	8	Inertial head pitch angle.	rad or in.lb	θ_2
	9	Inertial head roll angle.	rad or in.lb	ϕ_2
	10	Inertial right upper leg yaw angle.	rad or in.lb	ψ_3
	11	Inertial right upper leg pitch angle.	rad or in.lb	θ_3
	12	Inertial right upper leg roll angle.	rad or in.lb	ϕ_3
	13	Inertial left upper leg yaw angle.	rad or in.lb	ψ_4
	14	Inertial left upper leg pitch angle.	rad or in.lb	θ_4
	15	Inertial left upper leg roll angle.	rad or in.lb	ϕ_4
	16	Right knee relative ptich angle	rad or in.lb	θ_5
	17	Left knee relative ptich angle	rad or in.lb	θ_6

TABLE 39. SUBSCRIPT REFERENCE EXPLANATIONS

SUBSCRIPT REFERENCE NUMBER	SUBSCRIPT VALUES	SUBSCRIPT EXPLANATION	UNITS	SYMBOL
4	1-9	Elements of R(3,3), by columns	-	-
5	1	Partial with respect to pertinent ψ	-	-
	2	Partial with respect to pertinent θ	-	-
	3	Partial with respect to pertinent ϕ	-	-
	4	Time derivative	-	-
6	1	Yaw	-	-
	2	Pitch	-	-
	3	Roll	-	-
7	1	Partial with respect to θ_5	-	-
	2	Partial with respect to θ_6	-	-
8	1	Torso center of gravity to neck	in.	ρ_{1N}
	2	Head center of gravity to neck	in.	ρ_{2N}
	3	Right upper leg center of gravity to right hip.	in.	ρ_{H3}
	4	Left upper leg center of gravity to left hip.	in.	ρ_{H4}
	5	Right lower leg center of gravity to right knee.	in.	ρ_{K5}
	6	Left lower leg center of gravity to left knee.	in.	ρ_{K6}
	7	Right upper leg center of gravity to right knee.	in.	ρ_{3K}
	8	Left upper leg center of gravity to left knee	in.	ρ_{4K}
	9	Hip to knee	in.	ρ_{HK}
	10	Hip to knee	in.	ρ_{HK}
	11	Torso center of gravity to pelvis (H-point)	in.	ρ_{1P}
	12	Pelvis to either hip	in.	ρ_{PH}
9	1	Attachment point	-	-
	2	Anchor point	-	-
10	1	x,i-direction	-	-
	2	y,j-direction	-	-
	3	z,k-direction	-	-
11	1-4	Belt number	-	-
12	1	Belts 1 and 2	-	-
	2	Belts 1 and 3	-	-
	3	Belts 1 and 4	-	-
	4	Belts 2 and 3	-	-
	5	Belts 2 and 4	-	-
	6	Belts 3 and 4	-	-

TABLE 39. SUBSCRIPT REFERENCE EXPLANATIONS

SUBSCRIPT REFERENCE NUMBER	SUBSCRIPT VALUES	SUBSCRIPT EXPLANATION	UNITS	SYMBOL
13	1	Coefficient rates of surface relative to vehicle.	in.^{2}/sec	$\dot{p}$
	2	Coefficient rates of surface relative to vehicle.	in.^{2}/sec	$\dot{q}$
	3	Coefficient rates of surface relative to vehicle.	in.^{2}/sec	$\dot{r}$
	4	Coefficients of surface relative to vehicle.	in.^{2}	p
	5	Coefficients of surface relative to vehicle	in.^{2}	q
	6	Coefficients of surface relative to vehicle.	in.^{2}	r
	7	Coefficients of surface relative to vehichle.	in.^{3}	s
	8	Coefficients of surface relative to inertial space.	in.^{2}	A
	9	Coefficients of surface relative to inertial space.	in.^{2}	B
	10	Coefficients of surface relative to inertial space.	in.^{2}	C
	11	Coefficients of surface relative to inertial space.	in.^{3}	D
	12	Direction factor	-	-
	13	Coefficient rates of surface relative to vehicle.	in.^{3}/sec	s
	14	These are intermediate results	in.^{5}	-
	15-17	These are intermediate results.	in.^{3}	-
	18	These are intermediate results.	in.^{4}	-
	19-21	These are intermediate results.	in.^{3}	-
	22-23	Surface side lengths.	in.	-
	24-29	Combinations of (8,9,10) taken in pairs.	in.^{4}	-
	30	Square of (31).	in.^{4}	-
	31	Normalizing factor.	in.^{2}	-
14	1	First member of belt pair	-	-
	2	Second member of belt pair	-	-
15	1	Any of six belt pairs (see subscript reference 12)	-	-
	2	The pair of belts not included in the pair.	-	-
16	1	Torso yaw direction.	-	-
	2	Torso pitch direction	-	-
	3	Torso roll direction.	-	-
17	1	x-coordinate.	in.	-
	2	y-coordinate.	in.	-
	3	z-coordinate.	in.	-
	4-6	Time rates of change of x,y,z	in./sec	-

TABLE 39. SUBSCRIPT REFERENCE EXPLANATIONS

SUBSCRIPT REFERENCE NUMBER	SUBSCRIPT VALUES	SUBSCRIPT EXPLANATION	UNITS	SYMBOL
18	1	Torso	-	-
	2	Head	-	-
	3	Right upper leg	-	-
	4	Left upper leg	-	-
	5	Right lower leg	-	-
	6	Left lower leg	-	-
	7	Vehicle	-	-
19	1	Coordinate	-	-
	2	Velocity	-/sec	-
	3	Acceleration	-/sec^2	-
20	1	x-direction	in.	-
	2	y-direction	in.	-
	3	z-direction	in.	-
	4	Yaw	rad	-
	5	Pitch	rad	-
	6	Roll	rad	-
21	1	For plane containing influencer belt anchor point.	-	-
	2	For plane containing influencee belt anchor point.	-	-
22	1-5	Ellipsoid friction class.	-	-
23	1-10	Plane friction class	-	-
24	1	Neck or hip joint.	-	-
	2	Knee joint	-	-
25	1	First of ellipsoid-ellipsoid interaction pair.	-	-
	2	Second of ellipsoid-ellipsoid interaction pair.	-	-
26	1	Neck joint	-	-
	2	Right hip joint	-	-
	3	Left hip joint	-	-
	4	Right knee	-	-
	5	Left knee	-	-
27	1-3	Partials with respect to ψ_1, θ_1, ϕ_1	-	-
	4-6	Partials with respect to ψ, θ, ϕ of appendage	-	-
28	1	Relative yaw	-	-
	2	Relative pitch	-	-
	3	Relative roll	-	-
29	1	Upper stop	-	-
	2	Lower stop		-
30	1	Stop limit 1	-	η_1
	2	Stop limit 3	-	η_3
	3-12	Stop limits 5-14	-	$\eta_5 - \eta_{14}$
31	1	Relative pitch inside range $(-\frac{\pi}{2}, \frac{\pi}{2})$	-	-
	2	Relative pitch outside range $(-\frac{\pi}{2}, \frac{\pi}{2})$	-	-
32	1	i moment of inertia	-	-
	2	j moment of inertia	-	-
	3	k moment of inertia	-	-
	4	Mass		

TABLE 39. SUBSCRIPT REFERENCE EXPLANATIONS

SUBSCRIPT REFERENCE NUMBER	SUBSCRIPT VALUES	SUBSCRIPT EXPLANATION	UNITS	SYMBOL
33	1	Yaw stop location	rad.	η_1
	2	Positive pitch stop location with zero yaw	rad.	η_2
	3	Positive pitch stop location in the presence of full yaw	rad.	η_3
	4	Negative pitch stop location with zero yaw	rad.	η_4
	5	Negative pitch stop location in the presence of full yaw	rad.	η_5
	6	Positive roll stop in the presence of zero yaw and full positive pitch	rad.	η_6
	7	Pure roll stop	rad.	η_7
	8	Positive roll stop in the presence of zero yaw and full negative pitch	rad.	η_8
	9	Positive roll stop in the presence of full yaw and zero pitch	rad.	η_9
	10	Negative roll stop in the presence of full yaw and zero pitch	rad.	η_{10}
	11	Positive roll stop in the presence of full yaw and positive pitch	rad.	η_{11}
	12	Negative roll stop in the presence of full yaw and positive pitch	rad.	η_{12}
	13	Positive roll stop in the presence of full yaw and negative pitch	rad.	η_{13}
	14	Negative roll stop in the presence of full yaw and negative pitch	rad.	η_{14}
34	1	CPU time	sec	-
	2	Number of calls to ACCEL	-	-
	3	Number of successful integration time steps since the preceding print time	-	-
	4	Number of successful integration time steps	-	-
	5-14	Number of successful integration time steps at each level of halving	-	-
35	1	Beginning index in KCON if second index is 1; KC if second index is 2	-	-
	2-4	Plane or ellipsoid name if second index is 1; corresponding material name if second index is 2	-	-
36	1,2	See subscript reference 35	-	-
37	1-40	Plane-ellipsoid number, less than or equal to ITOT, with planes first, then ellipsoids	-	-
38	1-10	One for each of the established sets of body kinematics stored backward in time	-	-

TABLE 39. SUBSCRIPT REFERENCE EXPLANATIONS

SUBSCRIPT REFERENCE NUMBER	SUBSCRIPT VALUES	SUBSCRIPT EXPLANATION	UNITS	SYMBOL
39	1-60	Number of different force producing interactions occurring in the course of the integration	-	-
40	1-20	Number of contact planes(limited to 20 only for plane description in output page headings; see IDESCR)	-	-
41	1	Head linears to be put into relative coordinates	-	-
	2	Torso linears	-	-
	3	Right upper leg linears	-	-
	4	Left upper leg linears	-	-
	5	Right lower leg linears	-	-
	6	Left lower leg linears	-	-
	7	Right knee and foot positions	-	-
	8	Left knee and foot positions	-	-
	9	H-point position	-	-
42	1-17	One for each lever arm	-	-
	18	Deflection rate	-/sec	δ
43	1	First time point on a page of output, either a repeated time point from the preceding page or time equal zero	-	-
	2-41	Time point number on a page of output	-	-
44	1-6	See subscript Reference 20	in/sec^2	σ_k
	7	Debug hexadecimal control word	-	-
	8-60	Material tables as needed	lbs/in. or none	-
45	1	Number of points in table	-	-
	2	Beginning line in STOR	-	-
	3	Scan type switch	-	-
	4	Pointer at address of current x; negative if changes in table	-	-
	5	Beginning line in CUR or 0	-	-
46	1-24	Refer to LAA, LAB, and Subscript Reference Number 37	-	-
47	1-16	Refer to LAA, LAB, and subscript Reference Number 37	-	-
48	1	First evaluation of quantity for first material	-	-
	2	Second evaluation of quantity for first material	-	-
	3	Third evaluation of quantity for first material	-	-
	4	First evaluation of quantity for second material	-	-
	5	Second evaluation of quantity for second material	-	-
	6	Third evaluation of quantity for second material	-	-

TABLE 39. SUBSCRIPT REFERENCE EXPLANATIONS

SUBSCRIPT REFERENCE NUMBER	SUBSCRIPT VALUES	SUBSCRIPT EXPLANATION	UNITS	SYMBOL
49	1	Zeroth order coefficient of computed unloading or reloading polynomial in deflection	pounds	-
	2-4	First through third order coefficient of same polynomial	#/in., etc.	-
	5	Vestigial	-	-
	6	Deflection at which to use the following secondary computed unloading or reloading polynomial on deflection	inches	-
	7-10	Zeroth through third order coefficients of scondary computed coefficient	#, #/in. etc.	-
50	1	Last value of quantity for first material	-	-
	2	Last value of quantity for second material	-	-
51	1	Switch which is non-zero if secondary computed polynomial is to be considered for use	-	-
	2	Value of II for last loading portion	-	-
	3	Value of JJ for last loading portion	-	-
	4	+2 = regular unloading +1 = partially initialized unloading 0 = first loading -1 = partially initialized reloading -2 = regular reloading	-	-
52	1	Beginning index of material properties for slipping pair one	-	-
	2	Beginning index of material properties for slipping pair two	-	-
	3-6	Beginning index of material properties for "soft" body, i.e., shared deflection for belts one through four respectively	-	-

PHYSICAL FACILITIES

The Computing Center building is located at 1075 Beal Avenue on North Campus (immediately south of the IST Building). The main entrance is on the north side of the building; it provides direct access to the <u>second floor</u>. Two additional public entrances are located on the east side of the building; these entrances are at the <u>first floor</u> level. A large parking lot at the corner of Beal and Glacier Way has one area reserved for staff paid parking and another area that is unrestricted.

The following is a description of various areas and services of the Computing Center which are available to the authorized users of the equipment:

Business Office (Room 3204)

All questions dealing with the authorization for the use of the computer and the financial accounting procedures related to its use are handled in this office. Questions pertaining to programming are dealt with elsewhere (see Counseling). The various application forms for requesting the computing services, the renewal of service, rebates, lost passwords, and the restoration of files are processed here.

Work Room (Room 1202)

This is a general work area where the users of the computer may assemble their input or review their output. The room also contains the space set aside for the counselors (see Counseling Room) who provide assistance when needed. Various manuals and write-ups (Computing Center News and Computing Center Memos) on the use of the computer are also available in this room for easy reference.

A TV display gives continuous information on the status of the user's batch jobs from the time that they are accepted at the Input Window and assigned a job number to the time they are completed. When the status code indicates a job is completed, the user should await the announcement over the public-address system that it is ready for pick-up at the Output Window.

Counseling Room (Room 1206). See also "COUNSELING" section below.

The Computing Center provides a counseling staff to answer programming questions for all users. At least one counselor is on duty from 8:00 am to noon, 1:00 pm to 5:00 pm, and 7:00 pm to 11:00 pm Monday through Friday (except Friday night), and 8:00 pm to noon on Saturday during the normal University term. During holiday periods, reduced schedules are in effect. Usually there is a counseling schedule posted on the bulletin board in the Counseling Room.

Keypunch and Terminal Room (Room 1208)

The Keypunch Room currently contains eleven Model 029 Keypunches. These are available to users for preparation of card decks to be submitted to the computer under an authorized

Computing Center ID. Users of this equipment should limit themselves to no more than one hour within the Keypunch Room when there are others waiting to use the equipment. One of the keypunches is reserved for "express" jobs. Use of the express keypunch is limited to five cards or one minute per person.

All malfunctioning of the keypunches should be reported immediately to an attendant at the Model 20 Window. Unauthorized persons should not try to "fix" malfunctioning equipment in the Computing Center.

This room also contains six Model 35 KSR Teletype terminals. These are public terminals which are available to anyone with a valid Computing Center ID. There are approximately thirty other public Teletype terminals at other locations on campus; an exact list is given later in the Introduction.

The Keypunch Room also contains an IBM 083 Card Sorter. The card sorter should not be used by persons unfamiliar with this device; a manual is available in the library for reference, and the counselors are ready to give basic instruction on its use.

A limited number of bins are available in the work room to provide storage for a maximum of two card boxes per user. The Computing Center does not assume responsibility for the contents of the boxes stored in these bins. Boxes are removed and discarded at the end of the second week of each new term unless they display a properly dated sticker. The user may obtain date stickers in the Counseling Room before the deadlines.

Input Window

Input Windows are located on the north side of the first floor Machine Room (Room 1212) for the input of card decks and tapes. Cards submitted for batch runs at these windows are run through a card reader by an attendant and immediately returned to the user. Details on the processing of batch jobs will be found later in this introduction under "Operations".

Output Window

Several output windows face the user's work area. Output and plots from batch runs which are picked up by the user at this window must be identified with the associated job card and number. See the instructions in the section entitled "Picking Up Jobs" later in this Introduction.

Model 20 Window

Listings, reproduction, interpretation, etc. of card decks can be obtained by submitting the decks at this window. See "Model 20 Services" later in this volume for details. All malfunctioning equipment should be reported at this window.

Hours

The current Computing Center hours can always be obtained by signing onto MTS and issuing a $COPY *CCHOURS command. The hours in effect as of this publication are as follows:

Public Areas (Keypunch Room and Terminal Room, Work Room, Input Window, Output Window, and Model 20 Window)
These areas are open continuously during the following periods:

8 am Monday through 10 pm Saturday
2 pm through 10 pm Sunday
(the Input Window is closed until 2:30 pm on Sunday)

Business Office
8 am - 4:30 pm Monday through Friday.

During holidays and end-of-term periods special schedules go into effect. The specially scheduled hours are posted within the Computing Center area in advance of these periods and can also be obtained at these times from *CCHOURS.

North University Building Station (NUBS)

The Computing Center also operates a central campus station. This station is located in the North University Building (Building 145 on the official University campus map) on Forest Avenue at the pedestrian overpass. The main entrance is on the south side of the building facing the pedestrian overpass. The NUBS area can also be entered from the east side of the building where meter and staff paid parking accommodations are provided.

The following is a description of various areas and services which are available at NUBS to the authorized users of the equipment:

Work Room (Room 1013 NUB)
This is a general work area where the users of the computer may assemble their input or review their output.
A limited number of bins are available in the work room to provide storage for a maximum of two card boxes per person. The Computing Center does not assume responsibility for the contents of the boxes stored in these bins. Boxes are removed and discarded at the end of the second week of each new term unless they display a properly dated sticker. The user may obtain date stickers in the Counseling Room before the deadlines.

Counseling Room (Room 1015 NUB). See also "COUNSELING" section below.
The Computing Center provides a counseling staff to answer programming questions for all users. At least one counselor is on duty from 8:00 am to noon, 1:00 pm to 5:00 pm, and 7:00 pm to

Hours

The current Computing Center hours can always be obtained by signing onto MTS and issuing a $COPY *CCHOURS command. The hours at NUBS in effect as of this publication are as follows:

Public Areas (Keypunch Room, Terminal Room, Work Room, Input Window, Output Window)
These areas are open during the following periods:

8 am through midnight Monday through Friday

Telephone Numbers

The following telephone numbers serve the Computing Center on North Campus.

General Information (during Business Office hours)	764-2121	
Business Office	764-2121	
Computing Center Staff (for more detail, see official U. M. Telephone Directory)	764-2121 or 764-9595	
Director's Office	764-9572	
Status Information (answered 24 hours a day):		
Status of Batch Job	763-3360	
Status of MTS (recorded message)	763-0420	
Lines for Interactive Terminals (low-speed)		
Via the IBM 2703 Transmission Control		
Model 33 and 35 Teletypes	763-0300	(24 lines)
IBM 2741/1050 Terminals	763-0510	(24 lines)
Via the Data Concentrator (all terminals)	763-1500	(16 lines)
Via the Audio Response Unit	763-0590	(4 lines)
Lines for Remote Job Entry, Graphic Devices, etc.	(medium-speed)	
Via the IBM 2703 Transmission Control	763-0440	(8 lines)
Via the Data Concentrator and 201 Adapters	763-0570	(4 lines)
Via the Data Concentrator and 202 Adapters	764-4208	(1 line)

RATES FOR COMPUTING SERVICES

The rates charged for computing services are determined in accordance with the principles established by the federal government (Circular No. A-21, Bureau of the Budget) for defining the costs incurred by educational institutions in the completion of work performed under grants and contracts. These principles require that over any cost-recovery period the user's share of the total cost of operating the service facility is in the same proportion to the whole as his use of the computer is to the total of all use during this period. Thus, the rate of charge for a specific type of service is the quotient obtained by dividing the total of the costs over a fiscal period attributable to the performance of this service by the total number of chargeable units of service performed during the period.

The rates applied by the Computing Center are reviewed at regular intervals and are modified in accordance with the changing utilization of the computer and costs of operation. They are at all times subject to review by and approval of the Cost Reimbursement Office of the University. The rates currently in effect can be obtained from the computer by issuing the following command in MTS: $COPY *RATES

The services for which charges are made under MTS are measured in terms of observable quantities defined as follows:

Terminal Time - For those using batch, this is zero. For those operating from a terminal, this is the total real-time signed on.

Processing Time - This is a combination of the intervals of time the central processor unit (CPU) is assigned to the user's program and the space occupied in virtual memory by the program during these periods of time. The expression for this value in hours is (CPU time) + 0.01(VMI), where VMI is equal to the virtual memory integrated over CPU time. CPU time is in hours, the constant 0.01 is reciprocal pages (4096 bytes per page), and virtual memory integrated over CPU time is in page-hours.

Lines Printed - This is the number of lines printed by the printers on the 360/67 at the Computing Center as well as lines printed on the remote-job-entry devices.

Pages Printed - This is the number of pages of paper printed by the 360/67 printers as well as pages printed by the remote-job-entry devices.

Cards Punched - This is the number of cards punched on the 360/67 punches at the Computing Center as well as on remote-job-entry devices. The charge for cards punched includes cost of the cards at $0.90 per thousand cards.

Cards Read - This is the number of cards read by the 360/67 readers at the Computing Center as well as those read by the remote-job-entry devices.

File Storage on Disk - This is the amount of permanent and temporary file storage on 2314 disk storage in pages integrated over real-time.

File Storage on Data Cell - This is the amount of permanent file (data cell) storage on data cell in pages integrated over real-time.

Plotting - This is the amount of time the CALCOMP plotter is devoted to the user.

Tape Drive Use - This is the real-time a magnetic tape or paper tape occupies a tape drive or the paper tape reader or punch, i.e., the elapsed time from *MOUNT being run until *DISMOUNT is run for the same tape, or until the user signs off.

Tape Mounts - This is the number of magnetic and paper tapes mounted, for reading or punching.

Paper Tape Punched - This is the number of feet of paper tape punched.

There are two sets of rates for MTS. These are University-Government rates and Industrial rates. Generally, signon ID's starting with I or J are billed at the Industrial rates and all others are billed at the University-Government rates. The rates current at the time of publication are:

	University-Government	Industrial
Terminal Time	$ 3.00 per hour	$ 3.30 per hour
Processing Time	312.00 per hour	386.00 per hour
Lines Printed	0.45 per 1000	0.60 per 1000
Pages of Paper Printed	3.90 per 1000	3.90 per 1000
Cards Punched (and cards)	3.21 per 1000	3.54 per 1000
Cards Read	0.98 per 1000	1.20 per 1000
Disk Storage	0.00722 per pg.-day	0.010 per pg.-day
Data Cell Storage	0.00320 per pg.-day	0.004 per pg.-day
Plotting	13.00 per hour	36.00 per hour
Tape Drive Use	3.65 per hour	4.60 per hour
Tape Mount Charge	0.24 per mount	0.24 per mount
Paper Tape Punched	1.00 per 1000 feet	1.00 per 1000 feet

dispatcher adds a pink S-8 card to the front of the deck and places the deck in a tray to be read later. After the computing system is again operating and the card decks held in reserve have been read, the user should return to the Input Window, present his receipt card, and retrieve his deck. The pink DECK card on the front of his deck is then used to retrieve his output after the job has been run.

Job Status Monitors

The Computing Center and its North University Building Station contain TV monitors that display the status of all batch jobs submitted to MTS. On the monitors, each job is represented by its six-digit job number and a character denoting its status. The status characters and their meanings are as follows:

A	Job is awaiting execution
E	Job is in execution
M	Job is finished executing and is awaiting printing
P	Job is printing
T	Job has finished printing and is awaiting punching
U	Job is punching cards
*	Job is done - the clerks will announce the job's number over the public address system when they are prepared to dispatch the job

Jobs whose numbers do not appear on the monitor have been completed and purged from the display. A completed job's number is retained approximately ten minutes.

In addition to the status of the batch jobs, the monitors display the current time, the number of active and idle terminal lines, and the total number of jobs in the batch execution, print and punch queues.

Picking Up Jobs

Output from batch jobs should be picked up at the Output Window. It is given out in exchange for the white (or pink) DECK card, which is used as a receipt. Output should be picked up as soon as possible because of the limitations on the space available for storage. The Computing Center will not be responsible for output that is left longer than one week. Normally output for a job is returned to the station at which the job was submitted. However, the system allows for the routing of output to any one of the batch stations in the system. This is accomplished by specifying ROUTE=xxxx on the SIGNON card for the job. "xxxx" is a four-character mnemonic code for the various stations; the code is CNTR for the Computing Center and NUBS for the North University Building Station.

SYSTEM STATUS INFORMATION

The telephone number 763-0420 is the number of an automatic answering service station that gives the current status of the computing system. This number should be called for information on the state of the system if, after attempting a connection with the computer from a remote terminal, a busy signal is received, or no response whatsoever results. When this happens, the computer is probably not operating or is being readied for operation. In this case, the recording on the automatic answering unit will give the probable time at which the computer will again be available for service.

If, on dialing the computer from a terminal, the vocal message "MTS IS OPERATING" is received, but connection with the computer cannot be completed, this indicates that all available lines on the transmission control device to which the call was directed are busy. In this case, the answering service will report the same status information as that received on the terminal and should not be called.

JOB STATUS INFORMATION

The telephone number 763-3360 can be dialed 24 hours a day to see if a batch job is finished or not. This number is answered by a member of the staff in the Machine Room.

SYSTEM RELOADING POLICY

Except for failure of hardware or software that precludes further computing system operation, the operating system of the Computing Center will be shut down for the purpose of reloading in a different configuration only at fixed times. The schedule of regular and optional shutdowns is given below. The user of a remote terminal should become familiar with this schedule in order to anticipate possible interruptions in the service and be prepared for a self-imposed termination of a terminal session should a shutdown be announced. Such cooperation will allow making the necessary changes in the computing system's operating configuration quickly and smoothly.

Obviously, hardware and software failures are unanticipated events that preclude forewarning the users of the system. Such failures are becoming less and less frequent as errors in the system ensemble are detected, and corrections and improvements are made.

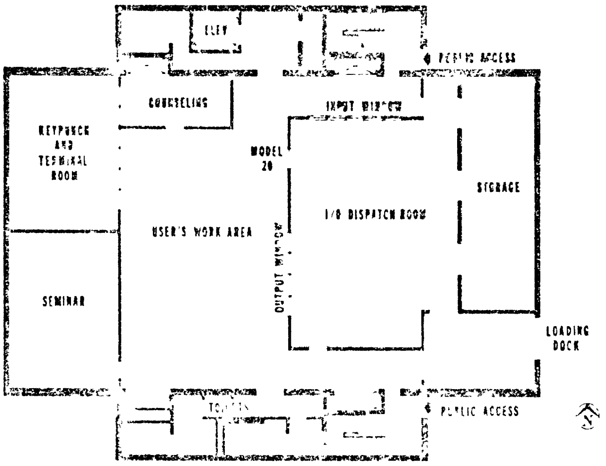
Planned interruptions of the system will, as stated above, conform to the "Schedule of System Reloading". Shutdowns which are scheduled as "Optional" will generally be bypassed unless it is deemed necessary to reconfigure the operating system at that time. A broadcast message to each active terminal connected to the system prior to the next scheduled shutdown will inform the user if the shutdown is to take place as scheduled (and as announced), and each terminal user must sign off prior to the scheduled time. Any user failing to sign off in time will be stopped automatically by the system. Reloading the system for restart is much more involved and, therefore, will be delayed if enforced stops must be made to terminate ongoing sessions at terminals. Thus, the operation of the system will be restored more quickly, and better service will be available to all, if terminal sessions are promptly terminated before the announced shutdowns.

Schedule of System Reloading Monday through Friday

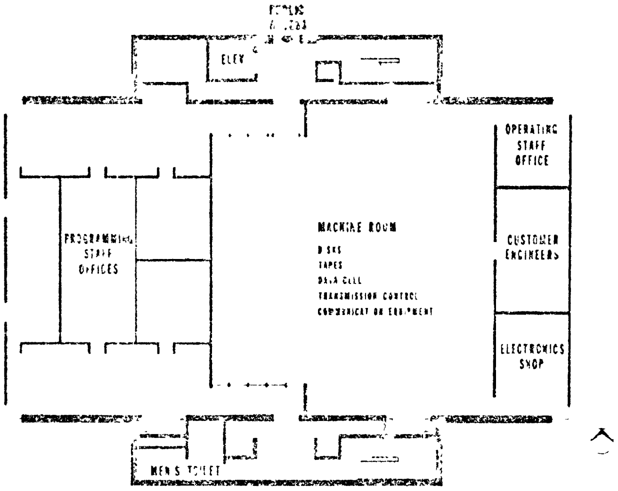
Time	Event
Midnight	Optional system shutdown.
12:15 am	System reloaded and in service.
3:00 am	(Tuesday only) System shutdown for file-save (no OS run on this day).
* 4:00 am	System shutdown for OS/360; system reloaded and file-save run at the end of OS/360 production.
* 5:45 am	System shutdown for preventative maintenance.
6:00 am	System reloaded in reduced capacity. The entire system will unavailable from 6 am to 8 am on each Monday morning and each Friday morning.
* 8:00 am	System shutdown at end of normal preventative maintenace.
* 8:15 am	System reloaded and in service.
10:00 am	Optional system shutdown.
10:15 am	System reloaded and in service.
12:30 pm	Optional system shutdown.
12:45 pm	System reloaded and in service.
6:30 pm	Optional system shutdown. Previously this shutdown was scheduled for 5:30 pm.
6:45 pm	System reloaded and in service.

The times marked with an "*" are the only system reloading times that are almost certain to occur every day. The other times may be used for reloading if needed, and the user will be notified by broadcast (or at signon) of the next scheduled reloading time. Reloading will not occur at any other times except for recovery from system failure.

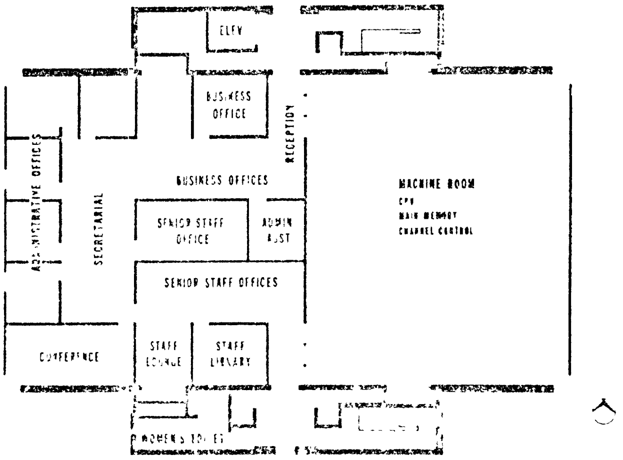
When the Computing Center is not open, such as on holidays and at certain times over the weekend, the computer might be operated by the systems programming staff and be available for use from a remote terminal. During such unscheduled operating periods, a terminal user may be requested to sign off on short notice. Also, since none of the regular operating staff is in attendance, tapes will not be mounted for the remote terminal user. When the system is available in this manner, the signon message so indicates.



FIRST LEVEL



SECOND LEVEL



THIRD LEVEL

Floor plan for Computing Center.

INTRODUCTION TO MTS

The style and format of this introduction were modeled after the writeup "So You Want to Use the IBM 360/67" (U67-0) by J. M. Kennedy of the University of British Columbia. For that matter, a lot of the content was borrowed too.

The IBM 360/67 can serve a large number of users concurrently offering each a wide variety of services. The job of keeping track of all the programs in the machine and of devoting some attention to each of them every second or two is handled by the MTS operating system (Michigan Terminal System). In order to request service from the computer, you must first identify yourself to MTS and then communicate your requests. This communication is done through the MTS Command Language. Because the system is both powerful and complex, the command language of MTS is a rich one. Fortunately, MTS usually has a default option wherever it offers you a choice; that is, if you don't state your choice explicitly, a plausible assumption is made and the job continues. In the following sections, some of the more important commands will be discussed. For a complete listing, see the section entitled "A Brief Overview of MTS" in this volume.

You may operate within MTS in one of two modes - batch or conversational. In conversational mode, you sit at a terminal and communicate directly with MTS through a typewriter-like keyboard. MTS processes each command as it is received and reports the results. Based on the results, you can decide what command to give next. Thus, conversational mode of operation is highly interactive.

Batch mode, on the other hand, is not interactive. You must completely pre-plan all requests, punch them on cards, and submit them to the Computing Center. Some time later--minutes or hours, depending on how long your program is and how busy the computer is -- you may pick up the results. Feedback is not immediate. ("The University of Michigan Computing Center", the "Conversational Usage of MTS", and the "Batch Usage Guide", all of which are contained in this volume, provide details on submitting a program in batch and using a terminal.)

The command language and its usage are essentially the same for both batch and conversational modes. The primary difference is that in conversational mode MTS replies after most commands, confirming what it just did or prompting you for further information. The descriptions that follow apply to both modes; any substantial differences between them will be noted as they occur.

INTRODUCING YOURSELF TO MTS

Here, and in later sections, the emphasis will be on illustrative examples accompanied by "rules". This is not the whole MTS story by any means, but it should put you in the proper frame of mind to read the more detailed descriptions in the rest of the manuals.

Example 1 is a trivial job that illustrates three rules about the MTS command language:

```
$SIGNON MYID PW=SESAME
$SIGNOFF
```

Example 1

Rule 1: The first character of a command to MTS is a "$". In batch mode, the "first character" is the character in column 1 of a card. In conversational mode, the "first character" refers to the first character you type in a line. (A blank is considered to be a character.) Though there are cases in which the "$" need not appear, it is always acceptable to include it.

Rule 2: The first card or typed line must say $SIGNON and must be immediately followed by one or more blanks and your user identification code. This first part of the identification is the four-character ID code (e.g., MYID) given to you by the Computing Center. The next part is the password associated with the ID. More is given on passwords below.

Rule 3: The last command should be $SIGNOFF to tell MTS that you have finished using its facilities. MTS will then give statistics on the completed run, e.g., how much it cost, how long it took, etc.

The purpose of the password is to keep others from using your ID. number. It is prudent to conceal it. One step toward this goal is to leave the password off the $SIGNON command and to supply it on the next card or line. This second card is not printed with your output in batch mode, and it is recommended that you turn off the printing on the keypunch or terminal when you type it. The "three-line" sequence in Example 2 has exactly the same effect as Example 1 and is the preferred method of signing on. We will use this method in all our subsequent examples.

```
$SIGNON MYID
SESAME
$SIGNOFF
```

Example 2

In conversational mode, if you don't include the password on the first line, MTS will prompt you for it by typing "ENTER USER PASSWORD".

When you get an ID number from the Computing Center, a password will already be assigned to it. You probably will want to change it to something more meaningful and hence more easily remembered. The $SET command is used to change your password. To change from your current password, OLDPAS, to a new one, NEWPAS, you can include the $SET command as part of any job:

```
$SIGNON MYID
OLDPAS
$SET PW=NEWPAS
$SIGNOFF
```

Example 3

From this point on, your password is NEWPAS.

When you $SIGNON in batch, MTS allows you a maximum of 30 seconds of processing time, 50 pages of printed output, and 0 punched cards. If you want more or less of any of these items, you can specify the request on the $SIGNON card as shown in Example 4 below.

```
$SIGNON MYID T=90 P=10 C=50
```

Example 4

Rule 4: To set the time, you write "T=time" in seconds. This example requests 90 seconds. If you prefer to use units of minutes, you may write T=1.5M, where M indicates minutes. To specify pages and cards, you write "P=number of pages" and "C=number of cards". This example asks for 10 pages and 50 punched cards.

This command does not mean that you must use this much; it simply means that you cannot use more. For a more detailed description of these and additional options for the $SIGNON command, see the description of the command language in this volume. In terminal mode, these options are ignored.

NOW THAT MTS KNOWS WHO YOU ARE ...

Now you can get the computer to do some real work for you. Let's say that you have some problem for which you have written a FORTRAN program. In order to run this program, i.e., to have the computer carry out your instructions, several steps are required:

1. The program you write in FORTRAN or any other language is known as the *source program*. A translator must *translate* your source program to a machine language *object program*. If you wrote the program in FORTRAN, then you use either the FORTRAN compiler or the WATFIV compiler to translate your FORTRAN statements. Similarly, for other languages.
2. The object program must be *loaded* into computer memory.
3. MTS can then *execute* your object program, that is, it can carry out the instructions in your program. Let's look at some sample WATFIV jobs.

```
$SIGNON MYID
SESAME
$RUN *WATFIV
$COMPILE
      READ,X
      U=SQRT(X)
      PRINT, X,U
      STOP
      END
$DATA
21.67035
$STOP
$SIGNOFF
```

Example 5

Rule 5: $RUN *WATFIV tells MTS to execute the program contained in the public file *WATFIV. The program in file *WATFIV is the WATFIV compiler. (A compiler is one type of translator.)

Rule 6: The control cards $COMPILE, $DATA, $STOP are commands to WATFIV, not to MTS. $COMPILE says "here comes a program for compilation". $DATA denotes the end of the source code and calls for execution of the compiled program; it must be included whether or not you have any input data. $STOP tells WATFIV to turn control back to MTS.

A succession of WATFIV tasks can be run by alternating $COMPILE and $DATA commands as shown in Example 6.

```
$SIGNON MYID
SESAME
$RUN *WATFIV
$COMPILE
   (Source cards for Job #1)
$DATA
   (Data cards for Job #1)
$COMPILE
   (Source cards for Job #2)
$DATA
   (Data cards for Job #2)
$STOP
$SIGNOFF
```

Example 6

Rule 7: Alternating $COMPILE and $DATA cards is more efficient than executing the WATFIV program separately each time. Note that these tasks are independent. If you have a main program and several subroutines which are to be executed together as a unit, they constitute one task and thus need only one $COMPILE and one $DATA card. In this case, WATFIV distinguishes the end of one routine from the beginning of the next routine by the END card which must be the last card of any WATFIV routine.

Example 7 shows a sample FORTRAN job.

```
$SIGNON MYID
SESAME
$RUN *FTN
     (FORTRAN source cards)
$ENDFILE
$RUN -LOAD
21.67035
$ENDFILE
$SIGNOFF
```

Example 7.

Rule 8: $RUN *FTN performs a similar function to $RUN *WATFIV in Example 5; i.e., it tells MTS to execute the program in the file *FTN, which contains the FORTRAN compiler.

Rule 9: $ENDFILE is used to signify the end of the source code and again to signify the end of the data. It is not a command.

Rule 10: Execution of your compiled program is invoked by the card $RUN -LOAD. This instructs MTS to run the program stored in a file called -LOAD. Fortunately, this is where FORTRAN has just put your object program since the first RUN command did not specify where the object program was to be stored.

This example points out a major difference between WATFIV and FORTRAN: namely that FORTRAN requires that the translated program be stored somewhere before running it, while WATFIV does not.

AND NOW, ANOTHER WORD ABOUT THE COMMAND LANGUAGE

So far, we have encountered several words of the MTS command language. There are many more, some of which will be met in the section on files that follows. In general, the command statements have a fairly free format. A safe rule is:

> Rule 11: Don't leave a space between the dollar sign and the command word. In general, you should leave a space between "words" when there is no explicit separator, such as in $SIGNON MYID. However, if there is a separator such as an equal sign (=), you should not leave any spaces around it. For example, within the "phrases" PW=SESAME and T=30 there should be no blanks.

The experts know abbreviations for the command words that will do just as well as the full word. Generally, the first three letters of the command is sufficient. Check to be sure.

Several different tasks can be performed between a single $SIGNON-$SIGNOFF pair. Example 6 showed a sequence of WATFIV tasks; you can have a sequence of WATFIV and FORTRAN tasks; in general, you can have almost any sequence of tasks, whether or not they are related.

THE MYSTERY OF FILES UNVEILED

We have mentioned files in our examples but have not explained what a file is. MTS stores files on disk and data cell storage. The best way to think of a file is as an area of this disk or data cell storage in which you can store information.

Files are composed of lines of information. If information is put in the file via the card reader, then a line is the contents of one card. If the information is put in the file by a FORTRAN program, then generally a line is the information contained in one FORTRAN output record. If the information is put in the file via a typewriter terminal, a line is the information typed before the "return" code is typed. The information contained in a file could be data, an object program, the FORTRAN compiler, a source program, a letter to the President, etc. Every file has a name so that you can communicate with MTS about it.

Here are some of the operations you can do with files: $CREATE them and $DESTROY them, $LIST them and $COPY them, $GET them and $RELEASE them, $RUN them, and $EMPTY them. How to carry out these operations is the subject of this section.

We have already seen some examples of $RUNning files. $RUN *WATFIV commands MTS to execute the program stored in the file called *WATFIV. Since the WATFIV compiler is the program contained in the file named

*WATFIV, MTS will make WATFIV start compiling or translating your program. Similarly, $RUN *FTN will result in the execution of the FORTRAN compiler in the file named *FTN. $RUN -LOAD, in Example 7, requests the execution of the program in file -LOAD. Since your object program has just been stored in -LOAD by FORTRAN, it is your program that will be run.

The most common type of file is one in which every line in the file has a number associated with it. These are, very conveniently, called *line files* and for the purposes of this introduction, when the word "file" is used, we will be referring to a line file. The line file is ordered by the line numbers. Thus, regardless of the order in which information was entered into the file (even if you gave line 10 before line 9), the information is effectively stored in the file with the line numbers in ascending order.

There are two ways to specify the line number which is to be associated with a line. One way is to write the numbers yourself at the beginning of each card or typed line. However, files are usually filled initially with a set of sequentially numbered lines, and we might as well let MTS number them for us via a $NUMBER command shown below.

Creating a File

Example 8 shows a simple batch job that creates a file called FILEFACTS, puts five lines of information into it, and then lists it. Example 9 is the same job but run in conversational mode.

```
$SIGNON MYID
SESAME
$CREATE FILEFACTS
$NUMBER
THIS SAMPLE FILE CONTAINS SOME
INFORMATION ON FILES IN MTS.
1. A FILE IS A SET OF NUMBERED
LINES STORED UNDER SOME UNIQUE
NAME
$UNNUMBER
$LIST FILEFACTS
$SIGNOFF
```

Example 8.

Rule 12: A file of modest size can be created by $CREATE followed by the name you wish to attach to it. It is retained for your later use until you $DESTROY it.

Rule 13: The command $NUMBER instructs MTS to number the lines that follow. In batch mode, MTS numbers the lines as they are put in the file. In conversational mode, MTS types the line number for you and then waits for you to type the content of that line. The numbering starts with 1 and goes up by increments of 1 thus giving 1,2,3,... See the NUMBER command description in the Command Language section of this volume for ways of specifying a different starting number or different increment. If the $NUMBER command is not given, lines to be put into the file must be numbered explicitly.

Rule 14: Once a file has been $CREATEd, you may enter information into it. MTS must be able to distinguish commands to be executed from text to be stored in a file. All lines of information which (1) start with a line number (either explicitly or via $NUMBER) and (2) do not have a single "$" following the number are put into the currently active file. The currently active file is the file whose name most recently appeared in a $CREATE or $GET statement. ($GET is explained below.) Any line not starting with a line number or containing a single "$" after a line number is assumed to be a command to be executed immediately. If the command is not legal, MTS will give an error comment.

Rule 15: $UNNUMBER turns off the automatic line numbers effected by $NUMBER. MTS still puts any lines with explicit line numbers into the file unless a single "$" follows the line number, or the file is $RELEASEd.

Rule 16: $LIST, followed by a file name, calls for a listing of the contents of the file starting from line 1. If the file has line numbers less than 1, they will not be listed. The listing includes the line numbers.

The following example was done on a terminal. The statements typed by the programmer are in lower case and the output to the user is in upper case. This example illustrates the concept of a prefix character.

```
MTS(LA33-0107)
WHO ARE YOU?
#$signon myid pw=sesame
#**LAST SIGNON WAS: 13:39.04  06-05-70
# USER "MYID" SIGNED ON AT 11:39.44 ON 06-12-70
#$create filefacts
# FILE "FILEFACTS" HAS BEEN CREATED.
#$number
#     1   this sample file contains some
#     2 information on files in mts.
#     3   1. a file is a set of numbered
#     4 lines stored under some unique
#     5 name.
#     6 $unnumber
#$list filefacts
>     1       THIS SAMPLE FILE CONTAINS SOME
>     2     INFORMATION ON FILES IN MTS.
>     3       1. A FILE IS A SET OF NUMBERED
>     4     LINES STORED UNDER SOME UNIQUE
>     5     NAME.
#END OF FILE
#$signoff
#OFF AT 15:49.42    01-26-71
#ELAPSED TIME        1.583 MIN.              $.08
#CPU TIME USED       1.193 SEC.              $.10
#CPU STOR VMI         .1   PAGE-MIN.         $.01
#WAIT STOR VMI        .17  PAGE-HR.
#DRUM READS          7
#APPROX. COST OF THIS RUN IS     $.19
#DISK STORAGE         .15  PAGE-HR.
#APPROX. REMAINING BALANCE:    $20.35
```

Example 9

Rule 17: The prefix character is typed by the system and is the first character of every line of output and the first character on a line expecting input. This character identifies who is producing the output line or who is expecting input. Each segment of the system has a distinct character. In this example we see the "#" when we're in MTS command mode and ">" when a listing is being produced. A complete listing of the system prefix characters is given in the "System Command Language" section in this volume.

Revising a File

Suppose that you find after creating a file that you have left out a line in the middle and intended to say more in line 5. You can edit your file on a subsequent run as shown in Example 10.

```
$SIGNON MYID
SESAME
$GET FILEFACTS
2.5, YOU SHOULD LEARN THEM.
5,NAME ASSIGNED BY THE USER.
$SIGNOFF
```

Example 10.

Rule 18: At the start of this run, there is no currently active file. $GET is used to notify MTS of the name of the file to be the active file. $GET FILEFACTS makes FILEFACTS the active file, regardless of whether or not another file had previously been the active file. $RELEASE will release a file from being the currently active file, thus returning to the status of no currently active file.

Rule 19: If $NUMBER isn't used, each line must be numbered explicitly; the number is separated from the text by a blank or a comma. (When a blank is used as the separator, it remains part of the text. A comma, however, used as a separator is generally stripped off.) If there is no line number, MTS assumes the line is a command to be executed immediately.

Rule 20: A line can be inserted between existing lines by giving it some intermediate number. This number can be fractional, or even negative. (But note that as stated in Rule 17, $LIST still lists starting from Line 1 (unless you take special precautions) even if your file has a line numbered .5).

A line with a number already in use in the file calls for a replacement of the old line with the new. Thus, in this example, the old line 5 is replaced by the new one.

After running Example 9 and then 10, FILEFACTS has 6 lines: 1,2,2.5,3,4,5.

Copying a File

After a certain amount of editing and insertion of new lines, a file may get rather messy, i.e., full of interpolated lines. For this or other reasons, you may want to copy the information into a new file. Example 11 shows how to do this.

```
$SIGNON MYID
SESAME
$CREATE NEWFILE
$COPY FILEFACTS TO NEWFILE
$SIGNOFF
```

Example 11.

Rule 21: The $COPY command copies the contents of one file into another. In this process the lines are numbered sequentially from 1 as they enter the new file, whatever their numbers may be in the old file. The old file is retained unaltered. For ways of copying only part of a file or of altering the numbering in the new file, see the COPY command description in the "Command Language" section of this volume.

Rule 22: Information that is no longer wanted can be deleted either by a command of the form

```
$EMPTY FILEFACTS
```

which removes the contents of the file but retains its identity, or by a command of the form

```
$DESTROY FILEFACTS
```

which deletes the file and returns the space on the disk to the pool of available storage.

Most of the time, you will want to use files for programs or for data. Example 12 shows the compilation and execution of a small WATFIV program which is set up in such a way that the source program is left in a file for later use. One method for putting lines that start with "$" into a file is illustrated. An alternate method is shown in Example 17 below.

```
$SIGNON MYID
SESAME
$CREATE PROG
$NUMBER
$$COMPILE
      DIMENSION K(5)
      DO 10 I = 1,5
10    K(I) = (I*5)+7
      STOP
      END
$$DATA
$$STOP
$UNNUMBER
$RUN *WATFIV SCARDS=PROG
$SIGNOFF
```

Example 12.

Rule 23: To prevent a card like $COMPILE from looking like an MTS command for immediate execution, the rule is that lines beginning with a single "$", whether they are preceded by a line number or not, are not entered into files but are treated as MTS commands. Lines beginning with a line number followed by "$$" are entered into a file with the first "$" removed.

The $RUN card needs some further explanation. WATFIV has to read input--your source program. It must know where to find the input. Is it on a card reader or on a terminal or in a file? And in which of the many card readers, terminals, or files is it? It is undesirable to have WATFIV always expect its input to come from a particular input device. Imagine what would happen if WATFIV insisted that all users input their programs from the 3rd terminal in Room 1007 of the Computing Center--there would be an intolerable line at that particular terminal and the others would probably be idle. This same problem arises for any program--be it the FORTRAN or WATFIV compiler or your own program which wants to read or write data.

To avoid the necessity of specifying a particular input or output device at the time of writing the program, MTS provides for *logical I/O* (input-output) *units*. These are symbolic names and do not refer to actual physical units. The most commonly used logical I/O units are SCARDS, SPRINT, SPUNCH, 0,1,2,...,9. The WATFIV compiler is an example of a program which uses the logical units SCARDS and SPRINT. It reads the source statements from logical unit SCARDS and writes the source listing on logical unit SPRINT. It depends on MTS to tell it *at execution time* which physical devices are associated with the logical units. It is up to you to give MTS this information.

At the time the $RUN command is given, you must specify for each logical I/O unit used by the program to be run which actual physical unit should be used. (In many cases, if you do not specify which device should be attached to the logical I/O unit, MTS makes a plausible assumption. This is discussed below.) Thus, in Example 12, the specification SCARDS=PROG on the $RUN command tells MTS to tell WATFIV that the source program is in a file named PROG. The reason that our earlier examples didn't have to specify SCARDS and SPRINT is that if MTS is not told explicitly, it assumes that

SCARDS refers to the device from which the $RUN command came and that SPRINT refers to the device that it has been using to print the command cards.

In the above example, if you wanted your program to read data and had a statement such as READ,X as in Example 5, WATFIV would assume the data could be found in the file PROG since you said SCARDS=PROG. But if you are likely to be varying the data, you would not want to put your data in PROG. You might want to keep your data on cards or in a different file. Example 13 illustrates how to read your data from cards, even when your source program is in a file.

```
$SIGNON MYID
SESAME
$CREATE PROG
$NUMBER
$$COMPILE
      READ(5,1) X
1     FORMAT(2F10.5)
      U=SQRT(X)
      WRITE(6,1) X,U
      STOP
      END
$$DATA
$$STOP
$UNNUMBER
$RUN *WATFIV SCARDS=PROG                -
              5=*SOURCE* 6=*SINK*
21.67035
$SIGNOFF
```

Example 13.

Rule 24: The statements READ(5,1) X and WRITE (6,1) X,U tell WATFIV to use logical unit 5 for input and logical unit 6 for output. Only the numbers 1,...,9 are acceptable in these statements. Use of different numbers or of SCARDS, SPRINT, SPUNCH is illegal. This is true in FORTRAN as well as WATFIV.

Rule 25: In the $RUN command, you must tell MTS with what to equate logical units 5 and 6. Thus, we have set 5=*SOURCE*, 6=*SINK*, where *SOURCE* and *SINK* are known as pseudo-device names which we will now explain.

Rule 26: If an MTS command line is too long to fit on a single input line (card or terminal line), a minus sign may be placed in the last column to indicate that the next line is to be considered as a continuation of the first line. The last column of a punched card is column 80; the last column of a terminal line is the last character typed before "return" is signaled.

We want MTS to tell WATFIV that, if we are in batch mode, logical unit 5 is to be the card reader that our commands have been coming from or, if we are in conversational mode, logical unit 5 should be the terminal that we have been typing on. Similarly, we want 6 to be a line printer or a terminal, depending on what mode we are in. But, in the case of batch mode, we do not care on which card reader our deck was placed or which line printer we are using. If a particular line printer, for example, is broken or is being used by someone else, we would prefer that MTS give us a different one instead of waiting for that particular one. If we are using a terminal, we would prefer not to have to worry about finding out some identification number for the terminal at which we are sitting. So we use another gimmick to avoid having to be too specific, the idea of a _pseudo-device_. Pseudo-devices allow you to take advantage of the fact that, even if _you_ don't know, MTS _does_ know what device your $SIGNON came from and which line printer it can use if you require one.

Wherever you have to name a file or device, you can use a pseudo-device name and let MTS assign a real physical device or file to the name. Pseudo-device names are characterized by the fact that they start with an asterisk followed by some string of alphabetic characters and end with an asterisk. The most important pseudo-devices which are predefined by MTS are *SOURCE*, *SINK*, *PUNCH*, and *DUMMY*:

*SOURCE*	means that you want the same device from which MTS has been receiving its commands. Thus, in batch mode, *SOURCE* is equated with the particular card reader from which your batch job is being read. In terminal mode, *SOURCE* is assigned to the terminal which you are currently using.
*SINK*	refers to the current output file or device. In batch mode, MTS assigns *SINK* to the line printer assigned to your job. In terminal operations, *SINK* is equated with the terminal you are using.
*PUNCH*	refers to the card punch in batch mode. It has no meaning in conversational mode.
*DUMMY*	is a name that can be used as an input or output device. If you read from *DUMMY*, you always get just an end-of-file. Used as an output device, it acts like an infinite wastebasket-- you may write as much as you want on it, but it is lost forever.

Example 14 shows how you can put your data into a file called DATA and then run the program that you put in file PROG using the data in the file DATA.

```
$SIGNON MYID
SESAME
$CREATE DATA
$NUMBER
2.173
3.576
4.873
$UNNUMBER
$RUN *WATFIV SCARDS=PROG
             5=DATA 6=*SINK*
$SIGNOFF
```

Example 14.

Rule 27: Now logical unit 5 is set to DATA since that is where the program is reading the data from.

Examples 15 and 16 show the corresponding procedure for FORTRAN.

```
$SIGNON MYID
SESAME
$CREATE FPROG
$NUMBER
         READ(5,1)X
1        FORMAT(2F10.5)
         U=SQRT(X)
         WRITE(6,1)X,U
         STOP
         END
$UNNUMBER
$CREATE OBFILE
$RUN *FTN PAR=SOURCE=FPROG       -
                LOAD=OBFILE
$RUN OBFILE 5=*SOURCE* 6=*SINK*
21.67035
$ENDFILE
$SIGNOFF
```

Example 15.

```
$SIGNON MYID
SESAME
$RUN OBFILE 5=*SOURCE* 6=*SINK*
3.1416
$ENDFILE
$SIGNOFF
```

Example 16.

Rule 28: When the source cards are read from a private file, it is not necessary to use a $ENDFILE card to signal the end of the input. MTS automatically supplies an "end of file" indicator when the end of the file is reached.

Rule 29: To tell FORTRAN to put the object program into a private file, one specifies "LOAD=filename" in the "PAR=" field on the $RUN *FTN card. If a file in which to put the object program is not specified, the object program is held temporarily in -LOAD but is then not available for subsequent jobs. By saving the object program as in Example 15, we do not have to recompile the source program in Example 16. Note that this could not be done with WATFIV since the WATFIV compiler does not provide facilities for retaining the object program.

If we wanted to put the data in a file, we would follow the same procedure as in Example 14.

In Example 12, we put a WATFIV program into a private file PROG. The following example shows a way of getting the same information into PROG without worrying about double dollar signs.

```
$SIGNON MYID
SESAME
$CREATE PROG
$COPY *SOURCE* TO PROG
$COMPILE
      DIMENSION K(5)
      DO 10 I=1,5
10    K(I)=(I*5)+7
      STOP
      END
$DATA
$STOP
$ENDFILE
$RUN *WATFIV SCARDS=PROG
$SIGNOFF
```

Example 17.

Rule 20: The $COPY command tells MTS to copy *everything* up to the first end-of-file indicator it sees. Since MTS is just looking for the end-of-file mark, lines which ordinarily would be commands requiring execution are copied blindly into the file. When $COPYing from *SOURCE*, the $ENDFILE line serves as the end-of-file indicator.

BUT HERE'S MORE ABOUT FILES ...

The examples so far have dealt primarily with *private files*, i.e., files created by the user for his personal use and retained from job to job. There are two other types, *temporary* (sometimes called *scratch*) *files* and *public files*. A temporary file has a name beginning with a negative sign. You may create and use temporary files just as you do ordinary private files. The only difference is that at $SIGNOFF all temporary files you created are destroyed. As your eligibility for private files is limited, you should use temporary files whenever possible. -LOAD is an example of a temporary file; in this case FORTRAN automatically creates it for you unless you specify SPUNCH to be some other file.

A *public file* has a name beginning, but not ending, with an asterisk. Anyone may use one, but only the elect may create one. We have already seen examples such as *WATFIV and *FTN. For a complete listing of all the public files available, see Volume 2 of the MTS Manual. Here we will just mention three more that might be useful, *STATUS, *CATALOG, and *PERMIT. Example 18 shows a run that combines two of these.

```
┌──────────────────────────────┐
| $SIGNON MYID                 |
| SESAME                       |
| $RUN *STATUS                 |
| $RUN *CATALOG                |
| $SIGNOFF                     |
└──────────────────────────────┘
```

Example 18.

Rule 31: The program in *STATUS asks MTS to give you a summary of all your computer usage with the ID. You get information such as how much money you have used and how much is left in your account, how much file space you have left, etc.

Rule 32: The program in *CATALOG lists all the private (permanent) files that you have currently occupying space on disks or data cells, i.e., all those that you have $CREATEd at some time but never $DESTROYed.

Ordinarily, you are the only one who can read or write on a file which you created. If you want to let other people read your files, you may set a "permit code" that allows it. If, for example, you feel that NEWFILE created in Example 11 ought to be made available to others, you can so specify. Example 19 shows how this is done.

```
┌──────────────────────────────┐
| $SIGNON MYID                 |
| SESAME                       |
| $RUN *PERMIT                 |
| NEWFILE RO                   |
| $ENDFILE                     |
| $SIGNOFF                     |
└──────────────────────────────┘
```

Example 19.

Rule 33: To $RUN *PERMIT, you then name the file you want to PERMIT and say what permission is to be extended. RO stands for "read only". This means that the file may only be read from. Neither the owner of the file nor anyone else may alter the contents of the file. You can later reverse this effect by running *PERMIT and specifying NONE after the name of the file instead of RO.

Now another user can read your file: he can copy it, run it (if it is an object program), or read it as data. Example 20 shows how user ABCD might copy NEWFILE.

```
$SIGNON ABCD
ALIBAB
$CREATE XEROX
$COPY MYID:NEWFILE TO XEROX
$SIGNOFF
```

Example 20.

Rule_34: Reference to files other than your own requires the owner's ID code and a colon (:) immediately preceding the file name. This is necessary since dozens of users may have files called NEWFILE.

To conclude this section, it is worth remarking that, within reason, input-output devices and files are interchangeable under MTS. You may either think of a file as a substitute for an input-output device, or the reverse. We have seen examples of this interchangeability in such phrases as SCARDS=*SOURCE* which refers to a device and SCARDS=MYFILE which refers to a file.

A LAST WORD CONCERNING TERMINAL VS. BATCH

All of our examples are applicable to batch or conversational modes. The main difference between the two is that in conversational mode, you get immediate feedback from MTS after giving it a command. This can be very helpful if you have made an error. For example, if you misspell the name of a file and MTS cannot find it, it will ask you to try another name. If you ask MTS to $DESTROY or $EMPTY file, it will ask you to confirm the request. To do this, you type in either OK or O.K. If you change your mind, type in NO, or enter a line without any characters.

Another difference in conventions between batch and terminal operations occurs in the running of *FTN and *WATFIV. Whereas in batch mode you get a listing of the source program and error comments, on a terminal the source code is normally not listed. Only the erroneous lines and their error messages appear.

> Rule_35: If you want your source program listed when running *FTN from a typewriter terminal, add the phrase PAR=SOURCE to your $RUN *FTN line. Note that there are no asterisks in SOURCE. In WATFIV to get your source program listed, you must include the parameter SOURCE on your $COMPILE card or line.

When you are entering text into a file, the text begins after the line number and any separator symbol that accompanies it. Thus, if you are entering a FORTRAN or WATFIV program and you want the text to start in column 7, you must give six spaces before you type the line. (There are two ways to avoid all the "space-bar hitting". All terminals have tab setting features which may be used. See the appropriate user's guide for the particular terminal being used. In addition, the program in file *FTN may be used to convert your statements from free-format to standard FORTRAN format. See Volume 2 for a description of this feature of *FTN.)

If you wish, you can create a batch job from a terminal. If, for example you have used the terminal to debug your program (i.e., locate and correct the errors), but you don't want to run the whole program on the terminal, you can request a batch run. Or if you want a listing of your program and would rather use the line printer (which is faster) instead of the teletypewriter, you should create a batch job. Example 21 illustrates how this can be done.

```
#$get -temp
#READY.
#$number
#      1 $$signon myid
#      2 sesame
#      3 $$run *ftn par=source=p
#      4 $$run -load
#      5 $$signoff
#      6 $unnumber
#$list -temp
>      1       $SIGNON MYID
>      2       SESAME
>      3       $RUN *FTN PAR=SOURCE=P
>      4       $RUN -LOAD
>      5       $SIGNOFF
#END OF FILE
#$copy -temp *batch*
> *BATCH* ASSIGNED RECEIPT NUMBER
  603772
#$signoff
#OFF AT 15:44.36     01-26-71
#ELAPSED TIME             1.933 MIN.
#CPU TIME USED            1.27  SEC.
#CPU STOR VMI             .116 PAGE-MIN
#WAIT STOR VMI             .207 PAGE-HR
#DRUM READS               11
#APPROX. COST OF THIS RUN IS      $
#DISK STORAGE              .3   PAGE-HR
#APPROX. REMAINING BALANCE:    $15.
```

Example 21.

Rule 36: To create a temporary file, you merely have to mention the name. Thus, in this example -TEMP is created implicitly in the $GET statement.

Rule 37: To run a batch job from a terminal, copy a file, in this case -TEMP, to *BATCH*. -TEMP must contain a complete batch job including $SIGNON and $SIGNOFF. A six-digit receipt number will be typed out which must be presented at the Output Window to collect the job. If the same signon is used for both the batch job and the present terminal session, the batch job will be run as soon as possible after the signoff at the terminal.

Rule 38: Note that when you $SIGNOFF, file -TEMP is destroyed since it is only a scratch file. This, however, is no problem since the program in *BATCH has already gotten all the information it needs from -TEMP. If you expect to use this sequence of commands again and would like to have them saved, you should use a permanent file instead of a scratch file.

All that remains to be said is:

```
$GOOD LUCK
$RUN TO COUNSELORS IN ROOM 1013.
```

MTS COMMAND LANGUAGE

In order to use the computer, one must first get the attention of MTS and identify himself through the $SIGNON command. Once he has done this and MTS has agreed that he is a legitimate user, the IBM 360/67 is at his disposal.

In this section, the commands will be listed in their most common form followed by a brief explanation of their function. Not every possible option and parameter will be mentioned. A detailed explanation of the commands will be found in "The System Command Language".

As stated earlier, command lines start with a "$" followed immediately by the command name or the command abbreviation. The "$" is required for batch runs but not necessarily for conversational runs. In a conversational interaction with MTS, the "$" for a command is not needed if (1) there is no line number at the front of the input line, and (2) automatic line numbering is off or there is no currently active file in which to place data lines. Under these conditions, the command line may start with the command name or the command abbreviation. If these conditions do not hold, then the leading "$" is required on all MTS commands. Note that these restrictions essentially say that MTS will attempt to interpret an input line as a command line, even without a leading "$", if it is not prepared to accept a data line from the user and if the user is in conversational mode.

A. Global Control

$SIGNON yyyy	tells MTS that the user with ID number "yyyy" wants to use the machine. The password associated with the ID must be entered either with the $SIGNON command or on the following line.
$SIGNOFF	signs the user off the machine and gives him a summary of the cost of the run.
$SET	is used to set various switches and variables in the system. These control such functions as setting the user's password, automatic errordumping, the line number separator character, upper- and lower-case conversion, implicit concatenation, plus a few more esoteric switches.
$SINK xx	makes the pseudo-device *SINK* refer to the file or device "xx" instead of the printer (in batch mode) or the terminal on which the user is typing (in conversational mode).
$SOURCE xx	makes the pseudo-device *SOURCE* refer to the file or device "xx" instead of the card reader (in batch mode) or the terminal on which the user is typing (in conversational mode).

B. Program Control

$RUN xx	tells MTS to load and execute the program in the file "xx". These files can be public, such as *FORTRAN or *STATUS, or private, such as MYPROGR or -TEMP.
$LOAD xx	tells MTS to load but not execute the program in the file "xx". The program can then be displayed and/or altered. Execution can be started by the $START command.
$START	starts the execution of a program which has already been loaded by a $LOAD command.
$RESTART	will restart the program at the point of the last interrupt or at a specified location. $START and $RESTART may be used interchangeably.
$UNLOAD	releases storage and devices from the previous $LOAD or $RUN. It is useful when the execution of a program did not terminate normally.

C. For Debugging

$ALTER xx yy	allows the user to change the contents of a general register, a floating point register, or a specified location in virtual memory. "yy" becomes the contents of "xx".
$MODIFY	is a synonym for $ALTER.
$DISPLAY xx	displays the contents of "xx", where "xx" may be a general register, floating-point register, or a specified region of virtual memory.
$HEXADD xx yy	prints out the hexadecimal sum of the hexadecimal numbers "xx" and "yy".
$HEXSUB xx yy	prints out the hexadecimal difference between the hexadecimal numbers "xx" and "yy".
$DUMP	prints out the contents of the general registers, floating-point registers, and all the virtual memory locations associated with the current job.
$ERRORDUMP	provides a dump of all the registers and storage if the execution of a program terminates abnormally. This command is effective in batch mode only.

D. File Handling

$CREATE xx	creates a file named "xx". If it is not a temporary file (that is, if its name does not begin with a minus sign), it is retained until the creator destroys it. "xx" becomes the currently active file.
$DESTROY xx	destroys the file named "xx" and returns the space on the disk or data cell to the pool of available storage.
$GET xx	makes "xx" the currently active file. If "xx" is a private file, it must have been created previously. If "xx" is a temporary file and does not already exist, it will be implicitly created by this statement.
$COPY xx TO yy	copies the contents of the file "xx" into the file "yy". Unless specified otherwise, the lines are numbered sequentially from 1 as they are entered in the new file regardless of their numbers in the old file. The old file is retained unaltered.
$LIST xx	lists (with line numbers) the contents of file "xx" on the line printer (batch mode) or the terminal (conversational mode).
$EMPTY xx	empties the contents of the file "xx" but retains its identity. Thus the file can be reused later.
$RELEASE	releases the currently active file if there is one.
$NUMBER	tells MTS to automatically number the lines that follow as they are put in the currently active file. Unless otherwise specified, numbering starts with 1 and increments by 1.

carriage will actually backspace and type over the deleted characters when the user corrects errors; on others such as Model 33 and 35 Teletypes, the carriage will not backspace.

(3) To end an input line and to transmit the entered line to MTS.

(4) To signal an end-of-file.

(5) To signal that the next character should not be interpreted to have any special meaning, but should be transmitted literally.

Table of Control Characters

	Teletype via IBM 2703	Teletype via Data Concentrator	IBM 2741 via IBM 2703 or Data Concentrator
End-of-line Character	CONTROL-S	RETURN	RETURN
Delete-line Character	CONTROL-N	RUBOUT	_ (underscore)
Delete-previous Character	CONTROL-H	CONTROL-H	BACKSPACE
Literal-next Character	CONTROL-Z	CONTROL-P	!
Attention Interrupt	BREAK	BREAK or CONTROL-E	ATTN
End-of-file	CONTROL-C	CONTROL-C	¢

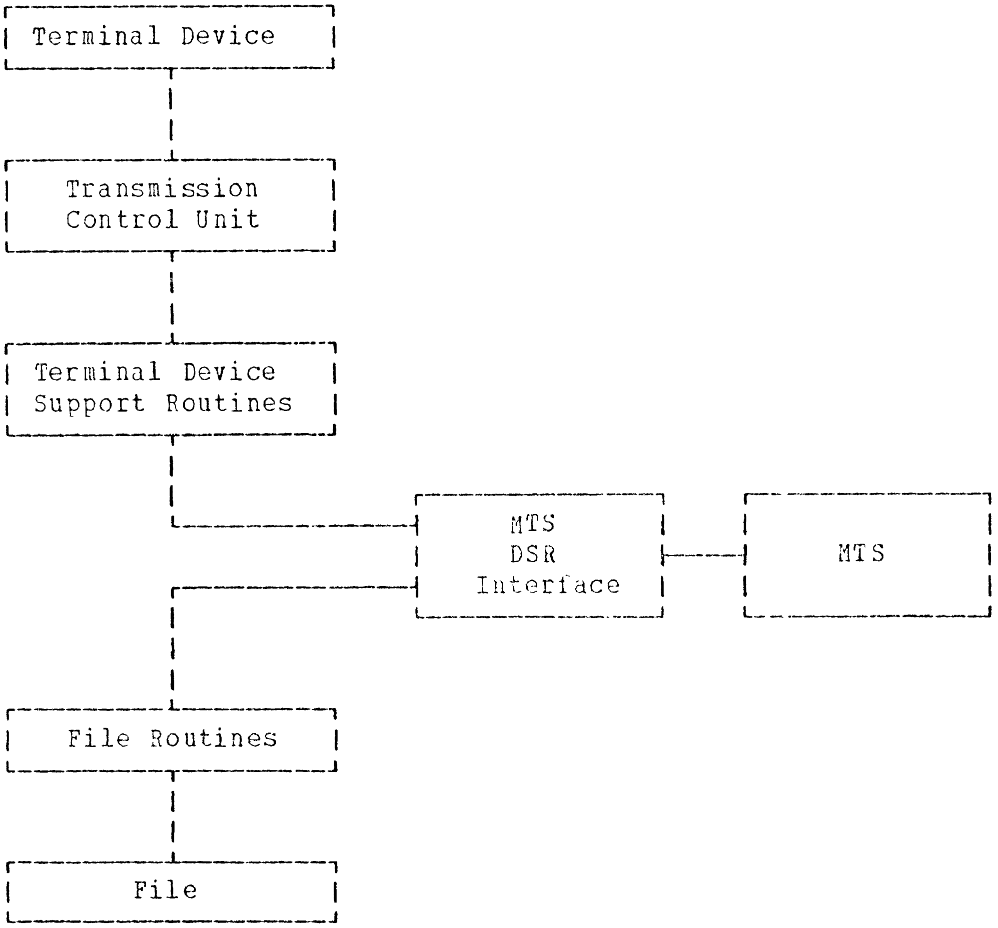
Input Restrictions

Some terminal devices are able to produce lower-case as well as upper-case characters. Normally alphabetic characters in an input line are

Processing of Input and Output Lines

For the user sitting at a terminal, there are several levels of processing that an input or output line must pass through. Each of these levels analyzes the line looking for a particular set of control characters or commands and performing the appropriate conversions. This process may be best explained by using a picture and an example.

Consider the case of a user sitting at a terminal and attempting to enter a line into a file. If he is at a terminal which supports both upper and lower-case letters, he will be concerned about if and when lower-case letters are converted to upper-case letters. This conversion may occur at any one of several levels depending on which device commands, global switches, or I/O modifiers have been specified.



After a line has been terminated and transmitted, an interpretation must be made of what has been typed. Line editing will be performed either by the transmission control unit or the terminal device support routines, depending on which transmission path is used.

all lower-case letters coming from *SOURCE* would be converted to upper case by the interface to MTS when the line is being sent to the file routines for processing. Hence the interface to MTS will have two chances to process the input line and perform upper-case conversion.

The last part of the system to process the input line will be the file support routines. The file support routines perform such functions as indexing (the @I modifier). After all the line processing is completed, the input line will finally be written into the file.

Batch Jobs from a Terminal

It is possible for the user to submit a job in batch from the terminal by using the pseudo-device name *BATCH*. The input must contain the $SIGNON command and password as the first input lines, and must contain all the necessary MTS commands to control the program.

In the following example, a batch job is set up by the user to run the program from the file SF67:RAM3 using the file "SETUP" for input data. The punched output will be saved in a file called "ZEOUT", and the cards will be punched. A listing will be made of the punched cards. After the batch job is set up and initiated, a FORTRAN compilation is run which will compile the contents of "INFILE" into the file "FORTFILE". The listing is printed onto "-FILE". The listing is then copied onto the line printer when the user determines that the compilation was successful. The lines typed by the user are in lower case; the lines from the system are in upper case.

```
#get -file
#READY.
#number
#     1_$$signon ccid t=2m p=100 c=1000 'batch demo'
#     2_password
#     3_$$create zeout
#     4_$$run sf67:ram3 4=zeout 5=setup 6=*sink*
#     5_$$copy zeout *punch*
#     6_$$list zeout
#     7_$$signoff
#     8_$unnumber
#copy -file *batch*
> *BATCH* ASSIGNED RECEIPT NUMBER 600012
#empty -file
#DONE.
#run *ftn par=source=infile print=-file load=fortfile
#EXECUTION BEGINS
#EXECUTION TERMINATED
#copy -file *print*
> *PRINT* ASSIGNED RECEIPT NUMBER 600045
#
```

The major disadvantage of batch mode is that the user has no interactive capability with his job. This limits his possibilities for error recovery and making decisions depending upon [illegible] conditions. Since there is currently no way for making MTS commands conditional, every command will be executed regardless of earlier results. For example, a disadvantage may arise in batch mode when the user wishes to compile and execute in the same job. If an error has occurred during compilation, the object deck may still be executed even though it is erroneous. This effect may or may not be desirable, but the user has little control over it.

DIFFERENCES BETWEEN BATCH USAGE AND CONVERSATIONAL USAGE

The dollar sign command flag "$" is required before all MTS commands in batch mode. This is necessary to avoid interpreting data as command lines and causing irreversible damage to files.

In batch mode, MTS recognizes the following global parameters from the SIGNON command:

Parameter	Meaning	Default
TIME=t	CPU time limit	30 seconds
PAGES=p	Printed page limit	50 pages
CARDS=c	Punched card limit	0 cards
COPIES=n	Number of copies of printed output	1 copy
PRINT={PN|TN}	Printer character set	PN character set
ROUTE=station	Output station for printed and punched output	Input station
PROUTE=station	Output station for printed output	Input station
CROUTE=station	Output station for punched output (Station is CNTR if the input station has no punching unit.)	Input station

If the user does not supply the parameters above for the $SIGNON command, the default values will be supplied automatically and the job will be held to them. The above global parameters are ignored in conversational mode.

The $DESTROY and $EMPTY commands do not require confirmation in batch mode. Confirmation is required only in conversational mode.

The $ERRORDUMP and $SET ERRORDUMP={ON|OFF} commands are effective in batch mode allowing the user to produce error dumps for his job. These commands are not effective in conversational mode.

The MTS pseudo-device names have the following defaults in batch and conversational mode:

FILES AND DEVICES

Data for a user's commands and programs is accessed from either files or devices. A file is a logical entity - a set of lines of information. A device is a physical entity such as a magnetic tape unit, a card reader, or a port for a user's terminal to call. The general specification of a file or device is called a File or Device Name in the MTS manuals, and is abbreviated as FDname. The purpose of this section of the manual is to describe the kinds of files and devices available, to give rules for constructing File or Device Names, and to show how they are used.

FILES

A file is an ordered set of zero or more lines. A line is a string of one or more characters (bytes). Both the maximum number of characters in a line and the maximum number of lines in a file depend on the type of file organization, which is discussed below. In the most restrictive case (line files), the maximum line length is 255 characters, and the maximum number of lines is about 10000 for an average file (depending on the length of the lines).

Long-term storage in MTS is organized on the basis of files and hence is referred to as file storage. These files may contain source decks, object decks, data sets, output listings, writeups, etc.

There are three bases of classification of a file:

(1) The availability of the file.

(2) The type of organization.

(3) The type of direct-access storage device on which it is located.

These three characteristics are fixed at the time the file is created. The first is determined by the form of the file name; the other two are specified by keywords on the MTS $CREATE command.

The Availability of Files

Public files are files containing components of the system, such as language translators and utility programs. Public files may be accessed by is located and where the object deck is to be placed, along with other information.

These specifications in the $RUN command can create immediate problems for the batch user in MTS. Since in a batch job, the input batch deck has been read and placed on a special file (unknown to the user) before the job is started, the batch user has no way of providing in the $RUN command a specific name for the file containing the source deck and/or data cards. This problem is circumvented by the specification of <u>pseudo-device names</u>.

Pseudo-device names are synonyms for the actual files or devices used. They begin with an asterisk, end with an asterisk, and have from one to fourteen characters in between. The same characters legal for simple file names are legal here. There are nine pseudo-device names which are automatically predefined for the user. In addition, others may be defined with names of the user's own choosing when mounting removable volumes on devices. (See the description of MOUNT in Volume 2, and the "Magnetic Tape User's Guide" and the "Paper Tape User's Guide" in Volume 5 for details.)

The predefined pseudo-device names are as follows:

SOURCE is defined by MTS as the current input (or source) file or device. Initially, the system defines *SOURCE* to be the same as *MSOURCE*. Thus, for batch runs, *SOURCE* is initially defined as the location of the user's input deck, while for terminal usage, *SOURCE* is initially defined as the terminal at which the user is signed on. Therefore, any reference by a batch user to *SOURCE* is equivalent to a reference to the batch input deck. The batch user may thus use the name *SOURCE* in place of the (unknown) name of the input stream.

The user can redefine *SOURCE* by using the MTS $SOURCE command. If *SOURCE* has been redefined by a user, an attention interrupt at a terminal, or an end-of-file on *SOURCE* when attempting to read a command, will cause *SOURCE* to be redefined back to *MSOURCE*.

SINK is defined as the current output (or sink) file or device. Initially, the system defines *SINK* to be the same as *MSINK*. Thus, for a batch job, MTS initially defines *SINK* as the printed output stream for that job, while for terminal usage, *SINK* is defined as the user's terminal. (Thus the batch user need not know the specific name of the place being used to collect his printed output, since he may refer to it by the pseudo-device name *SINK*.)

The user can redefine *SINK* using the MTS $SINK command. If *SINK* has been redefined by a user at a terminal, an attention interrupt will cause *SINK* to be redefined back to *MSINK*.

MSOURCE	is defined as the master input (or source) file or device, which is the terminal in conversational operation and the file or device from which the batch job is being read in batch operation. *MSOURCE* may not be redefined by the user.
MSINK	is defined as the master output (or sink) file or device which is the terminal for conversational operation and the printed output for batch operation. *MSINK* may not be redefined by the user.
AFD	is defined as the current active file or device (if any). The active file or device is established by the MTS $GET, $CREATE, or $EDIT commands. See the section "Putting Information into Files" below for details.
DUMMY	is defined as an infinite wastebasket for output (lines are accepted and they disappear) and an empty file for input (every time a line is requested, an end-of-file condition is returned). *DUMMY* is particularly convenient for specifying that output is to be ignored.
PUNCH	is defined slightly differently for batch and terminal usage. For batch jobs, it represents the punch output for the job. Anything written to *PUNCH* will be punched on cards, if the user has specified a big enough punch limit for his job. For terminal usage writing information to *PUNCH* will cause a new batch queue entry to be created to punch the output. A receipt number for use in picking up the punched output will be printed at the terminal.
PRINT	is the same as *MSINK* in batch. From a terminal, writing information to *PRINT* will cause a new batch queue entry to be created to print the output. A receipt number for picking up the printed output will be printed at the terminal.
BATCH	is defined for both batch and terminal usage. Writing information to *BATCH* will cause a new batch job to be created to run the input provided as a separate batch job. A receipt number for picking up the batch job's output will be printed at the terminal (if submitted from a terminal), or in the printed batch output of the submitting job (if submitted from batch).

SIMPLE FDNAMES

A *simple FDname* is one of the following:

(1) Simple file name
(2) Simple device name
(3) Simple pseudo-device name

TYPES OF FILE ORGANIZATION

The three types of file organization are

LINE	Line file (default)
SEQ	Sequential file
SEQWL	Sequential-with-line-numbers file

The file organization can be specified as the value of the TYPE keyword on the $CREATE command when the file is created. For example,

```
$CREATE  SF TYPE=SEQ
```

creates "SF" as a sequential file. Note that since the default is LINE, all temporary files that are implicitly created (by the first usage of the file) will be line files. If a different type is wanted, the temporary file must be explicitly created using the $CREATE command.

The SEQWL type is really a variation of the SEQ type, hence in the following discussion of line files versus sequential files, what is said for sequential files will also apply to sequential-with-line-numbers files.

Line Files

The basic MTS file type is LINE. A line file is an ordered set of zero or more lines. Each line consists of 1 to 255 characters (bytes). Each line has associated with it a unique line number (for that file) which is not part of the line. The lines in the file are numerically ordered. An exact definition of line numbers is given below; for the discussion here, it is a number from -99999.999 to 99999.999 inclusive. Note that while the line number for each line must be stored in the file, the line number is not part of the content of the line.

By using its line number, any line in the file may be directly accessed, either for reading or writing. An input or output operation on a file which explicitly indicates a specific line to be read or written is called an indexed operation. The more common input/output operations on a file specify a line number at which to begin reading or writing, and continue with the "next" line for successive records read or written. These are called sequential operations. These two methods may be intermixed, for example, using an indexed read operation to get to a given position in a file and then reading sequentially from there.

The type of operation used depends on the sequential/indexed modifier bits supplied for each FDname or input/output subroutine call. If, in the call on a subroutine, the modifier word supplied has the indexed bit set, or if @I was appended to the FDname when it was given, then an indexed input/output operation will be done. The default operation is sequential. (See Appendix A for the description of the modifier amalgamation process.)

Indexed Operations

When an indexed read or write operation is done, the line number given in the I/O subroutine call is used to specify the line to be accessed. A return code of 4 (end-of-file) occurs if there is no line in the file with that line number, or if the line number is outside the line number range given with the FDname. (The beginning and ending line numbers, if not specified explicitly in a line number range, default to 1 and 99999.999, respectively.)

Implicit and explicit concatentation with an indexed operation are handled in the following manner:

For an indexed read operation, if the line selected is a "$CONTINUE WITH" line and implicit concatenation is enabled (the default case), then concatenation will occur and the same line number will be selected for the new file or device specified by the FDname in the "$CONTINUE WITH" line.

If the file is part of an explicit concatenation (and not the last member) and a condition that would normally produce a return code of 4 occurs, a transfer to the next member in the concatenation will occur instead. Thus, a return code of 4 on an indexed read to a concatenation indicates that none of the members of the concatenation had a line of that number; a successful indexed read on a concatenation will select the specified line from the first member of the concatenation with that line number.

Sequential Operations

When a line file is written or read with an indexed operation, the line number is explicitly given. However, for sequential operations on a line file, the question of the beginning and ending line numbers arises. These are specified via the line number range (discussed earlier) which has the form

(b,e,i)

where b, e, and i are each line numbers as described below.

For a read operation, the beginning line number is b (which defaults to 1, if not given) and the ending line number is e (which defaults to 99999.999, if not given). If the increment i is not explicitly given, it is not used. Thus

A

is identical to

A(1,99999.999)

and specifies all lines with numbers between 1 and 99999.999 inclusive. If, however, the increment *i* is explicitly given, then it is used to select the next line. Thus

A(,,1)

is identical to

A(1,99999.999,1)

and specifies only the lines with integer line numbers from 1 through 99999 inclusive.

For a *write operation*, the beginning line number is *b* (which defaults to 1, if not given) and the increment is *i* (which defaults to 1, if not given). The first line written will have line number *b*, the second *b*+*i*, etc.

Note that *b* may be greater than *e*, and that *i* may be negative. Thus, reading from

A(LAST,1,-1)

will read the integer-numbered lines of A in reverse order (if LAST is integer-valued).

Mixed Operations

The following discussion applies to mixed sequential and indexed operations on the same logical I/O unit or FDUB-pointer. Accesses to the same file via other logical I/O units or other FDUB-pointers are independent.

An indexed read or write operation operates on the line specified by the line number parameter in the I/O subroutine call, regardless of the previous I/O operation.

If the first operation on a file is sequential, the behavior is as described above: the line is specified by the beginning line number *b*.

For a sequential operation that is not the first operation, the "next" line is chosen. For a read without an explicit increment, "next" is the next line in the file after the last one read or written. For a read operation with an explicit increment, the "next" line has the line number of the last line read plus the first multiple of the increment for which there is a line. For a write operation with an explicit increment, the "next" line has the line number of the last line written plus the increment.

Line Numbers

Externally, a line number is one of three forms:

(a) ±nnnnn.nnn

where "n" is a decimal digit (0 through 9). The minimum and maximum line numbers are therefore -99999.999 and 99999.999. When writing a line number, leading plus-signs and leading zeros, trailing decimal points, and trailing zeros after decimal points may be omitted. Examples of line numbers of this form are:

5   5.1   5.13   5.137   32505.137   -32505.137

(b) LAST

which has the value of the last (algebraically greatest) line number in the file. If the file is empty, the value is zero.

(c) LAST±m

where "±m" is a number of the form "±nnnnn.nnn" as described above. The value of this is the algebraic sum or difference of the two components; thus LAST-1 does not necessarily specify the line number of the next-to-last line, but merely a line number 1 less than that of the last line.

The internal form of a line number is a fullword binary integer whose value is 1000 times the external form. Thus, a line number whose external form is 1 is stored internally as 1000 (decimal) or 000003E8 (hex). The internal form of a line number must be supplied to the input/output subroutines when requesting an indexed operation, and the internal form of the line number of the line that was read is returned after a sequential read (or a sequential write in the case that the RETURNLINE# modifier was specified - see the Appendix A modifier description).

Sequential Files

A sequential file is an ordered set of zero or more lines. Each line consists of 1 to 32767 characters (bytes). The lines of a sequential file do not have line numbers and cannot be directly referred to by line number from a program or command.

```
$COPY  A SWF(LAST+1)
```

will add the lines from A to the end of SWF.

LOCATION OF FILES

There are two kinds of direct-access storage on which a file may be located. It may be on a disk pack mounted on an IBM 2314 Direct Access Storage Facility or on a data cell volume mounted on an IBM 2321 Data Cell Drive. All types of files may be on disk, but only sequential (and sequential-with-line-numbers) files may be on a data cell volume.

In terms of access and transfer time (i.e., the amount of real time it takes to find and then read or write a record of information), the 2314 disk drive is on the average five to ten times faster than the 2321 data cell drive. On the other hand, in terms of storage costs, data cell storage is about half as expensive as disk storage (based on current rates).

CREATING FILES

The availability, organization, and location of a file are all established at the time the file is created. Files are created by using the MTS $CREATE command or by calling the CREATE subroutine from a program. The syntax of the $CREATE command is given in the command description. The CREATE subroutine is described in Volume 3. The following discussion covers the specification of the file characteristics when using the $CREATE command.

The MTS $CREATE command has the basic form:

```
$CREATE  filename
```

which causes a file of this name to be created (unless there already exists a file of the same name, or the user has exceeded his file space allotment). There are several options which can be specified in the form of keyword expressions.

SIZE=n	n is number of average (50 byte) lines
SIZE=nP	n is number of pages (1 page = 4096 bytes)
SIZE=nT	n is number of 2314 tracks (one 2314 track = 7294 bytes)

For most files, this parameter is not needed. The default size for permanent line files is the smallest possible (one 2314 track) which is enough for about 75 average lines. Since files expand automatically when possible up to 16 times, most data sets can fit into a file of default size. (As a matter of interest, about 40%

of all user files in the system are one-track files, and about 20% are two-track files.) The following table gives the default sizes:

	Permanent			Temporary		
	Line	Sequential		Line	Sequential	
		Disk	Data Cell		Disk	Data Cell
Amount of Space Allocated	1 2314 track	1 2314 track	6 2321 tracks	5 2314 tracks	5 2314 tracks	6 2321 tracks
Pages Charged	2	2	3	9	9	3

For larger files, it is necessary to specify an estimated size. When estimating size in terms of pages (or tracks), it should be noted that there is a certain minimum overhead for each line or record in the file. These overheads are as follows:

Type	Min. Overhead
LINE	8 bytes/line
SEQ	6 bytes/line
SEQWL	10 bytes/line

Information on the internal structure of files and approximate formulas for the size required for a file will be found in Appendix C.

Files will be extended automatically when possible by the system. The conditions for automatic expansion are:

(1) The user has not exceeded his disk or data cell space allocation.
(2) Space is available on the direct-access volume on which the file was originally created.
(3) The file consists of no more than 15 distinct allocations (called "extents").

If any of the above three conditions is not met, the error comment

```
FILE "filename": SIZE EXCEEDED
```